AN APPROACH TO GROUP TECHNOLOGY
BY CLASSIFICATION AND CODING

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by

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DECLARATION

No part of the work described in this thesis has been submitted in support of an application for another degree or other qualification of this or any other Institution.

A W Boundy

P R E F A C E.

Many production engineering firms today have different interpretations of the meaning of the words - Group Technology.

A firm wishing to improve its design function and drawing office system does so by classifying and coding all of its component drawings and claims that it has introducted Group Technology. Another firm wishing to reduce throughput times and work in progress on the shop floor rearranges its machine layout into cells and consequently boasts of implementing Group Technology. Others, looking for a better employer-employee relationship decide to give the workers greater job satisfaction or enrichment and do so by broadening their range of tasks, raising and lowering the degree of skill required in their work and in so doing state that Group Technology has been employed to improve the lot of the worker and make them more contented employees.

Nobody can argue that the above claims are not true, but each one is a limited approach to Group Technology.

Group Technology has been acclaimed by many as a manufacturing technique and in fact when the 'limited approach' is applied, this is the case. The word 'technique' is generally used to describe, the best ways and means of performing a given task in a specific area. As Group Technology is applicable to all engineering functional areas it is best described as a system; a system consisting of a number of techniques which facilitate its implementation in specific areas of engineering.

The "systems concept" of Group Technology is widely ascribed to today and academics, consultants and experienced users are propounding to this approach when looking for the ultimate benefits which Group Technology can derive. Firms are being encouraged to look further afield than the particular trouble spot they wish to eliminate to see what the wider implications are and if modifications at this time will ensure a smooth flow on to other departments not being considered at this moment. The systems approach to Group Technology is by far and away the most profitable and beneficial and the only one which allows for complete homogeneity across the organisation.

With a smooth running system operating in a firm, the much publicised benefits of Group Technology, namely, reductions in work in progress, finished stocks, and throughput times and the achievement of reliable delivery dates automatically follow. The climate is then set to introduce, expand, refine and improve various techniques which will still further increase and ultimately maximise profits. Such techniques as, component standardisation, variety reduction in design, machine loading, labour flexibility in cells, the use of pre-set tooling, specially designed machine tools, jigs and fixtures in manufacture, and new methods of stock control and marketing by management, to name but a few, can be investigated as possible areas of improvement once a Group Technology system has been firmly established.

SUMMARY

This thesis outlines the approach to Group Technology by the application of a Classification and Coding System. Practical surveys have been carried out and these surveys illustrate the techniques used, the codes developed, methods of analysis, conclusions reached and lastly recommendations made for future work.

In addition to the practical report, a comprehensive literature survey is included, detailing all aspects of Group Technology, from methods of implementation to a full description of its benefits and effects on industry. Wide use is made of flow charts, photographs, drawings and tables to support the text and thus present as clear a picture as possible.

Appendix 4 includes a Group Technology Questionnaire which was distributed to some 180 firms in the U.K. and on the continent. Details of results of this questionnaire are not available at the time of writing, but indications are, that approximately 25 to 30 percent will be returned.

LIST OF FIGURES.

1. INTRODUCTION.

1.1 The Need for Improvement in Manufacturing Methods.

Since the last world war and the subsequent re-establishment of manufacturing industries in countries like West Germany, France, Italy and Japan, together with the birth of new industries in developing countries like Spain, Portugal, India, China and South-East Asia, the world's markets have been flooded with all kinds of manufactured articles at increasingly competitive prices. Great Britain has always been one of the world's greatest secondary producing nations backed up by an inheritance of technological skill second to none. However, the pressure of competition placed on British industry by the above development has created problems of survival for many firms which are poorly managed and are in the lower end of the profitability scale.

Worker unrest, the desire to constantly improve standards of living and keeping pace with the rate of inflation have led to wage demands and strike action which has brought ruin to many British companies.

The combination of the above problems has forced many firms to desperately seek ways and means to meet the workers' wage demands as well as answer the challenges from overseas competitors on world markets.

Accompanying the above general problems are the real 'in house', everyday production problems which have to be either solved or attended to so that the firm may function in a normal manner. Two of the most acute of these problems are,

(a) Long and un-reliable throughput times.

(b) Excessive work-in-progress stock.

1.2 Solving the Problems.

Many firms in dire need have obtained Government aid and changed their overall philosophy from one of 'management v's worker' to a 'total worker participation' approach. It is thought that this total involvement of the shop floor personnel will eliminate strikes and unrest and that the injection of Government money will enable investment in plant and new techniques which these firms so badly need to meet the standards and prices of their competitors. Whether this approach is successful or not, only time will tell as it has only been in operation for the last twelve months.

In the past, little has been done which offers a solution to the above problems of throughput times and work-in-progress. An approach which is gaining favour in this respect, and also involves 'worker-management' participation is the restructuring of manufacturing facilities to streamline and control production - Group Technology.

1.3 Extent of this Investigation.

The latter of the two approaches mentioned above is generally preferred by those companies who are in no real danger of collapse, but in foresight wish to avoid any possibility of facing the problems mentioned previously and at the same time enjoy increased profitability and harmony with their workforce.

Two such companies are Hawker Siddeley Aviation Ltd., Manchester, and The Bronx Engineering Co. Ltd., Lye, Stourbridge in Worcestershire. The former is one factory of a number which combine to form one of the largest aircraft manufacturing corporations in the world. The latter is a medium size company which manufactures a wide range of machines for use in the steel processing industry.

These companies approached the University of Aston independently, to carry out surveys on the feasibility of implementing Group Technology and this report deals with the investigations, conclusions and recommendations made as a result of a classification and coding and production flow analysis of component samples taken from the drawing files of both firms.

2. GROUP TECHNOLOGY.

2.1 Historical Development of Modern Group Technology.

The beginning of modern day Group Technology is generally attributed to the Russians and in fact it was traced as far back in Russia, as the 1920's by Grayson[1]. In 1930 Sokolovsky[2] introduced 'type technology' which identified a given set of related parts by their processing and operations sequence, the initial material size and form, and the machines, tooling and fixtures required to produce them. Type technology was a major step towards modern Group Technology and was improved on during the war years. In 1959 Mitrofanov[3] published his much acclaimed work on Group Technology which was subsequently translated into English and published in 1966[4].

An early approach used by the Russians to Group Technology was to bring together similar parts that could be machined on a single machine tool using a fixed tooling set-up. This method became known as the complex or composite component approach. It was based on the idea that a machine could be tooled to produce a component of a certain complexity, whilst the same set-up would also be capable of producing a number of components of lesser complexity than the complex component. Thus a family of parts could be established which was capable of being produced on any given machine tool with a certain basic tooling set-up. Such a family for production on a capstan lathe is shown in FIG.2-1.

In the early 1960's Professor Opitz of the Aachen University in East Germany broadened the scope of Group Technology with his studies on Workpiece statistics[5]. Opitz and his team carried out research within twenty-five firms in industry and this resulted in a detailed analysis of the components being produced within these firms. It was found that although the firms manufactured a variety of products, the component spectrum of each was remarkably similar. An analysis of their similarities produced further interesting data such as,

(a) 70% of all components were rotational.

(b) 80% of parts were less than 200mm in diameter, whilst the capacity of most machines producing them was greater than 200mm diameter.

(c) Only 22% of parts required threads and practically all machines were capable of producing threads.

Many other findings concerning workpiece statistics were revealed in Opitz's work.

His investigations carried out over a period of several years, led to his publication of a classification system which proposed to define the form geometry of machined components. This system is widely used today as one of the initial steps taken towards Group Technology implementation. It is freely available and is published in many languages including Englsh[6]; FIGS. 2-2 to 2-10 illustrate PART 1 of the system.

The growth of Group Technology in Great Britain began significantly after Opitz's work was published and today there are some 100 firms who have implemented it either partially or wholly with varying levels of success. Perhaps the most famous and certainly one of the most successful users of Group Technology is the firm of Serck Audco, who over a period of ten years from 1961-1971 made a complete change over to Group Technology. An account of this transformation is given in a book by G.M. Ranson[7]. This exercise, based on the Brisch classification system, FIG. 2-11, provided an outstanding example to the remainder of British industry of the benefits which could be realized by the 'systems approach' to Group Technology which followed.

Another later example of the potential which Group Technology offers to the ailing firm, was the introduction to Ferrodo[8,9], in 1968-70. This application showed how throughput times and work-in-progress could be cut by as much as 8 to 1, compared with the previous system[10,11].

Other well known firms such as Ferranti Ltd.[31], Thomas Mercer Ltd.[21], Rolls Royce[19], G.E.C.-Elliott Control Valves Ltd.[24], Mather and Platt Ltd.[23], and Baker Perkins Ltd.[25], successfully implemented Group Technology in the late 1960's.

In recent years, two outstanding examples are provided by Herbert Machine Tools[12], and Rank Xerox[13], both of which claim to have realised all the publicised benefits from their application. Many of the above firms are continuing to expand and improve their system, even though the present unfavourable economic climate resulting from cash-flow problems, rampant inflation and continuous worker unrest, is undoubtedly relegating such expansion to minor proportions.

2.2 Modern Batch Production.

The state of affairs as exists in a functional workshop of today needs little reminding to the production engineer associated with them.

Here we have a constant flow of unfinshed parts progressing slowly from one machine to the next and from one machining section to another in small batches which have varying orders of priority. Those high on the priority list are constantly leapfrogging over those of low priority which are being manufactured to appease the E.B.Q. concept. Intermingled with both of these are the specials (one or a few off) which are periodically put through on top priority, in order to win the approval of a much valued client. These specials invariably cost the firm a lot more than they are worth, due to the disruption they cause in production, but are a necessary evil in today's highly competitive industrial community.

The E.B.Q. orders quite often take many months in passing through production and only serve to contribute appreciably to the value of the work in progress, which the firm has, cluttering up the all to small storage areas around the machining centres. When these batches are completed they add to an already overstocked finished parts store, where they will probably lie for many months before being called for assembly. During this time they increase stores control costs as well as occupying valuable space which most factories can ill afford and which usually carry high overhead costs.

The haphazard routing of work through the various machining sections necessitates constant stripping down and setting up of tooling on machines to suit the different machining operations called for by the multitudinous variety of components passing through. The result is, that metal cutting times are low, whilst setting times are very high. Skilful scheduling can alleviate some of these problems, but there is always the unforseen top priority job which can disrupt the best of planning.

2.3 The Advent of Group Technology.

Since the days of the Industrial Revolution, firms have struggled with the problems associated with the functional layout of machines, accepting that these problems were a necessary 'evil' and something which had to be solved as part of the every day duties of a good production engineer. So universally accepted was the functional layout that any change proposed was either too insignificant or offered so little improvement as to be quickly discarded. Thus the functional system has been perpetrated through the decades; decades which have seen great changes in other areas associated with industrial activities. These changes have been influenced by developments in areas such as transport, communication, process technology and all of these aided by the even greater development of computer technology.

One can well understand that even the most irrational thinker would never have thought of changing the layout of a whole factory to solve the problems associated with the functional layout, when one considers the large number of machines involved as well as the resulting shut down necessary to make a complete change over. Group Technology started in a very small way commencing with a single machine concept and later extending to a small group of machines. It was only as a result of the great benefits which this small beginning indicated that experimentation developed over a period of 15 years leading to large machine groups, then to complete cellular layout, then flowlines and lastly to the systems concept where the ultimate in Group Technology benefits can be realised by the firm which is far sighted enough to implement it.

2.4 Definitions.

What then is Group Technology? Many and varied are the interpretations, but all seem to point towards a common goal; the achievement of production targets in the shortest possible, reliable times by the cheapest, most efficient and soul satisfying means.

Definitions of Group Technology have arisen from the work of consultants and engineers who have been associated with its implementation into industry. A few of these will suffice to explain the meaning of the term.

Ransom in his book[7] defines it as,
'The logical arrangement and sequence of all facits of company operation in order to bring the benefits of mass production to high variety, mixed quantity production'.

Thornley states[14],
'A method of achieving some degree of mass production technology in the batch production industry. It is a technique which enables the benefits of large batch production to be extended to the manufacture of small and medium batches'.

Gallagher and Knight in their book[28], describe it as,
'A technique for identifying and bringing together related or similar components in a production process in order to take advantage of their similarities by making use of, for example, the inherent economies of flow-production methods.'

How Group Technology is implemented, varies in many ways and successful applications can be found using all the published and otherwise available methods[7,8,10,12,13,19,20,21,23,24,25].

3. METHODS OF INTRODUCING GROUP TECHNOLOGY.

It is certain that the introduction of Group Technology into a company requires a lot of prior thought and planning before the actual reorganization of facilities can take place. A resumé of the more common methods used in its implementation is now given, followed by a detailed description of the recommended procedure.

3.1 Production Flow Analysis (P.F.A.)

This technique, proposed by Professor J.L. Burbidge, has been widely published in both seminar[15] and book form[16,17]. P.F.A., as it is called, is used for finding families of components and associated groups of machines for cellular layout. Route cards, which show operations and operation times, machines and departments visited are prepared for each component together with detailed listings of all plant used in manufacture. Analysis is then carried out in three stages:-

(a) Factory Flow Analysis - which finds the division of departments and the allocation of plant and components to these departments, which will provide the best material flow system. The analysis is carried out in nine (9) main steps, viz:-

1. Divide into departments.
2. Allocate plant to departments and find the usage frequency.
3. Determine the Process Route No. (P.R.N.) for each part.
4. Analyse the parts by P.R.N's.
5. Draw a basic flow chart.
6. Determine which parts are exceptions.
7. Eliminate the exceptions.
8. Check machine loads.
9. Specify the standard inter-department flow systems.

(b) Group Analysis - aims to divide the components already allocated to each department into families, and divide the plant allocated to each department into groups, in such a way, that each family is completely processed by one group only. The analysis is carried out in eight (8) main steps, as follows:-

1. Renumber operations on route cards.
2. Sort identical routes into packs.
3. Draw pack/machine chart, FIG. 3-1.
4. Find families and groups, FIG. 3-2.
5. Check load and allocate plant.
6. Investigate and eliminate exceptions.
7. Specify groups and families.
8. Draw final flow system network.

FIGS. 3-1 and 3-2 show the initial pack/machine charts before and after grouping respectively.

(c) Line Analysis - finds the sequence of layout for the machines which will give the nearest approximation to line flow. Each family of components is considered separately and this analysis takes place in seven (7) main steps:-

1. Renumber all operations in sequence.
2. Draw a machine/operation number frequency chart. FIG. 3-3 (a).
3. Adopt a single digit identification symbol for all work centres in the group.
4. Determine the Operation Route No. (O.R.N.) for every component in the family and analyse. FIG. 3-3 (b).
5. Draw the group flow network diagram and simplify. FIG. 3-4 (a) and (b).

Production Flow Analysis is a very useful technique for preliminary Group Technology investigation because it shows the present state of affairs, in which components are usually found to follow a multitude of different paths; the whole flow system usually being referred to as "spagetti layout". It also accomplishes the three types of analysis outlined above but its ability to form machining groups manually, FIGS. 3-1 and 3-2, in a situation which generally exists in industry, where a firm has in excess of 10,000 live components and machines numbering more than 100 is well nigh impossible. It is claimed that the machine grouping technique in cases like this can be solved by computerisation, using an analysis known as Nuclear Synthesis[18], but this method is somewhat hazy and doubts exist as to its success.

Factory Flow Analysis, the first stage of Production Flow

Analysis is well worth while in any initial manufacturing analysis, as it is basically the application of good production engineering principles and provides an excellent base on which to build a Group Technology implementation.

P.F.A. is a technique which can be applied by any individual company without outside assistance. In small firms which have a component list numbering a few hundred and a small list of say 20 to 30 machines, P.F.A. is a technique by which the company may rearrange its layout and achieve the benefits of Group Technology without incurring the cost of consulting fees. The main danger which lies here, is that the temptation to "cut corners" when forming cells could lead to a situation which would offer little, if any, improvement from the original layout. These temptations mainly concern the sharing of common facilities between cells such as,

1. Machines.
2. Operations.
3. Inspection Facilities and personnel.
4. Tool, jig and fixture stores.

"Sharing" tends to strip a cell of its singular identity and brings about a lessening of the team spirit, which is generated where a cell is completely independent for all its required functions. In some cases sharing is unavoidable and it is in making decisions such as this that the expertise of a consultant is invaluable. However, a well read engineer could quite easily recognize the dangers mentioned, avoid them and achieve desirable results.

3.2 Component Flow Analysis[22] (C.F.A.)

This technique is similar to Production Flow Analysis in many respects; its main difference being in the method used for the formation of component families and machine groups. C.F.A.

uses a manual analysis of computer printouts as the means of forming machine groups whereas P.F.A. uses a machine tool/ component matrix.

A thorough examination is made of existing manufacturing data and the following recommendations for minimum requirements before C.F.A. can commence are as follows,

(a) Each component has a unique identity i.e. drawing number.
(b) A product explosion into assemblies, subassemblies and components.
(c) Detailed process sheets for each component which should contain the following information.

1. A description of the machining operations required to be performed.
2. The machine tool or equipemnt on which each operation is to be carried out.
3. The set-up time required for the machine tool.
4. The operation times.

(d) A complete plant list with each item of plant identified by number.
(e) A reliable forecast of component demand covering a reasonable length of production and not one which is influenced by short-term fluctuations from one production period to another.

The above basic requirements are in fact those which are specified for P.F.A., and in general, for any investigation into Group Technology, these details of manufacturing are essential.

Component flow analysis is carried out in three stages outlined as follows:-

(a) First Stage.

The total component mix is analysed and sorted into categories according to manufacturing requirements.

The factory is divided into a number of broad sections, each containing the plant necessary to manufacture a specific sector of the component mix.

The analysis is computerised and two listings are obtained, one showing the complexity of machine-tool combinations required and the other pointing out any similarity in the nature of these combinations.

(b) Second Stage.

The second stage involves the manual sorting of all components into "rough" groups which fit various machine tool combinations. Exceptions are noted and investigated for modification so as to fit into a "rough" group. Those which cannot be accomodated are considered in the third stage of analysis.

(c) Third Stage.

The third stage determines the final structure of the production system. A study of component flow patterns and loads is carried out in order to determine:-

1. The best layout of machines to minimise reverse material flow.
2. The number of similar machines required to cope with the operator load imposed on the cell by the family of components allocated to it.

It is claimed[22] that C.F.A. has been used successfully to implement Group Technology, in two multi-product companies with 7000 and 14,000 components respectively. Benefits derived are comparable with those attained from other applications[7,26], viz:-

1. 70% reduction in through-put times.
2. A 30% reduction of work in progress.
3. A 50% reduction in scrap rate.

C.F.A. is a technique which is available to companies on a consultancy basis and not for their own introduction.

3.3 Classification and Coding.

3.3.1 Introduction.

Classification and coding is probably the most widely used and most successful method of implementing Group Technology. The coding of components in itself merely establishes a very sound data base from which the formation of component families and then the setting up of manufacturing cells can proceed. A list of code numbers representing every component manufactured within the firm provides an immense pool of knowledge about them e.g. geometrical shape relating to machining operations, dimensions, initial form, material type and other pertinent information which can be ascertained by combinations of digits and which may have an effect on the design, manufacture or assembly of the components.

Classification systems are designed to store component data according to the information value alotted to a digital system. The digits, arranged in the form of a code number, present a block of information about the component when the code is interpreted. Because of its digital structure, this type of system is easy to manipulate manually, as well as being ideally suited to computerisation.

3.3.2 Classification.

A short, concise definition of classification is given by Risk[27], who quotes:-

"Science is the detection of identity, and classification is the placing together either in thought or in actual proximity of space, those objects between which identity has been detected."

Middle[9], states:-

"A classification can be likened to a methodically arranged list of addresses, which designate the places where things may be occupied and where they may be found."

It is the way in which the addresses of a classification scheme are expressed and the relative significance to adjacent addresses which separates the various schemes available to industry. A classification scheme generally consists of one of the following structure types:-

(a) Alphabetical.
(b) Numerical.
(c) Alpha-numeric.
(d) Ideographic (use of small pictures).

The numerical form has been found to be the most suitable and is used in the majority of cases today. The relative significance of adjacent addresses decides whether the scheme is either,

(a) of fixed digit significance or,
(b) heirarchial in structure.

In the former, a certain digit value always indicates that the same feature is present. In other words, each digit stands alone, its meaning is precise and is not affected by a change in value of adjacent digits. An example is the Opitz system FIG. 2-2 to 2-10. On the other hand, a heirarchial classification is compounded in such a way that the information contained in each digit is dependent on the proceeding digit. An example is the Brisch system, FIG. 2-11.

There are five basic classification models as stated by Gombinski[29], viz.

(a) Product-orientated - in which components are grouped by the products for which they were originally designed.

(b) Function-orientated - in which components are grouped by names, indicative of their function, e.g. shafts, cams, brackets, covers etc..

(c) Design-orientated - in which components are grouped into families by the similarity of design manifest in their overall shape.

(d) Production-orientated - in which components are grouped into families requiring closely similar or identical technological processes.

(e) Design and Production-orientated - which aim at satisfying the requirements of designers and production engineers by a single system.

The first four are single purpose systems whilst the last is a dual purpose system. The product-orientated system is obsolete and of little value for G.T.. A function-orientated system has however, had some support by inovators in the past[30], but present and future trends seem to eliminate this method. The two most popular systems in use today are the design-orientated (D.O.) and production-orientated (P.O.) systems. The later has developed significantly since the advent of G.T. whilst the former has been in use for many decades for design retrieval and standardisation purposes. A dual purpose (D.O./P.O.) system has been proposed[29], but loses many attributes of the individual systems and the general conclusion now is that the ideal situation is to have the two single purpose systems, one for design and the other for production[28,29].

3.3.3 The Brisch Classification System.

The two outstanding classification systems used in Great Britain for the purposes of introducing Group Technology are the Opitz system FIGS. 2-2 to 2-10, which is production-orientated and the Brisch system FIG. 2-11, which is design-orientated. The latter system has been modified for Group Technology[29], by the inclusion of a subsystem of secondary polycodes which are added to, but do not form part of the primary monocodes, FIG. 3-5. These polycodes are necessary for the formation of G.T. component families and machine groups and are developed individually for a particular firm. FIG. 3-5(b) illustrates how the Brisch code is adapted to a Numerical Control programme where all the relevant data for N.C. is found fully identified in appropriate classes and can be easily retrieved for incorporation in the programme. The Brisch code is only available to firms through consultants at considerable cost, (£40,000 has been quoted[24] as an estimate in 1968). It is claimed that once established, the primary monocodes provide the design-oriented requirements and the secondary polycodes serve the production-orientated function. There is little doubt that if a firm is prepared to make a substantial investment in a Brisch Classification system, it would pave the way to a satisfactory implementation of Group Technology. Such successful examples as Ferranti Ltd.[31], Serck Audco[7], speak well for the Brisch system when properly applied.

3.3.4 The Opitz Classification System. (FIGS. 2-2 to 2-10).

The Opitz classification system has two distinct advantages over the Brisch system, which are quite often the deciding factors in a choice of systems for a company wishing to implement Group Technology, viz.

(a) It is a production-orientated system, which has been adapted to facilitate the formation of production families able to be produced on a certain grouping of machine tools.

(b) It is available at no real cost[6] to the firm, but modifications are always required to one or both parts of the code to suit the component mix and manufacturing conditions of the particular firm.

The first advantage is very important if a firm is primarily interested in the implementation of Group Technology to its production facilities. It does not however, preclude the Opitz system from being used for design retrieval and standardisation. A full description of its use will be dealt with in the next chapter.

Criticism has been levied at the Opitz system[33], claiming that it has inherent deficiencies which make it unsuitable for the formation of component families. i.e.

(a) It separates components which should be together.

(b) It brings together components which should be separated.

In answer to this, an Opitz based system modified to suit a company and built around a set of objectives which are backed up by a code manual defining the decision areas, will eliminate any possibility of the above occurring.

It is significant to note, that one large company[25] with a drawing file of 250,000 components had used a Brisch Code System in the past and many of their drawings were coded using this system. Upon looking at the existing system as an aid to the implementation of Group Technology, they decided to abandon it in favour of the Opitz System. The firm subsequently introduced Group Technology and claim to have realised all the associated benefits.

3.3.5 Other Classification Systems.

1. Uncoded System. - this system developed by the Russians[4,34], is carried out in a series of steps, FIG. 3-6(a). Firstly, the components are sorted according to the machines required for their manufacture, followed by groupings governed by geometrical shape, FIG. 3-6 (b). Further sorting is carried out on the basis of design and operations FIG. 3-6 (c), and lastly division is made by similarities of equipment, tooling and settings used, FIG. 3-6 (d). This method, whilst not the ultimate, does give some of the benefits of Group Technology and could quite easily be installed by a firm without any outside help.

2. Technical Data Retrieval (T.D.R) - is a system designed specifically for the coding of any component, assembly, or technical document so as to facilitate its retrieval from storage. The system is copyright to the American company of Allis-Chalmers and is available to other industrial organisations through Jay-Bergen consultants.

The basis upon which the code is designed is firstly by shape or physical characteristics and secondly by functional or descriptive characteristics. If components or assemblies cannot be coded by shape or physical characteristics respectively, then the functional or descriptive characteristics are used.

The code number consists of eight digits, the first of which is one of five major divisions as indicated by the descriptors in FIG. 3-7 (a). Once the class is determined from this table the remaining seven digits are selected from another table FIG. 3-8, which has sixteen variations of each characteristic under consideration. FIG.3-8 shows the table applicable to class 1 components (Concentrics, other than parallel) and also illustrates the coding of a typical component.

The T.D.R. code is not used as a part or drawing number because one T.D.R. code may pertain to many parts, as shown on the printout, FIG. 3-7 (b).

The code is of numerical-alphabetical sequence and is compatible with electronic data processing facilities. The sixteen characters consist of numbers 0 to 9 and letters A to F.

Whilst this code has independent digit significance which is desirable for Group Technology, its application in this area would be limited because the five major descriptors do not indicate machining families nor do subsequent digits show any such grouping ability.

3. <u>A Classification System to Improve Cost Estimating in the Foundry Industry.</u>[35] - a need was felt by a firm, which produced castings to customers orders, for a better method of estimating costs and finally quotations based on customers

drawings.

The present system relies on the experience and a good deal of guess-work on the part of the estimator. These are reinforced by a second hand knowledge of past scrap and reject rates which are never actually backed up by figures and hence the figure arrived at has often been referred to as a 'guestimate'.

It was concluded that more accurate estimates of cost could be achieved if the following provisions were made, viz:-

(a) All information necessary for the manufacture of the casting is obtained.

(b) A bank of historical information by which the estimator can compare new jobs with old ones.

(c) A system whereby all information is continuously being updated so that the estimator has current facts about such variables as inflation effects, changing scrap rates, material costs, overheads and techniques being used in the production of castings.

The overall system has been conceived in three parts viz:-

(a) Classification - the means of storing data for the categories or classes into which the castings fall so that when new jobs are classified and quoted for, they can be compared with similarly classified castings made previously. The purpose of the classification scheme is to provide,

1. an accurate product definition.
2. an accurate cost estimating system.

(b) Data Collection and Updating - the firm have their own computer, and it is envisaged that all information relating to costs would be stored and updated on a regular basis. An equation of the costing process has been developed and the variables are updated by the computer to ensure the latest possible information is available. The computer will serve three functions, viz:-

1. The output will allow comparisons between present and past costs of making a casting.
2. The present price of an old casting is always available for repeat orders.
3. It will eliminate human errors.

(c) Running the System - upon receiving a job for quotation the following steps are taken, viz:-

1. The job is classified.
2. A computer printout of similar jobs in numerical order of classification digits is obtained.
3. A store of similar drawings is referred to and scrap, reject and cost centre rates are established for the new job.
4. The quotation is calculated.

An analysis has been carried out to test the validity of the system by statistical means and the results look very promising. This led to the development of a costing equation, by means of regression analysis, whereby the digits of the classification number would be used as variables in the cost equation.

This 'classification-cost estimating' coupled system is a promising new development which would undoubtedly lend itself to other cost estimating jobbing industries.

4. A Classification System to Define a Specific Product.[8,9]

This system is recognized as being one of the best of its type; devised specifically for the classification of a particular product and its associated manufacturing features. The company, Ferodo Ltd. manufacture brake linings as well as other friction material products to customer's orders. Their throughput times and delivery dates were long and unreliable respectively and they decided to introduce Group Technology to thecylindrical linings section of the factory to see if the above deficiencies could be rectified. It was decided to classify and code all single products in the chosen area. Before this could be accomplished a satisfactory classification system had to be developed which would enable the formation of product groupings and hence facilitate the design of flowline cells to complete the machining of particular group features. The design of the system was governed by three basic constraints, viz:-

(a) It had to embody the existing Ferodo classification.

(b) It had to define the product and its characteristics.

(c) It had to have independent digital significance.

Researchers engaged on the project placed great importance on the successful completion of the code and indeed a thesis[9] was written on the design of the classification system alone.

FIG. 3-9 (a) represents an outline of the scheme. The unique product identifier is maintained and this is followed by three supplementary codes relating to material and assembly, function and features, shape and size respectively. Provision is also made for expansion to these codes as shown. The actual layout of the code as would appear on a drawing is shown in FIG. 3-9 (b).

It is interesting to note, that the constraint of independent digital significance originally placed on the design of the code could not be strictly adhered to. Although each of the supplementary codes are independent of each other, the first digit of each supplementary code establishes a meaning for the following digits of the code. However, these following digits are independent of each other.

FIGS. 3-10 (a),(b),(c), show how the first digit of each of the supplementary codes is selected and FIG. 3-11 (a),(b),(c), show how the remaining digits are chosen, once a particular first digit is selected. The remaining first digits lead to similarly structured codes for finding their second, third and fourth digits also.

The success of the project, which followed from the design of the classification system, can be gauged by a comparison of the before and after photographs of Group Technology. FIG. 3-12 (a), shows the high value of work in progress which existed before Group Technology, and FIG. 3-12 (b) shows a flowline in a G.T. cell after Group Technology. In the latter, a total absence of the accumulation of work in progress is evident, being replaced by a continuous flow of sequenced batches along the flowline conveyors connecting the various work stations of the cell.

A recent visit to this factory showed that this section of the company was still enjoying the full benefits of the G.T. system. However, a very strange situation exists in which the firm is manufacturing disc brake linings in a plant running paralled to the G.T. cells which is still being run along the lines indicated by FIG. 3-12 (a).

One immediately wonders how this state of affairs could be tolerated when it is realised that the firm has the expertise to instal G.T., the proof of its results and the acceptance of the labour force. Is it apathy on the part of management? Is the cost of conversion so great as to prohibit it? Is the economic climate of the country such that changes of this nature are discouraged? The reasons are undoubtedly sound but one cannot help conjecture, when such a successful implementation flounders at the halfway mark.

5. <u>P.E.R.A. Classification System.</u>[36,37] An unusual classification system was developed by the Production Engineering Research Association (PERA) as a result of an analysis of components taken from a wide cross section of engineering companies. The first survey[36] concerned itself with rotational

components whilst the second[37], included nonturned components.

The code developed consists of two parts, the first of which is called the General Statement and the second the Detailed Statement. FIG. 3-13 illustrates the two statements for a turned component. At the top of the figure, the General Statement consists of a company number, a component serial number, the total number of change points indicating the complexity of the external and internal surfaces, the change points at the maximum diameter and length, (the datums for these two dimensions are the axis of revolution and the extreme left-hand end respectively), then a three digit statement which records workpiece type, material and initial form, followed lastly by the batch size requirements.

The Detailed Statement describes the geometry and features of the component by a series of change points whose co-ordinates are given with respect to the datums referred to above. A table of surface element digits describe such variables as form, accuracy, surface finish, hardness etc., relating to the various surfaces indicated by the change points. The above data is stored on magnetic tape for quick and easy reference.

This type of code is ideal for a study of workpiece statistics but its value as an instrument for Group Technology would be limited, because neither statement relates to geometrical features formed by specific machining or production forming processes.

6. <u>ZAFO Classification System.</u> The ZAFO system was designed by the West German, Zimmerman[38,39], and is interesting as it illustrates how a code can be expanded in an attempt

to identify a component exactly, in terms of shape and miscellaneous features. FIG. 3-14 shows the overall structure of the code which consists of a total of 26 digits. The first three digits are heirachically arranged to describe the basic shape. FIG. 3-15, is the code sheet for class 3 - long solid form components. The group column which best fits the components is chosen, thus fixing the second digit and then the sub-group category determines the third digit. FIG. 3-15 describes all components from 300 to 389. The remaining digits 4-10, FIG. 3-14, complete the additional features section of this part of the code. The next ten digits, 11 to 20, are used as additional descriptors of the second and third digits of the main geometry code. The remaining six digits are mandatory and cover the degree of standardisation (one digit), design modifications (one digit), and individual identification (four digits).

This code is long and unwieldly and seems to contain far too much information for any specific purpose. As with all codes it would require a lot of familiarity to use it accurately and a study of FIG. 3-15 will give some idea how the line of interpretation is very finely drawn. This, along with the extreme length of the code must lead to many coding errors. Nevertheless, the code is copyright and when correctly used, it undoubtedly fulfills its designed function.

7. VPTI Classification System[40]. The Brisch and Opitz classification systems are effectually open-ended systems, because polycodes or secondary codes can be added to them to fulfil a specific function. In the Brisch case, to facilitate the formation of component families for Group Technology and

in the Opitz case to add supplementary features as an aid in design and work planning.

The VPTI system has been specifically designed in Russia, as an open-ended code for Group Technology and as such is of variable length. It consists of a three-digit main code, the first of which is selected from one of five classes, FIG. 3-16 (a), which determines the overall shape and size range.

The second digit, which depends on the first gives the actual size range whilst the third digit specifies heat treatment and accuracy required. Following the main code is a series of two-digit surface element codes which indicate machining features FIG. 3-16 (b). These codes may be added to or arranged to suit the component mix as required.

8. Miscellaneous Classification Systems. The above classification systems are but a few of the many available in industry today in European countries. A list of further classification systems from all over the world which have been mentioned in publications[28] follows:-

(a) The VUOSO Basic System (Czechoslovakia).
(b) The VUSTE System (Czechoslovakia).
(c) The KCI System (Japan).
(d) The PGM System (Sweden).
(e) The IAMA System (Yugoslavia).
(f) The Allis Chalmers System (U.S.A.).
(g) The Stuttgart System (West Germany).
(h) The Pittler System (West Germany).
(i) The Gildemeister System (West Germany).
(j) The Toyoda System (Japan).
(k) The Niitmash System (Russia).

(l) The Litmo System for Punched Cards (Russia).

Undoubtedly there are many more systems in use throughout the world as well as variations of the above. The important fact to be realized about the widespread use of classification is, the importance that industry places on it, as an aid to the management of all manufacturing systems.

3.4 Conclusions.

It is evident from the preceding sections that one of two methods can be chosen as the means of assembling and sorting manufacturing data necessary for the introduction of Group Technology. These are,

(a) Production Flow Analysis.

(b) Classification and Coding.

If the number of firms who have supported one or the other of these methods is any criterion, then the latter is by far the best. However, the arguments put forward by supporters of P.F.A. are well stated and there is little doubt that the first stage of P.F.A., viz, Factory Flow Analysis, could be advantageously applied before any change of system is considered. Supporters of P.F.A. make the following claims[41],

(a) Families and groups already exist within a manufacturing system and it is only necessary to find them not recreate them.

(b) P.F.A. is much cheaper than classification and much quicker and more efficient because it is based on information readily available.

(c) P.F.A. is a universal technique whereas classification has to be redesigned for each application.

(d) A standard computer programme can be designed to find the best division into families and groups. (This claim is unsupported to date, although it is still made[42].)

(e) P.F.A. finds a total division of the whole factory into families and groups and hence makes detailed planning and budgeting possible, before G.T. is introduced.

There is no doubt that component families and machining groups can be found by classification and coding in firms manufacturing any number of components, whereas this ability by P.F.A., especially when dealing with many thousands of components is not sure. Most aspects of Group Technology have been well documented, but one of the most critical of the exercise, that of family grouping, has not been given a clear cut solution. The reason for this is, that each application requires an individual analysis and past users hesitate to nominate a general step by step solution which can be applied in each and every case. It is with the aspect of family grouping that classification and coding shows its greatest advantage over other systems. Family grouping is covered in greater detail in section 4.6.

Classification and coding and the subsequent analysis can be carried out by the firm's employees with perhaps some assistance and guidance in the development and use of a suitable code. Assistance and guidance is readily available from Universities or Polytechnics and indeed as is the case with the projects in this thesis, a complete preliminary G.T. survey was carried out with little or no cost to the firms.

4. APPLICATION OF THE OPITZ CLASSIFICATION AND CODING SYSTEM.

4.1 Outline of Basic Structure and Coding Principles.

The outline structure of the system is shown in FIG. 2-2, which divides it into two codes viz., geometrical and supplementary. Both codes consist of ten digits, 0-9 and are split into class descriptors defining the parameters of the two codes. There are five descriptor classes in the geometrical code viz., component class, overall or main shape, rotational surface machining, plane surface machining and lastly auxiliary holes, gear teeth, forming. Component class is divided into two sections, rotational and non-rotational, in which six digits (0 to 5) are alotted to rotational and four digits (6 to 9) to non-rotational. The supplementary code consists of four descriptor classes viz., dimensions, material, initial form of raw material and accuracy.

The system has been published[6] and is available in two parts. PART 1, gives details of the code structure and PART 2 is a manual which broadly defines the digits allocated to the various class descriptors of both codes. The sequence of digits in the code number representing the classes of the geometrical code are arranged to generally correspond with the sequence of operations required to produce the component represented. For example in the case of a rotational component, the first three digits represent the elements produced by turning, digit four indicates plane surface machining, and auxiliary features, such as holes and gear teeth, which are normally produced last, are indicated by the fifth digit.
All geometrical descriptor classes have fixed digit significance except the first, which focuses attention on separate

digit parameters for the next four classes. These parameters depend on whether the component is rotational, rotational with deviation, flat, long or cubic as shown on FIGS. 2-3, 2-4, 2-6, 2-7, 2-8, respectively. All supplementary code descriptor classes have fixed digit significance FIG. 2-10.

Within each class descriptor the parameters have digit allocations in increasing order of complexity and should two features occur which are classified under the same digit, then the feature which records the highest digit is coded. For example, a rotational component which has an external plane surface machined on it as well as an internal keyway would record a 6 for the keyway even though a 1 for the external plane surface was also applicable. The above consequence may tend to suppress some features, but it is assumed that any machine which can produce the complex feature can also produce those features represented by the lower digit numbers. However, digit suppression is advantageous when working on the composite or complex component principle, FIG. 2-1, for a machine or cell, because it is a simple matter to select the highest digit values in each descriptor class and thus draw up the composite component, representative of the family under consideration.

In the rotational class section there are two coding charts, FIGS. 2-3 and 2-4, to distinguish between purely rotational components (digits 0,1,2) and rotational components with deviation (digits 3,4). A study of the two charts will show that the first three class descriptors are different, the fourth is identical and the fifth is different. A further rotational component class (digit 5) FIG. 2-5 is left blank, to allow a firm coding space for those parts which are unique to the firm and can be described only with difficulty by the first five digits. It has been recommended that a functional notation is best for these components[43]. It is also noted that a similar non-rotational class (digit 9) is provided for unique components in this category, FIG.2-9.

In the non-rotational class there are three charts, FIGS.2-6, 2-7, 2-8, and these distinguish between flat, long and cubic components respectively. The first two class descriptors are different for each, but the remaining three are identical, as shown in the above charts.

4.2 Using the Opitz Code.

Coding is carried out from the component drawing, which must be detailed for manufacture and showing material type and treatment together with its initial form. The first step is to select the component class digit which then directs coding to the relevant coding chart. FIG. 4-1 indicates how this is done by considering the shape aspect along with the size ratios which separate the various digits. Having selected the component class digit the selection of the remaining digits are best illustrated by an example. FIG. 4-2, shows a rotational component and its coding details which are obtained by reference to FIGS. 2-3 and 2-10. A non-rotational flat component is shown in FIG. 4-3 along with coding details which are obtained by reference to FIGS. 2-6 and 2-10.

4.3 The Code Manual.

The Code Manual is PART 2 of the publication[6] and it is designed to facilitate the introduction of the classification system and to ensure uniform and universal application.

In addition to including instructions on coding and suggestions for application in design, planning and production, its main function is to define the demarcations and concepts which are contained in a code. The definitions are arranged in component classes corresponding to the structure of PART 1 of the code and are clarified by sketches which show the features concerned as well as questionable features which are coded under other digits.

It must be understood however, that the definitions in PART 2 are not conclusive, and for any firm, modifications and extra definitions are essential to cope with the requirements peculiar to the firm. FIG. 4-4 illustrates a typical sheet from the coding manual showing a few modifications. The compilation of a comprehensive coding manual is an essential part of the classification system to ensure and provide,

(a) Consistent interpretation of digit significance.

(b) A standard reference for coding instruction.

(c) The rules upon which the system is based.

4.4 Modifications to the Opitz Code.

Users of the Opitz code have found it wanting in certain areas and have made modifications to suit their own needs, and this is one of the great advantages of the Opitz code. In one case, whilst maintaining the original structure of the code, a firm has completely revalued the digits of both the Geometrical and Supplementary codes[20]. FIG. 4-5 illustrates the outline structure of the modified system which should be compared with FIG. 2-2. Most applications do not require such drastic modifications and those carried out for the companies in this text were all that was necessary to satisfactorily code their components.

4.5 Learning to use the Opitz Code.

A great advantage which the Opitz classification system has over more complicated systems is the ease with which the code can be learnt and applied within the company. The people who are likely to be more associated with the coding and its interpretation viz., engineers, tradesmen, draughtsmen, apprentices and designers find it extremely simple to learn because of their technological background. Experience has shown that a seminar consisting of short lectures coupled with practical coding sessions is the best method of teaching the code. A brief outline of the Opitz code is initially given, together with some illustrations of how the code is modified to suit various companies. Participants are then given a set of drawings, which have been specially selected to cover a number of examples of each digit of the component classes. The correct answers are also supplied, so that it is a case of 'try and see'. A satisfactory coding ability is reached after approximately four days, when further expertise can only be gained by involvement in a practical coding exercise. Code comprehension increases with practice and it is not very long before coders are able to look critically at the Opitz code and suggest modifications for its use in the company with whom they are working.

The speed of coding depends on two factors viz.,

(a) The ability and motivation of the coder.

(b) The complexity and completeness of the drawings being coded.

One would expect a professional engineer to code more quickly and correctly than an apprentice, or a tradesman, and indeed this has been found to be the case[44]. On the other hand apprentices and tradesmen make more competent coders than do clerical workers because of the formers' ability to read and understand engineering drawings. The complexity of an engineering drawing being coded is a factor of coding speed. Simple rotational components can be coded at a rate of around 50 per hour whilst complicated components in the non-rotational (flat, long and cubic) category can be as slow as 6 to 10 per hour. It has been found that a rate of from 150 to 200 per day has been achieved in a practical coding exercise[44]. Experience with the components from the companies involved in this thesis has shown a slower rate of around 100 per day, mainly because of the number of complicated fabricated assemblies in the Bronx Engineering case, and the number of unique components requiring special machining sequences in the Hawker Siddeley application.

4.6 Formation of Component Families.

After modification of the Opitz code to suit a firm's individual requirements, and having applied the code to all component drawings, it is then possible to analyse the component code numbers with the object of forming family groups of components which are compatible with machine groupings able to be formed from existing machines on the shop floor.

Such analysis is simplified when one realizes that the first digit of the geometrical code immediately sorts components into specific categories of rotational and non-rotational, with further division into specific types of these two groups according to the component dimension ratios. A computer printout of component code numbers in numerical order will automatically achieve these divisions, FIG. 4-6 illustrates a section of computer printout showing how groups of components are divided into families according to the significance of the first digit which is described on the right hand side of the figure for each family. Further sorting is carried out within these classes by subsequent digits which are arranged to describe external and internal shape features, auxiliary holes etc.. The dimension digits of the Supplementary code create divisions which suit the size ranges of machine tools available, whilst the material, initial form and accuracy digits enable further sorting to be carried out.

A large amount of digital analysis can be done manually (as was the case in this report) or by further use of the computer when many thousands of components have to be considered. As an example, programmes have been written and used to determine the following[62],

1. Groups of components according to their total number of digits - Opus.

2. Groups of components according to the total number of digits of the Geometrical code - Oput.

3. A histogram showing the distribution of batch sizes - Opal.

4. (i) Details of milling operations.
   (ii) Separate sheet metal components from other non-rotational components - Gras.

5. Sort rotational components according to length to diameter ratios and deviation characteristics - Grassy.

The above programmes illustrate the versatility of a computer analysis of the code and it is this feature which makes the classification and coding approach to Group Technology so attractive.

The practical use of the code and the subsequent computer printout analysis will be explained in more detail in section 7. FIG. 4-7 (a) and (b) taken from Ivanov[34], illustrates how groups of similar shaped components can emerge from an apparently random mixture of rotational parts. It is this kind of sorting and grouping which can be achieved by the use of a properly designed classification system.

4.7 Other Uses of the Opitz Classification System.

While the Opitz code has been primarily used for the formation of component families in the implementation of Group Technology, its application in other areas has not been overlooked.

Perhaps its best support role is in the design department where it can be used for the following:-

(a) Retrieval of past design data.

(b) Standardisation of design procedures, components and component features.

4.7.1 Design Retrieval.

The main reasons for poor design retrieval methods in a company is the haphazard naming of similar type components, and the fact that drawing numbers do not convey the information necessary to identify design similarities. Component names vary according to the whim of the designer and geometrically similar components are given a variety of names e.g. bushes are also called spacers, bearings, rollers, washers, sleeves, liners, packers and collars. While these names do bear some semblance of similarity to the experienced designer, many names do not, e.g. a bush type component called a 'shaft stop' would bear no similarity to the bush type family. Hence, reliance on names for design retrieval, is generally ineffective.

The Opitz classification system affords a means of grouping components according to the geometric design features represented by successive digits of the code. If the code has been structured along technological lines, it is almost certain that some components with similar design features may not be grouped in the correct design family because of their manufacturing differences. The loss of accuracy caused by using the code universally, is reflected in the amount of manual sorting found necessary by design personnel. In application, the components are listed in code number order and this listing can be reproduced in one of two ways as proposed by Brankamp[43], viz., micro-film aperture punch cards or a reuse parts catalogue FIG. 4-8 (a) and (b) respectively. The punch card, besides containing component data can also carry a film image of the component enabling a visual reference which is quite often much quicker than a data reference when checking similar parts for re-use. In the case of simple, much used components of which there is always high variety, such as flanges, covers and bushes etc., a repeat part catalogue can be developed. The type illustrated shows a composite sketch of the general component and a computer listing of all existing parts which fit the sketch in part or whole.

Hence, when designing a new part, the designer must have a knowledge of the component's basic shape, size and material composition so that he may be able to code it and subsequently retrieve similar designs from the punched card file or the reuse catalogue.

4.7.2 Design Standardisation.

In many engineering firms the design of components is solely the responsibility of the designer who may allocate features according to his momentary whim or fancy, resulting in many similar components differing in such trivial features as chamfers, rounds, fillets, radii, undercuts etc.. Also many components are designed which are geometrically similar to other parts, although this fact may be unknown in cases where design retrieval facilities are not available. In fact if it were known, many existing designs could be reused, instead of creating new ones with only minute differences. To enable existing designs to be easily accessed, components are grouped according to code numbers and used to form a code number field as shown in FIG. 4-9 (a). The field is in the form of a matrix into which the code numbers of the component group are put. All digits are entered so that for any component of the group in question, its code number can be read off and the digits located in the matrix. If a component has features which are not required in the field, then the component should be omitted from the group under consideration. The code field shown in FIG. 4-9 (a), represents the long rotational class (digit 2) of the sample of components coded for Bronx Engineering using the modified Opitz code. All components considered in the matrix are ticked from the list shown in FIG. 4-10, whilst those not considered have a cross along side. These components comprise nearly all the class 2 components of the sample and represent a series of shafts stepped to both ends, with and without functional grooves and screw threads, without internal shape elements, with and without keyways and having auxiliary holes and gear teeth. The digits shown in the Supplementary code field indicate the dimension ranges of diameters and lengths, the material and its form used, and the type of contracted work considered in this field. The Bronx Supplementary code is shown in FIG. 7-7.

Having entered these components in the code number field it is then possible to draw a composite or complex component which incorporates all the features indicated by the digits entered in the field. The component is shown in FIG. 4-9 (b). It is now true to say that this complex component represents <u>all</u> the features of <u>all</u> the components ticked off on the computer printout sheet, FIG. 4-10. Thus standardisation of shafts in this group can be considered simply by referring to the composite component, FIG. 4-9 (b). The composite can be accompanied by lists of standard or preferred keyway sizes, gear teeth, auxiliary holes, thread forms etc., as well as information on supplementary code data, so that when designing similar shafts these preferences or standards can be adhered to. If changes in design affect the code field and hence the complex components, then they should be immediately updated to accomodate such changes.

If a series of code fields are drawn up to represent groups of frequently used components, considerable time can be saved in designing as well as substantial reductions in the variety of form features.

4.8 Conclusions.

The use of a classification and coding system is one of a number of methods used to introduce Group Technology. Its relative merits compared with other methods, has been, and will always be a point of conjecture. However, it has been proved successful and found to be one of, if not the most economical way in which a firm can approach the implementation of Group Technology.

The component analysis which is carried out in conjunction with the design of the classification system and the subsequent coding of parts, is in itself a 'cleaning out the cupboard' exercise and affords as well, a reappraisal of the component spectrum which in all probability is long overdue.

The time taken to code the drawings enables management to consolidate their ideas and formulate the best possible means of introducing the new system with the least disruption to all concerned.

The comprehensive data bank which is generated by the coding of all drawings gives the design department a new source of information on which to base their design procedures as well as instal design retrieval and component standardisation facilities.

A classification system must be designed to suit a particular company; there is no universal system which can be applied 'en toto' to the broad cross section of industry.

The Opitz Classification System does, however, offer a universal structure which can be applied across the board. The number and interpretations of structure digits can be manipulated and modified until the code is ideally suited to the firm concerned.

The 'classification and coding' approach to Group Technology is ideally suited to the present day, uncertain economic conditions for the following reasons:-

1. It can be installed by the firm's own personnel.

2. There is no great pressure on the firm to get things done, and progress can proceed at the firm's own pace or as money becomes available.

3. There is no committment on the part of the firm; the exercise can be aborted or held in obeyance at any stage.

5. EFFECTS AND BENEFITS OF GROUP TECHNOLOGY.

5.1 Introduction.

The effects and benefits of Group Technology have been well documented over the years in publications, academic presentations and articles written by engineers from various firms in industry. A resume' of the most important benefits and effects, and the manufacturing areas in which they are concerned is shown in FIG. 5-1.

These areas are:-

(a) Design.

(b) Production Planning.

(c) Production Control.

(d) Manufacture.

(e) Management.

The areas of Production Planning and Control which overall constitute Production Engineering, are by far the largest areas of interest as far as Group Technology is concerned. An analysis[45] carried out on 150 companies in 1972, by the once functioning Group Technology Centre established the major areas where firms sought solutions to problems. The areas and their relative importance expressed as a percentage of the number of firms seeking solutions in these areas are approximately:-

(a) Production Engineering - 56%.

(b) Management - 19%.

(c) Design - 14%.

(d) Manufacture - 11%.

Whilst many firms start out with the purpose of improving the function of one area or the other, in most cases the benefits of Group Technology become so apparent in the other areas, that an overall approach becomes desirable. However, it is worthwhile highlighting the benefits as they apply to the singular system areas as defined in FIG. 5-1.

5.2 Design.

(a) Ease of Retrieval of Past Design Data. An outline of design retrieval methods was covered in Section 4.8.1.

(b) Standardisation of Common Features. This topic was dealt with in Section 4.8.2.

(c) Standardisation of Components. This topic was dealt with in Section 4.8.2.

(d) Greater Application of Value Analysis. If a firm is seeking to improve its design function, then all techniques associated with the evaluation of components both from a functional as well as a manufacturing aspect become more important. The application of Value Analysis is not a 'must' as far as Group Technology is concerned, it is merely one of the most useful evaluation methods which firms turn to, when the 'wave of reappraisal and change' due to the implementation of Group Technology, strikes them.

(e) Standardisation of Procedures. The standardisation of procedures is a logical follow on from the establishment of (a), (b) and (c) above. Once the means of retrieval are in hand and design rules regarding common features and components have been formulated, standard procedures for creating a new design can be implemented. Such a procedure is outlined in FIG. 5-2. The use of a design plan ensures the following desirable results:-

(a) Elimination of a slovenly or short-cut approach to component design.

(b) Provides the best possible component to suit the assembly concerned.

(c) Ensures the cheapest possible component without sacrificing quality.

(d) Avoids the proliferation of identical or near-identical parts.

(e) Creates a sense of pride and job satisfaction, knowing that all components are designed to a minimum, basic, high standard.

If the methods outlined in this chapter are incorporated in a design department there is little doubt that personnel would feel they were part of a highly efficient, well organized system in which they are proud to work.

5.3 Production Planning.

(a) Production Data Retrieval. After the initial introduction of Group Technology and the function of the Production Planning section reverts to its routine role of planning, scheduling and routing components through the manufacturing cells, it has been found that the retrieval of past production data such as operation sheets, route sheets etc., for components is desirable because of the repetitive nature of these items. With a functional layout, identical components quite often require new operation and route sheets because they are machined in different cost centres. In a G.T. situation, components are routed to certain cells according to the component family to which they belong, thus creating a repetitive route for each manufacturing cycle. Each cell is equipped with all machines, tooling, jigs and fixtures necessary to complete all operations on the family of components for which it is designed. As a result, a repetitive sequence of operations is obtained for a particular component for each manufacturing cycle.

With this situation, it is only necessary for the planner to retrieve past production data and reissue it each time a component is scheduled through its manufacturing cell.

(b) Simplified Accounting and Estimating. In a functional situation, the accounting and estimating processes often assume nightmare proportions, where in the case of accounting, each cost centre (machine tool or process) has its own rate for costing purposes. The manufacturing cost of a component is determined by adding the individual cost of all cost centres which perform operations on the component. As well as the manufacturing cost, a percentage is added for overheads and profit margin to give the total cost to the customer. With the variable routes and consequently different cost centres visited, manufacturing costs vary for individual components and firms tend to allow for the highest when fixing sale prices for products. Hence their products are less competitive and on jobbing work where estimates and quotations are required, firms often lose valuable contracts because of exceptionally high prices quoted, which are attributable to unreliable estimating procedures.

In a G.T. situation, both accounting and estimating are greatly simplified. As components are coded, their routes through the manufacturing facilities are automatically fixed, i.e. they are produced by the cell designed to manufacture them. Thus the accounting cost is isolated in one cell of machines. In fact the cell can be looked upon as a cost centre with an hourly rate. The cell method of costing was adopted by Serck-Audco[7] and in fact Ranson suggests an hourly rate for a whole factory. Estimating costs for quotations and jobbing work, is also made easier, because once the job is coded and its manufacturing cell time is calculated, the manufacturing cost is simply the product of the time and the cell rate. Estimates calculated in this way are reliable and more competitive, because by knowing the exact manufacturing cost the sell price can be kept as low as possible without the fear of selling at a loss.

As well as the reliability of accounting and estimating associated with G.T., a firm can also enjoy more simplified procedures because of the combining of individual machine cost centres into cell or even factory cost centres.

(c) <u>Easy Preparation of Operation Schedules.</u> Operation schedules require much thought and careful planning in a functional workshop. A planner must know the route and machines (which often change after the schedules are made) a component will take and visit respectively, so that he may visualise the operations needed in order to complete the operation sheet accurately. Many components can be produced on more than one machine or series of machines, resulting in different operations and times and it is the planner's job to select the best schedule of operations available, at the same paying attention to such variable factors as the availability of machines, overloading conditions, available labour and raw materials.

Once again, G.T. makes the scheduling of operations a relatively simple exercise in the majority of straight forward repetitive cases. In fact, many companies using Group Technology allow the cell operators to schedule components through cells themselves, thus eliminating the operation sheet in many cases. With a firm manufacturing identical components in every cycle, it is understandable that cells manufacturing the same components repeatedly, could well dispense with operation sheets, or alternatively retain them in the cell for use on each occasion. In a jobbing workshop, however, operation sheets are always necessary; but how much easier the planner's job is, if all he has to do is direct the operation sheet to a particular cell in which he knows there are the ideal types of machines to give him the best sequence of operations without having to worry about the lurking variables mentioned in the last paragraph.

(d) Reducing Cost of Tooling Set-up. The main way in which this cost has been reduced in a G.T. workshop is in the time and frequency of set-up rather than in the actual cost of purchasing tools. However, claims by firms on this point vary considerably. By paying particular attention to the design of components machined at Alfred Herbert[46] on a twin spindle Max-E-Mill with a 40 tool magazine (20 for each spindle) it was possible to enable all operations on this machine to be completed on all components with a maximum of 20 tools, so that a new component required only the changing of the tape. The outcome of this exercise was a reduction of 65% in the number of tools required and a reduction in floor-to-floor times of 10%. The exercise could certainly have been carried out without a G.T. reference, but it must be remembered that the particular family of components suitable for the analysis would never have come together without the family grouping associated with Group Technology.

In support of the reduction in set-up time and frequency, the firm of G.E.C.-Elliott Control Valves Ltd. claim[47] a net saving in setting times of 60% on three machines viz., two capstan lathes and a vertical mill, which formed a G.T. cell to machine a family of components designated as 'seat rings'. As with the Herbert case, this saving is made possible by the grouping of similar components which can be sequenced through the machines in a preferred order to minimize tool adjustment or changes.

The output of any machine tool is directly proportional to the cutting time. In functional situations various percentages have been quoted for the proportions of cutting times and down times in industry. One example[12] quoted for a general purpose, small batch, machine shop lists the following percentages:-

10%	setting up the machine tool.
30%	metal cutting and machine manipulation.
5%	loading and unloading components.
55%	general waiting time, finding tools, reading drawings, maintenance, management problems.

A recent survey carried out in the West Midlands[48] and part published in the Birmingham Evening Post on 15th July, 1975 stated,

> 'Labour and equipment is effectively used for up to half the time in medium-sized West Midland firms. A survey showed that none of the firms checked had machines in production use for more than two thirds of the time. Figures as low as 17% were recorded. During a typical working day, machines in the electrical industry sample were idle more than 60% of the time, with management responsible for most of it. When inefficiencies were pointed out, firms involved in the survey were usually very prompt to ensure improvements. The great problem was that most inefficient firms were among the last to come forward.'

The analysis showed that up to 45% of manufacturing time was setting-time, so that if this could be reduced by 60%, then cutting time could be increased by as much as 27% with a corresponding increase in output. This being achieved of course, without any increase in total manufacturing time.

Decreases in setting-times are usually found to be one of the 'follow on' benefits of G.T. rather than a 'planned' benefit. As cells become more proficient in manipulating work loads and working out preferred sequences of operations, then reductions in setting-times is a logical result.

(e) Simplified Data Processing. All data concerned with Production Planning can generally be assumed to roughly correspond to the number of components processed and the number of cost centres used in processing. Thus a factory manufacturing 2000 components on 20 machines would have twice the data processing requirements as a factory manufacturing 1000 components on 10 machines.

In a G.T. System components are sorted into families and machines are grouped into cells. Hence the 2000 components mentioned above might form 20 families and the 20 machines might form 4 groups. These families and groups have corresponding data processing to the individual component and machines. Hence it can be expected that data processing requirements would decrease by a factor of from 50 to 75 per cent.

Such reductions have been bourne out by the application of G.T. in the small company of Thomas Mercer Ltd.[49].

5.4 Production Control.

(a) Improved Throughput Times. This factor of production engineering is perhaps one of the most fruitful areas to benefit from the application of Group Technology and is always quoted by firms as one of the major reasons for G.T. implementation. A look at the basic methods of shop floor manufacture relating to functional and G.T. layouts will show how very large reductions in throughput times can be achieved. A study of FIG. 5-3 shows a comparison of how throughput times compare for the manufacture of a component through a functional and a group layout of a lathe followed by a mill. It is assumed that the operation times for both turning and milling are 5 minutes in each layout. The component is a stepped shaft with keyways on both ends as shown and is manufactured from bright M.S. bar. One hundred components are required.

Commencing at the left of the diagram, all turning operations are completed in both layouts after 500 minutes. The main difference in the two procedures is that after the first component is turned in the group layout it proceeds immediately to the milling machine located nearby, where the keyways are then machined. This gives a total throughput time of 505 minutes. In the functional layout where the lathe section has no physical or functional connection to the mill section, all components have to be turned first before proceeding to the mill section where a further 500 minutes is required for the milling operations. Thus in operation times alone the group layout shows a 50% improvement over the functional layout. However, the big reduction in times is usually found to be work-in-progress (W.I.P.) times which are greatly reduced with cell manufacture, and can frequently amount to weeks and months in a functional system.

Many examples of outstanding gains in throughput times have been claimed e.g. Serck-Audco - 12 to 4 weeks[17], Alfred Herbert - 36 to 3 weeks[46], Thomas Mercer - 16 to 4 weeks[49], Baker Perkins - 9 days to 3 days[25].

(b) Improved Delivery Dates. The ability to quote short and reliable delivery dates is the most profound yearning of all production engineers. With the elimination of indeterminate work-in-progress times as explained in (a) and a planned sequence of manufacture, component completion dates are not only the shortest possible, but also very reliable and hence quotations for deliveries of completed assemblies are as correspondingly reliable. Reliable and short delivery dates are features of Group Technology which are much appreciated by the company salesmen who no longer have to quote delivery dates with a 'tongue in cheek' philosophy. Valuable contracts can often be won by a firm able to quote better delivery dates than its competitors.

* (c) Simplified Work Scheduling and Machine Loading. These two features of Production Control create the greatest

bottlenecks in production and are the crux of most problems associated with the flow of components through a functional workshop. Scheduling is carried out mainly by allocating materials to machines in the correct operation sequence and expecting the partly finished components to form queues awaiting their turn on one cost centre after another. Priorities are established and put into effect by progress chasers whose job it is to move high priority components to the front of queues in order to complete them more quickly. This of course plays havoc with tooling set-ups on machines and entirely disrupts any preferred order of components made to lessen tooling and jig and fixture changes.

Scheduling and loading go hand in hand and if components can be scheduled correctly then the machine tool concerned can handle a far greater load than if haphazard scheduling is carried out.

In a Group Technology situation, components are scheduled for processing in a cell in a preferred sequence taking into account their demand for assembly, as well as the operation sequence to take advantage of tooling set-ups within the cell. Due to the similar geometrical features of cell families, much greater thought can be given to loading in order to minimize tool changing and setting. If consecutive components can be accomodated on a machine simply by adjusting a few stops and making one or two minor changes, setting time is reduced and metal cutting time is increased significantly.

(d) Reduction of Work in Progress. The reduction of work in progress which inevitably results from Group

Technology methods is a direct benefit of the type of component flow necessary for the proper functioning of machine cells. The tooling set-up of cell machines is geared to receive a continuous flow of components. In the ideal situation, when one machine completes its operations, the component is immediately fed on to the next operation machine, and so on until all identical components are completed. Hence at no stage during manufacture are components queued or forming what is commonly known as 'work in progress'.

In firms which are manufacturing to capacity or over capacity, the build-up of work in progress often assumes gigantic proportions and stacks of unfinished components dominate the overall scene, FIG. 3-12 (a). Coupled to the extreme inconvenience caused by this accumulation of work, is the large outlay in capital costs necessary to have it there. With the near elimination of work in progress, this capital outlay is freed and able to be put to a more productive use, and in many cases more than pay for the cost of installing Group Technology.

A flow-on benefit which results from reductions of work in progress is a gain in factory floor space. In many instances usable factory space has been increased by between 25 and 30 percent. Such a saving makes way for the improved layout and streamlined component flow system synonomous with Group Technology.

A look at the published benefits of the following firms will illustrate this most important aspect of Group Technology.

1. G.E.C.-Elliott Control Valves Ltd.[24] - reduction of W.I.P. from 24% of annual turnover in 1968 to 18% in 1971.

2. Ferodo[10] - reduction of W.I.P. by a factor of 8 : 1.

3. Herbert Machine Tools[20] - reduction of W.I.P. and manufacturing stock from £4.5 million to £1.8 million, representing a percentage reduction of 72% (Ref. 46).

4. Rank Xerox Ltd.[13] - reduction of W.I.P. between 8 : 1 and 10 : 1.

5. Thomas Mercer Ltd.[50] - reduction of W.I.P. of 35%.

6. Fluidair Compressors Ltd.[51] - reduction of W.I.P. of 60% in the first year of G.T. operations.

(e) Improved Material Utilisation. The economic utilisation of raw materials during manufacture is of great concern in modern day industry because of the difficulty and uncertainty in obtaining them and also the very high costs involved.

In a functional situation where any machine or process can be the first operation station depending on the scheduling and loading arrangements, the allocation of raw materials is made to many points throughout the factory, requiring skilful planning and control.

Group Technology manufacture differs greatly from the above situation. Firstly, because of the singular identity of cells and the family of components which is machined in it, there is not the necessity to plan and control raw material flow like there is with a functional layout. All raw materials for a particular family of components automatically go to the cell associated with them.

Secondly, the number of raw material drop points is reduced considerably from that of single machine cost centres to the cellular group cost centres.

Thirdly, the scrap and reject rate of batches manufactured within cells has been found to be much less than similar batches manufactured in a functional workshop. Scrap and rejects occur most frequently during the setting and checking stage and as the later requirement is significantly reduced by Group Technology, then scrap and rejects are proportionately less.

The general improvement in quality of work and reduced scrap rates achieved within a cell is attributed to the greater degree of control over consecutive operations, coupled with a self generated sense of pride, which one might call 'team spirit', commonly associated with the small group of workers whose interlinked activities so greatly affect each other. The cellular control of component manufacture enables rectification of potentially scrap components to occur almost immediately faulty manufacture takes place. As components proceed through a cell and faults are discovered by subsequent operators, rectification of the faulty operation is immediately effected thus preventing further faults occuring as would be the case in a functional process where components are bin fed between operations.

The ultimate in raw material issue and handling has been proposed[17] as the provision of storage facilities within each cell to hold all raw material necessary to manufacture components for each cycle. Materials are moved to the cell before the start of each manufacturing cycle so that the optimum machine loading sequence of component manufacture can be determined and adhered to.

5.5 Manufacture.

(a) More Efficient Use of Machine Tools. It is in this area that Group Technology makes one of the most worthwhile contributions to production engineering. The efficient use of a machine tool, means the percentage of metal cutting or metal forming time compared with the total time. It can also mean whether the machine is being used for its designed purpose or capacity. The under-utilization of machine tools has long been realized by investigators but firms have made little effort over the years to improve the situation. It must also be understood that the life of a machine tool is long, and many machines in use today may have been purchased by the firm's predecessors 10, 20 and 30 years ago[55], when the need for improved methods was not as great as today. The findings of Professor Opitz's statistics have already been mentioned in Section 2.1 and even today, reports of the inefficient use of machines are still being made. To quote from Professor Dudley's analysis[48] of West Midland firms, Evening Mail, July 15th, 1975.

> 'Machines were often too big and, by implication, too expensive for the job they were doing. In one company one-third of all components produced on a 25 ton press could have been produced on one with a quarter of that capacity. Less than a quarter of the machines studied were working at the best speeds to ensure a satisfactory product, produced economically.'

The implementation of Group Technology does not mean that new machines have to be bought, although in many cases firms use the ensuring rearrangement of facilities to take the opportunity and throw out old equipment and replace it. In so doing they can choose designs which are more aptly suited to the cellular application. This aspect will be covered in Section 5.5 (c).

The reduction of setting times has already been dealt with and is one of the main ways in which machine tools can be used more efficiently. Another area which can be exploited is the development of specialized machine tool jigs and fixtures for use on component family manufacture rather than for single components.

An excellent example of this approach is given by S. Crescimone[52], a development engineer at the Fiat Co., Torino, Italy. FIG. 5-4 (a),(b), (c) and (d) illustrate four different components with the jig required to carry out the drilling operations on each. An examination of the four components shows that as far as the drilling, spot-facing, tapping and chamfering operations are concerned, they belong to the one technological family. The study led to the design of a common jig shown in FIG. 5-4 (e) with automatic, air-hydraulic clamping control and quick-change inter-changeable bushes. The big advantage which this combined jig and fixture offers is, that batches of all four of the components illustrated can be processed without any need for fixture change or adjustment as would be the case with the individual designs. The net result of this kind of production thinking is of course more efficient use of the machine tool concerned.

(b) Improved Factory Layout. Perhaps the most visible effect of Group Technology is in the rejuvenated layout of the factory floor. The two types of layout shown in FIG.5-5 (a) and (b) are respectively, Functional Layout and Group Layout. The former is the most common in industry today, because it has been perpetrated since the days of the Industrial Revolution. Group Layout is associated with

Group Technology and it is with this type that we are concerned. There is little doubt that Group Layout is superior to Functional Layout and it is characterised by the absence of, queues of work in progress and regimented arrangements of machine tools. Passageways are wide and uncluttered and there is an abundance of shop floor space.

Group or Cellular Layout is one of four basic types, viz:-

(i) A Fully Integrated Group Flowline System, FIGS. 3-12 (b) and 5-6 (a) - where the use of conveyors for work flow between machines is utilized. Machines are arranged in a sequence so that all operations performed are done so on proceeding machines, thus eliminating 'back-tracking'. A component need not visit every machine on the line and hence operators are required to move from machines not being used. The length of conveyors between machines is designed to create a buffer for components which may accumulate due to inbalance of operation times.

(ii) A Semi-intergrated Group Layout, FIG. 5-6 (b) - in which conveyors are used for between process storage and transportation purposes only. The conveyors do not connect consecutive machines and 'back-tracking' of components is possible.

(iii) Group Layout System, FIG. 7-14 - a cell of machine tools without any interconnected transportation facilities is grouped in the best possible order to carry out all the processes necessary on a family of similar parts. A general flow of work is assumed and the majority of components will follow this path, however, some 'back-tracking' will occur. It is also possible that a component may have to visit a machine more than once in the cycle, so that some delays may eventuate.

A feature of the Group Layout System is the complete independence of the group as far as the manufacture of components associated with it are concerned. It is recommended that the group has its own tool, jig and fixture store, raw material store, inspection, quality control, work planning and data facilities.

The cellular type of layout to date, is the one most commonly used for Group Technology implementation. The design of a homogeneous group of machines capable of handling a given work load and positioned in the most advantageous manner requires careful analysis and planning. A recent publication[53] featured one method of approach to this problem which proved successful in a practical Group Technology situation.

The method is outlined as follows:-

(a) The machines and their capacity utilisation required to set up the cell was determined by the use of two part number-machine matrices which,
   (i) Listed the operation time for each machine and each component.
   (ii) Obtained the annual load by multiplying each operation time by the annual component requirement.

   The annual load for each machine was divided by 2000 to give an indication of the machine and labour requirements.

(b) The number of direct operators needed was 33 and based on the ideal cell size of 6 to 10 personnel, the indication was, that 3 to 5 sub-groups were required, and a flow analysis was used to determine suitable break-points in the flow pattern to coincide with sub-group boundaries.

(c) A 'To-From' flow chart using the machines in question recorded movement of components from one machine to another. The overall frequence of movement indicated three levels of flow viz., primary, secondary and tertiary.

(d) A network of primary flow patterns proved very complex and was even more so with the secondary and tertiary patterns included, hence one primary flow pattern was determined and the others attached as subsidiaries. This was achieved by selecting the machine which had the greatest difference between 'From' and 'To' totals, indicating that it was the machine from which the majority of components start their operations. By starting from this machine and tracing through the highest transfer frequencies, the primary flow pattern was established. Other transfer frequencies were checked to complete the overall flow pattern.

(e) The flow-pattern was simply converted to machine tools, but proved somewhat difficult when the machine type appeared more than once on the chart, requiring further calculation.

(f) Sub-group boundaries emerged and taking into account particular manufacturing restrictions, 4 sub-groups or cells were decided upon.

(g) A model shop layout was constructed, based on the flow chart, where final cell design details were completed.

The cells designed to this plan have been partially implemented at the date of publication.

(iv) <u>A Single Machine Cell</u>. Many components, because of their simplicity or their uniqueness can or have to be produced completely on one machine and where the machine loading is great enough this machine can be treated as a single cell e.g. small rotational components produced in large batches on a capstan lathe, or large cubic shaped castings machined completely on a floor borer. The general approach to this situation is to analyse the component drawings of the family to be machined, and then produce an integrated drawing incorporating all the features found to exist on the individual drawings. The result is a 'composite' component, FIG. 2-1. The single machine is then tooled up to produce the composite component or any component having combinations of features which exist on the composite.

A single machine cell was very successfully applied by Ferranti, in Scotland[54] to small components. A Hardinge turret lathe was found suitable, because the tools could be set on a fixture away from the machine, thus reducing down-time. FIG. 5-7 (a) illustrates a typical set-up for this machine and FIG. 5-7 (b) a range of components which can be machined using the set-up in (a). FIG. 5-8 (a) and (b) show two further composite components and their tooling requirements. Different preset turrets are mounted on the lathe and checked within 15 minutes. Individual tools can be preset and put in the turret on the machine, in a minute each. Set-up time on the machine is kept to an absolute minimum and Ferranti quote it as 5% of conventional time. Stop setting has been eliminated by the use of digital readouts, thus making further reductions in machine setting.

Using this technique the firm was able to manufacture fortnightly quantities at a cheaper rate than they could previously for three monthly quantities, thus obtaining flexibility and at the same time substantially reducing finished stocks and hence holding costs.

(c) Development of Better Suited Machine Tools.

This is a feature of Group Technology which has not developed to any significant extent, because of the small number of firms using Group Layout, resulting in poor demand for the type of machine tools in question. Opitz's statistics[5] highlighted the underutilization of machine tools as did the later surveys[36,37] by PERA. They indicated the need for the development of a different breed of machine tool which was more specific in its application than the universal type commonly found in industry today. Typical designs of machine tools suitable for simple workpieces and use with G.T. were proposed by Moll[55]. Because of the elimination of unwanted features on these machines, FIG. 5-9 (a), they are cheaper and occupy less floor space than conventional machines, FIG. 5-9 (b). It is unlikely that machine tool manufacturers will design and produce any wide ranges of specialized machine tools unless the demand is there; but this may eventuate as Group Technology becomes more widely accepted by industry.

(d) Machine Operator Flexibility. Because of the under-utilization of secondary machines in a cell, it is necessary for some or all of the personnel of a cell to move to and from machines within the group, as the need arises. Operator flexibility is not common in a conventional shop where operators tend to stay on the one machine, and there are many instances of men spending 20 and 30 years on a particular machine. In some cases the resistance to flexibility hinders the progress of cellular operations, but firms have generally found that after an initial period of resistance, workers come to terms with the situation and eventually do what is required.

Should the occasion arise when an operator is absent from work for a day or even weeks, then his machine need not lay idle and this ability to cover up absences by labour flexibility also applies to holidays which can be planned so that the cell keeps going with a minimum of disruption.

In one case[13], it was found that operators working in the new environment of a cell moved freely from machine to machine whereas, before, in the functional shop, there had been great reluctance to do so.

In many cases there is an over emphasis placed on operator flexibility and opposition to it on the part of shop floor personnel is generally a way in which they are able to offer resistance to the implementation of G.T.. Before stressing operator flexibility as a requirement for G.T., the degree of flexibility required for cells should be determined and its requirements imposed on the cell personnel with a minimum of publicity once the cell has been set up.

Some practical G.T. installations have experienced opposition to flexibility of labour, whilst in others it has not been a problem. One compromise approach[13] has been to allow the key machine operators fixed responsibility and to have flexibility among the deburrers, millers and drillers. A half-way approach may prove feasible in companies where stiff opposition is encountered, and where complete acceptance of flexibility is expected to follow at a later date.

(e) Use of Preset Tooling. Preset tooling has already been treated under section (a) above, where the 'composite' component approach to cell design was described. The use of preset tooling, however, is not confined to a one machine application, and generally develops within a G.T. system once it is in full swing and engineers are looking at ways and means of improving methods to gain the utmost benefit. Tool manufacturers pay much greater attention to presetting devices for machine tools in present day industry. Quick-change tool holders for centre lathes enable a variety of turning tools to be preset and brought into action at a moment's notice.

As with many other techniques, presetting does not need Group Technology to introduce it, but in the general endeavour to improve, which Group Technology engenders, tool presetting along with other techniques is given much greater emphasis than it would normally.

5.6 Management.

(a) Employee Satisfaction and Job Enrichment. One of the greatest changes which has emerged from industry over the past five years is the change in relationship between employer and employee. No longer does a firm use its employees like so may robots whose job it is to get the work done irrespective of their personal feelings. No longer will the employee accept the automaton role, where his working conditions and environment are factors over which he has no control.

Whilst our manufacturing methods have changed little since the Industrial Revolution, human relations in industry have made giant strides and it seems that they will continue to do so. Many firms in industry today are paying large sums of money to study ways and means of wooing their workforce and such benefits as long service leave, bonus schemes, profit sharing, added value schemes and increased worker participation in management, are but a few of the ploys which have been used to improve employee satisfaction.

Group Technology also plays its part in increasing employee satifsaction. Two very good papers on the human aspects of Group Technology were delivered by well known authorities on the subject, viz. J.S. Wilford, Vice President-International, "Production" Journal and F.W. Craven, Planning and Development Director, Herbert Machine Tools. Ltd., Coventry. The first[56] lists the following social values, which are attributable to Group Technology in the order in which they become evident.

1. Identification with the product.
2. A sense of responsibility for quality.
3. The ability to communicate freely.
4. Job Enlargement.
5. Increasing autonomy.

The second paper[57] compares past with present human relations in general engineering workshops, the present situation and problems encountered in cellular groups and a forecast of the future of Group Technology with respect to human relations. The term 'job enrichment' naturally goes hand in hand with employee satisfaction, because if an employee is given more interesting, more absorbing and less monotonous work, he will surely be more satisfied.

Job satisfaction may be defined by the following indicators.

(i) Earnings - A worker might be satisfied or dissatisfied with his weekly earnings.

(ii) Working Conditions - Heating, lighting, acoustic environment etc. are all factors which affect job satisfaction.

(iii) The Job - Jobs done by workers vary from trivial, fragmented, short cycle tasks to complex and challenging jobs. The nature of these will affect job satisfaction.

(iv) His Colleagues - The relationship which a worker has with his colleagues will have a big bearing on job satisfaction.

(v) Management - The relationship with managers, superiors etc., in the enterprise is a factor of an employee's satisfaction.

(vi) Prospects - The hope that his job will lead to some desirable future will have a large influence on an employee's satisfaction with his job.

There are three ways in which jobs can be enriched, viz.,

(i) Raise and/or lower the degree of skill or mental effort required by an employee during the course of his daily activities.

(ii) Broaden or widen the range of tasks to give him greater variety, without requiring him to increase his skills or mental capacity.

(iii) A combination of (i) and (ii).

Case (ii) is also termed 'job enlargement' for obvious reasons.

Many well known firms have made changes in their production methods to incorporate one or more of the three cases mentioned. Burbridge quotes[17] such well known firms as Saab and Volvo (cars), Phillips (television sets) and I.B.M. (typewriters) as having dispensed with the line assembly of their products in favour of the autonomous group assembly. Volvo's transition is quite unique to the car industry and can be held up as an example to others of what can be achieved by fostering better management/worker relations. Volvo's aims have been stated[58] as,

> "We have tried to create a production system which will give people some meaning and satisfaction in their jobs and at the same time the chance to work in small friendly groups. A product made by people who find some meaning in their work can also attain a very high standard of quality."

The company has had only one day's strike in the last 10 years, but are convinced that by giving employees a more personalised role in planning and production, more benefits will accure, such as,

(i) lower turnover of personnel.

(ii) reduced absenteeism.
(iii) higher standards of quality.

Within the Volvo factory, the atmosphere of the small workshop has been built in, because within each group, they instal and become experts in entire functions of the car, e.g. electrical system, controls, internal fittings etc.. The groups enjoy an ideal physical working environment and attention has been paid to such detail as acoustics, so that it is possible to converse at normal volume. Groups have their own amenities right beside their workplaces and these include,

(i) 'coffee corners' with pantry, refrigerator, coffee machine, and wall to wall carpeting.

(ii) changing rooms with washing facilities, showers, saunas, toilets, drying cabinets, wardrobes and cupboards for clothes.

There is little doubt that Group Technology, besides offering a greatly improved and efficient manufacturing system, will also open up new avenues of desirable relationships between management and workers and thus stem the tide of unrest which is evident in industry today.

(b) Better Organisation of its Function. How often is it said by workers on the shop floor that top management have very little idea of what really goes on within a factory and that many routines and procedures carried out are done so in complete ignorance to top management. A sad state of affairs, and one which any company director would desire to eliminate, but with the present complex structures which exist in materials flow, stock control, conglomerate plant layout and long production cycles, there is little hope that a simple, clear picture of the whole enterprise will ever emerge.

Group Technology, applied as a 'systems approach' does offer a clear, unclouded insight into all aspects of a company's operations. The 'systems approach' has been investigated[59] and proposed for a large company. The framework of the proposed system is shown in FIG. 5-10. The nucleus of the system represents the three production process areas of design, process planning, and manufacturing and assembly. The system areas which directly affect these areas viz., Production System Design and Production System Control are grouped closely to them. The peripheral or indirect system areas of Corporate Planning and Organizational Structure, Procurement, Marketing and Sales, Quality Assurance and Accounting which complete the total corporation breakup, are shown around the outside perimeter. Group Technology lies within the area of Production System Design. The systems approach, however, is entirely new and corporations of the future may see it as the 'total approach' necessary to implement corporate policy with a full measure of insight and control.

The 'limited approach' to Group Technology as is most commonly applied, offers management, to a large extent, the control and ability to predict operational output which is not possible with a functionally laid out system. The areas or features affected by Group Technology are first tabulated and then explained as follows:-

Item	Feature	FROM CONVENTIONAL PRODUCTION	TO GROUP TECHNOLOGY PRODUCTION
1	Plant Layout	Functional Layout	Group Layout
2	Production Control	Stock Control	Single Cycle Flow Control
3	Production Ordering Cycle	Long (> 2months)	Short (≤ 2-4 weeks)
4	Component Loading Sequence	Random	Planned

CORPORATE CHANGES REQUIRED WHEN IMPLEMENTING GROUP TECHNOLOGY.

(i) Plant Layout:- This feature of Group Technology and its advantages over a functional system has been fully described in section 5.4 (b). However to summarise, a functional workshop flow pattern has been likened to a 'bowl of spagetti' where component routes follow random paths, criss-crossing and unordered between all machining and processing areas. The group layout is characterised by a well ordered system of repetitive flow paths forming a well defined pattern which can be properly designed to ensure free and unhindered flow. See FIG. 5-11.

(ii) Production Control:- Production control will be fully dealt with in Section 5.5 (d).

(iii) Production Ordering Cycle:- Very few batch production companies of today use an average ordering cycle of less than 8-10 weeks because of the fact that with Stock Control and Functional Layout, it is impossible to control production efficiently or economically with a shorter cycle. Short cycles are desirable for a number of reasons, viz.,

1. Smaller batches can be programmed, thus enabling shorter throughput times, smaller work in progress and finished stocks.

2. If the cycle is small enough, only the components needed for products which can be sold, have to be made. Alternatively, as orders for products are received, the components needed can then be manufactured with a delivery time equal to the cycle time.

3. It enables a quick response to market fluctuations; an increase in demand can be met within the period of a production cycle, thus eliminating stocks held for this purpose.

4. There is less chance of stock losses due to obsolesence or product design changes brought about by competitor product dominance.

5. Due to the short cycle and throughput times, the production system is much more flexible and able to respond very quickly to rush orders, cancellations and other unforseen variations which although undesirable are part and partial of every manufacturing system.

The use of a short cycle imposes certain requirements on the system for it to function correctly, these are,

1. Throughput times for all batches must be less than cycle times.

2. Setting-time losses due to increasing the number of set-ups, must not reduce capacity below the load requirement. (This of course is offset by family grouping and correct sequencing which will be explained next.).

(iv) <u>Component Loading Sequence</u>:- The stock control ordering system used with conventional production releases orders at random, making it impossible to use a pre-planned machine loading sequence and orders must be loaded as received; in a random sequence.

The Group Layout of machines and family grouping of components offers the opportunity to plan the sequence in which machines are loaded in order to obtain a minimum of set-up time. If a succession of components progressing through a cell require similar operations on the same machines, then adjustments required to set-ups between components is confined to fairly simple proportions e.g. changing tools (which can be pre-set), altering stops etc., all of which can be effected in a few minutes. With planned sequencing together with the use of specialized jigs and fixtures, the use of preset tooling according to the composite component principle, leads to the optimization of cell production.

Analytical Support for G.T. Production. A new Operational Research design technique called A.I.D.A. (Analysis of Interconnected Decision Areas) has been used to support the hypotheses put forward for Group Technology Production[60].

A.I.D.A. utilizes a decision network, FIG. 5-12 (a) showing all the decision areas involved as circles; all the options available in each decision area as spots, with lines known as 'links' joining any pairs of options which are incompatible. Strong links (full lines) indicate options which cannot go together, while weak links (dashed lines) indicate options which can be used together, but where such union is undesirable. FIG. 5-12 (a) is a part decision network for a mechanical engineering factory showing only the hypothesis areas. These are the only areas interconnected by strong links and if all possible combinations of options are found for these areas, they will form the basis for the final solution. The links shown in FIG. 5-12 (a) are identified for the following reasons:-

1. Link ag. Stock control ordering releases orders at random, making a pre-planned loading sequence impossible.

2. Link ae. A short cycle cannot be used with stock control because with the latter the lead time should be no more than 2/3 of the consumption time (ref. 61)

3. Link ad. Stock control produces a widely fluctuating machine-hour load of work on departments. Group Layout exaggerates this deficiency in the groups.

4. Link ce. Long throughput times are synonomous with a Functional Layout and short production cycles cannot be used.

5. Link cg. Because of the many different cost centres associated with functional layout a planned loading sequence is not compatible with it.

6. Link gf. A planned loading sequence cannot be used with a long cycle because of the impracticability of holding plans for long periods.

There are two options in each decision area of FIG. 5-12 (a), making a total of 2^4 or 16 combinations of options shown tabulated in FIG. 5-12 (b). Eliminating those precluded by links, leaves five possible solutions as shown in FIG.5-12(c).

The optimum solution is reached by considering the criteria for choice, of (i) cost and (ii) investment. An analysis[17] of these two factors lists the following as the greatest in each case.

	Cost.	Investment.
Plant Layout	Functional	Functional
Production Control	Stock Control	Stock Control
Ordering Cycle	Long or Short	Long
Loading Sequence	Random	Random

The best solution is the Group Technology system comprising group layout, flow control, short cycle and planned loading sequence. The worst solution is the Conventional system of functional layout, stock control, long cycle and random loading sequence.

(c) Using a Classification and Coding System. The use of classification and coding has already been fully described in Chapters 3 and 4. The way in which it benefits management is by simplifying the task of implementing the G.T. system and subsequently providing the means of analysing the component flow and planning the loading sequence.

(d) Better Stock Control Procedures. The 'Stock Control' system of maintaining a supply of components in stores to meet assembly requirements is outlined in FIG. 5-13. With this system, each component is controlled separately and orders for new batches are issued each time the stock of a component drops to its own special 're-order level'. The number ordered in each case is based on the Economic Batch Quantity (E.B.Q.) concept for economic production, rather than on the actual or forecast requirements for assembly and sales, and invariably leads to the production of much larger batches than required, necessitating the holding and consequently the investment of large stocks. The major deficiencies of the Stock Control ordering system are outlined in FIG. 5-14.

The Period Batch Control or Single Cycle Flow Control system which is advocated for Group Technology overcomes most of the deficiencies associated with Stock Control. Its method of operation is outlined in FIG. 5-15. The ordering of components for assembly is based on a series of short term production programmes drawn up from sales orders or forecasts and issued to a regular cycle. As previously stated the shorter the cycle the better, with between one to four weeks as the ideal, depending on operation times and demand.

(e) Reduction of Stock Inventories. As already stated in sections 5.5 (b) and (d) this benefit is a direct consequence of the use of Period Batch Control ordering coupled with a Single Cycle Flow Control production cycle. Savings in stock investment can be quite considerable as shown by the firms[26],

Serck Audco - 44% stock reduction.

G.E.C. Elliott Control Valves - 40% stock reduction.

5.7 Conclusions.

A useful resumé of economic savings outlined by Professor J.L. Burbridge[42] is included in FIG. 5-16.

It is hard for one not to be over enthusiastic about Group Technology when one realizes that the benefits and effects outlined in this chapter are real and proven and are there for the taking by any firm which has the foresight and courage to commit itself to a major restructuring of its corporate system.

6. THE PROJECTS.

6.1 Outline of a Feasibility Study for the Introduction of Group Technology into Bronx Engineering Co. Ltd., Lye, Stourbridge.

Bronx Engineering have been interested in the application of Group Technology for some years and first made approaches to the University of Aston in Birmingham, previous to November 1973, when Professor Thornley visited the company and issued a preliminary report pertaining to the suitability or otherwise of G.T. for the company. Subsequent to this report the company requested a deeper study to be made of the components in house and those subcontracted, either in total or partially. This study was commenced by the writer in February, 1975.

The approach chosen for this study was decided on in a number of stages as follows,

(a) Code a sample of drawings taken from a current production schedule, using the standard Opitz Code.

(b) Modify the Opitz Code to develop a code more suitable for the Bronx Engineering range of components and manufacturing procedures.

(c) Reclassify the sample to ensure the modified code's suitability.

(d) Study the existing plant layout and component flow patterns in order to highlight deficiencies in the present system.

(e) Obtain a computer printout of the coded components in numerical order and analyse the printout to determine the class breakup and divisions according to the parameters of the code.

(f) Using the firm's existing machines, design typical cells envisaged to be suitable for Bronx Engineering.

(g) Make recommendations for the ensuing change to Group Technology.

(h) Make a verbal presentation and issue a detailed report of the study.

Full details of this study are included in Section 7.

6.2 Outline of a Feasibility Study for the Introduction of Group Technology into Hawker Siddeley Aviation Ltd., Middleton, Manchester.

The possibility of applying G.T. to the general machine shop of the Hawker Siddeley Aviation Factory at Middleton, Manchester, has been prominent in the thoughts of the firm's Production Engineering Research engineers for several years. The firm has several undergraduate students doing production engineering sandwich courses at the University of Aston in Birmingham and it was arranged for two of these students to carry out the investigations necessary for the G.T. analysis as part of their requirements for their Undergraduate (Final Year) Project.

An initial survey of aircraft component drawings was undertaken by the writer in order to become familiar with aircraft component types and the project in general, so as to be able to act in an advisory capacity for the students' work.

The overall approach is basically the same as the Bronx Engineering project and is outlined as follows:-

(a) Code a sample of aircraft component drawings taken from past designs, using the standard Opitz code, to become familiar with a component mix typical to the aircraft industry.

(b) Analyse the components via the classification digits to ascertain proportions of various classes.

(c) Allocate areas of responsibility and specific tasks to the two undergradute students as outlined in the following two Project Statements.

(d) Make recommendations for the ensuing change to

Group Technology.

(e) Using the information collected, make a verbal presentation to Hawker Siddeley managerment and issue a detailed report on the study.

UNDERGRADUATE PROJECT STATEMENT NO.1.

1. Classify a sample of drawings, say 300 by the standard Opitz Code.

2. In consultation with engineers, planners, etc., at Hawker Siddeley establish a set of coding objectives around which modifications to the Opitz code can be made.

3. In consultation with Professor R. H. Thornley and A. W. Boundy develop a Hawker Siddeley code around the objectives stated in 2.

4. Classify a large sample of drawings, say 2000, using the modified code and record drawing and code numbers on to data sheets.

5. Punch cards for all components in the sample.

6. Sort cards in ascending numerical order.

7. Obtain computer printout of card sort.

8. Analyse printout showing breakup of components into digits and special categories as indicated by the Supplementary Code.

UNDERGRADUATE PROJECT STATEMENT NO.2.

1. Verify Machine Shop and Spar Milling Layouts and amend existing layout drawings if necessary.

2. Check listing of plant in the above sections and amend if necessary.

3. Check process sheets from present work schedule to determine actual routes and departments visited and ensure their accuracy.

4. Using a number of these process sheets, say 10, draw up component routes on layout drawings.

5. Select a number of rotational components from samples used in Project 1 and design and draw a suitable cell in consultation with Professor R.H. Thornley and A.W. Boundy.

6. Select a cross sectional sample of components from both commonplace and unique varieties, obtain their process sheets and determine their actual throughput

times. Include in this sample the components selected for the cell designed in 5.

7. Assess typical cell throughput times for these components and show the overall improvement in throughput times envisaged.

Further details of this study are included in Chapter 8.

7. GROUP TECHNOLOGY SURVEY IN A COMPANY MANUFACTURING MACHINES FOR THE STEEL PROCESSING INDUSTRY.

7.1 The Company Structure.

The Bronx Engineering Co. Ltd., Lye, Stourbridge, are manufacturers of a wide range of machines used in the steel forming and processing industry. Appendix 1 lists the range which Bronx Engineering make and gives examples of the unique and unusual types available, which are illustrated in the accompanying booklet. Their market is world wide and they have agents in most of the world's developed countries. A figure of between 70 and 80 per cent of their total manufacture is exported to overseas customers.
The corporate structure consists of three separate identies each controlled by its own Board of Directors, viz., Bronx Holdings Ltd., which has managerial control of the other two, Bronx Process Engineering Ltd., and The Bronx Engineering Co. Ltd.. The latter is responsible for the manufacture of all products, but management of the ordering, sales etc. is divisionally controlled, the product details for each division being listed in Appendix 1. All three companies above are located at the factory site at Lye, Stourbridge, Worcestershire.

The manufacturing company, Bronx Engineering, functions under the control of a number of Works Managers each responsible for a department e.g. Quality Control, Manufacture, Design, Production Planning and Control etc..

7.2 The Production Programme.

Manufacture is based on a schedule consisting of orders for machines which have been allocated a delivery date in consultation with the customer. Delivery dates vary from one to twelve months depending on the machine ordered.

A monthly Production Programme is drawn up taking into consideration the delivery dates promised for machines in the schedule and a fixed budget allocation. Programmes are balanced to coincide with the financial budget allocation by adjusting delivery dates and/or transferring work between programmes. FIG. 7-1 shows a typical monthly Production Programme.

The production flow chart, FIG. 7-2, illustrates the various stages of manufacture within the present Bronx production system. Factors which affect the determination of the Production Programme other than those mentioned above are:-

(a) The manufacturing times of components.

(b) The availability and delivery dates of bought-out items.

(c) Raw material supplies.

(d) The throughput times of sub-contracted components.

The Sales Department produces works orders which authorize the commencement of production of each product and from these works orders the Design Department produces drawings and a list of all parts both manufactured within and bought out necessary to complete a machine. Certain contracted items are pre-ordered at this stage in an endeavour to gain as much time as possible to ensure an early delivery. A schedule of parts and drawings is issued to the Works Department and the Buying Office so that manufacture of all components can begin. The Works Department assesses the work load and sub-contracts out that which it cannot handle along with certain processes such as gear cutting, grinding, balancing etc., which are automatically let out because of lack of production facilities at Bronx Engineering.

Each machine manufactured has its own progress chaser whose job it is to keep in touch with all components belonging to his machine and ensure that their manufacture is completed by the date when assembly is due to start. Assembly dates are set to meet the product delivery times stated in the Production Programme.

7.3 Problems of Manufacture and their Possible Solution.

Because of the uniqueness and the degree of specialization in the manufacture of their products, Bronx Engineering enjoy a share in a relatively stable world market for their products. They are able to compete successfully with overseas firms because their prices, delivery dates and service have been equal to or better than their competitors. Their delivery dates have been met by a programme of energetic and conscientious progress chasing. However, the meeting of delivery dates has become increasingly difficult and the firm's engineers are continually being plagued by this problem.

Added to the above problem are the escallation of manufacturing costs due to inflation, which have eroded the firm's profit margin, because in order to win overseas contracts, Bronx are required to maintain prices which are comparable with their overseas competitors. Britain has had one of the world's highest inflation rates in the past years and this has further enlarged Bronx's manufacturing costs problem in relation to that of their competitors.

As can be seen by the flow chart, FIG. 7-2, Bronx Engineering sub-contract a large proportion of their manufacture to outside firms. In fact this figure is freely quoted as 30% of the total manufacture. During the past two years Britain has gone through a period of industrial unrest and many firms have experienced cash flow problems as well. Hence with this large amount of outside contracted work, Bronx Engineering have been greatly inconvenienced by the above problems affecting their contractors and this has added to their own problems of meeting delivery dates.

Some staff personnel within the company have been interested in the possibility of changing the present manufacturing system to one employing Group Technology principles. They see Group Technology as achieving a two fold purpose, viz.

1. By the reduction of throughput times, work-in-progress and more efficient use of the work force, reduce manufacturing costs and maintain a reasonable profit margin.

2. With the cellular control of manufacture available through Group Technology, production of components for assembly can be accurately planned and hence product delivery dates more easily met.

The above thinking has led the company to approach Professor Thornley of the University of Aston in Birmingham, for his advice as to whether Group Technology would be suitable for the company or not.

7.4 Introduction to the Bronx Engineering Survey.

In consultation with Bronx Engineering it was decided that the survey should be carried out by University personnel and Bronx engineers would co-operate with the investigators in supplying details of works layout, process sheets, manufacturing details and sub-contracted work etc.. The firm also agreed to manual assistance if required.

7.5 The Initial Coding Exercise and Development of the Bronx Modified Code.

A sample of 813 drawings was obtained from Bronx Engineering representing a cross section of components from a current production programme. Coding was commenced using the Opitz code, but it soon became apparent that the code would be unsuitable unless it was modified in both the geometrical and supplementary sections. Modifications to the geometrical code were carried out as follows:-

1. Rotational Components - Classes 0,1,2,3 and 4.

The Opitz Code is usually found to be satisfactory by most users in its description of rotational components and this was the case with Bronx Engineering.

2. Non-Rotational Components - Classes, 6,7 and 8.

Flat, long and cubic class (6,7 and 8 respectively) components are often inadequately described by the Opitz code, because of the wide variation of possible geometrical configurations applicable to these classes. Hence, firms must first analyse the non-rotational components within their range and modify the Opitz Code digits to describe them in such a way as to facilitate the formation of similar technological families of these components.

An analysis was carried out on Bronx Engineering non-rotational components and it was decided to modify two of the above classes, namely flat and cubic. These modifications are as follows:-

Flat Components - Class 6. The Opitz code FIG. 7-3 (a) in the overall shape column, allocates five (5) digits (0 to 4) to the description of plane components, two (2) digits (5 and 6) to flat components, two (2) digits to curved and one (1) digit to others. Many components both fabricated and cast which fell into this category were either block-like or box-like and the only digit of the above which could be used for these is digit 6. It was decided to modify the overall shape digit, FIG. 7-3 (b) as follows:-

(a) Combine digits 1 and 2 thus reducing the plane digits to four in number.

(b) Reword digit 5 rename it digit 4.

(c) Reword digit 6 and insert digits 5 and 6 to describe block-like and box-like components respectively.

Cubic Components - Class 8. These are divided into two categories, block and block-like or box and box-like. The Opitz code FIG. 7-4 (a) in the overall shape column progresses through digits 0,1 and 2, with a description of rectangular prismatic and compounded rectangular prismatic components. However, digit 3 jumps to a description of components with a mounting or locating surface and a principal bore, but makes no provision for components which do not have a principal bore, of which there are many. Thus the Opitz Code would place the latter type of component in digit 5, which is higher in the complexity scale to digit 3, when in fact these components are comparable to digit 3 components. In order to place these components in the same category, digit 3 was modified as shown in FIG. 7-4 (b).

3. Supplementary Code. Before any appreciation of the modifications required for the supplementary code could be made, an outline of the manner in which components are manufactured at Bronx Engineering was necessary. The reason being that at least 30% of all components produced require contracted work to be done on them. A figure of 30% was quoted by the planning engineers but a later analysis of the

computer printout of the sample showed a figure of 20% for subcontracted work. The reason for the discrepancy is that the sample did not contain many wholly contracted components, these being left out purposely by the company's engineer when selecting the sample. Contracted work can be separated into two categories, viz:-

(a) Partially contracted.

(b) Wholly contracted.

(a) Partially contracted work - consists of a number of specialized processes outlined as follows:-

1. General Machining. - Includes turning, boring, milling, grinding, and drilling operations which cannot be accomodated on the firm's own machines because of insufficient capacity or overloading conditions.

2. Flame Cutting.- A small number of components have to be contracted out for this process because of overloading in the firm or lack of machine capability.

3. Heat Treatment. - Includes stress relieving of fabricated assemblies, flame hardening and any other heat treatment process which is carried out subsequent to processing at Bronx Engineering. Stress relieving is required on a large number of assemblies and represents a sizable portion of contracted work. Some assemblies have to go out twice for stress relieving during manufacture.

4. Balancing.- Represents a minor segment of contracted work.

5. Spur and Worm Gear Cutting - This area is, along with stress relieving one of the largest contracted processes. Bronx Engineering are essentially machine manufacturers and consequently a substantial proportion of their component mix consists of gears, pinions (both spur and helical), worms and worm wheels of all shapes and sizes. Gears mainly range in size from a few centimetres up to 50 to 60 centimetres in diameter. Materials used are mild steel, cast iron, phosphor bronz and medium carbon low alloy steels. Large gears, greater than 480 mm. diameter, are either made from forgings or are fabricated using a medium carbon, low alloy rim with a mild steel superstructure. Fabricated gears are contracted out for rim and teeth production as well as stress relieving. Many gear teeth are flame hardened which is also a fabricated process.

However, Bronx Engineering carry out all blank preparation and machining prior to gear cutting.

6. Surface Treatment - All components requiring surface treatment such as sulphinuz, chroming, coatings (rubber and plastic), galvanizing etc. are contracted out.

(b) Wholly contracted components - are designed and drawn by Bronx Engineering, but their complete manufacture is let out to contractors. Some shafts, components made from special materials (orkot etc.), guards and covers for machines, calibrated scales etc., fall into this category.

The supplementary code presented a formidable problem as there seemed to be far too many combinations of restraints requiring identification, for the code to handle. The restraints of course, being the contracted processes and the manner in which the products are manufactured. Initially an existing modified version of the Opitz code was used, FIG. 7-5[63], which replaced the accuracy digit with an extra dimension digit specifying the rotational length 'L' and the edge-length 'C' (non-rotational). This digit was located between the first dimension digit and the material digit. By dispensing with the accuracy digit, it is assumed that accuracy is a machining feature which is an inbuilt characteristic of the machine or cell on or in which the component is produced. The machines already 'in house' at Bronx Engineering are presently coping with the accuracy requirements of their component design. As Group Technology merely requires a rearrangement of these machines then it can be assumed that accuracy will still be adequately catered for and hence there is nothing to be gained by coding it. In a new factory layout being designed along G.T. lines, a comprehensive accuracy digit could be of some use to analyse the accuracy requirements of the component mix and so ensure that the correct machines were purchased to give the accuracy needed.

In an endeavour to meet the Bronx Engineering situation, the material and initial form digits were modified, as shown in FIG. 7-6. The material digit, for light alloys (digit 8) was incorporated in the 'other materials' (digit 9). Such a change was justified, as Bronx Engineering use very little light alloy and the modification made provision for an extra mild steel digit (No. 2) to distinguish between mild steel which is flame cut and that which is saw cut, in different sections of the works.

The 'initial form' digit, FIG. 7-6, was modified to include an 'outside contracted' digit (No. 7), to account for more than 30% of all components which were outlined previously. To enable the inclusion of this digit, digits 5 and 6 (sheet, plate and slab), FIG. 7-5 were combined as digit 5, FIG. 7-6. Digits 8 and 9 FIG. 7-5, were also modified to combine forgings with pre-machined components as Bronx Engineering contract their forgings in the pre-machined condition. Bought-out components were also included in this category, digit 9, FIG. 7-6.

Coding of the drawing sample was recommenced using the modifications outlined above. Although the code showed whether or not the components required outside contract work, it did not distinguish between the six (6) categories of partially contracted work previously outlined. Also, digit 7 ('outside contracted') was not a truly 'initial form' digit and this feature of these components was lost, as well as suppressing the digits which could also be applicable, below it. To overcome this difficulty the number of digits in the Supplementary Code was increased to five (5) creating a new digit headed 'Contracted Work', as shown in FIG. 7-7. After a few trial and error runs with the code, the new class was divided into three categories viz., (i) no contracted work - 1 digit, (ii) partially contracted - 6 digits, (iii) wholly contracted - 3 digits. A complexity order was determined in consultation with Bronx engineers, on the basis of the degree of difficulty to get completed. The digits of the 'partially contracted' category correspond to the six (6) categories mentioned previously with machining and flame cutting combined as these are seldom carried out together and it is hoped that Bronx Engineering will do all their own machining in the future thus leaving this digit, (No.1), for contracted flame cutting alone. A spare digit, (No. 6) is left for future allocation.

The 'wholly contracted' components needed to be split into two categories as shown (digit 8 and 9), because Bronx Engineering is not really concerned with how they are made and the broader classification is adequate. A spare digit (No. 7) is also available in this category.

The drawings were recoded using the new code and every component fitted the code perfectly and to ensure its accuracy, the writer and one of the firm's planners rechecked the last three digits of the Supplementary Code. The code which has been developed would appear to be ideally suited to Bronx Engineering.

Features of the code are as follows:-

1. <u>Contracted Work</u>: By allocating a separate supple-

mentary digit to contracted work, a comprehensive description of this feature is possible, without affecting other digits of the code. If and when contracting requirements change, digits of this code can be altered or deleted thus maintaining an up to date knowledge of this important feature.

2. Family Formation: In the formation of component families for Group Technology cells, those components requiring specific contracted work can be identified and allowance made for them in the production planning stage.

3. Analysis of Contracted Processes: A complete analysis of all contracted processes required for a production programme can be made in advance, thus allowing decisions to be made in advance instead of hurriedly or on the spot.

Examples of Specific Component Identities: The following examples will illustrate how the last three digits of the Supplementary Code can select specific components. See FIG.7-7.

(a)	A stress relieved component, manufactured by fabricated M.S. assembly	- XX362
(b)	A forged, medium carbon gear wheel	- XX474
(c)	A modified,bought-out standard M.S.component	- XX390
(d)	A M.S. component, flame cut from plate	- XX250
(e)	A phosphor-bronze cast worm wheel	- XX884
(f)	A M.S. machine guard	- XX358
(g)	A medium carbon roll requiring superfinishing	- XX405
(h)	An orkot (Fibre composition) shaft bearing	- XX929
(i)	A casting requiring contracted internal grinding	- XX081

The ability of the Bronx supplementary code to sort out specific contracted types will make it possible to take this feature into account when family groups are being considered.

7.6 Contracted Gear Cutting and Stress Relieving.

All parts requiring gear cutting are contracted out for this process and unreliable and long deliveries cause many delays in product assembly. If Group Technology is implemented by Bronx Engineering serious consideration should be given to purchasing gear hobbing facilities to cope with as much of this work as is practically possible and to incorporate these facilities in the design of G.T. cells.

Gears are a prime component in the assembly of the firm's products and their manufacture should be wholly controlled within the firm. Justification for the purchase of gear hobbing facilities should be straight forward when based on a cost saving analysis, which would highlight the following points:-

(a) Savings in transport costs.

(b) Savings in the difference between the cost of contracting work and processing within the firm.

(c) A reduction in the value of work in progress because of quicker throughput times. (A considerable amount since these are high value components).

(d) The elimination of delays of these components, because of cellular control within the works, thus enabling the assembly programme to proceed smoothly.

(e) Creation of a new area of employment within the firm.

Another process which represents a large proportion of outside contract work is stress relieving and the cost of 'inhouse' processing of certain parts should be seriously looked at. A cost analysis carried out in the same way as for gear cut components should reveal similar results. Even if small facilities capable of processing 80% of these components were installed, it could be quite beneficial.

7.7 <u>Existing Plant Layout and Work Flow Patterns.</u> The three Bronx Companies are located at the factory on Thorn's Rd., Lye, Stourbridge. The factory layout, FIG. 7-8, consists mainly of two large buildings named Top and Bottom Works as shown. The manufacturing floor area is approximately 80,000 s.ft. and there are 550 employees engaged on the site. A closer study of FIG. 7-8 will show that the Top Works houses the fabrication shop and caters for the machining of large fabricated components on a series of large table and floor borers, centre lathes, planers, mills and radial drills. The Bottom Works is mainly concerned with the production of small components and machines in use there are listed in FIG. 7-8.

An interesting feature of the machine layout in the Bottom Works is that a hybrid functional-group layout exists in No.1 and No. 2 machine shops. The layout was the result of the thinking of two Bronx engineers who had some G.T. knowledge and wished to derive some of its benefits without actually planning cellular layout to suit their workload. The situation could save the company considerable expense if and when they decide to adopt a G.T. system.

Even with the part group layout, it was thought that component routes between operations would be 'spagetti like' and to verify the thinking a number of route sheets for actual components were drawn to show the amount and variety of movement typical with the system. These route diagrams are numbered 1 to 9 and are included in Appendix 2. They do indeed show that components travel a lot between operations and in addition to movement within one Works, there is also a considerable component traffic between the Top and Bottom Works. The implication of this analysis is that work-in-progress is high and this is evidenced by the large quantities of unfinished components visible, around the factory.

7.8 Production Planning and Control.

These two sections are responsible for the manufacture of all components required for product assembly. Component drawings and the schedule of parts from the Design Department are firstly processed by Production Control to sort out known sub-contracted work. Production Planning then draw up process sheets for all components made 'in house' and assess the work load to see if it is within the factory's capacity. Any excess is sub-contracted in accordance with the over loading conditions. Planning engineers prepare route sheets which show the operation sequence, the machine required and the cost centre number for each operation. The week number in which the component is required for assembly is shown on the top right hand corner together with the latest start date of manufacture in order to meet the required assembly week number. The provision, though on paper only, is perhaps the best effort made to endeavour to get components through to assembly by the required date. However, setting milestones in production does not ensure that they will be met and this is in fact the way of life at Bronx Engineering.

Production control is carried out by the Production controller and his six (6) progress chasers, who are responsible for ensuring that the components needed for a particular product are manufactured by the product assembly date. Their job is difficult and progress chasing often involves rerouting components to obtain a quicker throughput. Although components are originally routed to certain machines it may well be that the machine in question is not available or is overloaded and the component is queued up for a long wait unless it is scheduled to a similar machine; perhaps located in another part of the works. The oft-quoted figure of one operation per week is freely admitted at Bronx Engineering. Hence, production control quite often consists of chasing components to endeavour to obtain the quickest possible route through the works by shunting them around to the various work centres with the lightest loads.

The result of this is undoubtedly long throughput times, high work in progress, and hit or miss delivery dates. One can imagine that the hybrid plant layout, as exists at Bronx Engineering, run along these lines would be even worse than a functional layout. At least in the latter, if a lathe for instance, is overloaded perhaps the one next to it would be available or the next, and so on, and a component would not have to travel from one shop to another to find a machine suitable for a given operation.

7.9 Assessment of the Main G.T. Requirements at Bronx Engineering.

A study of monthly Production Programmes shows that the component mix varies from one month to the next depending on the orders received for machines. Bronx Engineering only produce components necessary to meet the schedule of parts and hence batch sizes are extremely small - 1's,2's and 3's in most cases with few batches going above twelve (12).

The type of production flow at Bronx Engineering is ideally suited to Group Technology. It has been widely stated that Group Technology requires certain essential features for successful implementation and these are:-

(a) Group layout of machines.

(b) Single cycle flow control.

(c) Short ordering or production cycle.

(d) Planned loading sequence.

Bronx Engineering meets most of these requirements already, although they do not function as they would in a Group Technology situation, viz:-

(a) They do have a group layout of machines, which may or may not be suited to a planned sequence of operations.

(b) They do have the essential framework of a single cycle stock flow control.

(c) The production cycle of one month is as short as practicable for the size and complexity of the range of components manufactured.

(d) They do not have a planned sequence of manufacture and it is in this area that Group Technology would achieve its most beneficial results.

As already pointed out, although Bronx Engineering use a period batch control system, the schedule of components from one month to the next is not repetitive, because machines on order in one period may or may not be on order in the next period. They do however, have a standard range of machines available to customers and any cells formed would have to take into account the component range for all machines listed. Whilst this may not affect the type of cells required, it could have a bearing on the number of particular machines necessary to cope with the varying load schedules. Also the latter feature may require some over-lapping of capabilities in the design of cells, particularly turning cells, so that should on overload situation arise in one cell, it may shed some of its load to another.

7.10 Data Processing and Computer Printout Analysis.

Coding of the sample was completed on 29/4/75 and the coding data was punched on to Fortran cards. FIG. 7-9 illustrates the coding of a component, its subsequent entry on to the component data sheet, its punched card and its relative position on the computer printout. The component illustrated is a rotational '0' class component and is one of a family of seven (7) similar types shown bracketed in the printout. The layout of the Component Data Sheet consists of 80 columns to correspond with the 80 columns available on the punched card. Only 28 have been used in this exercise, but should the company decide to proceed with G.T., the remaining columns will be used to record component information necessary when determining production data for cell design. FIG. 7-10 illustrates two typical data collection sheet layouts. It will be noted that these are different and this will always be the case, as each layout is designed to suit the needs of a particular company.

The 813 punched cards, one for each drawing coded, were sorted in numerical sequence and a computer printout of the sequence was obtained. Parts of this sequence are shown in FIGS. 4-6, 4-10. A manual analysis of the printout is summarised in the bar chart, FIG. 7-11. This chart reveals the following break down of components:-

(a) The total for each digit of the Geometrical Code.

(b) The percentage of each category in the overall total.

(c) The number of components requiring gear or worm cutting in each digit of the rotational category.

(d) The number of components which are flame cut in each digit.

(e) The number of fabricated components in each digit.

(f) The number of cast components in each digit.

A further analysis of the printout revealed the following information:-

(a) Gear Teeth Cutting on 94 components represents 22% of rotational components or 11.6% of the whole sample.

(b) Contracted Work is required on 159 components representing 19.6% of the whole sample, and can be divided into two categories, partially contracted (16.6%) and wholly contracted (3%).

(c) Outside Machining or Flame Cutting is required on six (6) components.

(d) Stress Relieving is needed on 32 components, 22 of these in the flat, long and cubic categories and 10 in the rotational category.

(e) Balancing is required on only one (1) component.

(f) Surface Treatment is needed on four (4) components in some form or other as described by digit 5 of the 'Contracted Work' column of the Supplementary Code.

(g) Flame Cutting is required on 183 or 22.5% of all components, with 134 of these in the flat, long and cubic categories, which is understandable as most of these components are cut from sheet, plate or angle etc., and are required for fabricated assemblies. The large number of flame cut components (44) in the '0' digit indicates that these circular components larger than 6" diameter, are cut from plate and required for fabricated assemblies.

(h) Fabricated Assemblies number 96 or 11.8% of all components with the largest number of these (33) in the cubic digit category.

7.11 Formation of Cells.

It is obvious from FIG. 7-11, that basic turning cells can account for 52.6% of all components. Because of the large proportion of gears cut in each digit of the rotational components category, it is desirable to incorporate gear cutting machines in the cells if they are to function with the full measure of control, which is capable of being exercised in a cell. Inspection areas should also be included in the cell area.

Ready made cell/s exists in the fabrication section of the Top Works and correctly scheduled and planned the output of this cell should be able to be dovetailed in with the requirements and sequence of other cells.

Most of the large machines, viz., borers, grinders, lathes etc., are situated in the Top Works where machining operations are carried out on large fabricated assemblies. A number of these machines will undoubtedly operate as single machine cells, as some assemblies spend weeks on the one machine. However, some machines in this area also serve components which have the major number of operations performed in the Bottom Works as shown by the route diagrams, Appendix 2, and much thought will be needed in the planning of cells to eliminate travel between the two works areas.

It was decided to design two turning cells of the type which would be envisaged as typical for Bronx Engineering. Design was to be based on the machines already in use at Bronx and on a selection of rotational class digits taken from the sample of coded drawings. All manufacturing details for the components were obtained, including, operation sequence, machines needed per operation, date of issue to works and the actual manufacturing time from first to last operation. FIG. 7-12 shows the 15 components selected with the above data printed beneath each component drawing. The times (working days) noted on the drawing are only from first to last operation which varied from 4 to 37 working days. FIG. 7-13 is a list of these components indicating its machine sequence and the G.T. cell in which it would be manufactured. FIG. 7-14 shows the layout of the two typical G.T. turning cells suitable for machining the above components.

Features of these cells are as follows:-

(a) A total approach to the manufacture of a component

(b) Uninterrupted production ensuring a minimum through-put time and greatly reduced work in progress.

(c) Full utilization of key machines with support machines being generally under utilized.

(d) Independent stores for tools, jigs and fixtures.

(e) A layout generally suited to a specific work flow thus keeping back tracking to a minimum.

(f) Flexibility of labour particularly among the operators of support machines.

(g) A raw material store capable of holding all materials required for a production cycle.

(h) A work force carefully selected to form a team and man the cell on a regular basis.

(i) Self supervision, work loading, and planning within the scope of each cell production cycle.

(j) The use of setter operators, so that all setting between operation change overs is carried out by cell personnel.

Whilst these two cells are capable of machining the type of components illustrated, no analysis has been made of the loading requirements and this would be necessary so that the exact number of individual type machines for each cell could be determined.

Many firms are in favour of setting up a pilot cell as a preliminary to a complete plant change over to cellular groups for the following reasons.

(a) The firm can see for itself how a cell operates and what effect it will have on production.

(b) Benefits derived from the pilot cell can be assessed and if possible, any savings made used to offset further costs of implementation.

(c) To ascertain the reaction of the work force to Group Technology and solve any problems which may arise in this direction.

(d) To see which of the above 10 features of the typical cells would be applicable to the actual cells.

(e) To gain experience in loading, general running etc. of one cell before tackling the requirements of a number of cells.

If the decision to instal a pilot cell in isolation within a functionally laid out machine shop is made, it has a noticable effect on the output of machines is this area. Consider a group of milling machines which have their load decreased by the installation of a milling machine in a pilot turning cell. The effect is that the functional machines have their loads lightened because some of it is shed to the cell. The consequence of this is, that original throughput times, queues of components etc. that existed before the pilot cell, alter considerably and a new set of production figures are established. It is imperative therefore, that before any changes are made to the existing functional layout, a complete record is made of throughput times, route sheets and other production planning and control data so that a true comparison can be made of the 'before' and 'after' conditions relating to the implementation of G.T..

The manufacturing system at Bronx Engineering would undergo a complete reorganization during the implementation of Group Technology. FIG. 7-15 illustrates the new system resulting from the change. The positions of the turning cells (1 and 2) are indicated on the flow chart.

7.12 Added Value Payment Scheme.[64,65]

Bronx Engineering are desirous of introducing an added value payment scheme throughout their works. It is important to gauge what effect this scheme and the implementation of a Group Technology system will have on each other.

In isolation, the introduction of each of the new inovations may meet with considerable shop floor opposition, as indeed has been the case with the added value scheme. However, when proposed together, they compliment each other and the package seems a more attractive proposition. Before explaining this statement, an explanation of the concept of the added value proposal is necessary.

Briefly, added value means the difference between the sales value of goods produced and the cost of raw materials and bought-out parts. Added value is divided into three sections, as illustrated in FIG. 7-16, viz.,

(a) Overheads - includes salaries, rent and rates, advertising, depreciation etc.

(b) Profit - includes taxation, dividends, provision for expansion etc.

(c) Earnings Pool - is the employee's share of the added value.

The Earnings Pool is paid to the employee in two ways, i.e.

(a) As a Basic Wage resulting from new hourly rates, overtime premiums and long service payments.

(b) Productivity Bonus - that which remains in the earnings pool after basic wages have been paid. It is shared in a manner which is negotiated by employees and management.

Ways by which the added value can be increased are:-

(a) Increasing output.

(b) Reducing material waste.

(c) Maintaining a high quality of work and thus reducing scrap.

(d) Transferring to other work if required.

(e) Reduction of work-in-progress.

(f) Faster throughput times.

Upon looking at these six (6) ways of increasing added value through the eyes of a worker on the shop floor, one immediately realizes that the only way by which he can achieve these targets is by improving his own performance. This would virtually mean an admission on his part that at present he was working in a wasteful, slow and unco-operative manner, producing work of poor quality at a slow rate. Is it any wonder that the scheme was not accepted?

However the interaction of Group Technology with this scheme presents a far different picture. Here we have the workers, being presented by management, with the means of effecting an increase in added value simply by working at their normal rate and not having to admit to any failings in their own performance.

It is felt that problems which may arise within the Added Value Scheme and G.T. will be solved more easily by the complimentary requirements of the other e.g. flexibility within a G.T. cell often presents opposition, but it is also a requirement of the Added Value Scheme, and where an employee's earnings are affected he is more likely to co-operate. There is also little doubt that the change over to G.T. with the monetary rewards on offer will certainly improve the performance of the work force, thus ensuring an increase in productivity and the success of both the Added Value Scheme and Group Technology.

7.13 Conclusions.

The following conclusions were reached as a result of the sample analysis.

(a) Group Technology can certainly improve throughput times and ensure reliable delivery dates of components to assembly. An improvement of between 7:1 and 5:1 is envisaged in the respect of throughput times.

(b) By means of cellular control of component manufacture the correct sequence of parts required for assembly can be assured.

(c) Some under-utilization of support machines in the cells may occur, but key machines will be utilized more than they are at present which will more than compensate the first deficiency. In fact overall machine utilization should increase and this will be evidenced by the ability of the cells to manufacture more components than at present.

(d) Labour will be utilized to a greater extent than it is at the moment resulting in increased productivity per employee.

(e) A large number of rotational components require gear cutting and in order to schedule these through turning cells and gain complete control of their manufacture, serious thought must be given to the installation of gear cutting machines.

(f) Component routes will be much shorter in length and more ordered than they are at present. This feature coupled with faster throughput times will dramatically reduce the amount of work-in-progress. Figures of 50% and 60% are commonly quoted for reductions in this area.

(g) The present factory layout of machine tools and processes with its numerous segregated machine shops, fitting and fabrication areas, stores etc., is ideally suited for the re-arrangement of machines to form cells in these various areas.

(h) The implementation of Group Technology will indicate to employees that management is prepared to show them how productivity can be improved and will thus pave the way for the proposed Added Value incentive scheme to be introduced.

7.14 Recommendations to Bronx Engineering.

The following stages or steps were recommended to Bronx Engineering if they made the decision to implement Group Technology.

(a) Enter into contract with the University of Aston in Birmingham to act as consultants and give active support and supervision for the various stages of implementation.

(b) The formation of a Group Technology Committee to study and discuss all aspects of implementation and to make such recommendations to the Executive as will affect the best means of making the transition.

(c) Study and amend if necessary, the classification scheme, followed by its endorsement by all affected Bronx Engineering Departments viz., Production Eng., Design Dept, Drawing Office and Management.

(d) Coding of all component drawings to commence as soon as possible; this to be carried out by company staff and led and supervised by University personnel.

(e) A decision to be made on whether to instal gear cutting facilities or not.

(f) Form one or two pilot turning cells as quickly as possible so that some of the benefits of Group Technology may be realised and thus offset the initial costs of implementation.

(g) Develop the overall concept of the manufacturing system around such parameters as are resolved by the Group Technology Committee.

(h) Proceed with further development and installation of such cells as indicated by an analysis of the component classification printout.

(i) Develop tooling jigs and fixtures which will improve the utilization of machines within cells.

(j) Ensure a continuous feedback of results for analysis and in the light of this information modify and improve the system.

7.15 Presentation of the Report to Bronx Engineering.

On the completion of the survey a verbal presentation was made on 25/6/75 to key people within the company. These encluded the two joint Managing Directors, Engineering Director, Chief Executive and Deputy Chairman, Quality Control Manager, Production Manager, Works Manager and Chief Designer. Professor Thornley presented a general talk on Group Technology accompanied by slides and the writer presented a talk on the sample analysis carried out within the company. The presentation was well received and the receipients were so impressed that they requested a written report in order to have a deeper look at the details and the proposals made. The report was subsequently prepared and presented.

7.16 The Present Situation.

At the time of writing the company had not reached a decision on the subject of Group Technology, but the firm's engineering personnel, are hopeful that it would be in the affirmative.

8. A GROUP TECHNOLOGY SURVEY IN THE AIRCRAFT INDUSTRY.

8.1 Introduction.

The subject of Group Technology first arose between Professor R.H. Thornley of the University of Aston in Birmingham and Hawker Siddeley personnel at Manchester, when discussing possible projects for the company's students carrying out the industrial training part of the sandwich course which they are undertaking in the Production Engineering Department of the University.

It was agreed that the project work should lead up to a presentation to top management of the feasibility of introducing Group Technology to the component production areas. The writer's involvement consisted of an initial survey of component drawings via classification and coding followed by a role of advisory supervision of the students concerned.

8.2 The Company.

In July, 1962, the aviation interests of A.V. Roe & Co. together with those of the other aircraft manufacturers within the Hawker Siddeley Group, were merged to form one company - Hawker Siddeley Aviation Ltd., which is one of the largest aircraft manufacturing companies outside of America. Hawker Siddeley Aviation is part of the Hawker Siddeley Group, one of the largest industrial organisations in the world with branches in Australia, New Zealand, Canada, the U.S.A., South Africa, Argentine, India and Pakistan. The Group has over 80,000 employees and a turnover exceeding £1¼ million a day[67]. In addition to its aviation interests, the Hawker Siddeley Group's manufacturing facilities extend to cover missiles, aerospace equipment, diesel engines, electric power, general engineering and metals.

Hawker Siddeley Aviation Ltd. employ some 27,000 people, and have a total factory floor area in the U.K. exceeding 8 million s.ft. shared among eleven establishments scattered through-out the country. The company can trace its history back to the beginning of the 20th century when the two brothers, H.V. and A.V. Roe - the founders of the famous Avro Company, figured prominently in the first controversial attempts at sustained British flight. FIG. 8-1 (a) shows the 20th century development of the present company. FIG. 8-1 (b) indicates the deployment of Hawker Siddeley Aviation's factories in the U.K..

The company's aircraft designs span two world wars and many of their names have gone into the pages of history, e.g. Brisfit, Pike, Avro Anson, Lancaster, Lincoln and many others. Present day designs include such well known names as the Vulcan, Hawker Harrier and Nimrod. Hawker Siddeley factories manufacture aircraft for both civil and defence purposes and the factory at Manchester is involved in the production of assemblies for both types.

8.3 Hawker Siddeley Aviation Management Structure.

Hawker Siddeley Aviation is controlled by a Local Aviation Board, which consists of the Director and General Manager together with five (5) Executive Directors as shown in FIG. 8-2. The Director and General Manager represent the Local Board on the National Board, which formulates policy for all Hawker Siddeley factories in the U.K.. These policies are implemented into Hawker Siddeley establishments by the Local Board through the Executive Directors who are responsible for certain functional areas within each factory. Each director has a number of managers under his juristriction who control the various departments and sections as shown in FIG. 8-2, which represents the Manchester establishment.

Any decision to implement Group Technology would thus rest with the Executive Director, Production, with final approval probably being required by the Local Board because of the interaction which G.T. would have with other areas controlled by other Directors, e.g. the Executive Director and Chief Engineer in charge of Design.

8.4 Problems of Production.

The Hawker Siddeley factory at Manchester has a general machine shop similar to that found in any general engineering works in the U.K.. It is characterised by a functional layout of machine tools and with such has the usual production problems associated with the batch producing industries, in that it has a large variety of low volume parts.

A great deal of movement occurs between operations and there is no deliberate grouping of machines to shorten such movement or speed up throughput times. As a result there is an excessive amount of work in progress, and throughput times are long and unreliable. This state of affairs strains customer relationships and the Production Engineering Department look towards Group Technology as a possible means of solution to the above problems.

8.5 Products and Manufacturing Facilities.

Hawker Siddeley make components which go towards the production of sub-assemblies for various types of aircraft. They also manufacture spares for past aircraft designs which are currently in service. Batch sizes range mainly from 1's and 2's up to 20's and 30's.

A study of component drawings showed that two types of component existed viz.,

(a) Commonplace variety.

(b) Unique to the industry.

The first type are similar to those found in any general machining industry of today and are manufactured on the usual range of general purpose machines common to all industries. The second type, however, are quite distinguishable and their dimensions, methods and machines used in their manufacture, material type, and stringent design requirements make them truly unique components.

Machines used to produce the two types of components also fall into two categories, thus forming the machine groupings presently found in the factory, viz.,

(a) The Machine Shop.

(b) The Spar Milling Section.

The Spar Milling Section has a number of unique machines for machining aluminium alloy components from extrusions, slabs and bars. Many of these components fall into the long and flat categories and the machines used in their production are very large and able to machine to close tolerances. FIG. 8-3 illustrates a Marwin 60ft. x 12ft. numerically controlled milling machine for milling the wing skins for the A 300 Airbus.

The factory has numerous similar machines as well as special routers, bending, stretching and drilling machines to carry out further operations on the unique components. An example of a typical unique component is shown in FIG. 8-4 which details a Stringer, a component used in wing assemblies for tieing together ribs. A study of this drawing will show the demanding machining operations necessary to produce the component from the initial extruded form. This type of machining is commonplace at Hawker Siddeley and in fact many smaller components like this have some or all of their machining operations carried out within the Machine Shop on medium N.C. milling machines. Such a component is shown in FIG. 8-5 which shows a Skin Stabiliser between Ribs. Once again a study of the drawing will show that the complicated cross-section is machined entirely from an extruded aluminium alloy bar. FIG. 8-6 illustrates a small component, titled End Fitting (Front Strake) which is manufact-ured in the Machine Shop from high tensile steel. The process sheet (2 pages) for this component is shown in Appendix 3 and the same component also appears in Table 1.2 which summarises, the departments visited in sequence, the operation sequence, the total number of operations and the machine changes required to produce the component. Tables 1.1, 1.2, 1.3 and 1.4 are in fact, a summary of the process sheets for the components listed. Tables 2.1,2.2, and 2.3, list the department and machine codes which are applicable to the previous tables and the process sheet.

Machines in the Spar Milling section are huge, with extremely large capacity work tables, FIG. 8-3. They are mounted on massive foundations and the possibility of relocating them for any G.T. cell design is very remote. The only possibility of incorporating them into a G.T. system would be to group auxiliary machines around them so that components could be completed within the same area.

8.6 <u>Procedure for Component Manufacture</u>. FIG. 8-7 is a flow chart representing documentation and departments involved in the present manufacture of components, from the initial issue of of a works order, to the stage where a component is completed and in the stores.

Due to the variety of destinations for components it is difficult to define precisely the departments which are involved. For example production can be authorised for spares orders, unallocated customer aircraft, customer modification, prototypes, or commercial projects. Generally the departments involved are those shown on FIG. 8-7.

The Contracts Department issue a works order to Design, who in turn issue a master drawing and a Design Office Memorandum (D.O.M.) to the Production Engineering Dept.. The Programme Planning Dept. are responsible for the long term planning of aircraft manufacture, using past records of man-hour expenditure etc. to estimate an overall programme.

The Production Engineering Dept. is responsible for process planning and tooling. Change Control monitor the issue of drawings, D.O.M's and Change Release Orders (C.R.O.) to the Process Planning and Schedules sections. Assembly Process issue assembly process layouts and complete parts lists, which show all the sub-assemblies required to make an assembly. Detail Process Layouts (Appendix 3) or component operation sheets are prepared by the Detail Process Section. If special tooling is required, the Process Section issue a tool order card to the tooling sections who then design the jigs and tools and prepare tool process layouts.

Depending on the type of work, the Industrial Engineering Dept. then allocate a time for each operation on the process layout sheet, assuming a quantity of one off. Alternatively this may be carried out at a later stage when the job card has been issued to the production departments. In the case of Machine Shop items, the latter is more usual.

Process Layouts and schedules are issued to the Production Control Dept.. The Job Cards section print a job-card, route card (both similar format to process layout, App. 3), requisitions for drawings, material and tooling and time clocking dockets for the operators. The job is given a week number by the Load Control Section, who use information from Programme Planning and Production Engineering to determine the short term production programme. The Material Control section either allocates existing stocks of bought out items or raw material to the works order, or raises an assessment which instructs the Supplies Dept. to issue a purchase order. If there is insufficient capacity to manufacture some components, then this is dealt with by the Inter-Factory Transfer and Sub-Contract section. Tools are checked for availability by Tool Control and a drawing requisition is issued to Drawing Control. The relevant information is recorded on the computer W.I.P. file and a Job Traveller Card (J.T.C.) is issued, which is then used to update the W.I.P. file during subsequent manufacture.

Job Cards section despatch the job card pack (which includes route card, J.T.C., drawing, time dockets and requisitions) to the Loading Section (Machine Shop Items). The current week number is endorsed on the job-card by the Loading section and time estimates are then given for each operation (adjusted for batch size) by the Industrial Engineering Dept.. The job-card J.T.C. and requisitions are sent to the Steel Stores and the route card is filed on the loading section in the Steel Stores File. Time dockets are sent to the relevant sections and the drawing goes to the first section.

Material and documents are then returned from the Steel Stores to the Machine Shop and this is recorded on the computer W.I.P file and the route card is transferred to a Machine Shop W.I.P file on the Loading section. The week number on the job card is then updated and manufacture commences.

In each Machine Shop section the job is first marshalled, so that the operator is supplied with all the equipment needed to carry out the operation. On completion, the relevant time docket is clocked and the job sent to the next section. The times are recorded by Time Balance and the completed dockets are filed with the route card. This assists in job location during manufacture.

When all machining operations are completed, the route card is sent with the job-card, J.T.C., drawing, materials and remaining time dockets to the next department. Completed dockets (except the last one) are returned to Time Balance for filing under week number and clock number order. The last completed time docket is retained by the Loading Section and is filed in part number order as a record that the job has left the Machine Shop.

Although the Inspection and Treatment departments do not operate a piecework system, time dockets are issued for these operations. These dockets are signed with the date of completion of the operation and are filed to provide a record.

When the job is finally completed and sent to the Kit Marshall (K.M.) Store, the drawing is returned to the Drawings Store, the job-card placed in a history file and the upper portion of the route card is detached and used as a label on the component.

Whilst the above information does not relate directly to Group Technology it puts on record the 'before' conditions of manufacture, so that when improvements are effected, comparisons can be made of the 'before' and 'after' conditions relating to G.T..

8.7 Guide Lines and Proposals for Group Technology.

After a visit to Hawker Siddeley, Professor Thornley proposed broad guide lines for the implementation of Group Technology. These guide lines are as follows:-

(a) Determine full manufacturing details concerning the production of components.

(b) Devise a classification and coding system suitable to cover the shape and production characteristics of components.

(c) Ascertain production families which could be accomodated in one of the three types of Group Technology cells, viz:-

    (i) Single machine cell using the complex component technique.
    (ii) A cell, consisting of a variety of machine tools required to produce a family of parts.
    (iii) A flowline cell for continuous production.

(d) Develop a production control system and scheduling procedure to deal with the new system and layout of machine tools.

However, before any changes can be put into affect, the company must be provided with sufficient information to enable it to decide whether Group Technology should be applied or not. The following questions would need to be answered:-

(a) Which method of application should be used and what form should it take.

(b) To what extent can Group Technology be applied and which departments will come under its influence?

(c) What are the main effects on those departments likely to be?

(d) What are the main problems which are likely to arise?

(e) What benefits are likely to result and is there any area which is likely to be adversely affected?

(f) How much would Group Technology cost to apply in terms of both capital expenditure and man-hours required for reorganisation?

(g) What financial returns can be expected?

(h) How long will it take to implement Group Technology and how long will it be before its effects are felt?

A criticism which has been made of Group Technology within the aircraft industry is, that cells formed to produce families of components for the present will not necessarily be suitable to produce families for assemblies in the future.

What the critics are saying is that in general, families of components change in basic shape and geometrical configuration and will not be accomodated on machines in the future. They are of course at fault, because of their inability to think of items as individual components entirely disassociated from the product, which they will later combine to form. It is understandable that this is the thinking at Hawker Siddeley, when one realizes the large number of types and models of aircraft being produced.

However, it must be acknowledged that when the production of components is analysed and broken down into individual operations, the machines required to perform these operations are still basically the same lathes, mills, drills etc., which performed similar operations on components twenty years ago. If cells are formed with due thought and care in the first instance there is little doubt that these same cells will continue to produce components irrespective of model or aircraft changes over the years.

8.8 The Initial Sample Analysis.

It was decided to code a sample of component drawings using the

Opitz Code to see if classification and coding could be applied to a typical mix of aircraft component drawings. A sample size of 370 drawings taken from a wide cross section of the company's products was coded using the standard Opitz Geometrical Code, FIGS. 2-3 to 2-8, and a modified version of the Supplementary Code, FIG. 7-5. The sample coded satisfactorily with a few reservations regarding the suitability of the non-rotational classes, 6, 7 and 8. These were later modified to suit the component types found at Hawker Siddeley, as was the Supplementary Code. See Section 8.12.

An analysis of the sample code showed the following class groupings:-

Component Class	Digits	No. of Components	% of Total.
Rotational	0,1 & 2	148	40
Rotational with Deviation	3 & 4	59	16
Flat	6	52	14
Long	7	37	10
Cubic	8	74	20
		370	100%

Rotational Components.

These accounted for 56% of the total and were mainly small components less than $2\frac{1}{2}$" diameter and 6" long. They classified very well using the standard Opitz Code and there is little doubt of its suitability for these components.

Flat, Long and Cubic Components.

These accounted for 44% of the sample. In the flat class (6) most components were straight forward applications with the odd exception provoking some thought e.g. the component labelled, End Fitting (Front Strake), FIG. 8-6, which has raw material supplied as high tensile steel forging and is then machined in the Machine Shop (See Process Sheet Appendix 3). A total of 28 operations are listed on the Process Sheet, eight on milling, four grinding, one boring, one drilling and fourteen on miscellaneous auxiliary operations such as marking out, stress relieving, vacua blast, cadmium plate, crack detect, painting and inspection. On first sight one is tempted to classify this component as rotational with deviation (class 4), but on closer study of the machining operations, one can see that they are all carried out on non-rotational machines, with surface milling predominant. Hence the classification - non-rotational, flat, class 6, is best suited for this component. It is coded as 66174 - 4173.

A point which should be stressed here, is that when a coder is using a code to aid in the formation of technological families of parts, he should refer to the process sheets in doubtful cases, to make sure that the machines used are compatible with the code class he alots to the component. Without such a check, it is possible for components to fall into families and hence cells which are entirely unsuitable for their manufacture, as could be the case for the component, FIG. 8-6, just described.

Several other components in the non-rotational category necessitate quite complicated milling operations to produce them. In many cases the majority of these operations are carried out on the one machine and this fact need not be signified by the code. It is sufficient that the code indicates the geometry which will be produced by the key machine in the cell. Some of these components include the following -

Bracket (Outer) Outboard Pylon Pickup, Half Rib - Inner Pylon Pickup, Jacking Pad, Riblet, Fitting - Machined and Joint Plate (Rib 27).

In the long class of component - class 7, a number of components which are relatively small classified under this digit. However, a series of components which came under this category caused some concern, because of,

(a) Their extreme length

(b) The manner in which the component is produced from the raw material stage, i.e. being completely machined from plate or extruded bar.

(c) The numerous tolerances and high degree of surface finish generally required.

(d) The multiplicity and complexity of machining operations, including N.C.

(e) The amount of testing, inspection, and miscellaneous finishing operations required, all carried out in separate departments or areas within the factory.

Features (a), (b), (c) and (d) can be adequately catered for by the geometrical code, simply by ensuring that these components are directed into the correct family group and hence the cell of machines capable of machining them. However, feature (e) would have to be described in the supplementary code in such a way as to indicate whether the auxiliary process occurred during, before or after machining. If the process was not available in the cell and occurred during machining operations, then the component would have to leave the cellular control and return to complete machining at a later date. This is generally unsatisfactory, as one of the main advantages of the cell, that of predictable completion dates, is lost when components leave the cell for part processing. By the use of a properly structured supplementary code, the number of components in this category can be determined and if there are sufficient to warrant it, special facilities can be installed in the cell to maintain full control. Otherwise, it may be desirable to exclude such components from the cell load.

Many of the long components are of the unique variety, and as such are machined on the special purpose machines designed to produce them. These components include stringers, booms, spars, ribs, etc. Details of a Stringer are shown in FIG. 8-4 which although it classifies easily by the Opitz Code viz., 75074 - 9284, is mainly manufactured on specialized milling and routing machines whose location is fixed. Other machining operations are carried out on normal milling machines etc. It may be possible to group auxiliary machines e.g. mills and drills, around these specialized machines to carry out all operations in the one area and hence achieve the benefits of cellular control, i.e. reduction in throughput time and work in progress. As stringers list approximately 19 operations on the process sheets, (see tables, App. 3), these components are expected to be on the shop floor for 19 weeks. An examination of FIG. 8-4 will show that due to the complexity, accuracy and number of operations required, the value of the component increases rapidly from the first operation stage and any reduction in the throughput time would represent a sizable decrease in the value of work in progress.

Another long component (class 7) which illustrates the difference in machines required at Hawker Siddeley is shown in FIG. 8-5, Skin Stabiliser Between Ribs. It is machined from aluminium alloy in the extruded initial form (similarly to the stringer), but because of its much shorter length (274 ins. compared with

29ins.) can be accomodated on conventional N.C. milling machines situated in the Machine Shop. This is a complex component requiring 23 operations for manufacture, half of which are close toleranced milling operations necessitating the use of fixtures because of the oblique shape and changing cross section characteristics.

The above two components are classified identically by the Opitz Geometrical Code viz., 75074 and the only difference in the Supplementary Code is in the length digit, which sets them apart. The use of the dimension digits in the above respect illustrates their value when forming families for specific machining groups.

8.9 Recommendations for Code Modification.

As a result of the initial coding exercise by the writer, several recommendations for future modifications of the standard Opitz Code were made, viz.,

(a) Classes 6, 7 and 8 (flat, long and cubic) would inevitably need modification and to a lesser extent classes 3 and 4 (rotational with deviation). In the flat class (6), the overall shape column includes too many plane digits, leaving very few places for the description of composite components. Also the third digit (principal bore, etc.) of the flat, long and cubic classes allocates too many (6) categories to principal bores. This gives many components a '0' for this digit if they do not have a principal bore, when in fact the component could have rotational surface machining features e.g. boss, locating surface, annular groove or ridge, which would go uncoded. Other small modifications of these digits would also have to be made before a satisfactory code was developed.

(b) Inclusion of an extra digit in the Supplementary Code for treatments e.g. vacuablast, stress relieving, anodising, cadmium plate, painting and heat processes.

(c) Modifications to the initial form and material digits to adequately describe Hawker Siddeley components.

(d) A check to be made on the dimension digits of the Supplementary Code to see if the existing ranges were the best suited for the ranges of machines and components.

(e) It is essential to develop a coding manual simultaneously with the classification system, so that coding rules, interpretations etc., can be formulated and standardised at the time when decisions are made. This manual should form the basis of the classification system.

8.10 Conclusions Reached from the Initial Sample.

On the basis of the sample it was concluded that the Optiz Code could be adapted and used to classify components produced in the aircraft industry, whether they be of the commonplace or unique variety or not, but to do so satisfactorily, a list of objectives must first be established to define the purpose of the code. These may include some or all of the following:-

(a) To retrieve past design data.

(b) To formulate design standards and reduce component variety.

(c) To facilitate the formation of component families and subsequently groups of machine tools to manufacture these families.

A well designed classification system undoubtedly forms the best stating point for the implementation of Group Technology for the following reasons viz:-

(a) It lends itself to data processing techniques.

(b) It provides manufacturing data in the most compact, easily stored and retrieved manner available to industry today.

(c) It creates a familiarisation between all personnel who understand the code and the component mix, which is invaluable when the formation of families and loading of cells is being carried out.

The development of a suitable code and the subsequent classification of component drawings in a firm as large as Hawker Siddeley would be a long and tedious exercise, but the long term effect would be greatly appreciated as G.T. is implemented and expanded in the company.

8.11 The Undergraduate Projects.

At the time of writing, the two undergraduate projects outlined on page 78 have each reached stage 4 and are due for completion in December 1975. It is now intented to outline the work done up to this stage.

Both undergraduates attended an initial four day course conducted by the writer, on the use of the Opitz Code with particular emphasis being given to code modification. The students then went to the Manchester factory and coded a sample of 300 drawings from current production schedules using the standard Opitz Geometrical Code and the modified Supplementary Code, FIG. 7-5, with the object of making proposals for a new modified code. Both students were involved in the coding exercise, although it is only the responsibility of one to write up the report on this exercise.

8.12 The Hawker Siddeley Modified Classification System.

The proposed classification system which has been developed for Hawker Siddeley components is shown in FIGS. 8-8 to 8-12. It consists of a five (5) digit Geometrical Code plus a five (5) digit Supplementary Code. It is the result of various analyses and observations noted after the sample analysis of 370 components coded by the writer and the sample of 300 components coded by the students. The evolution of the code follows, and comparisons can be made with the standard Opitz Code, FIGS. 2-3 to 2-10.

Rotational Components, FIG. 8-8.

Two major alterations and several minor ones were made to the standard Opitz Code for these components.

Firstly, the use of gear teeth on aircraft components does not occur frequently and hole production is a machining operation which is not only common, but imposes some production difficulties because of the complicated patterns and angles involved. As these two features are both coded under the one digit (5) it was decided to remove gear teeth and expand the hole description to nine (9) classes instead of six (6). The three basic divisions of holes are, axial, radial and other directions - two digits each, and combinations of these - two digits (7 and 8). The terms 'related' and 'not related' refer to either dimensional or angular relationships between holes.

Gear teeth were put into one class and because the machining operation required to produce them is basically plane surface generation, they were coded under the 4th digit as class 9, thus suppressing all other plane surface machining features, which was thought desirable as <u>all</u> components with gear teeth could then be accounted for in the final analysis.

Secondly, the description of plane surface machining (4th digit) classes was altered to coincide with the production thinking of Hawker Siddeley engineers i.e. it is thought that curved surface production (class 3) is more difficult to achieve than an external groove or slot (class 2). Also an external spline or polygon (class 5) is more difficult to produce than external plane surfaces with angular relationship.

A slight alteration was made to the 3rd digit, internal shape elements, which now includes a blind bore in conjunction with classes 1 to 6. Also it was felt that the term 'machined thread' was a better description of what was meant than 'operating thread' in class 8 of digits 2 and 3. The former definition implying any thread that is produced by a single point tool, thus requiring a machine with screw cutting facilities.

Non-rotational Components - Flat, long and cubic, FIGS. 8-10, 8-11, 8-12.

It will be noticed that the 2nd digit (overall shape) of these three types of components is different for each type in the standard Opitz Code and the remaining digits (3,4 and 5) are identical. In the proposed code, the class format of the second digit is the same for these three types of components, with variations in the wording made to suit each type. It is thought that this will be a good feature as the same geometrical description applies to each class for each type of component, thus making coding simpler and the code easier to remember. The remaining three digits, (3,4 and 5), of the Hawker Siddeley Code are identical for each component class, but digit 5 is also identical to digit 5 of the Opitz Code.

In order to substantiate the alterations to the 2nd digit (overall shape), a bar chart analysis of the three types of components (flat, long and cubic) was made in the ten classes of the 2nd digit to see if a better distribution was achieved by the modified code. This analysis is shown in FIG. 8-14 (a) and (b).

Consider the 70 cubic components falling into class 5 of the standard Opitz Code, which describes them as'block and block-like components other than 0 to 4'. The description is not very clear and it seems as though this class is used as a 'dump' for components which will not fit into the other classes. Hence, class 5 would not be very helpful when forming families of similar components. The same reasoning applies to the 70 flat components which fall into class 6 of the standard Opitz Code, which describes them as 'flat components, round or of any other shape other than position 5'. By comparison the same sample of 300 classified by the modified code gives a more even distribution of the three types of component and makes use of all class descriptors. Each class is given a specific meaning and not just a general 'other than' classification as is the case with the Opitz Code. Also, each class digit in the modified code has a definite technological implication which leads towards family grouping. It is important that the 2nd digit (overall shape) is indicative of technological operations, as these are generally those performed by key machines in the cell.

Further modifications were made to the 3rd and 4th digits of the flat, long and cubic classes. Digit 3 was modified to include a class for 'rotational machining', class 3, which although the Opitz Code uses this term in the column heading, does not classify it. It was also thought that the class for annular surfaces and grooves (class 7) of the Opitz Code should be moved down to class 4 as it is principally a rotational surface machining digit, mainly applicable to production from one direction. Class 5, 'several principal bores' and class 8,'7 + principal bores' of the Opitz Code were considered to be unnecessary, because no components were found in these categories. Multiple bores are coded under classes 7 and 8 of the modified code.

The 4th digit, plane surface machining, was modified to give a much greater bias to the description of curved machined surfaces. This feature of aircraft components in the non-rotational classes, predominates, and a large proportion of these components are machined completely from the solid bar or slab initial state. The modified code alots four classes (1 to 4) to plane surfaces and five classes (5 to 9) to curved surfaces and combinations. It is felt that this code will not only satisfactorily classify plane surfaces, but will allow for a better division of component families into groups requiring special machines for the production of curved surfaces.

The 5th digit, (auxiliary holes etc.) of the modified code is the same as the Opitz Code. One point which may prove troublesome with the modified code during analysis is that gear teeth for rotational components are coded under digit 4 (plane surface machining), whilst for non-rotational components they are coded under digit 5 (auxiliary holes etc.).

<u>The Supplementary Code, FIG. 8-13</u>. The Supplementary Code caused quite a deal of discussion and went through several stages of development before reaching its final form.

It was initially thought that the accuracy digit should be used because of the many components which were toleranced and the high degree of surface finish usually specified. However, this initial thinking was reversed when it was realized that cells would be formed from existing machines which were already coping with the accuracy requirements and would continue to do so when placed into cellular groups.

The extra dimension digit (length) was thought to be a necessary inclusion, to aid in component family groupings. The use of two dimension digits in the Supplementary Code was proposed by Professor Thornely, FIG. 7-5, and an interesting feature of the Hawker Siddeley Code is the rearrangement of dimensions included in these digits. It will be noticed that the two length dimensions for both rotational and non-rotational components are combined under the 1st digit and the remaining two, diameter 'D' and edge length 'C' are combined under the 2nd digit. This modification is felt to be an improvement, as it clarifies the length dimension by putting it under the same digit for all components, whereas FIG. 7-5 uses two length digits, one for rotational (1st. digit) and one for non-rotational (2nd digit). This feature will be advantageous when analysing component lengths to determine their suitability for certain machines.

A bar chart analysis, FIG. 8-15 (a) and (b), was used to determine if the ranges specified in the Optiz Code were suitable for Hawker Siddeley components. FIG. 8-15 (a) shows the dispersion of the range digits and the use made of them by the various dimensions. It was concluded that the small range sizes were overloaded (326 components out of 400 coming under digits 0,1 and 2), and the larger range sizes were not used (23 out of 400 coming under digits 5,6,7,8 and 9). It was decided to increase the small range sizes (below 100mm or 4 ins) from three in the modified code, FIG. 7-5, to five in the Hawker Siddeley modified code, FIG. 8-13. The top three ranges, 7,8 and 9 of the code, FIG. 7-5 were eliminated to allow this. Fig. 8-15 (b) shows the dispersion of the range digits after these modifications using the same sample. It will be noticed that a more even spread is obtained, thus indicating a much better classification which will enable a more accurate analysis when determining component families.

The 3rd Digit (Material) was developed in consultation with Hawker Siddeley engineering personnel on the basis of a material machinability scale.

The 4th Digit (Initial Form) is similar to the Opitz Code.

The 5th Digit (Treatments) is an additional digit, thought to be necessary because of the wide range of treatments carried out on aircraft components. Many of these treatments are performed between machining operations and this digit aims to isolate these components so that decisions can be made on the desirability of including some treatments in cells should the number of components warrant it. It is of no concern if treatments are carried out before and/or after machining operations, because such treatments would not affect cellular operations.

At the time of writing, stage 4 of the Undergraduate Project Statement No. 1 is in progress with approximately 650 components coded out of an estimated, 2,500, using the Hawker Siddeley Modified Codes.

It is proposed, that on completion of the coding and its subsequent analysis and the two undergraduate projects, a full report and presentation on the feasibility of Group Technology within the factory will be made to top management, to enable them to make a decision on its implementation or otherwise.

8.13 Conclusions.

The classification and coding approach to a G.T. feasibility study of aircraft components is proving very successful. There is little doubt that the final analysis and report to top management will leave a clear picture in their minds of the implications involved and above all the benefits that can be expected to accrue as a result of implementing a Group Technology System. Management should then be in a position to make a firm decision whether to proceed with Group Technology or not.

9. FUTURE WORK.

9.1 Future of Group Technology at Bronx Engineering.

The present situation at Bronx Engineering is one of decision making. Having been presented with all the facts, management must make up its mind if the time is opportune to proceed with a change to Group Technology. There is little doubt, that all who attended the verbal presentation of the feasibility study and later received a written report were convinced that G.T. could provide the solutions to the problems at present facing the company.

Whether these solutions are attractive enough to offset other industrial problems, costs of changing the system and various economic pressures is debatable. The longer the decision is left, the further into the background will fade the favourable impressions which the survey first made and greatly lessen the chances of G.T. acceptance.

The future of G.T. in Bronx Engineering, would certainly be bright. The company is small to medium sized and as such represents the ideal type for a complete G.T. system to be introduced in a relatively short time. Benefits could be derived in a matter of weeks if the company decided to instal a pilot turning cell.

Bronx Engineering are desirous of fostering better employer/ employee relations and this is evidenced by their recent attempt to instal an Added Value Incentive Scheme. Their efforts were unsuccessful because employees would not accept the scheme. However, the interaction of such a scheme and a Group Technology System would be a far more attractive proposition and one which would not only add more to the employees pay packet, but would also bolster the flagging profit margins of the company.

9.2 The Future of Group Technology at Hawker Siddeley Aviation.

The thought of Hawker Siddeley Aviation introducing Group Technology is exciting, when one considers the possibile implication of extending the system to include all Hawker Siddeley establishments in the U.K.. A break through such as this is all that Group Technology needs to establish it as a major manufacturing system.

Although many large firms have implemented G.T., introductions are taking place at such a slow rate that progress on G.T. installations must be considered as neglegible. Hawker Siddeley would certainly be one of the largest concerns contemplating the G.T. system and if it is approved then advances in G.T. techniques such as cell design, cell loading, sequencing, machine utilization to name a few, would certainly be improved on in the ensuing research programme.

Large projects sometimes have small beginnings and it is to be hoped that the part feasibility study outlined in this thesis is the small beginning to a much larger Group Technology exercise.

10. DISCUSSIONS.

10.1 Introduction.

It is possible at this stage to look back and reflect on the classification and coding approach to Group Technology implementation and evaluate whether it achieves the desired objectives or not and if the work put into the coding exercise is worth while.

There is little doubt that the crux of a successful Group Technology installation is the formation of similar technological families of components and the subsequent grouping of machine tools and processes to produce these families. A measure of the success of the above groupings is the value of benefits derived. It is possible for a person, familiar with a firm's product mix, to 'walk around the shop' and divide the components into what he considers as similar families and then arrange the machines into groups by eye, to machine these families. Such an approach would be very fast and most inexpensive, but because of its casual nature would be doomed to partial if not total failure. Any success would simply be a reflection on the proposers good judgement. Firms require a more definite approach than this. An approach which will not only form the families and groups mentioned, but will do so in such a way as to ensure an optimumization of the expected benefits.

10.2 The Role of Classification.

It has been pointed out in this thesis that there are methods other than classification for forming similar families of components, but on taking a closer look at these methods, one sees that the principles involved are complicated or are not for general use. This aspect of component family formation by classification has always been unchallenged and in fact is taken for granted once the coding of drawings is completed and the data put on computer.

The geometrical features of similar families are automatically grouped according to the class digits allocated to them. Of course there are many classification systems for this purpose and one should ask - what are the criteria for selection of a suitable classification system? Anyone who has had experience with classification should be able to answer this question. A number of factors readily come to mind, viz:-

(a) Simple - the code should be simply structured and easy to understand so that its use and meaning is available to all within the firm using it.

(b) Precise - its format should be such as to give a clear interpretation of the objectives around which the code was designed.

(c) Short - the number of digits in the code should be as small as possible, bearing in mind the purpose for which the code was designed.

(d) Easily Modified - there is no universal code which can be used for all companies. Each situation is different and code structures must be open to modification.

(e) Flexible - its use must not be narrow or singular e.g. just for family formation. It should be structured so that its existence can be justified for other uses, e.g. design retrieval, standardisation etc..

(f) Easily Analysed - an important aspect, which one immediately associates with the ease by which coded data can be processed both by manual and computer analysis.

(g) Uniform - All definitions and interpretations of the code should be uniform in meaning and such uniformity put down in writing e.g. a code manual.

(h) Easy Application - the actual coding of a component should be a series of short, logical decisions each followed by a simple notation on the drawing.

(i) Repeatability - a component should code identically irrespective of the number of times it is coded and by whom.

(j) Universal - a code must be designed to accomodate all components manufactured within the firm and not just a large percentage.

The above ten factors are considered to be the main criteria for selecting a classification system and one could list many minor desirable features to be considered in the design of a system.

As the Opitz System was used on the projects in this thesis one must gauge how it measured up to the criteria listed above.

The structure of the Opitz Code, FIG. 2-2, is certainly simple and easy to follow when one compares it with the Brisch Code, FIG. 2-11, and other miscellaneous codes illustrated in this thesis. All classes within the Opitz Code have short, precise descriptions of the particular aspect referred to in each column heading. The code has nine (9) digits and is one of the shortest length codes available. It can be easily modified both in length and individual digit meaning, because it is an open ended code with each digit having independent significance. The use of the Opitz Code for design retrieval and standardisation has been described in this thesis, thus illustrating its flexibility of use.

Because of its totally numeric structure the Opitz Code is ideally suited to data processing facilities, thus making the task of code analysis a much easier one. The standard use of a code manual ensures that the definitions and interpretations of the Opitz Code are uniform, whilst coding is exactly that which is specified for easy application. The repeatability of application of the Opitz Code has been proven by many users, but this feature is largely a reflection on the manner in which class digits are stated i.e. singular or double meanings, or a feature being interpreted under more than one digit in the same column.

The last criteria, that of universal application must be adhered to when considering the components to be manufactured by a specific cellular system. There have been instances where more than one code has been used in the same factory. In a particular case[66] three codes were designed, one each for electrical contacts, levers and sheetmetal components. Three codes were necessary because of the incompatability of components in each of these classes to satisfactorily form manufacturing families under the one code. However, within each category, the code concerned was universal in its application and completely coded all components.

10.3 Conclusions.

Because of the benefits to be derived and the advantages to be gained, as outlined and discussed in this thesis, there is little doubt that classification and coding is the best way in which to approach a Group Technology exercise. Also the Opitz Classification structure is that which can be best modified to suit each and every firm desirous of adopting the classification and coding approach to Group Technology.

11. CONCLUSIONS.

1. Group Technology is a tried and proven system, one which will eventually make a major contribution to the small batch manufacturing industry.

2. The introduction of Group Technology into a firm must be a totally committed exercise on the part of both management and workforce if success is to be assured.

3. Group Technology can only be achieved by eliminating the functional layout of facilities and replacing it with group layout.

4. Group Technology cannot be implemented in isolation to the shop floor, it must be integrated into the whole corporate system.

5. Before Group Technology is introduced to the shop floor, a complete record of production data should be made so that the 'before' and 'after' conditions can be carefully assessed and compared.

6. The benefits of Group Technology have been documented many times and a company should take careful note of the 'before' values of these benefits so that estimates, of improvements directly attributable to Group Technology can be made.

7. Group Technology is a new manufacturing concept and many are ignorant of its implications. A firm should embark on a comprehensive educational programme to ensure that the principles and objectives are clearly stated and understood by all.

8. A workshop principle of Group Technology is that machine utilization is not of paramount importance, but labour

utilization is. Hence some degree of flexibility of labour is essential to ensure full utilization. Overall machine utilization usually improves, because key machines are more efficiently used than they were under the functional layout.

9. By giving cells a large measure of autonomy, employee job satisfaction is greatly improved, with a follow on improvement in product quality and productivity.

10. Some difficulties can occur with the labour flexibility requirements, but this aspect should not be 'overplayed' until the exact measure of flexibility is known, when it may be automatically accepted by employees as a necessity of the new system.

11. The implementation of a G.T. system is a good time to consider other changes which in themselves may not have warranted attention e.g. replacement of old machines, introduction of new processes, reorganization of personnel structure, study of products and elimination of non-profitable ones, the introduction of an incentive scheme etc..

12. The roles of Production Planning and Production Control change significantly with the introduction of G.T. and it is important to forecast and plan such changes so that all concerned are amicably satisfied.

13. A classification and coding approach to Group Technology requires the analysis of a representative sample of the component range in order to design a suitable code for complete adoption. A sample size of 10% of the live components is generally accepted as sufficient.

14. The installation of a pilot cell is desirable, to

illustrate the effects of G.T. as well as gain some benefit to offset the added costs.

15. A pilot cell should always be designed to integrate with subsequent cells.

16. A verbal presentation, coupled with a written report of a survey of component drawings is the best way to present top management with the necessary facts and figures to make a decision on Group Technology.

17. An expense which may prove to be large, is that incurred in purchasing auxiliary machines, so that cells may be independent for all their operations.

18. Labour requirements may decrease slightly as a result of Group Technology, because some positions such as progress chasers are not required and other personnel in quality control, inspectors etc., are required to a lesser degree.

19. Coding of drawings should be carried out by a firm's own personnel as this exercise develops expertise in the use of the code and gives a greater understanding of the requirements of cell types when cells are being designed.

20. Group Technology does not end with the formation and loading of machine groups. Techniques involving the complex component principle, specialization of jigs and fixtures, tool design, value analysis etc. can be employed to maximize the efficiency of cells and machines.

21. The establishment of cells to machine specific families of components, opens the way for the installation of special purpose machines designed especially to carry out those

operations required by the family of components concerned.

22. It is essential when analysing a large number of components, for a company to have a computer or alternatively access to computer facilities.

23. One of the most worthwhile aspects of Group Technology as far as sales personnel are concerned is the ability to quote short, reliable delivery dates for products as well as give accurate estimates and completion dates for jobbing work.

24. The chief factor in overcoming employee resistance to G.T. changes, is to gain the support and participation of union representatives on any committee established to promote the implementation of Group Technology.

25. When a classification system is based on technological as well as geometrical features of components, a coder quite often has to refer to process sheets, to ensure that the code alots the component to the correct family for machining.

26. The use of bar and flow chart analyses in reports are extremely valuable when illustrating results and sequenced steps respectively, after carrying out a G.T. survey.

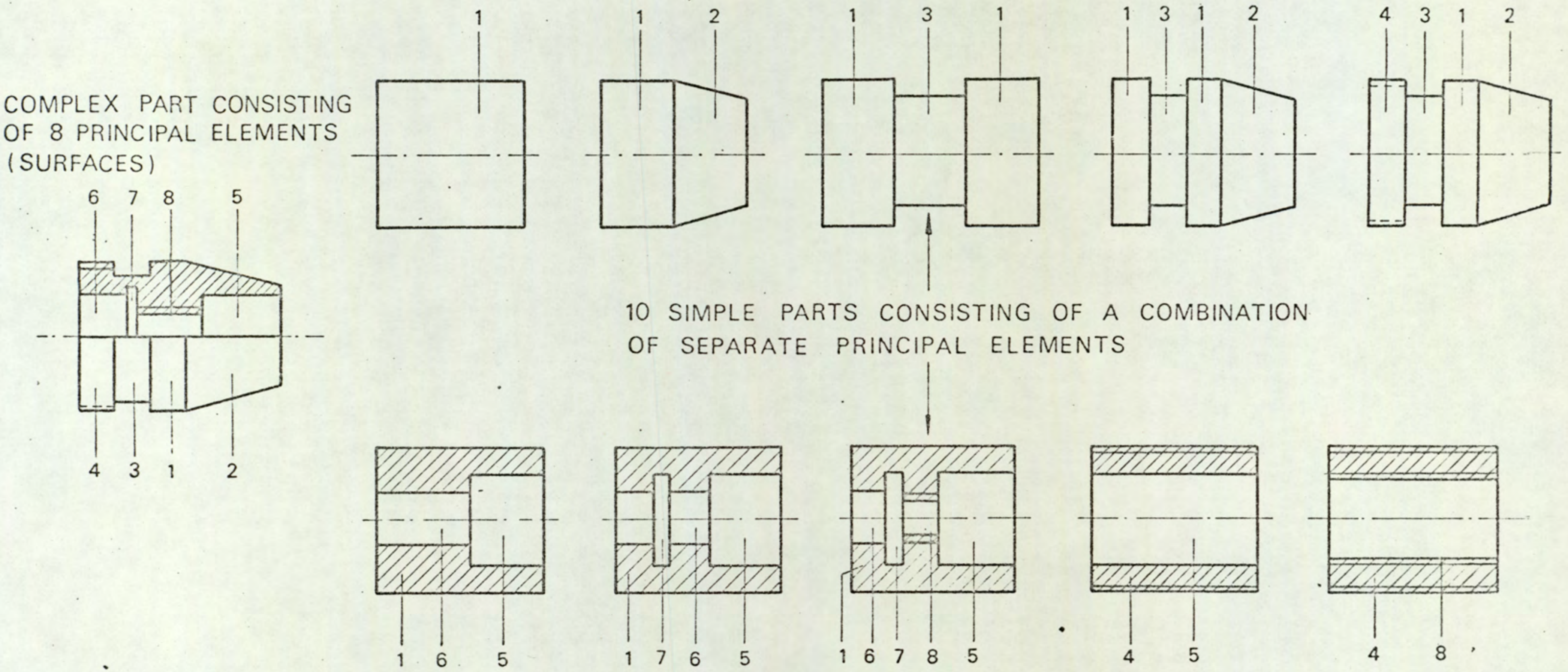
27. A company's sub-contract work can be satisfactorily analysed and assessed by a properly designed classification system.

28. Component route diagrams of existing manufacture provide a realistic demonstration to management of the long and haphazard journeys which components undertake during the course of production.

29. The accuracy digit of the Opitz Supplementary Code

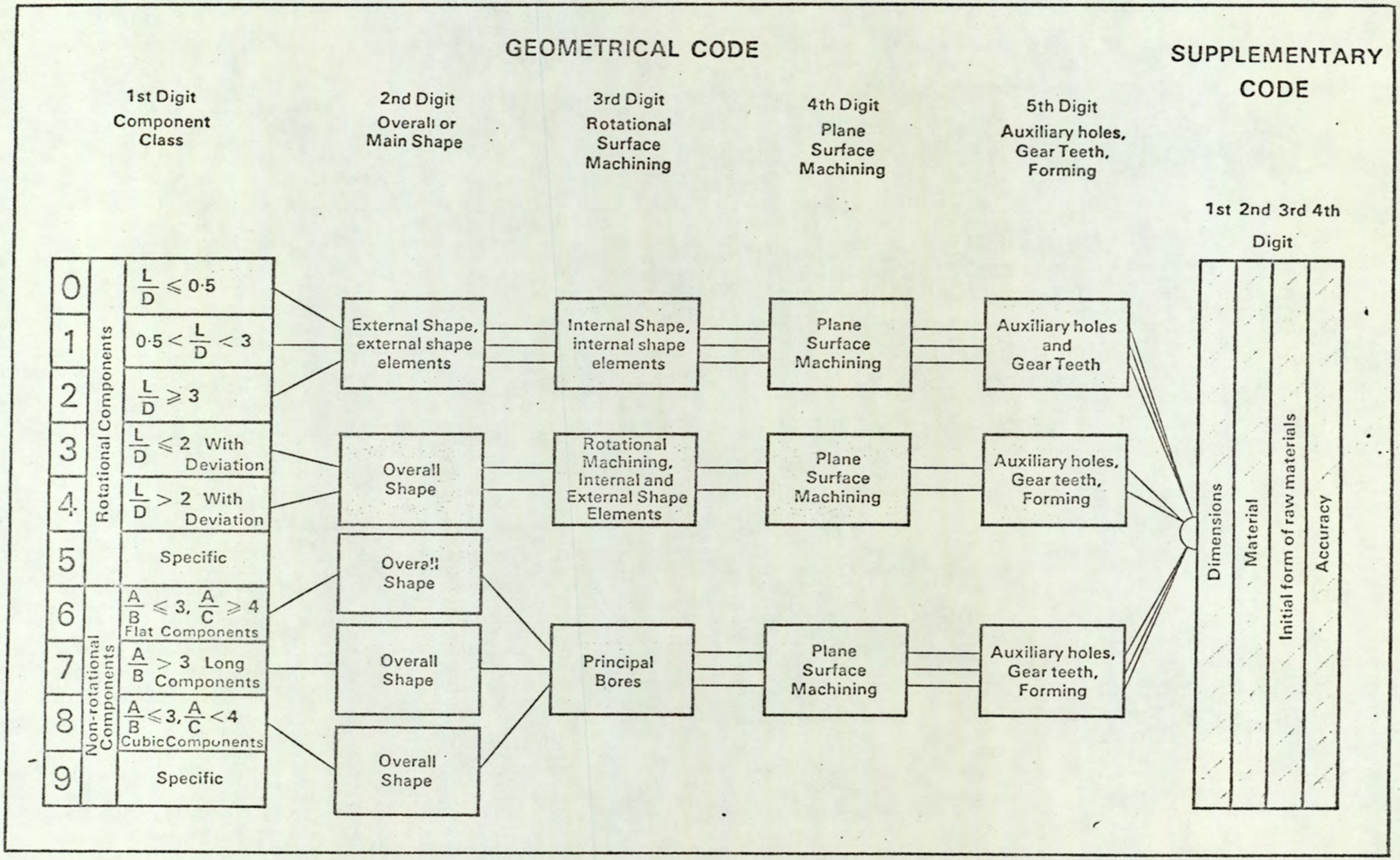
has been found to be unnecessary when using the code for the implementation of Group Technology, because existing machines are currently coping with accuracy requirements, and there is little to be gained in coding accuracy when the same machines are still going to be used.

30. The dimension digits of the Supplementary Code should be carefully analysed to ensure that the scales provided are suitable for the company's range of components and machines.



MITROFANOV'S COMPLEX PART PRINCIPLE FOR GROUP TECHNOLOGY (after Mitrofanov)

FIG. 2-1



STRUCTURE OF THE OPITZ CLASSIFICATION SYSTEM

FIG. 2-2

GEOMETRICAL CODE

1st Digit

Component Class		
0	Rotational Components	$\frac{L}{D} \leqslant 0{\cdot}5$
1	Rotational Components	$0{\cdot}5 < \frac{L}{D} < 3$
2	Rotational Components	$\frac{L}{D} \geqslant 3$

2nd Digit

External Shape, external shape elements		
0		Smooth, no shape elements
1	Stepped to one End	no shape elements
2	Stepped to one End or smooth	with screwthread
3	Stepped to one End or smooth	with functional groove
4	Stepped to both Ends (Multiple increases)	no shape elements
5	Stepped to both Ends (Multiple increases)	with screwthread
6	Stepped to both Ends (Multiple increases)	with functional groove
7		functional taper
8		Operating thread
9		Others (> 10 functional diameters)

3rd Digit

Internal Shape, internal shape elements		
0		Without through bore blind hole
1	Smooth or Stepped to one End	no shape elements
2	Smooth or Stepped to one End	with screwthread
3	Smooth or Stepped to one End	with functional groove
4	Stepped to both Ends (Multiple increases)	no shape elements
5	Stepped to both Ends (Multiple increases)	with screwthread
6	Stepped to both Ends (Multiple increases)	with functional groove
7		functional taper
8		Operating thread
9		Others (> 10 functional diameters)

4th Digit

Plane Surface Machining	
0	No surface machining
1	External plane surface and/or surface curved in one direction
2	External plane surfaces related to one another by graduation around a circle
3	External groove and/or slot
4	External spline and/or Polygon
5	External plane surface and/or slot and/or groove, spline
6	Internal plane surface and/or groove
7	Internal Spline and/or Polygon
8	External and Internal splines and/or slot and/or groove
9	others

5th Digit

Auxiliary Hole(s) and Gear Teeth		
0	no gear teeth	No auxiliary hole(s)
1	no gear teeth	axial hole(s) not related by a drilling pattern
2	no gear teeth	axial holes related by a drilling pattern
3	no gear teeth	radial hole(s) not related by a drilling pattern
4	no gear teeth	holes axial and/or radial and/or in other directions, not related
5	no gear teeth	holes axial, and/or radial and/in other directions related by drilling pattern
6	with gear teeth	spur gear teeth
7	with gear teeth	bevel gear teeth
8	with gear teeth	other gear teeth
9		others

ROTATIONAL CLASS DIGITS OF THE OPITZ CODE

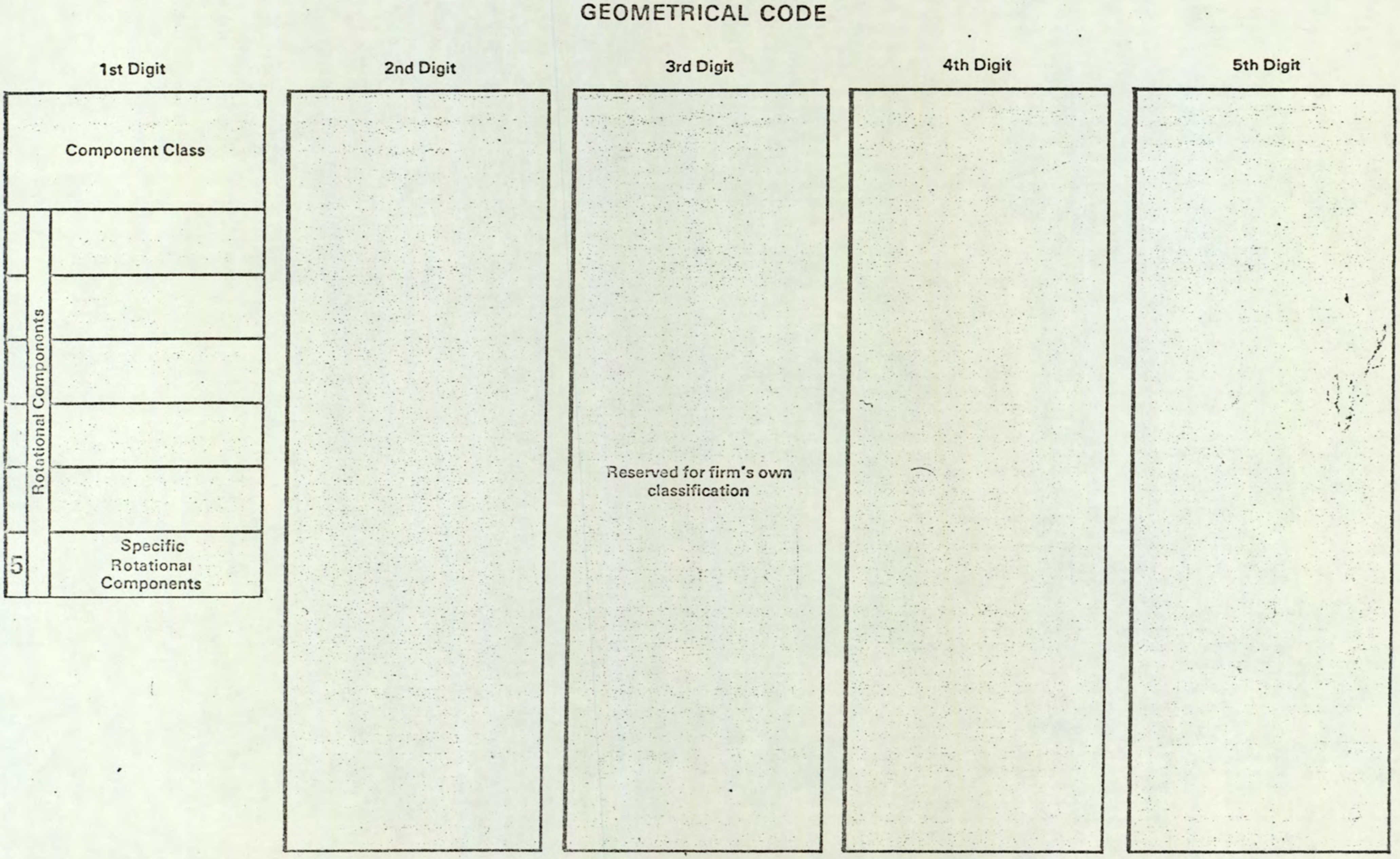
FIG. 2-3

GEOMETRICAL CODE

	1st Digit		2nd Digit		3rd Digit		4th Digit	5th Digit	
	Component Class		Overall Shape		Rotational Machining		Plane Surface Machining	Auxiliary Hole(s), Gear Teeth, Forming	
0	Rotational Components		Around one Axis No Segments	Hexagonal bar		No rotational machining	No Surface machining		No auxiliary holes, gear teeth and forming
1				Square or other regular Polygonal section	External Shape	machined	External plane surface and/or surface curved in one direction	No forming, No gear teeth	axial hole(s) not related by drilling pattern
2				Symmetrical cross-section producing no unbalance		with screwthread(s)	External plane surfaces related to one another by graduation around a circle		holes axial and/or radial and /or in other directions, not related
3		$\frac{L}{D} \leqslant 2$ with deviation		Cross-sections other than 0 to 2	Internal Shape	smooth	External groove and/or slot	related by a drilling pattern	axial holes
4		$\frac{L}{D} > 2$ with deviation		Segments after rotational machining		Stepped towards one or both ends (Multiple increases)	External spline and/or Polygon		holes axial and/or radial and/or in other directions
5				Segments before rotational machining		with screwthreads	External plane surface and/or slot and/or groove, spline	Forming, No Gear Teeth	Formed, no auxiliary holes
6			Around more than one axis	Rotational Components with curved axis	Ext. and Int. Shape	machined	Internal plane surface and/or groove		Formed, with auxiliary holes
7				Rotational Components with two or more parallel axes		screwthread(s)	Internal Spline and/or Polygon		Gear teeth, no auxiliary holes
8				Rotational Components with intersecting axes		External Shape Elements	External and Internal Spline and/or slot and/or groove		Gear teeth, with auxiliary hole(s)
9				Others		Other Shape Elements	Other		Other

ROTATIONAL WITH DEVIATION CLASS DIGITS OF THE OPITZ CODE

FIG. 2-4



SPARE ROTATIONAL CLASS DIGIT OF THE OPITZ CODE

FIG. 2-5

GEOMETRICAL CODE

	1st Digit	2nd Digit	3rd Digit	4th Digit	5th Digit
	Component Class	Overall Shape	Principal bore, rotational surface machining	Plane Surface Machining	Auxiliary hole(s) Forming, Gear Teeth
0		Plane: Rectangular	No rotational machining or bore(s)	No Surface Machining	No auxiliary holes, gear teeth and forming
1		Plane: Rectangular, with one deviation (Right Angle or Triangular)	One principal bore, smooth	Functional Chamfers (e.g. welding prep.)	No gear teeth, no forming: Holes drilled in one direction only
2		Plane: Rectangular, with angular deviations	One principal bore stepped to one or both ends	One plane surface	No gear teeth, no forming: Holes drilled in more than one direction
3		Plane: Rectangular with circular deviation	One principal bore with shape elements	Stepped plane surfaces	No gear teeth, no forming, related by a drilling pattern: Holes drilled in one direction only
4		Plane: Any flat shape other than 0 to 3	Two principal bores, parallel	Stepped plane surfaces at right angles, inclined and/or opposite	No gear teeth, no forming, related by a drilling pattern: Holes drilled in more than one direction
5		Flat components, rectangular or right angled with small deviations due to casting, welding, forming	Several principal bores, parallel	Groove and/or Slot	Forming, no Gear Teeth: Formed, no auxiliary holes
6	Flat Components $\frac{A}{B} \leqslant 3$, $\frac{A}{C} \geqslant 4$	Flat Components, round or of any shape other than position 5	Several principal bores, other than parallel	Groove and/or Slot and 4	Forming, no Gear Teeth: Formed, with auxiliary holes
7		Flat Components regularly arched or dished	Machined annular surfaces, annular grooves	Curved Surface	Gear teeth, no auxiliary hole(s)
8		Flat Components irregularly arched or dished	7 + principal bore(s)	Guide Surfaces	Gear teeth, with auxiliary hole(s)
9		Others	Others	Others	Others

FLAT CLASS DIGIT OF THE OPITZ CODE

FIG. 2-6

GEOMETRICAL CODE

	1st Digit	2nd Digit		3rd Digit	4th Digit	5th Digit	
	Component Class	Overall Shape		Principal bore, rotational surface machining	Plane Surface Machining	Auxiliary hole(s) Forming, Gear Teeth	
0		Shape Axis—Straight, Uniform Cross-Section	Rectangular	No rotational machining or bore(s)	No Surface Machining		No auxiliary holes, gear teeth and forming
1		Shape Axis—Straight, Uniform Cross-Section	Rectangular with one deviation (Right Angle or Triangular)	One principal bore, smooth	Functional Chamfers (e.g. welding prep.)	No gear teeth, no forming	Holes drilled in one direction only
2		Shape Axis—Straight, Uniform Cross-Section	Any cross-section other than 0 and 1	One principal bore stepped to one or both ends	One plane surface	No gear teeth, no forming	Holes drilled in more than one direction
3		Shape Axis—Straight, Varying Cross-Section	Rectangular	One principal bore with shape elements	Stepped plane surfaces	No gear teeth, no forming; related by a drilling pattern	Holes drilled in one direction only
4		Shape Axis—Straight, Varying Cross-Section	Rectangular with one deviation (Right Angle or Triangular)	Two principal bores, parallel	Stepped plane surfaces at right angles, inclined and/or opposite	No gear teeth, no forming; related by a drilling pattern	Holes drilled in more than one direction
5		Shape Axis—Straight, Varying Cross-Section	Any cross-section other than 3 and 4	Several principal bores, parallel	Groove and/or Slot	Forming, no Gear Teeth	Formed, no auxiliary holes
6	Non-rotational Components	Shape Axis Curved (bent)	Rectangular, angular and other cross-sections	Several principal bores, other than parallel	Groove and/or Slot and 4	Forming, no Gear Teeth	Formed, with auxiliary holes
7	Non-rotational Components: Long components $\frac{A}{B} > 3$	Shape Axis Curved (bent)	Formed Component	Machined annular surfaces, annular grooves	Curved Surface		Gear teeth, no auxiliary hole(s)
8		Shape Axis Curved (bent)	Formed Component with deviations in the main axis	7 + principal bore(s)	Guide Surfaces		Gear teeth, with auxiliary hole(s)
9		Shape Axis Curved (bent)	others	Others	Others		Others

LONG CLASS DIGIT OF THE OPITZ CODE

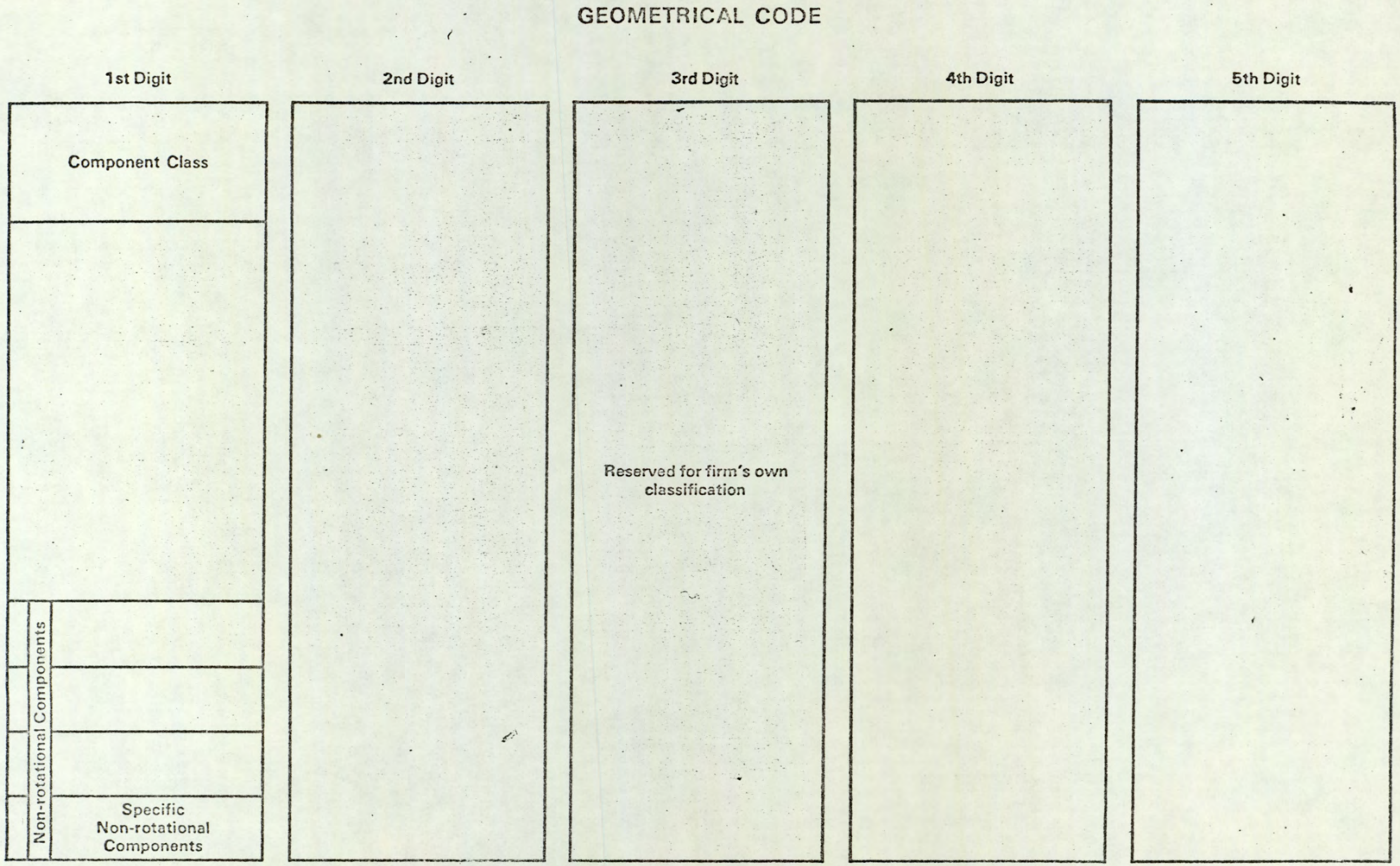
FIG. 2-7

GEOMETRICAL CODE

	1st Digit		2nd Digit			3rd Digit	4th Digit	5th Digit		
	Component Class		Overall Shape			Principal bore, rotational surface machining	Plane Surface Machining	Auxiliary hole(s) Forming, Gear Teeth		
0			Block and Block-like Components		Rectangular Prism	No rotational machining or bore(s)	No Surface Machining			No auxiliary holes, gear teeth and forming
1					Rectangular with deviations (Right Angle or Triangular)	One principal bore, smooth	Functional Chamfers (e.g. welding prep.)	No gear teeth, no forming		Holes drilled in one direction only
2					Compounded of Rectangular Prisms	One principal bore stepped to one or both ends	One plane surface			Holes drilled in more than one direction
3					Components with a mounting or locating surface and principal bore	One principal bore with shape elements	Stepped plane surfaces		related by a drilling pattern	Holes drilled in one direction only
4					Components with a mounting or locating surface, principal bore with dividing surface	Two principal bores, parallel	Stepped plane surfaces at right angles, inclined and/or opposite			Holes drilled in more than one direction
5					Components other than 0 to 4	Several principal bores, parallel	Groove and/or Slot	Forming, no Gear Teeth		Formed, no auxiliary holes
6	Non-rotational Components		Box and Box-like Components	Not split	Approximate or compounded of rectangular prisms	Several principal bores, other than parallel	Groove and/or Slot and 4			Formed, with auxiliary holes
7					Components other than 6	Machined annular surfaces, annular grooves -	Curved Surface			Gear teeth, no auxiliary hole(s)
8		Cubic Components $\frac{A}{B} \leqslant 3$, $\frac{A}{C} < 4$		Split	Approximate or compounded of rectangular prisms	7 + principal bore(s)	Guide Surfaces			Gear teeth, with auxiliary hole(s)
9					Components other than 8	Others	Others			Others

CUBIC CLASS DIGIT OF THE OPITZ CODE

FIG. 2-8



SPARE NON-ROTATIONAL CLASS DIGIT OF THE OPITZ CODE

FIG. 2-9

OPITZ SUPPLEMENTARY CODE

1st Digit

DIAMETER 'D' or EDGE LENGTH 'A'		
	MM's	Inches
0	≤ 20	≤ 0·8
1	> 20 ≤ 50	> 0·8 ≤ 2·0
2	> 50 ≤ 100	> 2·0 ≤ 4·0
3	> 100 ≤ 160	> 4·0 ≤ 6·5
4	> 160 ≤ 250	> 6·5 ≤ 10·0
5	> 250 ≤ 400	> 10·0 ≤ 16·0
6	> 400 ≤ 600	> 16·0 ≤ 25·0
7	> 600 ≤ 1000	> 25·0 ≤ 40·0
8	> 1000 ≤ 2000	> 40·0 ≤ 80·0
9	> 2000	> 80·0

2nd Digit

MATERIAL	
0	Cast Iron
1	Modular graphitic cast iron and malleable cast iron
2	Steel ≤ 26.5 tonf/in² Not heat treated
3	Steel > 26.5 tonf/in² Heat treatable low carbon and case hardening steel, not heat treated
4	Steels 2 and 3 Heat treated
5	Alloy Steel (Not heat treated)
6	Alloy Steel Heat treated
7	Non-ferrous Metal
8	Light Alloy
9	Other Materials

3rd Digit

INITIAL FORM	
0	Round Bar, black
1	Round Bar, bright drawn
2	Bar-triangular, square, hexagonal, others
3	Tubing
4	Angle, U-, T-, and similar sections
5	Sheet
6	Plate and Slabs
7	Cast or forged Components
8	Welded Assembly
9	Pre-machined Components

4th Digit

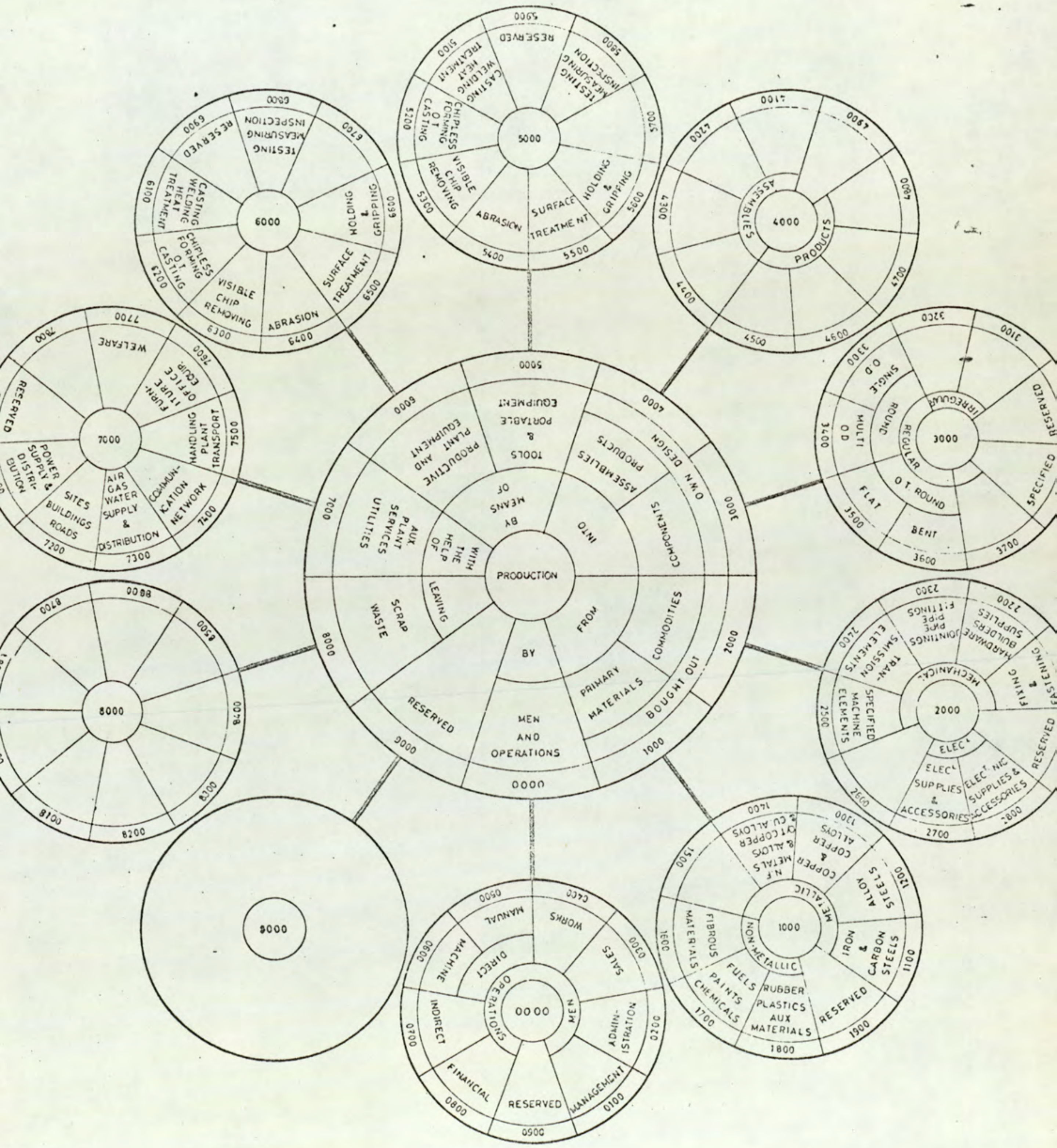
ACCURACY IN CODING DIGIT	
0	No Accuracy Specified
1	2
2	3
3	4
4	5
5	2 and 3
6	2 and 4
7	2 and 5
8	3 and 4
9	(2 + 3 + 4 + 5)

FIG. 2-10

.G. BRISCH
& PARTNERS
LONDON, S.W.1

INDUSTRIAL CLASSIFICATION AND CODING

DATE



(after Gombinski)

FIG. 2-11

	K48251A	L48388	L48267B	M44276E	M47693F	L48388	M48195C	M44276D	E41795	E48596	E34267	E12204	E12288	K47697	E47782	E48586	K34596	E33494	M48265D	K44278C	M45691D	M45691	M48386	K34098A	E7392	E46384	E33295	K45199	K43390	M61592	E18694
DMT(3)		√									√			√	√	√								√		√		√	√		√
DM(3)			√	√				√				√		√			√	√	√					√			√	√	√	√	
PG			√			√											√	√	√	√											
OXY(3)	√	√	√														√							√				√	√	√	
P&GR					√																										
PGR													√													√					
PGH																															
PGG																					√	√					√				
P&G							√	√	√	√	√	√											√	√			√	√	√	√	√
RP																									√						
PGB				√										√	√						√	√					√				
W&P	√						√																	√				√	√		
WG 3												√																			

COMPONENT/MACHINE CHART - INITIAL RECORD (after Burbidge)

FIG. 3-1

	L48267B	K35496	M48265	E33494	K44278C	L48388	E7392	K34098	K45199	K43390	M61592	M48195C	M44276	E34267	E12204	E18694	E41795	E48596	M48366	K48251A	L48388	M45691	M45691B	M44276B	K47697	E47782	E46384	E12288	E33295	E48586	M47693F
PG	✓	✓	✓	✓	✓	✓																									
DM3/1	✓	✓	✓	✓																											
OXY3/1	✓	✓																													
RP							✓																								
P&G								✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓										✓		
DMT3/2								✓	✓	✓				✓		✓					✓										
DM3/2								✓	✓	✓	✓		✓		✓					✓											
OXY3/2								✓	✓	✓	✓	✓								✓	✓										
W&P								✓	✓	✓																					
NG3															✓																
PGG																						✓	✓						✓		
PGB																						✓	✓	✓	✓	✓			✓		
PGR																											✓	✓			
DMT3/3																									✓	✓	✓			✓	
DM3/3																								✓	✓				✓		
P&GR																															✓

1 GROUP
1 FAMILY
2 GROUP
2 FAMILY
3 GROUP
FAMILY 3
ONE "EXCEPTION"

COMPONENT/MACHINE CHART - AFTER FAMILY GROUPING (after Burbidge)

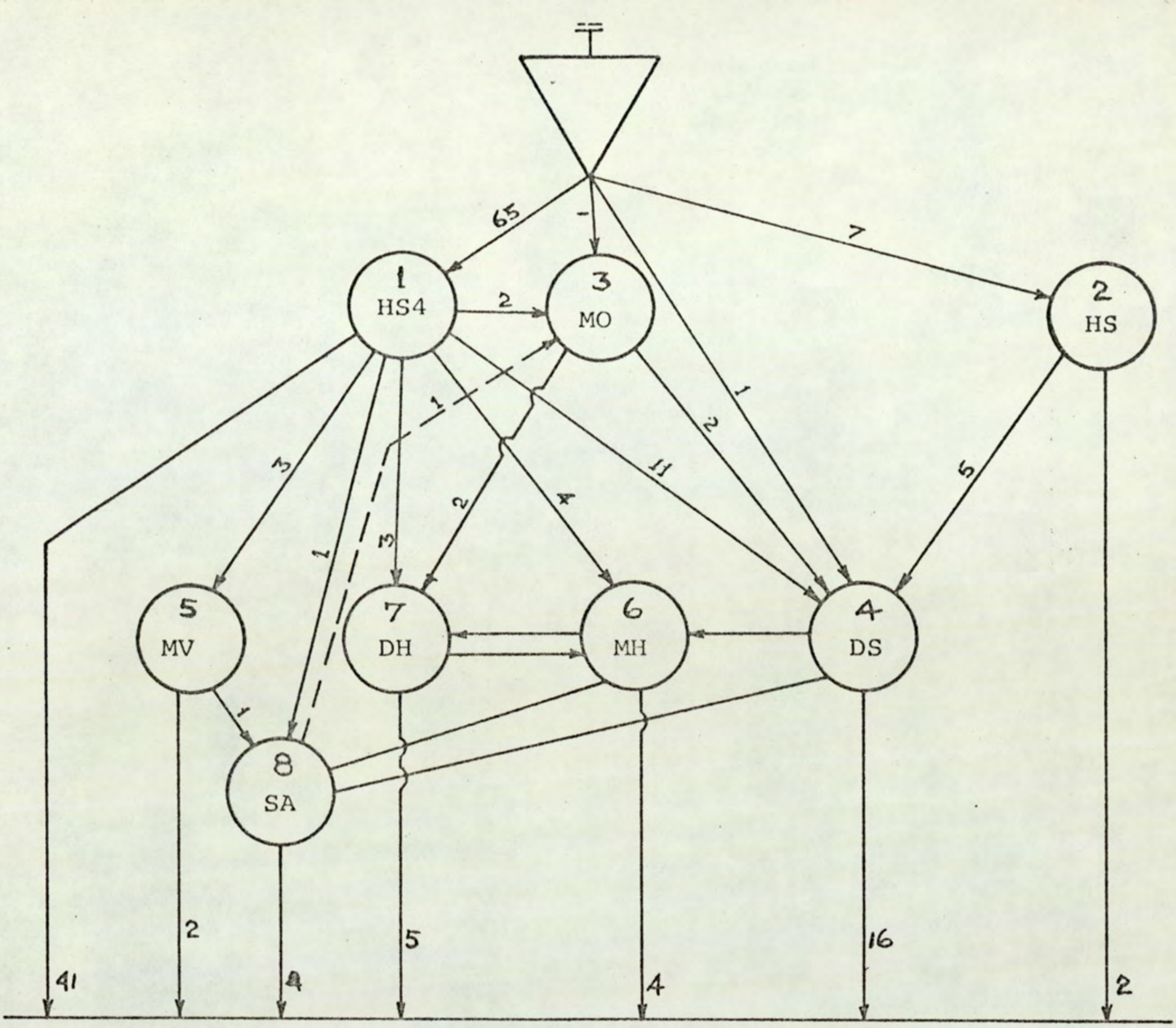
FIG. 3-2

WORK CENTRES No.	WORK CENTRES Type	OP 1	OP 2	OP 3	OP 4	OP 5
1	H.S.4 LATHE	65	1			
2	H.S. LATHE	7				
3	MARK OUT BENCH	1	2		1	
4	DS DRILL	1	17	1		
5	MV VERT-MILL		3			
6	MH HORIZ-MILL		4	3		1
7	DM DRILL		3	2		
8	DE-BURR BENCH		1	2	2	

FIG. 3-3 (a) - MACHINE/OPERATION N° FREQUENCY CHART.

ORN	No. of parts		ORN	No. of parts	
1	40		1 7	2	
1 1	1		1 7 6 8	1	
1 3 4	1	*	1 8	1	
1 3 7	1	*	2	2	*
1 4	10		2 4	3	*
1 4 6	1		2 4 6 8	1	*
1 5	2		2 4 8	1	*
1 5 8 3 7	1	*	3 4	1	*
1 6	3		4	1	*
1 6 7	1			*ORNs later eliminated during simplification.	

O.R.N. FREQUENCY CHART (after Burbidge)
FIG.3-3 (b)



GROUP FLOW NETWORK DIAGRAM
FIG. 3-4(a)

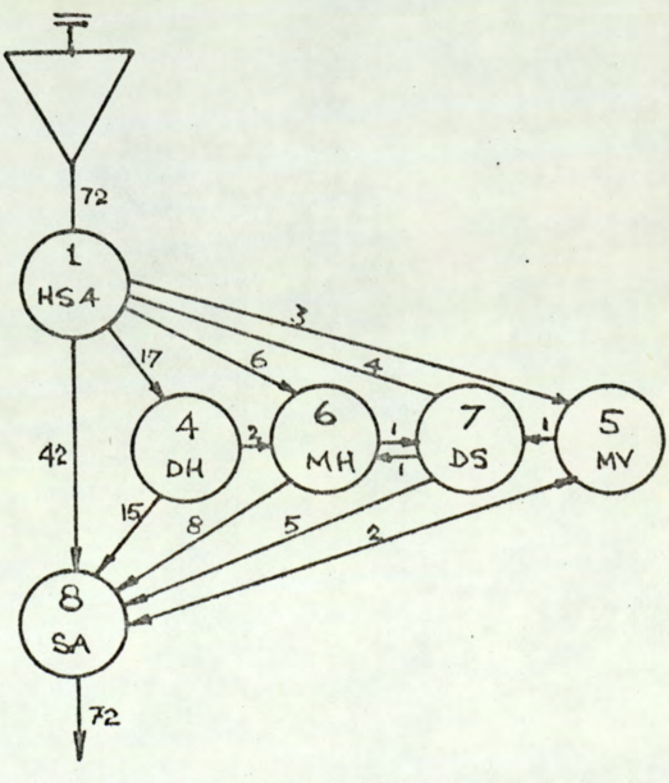
<u>Group flow simplified by:-</u>

1 Transfer 34 & 4 ORNs to Group 6.

2 Change ORNs 134 to 14; 137 to 17; 15837 to 1578 -by Jigging instead of Mark out.

3 Change ORNs 2 to 1; 24 to 14; 2468 to 1468; 248 to 148 - Reroute from H5 to H54.

4 All parts routed to bench (8) for quantity check and visual inspection.



SIMPLIFIED GROUP FLOW NETWORK
FIG. 3-4(b) (after Burbidge)

POSITION	VALUE	ANCILLARY DATA	POSITION	VALUE	EXTERNAL	POSITION	VALUE	INTERNAL	POSITION	VALUE	OPERATIONS	POSITION	VALUE	M/C TOOLS
1	1/9	COMPONENT (No. OR MONOCODE)	11	1/9	CONFIGURATION	31	1/9	CONFIGURATION	51	1/9	HOLDING/ GRIPPING	71	1/9	TURNING
2	01/99	BATCH SIZE/ FOR THE PERIOD	12	1/9	DIAMETERS, No.	32	1/9	CENTRE HOLE	52			72	1/9	DRILLING
3	1/9	MAKE OR BUY	13	1/9	CHAMFERS	33	1/9	AXIAL HOLES	53	1/9	TURNING	73	1/9	BORING
4	1/9	PRODUCTION GROUP (G.T.)	14	1/9	RADII	34	1/9	RADIAL HOLES	54	1/9	HOLES: MACHINING	74		
5	1/9	HANDLING WEIGHT RANGE	15	1/9	THREAD	35	1/9	THREAD	55	1/9	THREADING/ SCREWING	75	1/9	THREADING/ SCREWING
6	1/9	MADE FROM	16			36			56	1/9	MILLING	76		
7	001/999	MAX. O/D TO FIRST DECIMAL	17	1/9	TEETH, FORM	37			57	1/9	GRINDING	77		
8	01/99	LENGTH TO NEXT HIGHER INCH	18	01/99	TEETH, No.	38			58	1/9	TEETH CUTTING AND FINISHING	78	1/9	TEETH CUTTING AND FINISHING
9	1/9	MATERIAL GROUP	19	1/9	TEETH, PITCH/ MODULE	39			59	1/9	HEAT TREATMENT	79		

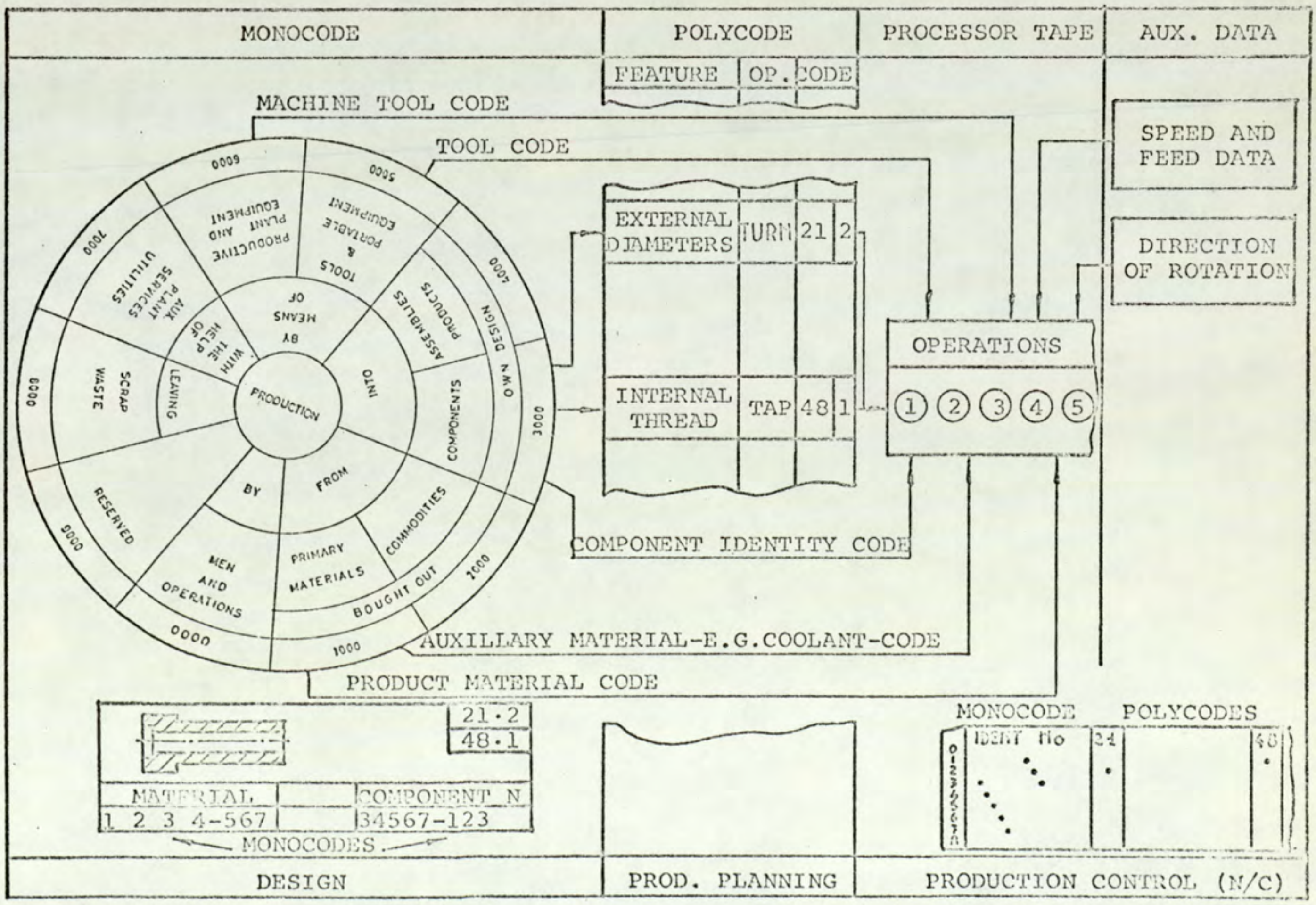
Brisch Polycodes.

FIG. 3-5 (a)

VALUE	34
1	ONE
2	TWO OR MORE RADIALLY SPACED
3	RADIALLY EQUISPACED
4	AXIALLYSPACED
5	2 + 4
6	3 + 4

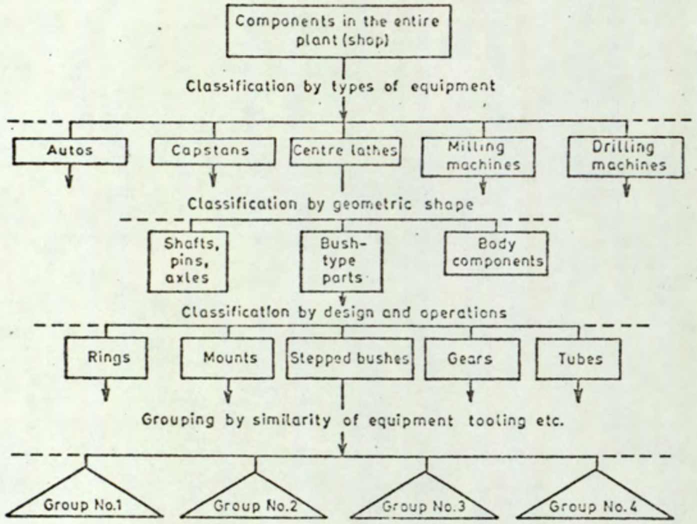
VALUE	54
1	DRILLING
2	BORING
3	REAMING
4	BROACHING
5	1 + 3
6	2 + 3

VALUE	72
1	VERTICAL, SINGLE
2	VERTICAL, MULTI.
3	
4	RADIAL
5	
6	HORIZONTAL



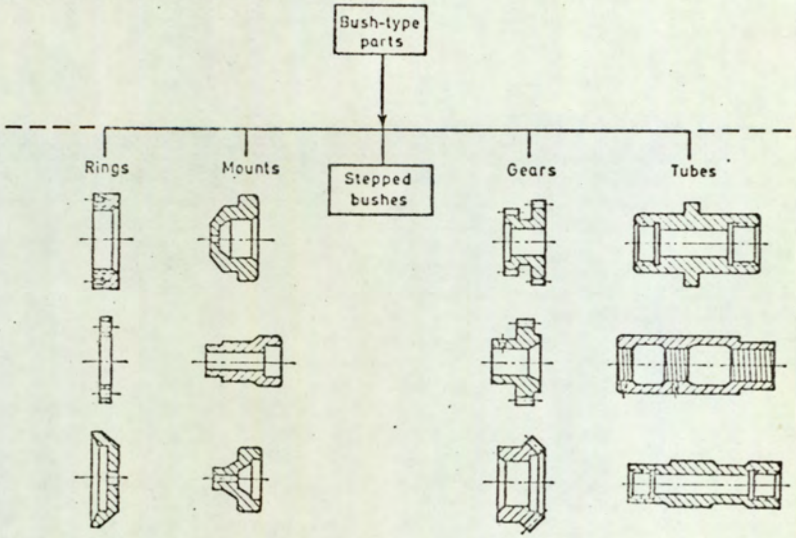
Brisch N.C. Programme FIG. 3-5 (b) (after Gombinski)

AN UNCODED CLASSIFICATION SYSTEM



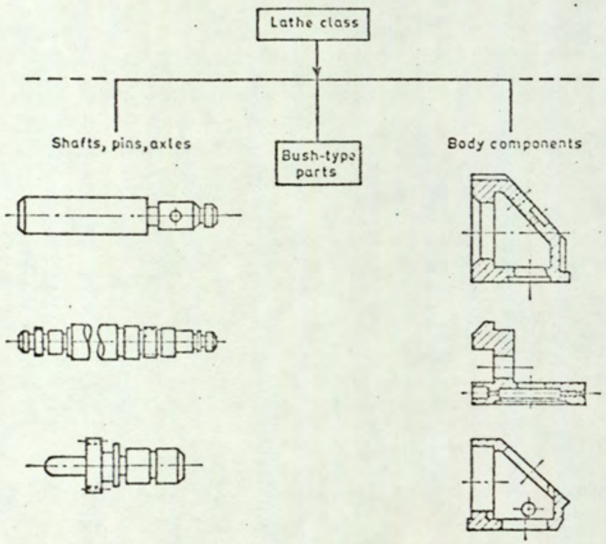
General Scheme of Component Classification. (after Ivanov)

(a)



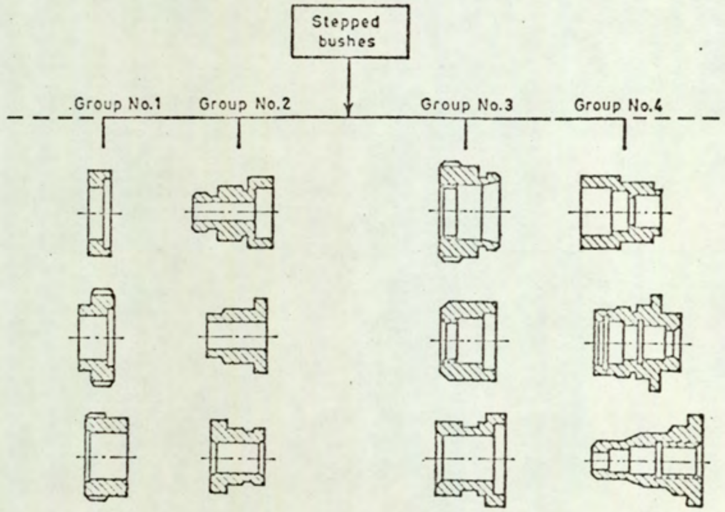
Component Classification on the basis of design and operations. (after Ivanov)

(c)



Component Classification on the basis of geometric shape. (after Ivanov)

(b)



Component Classification on the basis of similarities in the equipment, tooling and settings used. (after Ivanov)

(d)

FIG. 3-6

(after Ivanov)

SAMPLE ONLY

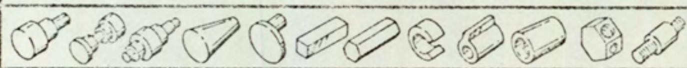
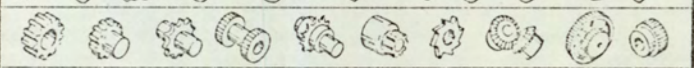
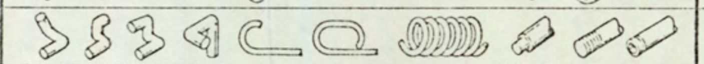
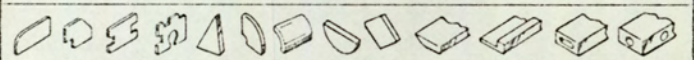
TECHNICAL DATA RETREIVAL SYSTEM

CODE NO.	DESCRIPTION		MATL	FINISH	DIM. 1	DIM. 2	DIM. 3	DIM. 4	PART NO.	LEV
11100031	PIN		1112		0.155	0.000	0.000	0.250	421272	
11100031	PIN		LTHR		0.156	0.000	0.000	0.063	4867000	
11100031	PLUG		FIBER		0.156	0.000	0.000	0.063	171058	A
11100031	PIN		1112		0.186	0.000	0.000	0.250	421205	A
11100031	PLUG		R5108		0.188	0.000	0.000	0.250	2565009	A
11100031	PLUG		FELT		0.198	0.000	0.000	0.156	176002	
11100032	PIN	NP	1112		0.155	0.000	0.000	0.316	21205	C
11100032	PIN		CRS		0.156	0.000	0.000	0.375	21202	
11100032	PIN		COML		0.156	0.000	0.000	0.437	5612017	
11100032	PIN		R2313		0.156	0.000	0.000	0.450	311255	A
11100032	PIN	NP	R2313		0.187	0.000	0.000	0.563	191203	A
11100032	PIN		CRS		0.188	0.000	0.000	0.500	11210	
11100032	PIN		R2311		0.189	0.000	0.000	0.375	311236	B
11100033	PIN		1112		0.155	0.000	0.000	0.875	271214	B
11100033	PIN		CRS		0.156	0.000	0.000	0.687	21208	
11100033	PIN		COML		0.156	0.000	0.000	0.687	5612001	
11100033	PIN		R2313	PS 7A	0.157	0.000	0.000	0.594	8012008	
11100033	PIN		R2313	NI PL	0.157	0.000	0.000	0.875	3512014	

(b)

TECHNICAL DATA RETRIEVAL Standards

MAJOR DIVISIONS OF EIGHT DIGIT CODE

FIRST DIGIT	DESCRIPTORS	TYPICAL ILLUSTRATIONS OR DESCRIPTIONS	TERMS AND DEFINITIONS
1	CONCENTRICS, other than profiled		parts that are round or polygonal having the main shape concentric about a common axis - including parts with internal gear teeth or splines
2	CONCENTRICS, PROFILED		parts with gear teeth, splines, grooves, serrations, alpha-numeric wheels & polygonal parts with spur gear on minor diameter
3	BENT ROD OR TUBE		uniform cross section - solid or hollow
4	BENT OR SEEMINGLY BENT, other than rod or tube		prebending material has rectangular cross section other than square
5	FLAT, uniform or non-uniform thickness		thickness surfaces parallel to each other

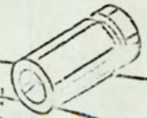
(a)

FIG. 3-7

TECHNICAL DATA RETRIEVAL

Standards

11201046



1 CONCENTRICS, other than profiled

DESCRIPTOR NUMBERS	SECOND	THIRD	FOURTH	FIFTH	SIXTH	SEVENTH	EIGHTH	DESCRIPTOR NUMBERS
	O. D. OR SECTION	CENTER HOLE	HOLES (other than center hole)	GROOVES (external internal) THREADS (on O.D.)	MISCELLANEOUS	MAX. O.D. or section across flats	MAX. OVERALL LENGTH	
0	OTHER THAN	OTHER THAN	OTHER THAN OR NONE	OTHER THAN OR NONE	OTHER THAN OR NONE	NONE	NONE	0
1	CYLINDER single	NONE	LONGITUDINAL other than bolt circle	GROOVE (S) [9] MAX .125 external	CONCENTRIC VARIATIONS [(3)(4)] O/T 30° or 45° or > 1/16	≤ .10	≤ .25	1
2	CYLINDER multi-concave	SINGLE I. D. [4] thru going	RADIAL round	GROOVE (S) MAX .093 internal	PROTRUSION (S) [5] from main shape	> .10 ≤ .15	> .25 ≤ .50	2
3	CYLINDER multi-convex	SINGLE I. D. [4] blind	1 & 2	1 & 2	1 & 2	> .15 ≤ .20	> .50 ≤ 1.10	3
4	CYLINDER multi-conical	SINGLE I. D. [4] thru going threaded	RADIAL [6] other than round	GROOVES [1] on face (s)	SLOT (S)	> .20 ≤ .26	> 1.10 ≤ 1.60	4
5	CYLINDER multi-variable	SINGLE I. D. [4] blind threaded	1 & 4	1 & 4	1 & 4	> .26 ≤ .30	> 1.60 ≤ 2.30	5
6	CONE single	MULTI I. D. [4] thru going	2 & 4	2 & 4	2 & 4	> .30 ≤ .40	> 2.30 ≤ 3.10	6
7	ECCENTRIC hex, square, rectangular, round, D or trilobe	MULTI I. D. [4] blind	1, 2 & 4	1, 2 & 4	1, 2 & 4	> .40 ≤ .60	> 3.10 ≤ 5.10	7
8	DOUBLE-CONVEX	MULTI I. D. thru going threaded	BOLT CIRCLE min. two holes or slots	THREADS on O. D.	FLAT (S) [7] hex, trilobe, square, D, etc	> .60 ≤ .80	> 5.10 ≤ 7.10	8
9	SPHERICAL PORTION	MULTI I. D. [4] blind threaded	1 & 8	1 & 8	1 & 8	> .80 ≤ 1.10	> 7.10 ≤ 10.10	9
A	CYLINDER MAX. SECTION triangular, diamond, square, rectangular or D	ECCENTRIC [4] other than bolt hole	2 & 8	2 & 8	2 & 8	> 1.10 ≤ 2.10	> 10.10 ≤ 14.10	A
B	CYLINDER MAX. SECTION hexagon or trilobe	TAPERED [4]	1, 2 & 8	1, 2 & 8	1, 2 & 8	> 2.10 ≤ 3.60	> 14.10 ≤ 24.10	B
C	RESERVED	SPHERICAL [4] I. D.	4 & 8	4 & 8	4 & 8	> 3.60	> 24.10	C
D	POLYGONAL [2] D, square, trilobe or hex	POLYGONAL [4] thru going or blind	1, 4 & 8	1, 4 & 8	1, 4 & 8			D
E	CYLINDER segment ≥ 180°		2, 4 & 8	2, 4 & 8	2, 4 & 8			E
F	CYLINDER [10] eccentric face to face		1, 2, 4 & 8	1, 2, 4 & 8	1, 2, 4 & 8			F

(1) Grooves shall be ignored for coding unless 360° on face of part.

(2) Classify in division 5, if length is < diameter or dimension across flats.

(3) External end chamfers, tapers > 1/16" or other than 30° or 45°, including round or spherical ends, shall be considered a CONCENTRIC VARIATION

(4) Internal center hole end chamfers, tapers ≤ 1/16" other than specified as a radii, XXX x 30° or 45° shall be considered as a concentric variation. Chamfers and tapers > 1/16" shall be considered as having a multi-center hole

(5) Classify as PROTRUSION only if projection from main shape is not thru from face to face. Refer to note (10)

(6) Blind or thru going, but shall not break out one or both ends of part

(7) A section of the part parallel to the longitudinal axis, other than 1A, 1B, 1D or 1XX4

(8) Dimension across cross section. Not applicable for 1XXXX2

(9) Grooves that exceed .125" in width shall be considered as having a multi O. D. or section.

(10) 'Face to face' will exist regardless of any relief to the eccentric portion between faces. Refer to note (5).

1

FIG. 3-8

UNIQUE IDENTITY OF PRODUCT	SUPPLEMENTARY CODES FOR PRODUCT PARAMETERS			
SPECIFICATION NUMBER	MATERIAL AND ASSEMBLY PROCESS CODE	FUNCTION AND FEATURES CODE PLUS THE FIRST DIGIT OF THE SHAPE AND SIZE RANGE CODE	REMAINING THREE DIGITS OF THE SHAPE AND SIZE RANGE CODE	FOR EXPANSION
6 DIGITS	4 DIGITS	5 DIGITS	3 DIGITS	—

GENERAL FORM OF CLASSIFICATION SCHEME.

(a)

597635	2608	10333	523	—

CODE LAYOUT ON DOCUMENTS.

(b)

FIG. 3-9 (after Connolly et al)

CODE FOR MATERIAL & ASSEMBLY PROCESS.

SELECT FIRST DIGIT BELOW

<table>
<tr><th>FIRST DIGIT</th><th colspan="2">MATERIAL GROUPS</th><th>TURN UP FOR MATERIAL TYPE</th></tr>
<tr><td>0</td><td colspan="2">FOR EXPANSION</td><td>0</td></tr>
<tr><td>1</td><td rowspan="3">FERODO FRICTION MATERIAL</td><td>MAINLY PROCESSED AT CAERNARVON FACTORY</td><td>1</td></tr>
<tr><td>2</td><td>MAINLY PROCESSED AT.</td><td>2</td></tr>
<tr><td>3</td><td>CHAPEL FACTORY</td><td>3</td></tr>
<tr><td>4</td><td colspan="2">FOR EXPANSION</td><td>4</td></tr>
<tr><td>5</td><td colspan="2">FOR EXPANSION</td><td>5</td></tr>
<tr><td>6</td><td colspan="2">FERODO METAL PARTS
CUSTOMERS METAL PARTS</td><td>6</td></tr>
<tr><td>7</td><td colspan="2">EXPERIMENTAL MATERIALS</td><td>7</td></tr>
<tr><td>8</td><td colspan="2">ASSEMBLY PROCESS AND CUSTOMER SERVICES</td><td>8</td></tr>
<tr><td>9</td><td colspan="2">PURCHASED PRODUCTS</td><td>9</td></tr>
</table>

FIG. 3-10 (a) (after Connolly et al)

CODE FOR TYPE OF PRODUCT AND PRODUCT CHARACTERISTICS

SELECT FIRST DIGIT BELOW

FIRST DIGIT	PRODUCT GROUP	TURN UP FOR PRODUCT CHAR.
0	FOR EXPANSION	0
1	BRAKE LININGS RADIUSED SHEETS (SEMI–FINISHED PADS) METAL PARTS APPERTAINING TO ABOVE PRODUCTS ASSEMBLIES OF ABOVE PRODUCTS	1
2	ROLL and STRIP METAL PARTS APPERTAINING TO ABOVE PRODUCTS ASSEMBLIES OF ABOVE PRODUCTS	2
3	CLUTCH FACINGS METAL PARTS APPERTAINING TO ABOVE PRODUCTS ASSEMBLIES OF ABOVE PRODUCTS	3
4	FOR EXPANSION	4
5	STAIRTREAD and STAIRTILES METAL PARTS APPERTAINING TO ABOVE PRODUCTS ASSEMBLIES OF ABOVE PRODUCTS	5
6	RAILWAY BLOCKS, BANDS, FERODO METAL PRODUCTS and SPECIAL SHAPED PRODUCTS. METAL PARTS APPERTAINING TO ABOVE PRODUCTS ASSEMBLIES OF ABOVE PRODUCTS	6
7	DISC BRAKE PADS METAL PARTS APPERTAINING TO ABOVE PRODUCTS ASSEMBLIES OF ABOVE PRODUCTS	7
8	BELTS	8
9	RESALE GOODS	9

FIG. 3-10 (b) (after Connolly et al)

CODE FOR SHAPE & SIZE RANGES

SELECT FIRST DIGIT BELOW

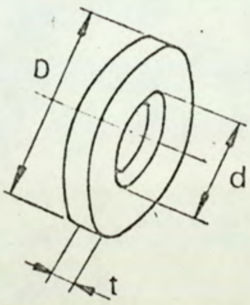
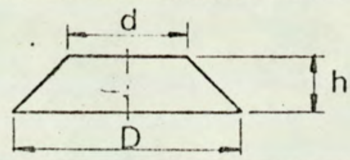
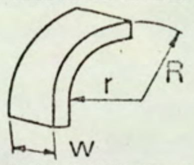
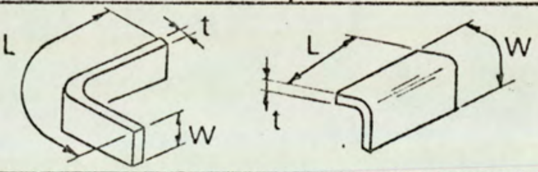
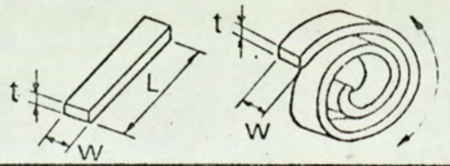
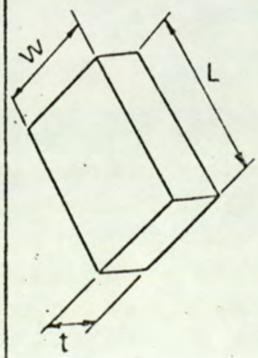
FIRST DIGIT	BASIC SHAPE				TURN UP FOR SIZE RANGE
0	ROTATIONAL SHAPES	COMPLETE OR PART OF A CYLINDER EXCLUDING SHAPES DEFINED UNDER DIGIT No 3		$\frac{t}{D} \leq \frac{1}{20}$	0
1				$\frac{t}{D} > \frac{1}{20}$	1
2		COMPLETE OR PART OF CONE			2
3		PART OF AN ANNULUS		$\frac{R-r}{W} \leq 1$	3
4	NONE-ROTATIONAL SHAPE	BENT SHAPES			4
5		SPIRAL OR STRIP $\frac{L}{W} \geq 10$			5
6		SOLIDS $\frac{L}{W} < 10$		$L \leq 2$	6
7				$2 < L \leq 10$	7
8				$L > 10$	8
9	OTHER CODED PRODUCTS				9

FIG. 3-10 (c) (after Connolly et al)

CODE FOR MATERIAL AND ASSEMBLY PROCESS

SELECT DIGIT NUMBERS 6000 — 6999 BELOW

SECOND DIGIT		THIRD DIGIT		FOURTH DIGIT	FIRST DIGIT
CUSTOMER		MATERIAL		SHAPE OF THE PART OR COMPONENT	
FERODO METAL PARTS		FERROUS MATERIAL	CAST IRON	BAR OR TUBE	0
CUSTOMERS METAL PARTS	GIRLING		$\leqslant$ 27 TON. F/IN^2 U.T.S.	STRIP	1
	LOCKHEED		$>$ 27 TON. F/IN^2 U.T.S.	SHEET	2
	AUTOMOTIVES		HEAT TREATED	MESH	3
	BORG & BECK		CUSTOMERS METAL PARTS	WIRE	4
	RAYBESTOS BELACO	NON FERROUS MATERIAL	ALUMINIUM & AL. ALLOYS	ANGLE. CHANNEL. TEE. OR SIMILAR CROSS SECTIONS	5
	DUNLOP			CAST. FORGED. OR WELDED CONSTRUCTION	6
	FORD		COPPER & COPPER ALLOYS		7
	BRITISH RAILWAYS			PRE-MACHINED PARTS	8
	OTHER CUSTOMERS		CUSTOMERS METAL PARTS		9

FIG. 3-11 (a) (after Connolly et al)

PRODUCT & PRODUCT CHARACTERISTIC CODE

SELECT DIGIT NUMBERS 3000 — 3999 BELOW

SECOND DIGIT		THIRD DIGIT				FOURTH DIGIT				FIRST DIGIT
PRODUCT TYPE		BASIC CHARACTERISTICS								
FRICTION MATERIAL PRODUCT AND ASSEMBLIES		FRICTION MATERIAL ON ONE FACE ONLY	NOT GROOVED OR SLOTTED ON FACE (S)	FACE PLAIN	EXCLUDING DRILLING	UNDRILLED	NO PERIPHERAL SLOTS INSIDE OR OUTSIDE			0
	DISCS > 3 IN DIA.			WITH OTHER FACE FEATURES			PERIPHERAL SLOTS I/S–O/S	INSIDE ONLY	GEARED	1
	CONES		GROOVED &/OR SLOTTED ON FACE (S)	CURVED GROOVES &/OR SLOTS					SLOTTED OR SPLINED	2
	INSERTS			STRAIGHT GROOVES &/OR SLOTS				OUTSIDE ONLY OR O/S AND I/S	GEARED OUTSIDE	3
	SEGMENTS			STRAIGHT & CURVED GROOVES &/OR SLOTS					SLOTTED OR SPLINED OUTSIDE	4
	DISCS ≤ 3 IN DIA.	FRICTION MATERIAL ON BOTH FACES OR NONE (E.G. METAL PARTS)	NOT GROOVED OR SLOTTED ON FACE (S)	FACE PLAIN	EXCLUDING DRILLING	DRILLED	NO PERIPHERAL SLOTS INSIDE OR OUTSIDE			5
				WITH OTHER FACE FEATURES			PERIPHERAL SLOTS I/S–O/S	INSIDE ONLY	GEARED	6
			GROOVED &/OR SLOTTED ON FACE (S)	CURVED GROOVES &/OR SLOTS					SLOTTED OR SPLINED	7
				STRAIGHT GROOVES &/OR SLOTS				OUTSIDE ONLY OR O/S AND I/S	GEARED OUTSIDE	8
METAL PARTS FOR CLUTCH ASSEMBLIES				STRAIGHT & CURVED GROOVES &/OR SLOTS					SLOTTED OR SPLINED OUTSIDE	9

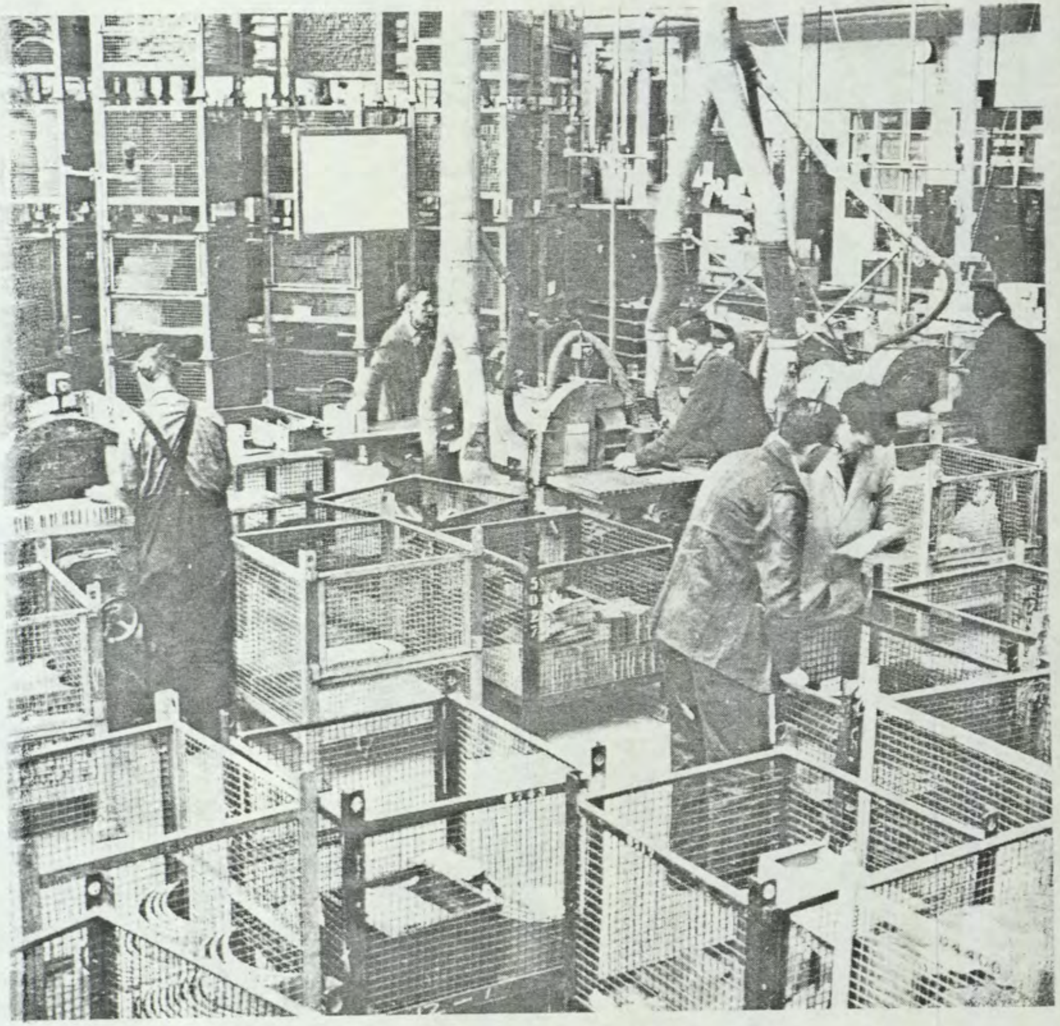
FIG. 3-11 (b) (after Connolly et al)

SHAPE & SIZE RANGE CODE

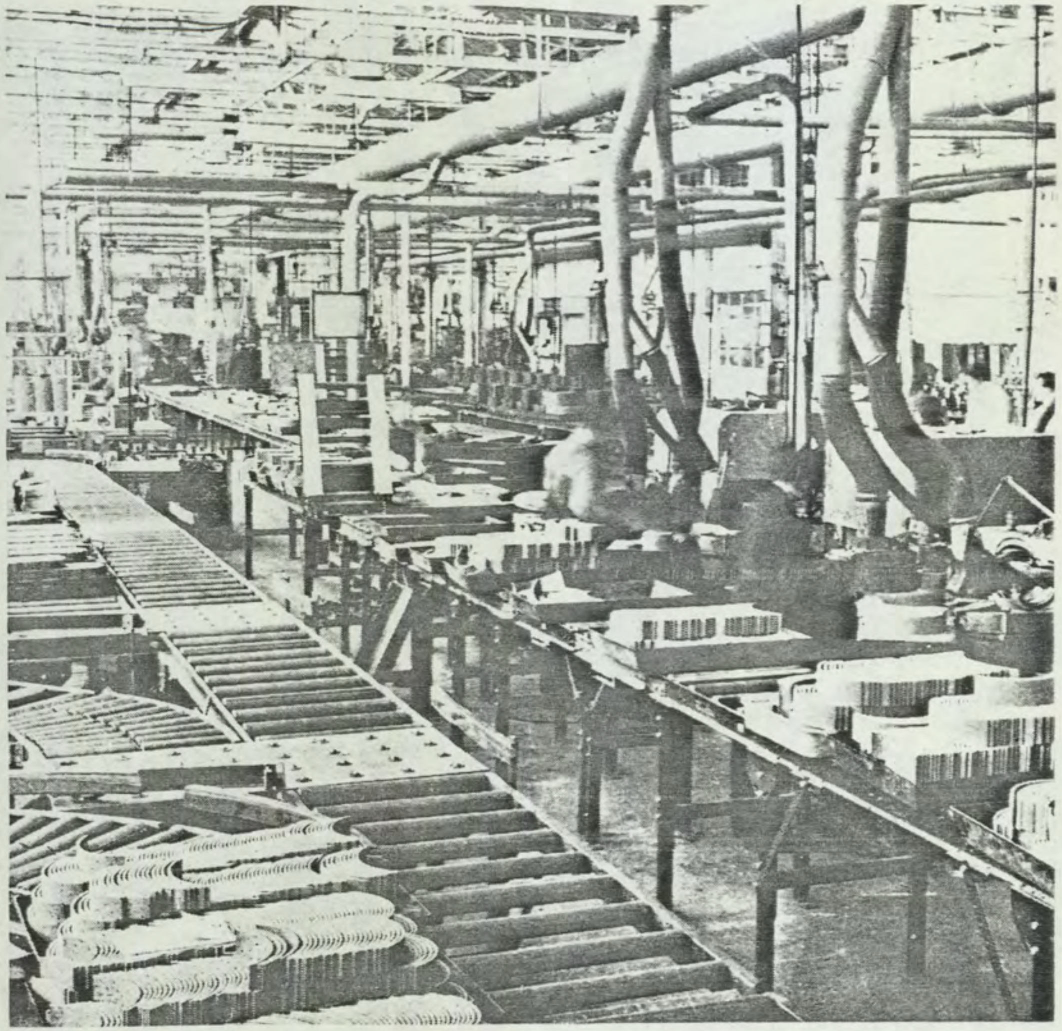
SELECT DIGIT NUMBERS 5000 — 5999 BELOW

SECOND DIGIT	THIRD DIGIT	FOURTH DIGIT	FIRST
DEVELOPED LENGTH &/OR LENGTH (L)	WIDTH (W)	THICKNESS (t)	DIGIT
$L \leq 2$	$W \leq 1{\cdot}312$	$t \leq 0{\cdot}156$	0
$2 < L \leq 4$	$1{\cdot}312 < W \leq 1{\cdot}625$	$0{\cdot}156 < t \leq 0{\cdot}180$	1
$4 < L \leq 8$	$1{\cdot}625 < W \leq 1{\cdot}875$	$0{\cdot}180 < t \leq 0{\cdot}190$	2
$8 < L \leq 12$	$1{\cdot}875 < W \leq 2{\cdot}125$	$0{\cdot}190 < t \leq 0{\cdot}205$	3
$12 < L \leq 24$	$2{\cdot}125 < W \leq 2{\cdot}50$	$0{\cdot}205 < t \leq 0{\cdot}235$	4
$24 < L \leq 48$	$2{\cdot}50 < W \leq 3{\cdot}00$	$0{\cdot}235 < t \leq 0{\cdot}280$	5
$48 < L \leq 96$	$3{\cdot}00 < W \leq 4{\cdot}00$	$0{\cdot}280 < t \leq 0{\cdot}375$	6
$96 < L \leq 120$	$4{\cdot}00 < W \leq 5{\cdot}00$	$0{\cdot}375 < t \leq 0{\cdot}50$	7
$120 < L \leq 144$	$5{\cdot}00 < W \leq 6{\cdot}125$	$0{\cdot}50 < t \leq 0{\cdot}75$	8
$144 < L$	$6{\cdot}125 < W$	$0{\cdot}75 < t$	9

FIG. 3-11 (c) (after Connolly et al)



(a) Before G.T.



(b) After G.T.

MANUFACTURING AT FERODO LTD. (after Thornley)

FIG. 3-12

PRODUCTION ENGINEERING RESEARCH ASSOCIATION
OF GREAT BRITAIN

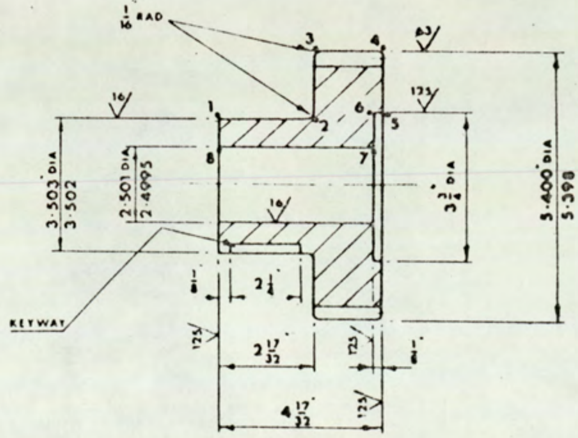
D.S.I.R. PROJECT. P636. WORKPIECE CHARACTERISTICS

General Statement.

Company Ref No	Serial No	Total Change Points	Change Point for Maximum Diameter	Change Point for Maximum Length	Workpiece Type	Material	Initial Form	Quantity
60	30	08	03	04	1	0	0	0002

Detailed Statement.

Change Points	x Co-ordinates	y Co-ordinates	Corner Construction	Form	Accuracy	Surface Finish	State of Hardness	Function	Additional Machining Features
01	00000	00175	1	0	3	3	2	6	7
02	00253	00175	3	0	9	7	2	1	1
03	00253	00270	3	0	3	6	2	1	6
04	00453	00270	3	0	9	8	2	1	1
05	00453	00188	1	0	7	8	2	1	1
06	00440	00188	1	0	9	8	2	2	1
07	00440	00125	1	0	3	3	2	6	1
08	00000	00125	1	0	9	8	2	2	1



Spur Gear

MATERIAL En 32A
CASE HARDEN

P.E.R.A. CODING SYSTEM.

FIG.3-13

MAIN GEOMETRY
AND ADDITIONAL FEATURES OF 1ST CATEGORY
AS WELL AS OTHER DISTINCTIONS.

digit	
1	class main geometry
2	group additional features of 1st category
3	sub-group additional features of 1st category
4	geometric cross-section and arrangement of features
5	tolerance on main geometry and additional features of 1st category
6	surface finish of main geometry and additional features of 1st category
7	material
8	dimensions - length
9	dimensions - width
10	dimensions - height

ADDITIONAL FEATURES OF 2ND AND 3RD CATEGORY

	digit		digit	
Additional features of 2nd category	11	nature of additional features	16	Additional features of 3rd category
	12	locus and direction of additional features	17	
	13	arrangement and condition	18	
	14	tolerance of additional feature	19	
	15	surface finish of additional feature	20	

SUPPLEMENTARY CODE FOR INTERNAL USE IN COMPANY

digit			digit
21	degree of standardisation	association and individualisation	23, 24, 25, 26
22	modification of drawing		

MAIN CLASSES UNDER DIGIT 1

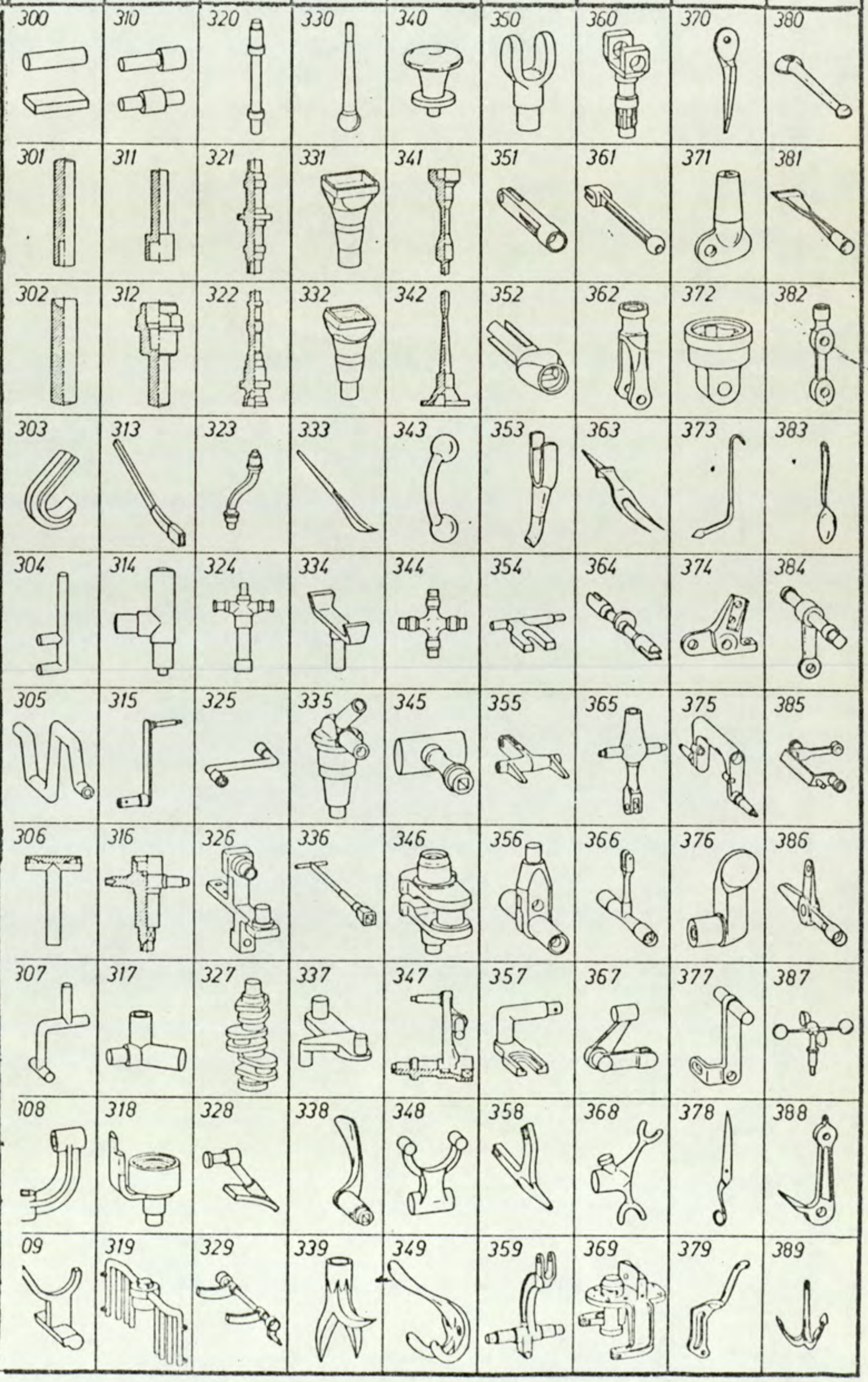
1. Squat Form ($l \simeq b \simeq h$)
2. Disc Form ($l \geqslant b$, $h \leqslant \frac{1}{2}b$)
3. Long Solid Form ($l \geqslant b \geqslant h$, $2h \geqslant l$)
4. Long Hollow Form ($l \geqslant b \geqslant h, 2h \geqslant l$)
5. Long with Complex Cross Sections ($l \geqslant b \geqslant h$)
6. Complex and Fabricated Parts not in Classes 1-5.

STRUCTURE OF ZAFO CODE

FIG.3-14

LONG SOLID FORM CLASS 3

Group / Sub Group	Uniform Cross Section	Stepped Diameter: Decreasing Unilaterally	Stepped Diameter: Increasing Bi or Unilaterally	Varying Diameter Conical or Curved: Decreasing Unilaterally	Varying Diameter Conical or Curved: Increasing Bi or Unilaterally	With forks not otherwise the same: 1 or 3	With forks not otherwise the same: 2 or 4	With eyes or flats not the same: 1 or 3	With eyes or flats not the same: 2 or 4
Uniaxial and rectilinear	300	310	320	330	340	350	360	370	380
Uniaxial, rectilinear with one eyed hole smooth in the axis	301	311	321	331	341	351	361	371	381
Uniaxial, rectilinear with one eyed hole increasing in the axis	302	312	322	332	342	352	362	372	382
Uniaxial curved otherwise not the same 0, 1 or 2	303	313	323	333	343	353	363	373	383
Many rectilinear axis in a plane. Not otherwise the same. 0	304	314	324	334	344	354	364	374	384
Many rectilinear axis in a plane. Not otherwise the same. 1 or 2	305	315	325	335	345	355	365	375	385
Many rectilinear axis in a plane. Not otherwise the same. 2	306	316	326	336	346	356	366	376	386
Many rectilinear axis in more than one plane otherwise not the same. 0, 1 or 2	307	317	327	337	347	357	367	377	387
Many axis in a plane which one or more are curved. Not otherwise the same. 0, 1 or 2.	308	318	328	338	348	358	368	378	388
Many axis in many planes which one or more are curved. Not otherwise the same. 0, 1 or 2	309	319	329	339	349	359	369	379	389



ZAFO CODE

FIG. 3-15

TYPE 1		
SOLID CYLINDRICAL, L/D >1		
DIMENSIONAL CHARACTERISTIC		
L/D < 12	D<50	0
	D 50 - 100	1
	D 100 - 150	2
	D 150 - 250	3
	D 250 - 350	4
	D > 350	5, 6
L/D > 12	D < 60	7
	D > 60	8, 9

TYPE 2		
HOLLOW CYLINDRICAL, L/D >1		
DIMENSIONAL CHARACTERISTIC		
L/D < 10	D<35	0
	D 35-60	1
	D 60-120	2
	D 120-300	3
	D 300-500	4
	D > 500	5
L/D > 10	D < 120	6
	D 120 - 300	7
	D 300 - 500	8
	D > 500	9

TYPE 3	
SOLID & HOLLOW CYL., L/D < 1	
DIMENSIONAL CHARACTERISTIC	
D<60	0
D 60-250	1
D 250 - 450	2
D 450 - 800	3
D 800 - 1500	4
D>1500	5
	6
	7
	8
	9

TYPE 4	
HOUSING	
DIMENSIONAL CHARACTERISTIC	
L<700, B&H <350	0
L<1200, B&H < 500	1
L<3000, B& H<800	2
L<500, B& H<1800	3
L, B& H > 1800	4
	5
	6
	7
	8
	9

TYPE 5		
FLAT, ANGULAR, SHAPED		
DIMENSIONAL CHARACTERISTIC		
FLAT	L or D<700, B& H<350	0
	L or D<1200, B& H<450	1
	L or D<3000, B& H<800	2
	L or D<500, B& H<1800	3
	B& H > 1800	4, 5
SHAPED	L or D<700, B & H<350	6
	L or D< 1200, B&H<450	7
	L or D<3000, B&H<800	8
		9

VPTI Main Code.

(a)

CLASSIFICATION AND NUMBERING OF MACHINED SURFACES		
EXTERNAL SURFACES		
Solids of rotation		
cylindrical	with annular grooves	10
cylindrical	with spiral grooves	11
cylindrical	crank	12
cylindrical	articulated	13
cylindrical	crossed axes	14
	tapered	15
	spherical and radiused	16
face	recessed	17
face	with annular grooves	18
face	spherical	19
	threads	20
	worms	21
	splines	22
gears	cylindrical	23
gears	herring-bone	24
gears	bevel	25
gears	worm	25
gears	double enveloping	27
gears	sprockets & ratchets	28
gears		29
Housing and flat surfaces		
	single-plane	30
	with parallel planes	31
	with perpendicular planes	32
	31 & 32	33
	planes at diff'r'nt angles	34
	cylindrical	35
	shaped	36
	profiled	37
		38
		39
General		
slots and grooves, longitudinal	open	40
slots and grooves, longitudinal	closed	41
slots and grooves, lateral	open	42
slots and grooves, lateral	closed	43
slots and grooves	radial (on end faces of solids revolution)	44
slots and grooves	shaped	45
slots and grooves	radiused	46
	polyhedrous sfc's	
	flats, chamfers	48
	rack teeth	49
INTERNAL SURFACES		
Holes — Characteristic		
smooth	through	50
smooth	blind	51
stepped	through	52
stepped	blind	53
	deep, L>5D	54
	tapered	55
	spherical	56
	threaded	57
	splined	58
	geared	59
Holes — Position		
	on a common axis	60
	with parallel axes	61
	perpendicular axes	62
	axes at diff'r'nt angles	63
		64
		65
		66
		67
		68
		69
Holes for clamping, cooling, and lubrication		
deep	on axis of rotation	70
deep	parrallel to axis	71
deep	radial to axis	72
deep	at angle to axis or base	73
deep	perpendicular to base	74
shallow	as 70	75
shallow	as 71	76
shallow	as 72	77
shallow	as 73	78
shallow	as 74	79
Flat surfaces, slots, grooves		
	as 30	80
	as 31	81
	as 32	82
	as 33	83
	polyhedrous sfc's	84
	as 37	85
slots	open	86
slots	closed	87
grooves	open	88
grooves	closed	89

VPTI Surface Element Codes.

(b)

FIG.3-16

ESTABLISHING COMPONENT CLASSES

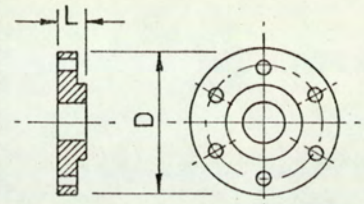
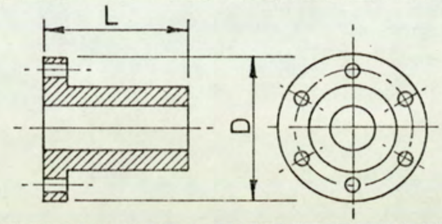
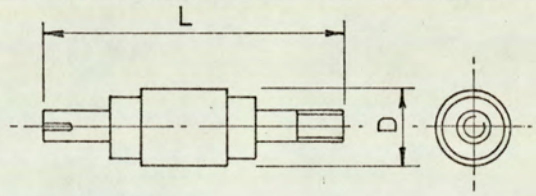
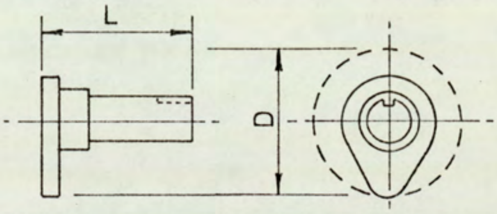
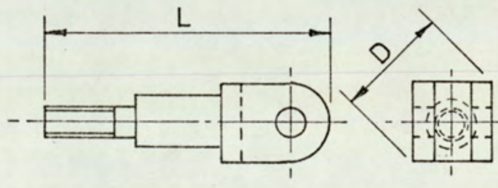
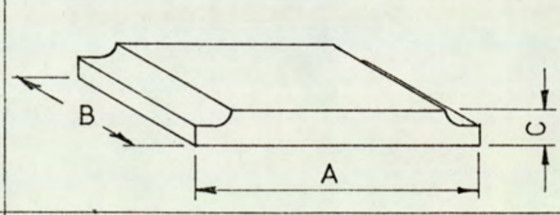
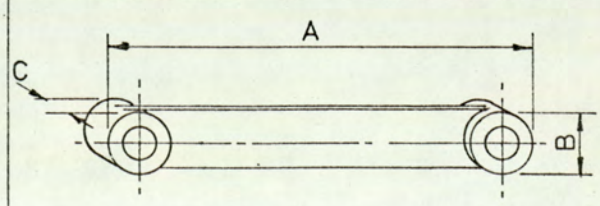
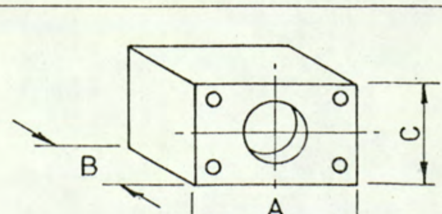
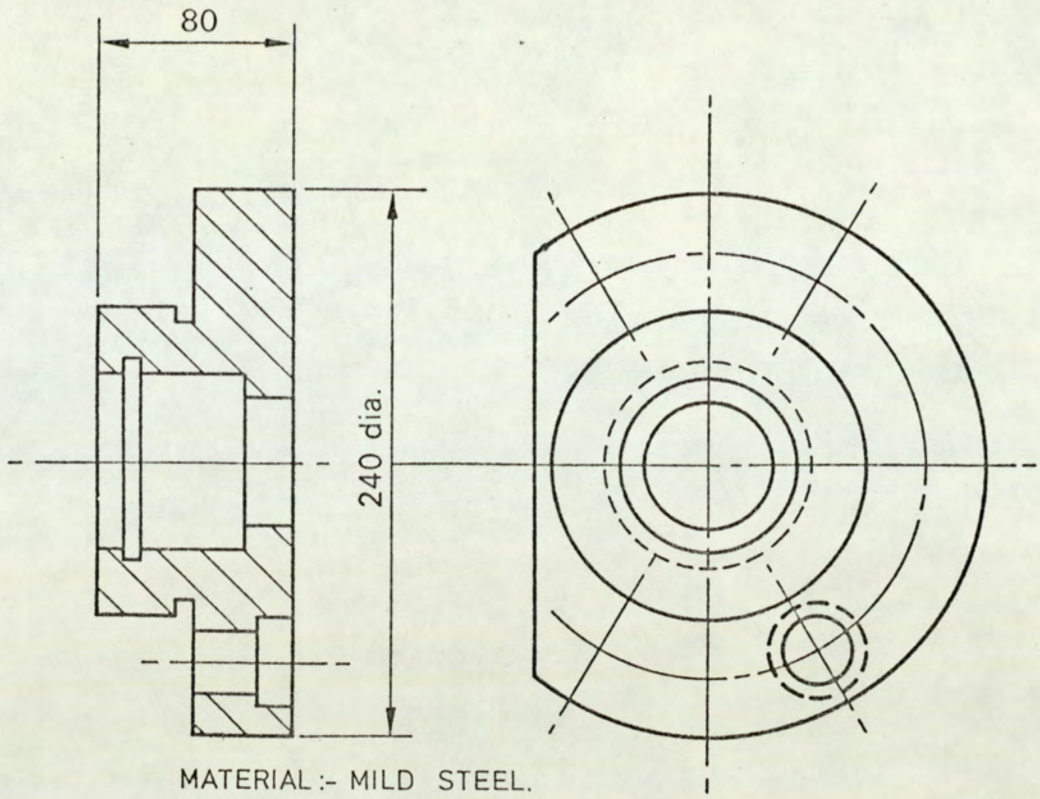
DIGIT — TYPE		SIZE RATIOS	DRAWING REPRESENTATION
0 - ROTATIONAL		$\frac{L}{D} \leqslant 0{\cdot}5$	
1 - ROTATIONAL		$0{\cdot}5 < \frac{L}{D} < 3$	
2 - ROTATIONAL		$\frac{L}{D} \geqslant 3$	
3 - ROTATIONAL WITH DEVIATION		$\frac{L}{D} \leqslant 2$	
4 - ROTATIONAL WITH DEVIATION		$\frac{L}{D} > 2$	
6 - FLAT	NON-ROTATIONAL WHERE A > B > C	$\frac{A}{B} \leqslant 3, \frac{A}{C} \geqslant 4$	
7 - LONG		$\frac{A}{B} > 3$	
8 - CUBIC		$\frac{A}{B} \leqslant 3, \frac{A}{C} < 4$	

FIG. 4-1



OPITZ CODE NO. :- 01312 / 4270

Rotational Component, L/D ≤ 0·5.

External Shape - Stepped to one end, no shape elements.

Internal Shape - Stepped to one end, with functional groove.

Plane Surface Machining - External plane surface.

Auxiliary Holes and Gear Teeth - Axial holes related by a drilling pattern, no gear teeth.

0 1 3 1 2 — GEOMETRICAL CODE

4 2 7 0 — SUPPLEMENTARY CODE

Accuracy - None specified.

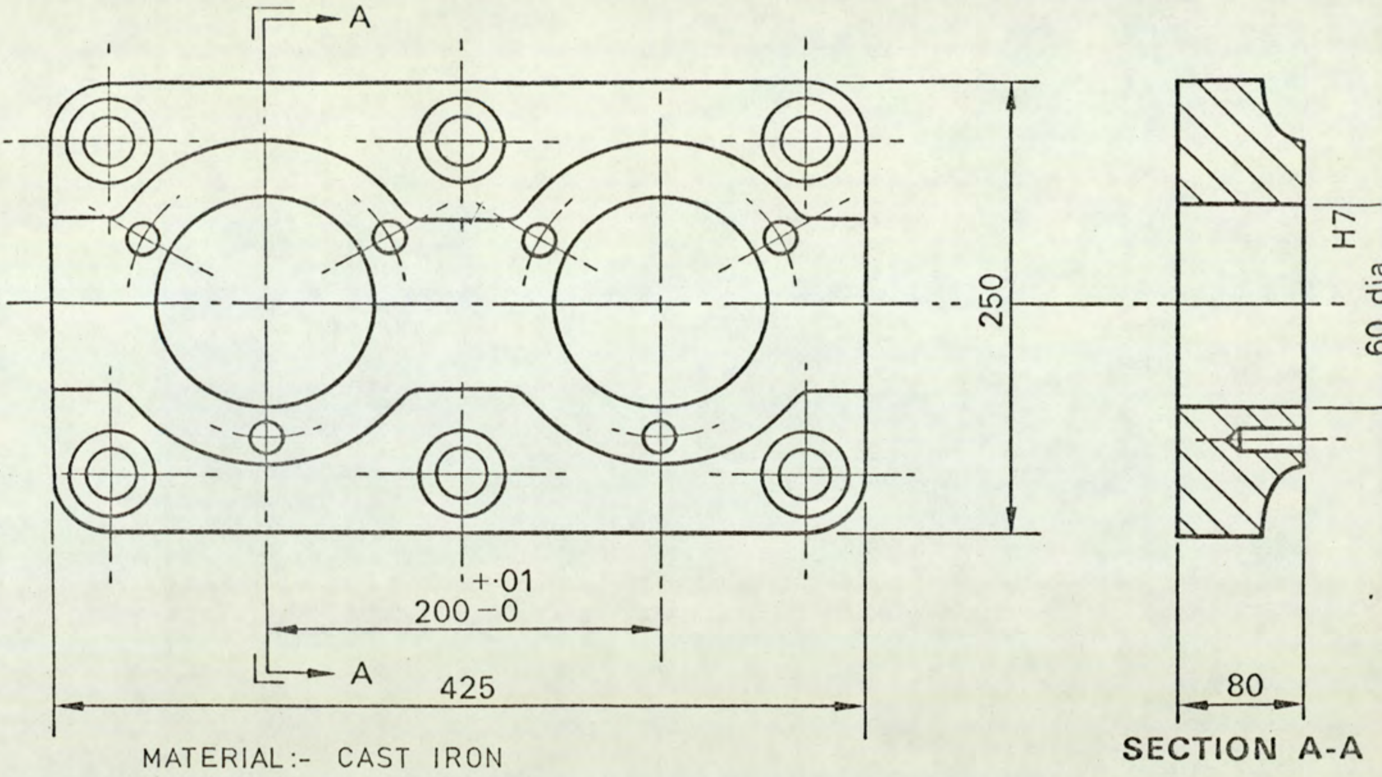
Initial Form - Forging.

Material - Mild steel.

Maximum Diameter - > 160 ≤ 250.

CODING OF ROTATIONAL COMPONENT.

FIG. 4-2



OPITZ CODE NO. :- 65443 / 6072

Non-rotational, flat component. A/B ≤3, A/C>4.

Overall Shape - Flat, rectangular with small deviations due to casting, welding or forming.

Two principal bores, parallel.

Plane stepped surfaces, at right angles, inclined and/or opposite.

Holes related by a drilling pattern, drilled in one direction, no gear teeth, no forming.

6 5 4 4 3 — GEOMETRICAL CODE

6 0 7 2 — SUPPLEMENTARY CODE

Accuracy - Bores, H7 specified.

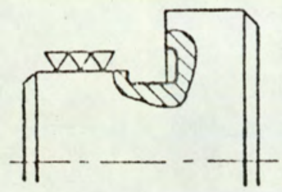
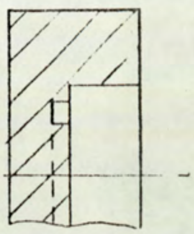
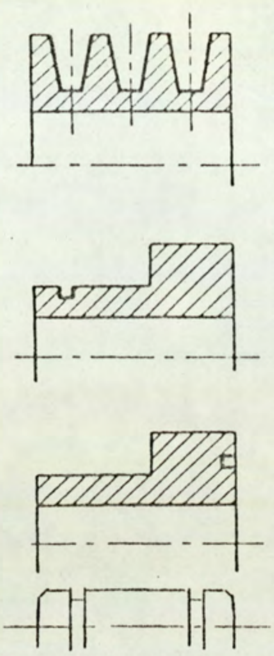
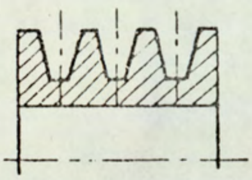
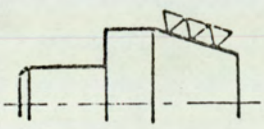
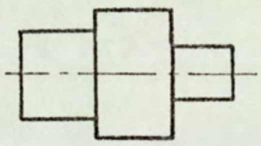
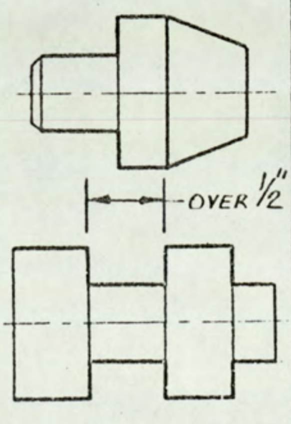
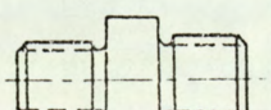
Initial Form - Cast component.

Material - Cast iron.

Edge Length 'A' - > 400 ≤600.

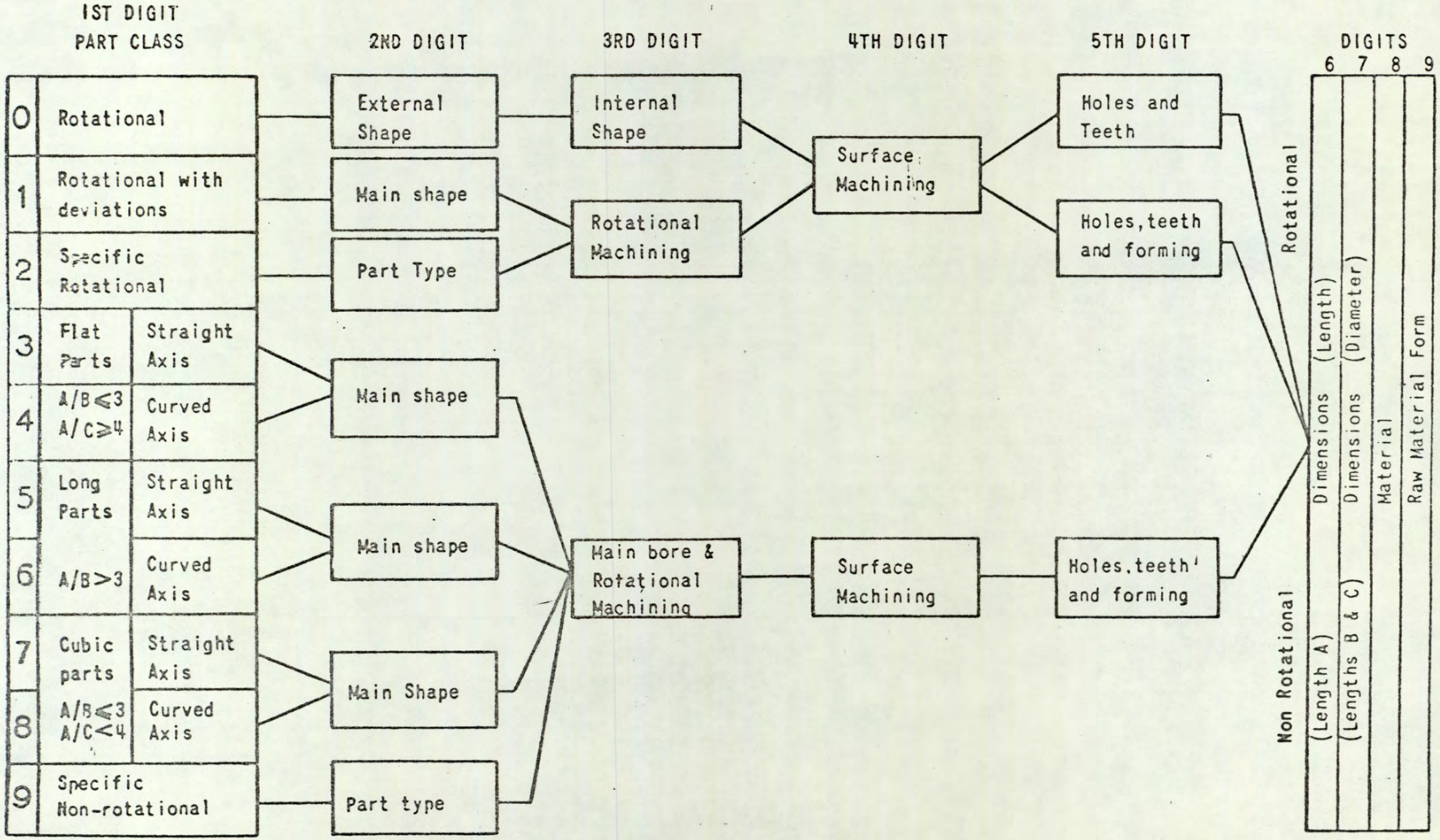
CODING OF NON-ROTATIONAL COMPONENT.

FIG. 4-3

No	Yes	Pos.	Designation	Coding digit
 x1xxx  X X 3 X X		3	*Stepped to one end or smooth, with functional groove* Only grooves fulfilling a definite function and imposing rather high demands on production; e.g. grooves for V-belts, labyrinth glands, circlips, etc. In contrast, undercuts for threads, chamfers, etc., do not come in this position. Grinding relief and oil grooves are ignored unless rigorous machining requirements are called up/ Any turned groove on the periphery or the faces unless faces are internal.	2
 x3xxx  x7xxx	 	4	*Stepped to both ends (multiple increases), no shape elements* Rotational components with several diameters distributed along the length and alternately increasing and decreasing.	
		5	*Stepped to both ends (multiple increases), with screw threads* All threads except those mentioned under operating threads.	

OPITZ CODE MANUAL

FIG. 4-4



MODIFIED OPITZ CLASSIFICATION SYSTEM (after Perrins)

FIG. 4-5

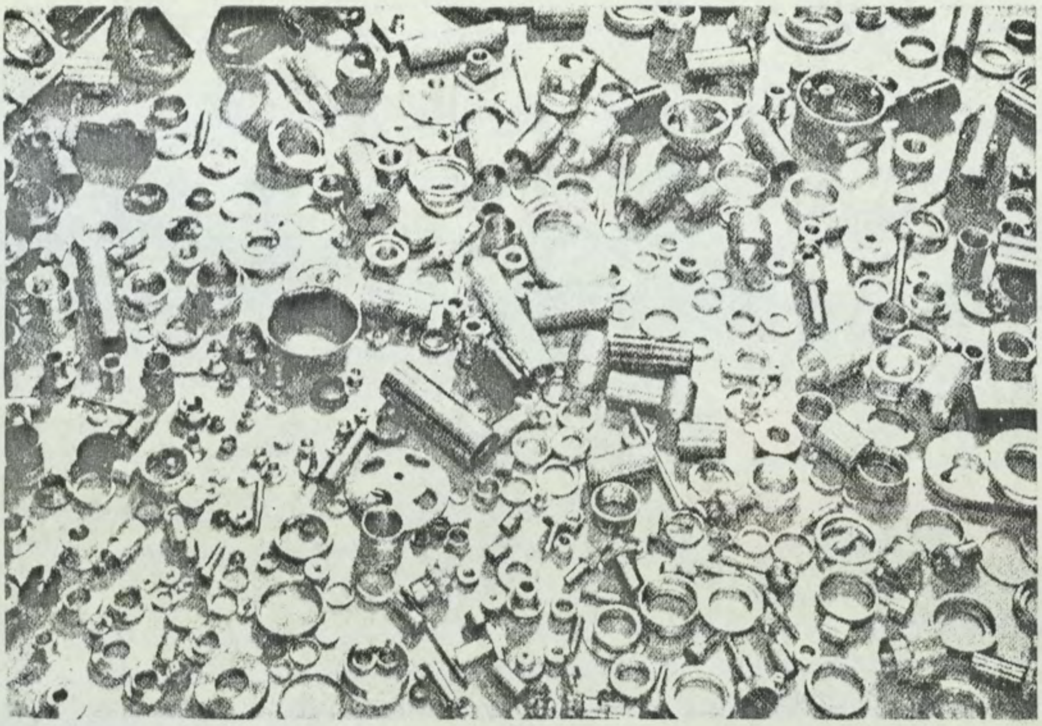
CONTINUED

COMPONENT CODE NUMBERS		COMPONENT DRAWING NUMBERS	CODING SHEET REFERENCE	
28008	14304	UH50/148 F	005	Rotational components L/D ≥ 3
28030	26300	11/5563 B	025	
28030	15300	11/5558 A	003	
28032	29408	H400/390 A	005	
28032	37400	5/4430 A	001	
28032	28300	11/13996 D	32	
28036	35404	83/6792 E	001	
28435	59472	11/16436 A	020	
29030	39402	11/9380 B	026	
29030	39402	11/9380 A	026	
30202	21320	83/6769 D	019	Rotational with deviation components L/D ≤ 2
32103	21360	20/3390 C	031	
32202	10390	10/3263 L	016	
32653	76480	2/12540 C	025	
32653	76480	2/12540 B	025	
32653	77480	2/12540 A	025	
33314	54080	11/4565 B	031	
33354	64480	83/6806 A	011	
33414	56080	5/4492 A	001	
33602	30360	1/5988 Y	018	
33613	30400	83/6810 K	030	
33662	20360	20/3390 A	031	
33684	62080	2/11845 A	022	
33684	62080	2/11845 B	022	
33684	62250	2/11435 B	020	
33884	62250	2/11435 F	021	
34303	81250	1/8138 G	017	
34603	30250	2/11440 B	021	
34603	42300	11/16462 C	031	
34603	20300	11/5558 H	003	
34603	40250	83/6736 G	002	
34614	53300	83/6799 K	030	
34614	53300	83/6799 J	030	
37222	23400	H400/407 C	004	
37630	44300	2/12541 L	021	
38614	42360	2/7820 J	019	
38614	42360	2/7820 K	019	
38730	32420	11/16443 B	014	
40001	13390	11/12330 A	014	Rotational with deviation components L/D > 2
40100	2320	UH50/150 N	006	
40100	18320	40/3337 D	010	
42103	46360	11/16462 B	031	
42103	59360	11/4565 C	031	
42204	48390	10/3263 M	016	
42603	21929	UH50/148 C	005	
42822	58470	83/6810 A	030	
43213	67360	83/6799 E	030	
43613	42080	11/5558 D	003	
43613	42080	11/5558 B	003	
47131	28470	40/3337 F	009	
47131	28370	40/3337 A	009	
47133	38370	20/3378/2 A	029	
47242	12420	UH50/149 C	004	
60000	41250	11/14038 B	33	Non-rotational flat components A/B ≤ 3, A/C ≥ 4
60000	61250	11/10074(C)	028	
60000	51250	11/16451(C)	023	
60000	51250	11/16452(A)	023	
60000	51250	11/16452(B)	023	
60000	40250	83/6769(H)	019	
60000	10250	83/6769(G)	019	
60000	10250	83/6769(F)	019	
60000	10250	83/6769(E)	019	

CONTINUED

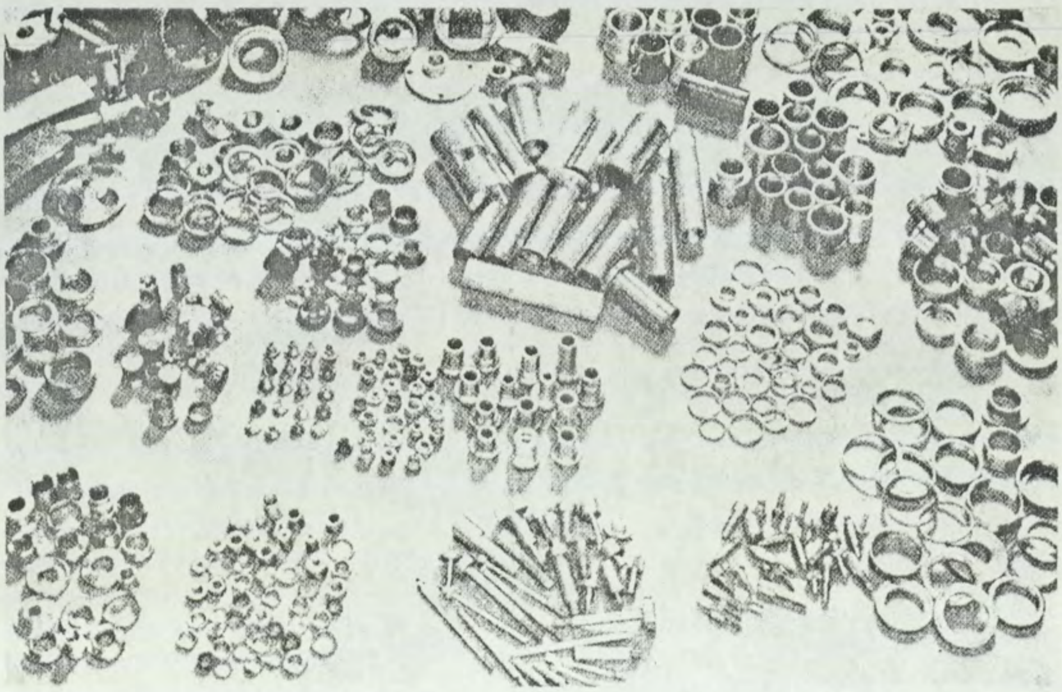
COMPUTER PRINTOUT SHOWING COMPONENT FAMILY TYPES

FIG. 4-6



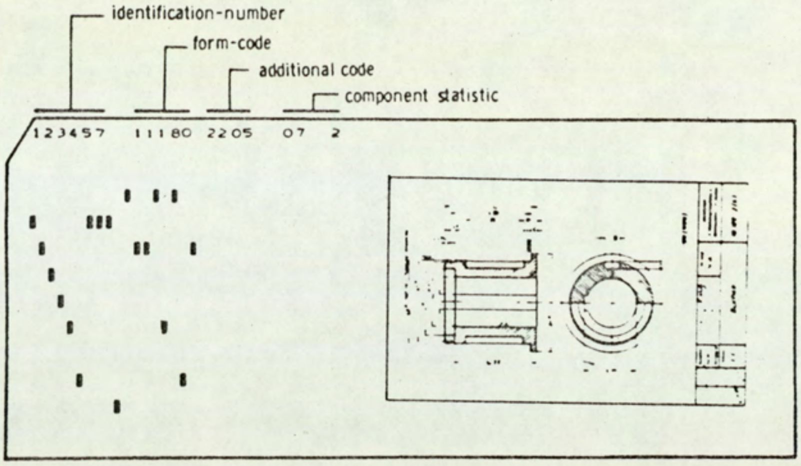
A RANGE OF ROTATIONAL COMPONENTS BEFORE GROUPING

FIG. 4-7 (a)



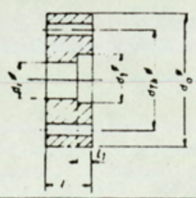
THE ABOVE RANGE OF ROTATIONAL COMPONENTS AFTER GROUPING

FIG. 4-7 (b) (after Ivanov)



MICRO-FILM PUNCHED CARD FOR DESIGN RETRIEVAL

FIG. 4-8 (a)



Inner dia d_i	Outer dia d_a	Total length	Material	pitch circle d_{tk}	fastening holes	other dia d_1	d_2	other length l_1	l_2	drawing number	
5.50	54.00	5.0	C35	9.0	1x4H7					25-000.362-0	4
11.00	80.00	8.0	C60	18.0	1x6H7					25-000.361-0	4
13.50	100.00	14.0	C35	50.0	1x=12	070		004		25-000.456-0	4
17.00	56.00	13.0	C35	44.0	3x= 5	037	022	007	011	43-000.188-0	4
17.00	115.00	17.0	C35	50.0	1x=16	083		005		25-000.451-0	4
17.50	70.00	11.0	C35	36.0	1x=16	048		004		25-000.612-0	4
17.50	70.00	11.0	C35	37.0	1x=16	045		003		25-000.701-0	4
22.00	80.00	11.0	C35	44.0	1x=20	055		003		25-000.594-0	4
22.00	90.00	14.0	C35	48.0	1x=20	060		004		25-000.700-0	4
30.00	110.E8	11.0	C35	94.0	4x= 8	078		003		17-002.118-0	4
32.00	110.E8	11.0	C35	94.0	4x= 8	078	051	003	007	17-001.443-0	4
34.00	110.00	11.0	C35	74.0	4x= 8	078		003		17-002.119-0	4
38.00	110.E8	11.0	C35	94.0	4x= 8	078	051	003	007	17-001.446-0	4
45.00	110.E8	11.0	C35	94.0	4x= 8	078		003		17-002.120-0	4
46.00	110.E8	11.0	C35	94.0	4x= 8	079		001		17-002.296-0	4
50.00	110.E8	11.0	C35	94.0	4x= 8	078		001		17-001.976-0	4
54.00	92.00	15.0	ST37	80.0	3x= 5	072	068	003	012	43-000.376-0	3
54.00	125.M6	11.0	C35	108.0	4x= 8	092		003		17-001.745-0	3
80.00	125.M6	11.0	C35	108.0	4x= 8	092		003		17-001.743-0	3
122.00	160.M6	11.0	MRST37-2	143.0	8x= 8	132		003		17-001.548-0	3
205.00	310.00	20.0	ST37	225.0	8x= 8	300		015		30-000.109-0	3
220.00	299.00	14.0	MRST37-2	250.0	6x=12	270		004		14-002.604-0	4
228.00	289.00	15.0	MRST37-2	252.0	6x=12	270		005		14-002.152-0	4
340.00	408.00	8.0	MRST37-2	360.0	6x= 6	402		005		30-000.110-0	3
380.00	478.00	15.0	MRST37-2	410.0	6x=10	440		003		14-002.953-0	3

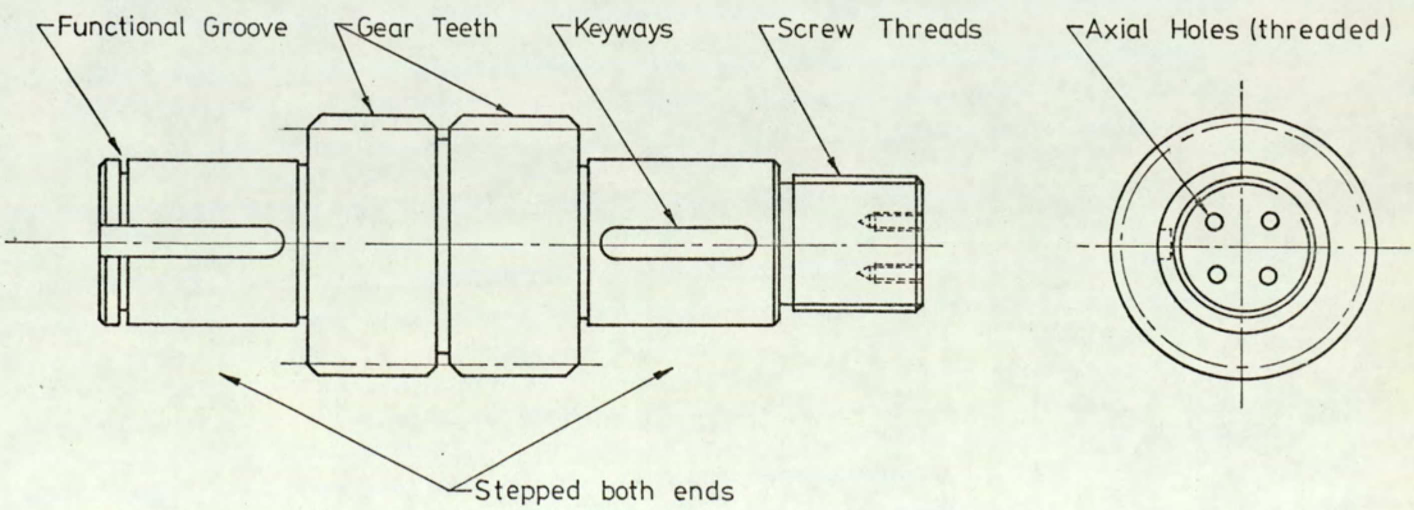
SECTION OF A REUSE PARTS CATALOGUE

FIG. 4-8 (b) (after Brankamp)

	Geometrical Code					Supplem'try Code				
	Component Class	External Shape Elements	Internal Shape Elements	Machined Plane Surfaces	Drilled Holes, Gear Teeth	Diameter Ranges	Length Ranges	Material	Initial Form	Contracted Work
	1	2	3	4	5	6	7	8	9	10
0			0	0	0	0			0	0
1					1	1			1	
2	2				2	2	2			2
3				3		3	3	3		
4		4				4	4	4		4
5		5					5	5		5
6		6			6		6		6	
7							7			
8							8	8		
9							9		9	

CODE NUMBER FIELD FOR ROTATIONAL, CLASS 2 COMPONENTS

FIG. 4-9 (a)



COMPOSITE COMPONENT REPRESENTING CODE NUMBER FIELD

FIG. 4-9 (b)

SELECTION OF COMPONENTS FOR CODE NUMBER FIELD

	COMPONENT CODE NUMBERS		COMPONENENT DRAWING NUMBERS	CODING SHEET REFERENCE
✓	24000	29360	27/0379 C	015
✓	24000	29360	27/0379 D	016
✓	24000	38502	3/4041 C	009
✓	24000	48502	3/4041 A	009
✓	24001	38365	3/4042 B	009
✓	24002	24300	3/4042 F	009
×	24008	15304	2/7820 E	018
×	24008	22804	2/7820 F	018
✓	24030	28300	40/3337 B	010
✓	24030	18310	3/4046 A	008
✓	24030	39402	3/4042 A	009
✓	24030	24300	83/6806 F	011
✓	24030	16300	11/5558 F	005
✓	24030	14300	1/5879 S	017
✓	24030	35305	2/12149 A	024
✓	24030	28390	11/4356 F	025
✓	24031	28360	UH50/189 B	004
✓	24031	28360	UH50/150 A	005
✓	24032	29300	40/3337 C	010
✓	24032	37300	83/6792 F	012
✓	24032	37300	83/6792 F	001
✓	24032	29300	20/3378/2 B	029
✓	24032	39502	3/4041 D	009
✓	24032	49502	3/4041 B	009
✓	24036	28404	83/6736 A	002
✓	24036	37404	83/6736 B	002
✓	24036	37404	83/6736 C	002
✓	24036	48404	83/6736 D	002
✓	24036	37404	83/6736 C	024
✓	24036	48404	83/6736 D	024
✓	24036	28404	83/6736 A	025
✓	24036	37404	83/6736 B	024
✓	24036	26404	1/5879 F	017
✓	24036	47404	5/4481 A	027
×	24038	37404	83/6798 F	011
×	24038	36404	11/16428 E	002
×	24038	36404	83/6806 D	011
×	24138	37404	83/6798 F	011
✓	25000	38310	2/12541 A	021
✓	25000	16310	11/16462 G	031
✓	25000	15400	2/12541 H	021
✓	25000	2390	2/12543 F	022
✓	25020	14402	10/3263 K	016
×	25025	14300	27/0379 R	015
✓	25030	48400	5/4403 C	031
✓	25030	48400	5/4403 A	030
✓	25030	28300	11/4565 F	031
✓	25030	16410	2/12543 B	022
✓	25030	16400	10/3243 A	016
✓	25030	17400	10/3263 B	016
✓	25030	18300	11/5558 G	005
✓	25031	28400	2/7820 D	018
✓	25032	37400	5/4480 A	028
✓	25032	36400	5/4467 G	012
✓	25032	48300	11/3577/3 N	015
✓	25032	36400	5/4467 F	012
×	25035	37400	5/4467 H	012
×	25035	38400	5/4467 J	012
✓	25036	48404	11/11183 C	012
✓	25036	36404	1/5879 G	017
✓	25036	37404	5/4467 E	011
✓	25036	35404	83/6792 F	012
×	25160	19310	27/0379 F	016
✓	26000	2310	2/11845 F	022
✓	26000	13300	1/5988 Q	018
✓	26000	12300	1/5988 P	018
✓	26030	27310	11/3577/3 P	015

FIG. 4-10

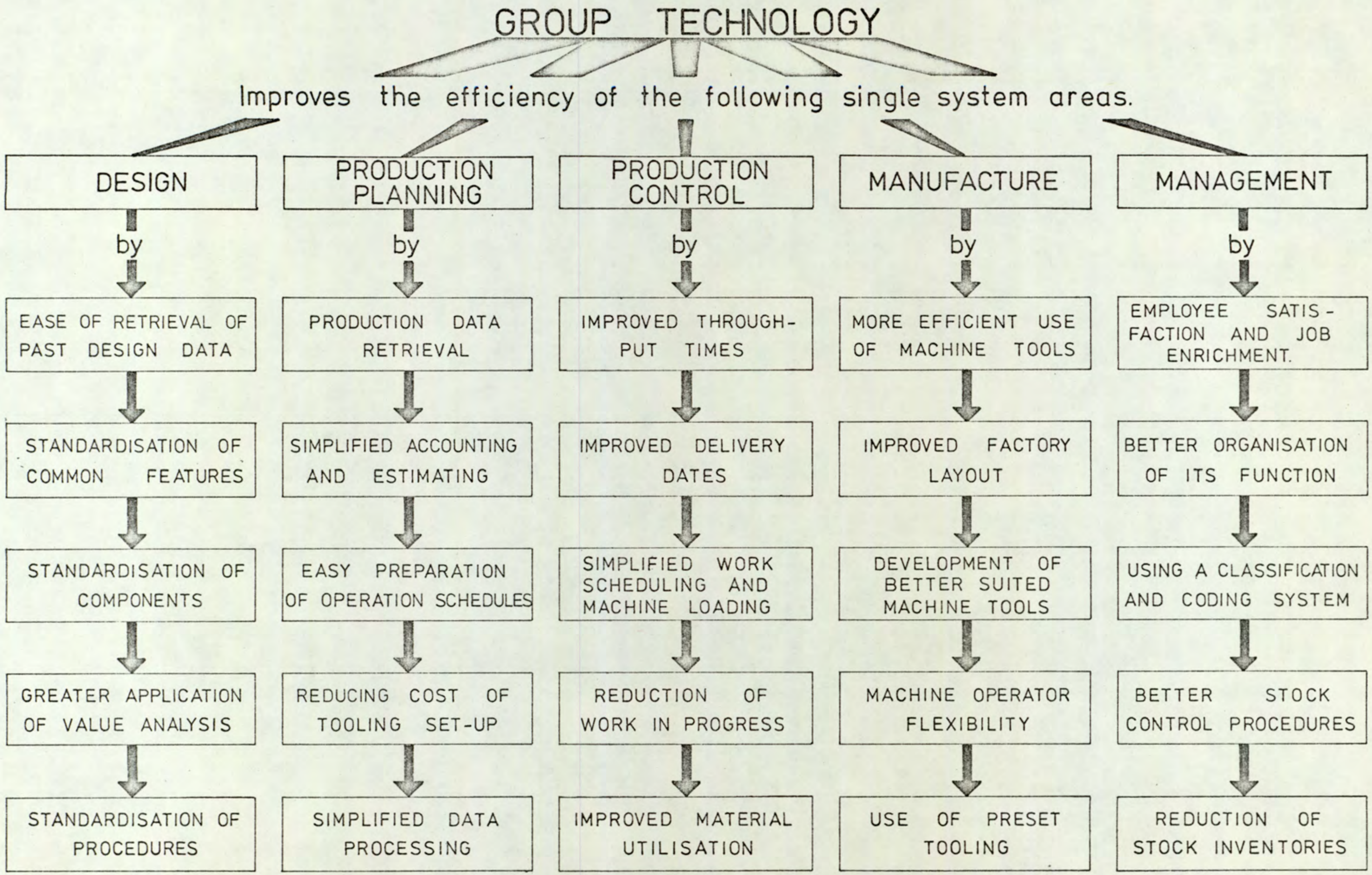

GROUP TECHNOLOGY
Improves the efficiency of the following single system areas.
DESIGN
by
EASE OF RETRIEVAL OF PAST DESIGN DATA
STANDARDISATION OF COMMON FEATURES
STANDARDISATION OF COMPONENTS
GREATER APPLICATION OF VALUE ANALYSIS
STANDARDISATION OF PROCEDURES
PRODUCTION PLANNING
by
PRODUCTION DATA RETRIEVAL
SIMPLIFIED ACCOUNTING AND ESTIMATING
EASY PREPARATION OF OPERATION SCHEDULES
REDUCING COST OF TOOLING SET-UP
SIMPLIFIED DATA PROCESSING
PRODUCTION CONTROL
by
IMPROVED THROUGH-PUT TIMES
IMPROVED DELIVERY DATES
SIMPLIFIED WORK SCHEDULING AND MACHINE LOADING
REDUCTION OF WORK IN PROGRESS
IMPROVED MATERIAL UTILISATION
MANUFACTURE
by
MORE EFFICIENT USE OF MACHINE TOOLS
IMPROVED FACTORY LAYOUT
DEVELOPMENT OF BETTER SUITED MACHINE TOOLS
MACHINE OPERATOR FLEXIBILITY
USE OF PRESET TOOLING
MANAGEMENT
by
EMPLOYEE SATIS-FACTION AND JOB ENRICHMENT.
BETTER ORGANISATION OF ITS FUNCTION
USING A CLASSIFICATION AND CODING SYSTEM
BETTER STOCK CONTROL PROCEDURES
REDUCTION OF STOCK INVENTORIES

FIG. 5-1

STANDARD DESIGN PROCEDURE

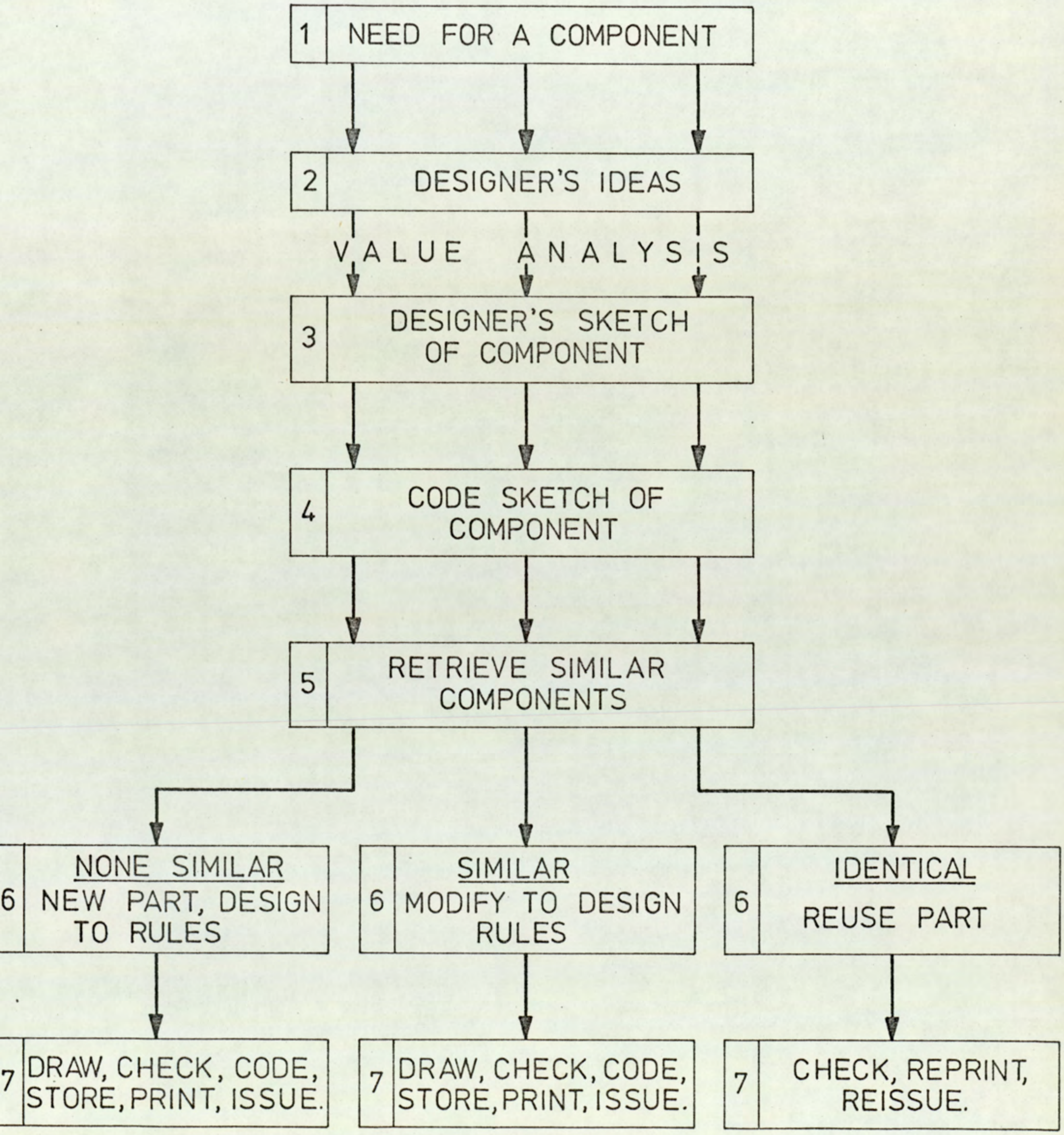


FIG. 5-2

COMPARISON OF THROUGHPUT TIMES BETWEEN FUNCTIONAL AND GROUP LAYOUT

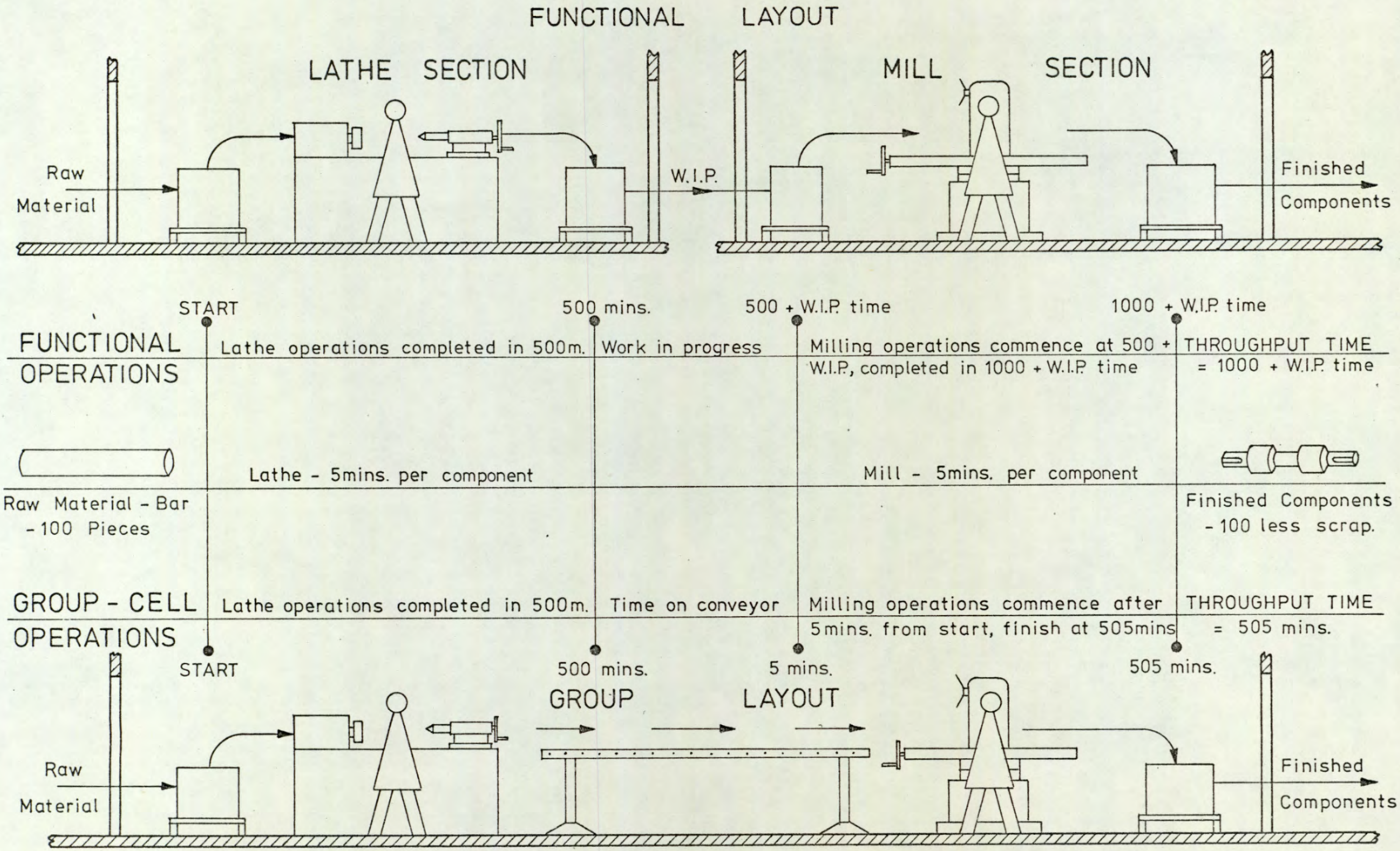
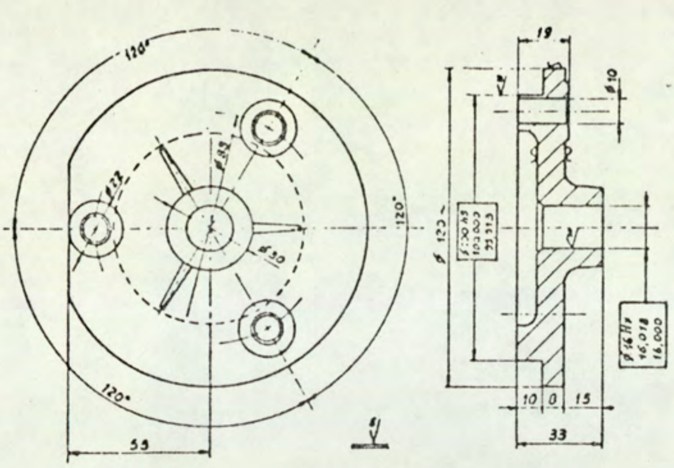
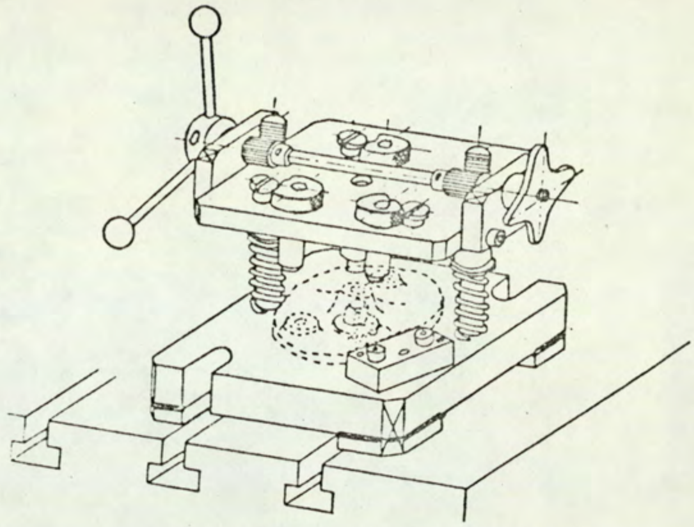


FIG. 5-3

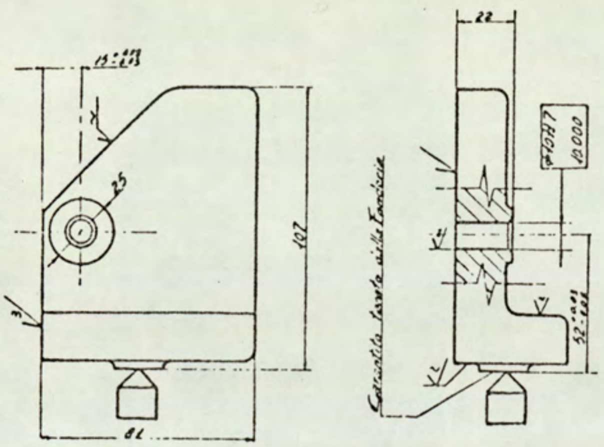


COMPONENT 'A'

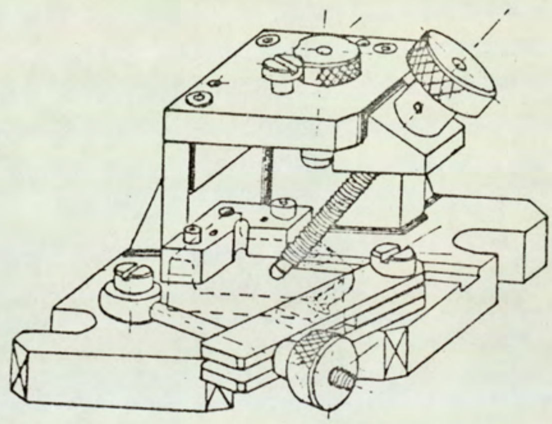


JIG FOR MACHINING COMPONENT 'A'

FIG. 5-4 (a)

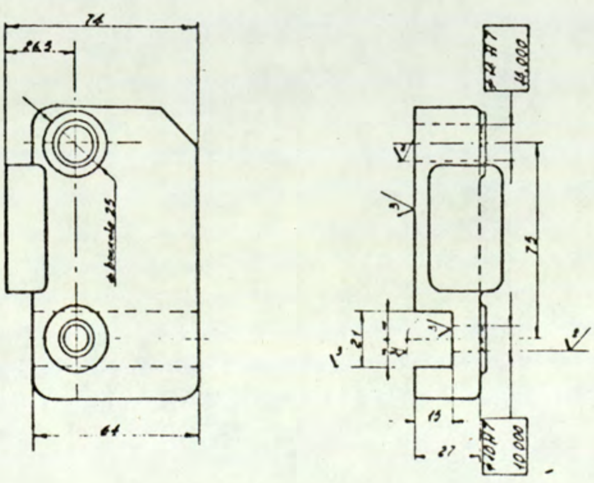


COMPONENT 'B'

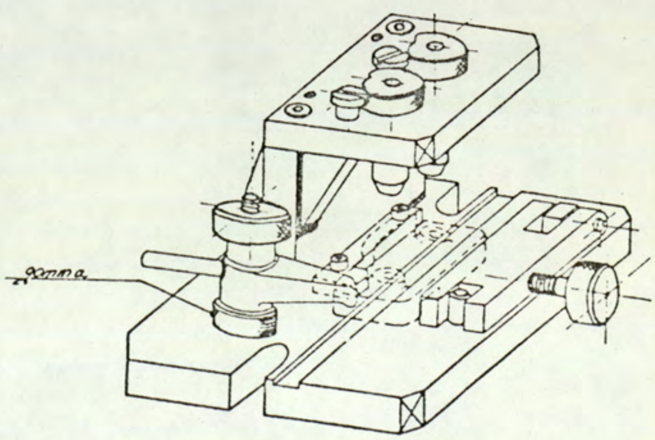


JIG FOR MACHINING COMPONENT 'B'

FIG. 5-4 (b)

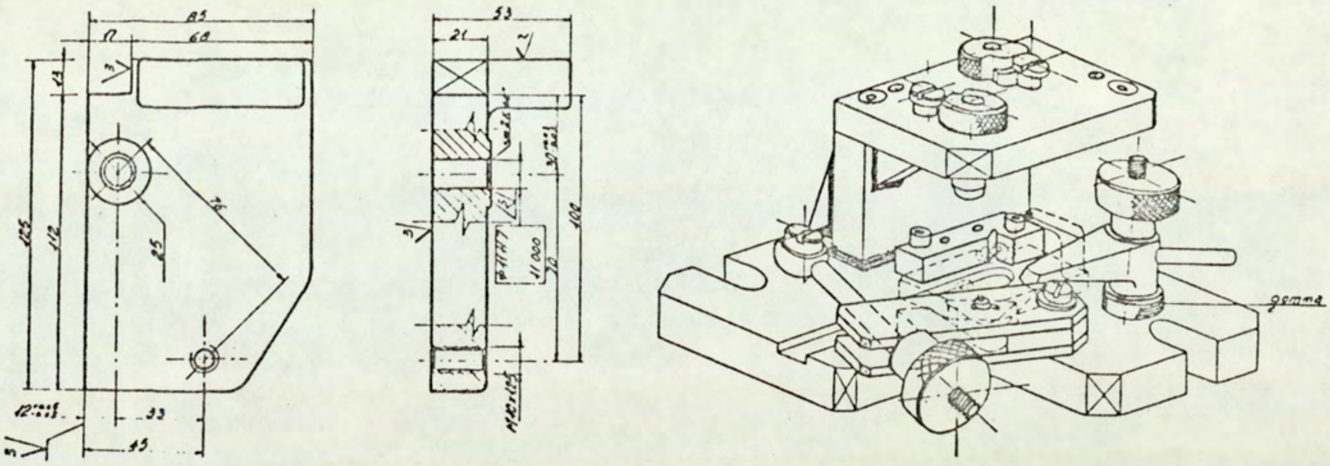


COMPONENT 'C'



JIG FOR MACHINING COMPONENT 'C'

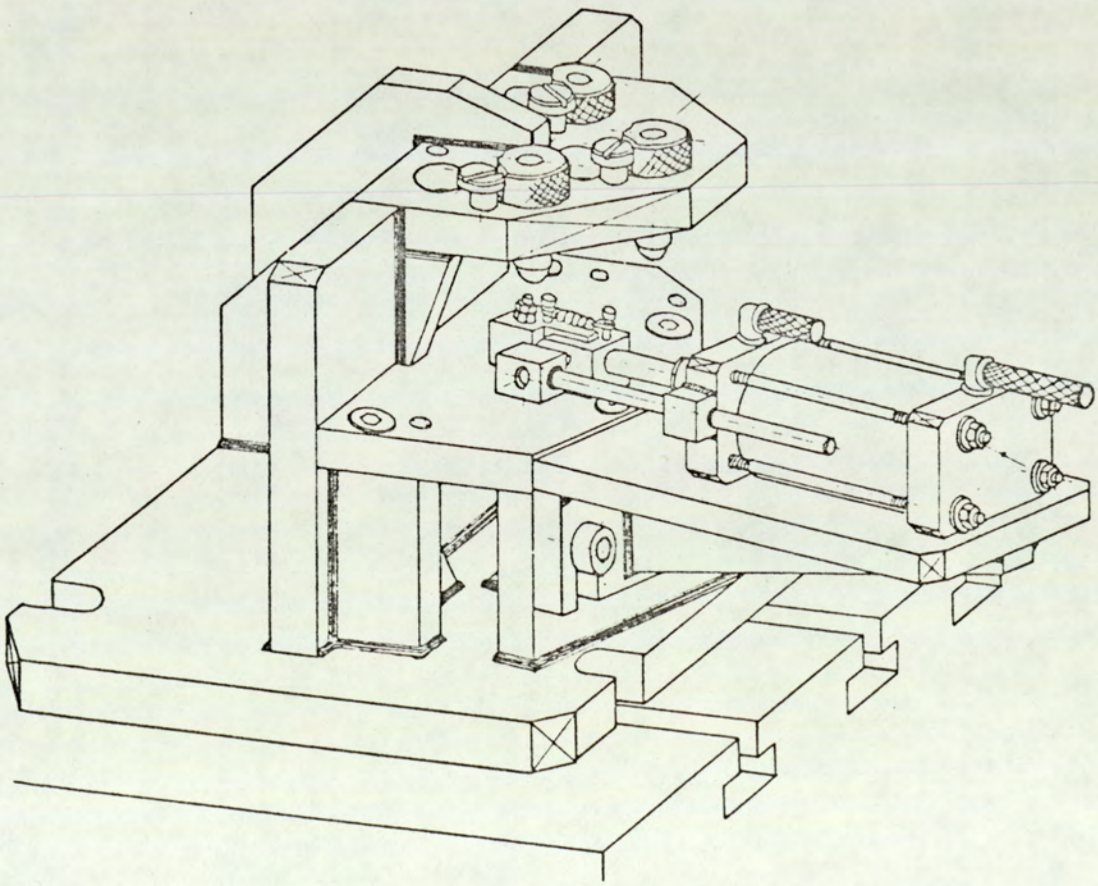
FIG. 5-4 (c) (after Crescimone)



COMPONENT 'D'

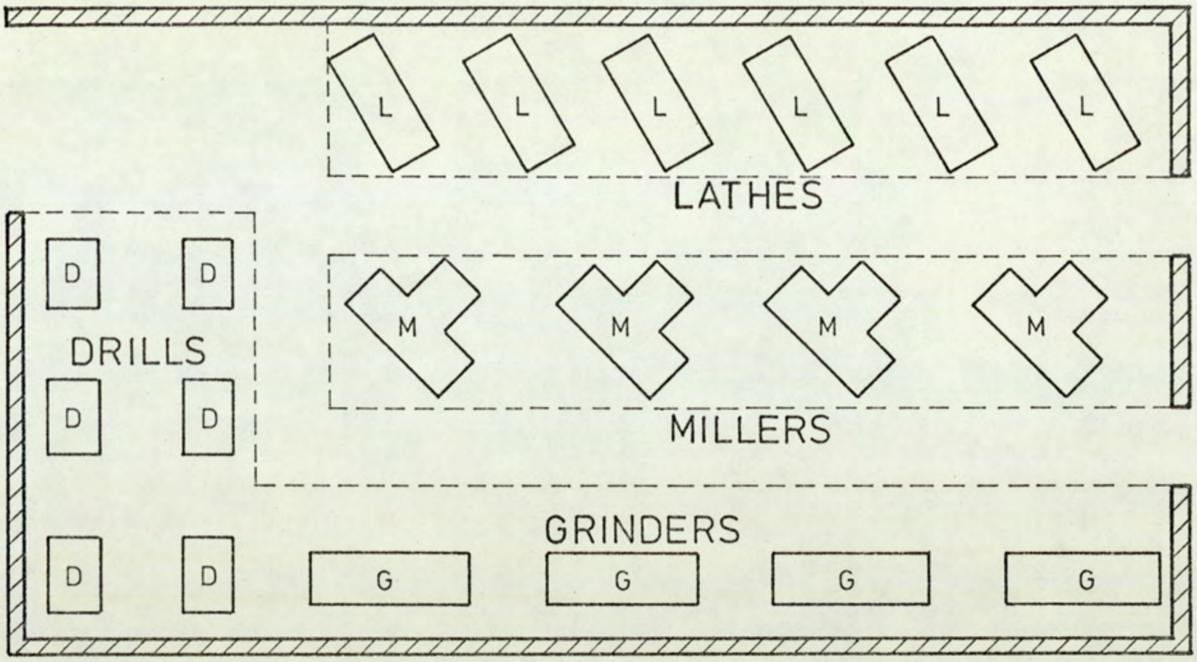
JIG FOR MACHINING COMPONENT 'D'

FIG. 5-4 (d)



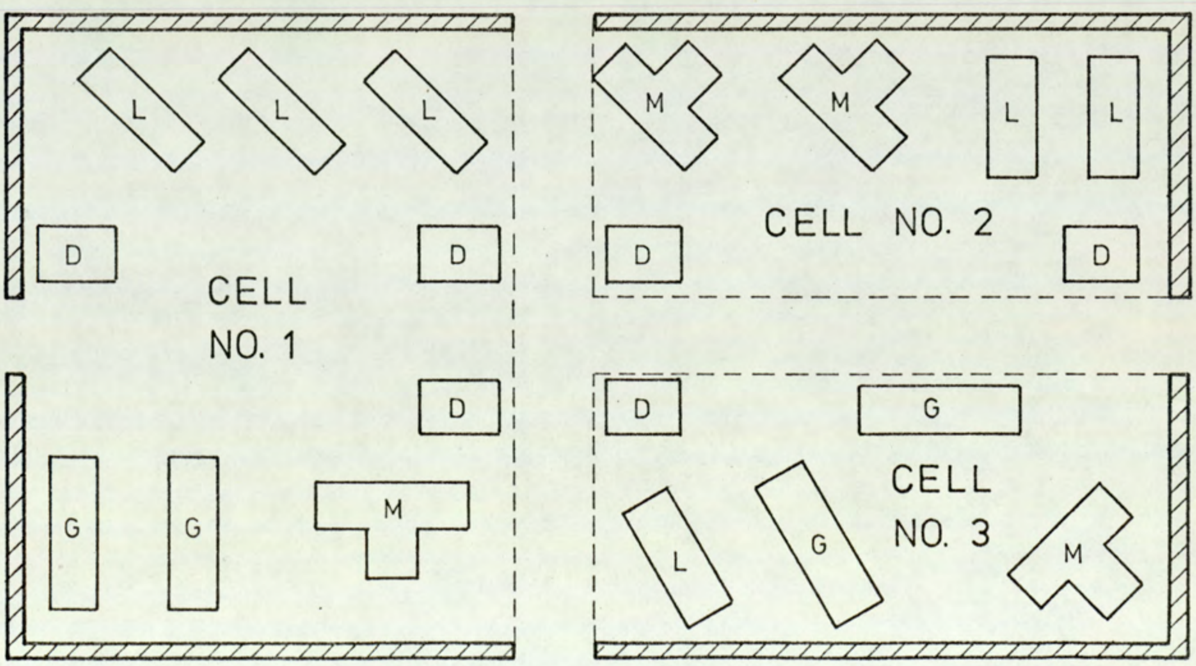
MULTIPLE JIG FOR MACHINING ALL FOUR COMPONENTS

FIG. 5-4 (e) (after Crescimone)



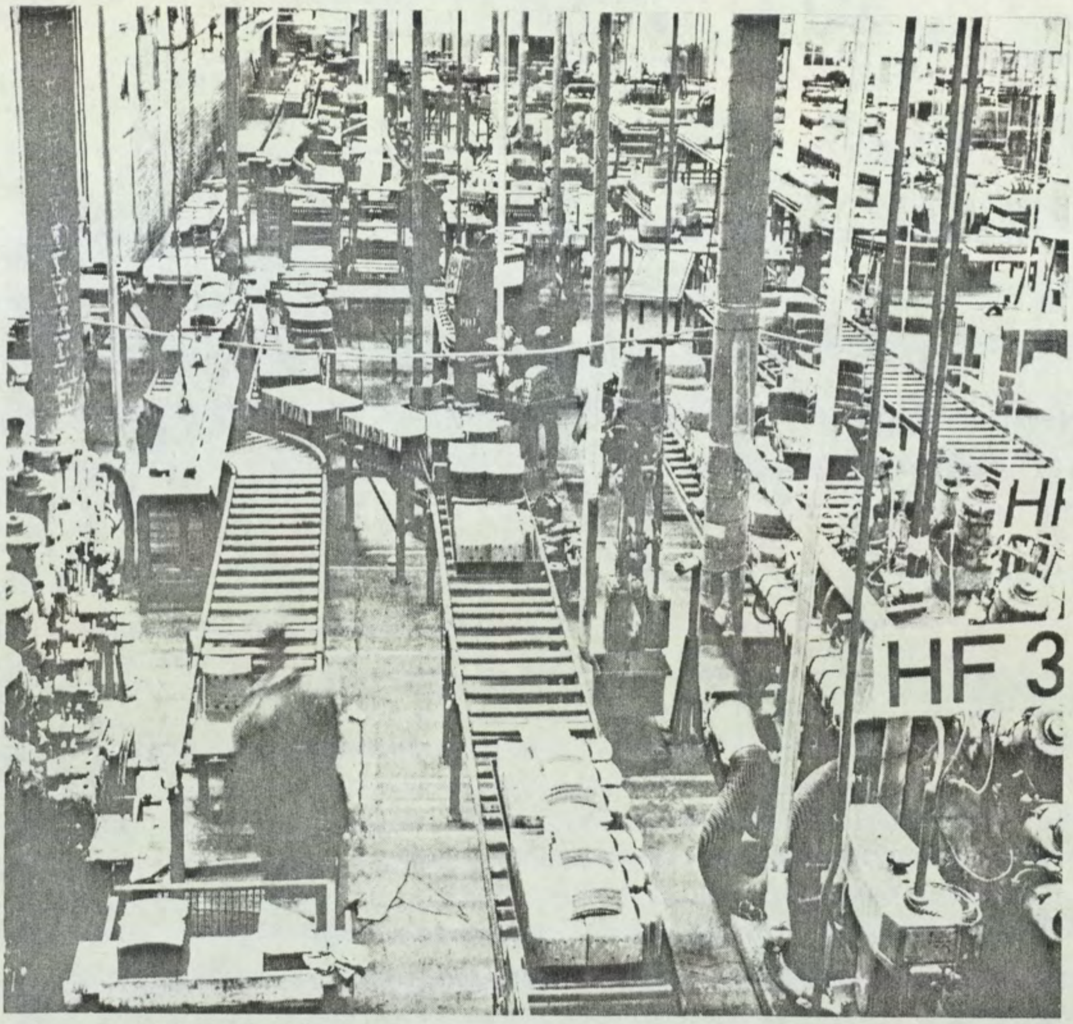
FUNCTIONAL LAYOUT OF MACHINE TOOLS

FIG. 5-5 (a)



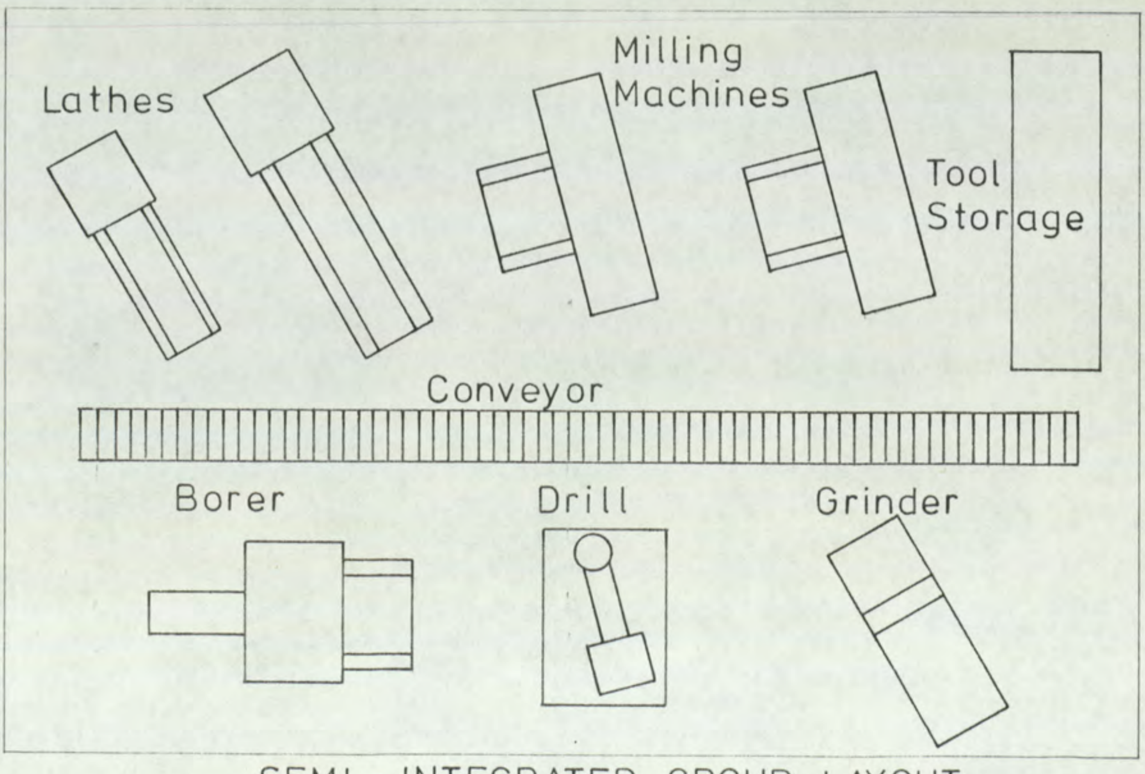
GROUP LAYOUT OF MACHINE TOOLS

FIG. 5-5 (b)



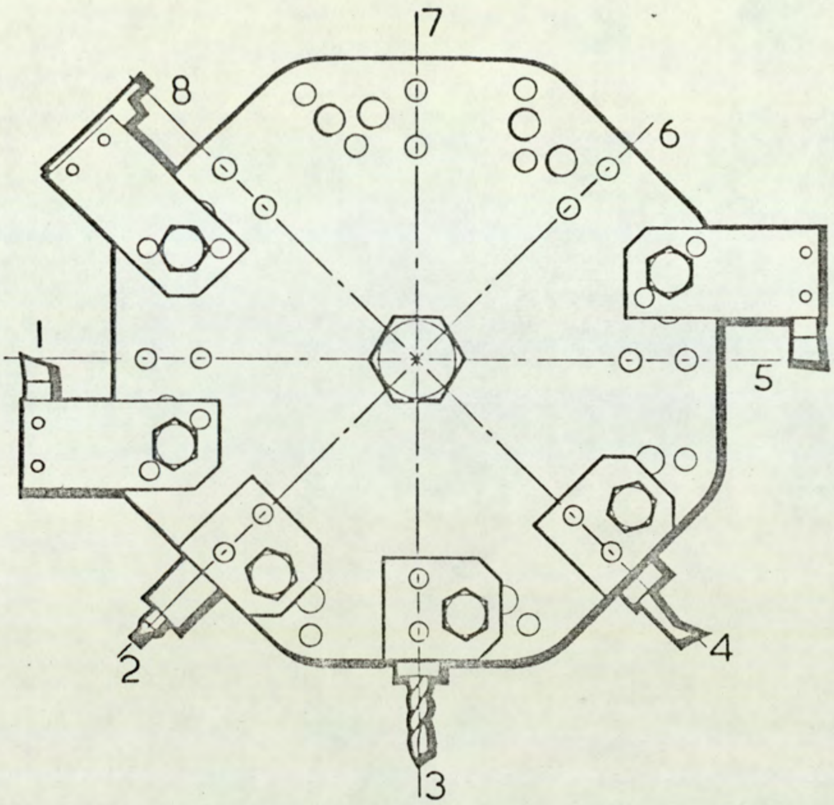
FULLY INTEGRATED FLOWLINE SYSTEM

FIG. 5-6 (a) (after Thornley)



SEMI - INTEGRATED GROUP LAYOUT

FIG. 5-6 (b)



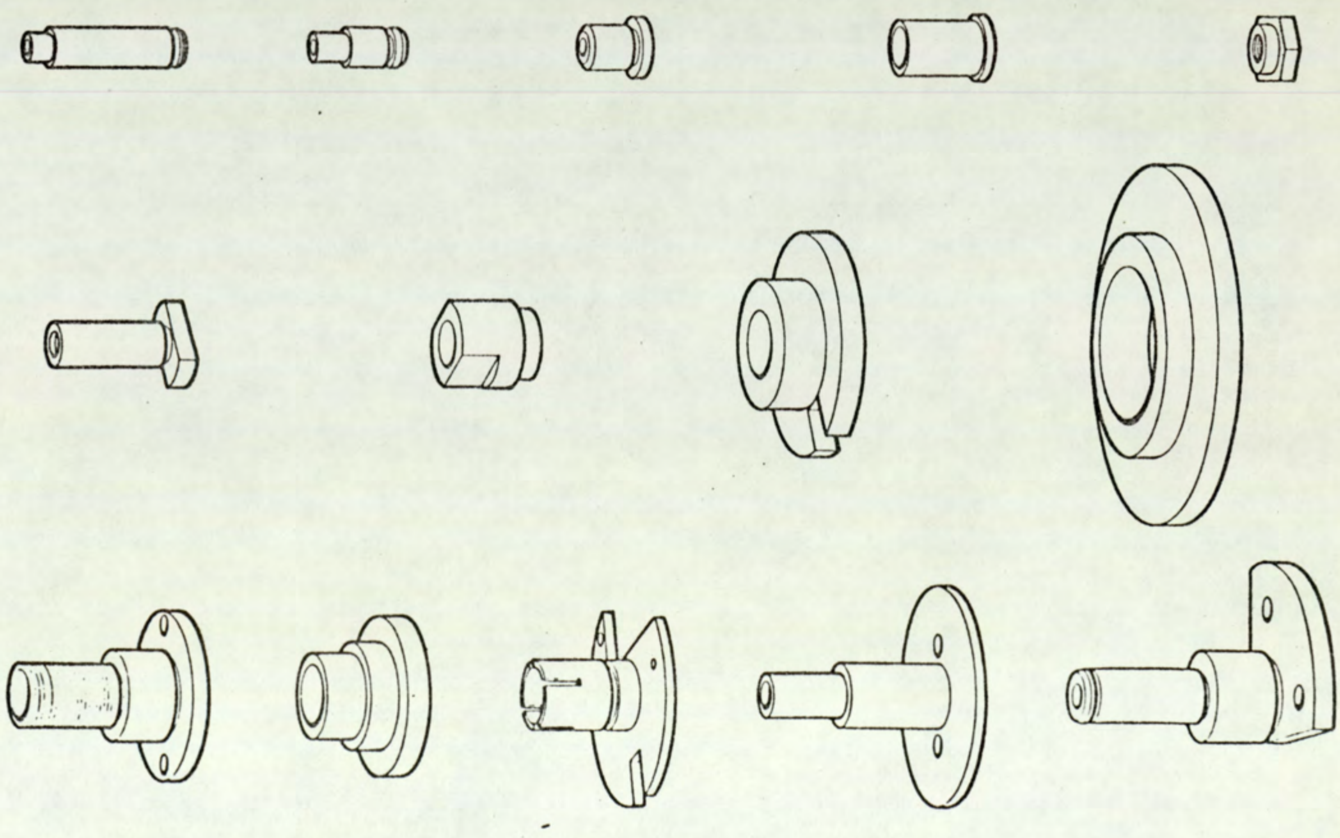
Turret Position	Tool description
1	Face and Rgt. Turn (use as stop)
2	Centre
3 *	Drill
4 *	Boring
5	Finish Turn
6	Free
7	Free
8	Part Off

* Change to suit requirements.

Notes:
Additional tools should be placed in a free position where possible thus preserving the basic settings.

TYPICAL TURRET SET-UP FOR COMPOSITE COMPONENT

FIG. 5-7 (a)



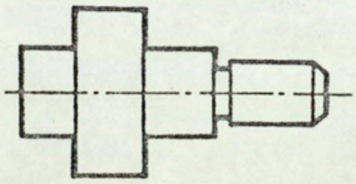
FAMILY OF COMPONENTS MACHINED BY COMPOSITE COMPONENT SET-UP ABOVE

FIG. 5-7 (b) (after Durie)

Hardinge Turret set-up for G.T. Line 1

TURRET No. 1

COMPOSITE COMPONENT



Ferrous material

3 or more diameters.

Turret Position	Tool description
1	Stop.
2	Face and rough turn.
3	Finish turn.
4	45° Chamfer tool.
* 5	Radius or form tool as required.
* 6	Undercut tool.
7	Back turn.
8	Part off tool.

* This tool may be changed to suit requirements.

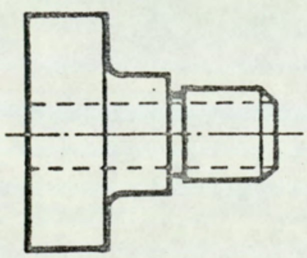
COMPOSITE COMPONENT WITH 3 OR MORE DIAMETERS

FIG. 5-8 (a)

Hardinge Turret set-up for G.T. Line 1

TURRET No. 2

COMPOSITE COMPONENT



Ferrous material

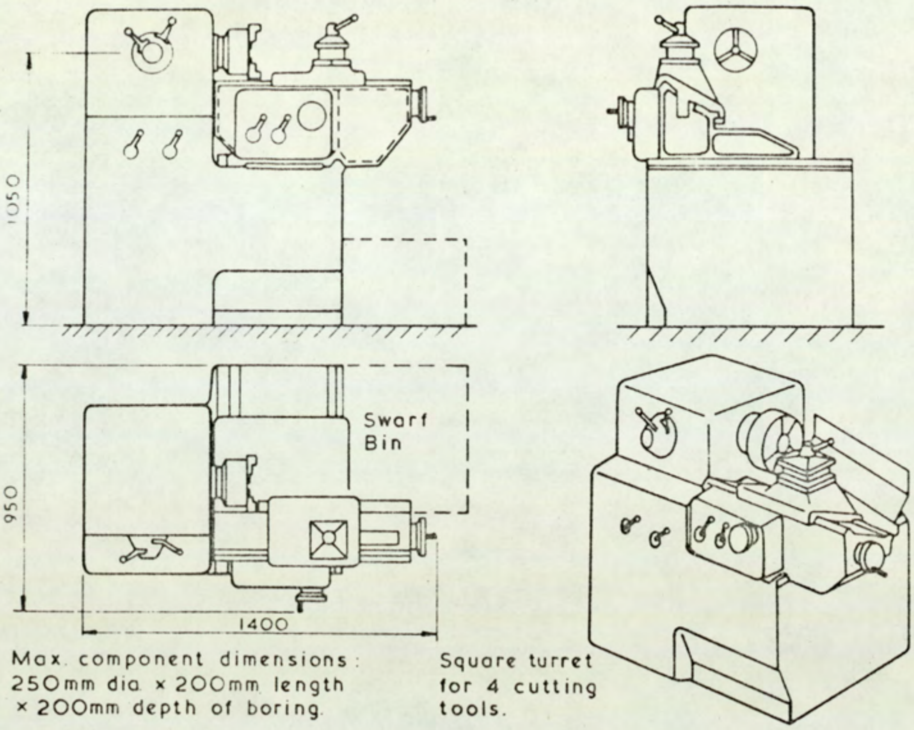
2 or more O/Dias. - 1 In/Dia.

Turret Position	Tool description
1	Stop.
2	Face and rough turn.
3	Finish turn.
4	Centre.
* 55	Drill.
* 6	Bore.
* 7	Undercut.
8	Part off.

* This tool may be changed to suit requirements.

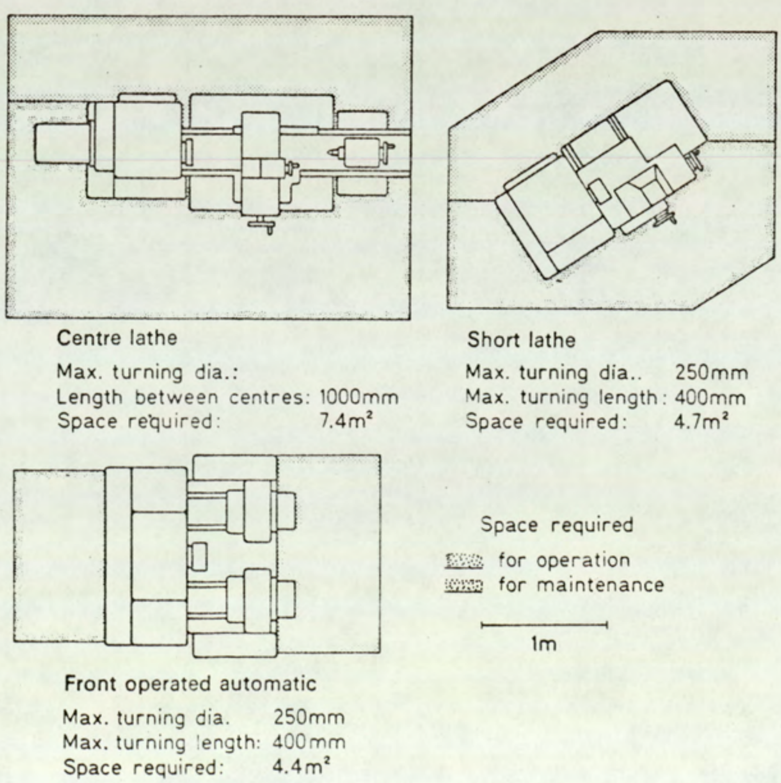
COMPOSITE COMPONENT WITH 2 OR MORE O.D's. AND 1 I.D.

FIG. 5-8 (b) (after Durie)



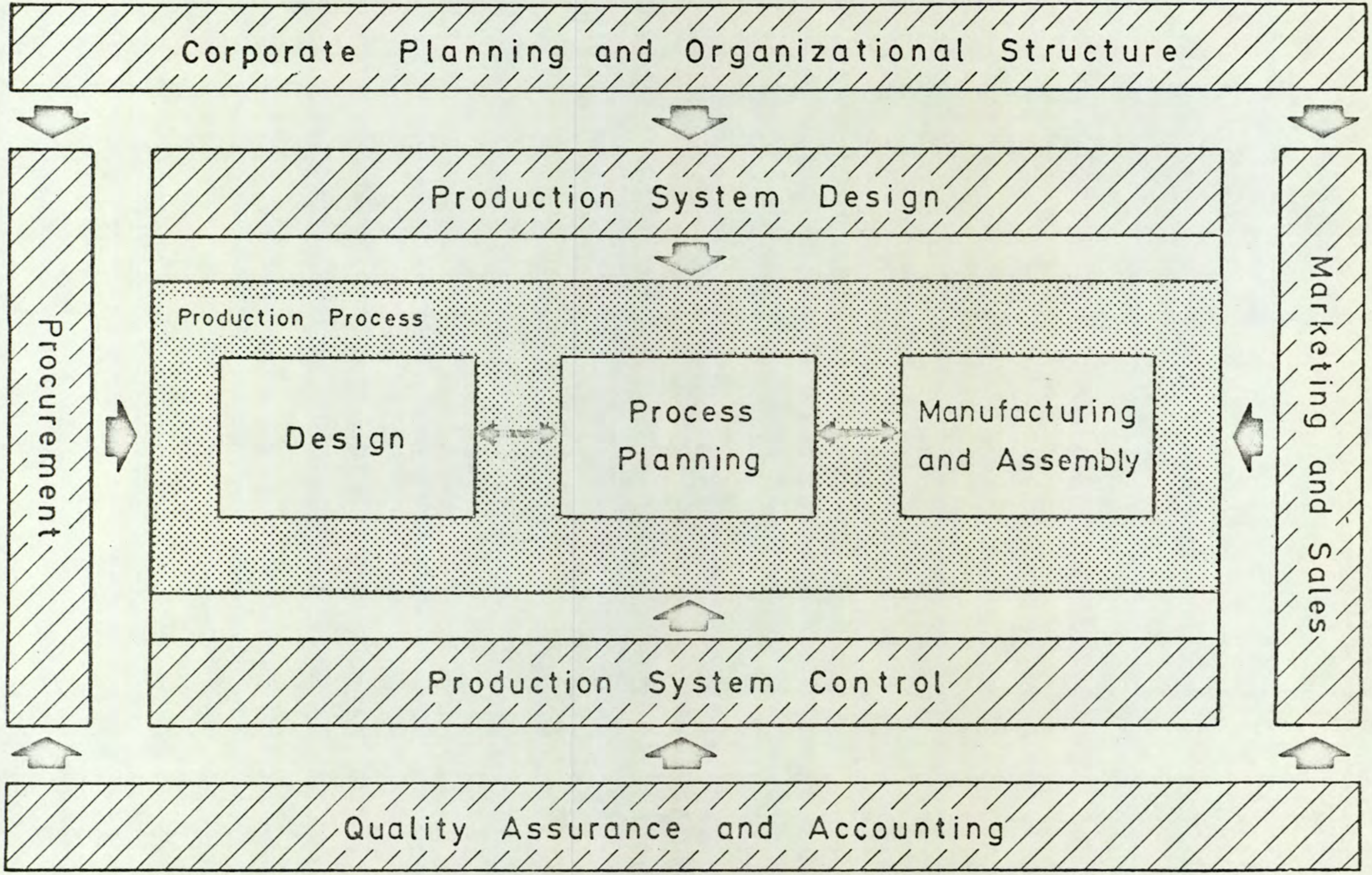
DESIGN OF A SIMPLE SHORT BED LATHE

FIG. 5-9 (a)



COMPARISON OF FLOOR AREAS FOR VARIOUS TYPES OF LATHES

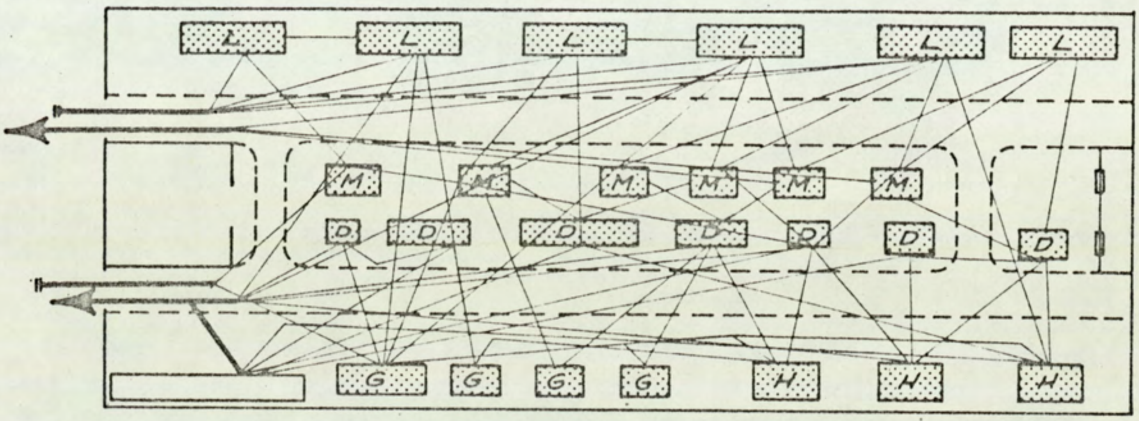
FIG. 5-9 (b) (after Moll)



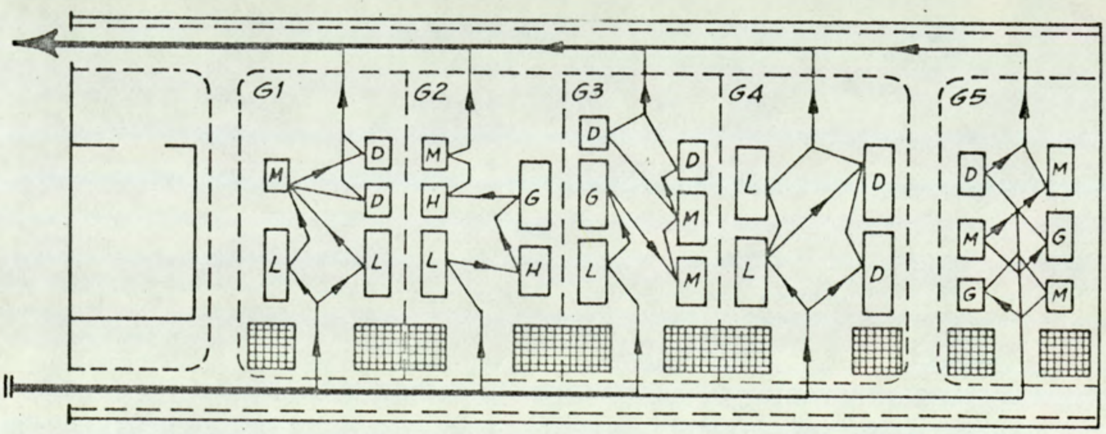
SYSTEM AREAS AT CORPORATE LEVEL

FIG. 5-10 (after Arn)

A. <u>COMPLICATED MATERIAL FLOW SYSTEM</u> (Functional layout)

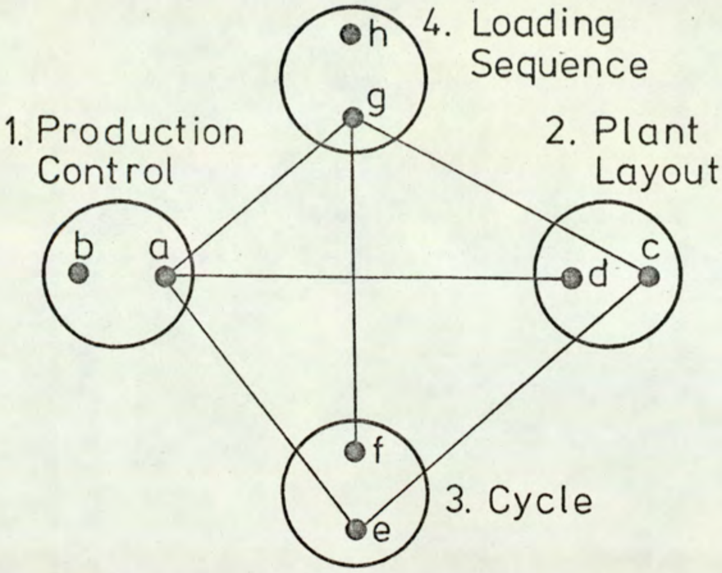


B. <u>SIMPLE MATERIAL FLOW SYSTEM</u> (Group layout)



<u>LAYOUT AND MATERIAL FLOW</u>

FIG. 5-11 (after Burbidge)



a - Stock Control
b - Flow Control
c - Functional Layout
d - Group Layout
e - Short Cycle
f - Long Cycle
g - Planned Loading Sequence
h - Random Loading Sequence

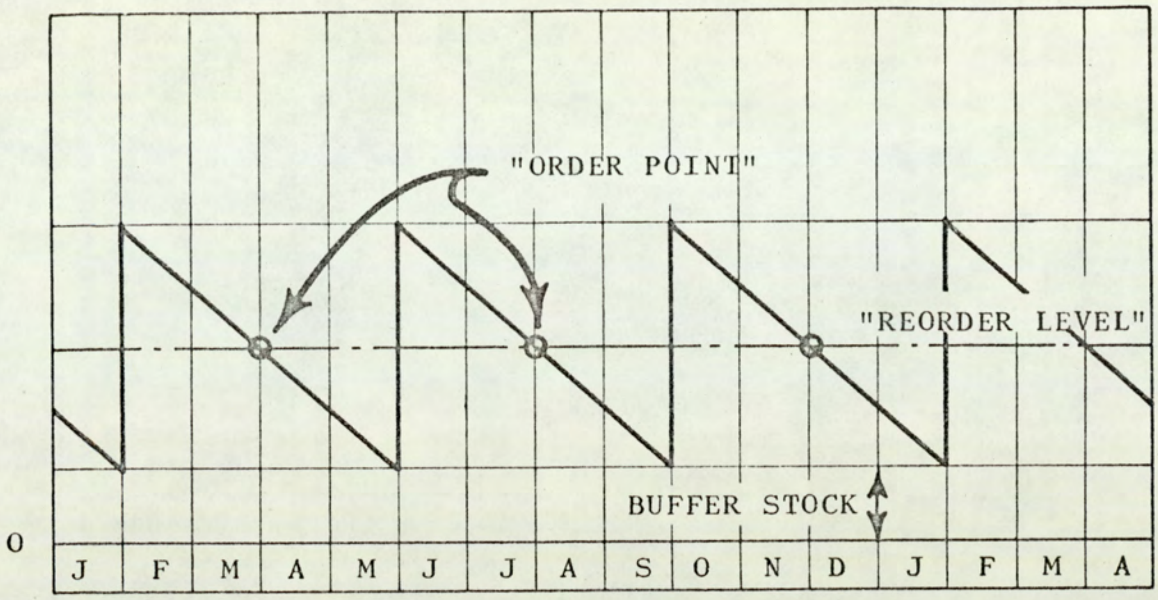
AIDA DECISION NETWORK
FIG. 5-12 (a)

Excluding Links		ag ae	ae	ag		ad ag ae	ad ae	ad fg	cg ad	ce	ce	fg				fg	
Y(yes)	N(no)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
a	(b)	Y	Y	Y	Y	Y	Y	Y	Y	N	N	N	N	N	N	N	N
c	(d)	Y	Y	Y	Y	N	N	N	N	Y	Y	Y	Y	N	N	N	N
e	(f)	Y	Y	N	N	Y	Y	N	N	Y	Y	N	N	Y	Y	N	N
g	(h)	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N

COMBINATIONS OF POSSIBLE OPTIONS
FIG.5-12(b)

4	acfh	S.C	Funct.	Long cy.	Random	TRADITION
12	bcfh	PBC	Funct.	Long cy.	Random	
13	bdeg	PBC	G.L	Short cy.	Planned	G.T.
14	bdeh	PBC	G.L	Short cy.	Random	
16	bdfh	PBC	G.L	Long cy.	Random	

COMBINATIONS OF POSSIBLE SOLUTIONS
FIG.5-12(c) (after Burbidge)



1. ALL FINISHED ITEMS IN A CONTROLLED STORE.
2. ALL RECEIPTS COVERED BY "STORES RECEIPT NOTES".
3. ALL ISSUES COVERED BY "STORES ISSUE NOTES".
4. THESE BASIC DOCUMENTS USED TO MAINTAIN A

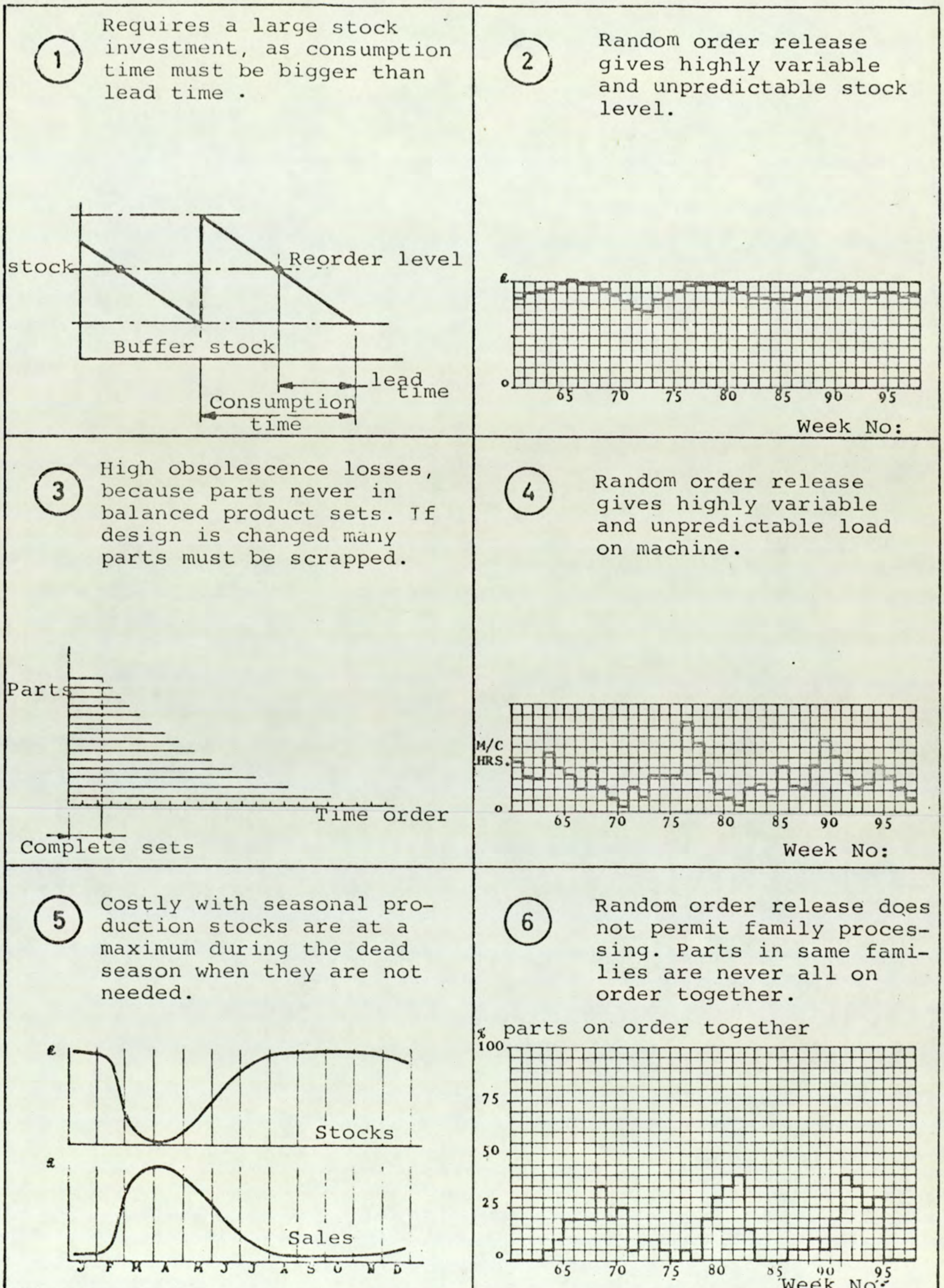
"BALANCE OF STOCK RECORD" :

PART Bracket		Part No: 7201	
	OQ 25	O.P = 10	
Date	In	Out	Balance
10.2	25	3	22
12.2	-	1	21
12.2	-	2	19
15.2	-	4	15
16.2	-	1	14
18.2	-	5	9 *

5. WHEN STOCK DROPS BELOW "ORDER POINT".
6. ISSUE ORDER FOR NEW BATCH

STOCK CONTROL ORDERING SYSTEM

FIG. 5-13 (after Burbidge)



DEFICIENCIES IN STOCK CONTROL ORDERING

FIG. 5-14 (after Burbidge)

1. SHORT TERM PRODUCTION PROGRAMME EACH CYCLE

NOV 1969	
PRODUCT	QTY.
A	10
B	40
C	5

2. "EXPLODE" TO FIND REQUIREMENT SCHEDULE FOR PARTS

PRODUCT C

PRODUCT B

PRODUCT A		
Part No	Set	Qty.
1	1	10
2	1	10
3	4	10
4	1	10

3. ADD SPARES ORDERS AND SCRAP ALLOWANCES

PART No 1	
Prod.	10
Spares	1
Scrap	1
TOTAL	12

4. ORDER TO STANDARD SCHEDULE, REPEATED EACH CYCLE

SALES	JULY	AUG	SEPT	OCT	NOV	DEC
OCT	ORDER	MAKE	ASSY	SALES		
NOV		ORDER	MAKE	ASSY	SALES	
DEC			ORDER	MAKE	ASSY	SALES

Programme meeting for Nov. sales

Issue shop orders

Due-date parts for Nov. sales

PERIOD BATCH OR SINGLE CYCLE FLOW CONTROL ORDERING SYSTEM

FIG. 5-15 (after Burbidge)

	SAVING	REASON
1	Reduced throughput times	Machines close together. All under one foreman
2	Reduced stock investment	Short ordering cycle and short throughput times
3	Reduced handling cost	Machines close together
4	Reduced setting cost	Planned loading sequence and family processing
5	Increased capacity	Reduced setting time
6	Reduced indirect labour	Simpler material flow system
7	Obsolescence eliminated	Parts ordered in balanced product sets to a short cycle
8	Reduced material costs	Planned loading sequence for minimum cutting losses
9	Reliable delivery by due-date	One foreman controls all processes
10	Better quality	One foreman controls all processes
11	Reduced tooling investment	Planned loading encourages tool design for families
12	Reduced machine investment	Increased m/c capacity reduces m/c investment per unit of output
13	Reduced building investment	Less work in progress. Eliminates inter-process stores
14	Reduced direct labour	Tooling families permit use high quantity methods for small outputs

ECONOMIC SAVINGS WITH GROUP TECHNOLOGY

FIG. 5-16 (after Burbidge)

MARCH PRODUCTION PROGRAMME.

	A	Stock		8 upstrokers
	A7892	Blaw Knox Ltd.	H.	300/335-10-H
	A7963	Stock		Series 910
	A7961	Stock		250-10-H
	7963	Stock		90Ton x 10ft. Mech.
	B7700 (new design)	Stock		6. CR.4½
	C7889	British Leyland	H.	Leveller
	C7823	Acrow-Iran	E.	Bending rolls
P	C7893	T.T.S.,Norway (for Taiwan)	E.	5 roll plate leveller
	D7712	British Leyland (Press feed line)	H.	Twin mandrel uncoiler
	D7714	"		4 roll flattener
	D7717	"		11 roll leveller
	D7719	"		Feed rolls
	D7716	"		Wash and brush unit
	D7853	Kent Steels, Canada	E.	Single mandrel uncoiler
	D7856	" "		Slitter
	D7858	" "		Recoiler
	D7864	" "		One replacement slitter head
P	E7653	Granges Aluminium Sweden	E.	Uncoiler
	E7656	" "		Edge trimmer and feed pinch rolls
	E7665	" "		Recoiler with automatic edge control.
	E7669	" "		Belt wrapper
	E7657	" "		Scrap baller
	E6590 (part)	Morgan, U.S.A. (Enfield)	H.	Spare gears

MADE OUT

P	E7728	Nordisk, Norway (Coating line)	E.	Coil car No. 1
	E7729	"		Coil car No. 2
	E7732	"		Carryover table
	E7733	"		Thread table
	E7734	"		Entry pinch roll
	E7735	"		Entry shear
	E7737	"		Bridle No. 1
	E7738	"		Entry accumulator
	E7739	"		No. 1 steering unit
	E7741	"		Passline roll
	E7742	"		Rinse tank
	E7743	"		Support rolls - 3 off
	E7744	"		No. 2 steering unit
	E7745	"		Bridle No. 2
	E7746	"		Bypass roll
	E7747	"		Passline roll
	E7748	"		Steering unit
	E7750	"		No. 1 coater drive stand
	E7751	"		No. 1 coater platform
	E7752	"		Capacitance bracket
	E7753	"		No. 1 squeegee roll

FIG. 7-1

BRONX MANUFACTURING SYSTEM

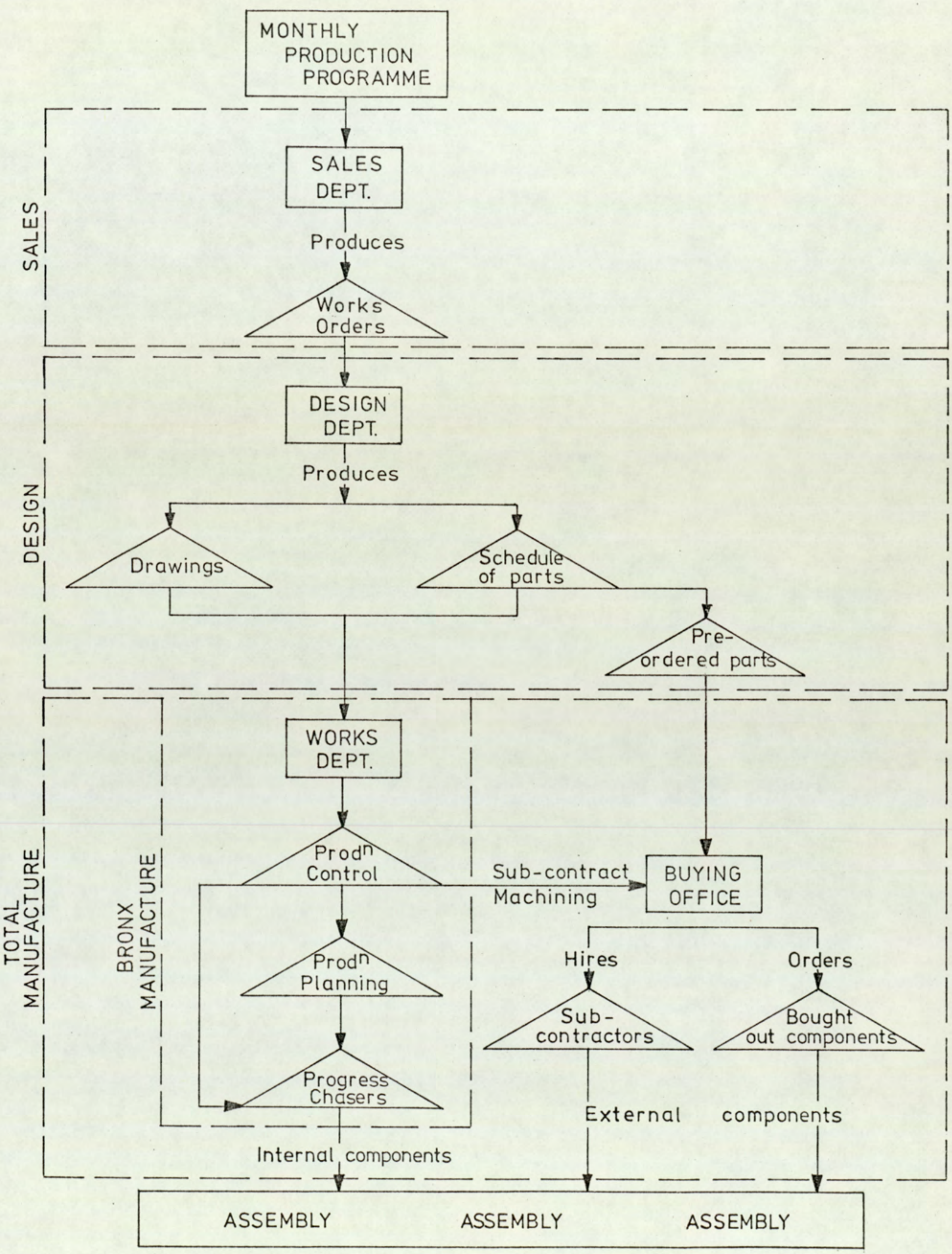


FIG. 7-2

OPITZ CODE

COMPONENT CLASS		OVERALL SHAPE		
		0	PLANE	RECTANGULAR
		1	PLANE	RECTANGULAR WITH ONE DEVIATION.(RT. ANG. OR TRIANGULAR).
		2	PLANE	RECTANGULAR WITH ANGULAR DEVIATIONS.
		3	PLANE	RECTANGULAR WITH CIRCULAR DEVIATION.
		4	PLANE	ANY FLAT SHAPE OTHER THAN 0 TO 3.
		5		FLAT COMPONENTS, RECT., OR RT. ANGULAR WITH SMALL DEVS. DUE TO CASTING, WELDING, ETC.
6	FLAT COMPONENTS $\frac{A}{B} < 3$, $\frac{A}{C} \geqslant 4$	6		FLAT COMPS. ROUND OR OF ANY SHAPE OTHER THAN POSITION 5.
		7		FLAT COMPONENTS REGULARLY ARCHED OR DISHED.
		8		FLAT COMPONENTS IRREGULARLY ARCHED OR DISHED.
		9		OTHERS

(a)

MODIFIED CODE

COMPONENT CLASS		OVERALL SHAPE		
		0	PLANE	RECTANGULAR
		1	PLANE	RECTANGULAR WITH DEVIATIONS - RT. ANG., TRIANG. OR ANGULAR.
		2	PLANE	RECTANGULAR WITH DEVIATIONS-CIRCULAR OR PART CIRCULAR.
		3	PLANE	ANY PLANE SHAPE OTHER THAN 0 TO 2.
		4		PLANE COMPONENTS SUCH AS 0 TO 3 WITH SMALL DEVS. DUE TO CASTING, WELDING OR FORMING.
		5		FLAT, BLOCK-LIKE COMPS. COMPOUNDED OF PRISMS BY CASTING, WELDING, OR FORGING.
6	FLAT COMPONENTS $\frac{A}{B} < 3$, $\frac{A}{C} \geqslant 4$	6		FLAT, BOX-LIKE COMPS. COMPOUNDED OF PRISMS BY CASTING AND WELDING.
		7		FLAT COMPONENTS REGULARLY ARCHED OR DISHED.
		8		FLAT COMPONENTS IRREGULARLY ARCHED OR DISHED.
		9		OTHERS

(b)

FIG. 7-3

MODIFICATION OF OPITZ CODE

OPITZ CODE

Component Class	Digit			Overall Shape
	0	BLOCK & BLOCK-LIKE COMPONENTS		RECTANGULAR PRISM
	1			RECTANGULAR WITH DEVIATIONS, RHT. ANG. OR TRIANGULAR.
	2			COMPOUNDED OF RECTANGULAR PRISM.
	3			COMPONENTS WITH A MOUNTING OR LOCATING SURFACE & PRINCIPAL BORE.
	4			COMPTS. WITH MOUNTING OR LOCAT. SURF., PRINC. BORE WITH DIVIDING SURFACE.
	5			COMPONENTS OTHER THAN 0 TO 4
	6	BOX & BOX-LIKE COMPONENTS	NOT SPLIT	APPROXIMATE OR COMPOUNDED OF RECT'ULAR PRISMS.
	7			COMPONENTS OTHER THAN 6.
8 CUBIC COMPONENTS $\frac{A}{B} \leqslant 3$, $\frac{A}{C} < 4$	8		SPLIT	APPROXIMATE OR COMPOUNDED OF RECT'ULAR PRISMS
	9			COMPONENTS OTHER THAN 8

(a)

MODIFIED CODE

Component Class	Digit			Overall Shape
	0	BLOCK & BLOCK-LIKE COMPONENTS		RECTANGULAR PRISM
	1			RECTANGULAR WITH DEVIATIONS, RHT. ANG. OR TRIANGULAR.
	2			COMPOUNDED OF RECTANGULAR PRISMS.
	3			COMPONENTS WITH A MOUNTING OR LOCATING SURFACE &/OR PRINC. BORE/S.
	4			COMPTS. WITH MOUNTING OR LOCAT. SURF. & PRINC. BORE/S WITH DIVIDING SURFACE.
	5			COMPONENTS OTHER THAN 0 TO 4
	6	BOX & BOX-LIKE COMPONENTS	NOT SPLIT	APPROXIMATE OR COMPOUNDED OF RECT'ULAR PRISMS.
	7			COMPONENTS OTHER THAN 6.
8 CUBIC COMPONENTS $\frac{A}{B} \leqslant 3$, $\frac{A}{C} < 4$	8		SPLIT	APPROXIMATE OR COMPOUNDED OF RECT'ULAR PRISMS.
	9			COMPONENTS OTHER THAN 8

(b)

FIG. 7-4

MODIFIED OPITZ SUPPLEMENTARY CODE.

	1st DIGIT		2nd DIGIT		3rd DIGIT	4th DIGIT
	DIAMETER 'D' or EDGE LENGTH 'A'		LENGTH 'L' (ROTATIONAL) or EDGE LENGTH 'C' (NON-ROT.)		MATERIAL	INITIAL FORM
	mm's	ins.	mm's	ins.		
0	≤20	≤0·8	≤20	≤0·8	Cast Iron	Round Bar, black.
1	>20 ≤50	>0·8 ≤2·0	>20 ≤50	>0·8 ≤2·0	S.G. Iron, Meehanite	Round Bar, bright drawn
2	>50 ≤100	>2·0 ≤4·0	>50 ≤100	>2·0 ≤4·0	Mild Steel	Bar - rectangular, square, hexagonal and others.
3	>100 ≤160	>4·0 ≤6·5	>100 ≤160	>4·0 ≤6·5	Medium / High Carbon and Low Alloy Steels	Tubing
4	>160 ≤250	>6·5 ≤10·0	>160 ≤250	>6·5 ≤10·0	2 and 3 Heat treated	Angle, U, T and similar sections
5	>250 ≤400	>10·0 ≤16·0	>250 ≤400	>10·0 ≤16·0	High Alloy Steels (Not heat treated)	Sheet
6	>400 ≤600	>16·0 ≤25·0	>400 ≤600	>16·0 ≤25·0	High Alloy Steels (Heat treated)	Plate and Slabs
7	>600 ≤1000	>25·0 ≤40·0	>600 ≤1000	>25·0 ≤40·0	Non-ferrous metal	Cast or Forged components
8	>1000 ≤2000	>40·0 ≤80·0	>1000 ≤2000	>40·0 ≤80·0	Light Alloy	Welded Assembly
9	>2000	>80·0	>2000	>80·0	Other Materials	Pre-machined components

FIG. 7-5 (after Thornley)

FIRST BRONX MODIFIED SUPPLEMENTARY CODE

	DIAMETER 'D' (ROT.) OR EDGE LENGTH 'A' (NON-R)			LENGTH 'L' (ROT.) OR EDGE LENGTH 'C' (NON-R)			MATERIAL		INITIAL FORM.
	MM's	INS.		M.M's	INS.				
0	≤ 20	≤ 0.8	0	≤ 20	≤ 0.8	0	CAST IRON	0	ROUND BAR, BLACK UP TO 12"
1	> 20 ≤ 50	> 0.8 ≤ 2.0	1	> 20 ≤ 50	> 0.8 ≤ 2.0	1	S.G. IRON, MEEHANITE.	1	ROUND BAR, BRIGHT DRAWN. - B.D.M.S.
2	> 50 ≤ 100	> 2.0 ≤ 4.0	2	> 50 ≤ 100	> 2.0 ≤ 4.0	2	MILD STEEL - FLAME CUT	2	BAR - RECTANGULAR SQUARE, HEX., ETC.
3	> 100 ≤ 160	> 4.0 ≤ 6.5	3	> 100 ≤ 160	> 4.0 ≤ 6.5	3	MILD STEEL	3	TUBING.
4	> 160 ≤ 250	> 6.5 ≤ 10.0	4	> 160 ≤ 250	> 6.5 ≤ 10.0	4	MED/HIGH CARBON, CAST & LOW ALLOY STEELS	4	ANGLE, CHANNEL, I, T, EXTRUDED OR SIMILAR SECT.
5	> 250 ≤ 400	> 10.0 ≤ 16.0	5	> 250 ≤ 400	> 10.0 ≤ 16.0	5	3 & 4 HEAT TREATED.	5	SHEET, PLATE OR SLAB
6	> 400 ≤ 600	> 16.0 ≤ 25.0	6	> 400 ≤ 600	> 16.0 ≤ 25.0	6	HIGH ALLOY STEELS (NOT HEAT TREATED)	6	COMPONENTS FOR FABRICATED ASSY
7	> 600 ≤ 1000	> 25.0 ≤ 40.0	7	> 600 ≤ 1000	> 25.0 ≤ 40.0	7	HIGH ALLOY STEELS. (HEAT TREATED)	7	OUTSIDE CONTRACTED
8	> 1000 ≤ 2000	> 40.0 ≤ 80.0	8	> 1000 ≤ 2000	> 40.0 ≤ 80.0	8	NON-FERROUS METAL.	8	CASTING
9	> 2000	> 80.0	9	> 2000	> 80.0	9	OTHER MATERIALS (LIGHT ALLOYS, PLASTICS, ETC. TUFNOL, RAILKO, DRKAT)	9	FORGED OR ROLLED AND/OR PRE-MACHINED AND BOUGHT OUT COMPONENTS

FIG. 7-6

BRONX ENGINEERING SUPPLEMENTARY CODE

DIAMETER 'D' (ROT.) OR EDGE LENGTH 'A' (NON-R)			LENGTH 'L' (ROT.) OR EDGE LENGTH 'C' (NON-R)			MATERIAL		INITIAL FORM		CONTRACTED WORK		
	mm's	ins		mm's	ins							
0	≤20	≤0·8	0	≤20	≤0·8	0	CAST IRON	0	ROUND BAR, BLACK. (UP TO 12" DIAM.)	0		NIL
1	>20 ≤50	>0·8 ≤2·0	1	>20 ≤50	>0·8 ≤2·0	1	S. G. IRON, MEEHANITE.	1	ROUND BAR, BRIGHT DRAWN.	1	PARTIALLY CONTRACTED	MACHINING, FLAME CUTTING.
2	>50 ≤100	>2·0 ≤4·0	2	>50 ≤100	>2·0 ≤4·0	2	MILD STEEL, FLAME CUT.	2	BAR-RECT., SQUARE, HEX., ETC. INCLUDING BRIGHT DRAWN.	2		HEAT TREATMENT.
3	>100 ≤160	>4·0 ≤6·5	3	>100 ≤160	>4·0 ≤6·5	3	MILD STEEL	3	TUBING	3		BALANCING
4	>160 ≤250	>6·5 ≤10·0	4	>160 ≤250	>6·5 ≤10·0	4	MED/HIGH CARBON, CAST AND LOW ALLOY STEELS.	4	ANGLE, CHANNEL, I, T, EXTRUDED OR SIMILAR SECTIONS.	4		SPUR AND WORM GEARS
5	>250 ≤400	>10·0 ≤16·0	5	>250 ≤400	>10·0 ≤16·0	5	3 AND 4 HEAT TREATED.	5	SHEET, PLATE OR SLAB.	5		SURFACE TREATMENT
6	>400 ≤600	>16·0 ≤25·0	6	>400 ≤600	>16·0 ≤25·0	6	HIGH ALLOY STEELS	6	COMPONENTS FOR FABRICATED ASSY.	6		
7	>600 ≤1000	>25·0 ≤40·0	7	>600 ≤1000	>25·0 ≤40·0	7	HIGH ALLOY STEELS, HEAT TREATED.	7	FORGED, ROLLED AND OR PRE-MACHINED	7	WHOLLY CONTRACTED	
8	>1000 ≤2000	>40·0 ≤80·0	8	>1000 ≤2000	>40·0 ≤80·0	8	NON-FERROUS METAL	8	CASTING	8		METALLIC COMPTS. DESIGNED BY THE FIRM
9	>2000	>80·0	9	>2000	>80·0	9	OTHER MATERIALS	9	BOUGHT-OUT STANDARD COMPONENT	9		NON-METALLIC COMPTS. DESIGNED BY THE FIRM.

FIG. 7-7

PRODUCTION MACHINE TOOLS.

BOTTOM WORKS.

1. SEF. WEBSTER AND BENNET VERT. BORER.
2. 10AC. BUTLER SLOTTER.
3. 35A ARCHDALE VERTICAL MILLER.
4. 40AB. ASQUITH RADIAL DRILL.
5. SEF. WEBSTER & BENNET VERT. BORER.
6. 40C. S.M.T. PITCH CIRCLE DRILLER.
7. 15CG. D.S.& G. CENTRE LATHE.
8. 15CG. D.S.& G. CENTRE LATHE.
9. 25C. NORTON SURFACE GRINDER.
10. 10C. FROMAG SLOTTER.
11. 20A. HERBERT NO.7 TURRET LATHE.
12. 15E. STANLEY CENTRE LATHE.
13. 25E. HEALD INTERNAL GRINDER.
14. 20A. HERBERT NO.9 TURRET LATHE.
15. 15CG. NILES CENTRE LATHE.
16. 15CG. NILES CENTRE LATHE.
17. 15CG. NILES CENTRE LATHE.
18. T. CLARKSON TOOL AND CUTTER.
19. T. HERBERT DRILL GRINDER.
20. T. ABWOOD GRINDER AND LAPPER.
21. 5B. KITCHEN & WADE BORER.
22. 40AB. TOS PILLAR DRILL.
23. 30E. PLANERS PLANING M/C.
24. 5G. NEWALL JIG BORER.
25. 15AB. D.S. & G. CENTRE LATHE.
26. 15A. D.S. & G. ROLL POL. LATHE.
27. 25D. BRONX ROLL GRINDER.
28. 30D. BRONX ROLL GRINDER. PBR.
29. 35A. INDUMA VERTICAL MILL.
30. 35A. SOVIET VERTICAL MILL.
31. 30C. PLANERS PLANING M/C.
32. 30D. PLANERS PLANING M/C.
33. 30H. BUTLER SHAPER.
34. 5C. UNION TABLE BORER.
35. 5C. UNION TABLE BORER.
36. 15G. D.S. & G. CENTRE LATHE.
37. 15D. TOS CENTRE LATHE.
38. 15E TOS CENTRE LATHE.
39. 15G. D.S. & G. CENTRE LATHE.
40. 15C. TOS CENTRE LATHE.
41. 5C. UNION TABLE BORER.
42. 20B. WARD NO.3A CAPSTAN.
43. 20B. HERBERT NO.4 CAPSTAN.
44. 15F. TOS CENTRE LATHE.
45. 15F. COLCHESTER LATHE.

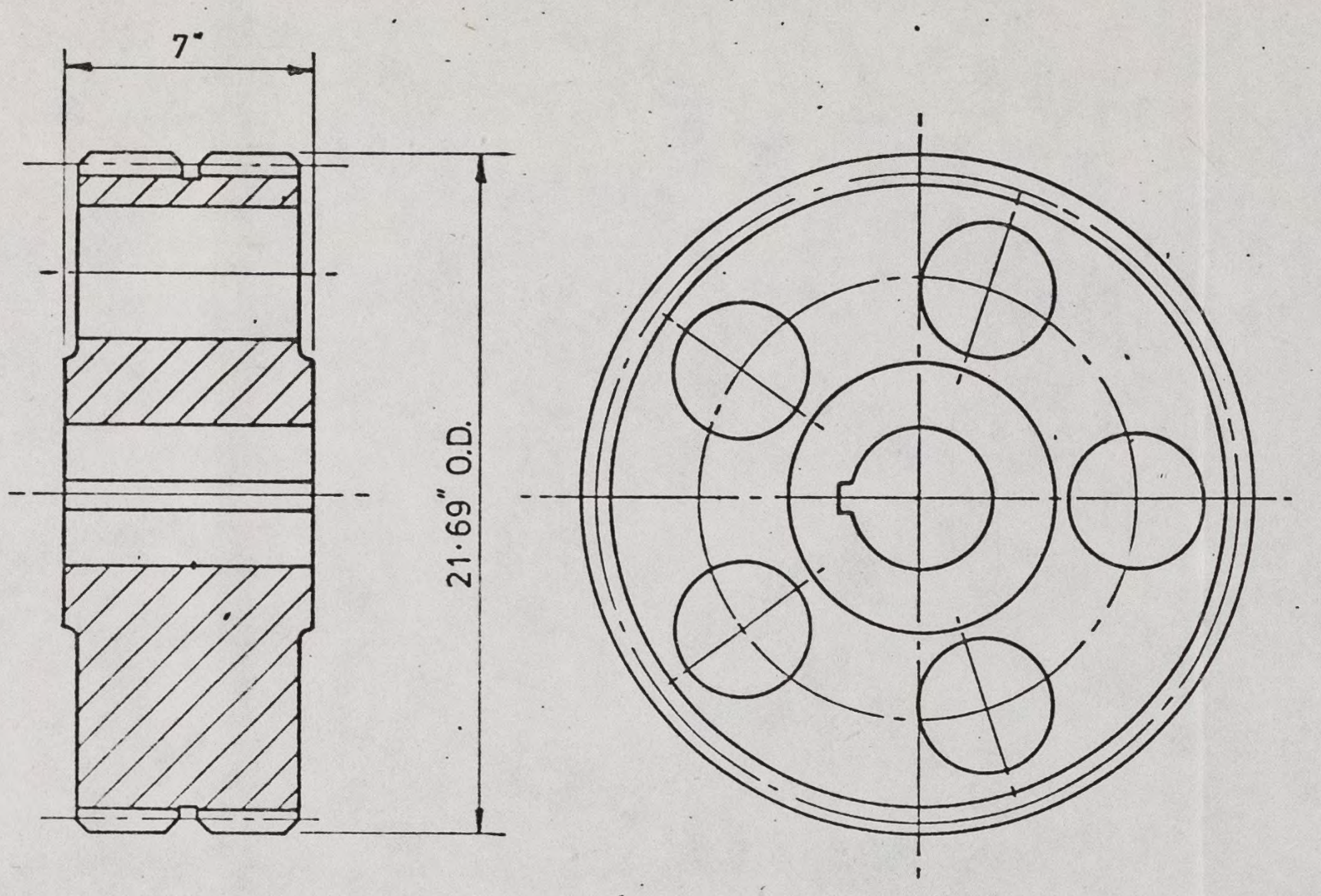
TOP WORKS.

1. 30B. PLANERS LARGE PLANER.
2. 5A. CONTI FLOOR BORER.
3. 5B. K.& W. FLOOR BORER.
4. 40A. K.& W. RADIAL DRILL.
5. 40B. K.& W. RADIAL DRILL.
6. 5C. GIDDINGS & LEWIS TABLE BORER.
7. 5C. G.& L. TABLE BORER.
8. 5C. SCHARMANN TABLE BORER.
9. 5C. RUSSIAN TABLE BORER.
10. 40B. K.& W. RADIAL DRILL.
11. 5A. COLLET AND ENGEL-HARDT BORER.
12. 40A. ARCHDALE RADIAL DRILL.
13. 30A. PLANERS FUTURMILL PLANER.
14. 35E. RUSSIAN VERT. MILL.
15. 15A. CRAVEN CENTRE LATHE.
16. 15A. RUSSIAN CENTRE LATHE.
17. 25B. NORTON CYL. GRIND.
18. 25A. CHURCHILL CYL. GRIND.
19. 35D. KENDALL & GENT MILL.

BRONX ENGINEERING CO. LTD., LYE, ENGLAND. SCALE 1 : 500

FIG. 7-8

DATA PROCESSING PROCEDURE



85 TEETH, AT 4 D.P. ON 21·25" P.C.D.
20° P.A. 30° DOUBLE HELICAL.

83/6735 - 3RD. REDUCTION GEAR - 1 OFF - EN9

CODE NO.	04166/64474

EXPLANATION OF CODE.

OMETRIC CODE - 04166

DIGIT	CODE NO.	REASON
1	0	$\frac{L}{D}$ RATIO $\leq 0{\cdot}5$
2	4	EXT. SHAPE - STEPPED BOTH ENDS - NO SHAPE ELEMENTS.
3	1	INT. SHAPE - SMOOTH - NO SHAPE ELMS.
4	6	PLANE SURF. MACH. - INT. GROOVE.
5	6	DOUBLE HELICAL GEAR TEETH.

PPLEMENTARY CODE - 64474

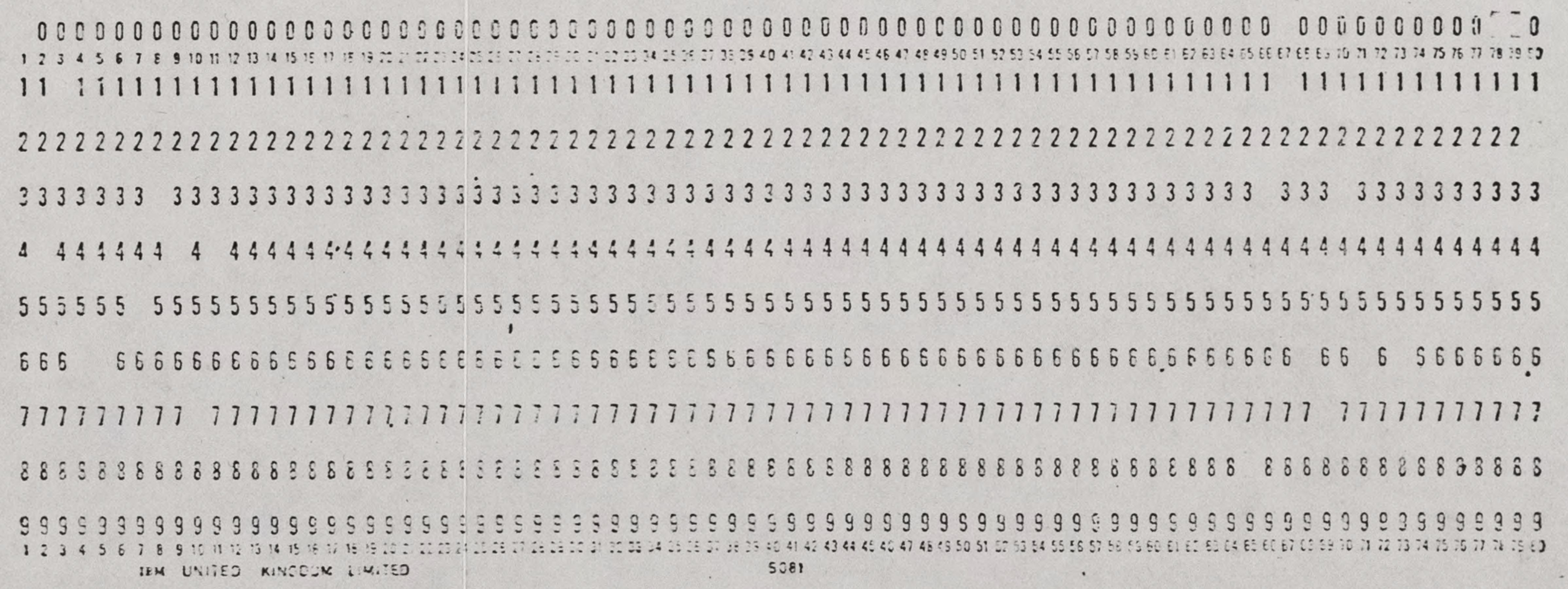
DIGIT	CODE NO.	REASON
1	6	DIA., > 16" < 25".
2	4	LENGTH, > 6·5" < 10".
3	4	MATERIAL - MEDIUM ALLOY STEEL.
4	7	INITIAL FORM - FORGING.
5	4	PART CONTRACTED - GEAR TEETH.

BRONX ENGINEERING — COMPONENT DATA SHEET 3

DATE :- 5/4/75 CODER :- Awb.

[redacted] CODE GEOMETRIC 1	SUPPLEM. 7		DRAWING NUMBER 65	CODE SHEET NO. 78
3 4 6 Ø 3	2 Ø 3 Ø Ø		1 1 / 5 5 5 8 N	3
Ø Ø Ø 1 Ø	1 Ø 3 Ø Ø		1 1 / 5 5 5 8 P	3
4 3 6 1 3	4 2 Ø 8 Ø		1 1 / 5 5 5 8 Q	3
4 3 6 1 3	4 2 Ø 8 Ø		1 1 / 5 5 5 8 R	3
0 4 1 6 6	6 4 4 7 4	*	* 8 3 / 6 7 3 5 A	3
1 4 1 6 6	6 5 4 7 4		8 3 / 6 7 3 5 B	3
1 1 1 6 6	5 4 4 7 4		8 3 / 6 7 3 5 C	3
1 1 1 6 6	5 4 4 7 4		8 3 / 6 7 3 5 D	3
2 8 Ø 3 2	2 9 4 Ø 8		H 4 Ø Ø / 3 9 Ø A	3
Ø 1 1 Ø 2	3 1 3 Ø Ø		H 4 Ø Ø / 3 9 Ø B	3

04166 64474 83/6735 A 003



PUNCHED CARD

09.38.05←	04162 84360		11/5577/3 A	012
09.38.05←	04166 53474		83/6736 F	024
09.38.05←	04166 53404		83/6736 F	024
09.38.05←	04166 63474		83/6792 G	012
09.38.06←	04166 42404		83/6806 G	011
09.38.06←	04166 83474		83/6792 G	001
09.38.06←	04166 64474	*	* 83/6735 A	003
09.38.06←	04166 53474		83/6736 F	002
09.38.06←	04205 11300		11/4556 J	025
09.38.06←	04402 41080		11/16428 B	002
09.38.06←	10000 20300		3/4042 G	009
09.38.07←	10000 33300		11/10073(J)	007
09.38.07←	10001 23300		2/11440 L	022
09.38.07←	10001 24400		83/6806 E	011
09.38.07←	10001 13310		11/10078 D	007

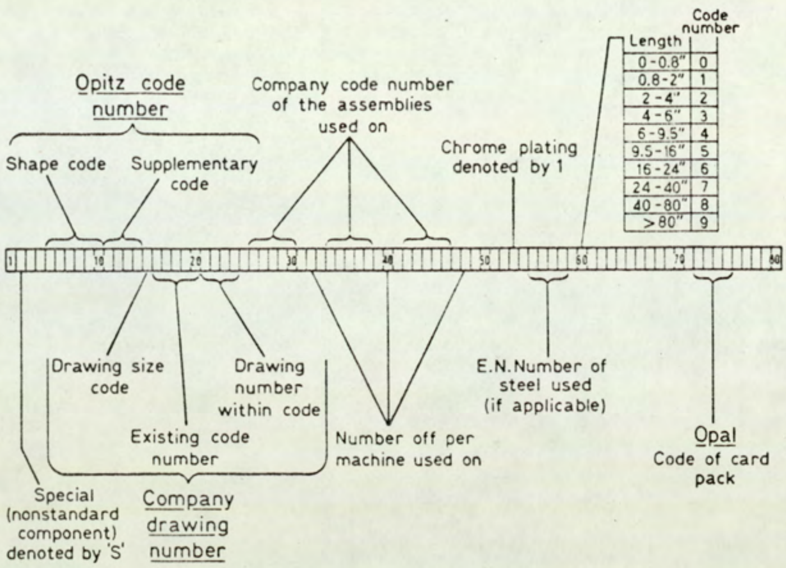
0

1

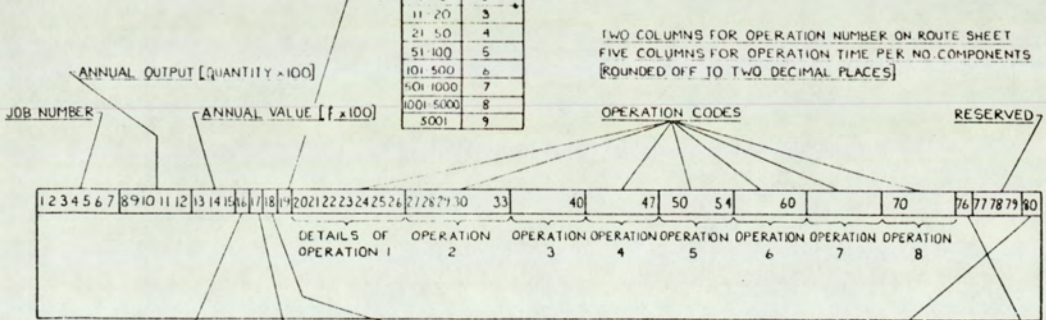
COMPUTER PRINTOUT.

FIG. 7-9

EXAMPLES OF DATA SHEET AND PUNCHED CARD LAYOUT



Length	Code number
0-0.8"	0
0.8-2"	1
2-4"	2
4-6"	3
6-9.5"	4
9.5-16"	5
16-24"	6
24-40"	7
40-80"	8
>80"	9



NUMBER OF MOULDINGS PER TRAY OR CARTON

QUANTITY	DIGIT
1	0
2-4	1
5-10	2
11-20	3
21-50	4
51-100	5
101-500	6
501-1000	7
1001-5000	8
5001	9

SIZE
MAXIMUM DIA OR LENGTH

DIGIT	RANGE (INCHES)
0	≤ 1/2
1	> 1/2 ≤ 1
2	> 1 ≤ 2
3	> 2 ≤ 4
4	> 4 ≤ 6
5	> 6 ≤ 9
6	> 9 ≤ 15
7	> 15 ≤ 24
8	> 24

SHAPE

CHARACTERISTIC		DIGIT
ROUND	CYLINDRICAL	0
	FLAT	1
	HOLLOW	2
NON ROUND	BOX LIKE	5
	" " NESTING	6
	FLAT	7
	CONTOURED	9

CARTON TYPE

TYPE	SIZE (INCHES)	DIGIT
LIB	11 x 5 x 9½	0
SLCL	11½ x 11 x 10	1
GP	19⅝ x 10½ x 14	2
NCM	23 x 12¾ x 23	3
S/29	25¾ x 17 x 11¾	4
SPECIAL	—	5

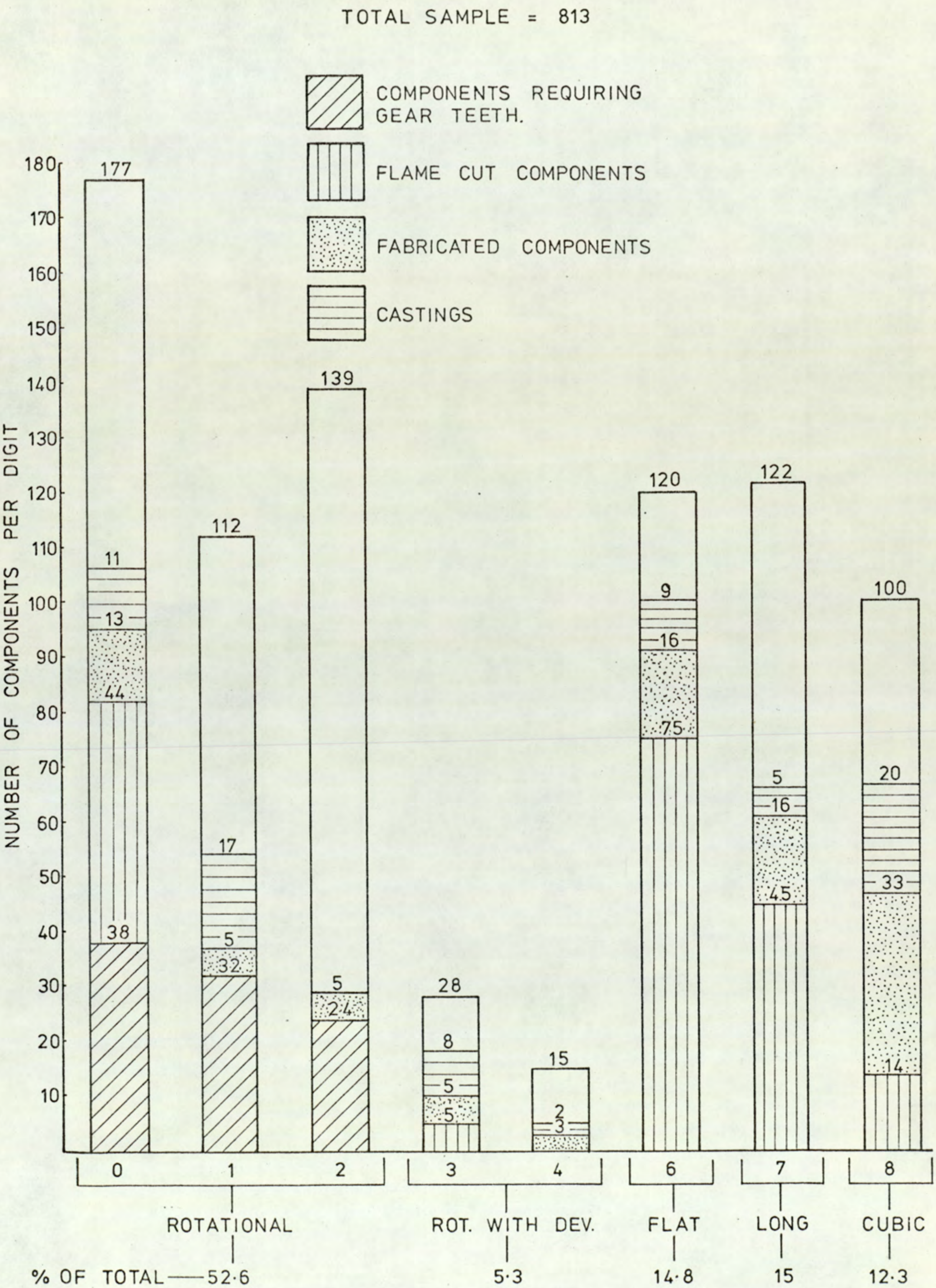
NUMBER OF OPERATIONS & WORK CARRIER

OPERATION	CARRIER	DIGIT
>8	CARTON	0
	TRAY	1
	CONVEYOR	2
	RESERVED	3
	"	4
<8	TRAY	5
	CONVEYOR	6
	RESERVED	7
	"	8
	"	9

JOB FREQUENCY & OCCURENCE

Nº OF PERIOD	PERIOD Nº	DIGIT
1	2	0
	3	1
2	1 & 2	2
	1 & 3	3
	3 & 4	4
3	1 + 2 + 3	5
	RESERVED	6
		7
		8
		9

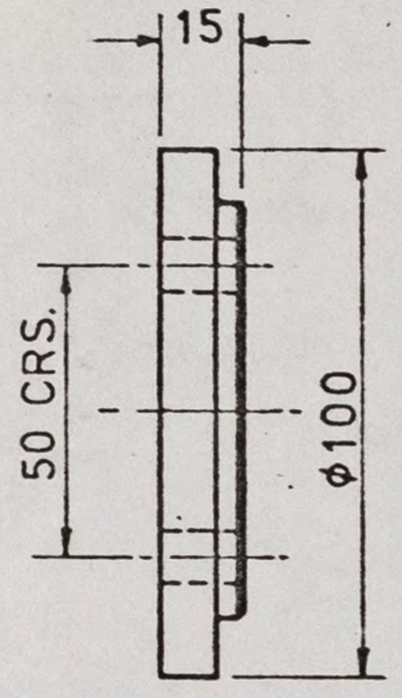
FIG. 7-10 (after Gallagher & Knight)



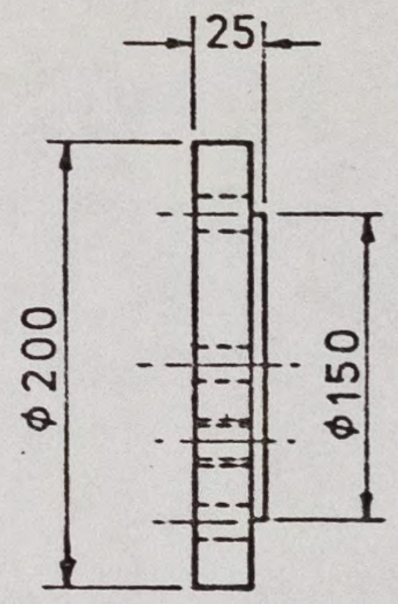
BREAK DOWN OF SAMPLE INTO DIGITS AND CATEGORIES.

FIG. 7-11

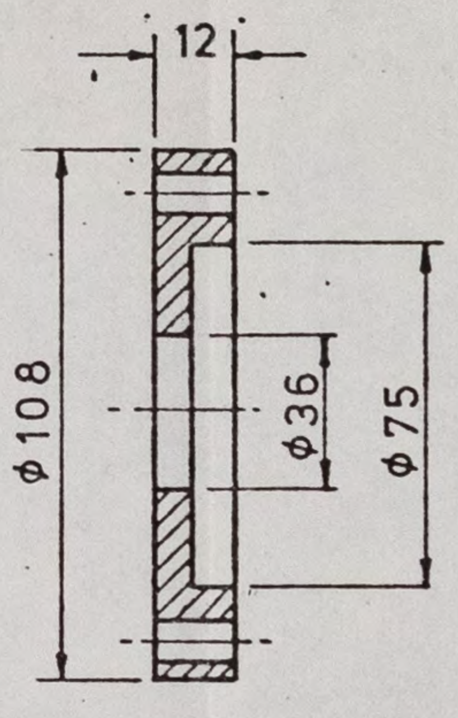
COMPONENTS SELECTED FOR TYPICAL TURNING CELLS



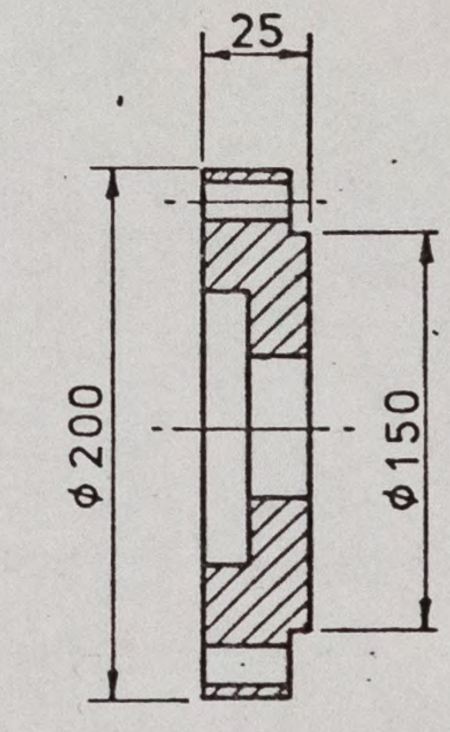
1. DRIVE PLATE END CAP.
1 OFF, M.S., M/C -33 DAYS.
CODE - 01002/20300.



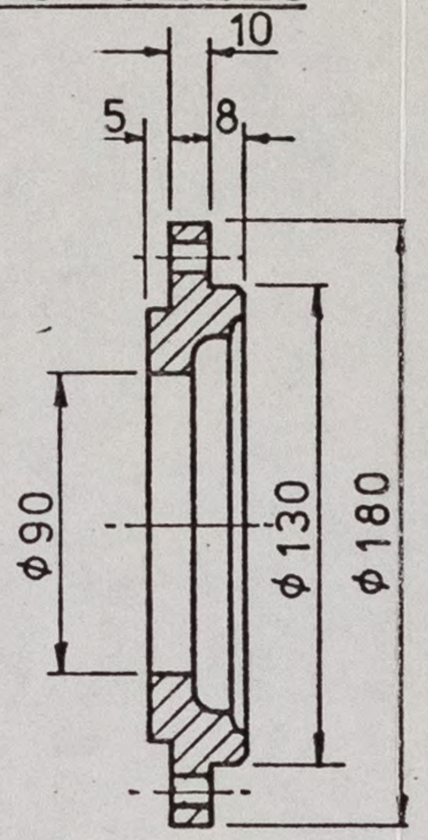
2. END CAP.
1 OFF, M.S., 19 DAYS.
CODE - 01002/41250.



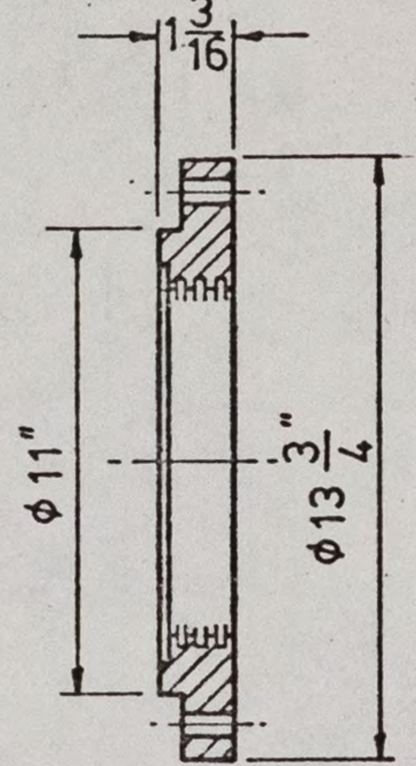
3. RETAINING PLATE.
3 OFF, M.S., 30 DAYS.
CODE - 00102/30300.



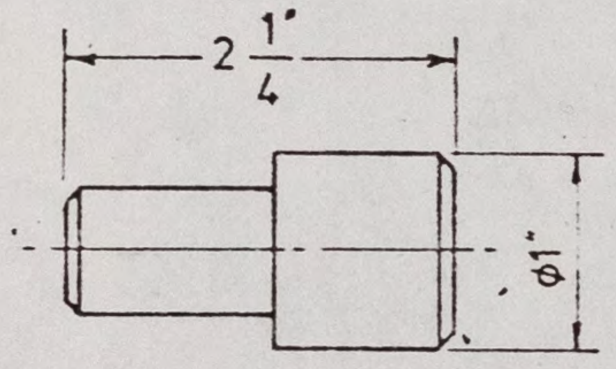
4. END CAP.
1 OFF, M.S., 19 DAYS.
CODE - 01102/41250.



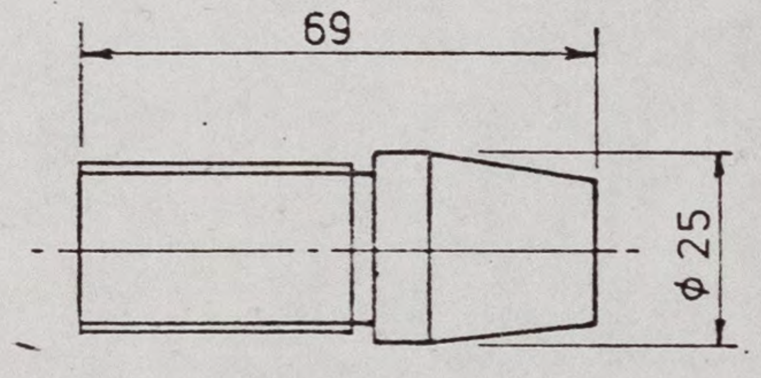
5. END CAP.
2 OFF, C.I., 24 DAYS.
CODE - 04402/41080.



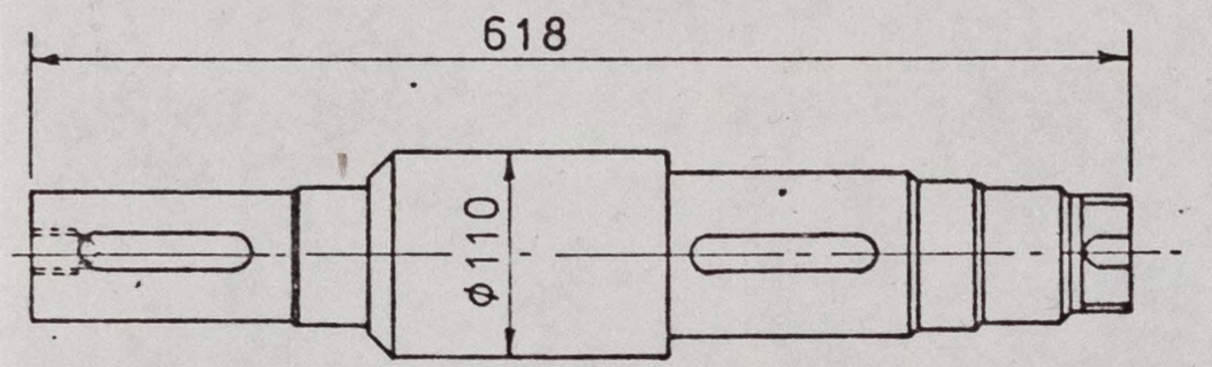
6. LABYRINTH RING.
1 OFF, M.S., 48 DAYS.
CODE - 01802/51250.



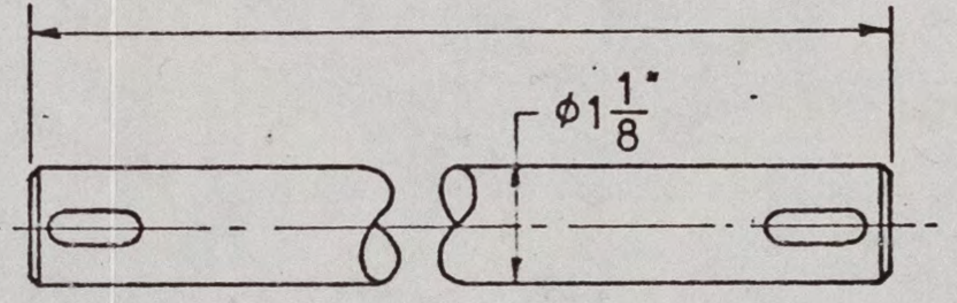
7. CENTRE DOWEL.
2 OFF, M.S., 1 DAY
CODE - 11000/12300.



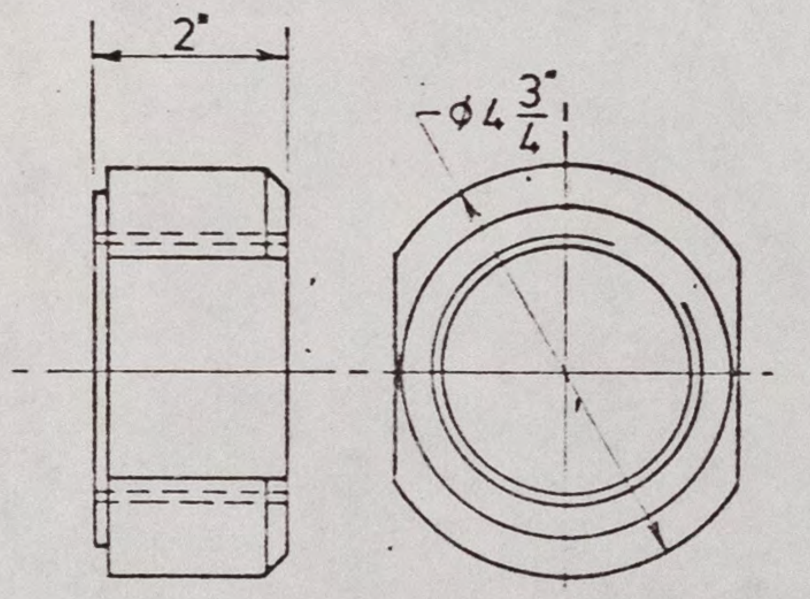
8. DOWEL PIN.
8 OFF, M.S., 1 DAY.
CODE - 15000/12300



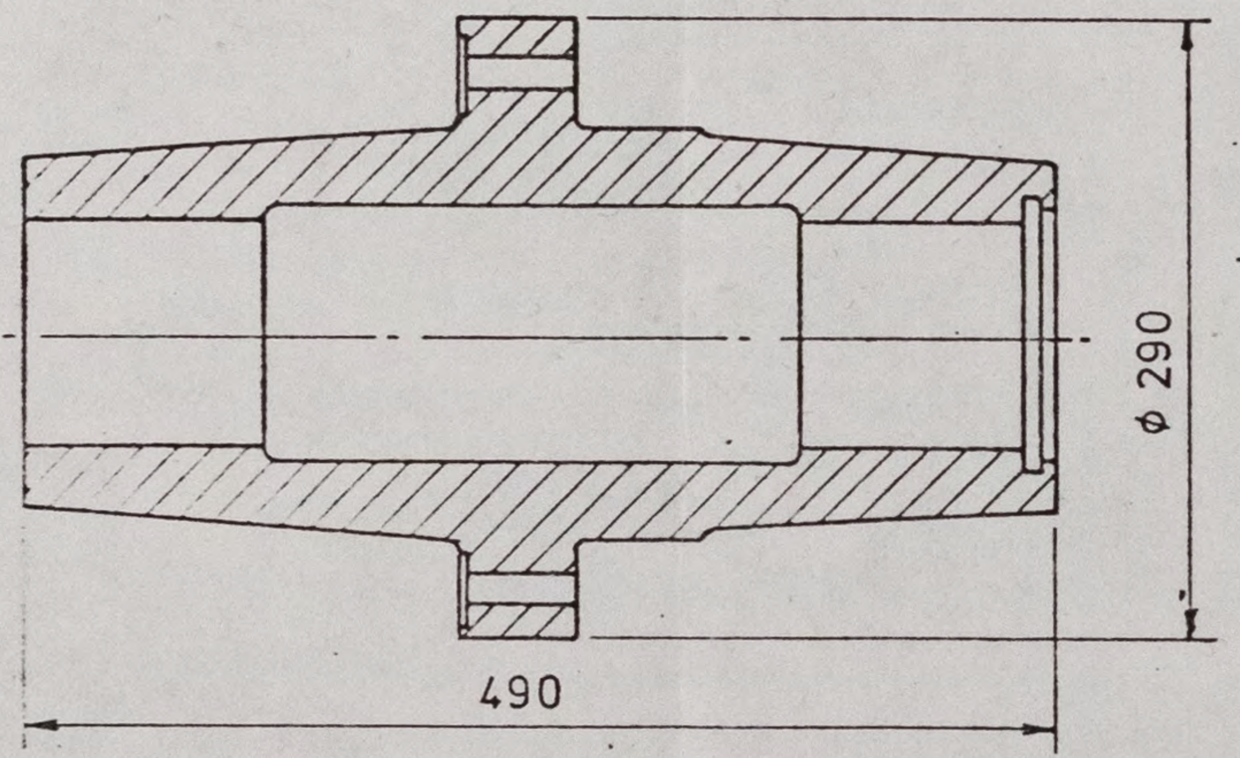
9. OUTPUT SHAFT.
2 OFF, EN9, 28 DAYS.
CODE - 24230/37400.



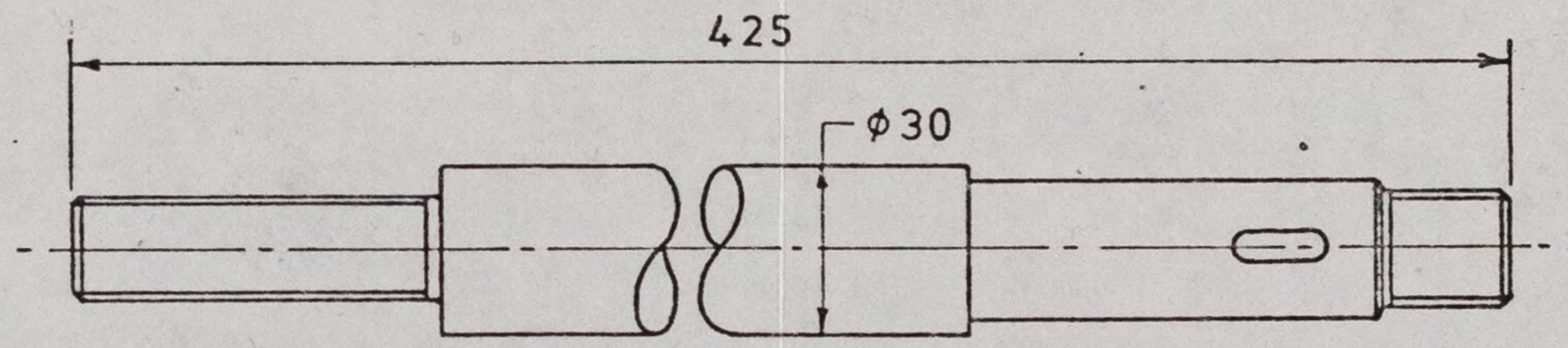
10. BEAM ADJ. SHAFT.
1 OFF, B.D.M.S., 9 DAYS.
CODE - 20030/15310.



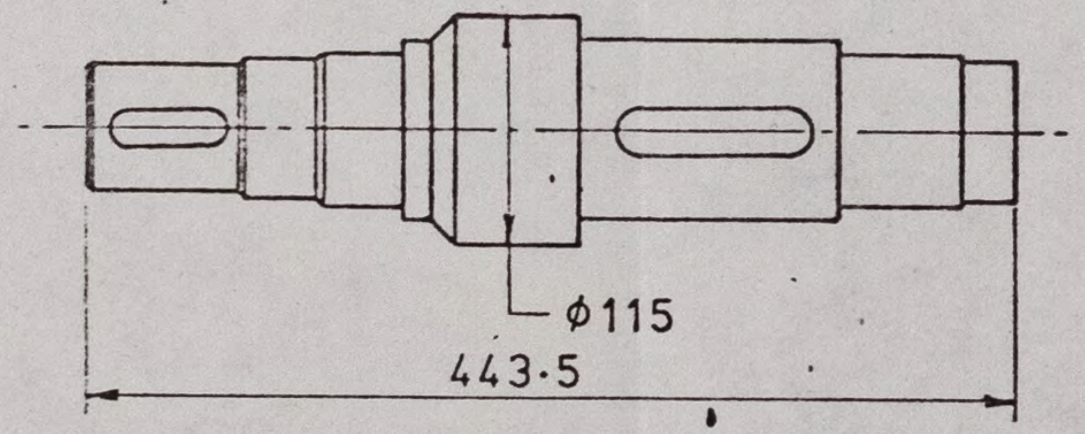
11. PISTON HEAD NUT
2 OFF, M.S., 14 DAYS.
CODE - 11230/31300.



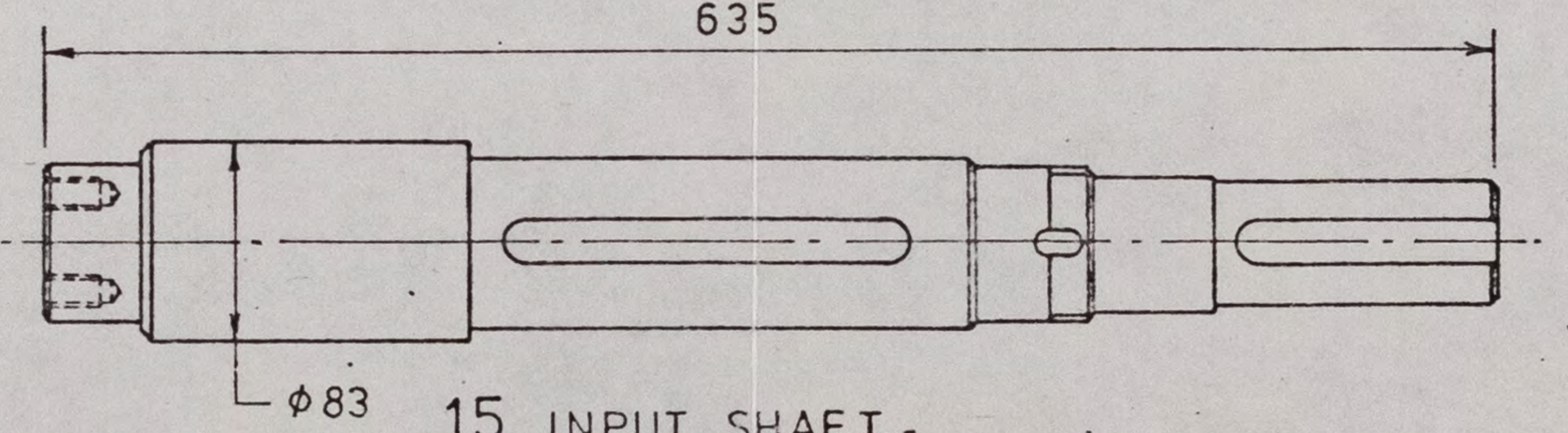
12. COLUMN BUSH
4 OFF, C.I., 10 DAYS.
CODE - 17605/56080.



13. ANG. ADJ. SHAFT.
6 OFF, EN9, 13 DAYS.
CODE - 25030/16400.



14. OUTPUT SHAFT.
6 OFF, EN8, 53 DAYS.
CODE - 24030/36400.



15. INPUT SHAFT -
1 OFF, M.S., 22 DAYS.
CODE - 25032/27300.

FIG. 7-12

COMPONENTS SELECTED FOR TYPICAL TURNING CELLS

No.	Component	M/C operations reqd.	Cell
1	DRIVE END PLATE	TURRET LATHE, MARKOUT, DRILL	1
2	END CAP	MED.CENTRE LATHE, PITCH CIRCLE DRILL	2
3	RETAINING PLATE	TURRET LATHE, MARKOUT, DRILL	1
4	END CAP	MED. CENTRE LATHE, PITCH CIRCLE DRILL	2
5	END CAP	MED. CENTRE LATHE, PITCH CIRCLE DRILL	2
6	LABYRINTH RING	MED. CENTRE LATHE, PITCH CIRCLE DRILL	2
7	CENTRE DOWEL	CAPSTAN	1
8	DOWEL PIN	CAPSTAN	1
9	OUTPUT SHAFT	MED. CENTRE LATHE, GRIND, V.MILL	2
10	BEAM ADJ.SHAFT	CAPSTAN, V.MILL	1
11	PISTON HEAD NUT	MED. CENTRE LATHE, MARKOUT, V.MILL	2
12	COLUMN BUSH	MED. CENTRE LATHE, MARKOUT, DRILL	2
13	ANG.ADJ.SHAFT	MED. CENTRE LATHE, V.MILL	2
14	OUTPUT SHAFT	MED. CENTRE LATHE, GRIND, V.MILL	2
15	INPUT SHAFT	MED. CENTRE LATHE, GRIND, V.MILL	2

FIG. 7-13

TYPICAL TURNING CELLS FOR ROTATIONAL COMPONENTS.

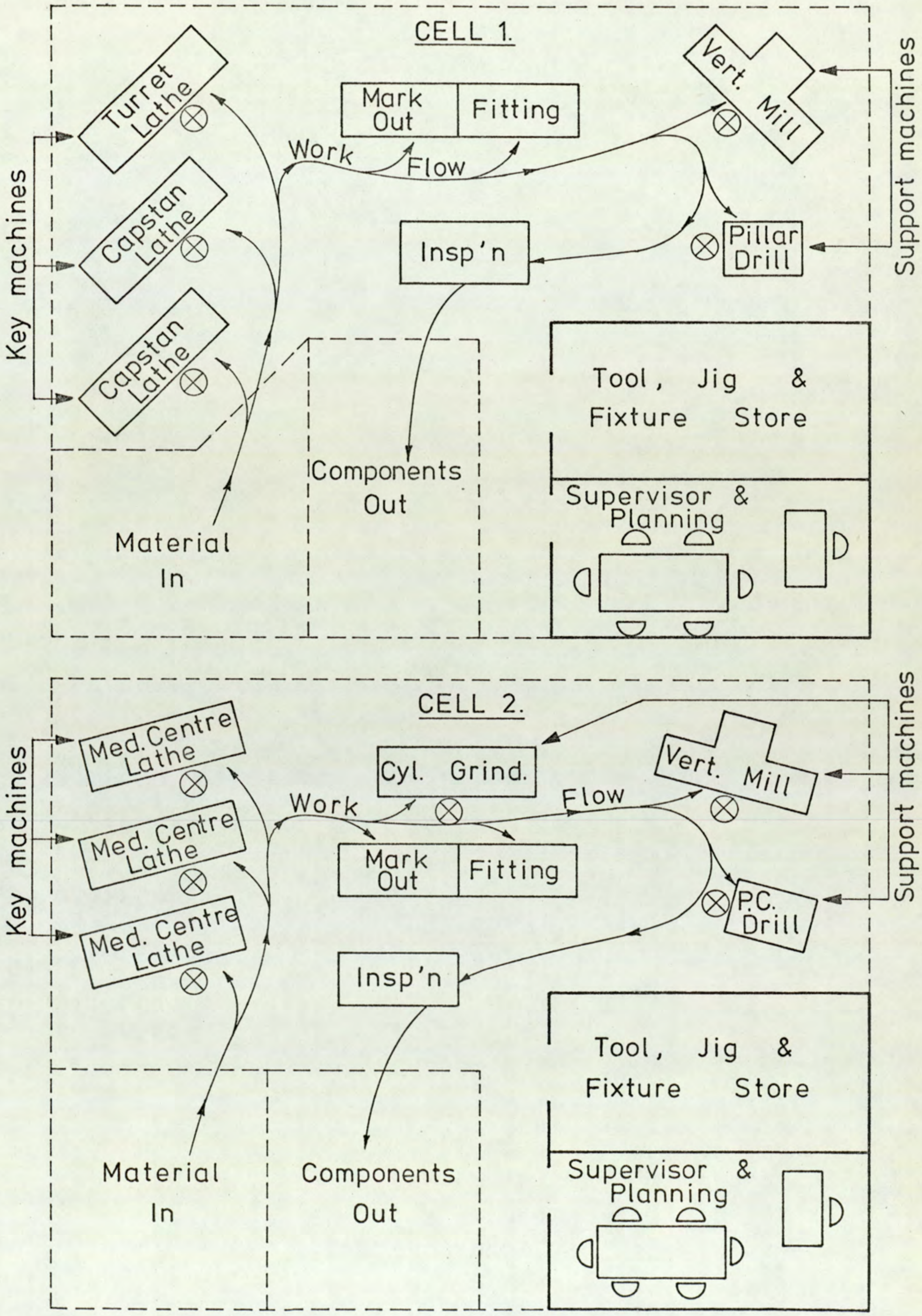


FIG. 7-14

BRONX MANUFACTURING FLOW CHART
—— AFTER GROUP TECHNOLOGY ——

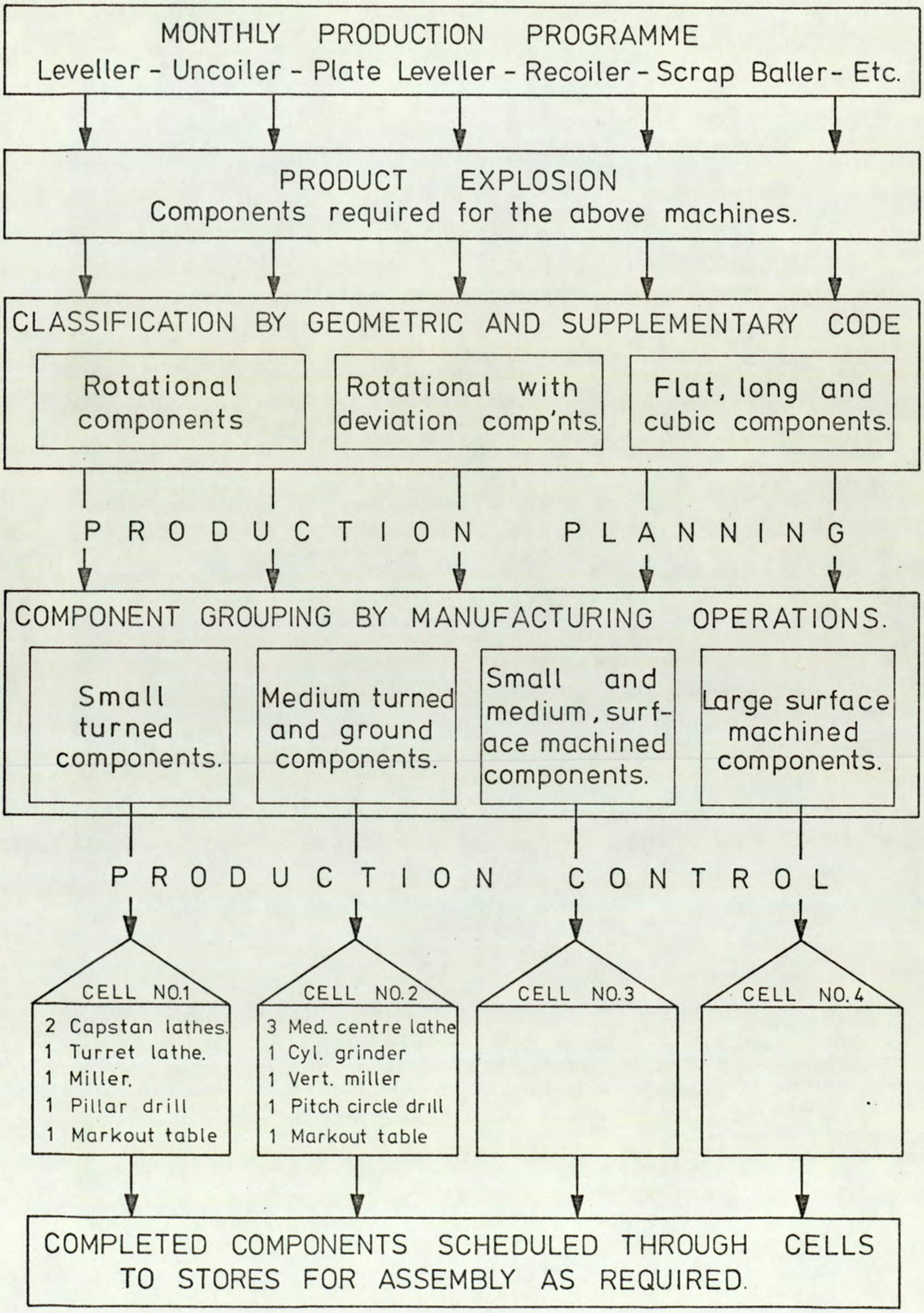


FIG. 7-15

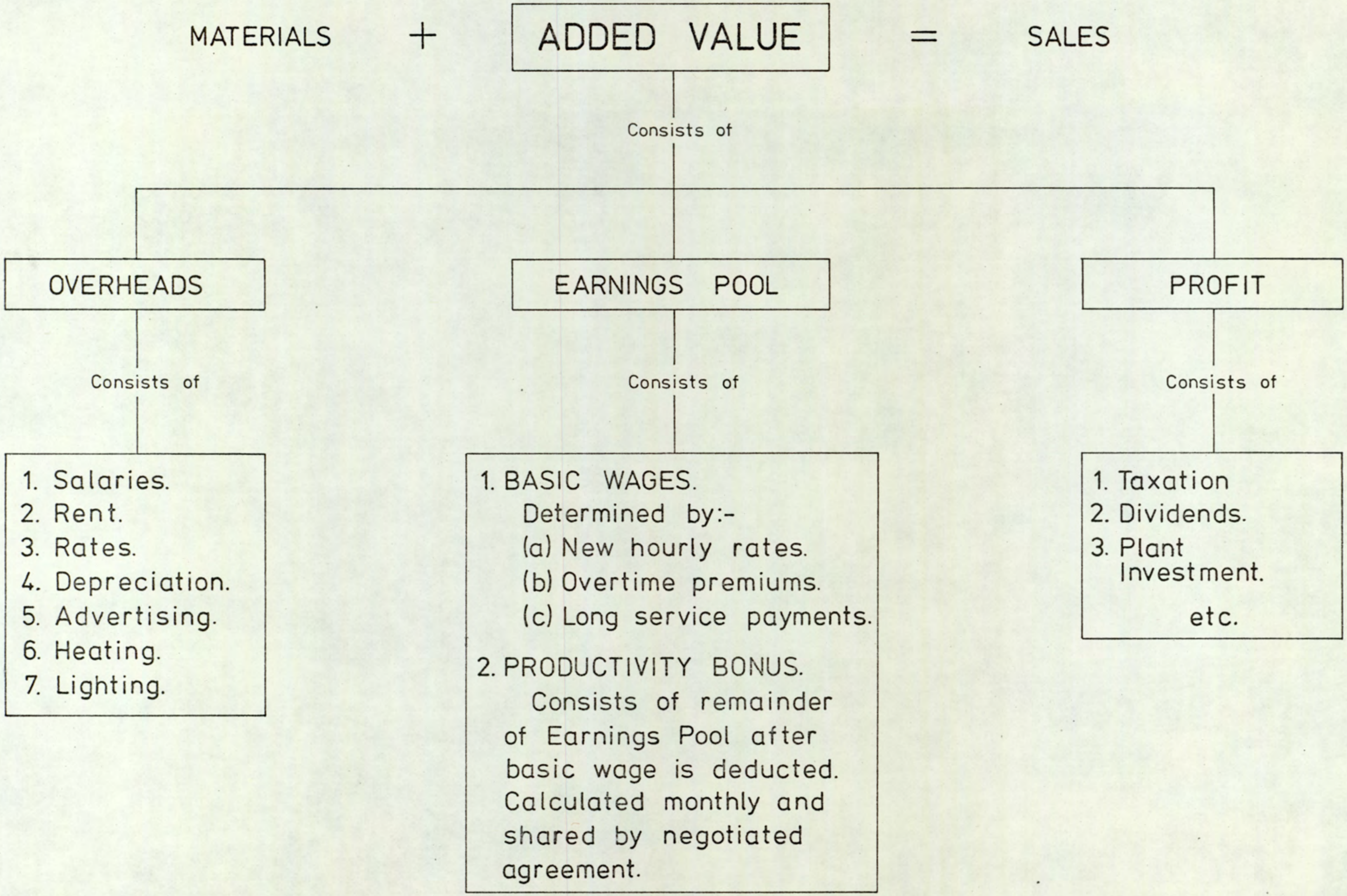
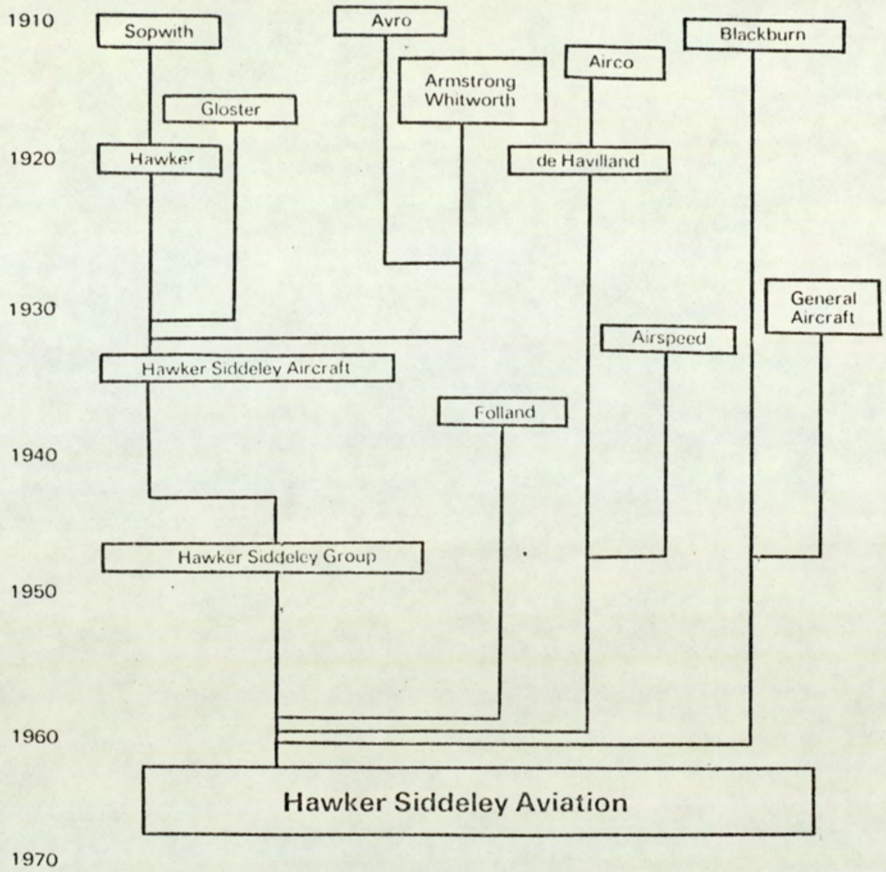

MATERIALS + ADDED VALUE = SALES
Consists of
OVERHEADS
Consists of
1. Salaries.
2. Rent.
3. Rates.
4. Depreciation.
5. Advertising.
6. Heating.
7. Lighting.
EARNINGS POOL
Consists of
1. BASIC WAGES.
Determined by:-
(a) New hourly rates.
(b) Overtime premiums.
(c) Long service payments.
2. PRODUCTIVITY BONUS.
Consists of remainder of Earnings Pool after basic wage is deducted. Calculated monthly and shared by negotiated agreement.
PROFIT
Consists of
1. Taxation
2. Dividends.
3. Plant Investment.
etc.

FIG. 7-16



HISTORICAL DEVELOPMENT OF HAWKER SIDDELEY AVIATION LTD.

FIG. 8-1 (a)

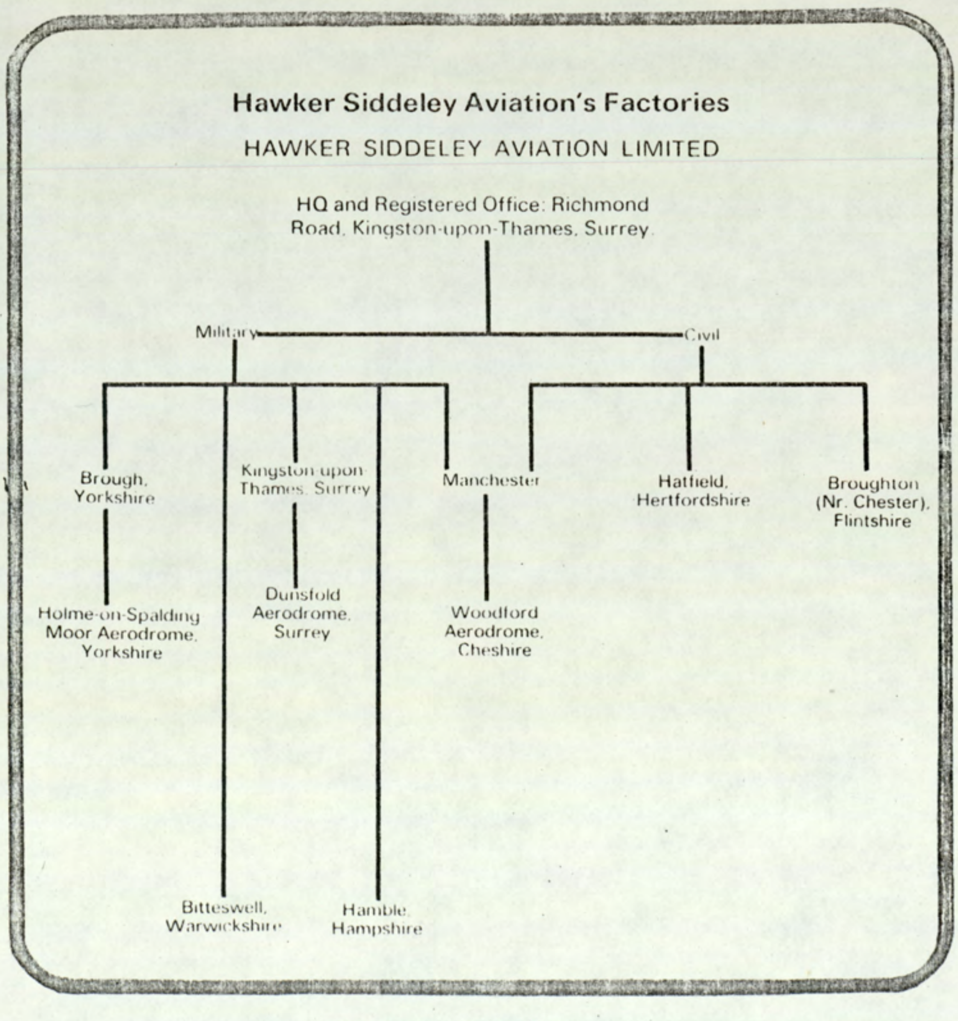


FIG. 8-1 (b)

HAWKER SIDDELEY AVIATION MANAGEMENT STRUCTURE AT MIDDLETON, MANCHESTER.

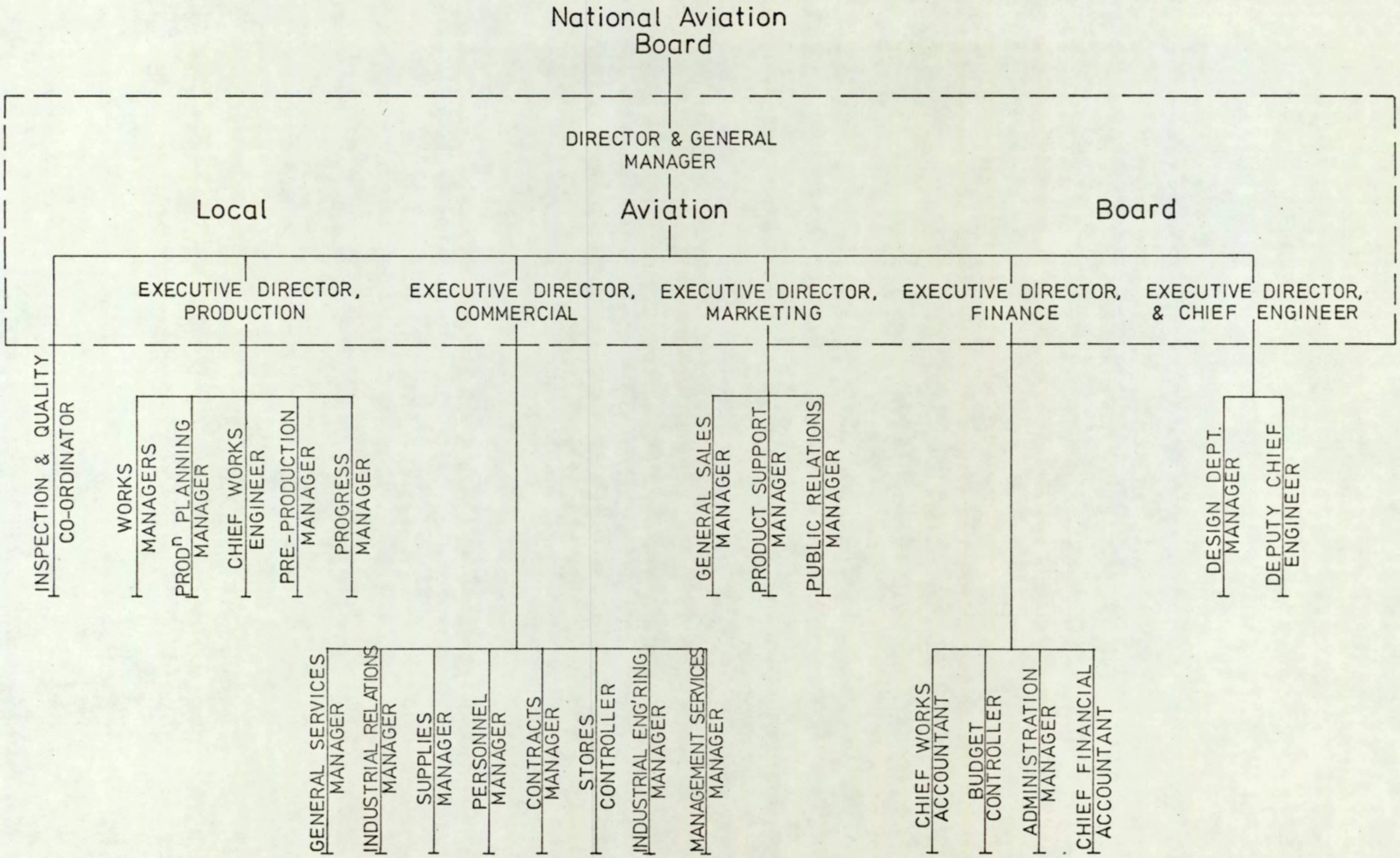
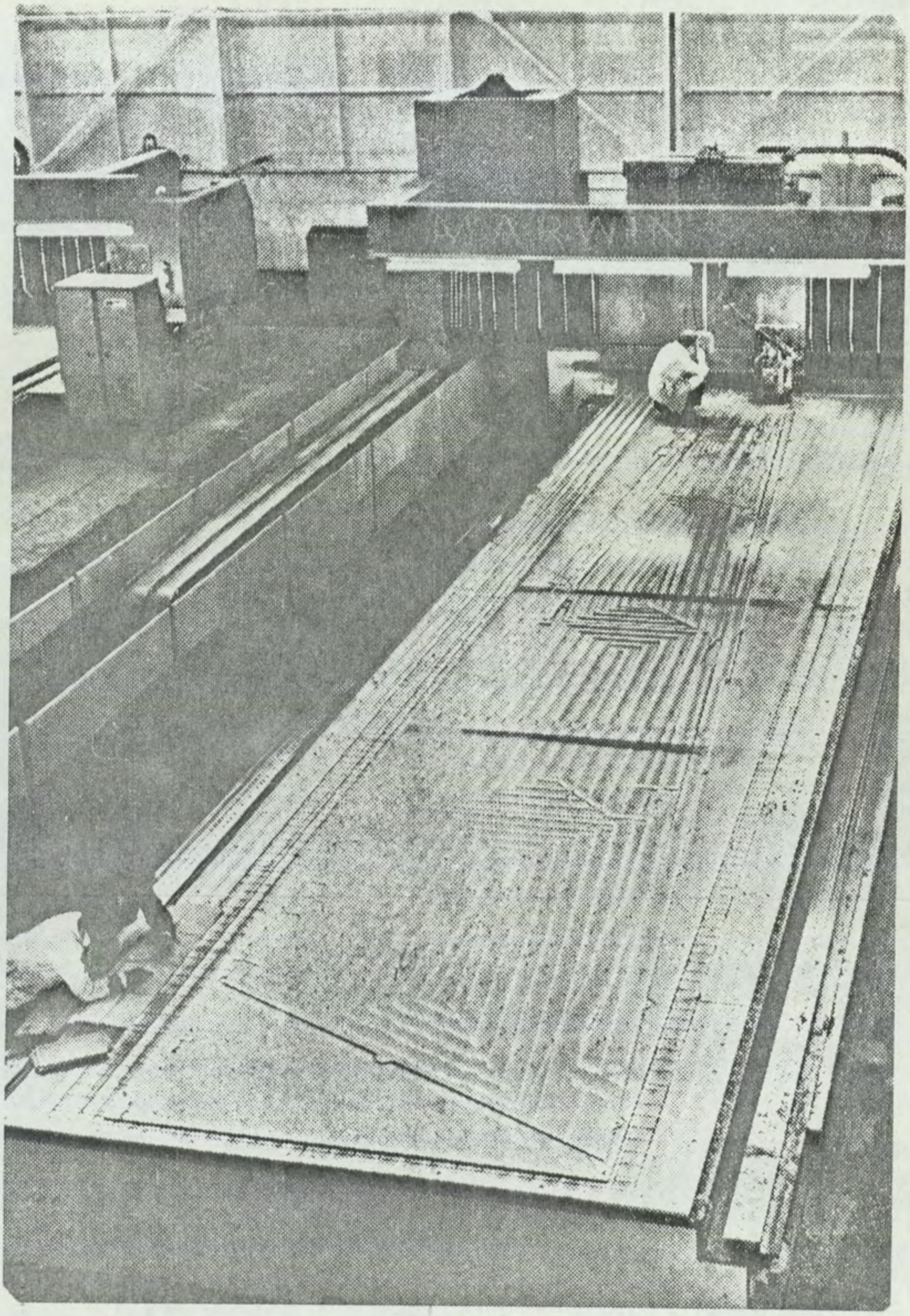
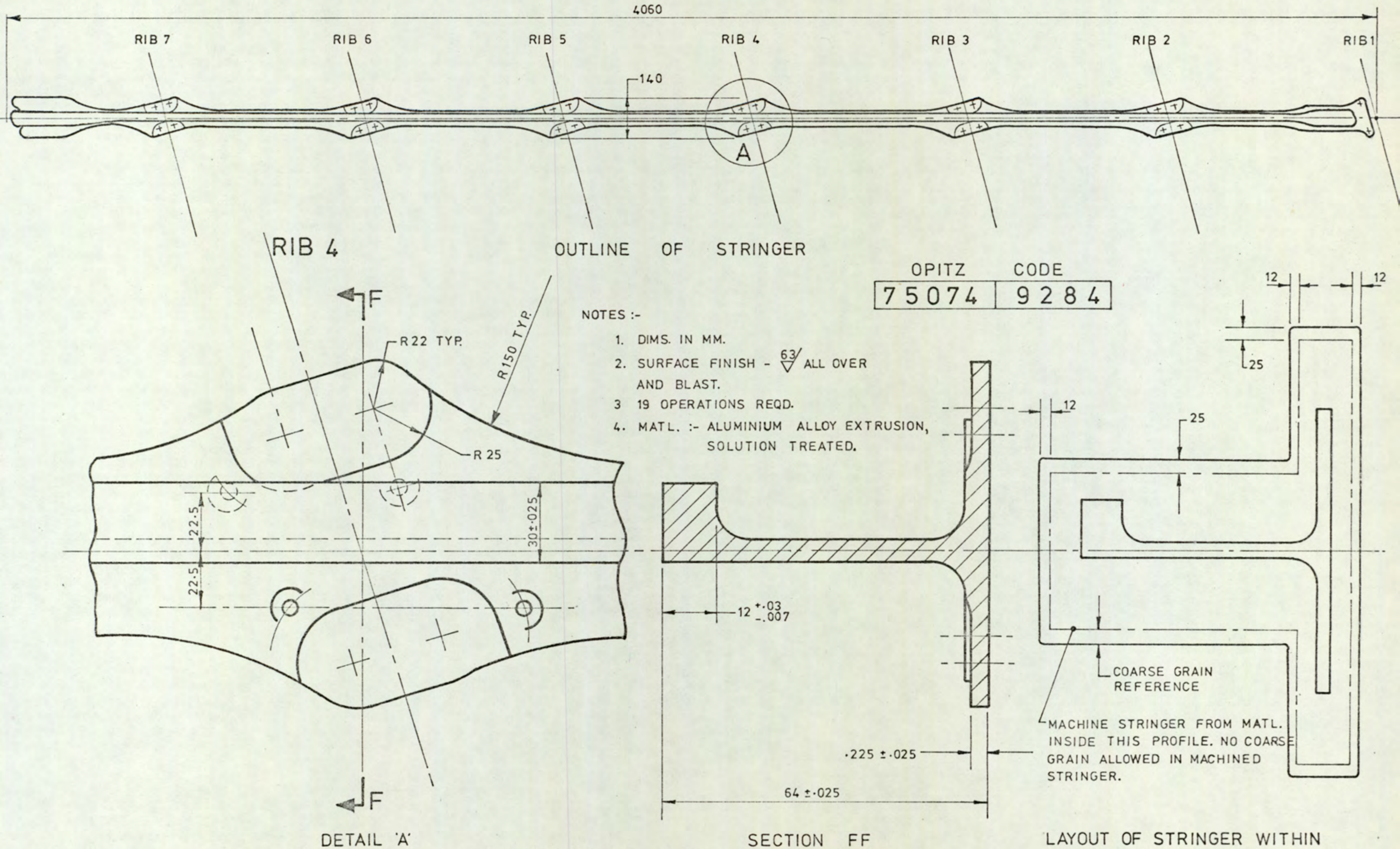


FIG. 8-2



MARWIN MAXETRACE MILLING MACHINE

FIG.8-3



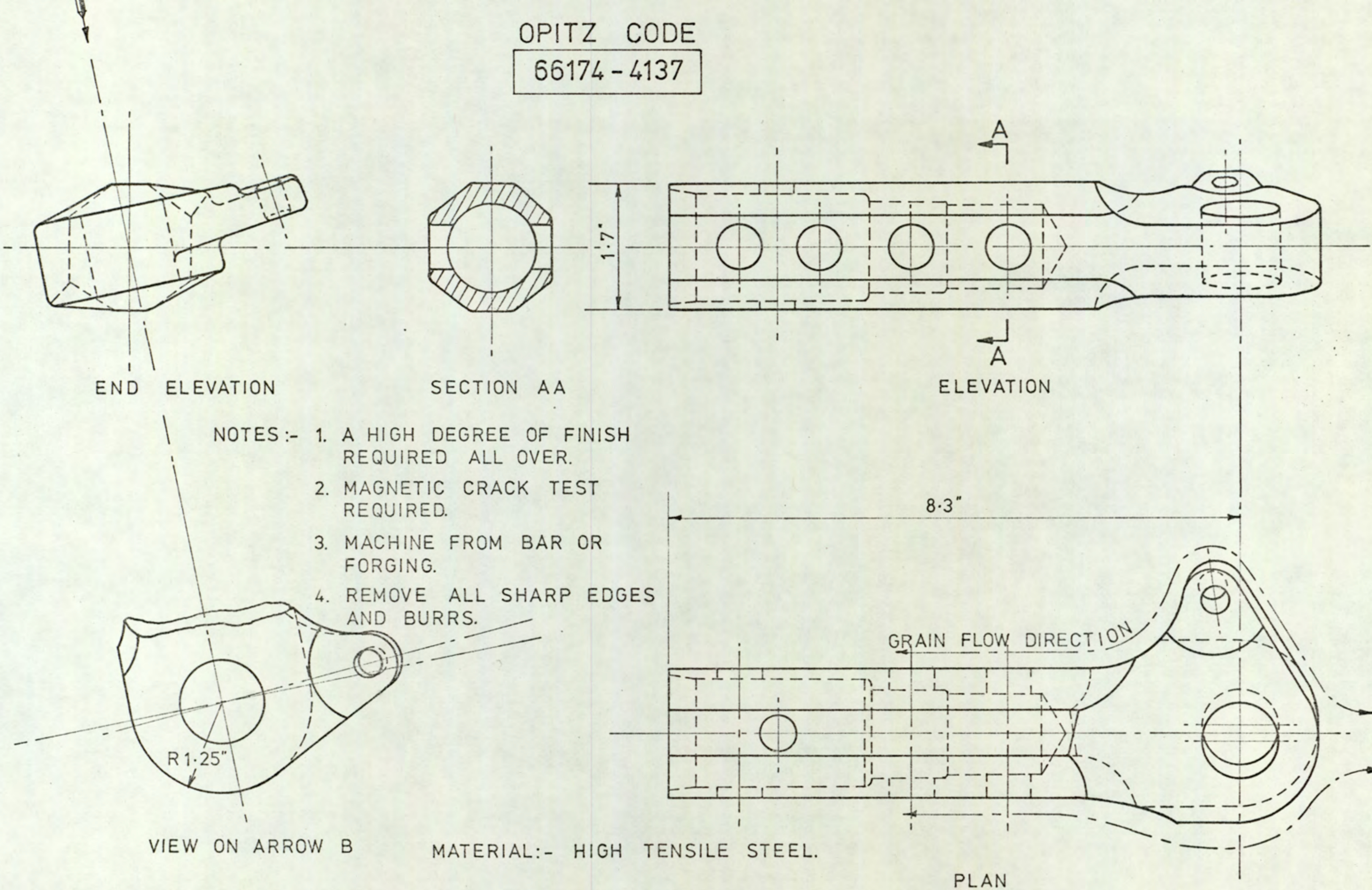
DETAILS OF STRINGER

FIG 8-4

SKIN STABILISER BETWEEN RIBS.

FIG.

FIG. 8-5



END FITTING (FRONT STRAKE)

FIG. 8-6

HAWKER SIDDELEY AVIATION
COMPONENT MANUFACTURING PROCEDURES
AND DEPARTMENTS INVOLVED

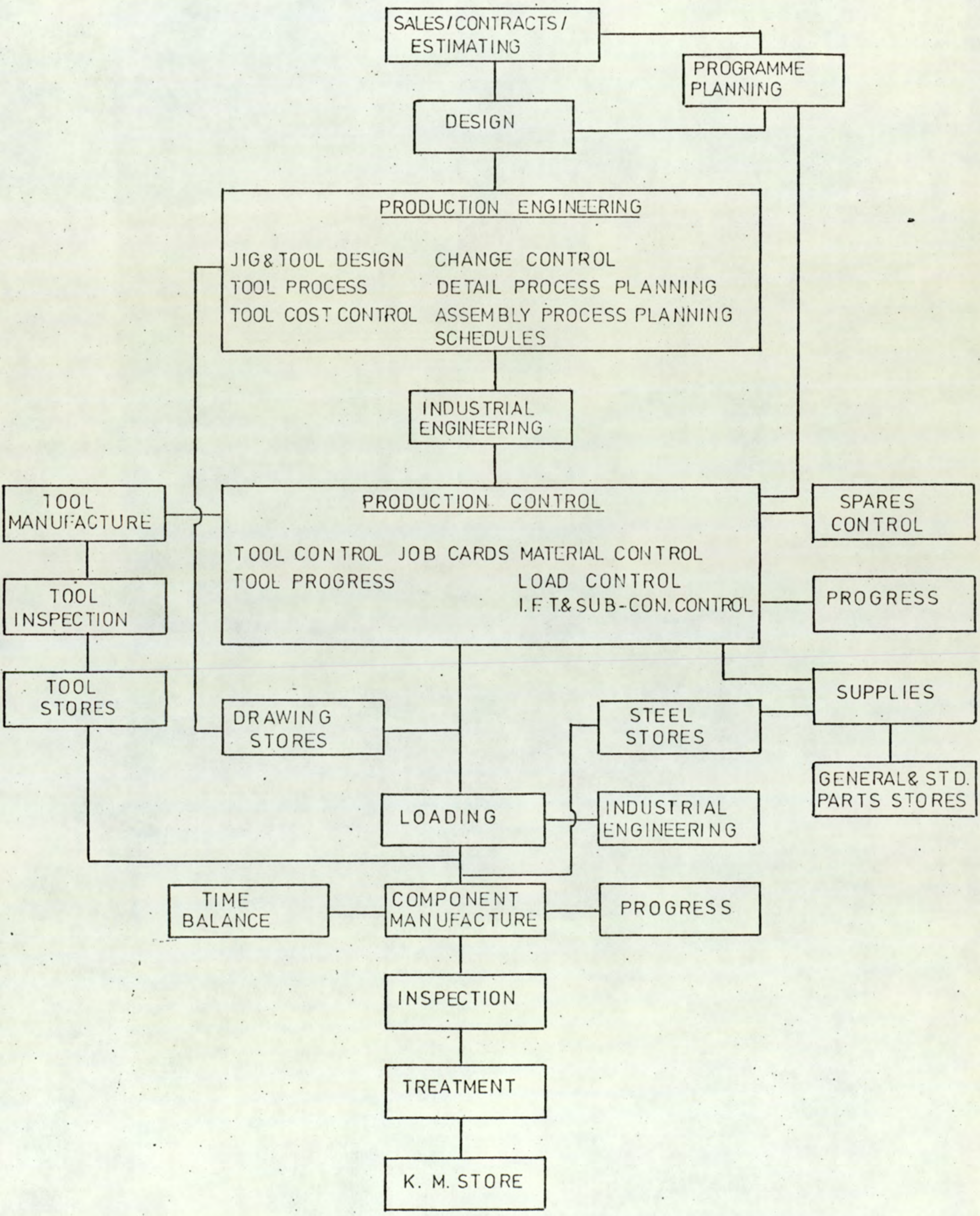


FIG.8-7

HAWKER SIDDELEY GEOMETRICAL CODE

1st DIGIT — Component Class

Digit	Group	Description
0	Rotational Components	$\frac{L}{D} \leq 0.5$
1	Rotational Components	$0.5 < \frac{L}{D} < 3$
2	Rotational Components	$\frac{L}{D} > 3$
3		
4		
5		
6		
7		
8		
9		

2nd DIGIT — External Shape Elements

Digit	Group	Description
0		Smooth, no shape elements
1	Stepped to one end	no shape elements
2	Stepped to one end or smooth	with screwthread
3	Stepped to one end or smooth	with functional groove
4	Stepped to both ends (multiple increases)	no shape elements
5	Stepped to both ends (multiple increases)	with screwthread
6	Stepped to both ends (multiple increases)	with functional groove
7		functional taper
8		Machined thread
9		Others (Spherical shape elements)

3rd DIGIT — Internal Shape Elements

Digit	Group	Description
0		None
1	Smooth; stepped or blind bore to one end	no shape elements
2	Smooth; stepped or blind bore to one end	with screwthread
3	Smooth; stepped or blind bore to one end	with functional groove
4	Stepped or blind bore to both ends	no shape elements
5	Stepped or blind bore to both ends	with screwthread
6	Stepped or blind bore to both ends	with functional groove
7		functional taper
8		Machined thread
9		Others (Spherical shape elements)

4th DIGIT — Plane Surface Machining

Digit	Description
0	None
1	External plane surface
2	External groove and/or slot
3	External curved surface
4	External plane surfaces with an angular relationship
5	External spline or polygon
6	Internal plane surface and/or groove
7	Internal spline and/or polygon
8	External and internal splines and/or slot and/or groove
9	Gear teeth

5th DIGIT — Auxiliary Hole(s)

Digit	Group	Hole type	Description
0			None
1	Smooth and/or tapped - relationship by drilling pattern where shown	Axial hole(s)	Not related
2	Smooth and/or tapped - relationship by drilling pattern where shown	Axial hole(s)	related
3	Smooth and/or tapped - relationship by drilling pattern where shown	Radial hole(s)	Not related
4	Smooth and/or tapped - relationship by drilling pattern where shown	Radial hole(s)	related
5	Smooth and/or tapped - relationship by drilling pattern where shown	Other hole(s)	Not related
6	Smooth and/or tapped - relationship by drilling pattern where shown	Other hole(s)	related
7	Smooth and/or tapped - relationship by drilling pattern where shown		Any combination of 1, 3 or 5.
8	Smooth and/or tapped - relationship by drilling pattern where shown		Any hole combination other than 1 to 7
9			Others

FIG. 8-8

HAWKER SIDDELEY GEOMETRICAL CODE

1st DIGIT — Component Class

Code	Group	Description
0	Rotational Components	
1	Rotational Components	
2	Rotational Components	
3	Rotational Components	$\frac{L}{D} \leq 2$ with deviation
4	Rotational Components	$\frac{L}{D} > 2$ with deviation
5		
6		
7		
8		
9		

2nd DIGIT — Overall Shape

Code	Group	Description
0	Around one axis, no segments.	Hexagonal bar
1	Around one axis, no segments.	Square or other regular polygonal section
2	Around one axis, no segments.	Symmetrical cross-section producing no unbalance
3	Around one axis, no segments.	Cross-sections other than 0 to 2
4		Segments after rotational machining
5		Segments before rotational machining
6	Around more than one axis	Rotational components with curved axis
7	Around more than one axis	Rotational components with 2 or more parallel axes
8	Around more than one axis	Rotational components with intersecting axes
9		Others (spherical shape elements)

3rd DIGIT — Rotational Machining

Code	Group	Description
0		None
1	External shape	machined
2	External shape	with screwthread(s)
3	Int. shape (thro' or blind)	smooth
4	Int. shape (thro' or blind)	Stepped towards one or both ends (multiple increases)
5	Int. shape (thro' or blind)	with screwthreads
6	Ext. & int. shape	machined
7	Ext. & int. shape	screwthread(s)
8		Ext. or int. shape elements (functional taper, vee grooves etc)
9		Curved shape elements (spheres etc.)

4th DIGIT — Plane Surface Machining

Code	Description
0	None
1	External plane surface
2	External groove and/or slot
3	External curved surface
4	External plane surfaces with an angular relationship
5	External spline or polygon
6	Internal plane surface and/or groove
7	internal spline and/or polygon
8	External and internal splines and/or slot and/or groove
9	Gear teeth

5th DIGIT — Auxiliary Hole(s)

Code	Group	Subgroup	Description
0			None
1	Smooth and/or tapped - relationship by drilling pattern where shown	Axial hole(s)	Not related
2	Smooth and/or tapped - relationship by drilling pattern where shown	Axial hole(s)	related
3	Smooth and/or tapped - relationship by drilling pattern where shown	Radial hole(s)	Not related
4	Smooth and/or tapped - relationship by drilling pattern where shown	Radial hole(s)	related
5	Smooth and/or tapped - relationship by drilling pattern where shown	Other hole(s)	Not related
6	Smooth and/or tapped - relationship by drilling pattern where shown	Other hole(s)	related
7	Smooth and/or tapped - relationship by drilling pattern where shown		Any combination of 1, 3 or 5
8	Smooth and/or tapped - relationship by drilling pattern where shown		Any hole combination other than 1 to 7
9			Others

FIG.8-9

HAWKER SIDDELEY GEOMETRICAL CODE

1st DIGIT — Component Class

6	Flat Components $\frac{A}{B} \leqslant 3$ $\frac{A}{C} \geqslant 4$

2nd DIGIT — Overall Shape

0	Plane shapes	Rectangular
1	Plane shapes	Rectangular with angular and/or circular deviations
2	Plane shapes	Any other plane shape
3	Machined on mounting surface(s) only	Flat components with shape elements on one face
4	Machined on mounting surface(s) only	Flat components with shape elements on more than one face
5	Machined on mounting surface(s) only	Flat components, hollow or compounded of webs & flanges
6	Machined all over	Flat components with shape elements on one face
7	Machined all over	Flat components with shape elements on more than one face
8	Machined all over	Flat components, hollow or compounded of webs & flanges
9		Others

3rd DIGIT — Principal Bore, Rotational Surface Machining

0	None
1	One principal bore, smooth
2	One principal bore, stepped to one end
3	Rotational machining
4	Machined annular surfaces, annular grooves
5	One principal bore, stepped to both ends.
6	One principal bore with shape elements
7	Two or more principal bores, parallel.
8	Two or more principal bores, other than parallel.
9	Others

4th DIGIT — Plane Surface Machining

0	None
1	Plane surface(s) - one or stepped.
2	Plane surfaces - perpendicular and/or opposite
3	Groove and/or slot
4	Inclined plane surfaces
5	Curved surfaces
6	5 + 1
7	5 + 2
8	5 + 3
9	5 + 4

5th DIGIT — Auxiliary Hole(s) Forming, Gear Teeth

0			No auxiliary holes, gear teeth or forming
1	No gear teeth, no forming		Holes drilled in one direction only
2	No gear teeth, no forming		Holes drilled in more than one direction
3	No gear teeth, no forming	related by a drilling pattern	Holes drilled in one direction only
4	No gear teeth, no forming	related by a drilling pattern	Holes drilled in more than one direction
5	Forming, no gear teeth		Formed, no auxiliary holes
6	Forming, no gear teeth		Formed, with auxiliary holes
7			Gear teeth, no auxiliary holes
8			Gear teeth, with auxiliary holes
9			Others

FIG.8-10

HAWKER SIDDELEY GEOMETRICAL CODE

1st DIGIT

Component Class		
0		
1		
2		
3		
4		
5		
6	Non-rotational components	
7	Non-rotational components	Long Components $\frac{A}{B} > 3$
8		
9		

2nd DIGIT

Overall Shape			
0	Uniform cross-section		Rectangular cross-section
1	Uniform cross-section		Rectangular cross-section with angular deviations
2	Uniform cross-section		Rectangular cross-section with circular deviations
3	Varying cross-section	Machined on mounting surface(s) only	Long components with shape elements on one face
4	Varying cross-section	Machined on mounting surface(s) only	Long components with shape elements on more than one face
5	Varying cross-section	Machined on mounting surface(s) only	Long components, hollow or compounded of webs & flanges
6	Varying cross-section	Machined all over	Long components with shape elements on one face
7	Varying cross-section	Machined all over	Long components with shape elements on more than one face
8	Varying cross-section	Machined all over	Long components, hollow or compounded of webs & flanges
9	Others		

3rd DIGIT

Principal Bore, Rotational Surface Machining	
0	None
1	One principal bore, smooth
2	One principal bore, stepped to one end
3	Rotational machining
4	Machined annular surfaces, annular grooves
5	One principal bore, stepped to both ends.
6	One principal bore with shape elements
7	Two or more principal bores, parallel.
8	Two or more principal bores, other than parallel.
9	Others

4th DIGIT

Plane Surface Machining	
0	None
1	Plane surface(s) - one or stepped.
2	Plane surfaces - perpendicular and/or opposite
3	Groove and/or slot
4	Inclined plane surfaces
5	Curved surfaces
6	5 + 1
7	5 + 2
8	5 + 3
9	5 + 4

5th DIGIT

Auxiliary Hole(s) Forming, Gear Teeth			
0	No auxiliary holes, gear teeth or forming		
1	No gear teeth, no forming		Holes drilled in one direction only
2	No gear teeth, no forming		Holes drilled in more than one direction
3	No gear teeth, no forming	related by a drilling pattern	Holes drilled in one direction only
4	No gear teeth, no forming	related by a drilling pattern	Holes drilled in more than one direction
5	Forming, no gear teeth.		Formed, no auxiliary holes
6	Forming, no gear teeth.		Formed, with auxiliary holes
7	Gear teeth, no auxiliary holes		
8	Gear teeth, with auxiliary holes		
9	Others		

FIG.8-11

HAWKER SIDDELEY GEOMETRICAL CODE

	1st DIGIT	2nd DIGIT	3rd DIGIT	4th DIGIT	5th DIGIT
	Component Class	Overall Shape	Principal Bore, Rotational Surface Machining	Plane Surface Machining	Auxiliary Hole(s) Forming, Gear Teeth
0		Rectangular prism	None	None	No auxiliary holes, gear teeth or forming
1		Rectangular prism with angular deviations	One principal bore, smooth	Plane surface(s) - one or stepped.	No gear teeth, no forming — Holes drilled in one direction only
2		Rectangular prism with circular deviations	One principal bore, stepped to one end	Plane surfaces - perpendicular and/or opposite	No gear teeth, no forming — Holes drilled in more than one direction
3		Machined on mounting surface(s) only — Cubic components with shape elements on one face	Rotational machining	Groove and/or slot	No gear teeth, no forming — related by a drilling pattern — Holes drilled in one direction only
4		Machined on mounting surface(s) only — Cubic components with shape elements on more than one face	Machined annular surfaces, annular grooves	Inclined plane surfaces	No gear teeth, no forming — related by a drilling pattern — Holes drilled in more than one direction
5		Machined on mounting surface(s) only — Cubic components, hollow or compounded of webs & flanges	One principal bore, stepped to both ends	Curved surfaces	Forming, no gear teeth — Formed, no auxiliary holes
6		Machined all over — Cubic components with shape elements on one face	One principal bore with shape elements	5 + 1	Forming, no gear teeth — Formed, with auxiliary holes
7		Machined all over — Cubic components with shape elements on more than one face	Two or more principal bores, parallel	5 + 2	Gear teeth, no auxiliary holes
8	Non-rotational components — Cubic Components $\frac{A}{B} \leq 3$, $\frac{A}{C} < 4$	Machined all over — Cubic components, hollow or compounded of webs & flanges	Two or more principal bores, other than parallel	5 + 3	Gear teeth, with auxiliary holes
9		Others	Others	5 + 4	Others

FIG.8-12

HAWKER SIDDELEY SUPPLEMENTARY CODE

	1st DIGIT: LENGTH (Rotational or non-rotational) mm	1st DIGIT: inches	2nd DIGIT: DIAMETER 'D' (rotational) or EDGE LENGTH 'C' (non-rotational) mm	2nd DIGIT: inches	3rd DIGIT: MATERIAL	4th DIGIT: INITIAL FORM	5th DIGIT: TREATMENTS	
0	≤ 13	≤ 0.5	≤ 13	≤ 0.5	Aluminium alloy	Round bar (black)		None
1	> 13 ≤ 25	> 0.5 ≤ 1.0	> 13 ≤ 25	> 0.5 ≤ 1.0	Aluminium alloy (stretched)	Round bar (bright drawn)	Between machining operations	Protective treatment
2	> 25 ≤ 38	> 1.0 ≤ 1.5	> 25 ≤ 38	> 1.0 ≤ 1.5	Magnesium alloy	Bar (other sections)		Heat treatment
3	> 38 ≤ 50	> 1.5 ≤ 2.0	> 38 ≤ 50	> 1.5 ≤ 2.0	Brasses & bronzes	Tubing		Surface finish treatment
4	> 50 ≤ 100	> 2.0 ≤ 4.0	> 50 ≤ 100	> 2.0 ≤ 4.0	Aluminium-pure (L34)	Angle ('U' 'T' & similar sections)		Special inspection procedures
5	> 100 ≤ 160	> 4.0 ≤ 6.5	> 100 ≤ 160	> 4.0 ≤ 6.5	Carbon steels	Sheet		N.C. machining
6	> 160 ≤ 250	> 6.5 ≤ 10	> 160 ≤ 250	> 6.5 ≤ 10	Stainless steels	Plate		5 + 2
7	> 250 ≤ 400	> 10 ≤ 16	> 250 ≤ 400	> 10 ≤ 16	Alloy steels	Cast or forged components		5 + 1, 3 or 4
8	> 400 ≤ 600	> 16 ≤ 25	> 400 ≤ 600	> 16 ≤ 25	Titanium	Pre-formed components		
9	> 600	> 25	> 600	> 25	Others	Pre-machined components		

FIG. 8-13

COMPARISON OF STANDARD OPITZ & MODIFIED OPITZ CODES FOR DESCRIPTION OF NON-ROTATIONAL OVERALL SHAPE.

SAMPLE SIZE - 300

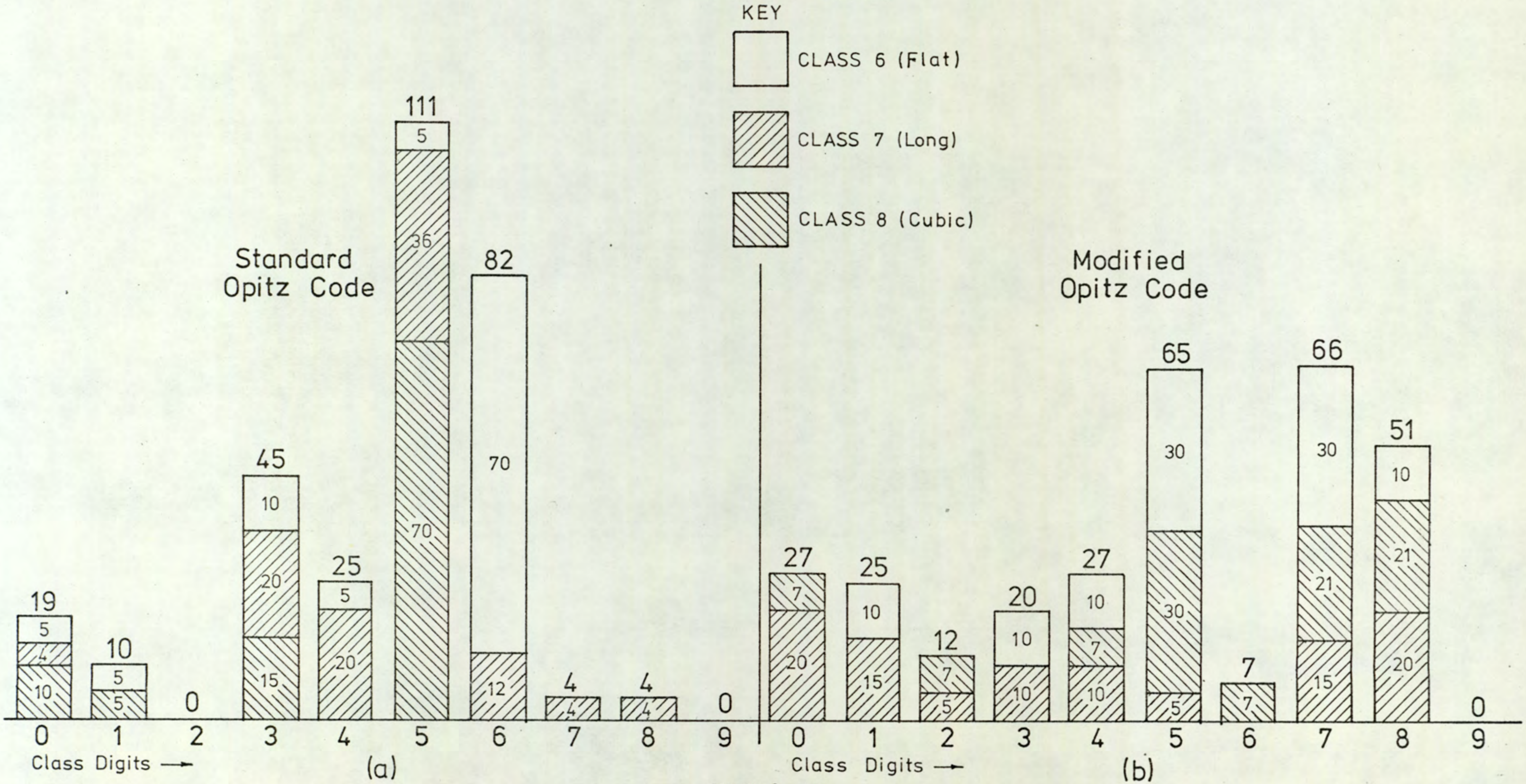


FIG. 8-14

COMPARISON OF STANDARD OPITZ & MODIFIED OPITZ CODES FOR 1st & 2nd DIGIT OF SUPPLEMENTARY CODE

Sample Size - 400

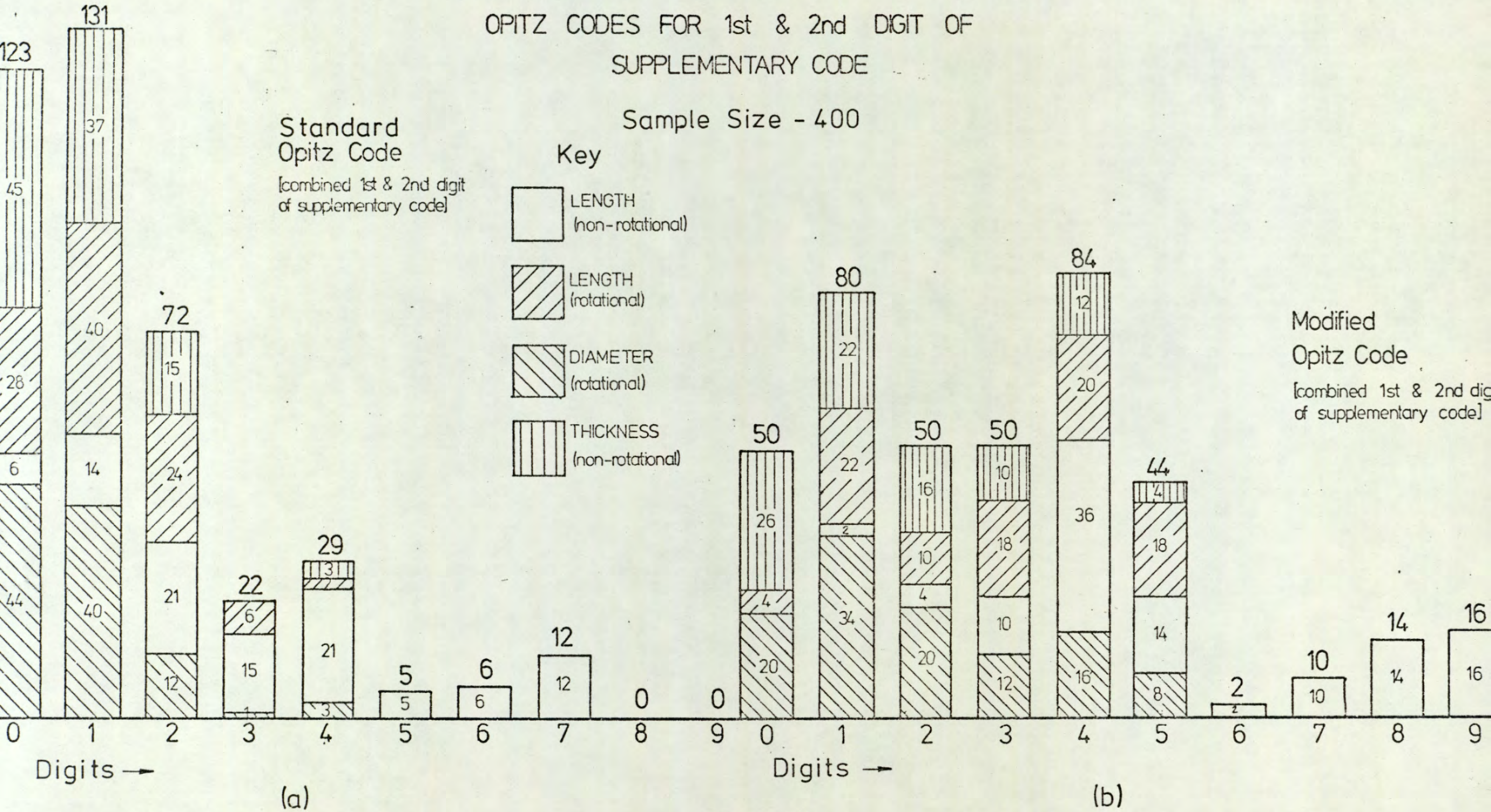


FIG. 8-15

APPENDIX 1

A. LIST OF PRODUCTS MANUFACTURED BY THE BRONX ENGINEERING COMPANY LIMITED.

PRESS DIVISION

Hydraulic and Mechanical Press Brakes . Hydraulic and Mechanical Presses, Section Punching Presses . Portal Presses . Tensile Testing Machines.

BAR AND TUBE DIVISION

Tube Straightening Machines - Bar Straightening and Polishing Machines, Wire Straightening and Polishing Machines . Bar and Tube Cut-to-length Lines . Bar and Tube Handling Equipment . Section Straightening Machines.

COIL PROCESSING DIVISION

Cut-to-length Lines of Flying Die, Rocking Shear or stationery Up-Cut Shear Design Slitting Lines . Precision Levelling Machines of 4 and 6 high design.

ROLLS AND LEVELLER DIVISION

Plate Bending Rolls . Plate and Strip Levellers . Process Levellers . Edge Bending Presses . Guillotines . Hydraulic Stretching Machines for Sheets or Profiles . Spade and Hoe Mills . Forging Rolls.

BRONX PROCESS ENGINEERING LIMITED

Continuous Coil Coating Lines for paints, lacquers, laminates, etc. . Hot Dip Metal Coating Lines . Continuous Heat Treatment Lines for normalising, annealing, hardening, etc. . Continuous Surface Grinding and Surface Polishing Plant . Continuous Process Tension Levelling of steel, stainless steel, aluminium and other non-ferrous materials . Pickling . Washing . Degreasing, etc.

PRESS BRAKE EQUIPMENT (FELBRIDGE) LIMITED

Press Guards . Guillotine Shears . Machine Tools.

B. ILLUSTRATIONS OF PRODUCTS MANUFACTURED BY THE BRONX ENGINEERING COMPANY LIMITED.
(refer to enclosed booklet)

FIG. 1 - SLITTING LINE for 15 ton coils, capacity 1500 mm x 3mm.

FIG. 2 - FLYING SHEAR LINE, capacity 1800mm x 3mm with up cut flying shear.

FIG. 3 - HUMP TYPE CUT UP LINE, with hand stacking position, capacity 1500mm x 3mm.

FIG. 4 - SLITTING LINE for 15 ton coils up to 1500mm x 3mm, has double-mandrel uncoiler and four-roll flattener.

FIG. 5 - FLYING SHEAR CUT UP LINE with up cut shear, capacity 1800mm x 3mm.

FIG. 6 - GRIP FEED CUT UP LINE, including edge trimming, capacity 1060mm x 1.6mm.

FIG. 7 - HUMP TYPE CUT UP LINE with 15 ton capacity, floor-mounted coil car for coils up to 1500mm x 3mm. Seventeen roll precision leveller has powered adjustments.

FIG. 8 - SLITTING LINE for 15ton coils up to 1830mm x 3mm, has double-mandrel uncoiler and accentric-arbor interchangeable head slitter.

FIG. 9 - HUMP TYPE CUT UP LINE with edge trimming, capacity 1500mm x 2.75mm.

FIG. 10 - SLITTING LINE for 15 ton coils up to 1200mm x 3mm. Slit coils are transferred by coil to twin-arm capstan which feeds semi-automatic coil strapping station.

FIG. 11 - SEMI-AUTOMATIC COIL STROPPING STATION, receives slit coils from twin-arm capstan with hydraulic push-off. Strapped coils are discharged to selected storage points at the rate of one per minute.

FIG. 12 - HUMP TYPE CUT UP LINE, capacity 1800mm x 3mm with hod-type semi-automatic stacker.

FIG. 13 - HEAVY DUTY STEELWORKS SLITTING LINE, for stainless steel coils up to 1420mm x 5mm with 27 tonne capacity, double-mandrel uncoiler and 15 tonne capacity recoiler.

FIG. 14 - FLYING SHEAR LINE, capacity 1800mm x 3mm, and SLITTING LINE, capacity 1800mm x 3mm, installed in works of British steel stockholder.

FIG. 15 - FLYING SHEAR LINE, capacity 1800mm x 3mm with up cut flying shear.

FIG. 16 - HEAVY DUTY STOP-START CUT UP LINE has capacity for 20 ton coils, 2000mm x 13mm. Eleven-roll precision leveller has fully motorised adjustments. "Bomb-door" stacker provides automatic stacking of plates up to 5m long. Plates up to 8m long can be individually processed.

FIG. 17 - HUMP TYPE CUT UP LINE for stainless steel with 23-roll, 6 high leveller, capacity 1500mm x 2mm.

FIG. 18 - FLYING SHEAR LINE for stainless steel incorporating automatic paper interleaving and stacking and automatic sheet classification into grade 1, grade 2 and scrap. Capacity for strip up to 3mm thick.

FIG. 19 - FLYING SHEAR AND LEVELLER from line shown in FIG. 18. Leveller is of 17-roll 6 high type and has powered adjustments.

FIG. 20 - SLITTING LINE for aluminium with twin recoilers. Capacity 1066mm x 1mm.

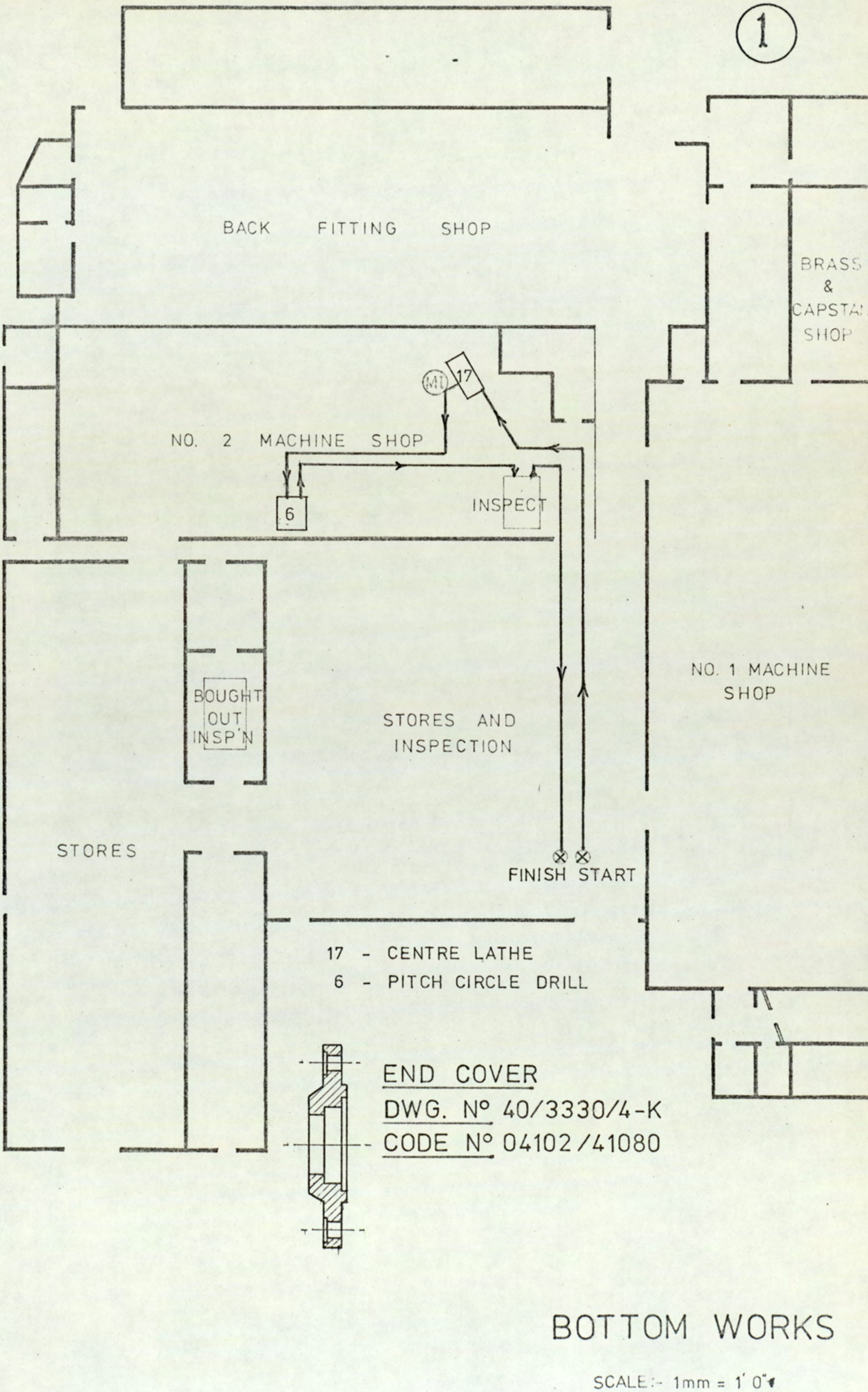
FIG. 21 - CUT UP LINE, capacity 2000mm x 12.75mm.

FIG. 22 - FLYING SHEAR CUT UP LINE for 20 ton coils up to 1500mm x 3.66mm, has 17-roll precision leveller with all adjustments powered, flying die up-cut shear and scrap ejector.

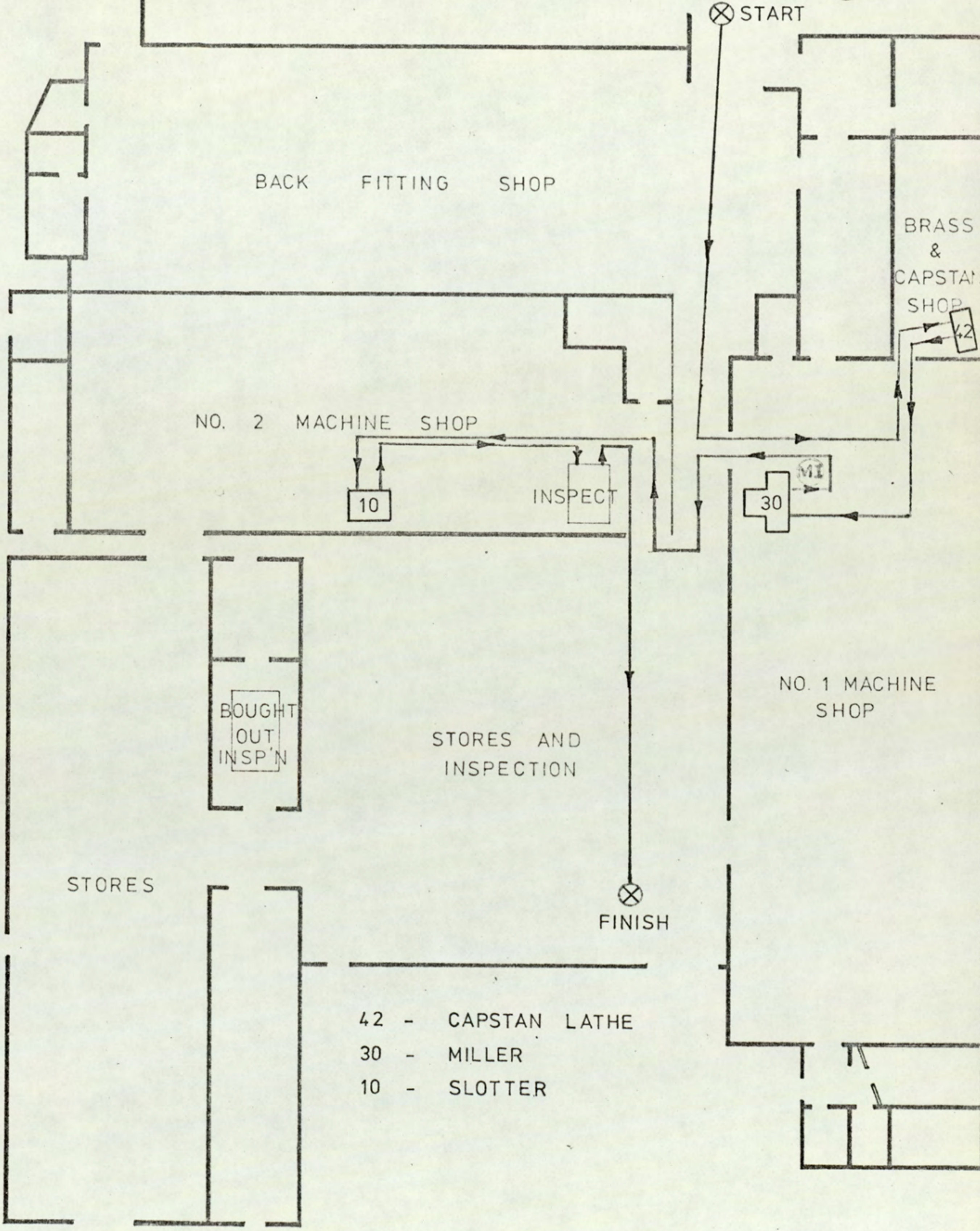
FIG. 23 & 24 - AIR FLOTATION-TYPE STACKER in flying shear cut up line, ensures scratch-free stacking of lengths up to 3.6m. Slat conveyor system provides storage for stock before weighing and strapping.

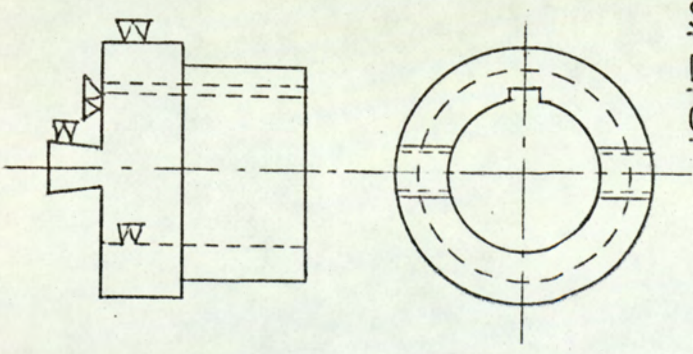
APPENDIX 2.

COMPONENT ROUTE DIAGRAMS BEFORE GROUP TECHNOLOGY AT THE BRONX ENGINEERING CO., LTD.


1
BACK FITTING SHOP
BRASS & CAPSTAN SHOP
NO. 2 MACHINE SHOP
MI
17
6
INSPECT
BOUGHT OUT INSP'N
STORES AND INSPECTION
NO. 1 MACHINE SHOP
STORES
FINISH START
17 - CENTRE LATHE
6 - PITCH CIRCLE DRILL
END COVER
DWG. Nº 40/3330/4-K
CODE Nº 04102/41080
BOTTOM WORKS
SCALE:- 1mm = 1' 0"

2





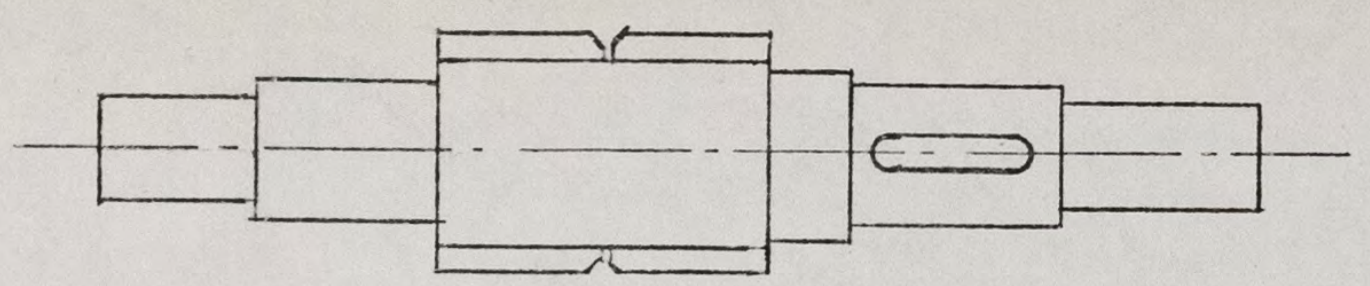
SLIDING DOG

DWG. Nº STD 250/2

CODE Nº 11160/12300

BOTTOM WORKS

SCALE:- 1mm = 1' 0"



3

4TH MOTION PINION
DWG. N° 83/6736 - D
CODE N° 24036/37404

PRODUCTION MACHINE TOOLS.

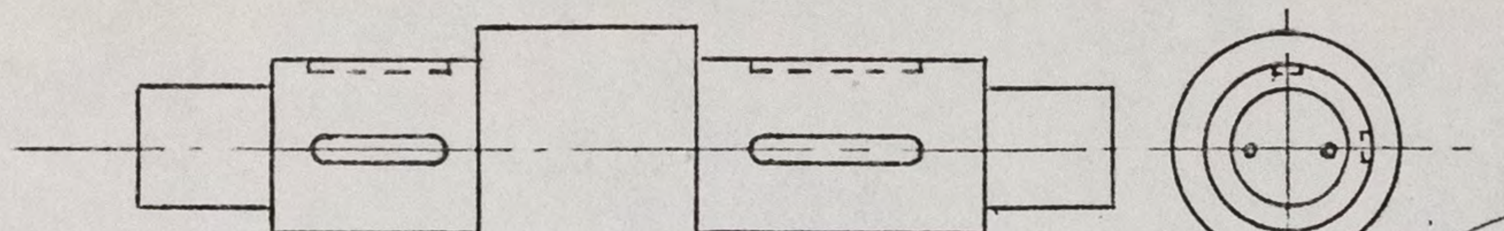
BOTTOM WORKS.

1. 5EF. WEBSTER AND BENNET VERT. BORER.
2. 10AC. BUTLER SLOTTER.
3. 35A. ARCHDALE VERTICAL MILLER
4. 40AE. ASQUITH RADIAL DRILL.
5. 5EF. WEBSTER & BENNET VERT. BORER.
6. 40C. S.M.T. PITCH CIRCLE DRILLER
7. 15CG. D.S.& G. CENTRE LATHE.
8. 15CG. D.S.& G. CENTRE LATHE.
9. 25C. NORTON SURFACE GRINDER.
10. 10C. FROMAG SLOTTER.
11. 20A. HERBERT NO.7 TURRET LATHE.
12. 15E. STANLEY CENTRE LATHE
13. 25E. HEALD INTERNAL GRINDER.
14. 20A. HERBERT NO.9 TURRET LATHE.
15. 15CG. NILES CENTRE LATHE.
16. 15CG. NILES CENTRE LATHE.
17. 15CG. NILES CENTRE LATHE.
18. T. CLARKSON TOOL AND CUTTER.
19. T. HERBERT DRILL GRINDER.
20. T. ABWOOD GRINDER AND LAPPER.
21. 5B KITCHEN & WADE BORER.
22. 40AB. TOS PILLAR DRILL.
23. 30E. PLANERS PLANING M/C.
24. 5G. NEWALL JIG BORER.
25. 15AB. D.S.& G CENTRE LATHE.
26. 15A. D.S.& G. ROLL POL. LATHE.
27. 25D. BRONX ROLL GRINDER.
28. 30D. BRONX ROLL GRINDER PBR.
29. 35A. INDUMA VERTICAL MILL.
30. 35A. SOVIET VERTICAL MILL.
31. 30C. PLANERS PLANING M/C.
32. 30D. PLANERS PLANING M/C.
33. 30H BUTLER SHAPER.
34. 5C. UNION TABLE BORER.
35. 5C. UNION TABLE BORER.
36. 15G. D.S.& G. CENTRE LATHE.
37. 15D. TOS CENTRE LATHE.
38. 15E TOS CENTRE LATHE.
39. 15G. D.S.& G. CENTRE LATHE.
40. 15C. TOS CENTRE LATHE.
41. 5C. UNION TABLE BORER.
42. 20B. WARD NO.3A CAPSTAN.
43. 20B. HERBERT NO.4 CAPSTAN.
44. 15F. TOS CENTRE LATHE.
45. 15F. COLCHESTER LATHE

TOP WORKS.

1. 30B. PLANERS LARGE PLANER.
2. 5A. CONTI FLOOR BORER
3. 5B. K.& W. FLOOR BORER.
4. 40A. K.& W. RADIAL DRILL
5. 40B. K.& W. RADIAL DRILL.
6. 5C. GIDDINGS & LEWIS TABLE BORER.
7. 5C. G.& L. TABLE BORER.
8. 5C. SCHARMANN TABLE BORER.
9. 5C. RUSSIAN TABLE BORER.
10. 40B. K.& W. RADIAL DRILL.
11. 5A. COLLET AND ENGELHARDT BORER.
12. 40A. ARCHDALE RADIAL DRILL.
13. 30A. PLANERS FUTURMILL PLANER.
14. 35E. RUSSIAN VERT. MILL.
15. 15A. CRAVEN CENTRE LATHE.
16. 15A. RUSSIAN CENTRE LATHE
17. 25B. NORTON CYL. GRIND.
18. 25A. CHURCHILL CYL. GRIND.
19. 35D. KENDALL & GENT MILL

BRONX ENGINEERING CO. LTD., LYE, ENGLAND. SCALE 1 : 500



④ SHAFT
DWG Nº 83/6792 F
CODE Nº 24032/37300

PRODUCTION MACHINE TOOLS.

BOTTOM WORKS.

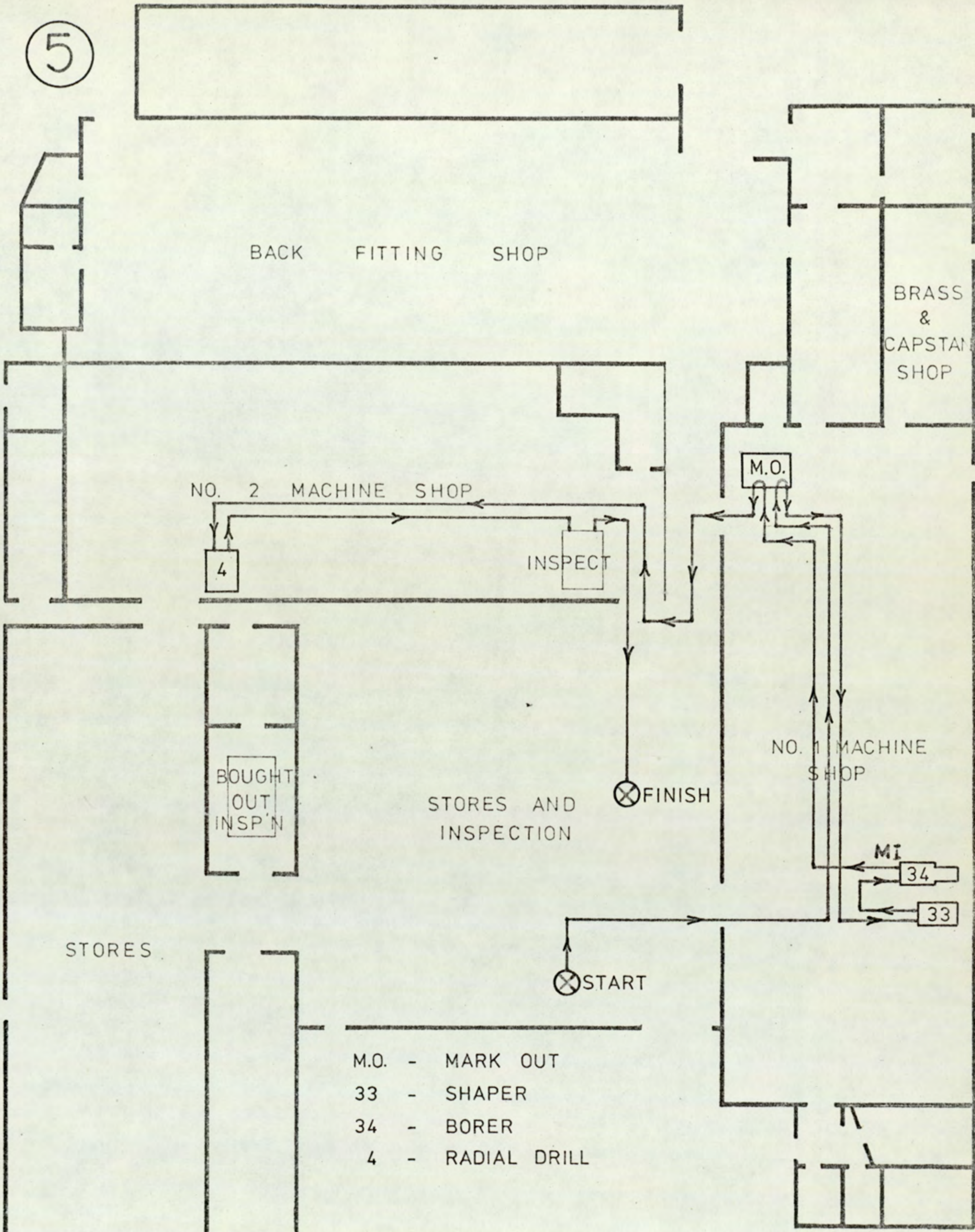
1. 5EF. WEBSTER AND BENNET VERT BORER.
2. 10AC. BUTLER SLOTTER.
3. 35A. ARCHDALE VERTICAL MILLER
4. 40AB. ASQUITH RADIAL DRILL.
5. 5EF. WEBSTER & BENNET VERT. BORER
6. 40C. SMT PITCH CIRCLE DRILLER
7. 15CG. D.S&G. CENTRE LATHE
8. 15CG. D.S.&G. CENTRE LATHE.
9. 25C. NORTON SURFACE GRINDER.
10. 10C. FROMAG SLOTTER.
11. 20A. HERBERT NO.7 TURRET LATHE.
12. 15E. STANLEY CENTRE LATHE.
13. 25E. HEALD INTERNAL GRINDER.
14. 20A. HERBERT NO.9 TURRET LATHE.
15. 15CG. NILES CENTRE LATHE.
16. 15CG. NILES CENTRE LATHE.
17. 15CG. NILES CENTRE LATHE
18. T. CLARKSON TOOL AND CUTTER.
19. T. HERBERT DRILL GRINDER.
20. T. ABWOOD GRINDER AND LAPPER.
21. 5B. KITCHEN & WADE BORER.
22. 40AB. TOS PILLAR DRILL.
23. 30E. PLANERS PLANING M/C.
24. 5G. NEWALL JIG BORER.
25. 15AB. D.S.&G. CENTRE LATHE.
26. 15A. D.S.&G. ROLL POL. LATHE.
27. 25D. BRONX ROLL GRINDER.
28. 30D. BRONX ROLL GRINDER P3R.
29. 35A. INDUMA VERTICAL MILL.
30. 35A. SOVIET VERTICAL MILL.
31. 30C. PLANERS PLANING M/C.
32. 30D. PLANERS PLANING M/C.
33. 30H. BUTLER SHAPER.
34. 5C. UNION TABLE BORER.
35. 5C. UNION TABLE BORER.
36. 15G. D.S.&G. CENTRE LATHE.
37. 15D. TOS CENTRE LATHE.
38. 15E. TOS CENTRE LATHE.
39. 15G. D.S.&G. CENTRE LATHE.
40. 15C. TOS CENTRE LATHE.
41. 5C. UNION TABLE BORER.
42. 20B. WARD NO.3A CAPSTAN.
43. 20B. HERBERT NO.4 CAPSTAN.
44. 15F. TOS CENTRE LATHE.
45. 15F. COLCHESTER LATHE.

TOP WORKS.

1. 30B. PLANERS LARGE PLANER
2. 5A. CONTI FLOOR BORER
3. 5B. K&W. FLOOR BORER.
4. 40A. K&W. RADIAL DRILL.
5. 40B. K&W. RADIAL DRILL.
6. 5C. GIDDINGS & LEWIS TABLE BORER.
7. 5C. G&L. TABLE BORER
8. 5C. SCHARMANN TABLE BORER.
9. 5C. RUSSIAN TABLE BORER.
10. 40B. K&W. RADIAL DRILL.
11. 5A. COLLET AND ENGELHARDT BORER.
12. 40A. ARCHDALE RADIAL DRILL.
13. 30A. PLANERS FUTURMILL PLANER.
14. 35E. RUSSIAN VERT. MILL.
15. 15A. CRAVEN CENTRE LATHE.
16. 15A. RUSSIAN CENTRE LATHE.
17. 25B. NORTON CYL. GRIND.
18. 25A. CHURCHILL CYL. GRIND.
19. 35D. KENDALL & GENT MILL.

BRONX ENGINEERING CO. LTD., LYE, ENGLAND. SCALE 1 : 500

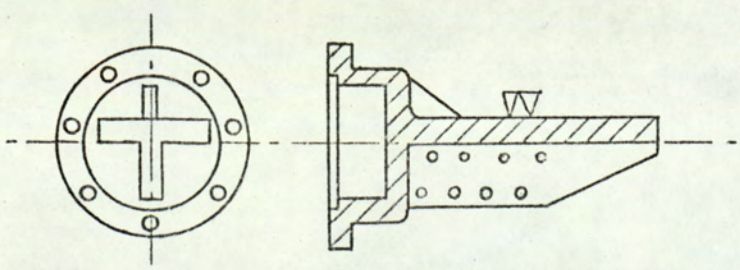
5



GEAR UNIT SUPPORT BRACKET

DWG. Nº 54492/A

CODE Nº 33414/56080



BOTTOM WORKS

SCALE:- 1mm = 1' 0"

6

GEAR BOX
DWG N° 2/7820 - K
CODE N° 38614/42360

PRODUCTION MACHINE TOOLS.

BOTTOM WORKS.

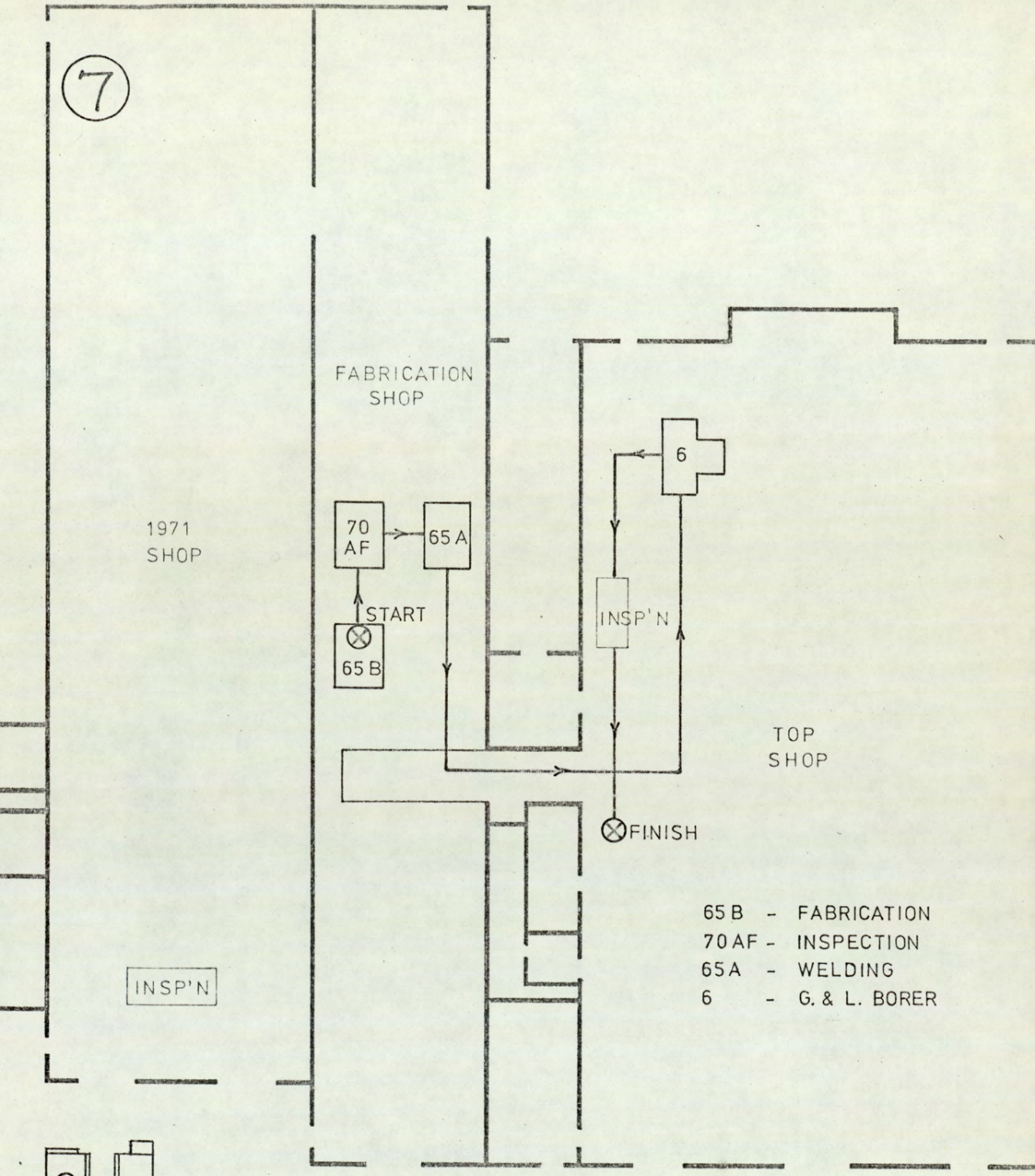
1. 5EF. WEBSTER AND BENNET VERT. BORER.
2. 10AC. BUTLER SLOTTER.
3. 35A ARCHDALE VERTICAL MILLER.
4. 40AB. [illegible] RADIAL DRILL.
5. 5EF. WEBSTER & BENNET VERT. BORER.
6. 40C. SMT PITCH CIRCLE DRILLER.
7. 15CG. D.S.&G. CENTRE LATHE.
8. 15CG. D.S.&G. CENTRE LATHE.
9. 25C. NORTON SURFACE GRINDER.
10. 10C. FROMAG SLOTTER.
11. 20A. HERBERT NO.7 TURRET LATHE.
12. 15E. STANLEY CENTRE LATHE.
13. 25E. HEALD INTERNAL GRINDER.
14. 20A. HERBERT NO.9 TURRET LATHE.
15. 15CG. NILES CENTRE LATHE.
16. 15CG. NILES CENTRE LATHE.
17. 15CG. NILES CENTRE LATHE.
18. T. CLARKSON TOOL AND CUTTER.
19. T. HERBERT DRILL GRINDER.
20. T. ABWOOD GRINDER AND LAPPER.
21. 5B KITCHEN & WADE BORER.
22. 40AB. TOS PILLAR DRILL.
23. 30E. PLANERS PLANING M/C.
24. 5G. NEWALL JIG BORER.
25. 15AB. D.S.&G CENTRE LATHE.
26. 15A. D.S.&G. ROLL POL. LATHE.
27. 25D. BRONX ROLL GRINDER.
28. 30D. BRONX ROLL GRINDER PBR.
29. 35A. INDUMA VERTICAL MILL.
30. 35A. SOVIET VERTICAL MILL.
31. 30C. PLANERS PLANING M/C.
32. 30D. PLANERS PLANING M/C.
33. 30H BUTLER SHAPER.
34. 5C UNION TABLE BORER.
35. 5C. UNION TABLE BORER.
36. 15G D.S.& G. CENTRE LATHE.
37. 15D. TOS CENTRE LATHE.
38. 15E TOS CENTRE LATHE.
39. 15G. D.S.& G. CENTRE LATHE.
40. 15C. TOS CENTRE LATHE.
41. 5C. UNION TABLE BORER.
42. 20B. WARD NO.3A CAPSTAN.
43. 20B. HERBERT NO.4 CAPSTAN.
44. 15F. TOS CENTRE LATHE.
45. 15F. COLCHESTER LATHE

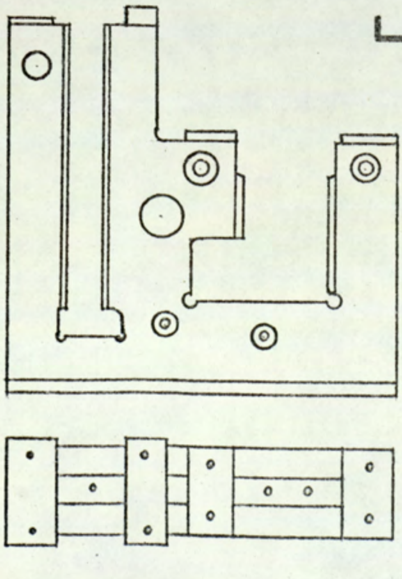
TOP WORKS.

1. 30B. PLANERS LARGE PLANER.
2. 5A CONTI FLOOR BORER.
3. 5B. K.&W. FLOOR BORER.
4. 40A. K.&W. RADIAL DRILL.
5. 40B. K.&W. RADIAL DRILL.
6. 5C. GIDDINGS & LEWIS TABLE BORER.
7. 5C. G.& L. TABLE BORER.
8. 5C. SCHARMANN TABLE BORER.
9. 5C. RUSSIAN TABLE BORER.
10. 40B. K.&W. RADIAL DRILL.
11. 5A COLLET AND ENGELHARDT BORER.
12. 40A. ARCHDALE RADIAL DRILL.
13. 30A. PLANERS FUTURMILL PLANER.
14. 35E. RUSSIAN VERT. MILL.
15. 15A. CRAVEN CENTRE LATHE.
16. 15A. RUSSIAN CENTRE LATHE.
17. 25B NORTON CYL. GRIND.
18. 25A. CHURCHILL CYL. GRIND.
19. 35D. KENDALL & GENT MILL.

BRONX ENGINEERING CO. LTD., LYE, ENGLAND. SCALE 1 : 500

7





REAR SIDE FRAME
DWG. Nº 3/4039 - A
CODE Nº 65584/74360

TOP WORKS

SCALE:- 1mm = 1' 4"

8

OPERATING ARM
DWG. Nº 11/4565 - G
CODE Nº 75440/82360

PRODUCTION MACHINE TOOLS.

BOTTOM WORKS.

1. 5EF. WEBSTER AND BENNET VERT. BORER.
2. 10AC. BUTLER SLOTTER.
3. 35A. ARCHDALE VERTICAL MILLER.
4. 40AE. ASQUITH RADIAL DRILL.
5. 5EF. WEBSTER & BENNET VERT. BORER.
6. 40C. S.M.T. PITCH CIRCLE DRILLER.
7. 15CG. D.S.&G. CENTRE LATHE.
8. 15CG. D.S.&G. CENTRE LATHE.
9. 25C. NORTON SURFACE GRINDER.
10. 10C. FROMAG SLOTTER.
11. 20A. HERBERT NO.7 TURRET LATHE.
12. 15E. STANLEY CENTRE LATHE.
13. 25E. HEALD INTERNAL GRINDER.
14. 20A. HERBERT NO.9 TURRET LATHE.
15. 15CG. NILES CENTRE LATHE.
16. 15CG. NILES CENTRE LATHE.
17. 15CG. NILES CENTRE LATHE.
18. T. CLARKSON TOOL AND CUTTER.
19. T. HERBERT DRILL GRINDER.
20. T. ABWOOD GRINDER AND LAPPER.
21. 5B. KITCHEN & WADE BORER.
22. 40AB. TOS PILLAR DRILL.
23. 30E. PLANERS PLANING M/C.
24. 5G. NEWALL JIG BORER.
25. 15AB. D.S.&G. CENTRE LATHE.
26. 15A. D.S.&G. ROLL POL. LATHE.
27. 25D. BRONX ROLL GRINDER.
28. 30D. BRONX ROLL GRINDER PB.
29. 35A. INDUMA VERTICAL MILL.
30. 35A. SOVIET VERTICAL MILL.
31. 30C. PLANERS PLANING M/C.
32. 30D. PLANERS PLANING M/C.
33. 30H. BUTLER SHAPER.
34. 5C. UNION TABLE BORER.
35. 5C. UNION TABLE BORER.
36. 15G. D.S.&G. CENTRE LATHE.
37. 15D. TOS CENTRE LATHE.
38. 15E. TOS CENTRE LATHE.
39. 15G. D.S.&G. CENTRE LATHE.
40. 15C. TOS CENTRE LATHE.
41. 5C. UNION TABLE BORER.
42. 20B. WARD NO.3A CAPSTAN.
43. 20B. HERBERT NO.4 CAPSTAN.
44. 15F. TOS CENTRE LATHE.
45. 15F. COLCHESTER LATHE.

TOP WORKS.

1. 30A. PLANERS LARGE PLANER.
2. 5A. CONTI FLOOR BORER.
3. 5B. K.&W. FLOOR BORER.
4. K.&W. RADIAL DRILL.
5. B.K.&W. RADIAL DRILL.
6. GIDDINGS & LEWIS TABLE BORER.
7. G.&L. TABLE BORER.
8. SCHARMANN TABLE BORER.
9. 5C. RUSSIAN TABLE BORER.
10. 40B. K.&W. RADIAL DRILL.
11. 5A. COLLET AND ENGELHARDT BORER.
12. 40A. ARCHDALE RADIAL DRILL.
13. 30A. PLANERS FUTURMILL PLANER.
14. 35E. RUSSIAN VERT. MILL.
15. 15A. CRAVEN CENTRE LATHE.
16. 15A. RUSSIAN CENTRE LATHE.
17. 25B. NORTON CYL. GRIND.
18. 25A. CHURCHILL CYL. GRIND.
19. 35D. KENDALL & GENT MILL.

BRONX ENGINEERING CO. LTD., LYE, ENGLAND. SCALE 1 : 500

APPENDIX 3.

A. COMPONENT PROCESS SHEET.

B. TABLES SUMMARISING COMPONENT PROCESS SHEETS FOR SELECTED COMPONENTS.

C. DEPARTMENTAL AND MACHINE CODES.

801/1/FS/608

PROCESS LAYOUT

DESCRIPTION	PART NO.	ISSUE NO.
END FITTING (FRONT STRAKE)	6-4B-FS-3111	

DRG. NO.	ISSUE NO	STAGE NO.
6-4B-FS-3111		FS 1

MATL. SPEC.	MATL. CODE	1 OFF SIZE	D	THICKNESS	DIA / SIZE	WIDTH	LENGTH
S97							

DESCRIPTION MATL.	TEST ALLCE.	M	MAKES	WIDTH	LENGTH
H.T.S. CLASS 1 FORGING 6-4-FS-8027					

USED ON		EST. QTY. PER A/C	COMPLETE / INCOMPLETE TO DWG.	TYPE OF PART	BATCH CAT.	PROD CAT.	CYCLE TIME	PRIOR
			SPARES / PRODUCTION ONLY					

ISS ACT	OP	DEPT	M/C	OPERATION	NO. OF OPS.	TOOLS/GAUGES	L	SET HRS MIN	RUN HRS MIN	PER
	01	535	000	Issue forgings 6-4-FS-8027.			B			
	05	010	752	Mark out for length and rectangular faces.			A			
	10	010	261	Mill to length +.050"			A			
	15	010	261	Mill rectangular faces to 1.8" x 1.7" dims leave plus .010" for grinding.			A			
	20	010	261	Mill four chamfers			A			
	25	010	117	Grind two faces to 1.70" dim.			A			
	30	010	261	Mill each side of eye end to 1.124" dim. and at 11° 41' to the sides (Leave plus .010" for grinding		41/T1-2 on 6-4-FS.8027-8	A			
	35	010	261	Mill each side of lug to limits		41/1-2 and 99/T3-4 on 6-4-FS-8027-8	A			
	40	010	378	Face bore to depth, c/bore and chamfer.		43/T5 on 6-4-FS-8027-8 TL.14109.	A			
	45	010	117	Grind two faces to 1.7964" /1.7984" dim.		46/T6 on 6-4-FS-8027-8	A			
	50	010	117	Grind each side of eye end to pre-plating limits.		TST-2 on 6-4-FS-8027-8	A			
	55	010	201	Bore limit dia. hole in eye end -.010" for finish bore		44/T7 on 6-4-FS-8027-8	A			

ISS	DATE	INTLS.	AUTHORITY	FACTORY 227	SHT. NO. 1 OF 2 SHTS.				
				ALTERATION AND APPLICABILITY	DEPTS. AFFECTED	O	T/O	T/D	C
6.	14.3.69.	GM.	Re-type.						

PROCESS LAYOUT CONTINUATION SHEET	PART NO.	6-4B-FS-3111

ISS ACT	OP	DEPT	M/C	OPERATION	TOOLS / GAUGES	L	SET HRS	SET MIN	RUN HRS	RUN MIN
	60	010	266	Profile .25" rad. on eye end.	413T8-9 and 99/T1 on 6-4-FS-8027-8	A				
	65	010	232	Drill and ream 3/8" dia. hole in lug.Ref. C.6	34/T11-12 on 6-4-FS-8027-8	A				
	70	010	266	Profile mill lug and blend.	41/T8-9 and 99/T.10 on 6-4-FS-8027-8	A				
	75	010	261	Blend mill lug face to 1.25" rad. (Note 1/8" corner rad) Ref. Grid E5. and E13.	T1-2-3-3-4 on 6-4-FS-8027-8	A				
	80	010	000	File .06" rad on each side of eye end file .06" rad on each side of lug and file and blend radii on all corners on neck and shank.		A				
	85	010	113	Finish grind hole in eye end to limits.	44/T1 on 6-4-FS-8027-8	A				
	90	997	000	Inspect. Note other holes drilled on assembly. Record batch No.		A				
	95	211	906	Stress Relieve		B				
	100	212	184	Vacua Blast Mask holes.		B				
	105	210	938	Cadmium to limits		B				
	110	211	400	De-embrittle.		B				
	115	997	000	Inspect		A				
	120	997	000	Crack detect.		A				
	125	210	974	Clean off fluid		B				
	130	200	000	Finish paint silver TT.16		B				
	135	997	000	Re-Ident and itemise. PROV AND PROD		B				

ISS	DATE	INTLS	AUTHORITY	FACTORY ALTERATION AND APPLICABILITY	SHT NO 2 OF 2 SHTS DEPTS AFFECTED	O	T/D	T/D	C
6.	14.3.69.	GM.	Re-type.						

TABLE 1.1

MANUFACTURE OF SPARS AND BOOMS

Title Dwg No. Code No.	Depts. Visited	Department Sequence per Operation	No. of Ops.	Machine Sequence per Operation	No. of M/c. Changes Required
Rear Spar Ribs 9 - 29 A571-40876 75074/9286	10	535,230,010,010,020 019,997,212,212,214 212,200	12	000,000,021,021,000 000,000,974,934,184 934,000	0
Rear Spar Ribs 1 - 9 A571-40885 75074/9387	11	535,019,010,010,010 211,010,019,997,212 214,212,200	13	000,000,037,037,037 906,037,000,000,934 184,934,000	1
Front Spar Ribs 9 - 29 A571-40800 & A571-40875 75074/9286	10	535,230,010,010,020 019,997,212,212,214 212,200	12	000,000,039,039,000 000,000,974,934,184 934,000	0
Upper Boom Centre Spar Ribs 1 - 7 A571-40889 75074/9284	12	535,010,010,010,010 010,010,010,010,010 010,010,010,010,010 010,010,010,010,019 010,211,010,010,019 997,212,214,212,200	30	000,255,255,255,255 255,255,255,255,255 255,255,255,255,800 260,260,260,260,000 542,000,800,261,000 000,934,184,934,000	3
Top Boom Rib 3 Centre 6M4-WC-275/6 78073/9184	17	535,010,211,010,997 010,997,010,211,997 212,997,019,214,212 200,997	17	434,256,906,501,000 256,000,501,000,000 934,000,000,184,934 774,000	3
	(Details of Milling Ops. not included - 010)				
Rear Spar Boom Top 6M4-WC-137/8 75070/9284	14	435,010,400,211,400 400,010,400,210,400 019,212,210,400	14	434,254,750,900,750 750,752,750,934,750 000,184,934,750	1
	(This Dwg. dated 11.4.62 - Machining Ops.not incl.-)				
Bottom Boom Rib 3 Centre 6M4-WC-12863/4 78073/9284	17	435,010,010,010,010 010,010,010,010,010 010,010,010,010,010 010,010,010,010,010 211,010,400,010,010 010,010,010,010,010 400,010,211,400,212 400,019,214,212,200 400	41	434,256,256,256,256 256,256,256,256,256 256,256,256,256,256 256,256,256,256,256 900,501,000,256,256 256,256,256,256,256 000,501,900,000,934 000,000,184,934,000 000	3

TABLE 1.2

Title Dwg. No. Code No.	Depts. Visited	Department Sequence per Operation	No. of Ops.	Machine Sequence per Operation	No. of M/c. Changes Required
Rear Spar 1 to 9 A571-40014 75074/9387	7	435,211,010,010,010 019,400,212,200	9	000,906,021,021,021 000,000,934,000	0
Rib 23 (Port) A571-40932 75074/8186	9	535,010,010,010,010 019,091.020,997,212 214,212,200	13	432,245,252,047,057 000,000,000,000,934 184,934,000	3
Half-Rib A571-40837 66074/7286	8	535,010,010,010,010 010,010,010,010,010 010,010,019,997,212 214,212,200	18	000,800,436,254,251 057,021,021,261,261 261,261,000,000,934 184,934,000	5
Main Gear Jack Pick-up A572-40397 83473/6487	6	435,010,010,010,010 010,010,010,010,010 010,010,010,010,010 010,010,010,010,010 019,400,400,212,200	25	000,000,261,261,251 251,232,205,263,263 263,261,263,263,263 263,261,261,251,205 000,000,000,957,000	9
Riblet,Aft. A572-42055 66074/5186	7	535,010,010,010,010 010,010,010,019,997 214,212,200	13	000,800,436,262,251 057,021,228,000,000 184,934,000	5
Strap, Rib 9 A571-40986 75073/9186	22	535,010,997,010,997 010,010,010,010,010 010,010,010,010,020 019,997,211,090,090 010,010,010,010,010 010,019,010,019,010 010,010,010,010,010 010,019,997,212,214 212,200	42	000,295,000,256,000 295,295,295,295,295 295,295,295,800,000 000,000,906,576,000 800,436,236,295,039 039,000,295,000,262 262,262,262,262,262 262,000,000,934,184 934,000	9
End Fitting (Front Strake) G-4B-FS-3111 66174/4227	11	535,010,010,010,010 010,010,010,010,010 010,010,010,010,010 010,010,010,997,211 212,210,211,997,997 210,200,997	28	000,752,261,261,261 117,261,261,378,117 117,201,266,232,266 261,000,113,000,906 184,938,400,000,000 974,000,000	10
Boom Centre Spar A571-40890/200 /201	8	535,010,010,010,010 010,010,010,010,010 010,010,010,010,010 010,020,019,997,997 214,212,200	23	000,255,256,256,256 256,256,256,256,295 800,436,261,261,261 261,000,000,000,000 184,934,000	4

TABLE 1.3

Title Dwg. No. Code No.	Depts. Visited	Department Sequence per Operation	No. of Ops.	Machine Sequence per Operation	No. of M/c. Changes Required
Skin Stab- iliser Rib 7-9 A571-40207 75071/7282	9	435,010,010,010,010 010,010,010,010,010 010,010,010,010,010 010,019,400,214,212 400,212,200	23	000,261,800,252,263 263,263,263,263,263 259,259,259,259,259 259,000,000,184,934 000,934,000	3
Skin Stabiliser Rib7-9 Bttm. Skin A571-40207 75071/7282	9	435,010,010,010,010 010,010,010,010,010 019,400,214,212,400 212,200	17	000,261,261,037,037 037,037,258,258,258 000,000,185,938,000 938,000	2
Pylon O/B Outer A571-40212 66174/6387	2	435,010,010,010,010 010,010,010,010,010 010	11	000,000,261,261,205 263,263,263,261,261 261	3
Pylon O/B Inner A571-40211 75073/6387	2	435,010,010,010,010 010,010,010,010,010 010,010	12	000,000,261,261,205 263,263,261,261,261 261,261	3
Stiffener A571-40981 75071/7282	8	535,010,010,010,010 010,010,010,010,080 997,212,214,212,200	15	000,800,436,261,261 261,261,261,266,000 000,934,184,934,000	2
Spar Fitting Rib 8 Jacking Point A572-40867 85074/5382	8	535,010,010,010,010 010,010,010,010,010 010,010,010,010,010 019,997,212,214,212 200	21	000,800,436,262,262 250,021,021,021,262 250,250,250,800,232 000,000,934,184,934 000	6
Pylon Sealing Angles.on Centre Spar A571-40779 76074/7282	10	435,000,010,010,010 010,010,010,010,010 010,010,010,010,010 010,010,010,019,400 212,400,214,212,200	25	000,080,438,262,250 232,021,021,021,021 021,021,021,021,021 021,021,021,000,000 934,000,184,934,000	4
Stringers 11 To 16 STBD & Port - 262" to 277" A571-40936	9	535,010,010,010,010 010,010,020,019,997 212,214,212,200	14	000,254,236,039,295 261,261,000,000,000 934,184,934,000	4
Stringers 14A to 17A STBD & Port - 309" to 318" A571-40936 75074/9284	9	535,010,010,010,010 020,019,997,212,214 212,200	12	000,254,236,039,261 000,000,000,934,184 934,000	3

TABLE 1.4

Title Dwg. No. Code No.	Depts. Visited	Department Sequence per Operation	No. of Ops.	Machine Sequence per Operation	No. of M/c. changes required
Stringers 11 & 8 Stbd.& Port 268.5" BTM 1/B A571-40802 75074/9284	11	535,010,010,010,010 010,010,020,019,997 010,997,212,214,212 200	16	000,254,236,039,236 295,261,000,000,000 542,000,934,184,934 000	6
Stringer 9 Stbd.& Port Top 1/B,274.5" A571-40790 75074/9284	12	535,010,010,010,010 010,010,010,010,020 010,019,010,997,212 211,214,212,200	19	000,000,432,236,039 236,295,295,295,000 201,000,542,000,934 000,184,934,000	6
Stringers 10& 11 Stbd.&Port Top 1/B 274.5" A571-40793 75074/9284	11	535,010,010,010,010 010,010,010,010,010 020,019,010,997,212 211,214,212,200	19	000,254,432,236,000 236,295,295,295,261 000,000,542,000,934 000,184,934,000	6
Stringer 19 Stbd.Btm/1/Bd. Panel No.2 A571-40235 75074/9284	13	435,010,010,010,010 010,010,010,010,020 019,010,400,010,400 212,400,214,212,200	20	000,254,236,039,039 039,039,236,261,000 000,261,000,542,000 934,000,184,934,000	6
Stringer 2 Port Top 1/Bd. Panel No.1 A571-40223 75074/9284	14	435,010,010,010,010 010,010,010,010,010 020,019,010,400,010 400,212,400,210,214	22	000,254,432,236,039 039,039,039,236,261 000,000,261,000,542 000,934,000,000,184	6
Bottom Fitting A571-40381 75074/6387	9	535,010,010,010,010 020,010,010,010,010 010,010,010,010,010 010,019,997,212,214 212,200	22	000,254,250,057,021 000,800,436,021,800 260,260,260,260,260 260,000,000,934,184 934,000	6
Joint Plate (Rib 27) A571-40509 64073/7085	7	435,010,010,010,010 010,010,010,010,010 010,010,019,040,400 400,212,200	18	000,000,436,262,232 000,436,295,295,295 295,295,000,555,000 000,934,000	4
Joint Fitting A571-40826 76074/5382	8	535,435,010,010,010 010,010,010,010,010 010,010,010,010,010 010,010,019,997,214 212,200	22	000,436,262,250,232 263,263,263,260,263 263,263,258,258,258 258,232,000,000,182 934,000	7

TABLE 2.1

DEPARTMENT MACHINE CODE.

DEPARTMENT.	MACHINE.	TYPE.
010	011	M&C MILL N C VERT MK 4B
010	021	M&C MILL FERRANTI 4C MAR
010	032	M&C MILL NC HOR B&B 3120
010	037	M&C MILL NC MARWIN 45D
010	038	M&C MILL NC HS MARW65MTT
010	039	M&C MILL NC MARW65M4
010	057	M&C NCTD (1 IN)40X20GE 120
010	088	M&C BATCHMATIC LATHE
010	100	M&C TOOL & CUTTER GRIND
010	110	M&C PLAIN CYLIND GRIND
010	111	M&C CENTRELESS GRIND
010	112	M&C INT GRIND UP TO 10 IN
010	113	M&C INT GRIND OVER 10 IN
010	115	M&C UNIV GRIND
010	117	M&C SURF GRIND HORIZ
010	118	M&C SUR GRIND VERT
010	131	M&C HONING DAYBROOK
010	201	M&C BORER HORIZ STD
010	202	M&C BORER HORIZ FINE
010	205	M&C JIG BORER
010	212	M&C BROACH HORIZ
010	222	M&C SINGLE MED DRILL
010	226	M&C SINGLE HEAVY DRILL
010	228	M&C MULTI LIGHT DRILL
010	232	M&C MEDIUM RAD DRILL
010	233	M&C HEAVY RAD DRILL
010	234	M&C ASQUITH 96 DRILL
010	236	M&C SPECIAL PURPOSE DRILL

TABLE 2.2

010	242	M&C PANTO ENGRAVER
010	245	M&C GEAR SHAPER
010	246	M&C HOBBING M&C
010	248	M&C KEY SEATER
010	250	M&C LIGHT HORIZ MILLER
010	251	M&C MED HORIZ MILLER
010	252	M&C HEAVY HORIZ MILLER
010	253	M&C MILL HOR TRAC HYDROMAT
010	254	M&C PLANO MILLER
010	255	M&C SPAR VAR ANGLE MIL
010	256	M&C MILL TRAC SPAR OVER 20
010	257	M&C SMALL UNIV MILLER
010	258	M&C MED UNIV MILLER
010	259	M&C LARGE UNIV MILLER
010	260	M&C LIGHT VERT MILLER
010	261	M&C MED VERT MILLER
010	262	M&C HEAVY VERT MILLER
010	263	M&C HYDROTEL VERT MILL S
010	264	M&C HYDROTEL VERT MILL L
010	266	M&C LIGHT PROFILER
010	272	M&C BRIDGEPORT TINE A MILL
010	290	M&C PROFILE
010	295	M&C HEAVY DUTY ROUT
010	316	M&C OPTICAL ROUTERTRACE
010	322	M&C SHAPER HORIZ COPY
010	324	M&C SLOTTER HORIZ
010	327	M&C SLOTTER SCREWHEAD
010	354	M&C TAPPING
010	356	M&C THREAD MILL
010	358	M&C THREAD ROLL

TABLE 2.3

010	359	M&C THREAD GRINDER
010	369	M&C PLUGBOARD SEQU CAPST
010	370	M&C LIGHT AUTO LATHE
010	371	M&C MED AUTO LATHE
010	374	M&C CAPSTAN LIGHT BAR
010	375	M&C CAPSTAN LIGHT CHUCK
010	376	M&C MED TURN CAPSTAN
010	377	M&C MED TURRET LATHE
010	378	M&C HEAVY COMBIN LATHE
010	381	M&C CENTRE LATHE
010	382	M&C MED CENTRE LATHE
010	383	M&C LARGE CENTRE LATHE
010	384	M&C PROFILE LATHE
010	385	M&C VERT BORING LATHE
010	394	M&C SPECIAL LATHE
010	395	M&C SPECIAL LATHE
010	396	M&C MILL SPECIAL PURPOSE
010	432	M&C PART OFF SAW
010	436	M&C BANDSAW
010	462	M&C STRINGER PIERCE
010	501	M&C 4 ROLL SPAR BEND
010	502	M&C SPAR BENDING HOT
010	505	M&C COLD HEADING
010	533	M&C HYD HOR PRESS CARV 800
010	542	M&C SPAR LIGHT HYD PRESS
010	800	M&C MARK OUT
019	000	M&C FINISHING FITTERS
020	000	M&C FINISHING SEMIS
200	000	CHAD PAINT LABOUR
211	000	HEAT TREAT LABOUR
212	000	PLATING LABOUR
400	000	INSPECTION

APPENDIX 4.

QUESTIONNAIRE ON THE EFFECTS AND BENEFITS OF GROUP TECHNOLOGY.

THE UNIVERSITY
OF ASTON
IN BIRMINGHAM

Gosta Green, Birmingham B4 7ET/Tel: 021.359 3611 Ex

Department of Production Engineering
Head of Department: Professor R H Thornley MScTech, PhD, AMCT, CEng, FIMechE, FIProdE
Professor of Applied Mechanics: T C Hsü BSc, PhD

PROD/AWB/LBM

Dear Sir,

As a lecturer on study leave from the College of Advanced Education in Toowoomba, Queensland, Australia, I am undertaking research into Group Technology under the supervision of Professor R H Thornley of the University of Aston in Birmingham where I am registered as a research student.

In preliminary readings and discussions on the subject it has become apparent how little is known of the precise overall effect Group Technology has on industry in Great Britain, Europe and the USA and especially on firms who have had the foresight to implement it.

We are familiar with the many claimed benefits attributed to Group Technology and a number of firms have freely stated the nature and amount of benefits they have derived from its introduction. However, one is left to conjecture whether these experiences are general or whether they represent only the most successful.

In consultation with Professor Thornley I have drawn up a questionnaire which I hope you will complete and return to the undersigned at the above address, as soon as possible.

Any information supplied will not be published individually nor will the names of the firms be revealed. Indeed respondents may remain anonymous if they so wish. An analysis of all the forms returned will be made and publication of general statistical findings will follow. It is to be hoped that an overall indication of the benefits available to firms will be forthcoming and that this information can in turn be used to spread the Group Technology concept further afield.

If you would like a free copy of the published results please tick the box at the bottom of page 3 of the questionnaire.

Thanking you in anticipation of your assistance and assuring you of our utmost discretion,

Yours faithfully

A W Boundy

Telex 336997

REF. NO.

QUESTIONNAIRE

ON

THE METHODS, EFFECTS AND BENEFITS OF IMPLEMENTING GROUP TECHNOLOGY

PRODUCTION ENGINEERING DEPARTMENT

UNIVERSITY OF ASTON IN BIRMINGHAM

1. NAME AND ADDRESS OF FIRM: (optional) . . . .

. . . .

. . . .

GENERAL DESCRIPTION OF PRODUCT RANGE: . . . .

. . . .

. . . . NO. OF EMPLOYEES . . . . .

NAME AND POSITION OF RESPONDENT: (optional) . . . .

. . . .

2. INDICATE WHICH OF THE FOLLOWING WERE USED AND IN WHAT ORDER G.T. IMPLEMENTATION WAS CARRIED OUT:

			e.g.
a)	classification and coding of component drawings	☐	-
b)	formation of component families	☐	2
c)	set up a pilot cell	☐	-
d)	'a' and 'c' simultaneously	☐	1
e)	set up a number of cells after 'b'	☐	3
f)	any other (state)	☐	-

3. INDICATE THE NAME OF THE CODING SYSTEM USED (if applicable): . . . .

. . . . No. OF DRAWINGS CODED: . . . . .

4. TYPE OF CONSULTANCY USED (✓ appropriate box)

a) management consultants ☐

b) university academics ☐

c) no outside help ☐

5. NUMBER AND TYPE OF CELLS FORMED (insert number in appropriate box)

a) single G.T. machine ☐

b) group of machines ☐

c) flowline groups ☐

10. WITH REGARD TO CELL OPERATIONS HAVE YOU, (yes or no)

a) independent cell tool and fixture stores

b) setter operators

c) flexibility of operators to suit machine loadings.

d) allowed cells to schedule their load

e) adopted cell quality control

f) An incentive scheme (type . . . .)

g) used preset tooling

h) developed specialized jigs and fixtures

11. STATE THE PERCENTAGE REDUCTION FOUND IN THE FOLLOWING AFTER G.T.

a) throughput times (average)

b) work in progress

c) finish component stock

d) tool preparation and setting costs

e) tooling purchases (if increase, state)

f) raw material stocks

g) pre-production costs (planning, data, jigs, fixtures)

h) reworked and scrap component costs

i) indirect labour costs

j) machine setting times

k) any other quantifiable effect (state) . . . .

12. HAS EMPLOYEE REACTION TO G.T. BEEN (√ or state % if possible)

a) enthusiastic and helpful with change to G.T.

b) indifferent at first but later improving

c) suspicious and resentful

d) less absenteeism since G.T. %

e) more punctual start since G.T.

13. WHAT IS YOUR ESTIMATE OF THE OVERALL COST OF G.T. IMPLEMENTATION?

. . . .

14. TICK BOX FOR FREE COPY OF PUBLISHED RESULTS

REFERENCES.

1. Grayson, T.J. — Group Technology - East and West. Paper presented to the Inst. Prod. Engrs., Huddersfield, March, 1968.

2. Sokolovsky, A.P. — Problema Tipizatsiyii Tekhnologicheskikh Protsessov, 1938. ONTI, NKTP, SSSR.

3. Mitrofanov, S.P. — Nauchnye Osnovy Gruppovoi Tekhnologii, 1959, Lenizdat.

4. Mitrofanov, S.P. — The Scientific Principles of Group Technology, 1966. Trans. by National Lending Library.

5. Opitz, H. — Workpiece Statistics and the Manufacture of Workpiece Families. VDI-Zeit, V.106, 1964.

6. Opitz, H. — A Classification System to Describe Workpieces, Parts 1 and 2, Pergamon Press, Oxford, 1970.

7. Ranson, G.M. — Group Technology, Pub. by McGraw Hill, 1972.

8. Connolly, R. — The Integiation of Group Technology Principles into a Manufacturing System. Ph.D. Thesis, Victoria University of Manchester, 1969.

9. Middle, G.H. — The Development and Design of an Industrial Classification and Coding Scheme with Reference to its Application to a Group Technology Manufacturing Concept and other Organisational Needs. M.Sc. Thesis, UMIST, 1968.

10. Connolly, R., Middle, H., Thornley, R.H. — Organising the Manufacturing Facilities in Order to obtain a Short and Reliable Manufacturing Time. 11th. M.T.D.R. Conf., Birmingham, 1970.

11. Connolly, R., Middle, H., Thornley, R.H. — Organisation Problems and the Relevant Manufacturing System. Int. G. Prod. Res. 1971, Vol.9.

12. Moreton, R.J. — Production Engineering in G.T. 4th Annual Conf. on Group Technology, Coventry, 1974.

13. Wood, J.M. — A Case Study of G.T. at Rank Xerox,Mitcheldean. 4th Annual Conference on Group Technology, Coventry, 1974.

14. Thornley, R.H. — Group Technology - A Complete Manufacturing System. Inaugral Lecture, Uni. of Aston in Birmingham, October, 1971.

15. Burbidge, John L. — Group Technology edited by J.L. Burbidge, Proceedings of International Seminar, Sept. 1969, Turin.

16. Burbidge, John L. — Production Planning, Pub. by Heinemann, London, 1971.

17. Burbidge, John L. — The Introduction of Group Technology, Pub. by Heinemann, London, 1975.

18. Burbidge, John L. — Production Flow Analysis on the Computer 3rd. Annual Conf. on Group Technology, Sheffield, 20/21st. Nov., 1973.

19. Lepper, C. — G.T. Methods at Rolls Royce (1971) Ltd. 3rd Annual Conf. on Group Technology, Sheffield, 20/21st. Nov., 1973.

20. Perrins, H.R. — Group Technology Application in a Large Company, 2nd Annual Conf. on G.T., Banbury, 28/29th. Nov., 1972.

21. Bryan, D. — Group Technology Application in a Small Company, 2nd. Annual Conf. on G.T. Banbury, 28/29th. Nov., 1972.

22. El-Essawy, Dr. I.G.K. and Torrance, J. — Component Flow Analysis - an effective approach to Production Systems' Design, The Production Engineer, May, 1972.

23. Caudwell, F.W. — Medium to Heavy Engineering, 2nd Annual Conference on G.T., Banbury, 28/29th Nov. 1972.

24. Nichol, J.D. — Formation of Man-Machine Groups. Seminar at Uni. of Aston in Birmingham, 17/18th Nov., 1971.

25. Eldred, A.H. — Implementation of Group Technology, Seminar at Uni. of Aston in Birmingham, 17/18th Nov., 1971.

26. Nicol, J.D. — Production Cost Savings, 2nd Annual Conf. on G.T., Banbury, 28/29th Nov., 1972.

27. Risk, J.M. — The Classification and Coding of Accounts. The Institute of Cost and Works Accountants, Paper No. 2, 1956.

28. Gallagher, C.C. Knight, W.A. — Group Technology, Pub. by Butterworths, 1973.

29. Gombinski, J. — The Brish Classification and Group Technology Proceedings of International Seminar, Sept.1969, Turin, Italy.

30. Williamson, D.T.N. — A New Pattern of Batch Manufacture, The Chartered Mechanical Engineer, July, 1968.

31. Haworth, E.A. — Formation of Man-Machine Groups. Seminar at Uni. of Aston in Birmingham, 17/18th Nov., 1971.

32. Sidders, P.A. — Group Machining Improves Output of Electric Motor Components (English Electric Co. Ltd., Bradford).
Machinery and Production Engineering, Vol.108, Vol. 2794, June, 1966.

33. Edwards, G.A.B. — Readings in Group Technology,
The Machinery Publishing Co. Ltd., 1971.

34. Ivanov, E.K. — Group Production Organization and Technology,
Business Publications, London, 1968.

35. Newman, T.D. — An Approach to the Development of Classification Schemes in the Foundry Industry with Particular Reference to Cost-Estimating.
M. Phil. Thesis, Uni.of Aston in Birmingham, 1975.

36. - - - — A Survey of the Turning Requirements for Industry, PERA, (1966).

37. - - - — A Survey of the Machining Requirements for Industry, PERA, (1969).

38. Zimmerman, D. — 'Zafo-Eine allgemeine Formenordnung fur Werkstucke',
Technischer Verlag Gunter Grossman, Stuttgart, 1967.

39. Zimmerman, D. — 'Design - The Focal Point for Rationalisation',
Engineers' Digest, 1968.

40. Yarko, E.A. — 'Standardisation of Machining Processes in Engineering'.
Russian Engineering Journal, 1962.

41. Burbidge, J.L. — Final Report, Proceedings of International Seminar on Group Technology, Turin, 1969.

42. Burbidge, J.L. — Group Technology, InComTec Seminar,
Piccadilly Hotel, London, 7/8th April, 1975.

43. Brankamp, K. — Objectives, Layout and Possibilities of a Workpiece Classification System,
Proceedings of International Seminar, Turin, 1969.

44. Kruse, G. — 'Feasibility Study for the Implementation of a G.T. System in a Multi-Product Company'.
M. Phil. Thesis, Uni. of Aston in B'ham,1974.

45. MacConnell, W.R. — 'Why Companies make the Decision to Implement Group Technology',
2nd Annual G.T. Conference,Banbury, 1972.

46. Hawkins, W.A. — 'Herberts Big Switch to G.T.'
Metalworking Production, July, 1973.

47. Nichol, N.A. — 'Formation of Man-Machine Groups',
G.T. Seminar, Univ. of Aston in Birmingham, 17/18th Nov. 1971.

48. Dudley, N.A. Comparative Productivity Analysis, Dept. of Production Engineering, University of Birmingham, 1975.

49. Bryan, D. Group Technology Application in a Small Company, 2nd Annual Conf. on G.T. at Banbury,28/29th Nov. 1972.

50. Hutton, M.A. Whitfield, T. Scheduling and Programming, Fourth Annual G.T. Conf., Coventry, 20/21st Nov. 1974.

51. Marklew, J.J. An Application of the Cell System in a Small Machine Shop, Machinery and Production Engineering, Aug., 1972.

52. Crescimone, S. An Application of the "Technological Families" Method, Proceedings of International Seminar, Turin, 1969.

53. Kruse, G. Swinfield, D.G.J. Thornley, R.H. Design of a Group Technology Plant and its Associated Production Control System, The Production Engineer, July/Aug., 1975.

54. Durie, F.R.E. Group Technology as Applied in an Electronic Firm, Proceedings of International Seminar, Turin, Sept., 1969.

55. Moll, H. A User's View Point of the Machine Tool of the Future, 4th MTDR Conference, 1963, Pergamon Press, Oxford, 1964.

56. Wilford, J.S. Human Aspects in G.T. Systems, 4th Annual G.T. Conference Held at Coventry, 20/21st Nov., 1974.

57. Craven, F.W. Human Aspects of Group Technology, 4th Annual G.T. Conference held at Coventry, 20/21st Nov., 1974.

58. - Volvos New Car Plant has no Assembly Line, Metalworking Production, July,1974.

59. Arn, E. Application of Systems Engineering to Group Technology, Ph.D. Thesis, March,1974. University of Aston in Birmingham.

60. Burbidge, J.L. A.I.D.A. and Group Technology, Turin International Centre, Torino, Italy, 1972.

61. Burbidge, J.L. The Principles of Production Control, 3rd Edition, McDonald and Evans Ltd., 1971.

62. Hunt, R.M. 'An Investigation into the Application of Group Technology Principles for a Company Manufacturing Complex Products in Small Batches.' M.Sc. Dissertation, University of Aston in Birmingham, Oct., 1972.

63. Thornley, R.H. By private communication.

64. Swannack, A.R.; Samuel, P.J. 'The Added Value of Men and Materials', Personnel Management, Feb., 1974.

65. Grange Moore, J. Added Value as an Index of Industrial Effectiveness, Work Study and Management Services, The Journal of the Institute of Work Study Practioners, Jan. 1973.

66. Dransfield, J.D. The Introduction of Group Technology Via Coding Techniques, A Case Study, M.Phil. Thesis, University of Aston in Birmingham, June, 1974.

67. - A Hawker Siddeley Brochure.

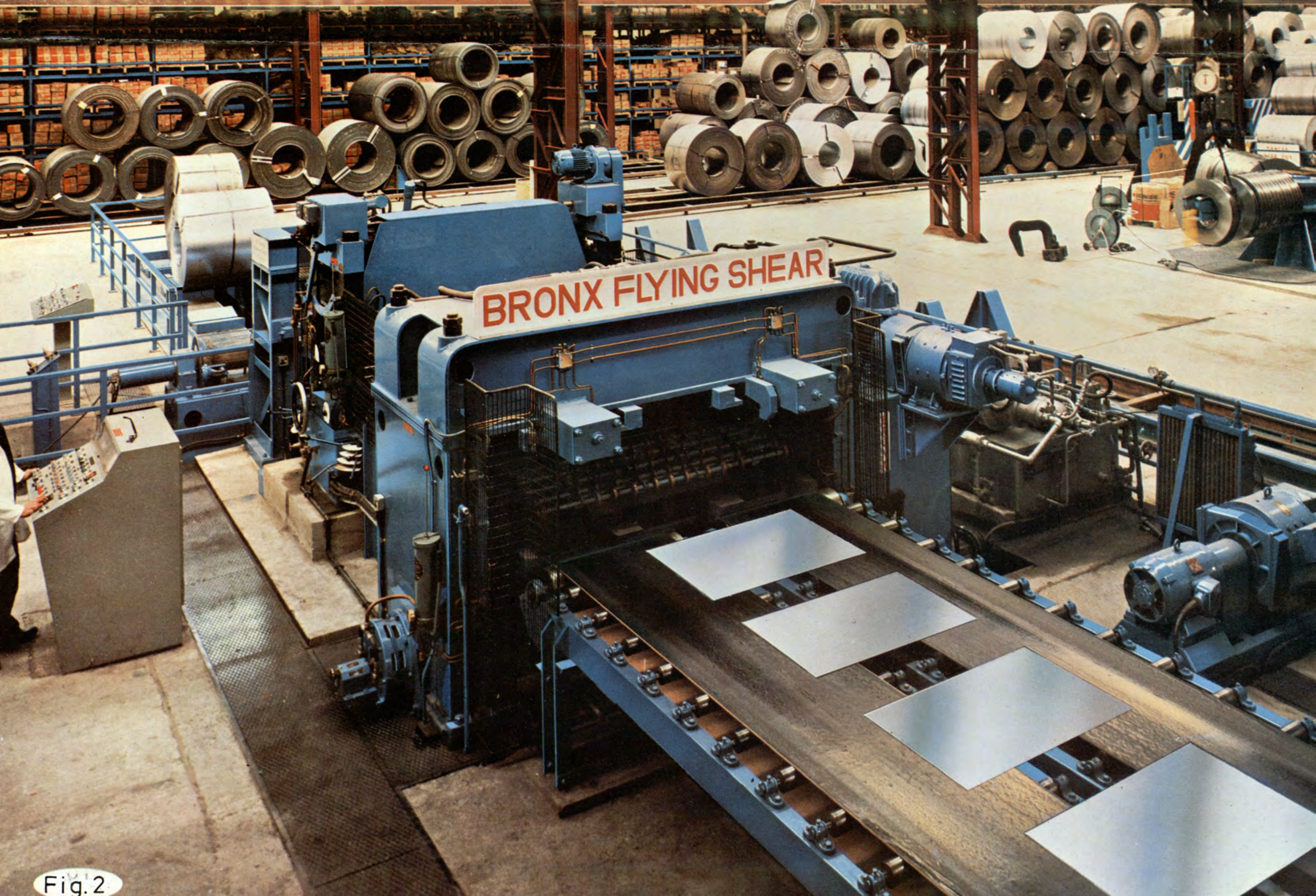


Fig. 2

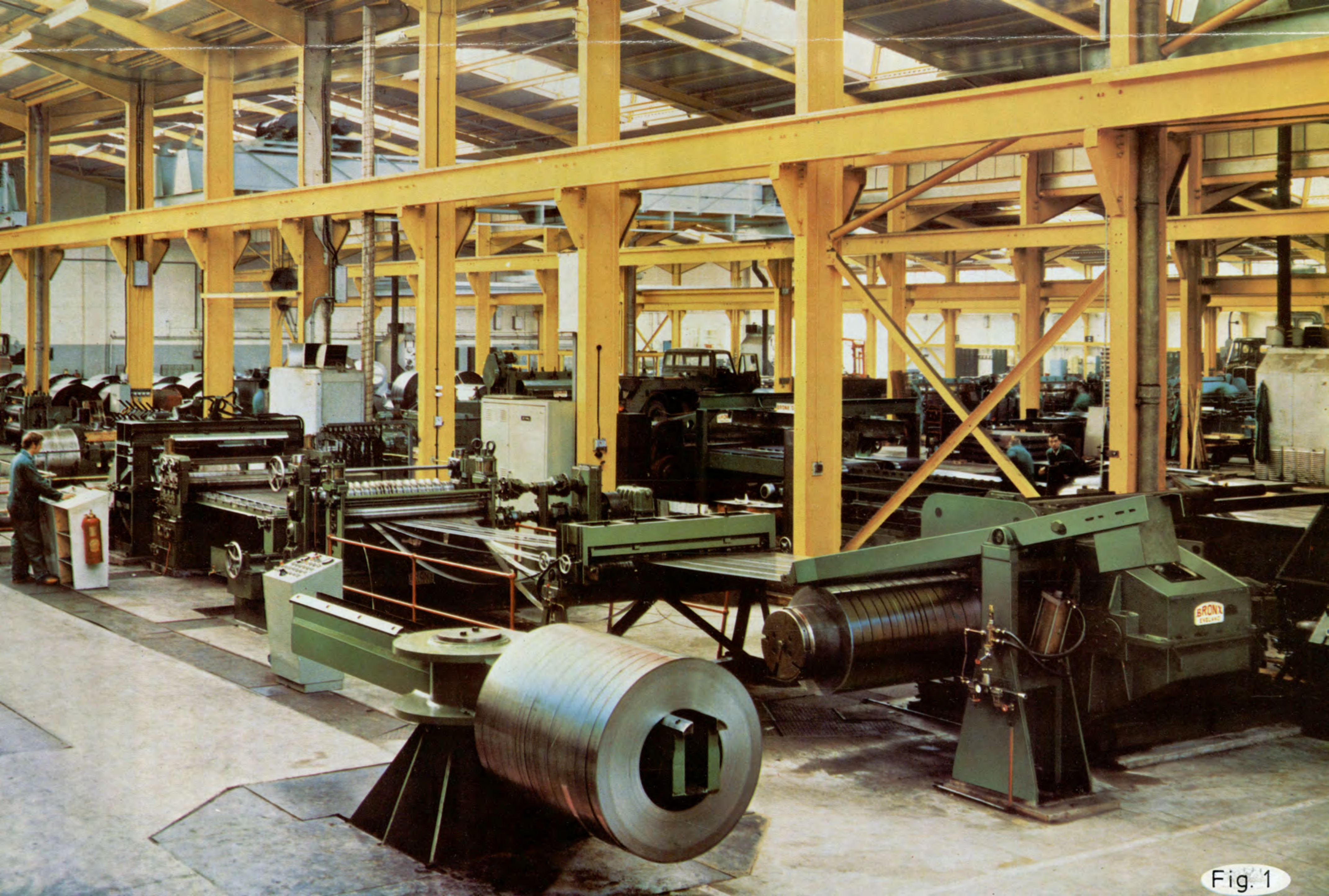
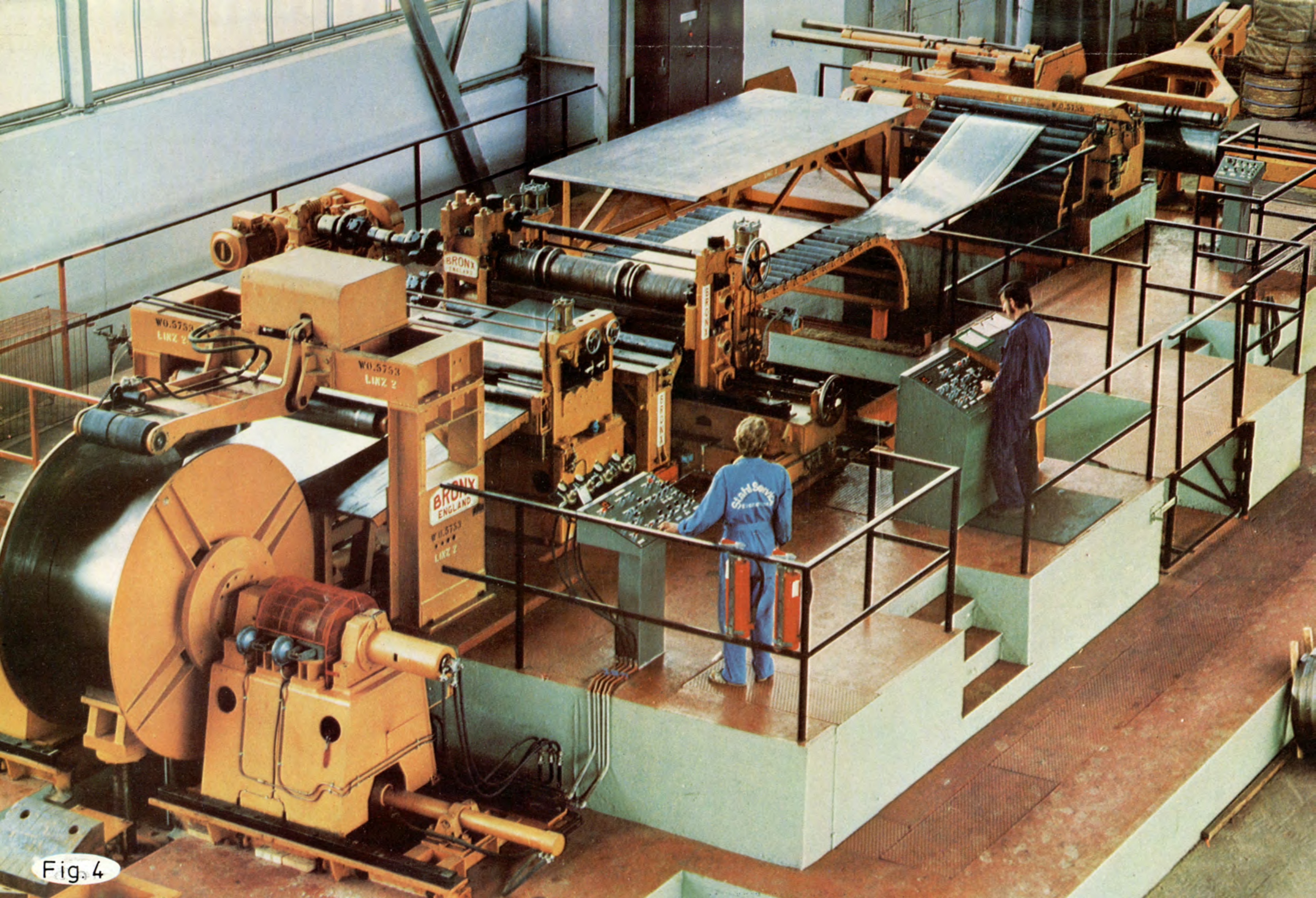


Fig. 1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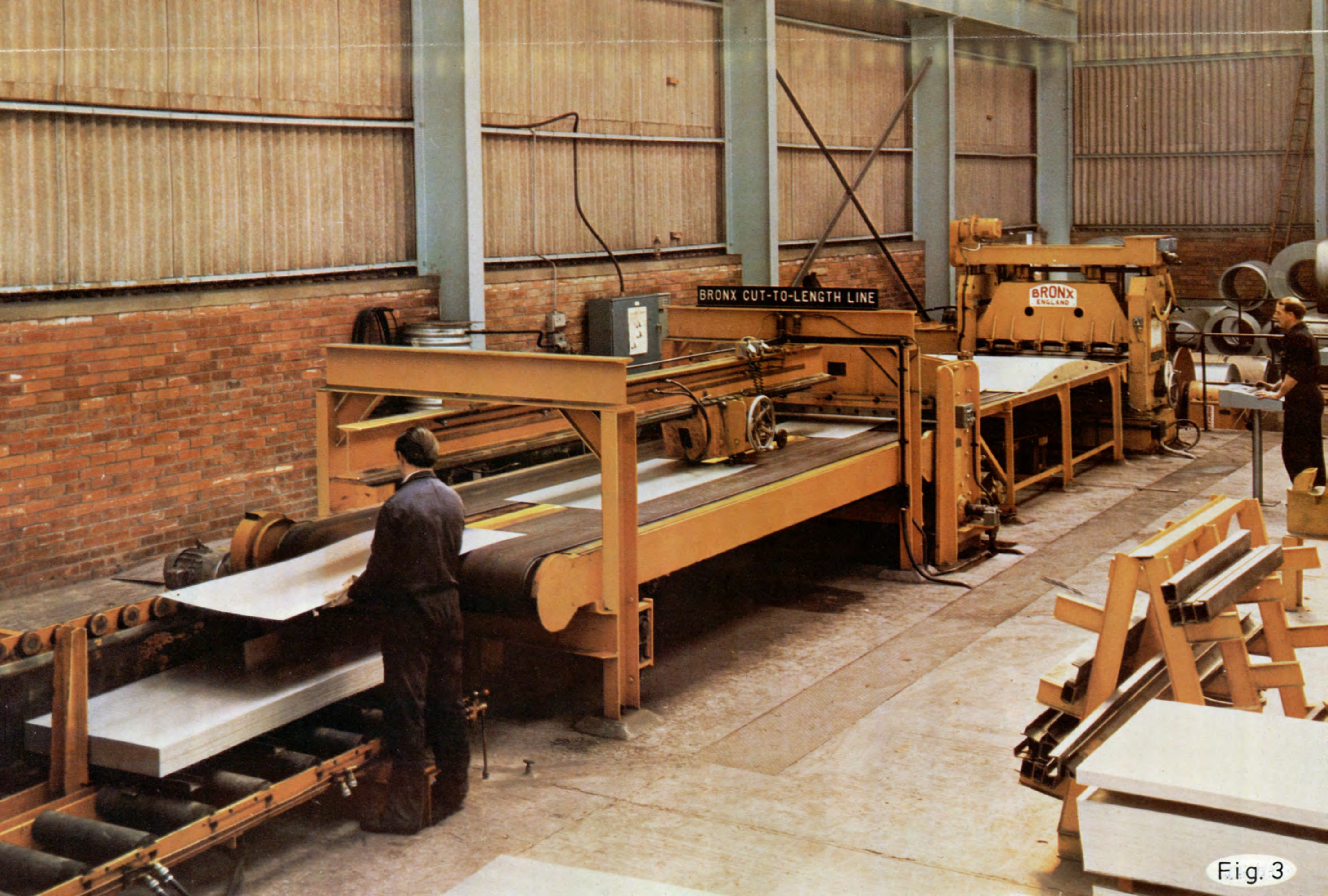
W0.5753 LINZ 2
W0.5753 LINZ 2
BRONX ENGLAND
W0.5753 LINZ 2
Fig. 4



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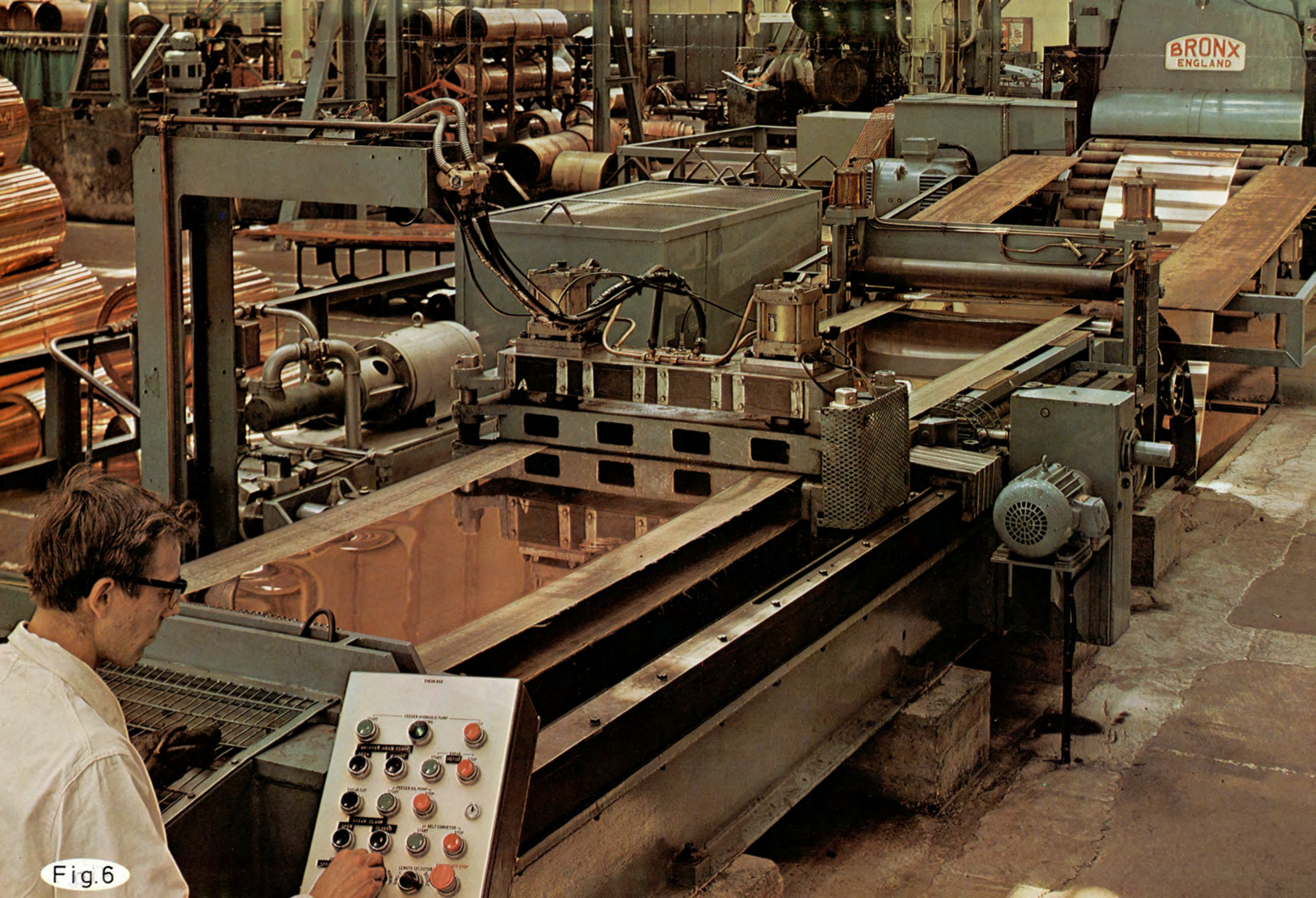
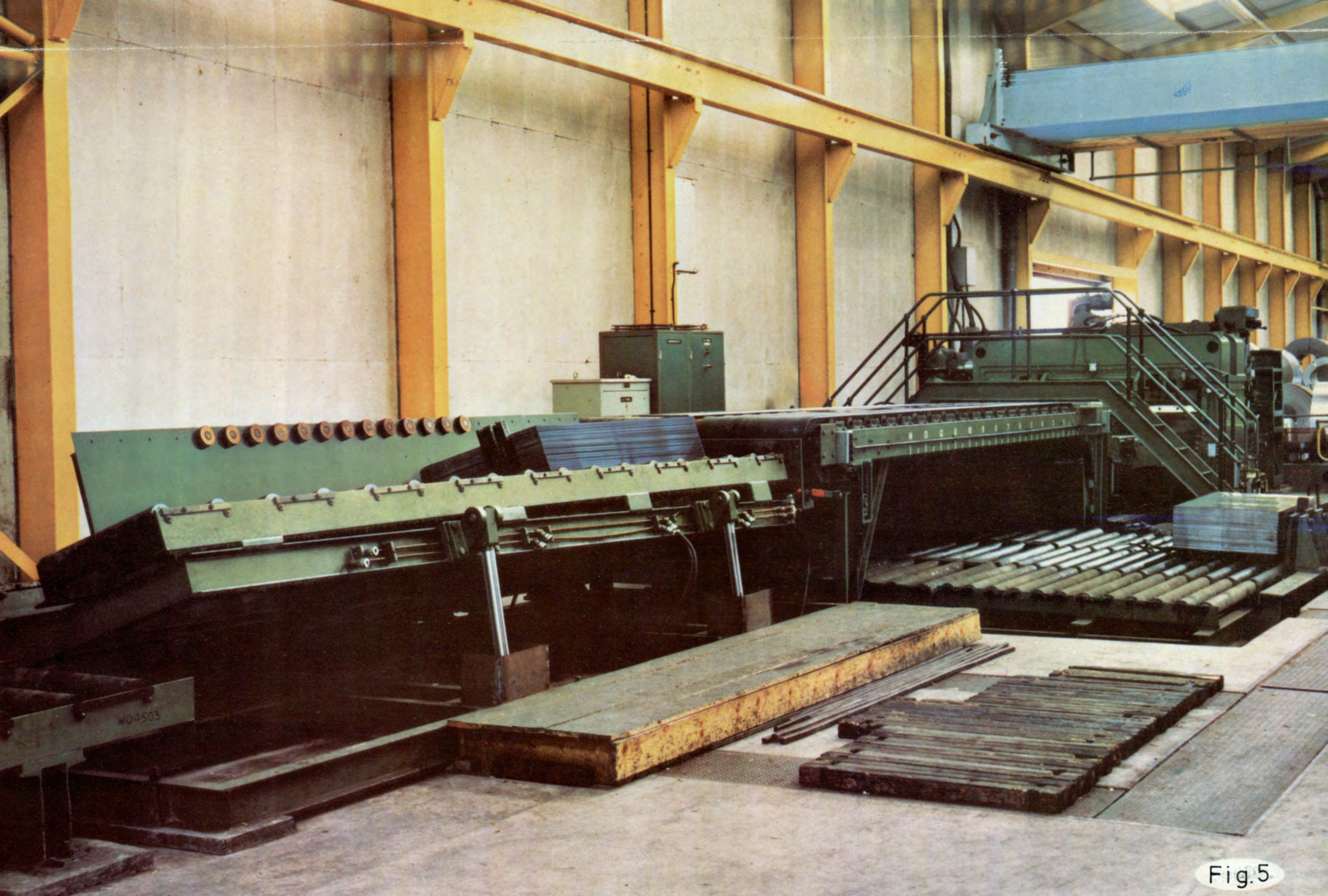

BRONX
ENGLAND
SHEAR BOX
FEEDER HYDRAULIC PUMP
START
STOP
SHEAR CUT
FEEDER OIL PUMP
START
STOP
SHEAR CLAMP
OPEN
CLOSED
BELT CONVEYOR
START
STOP
LENGTH SELECTOR

Fig.6



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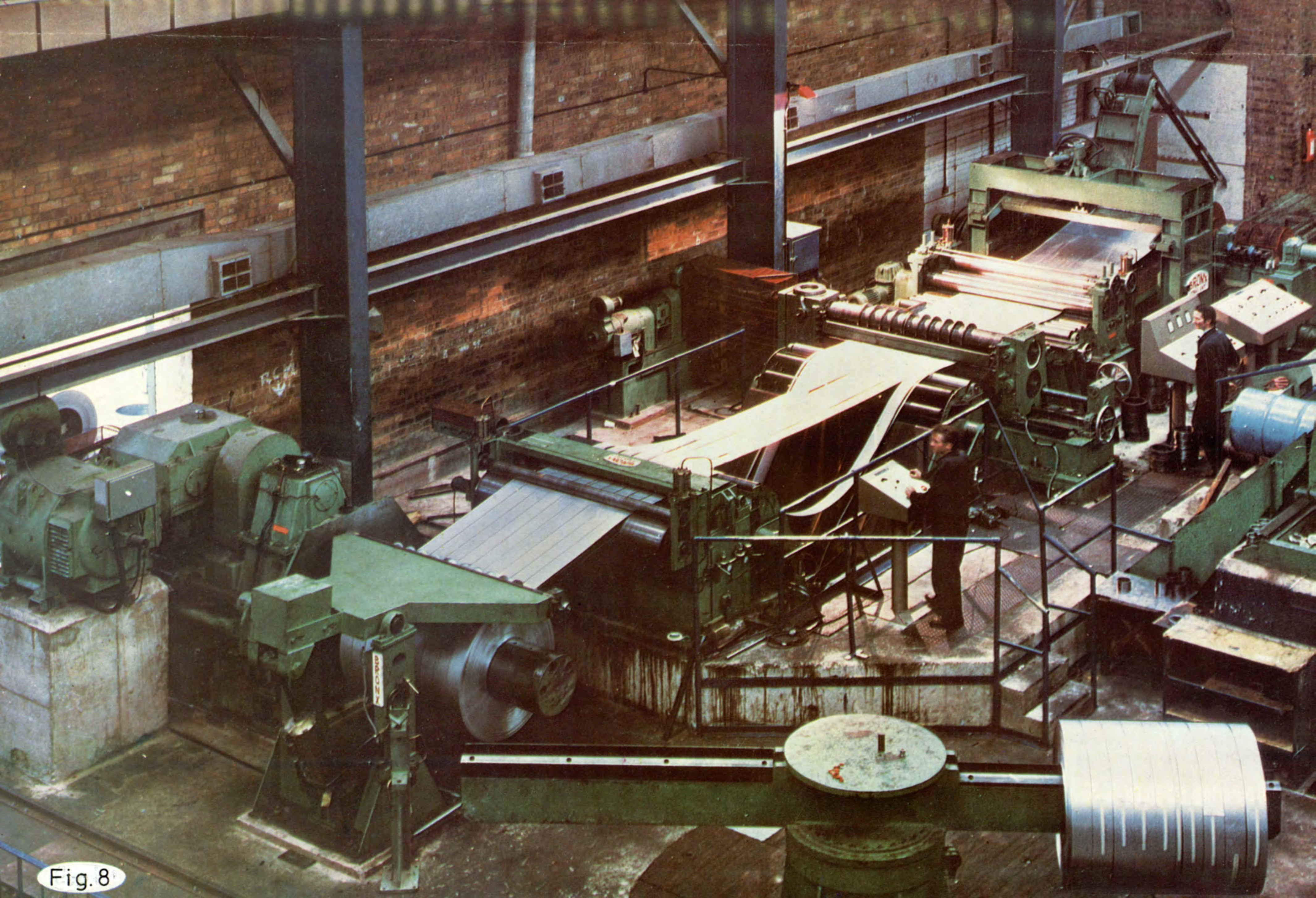


Fig. 8

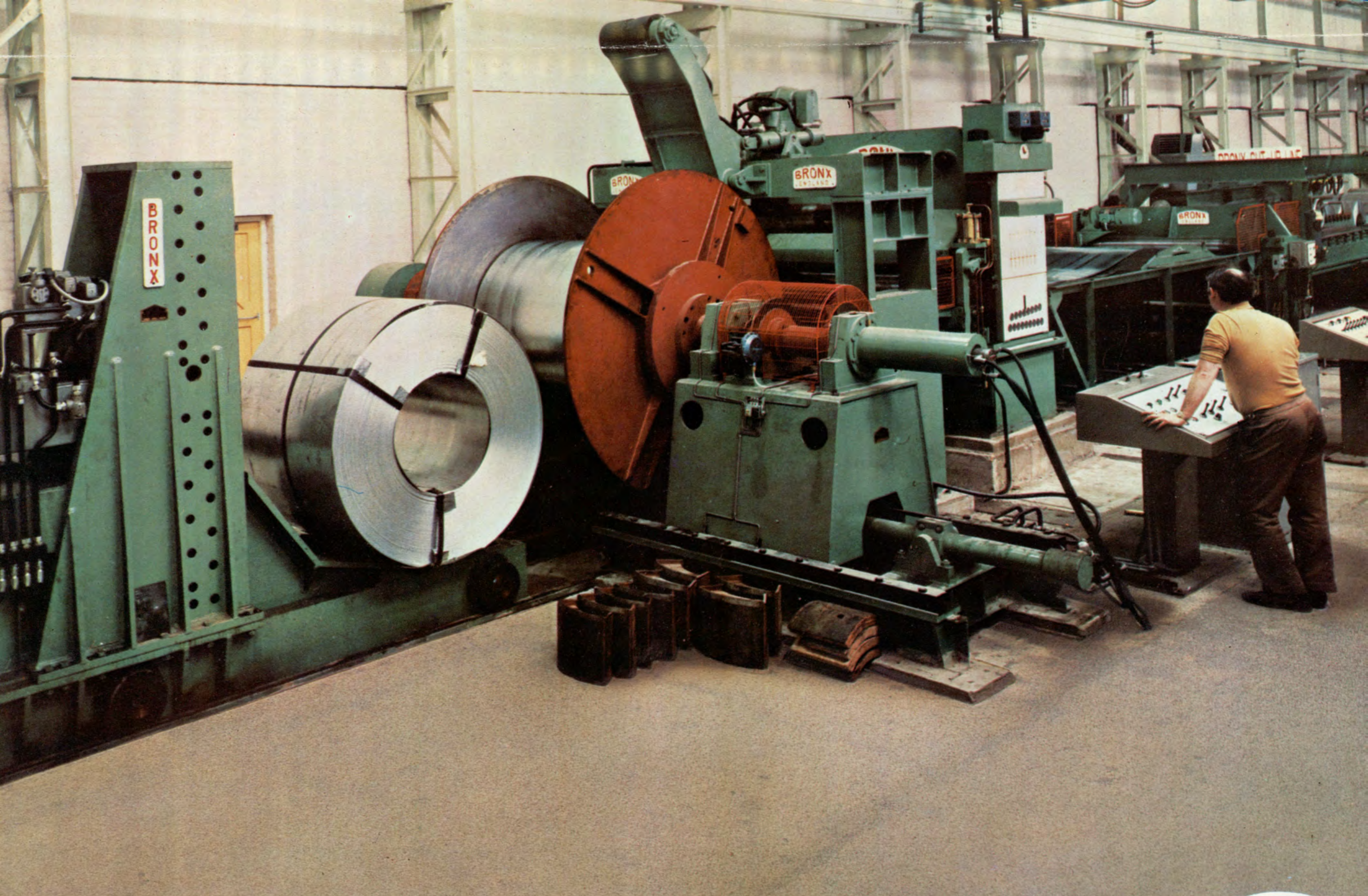


Fig.7

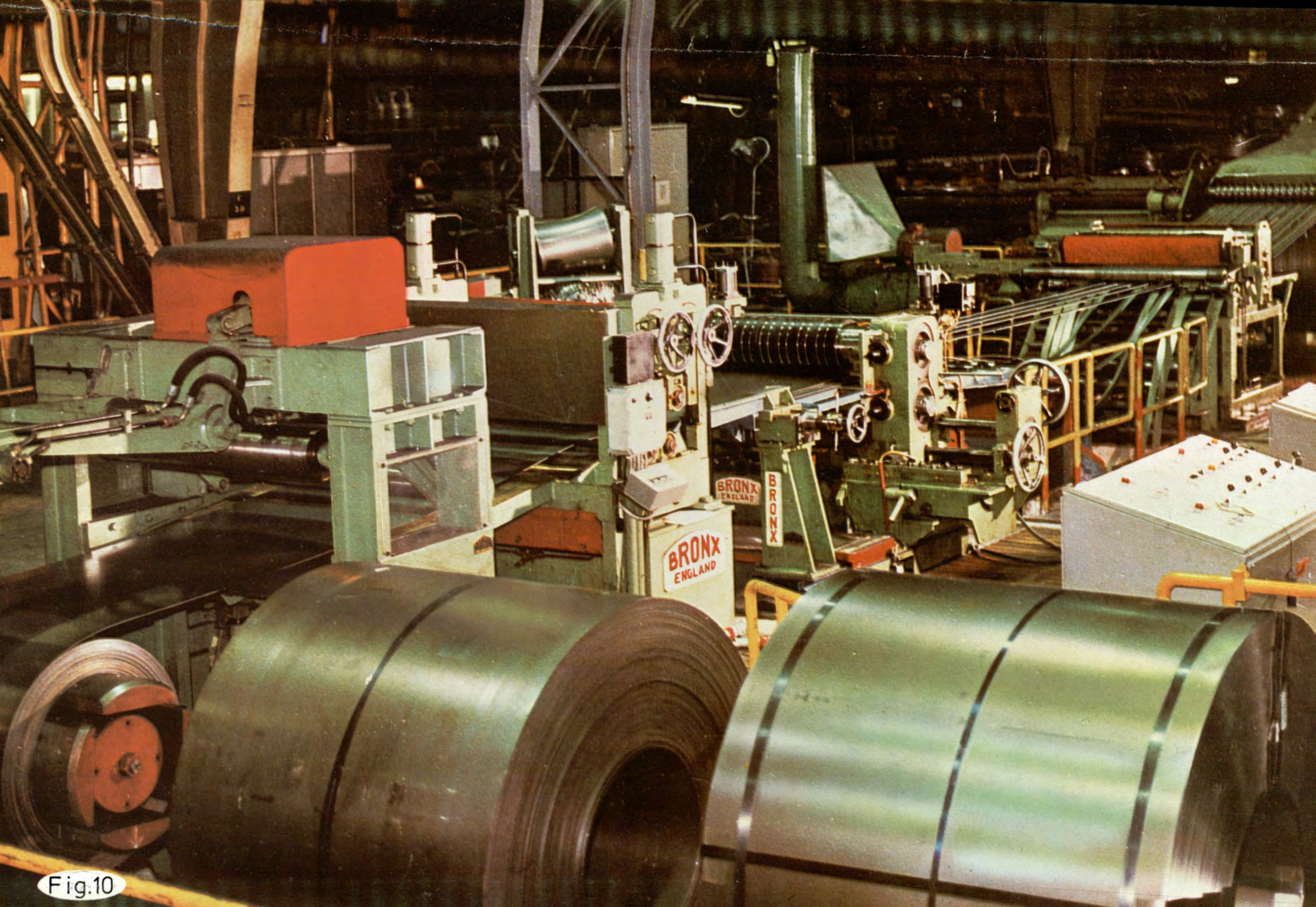


Fig.10

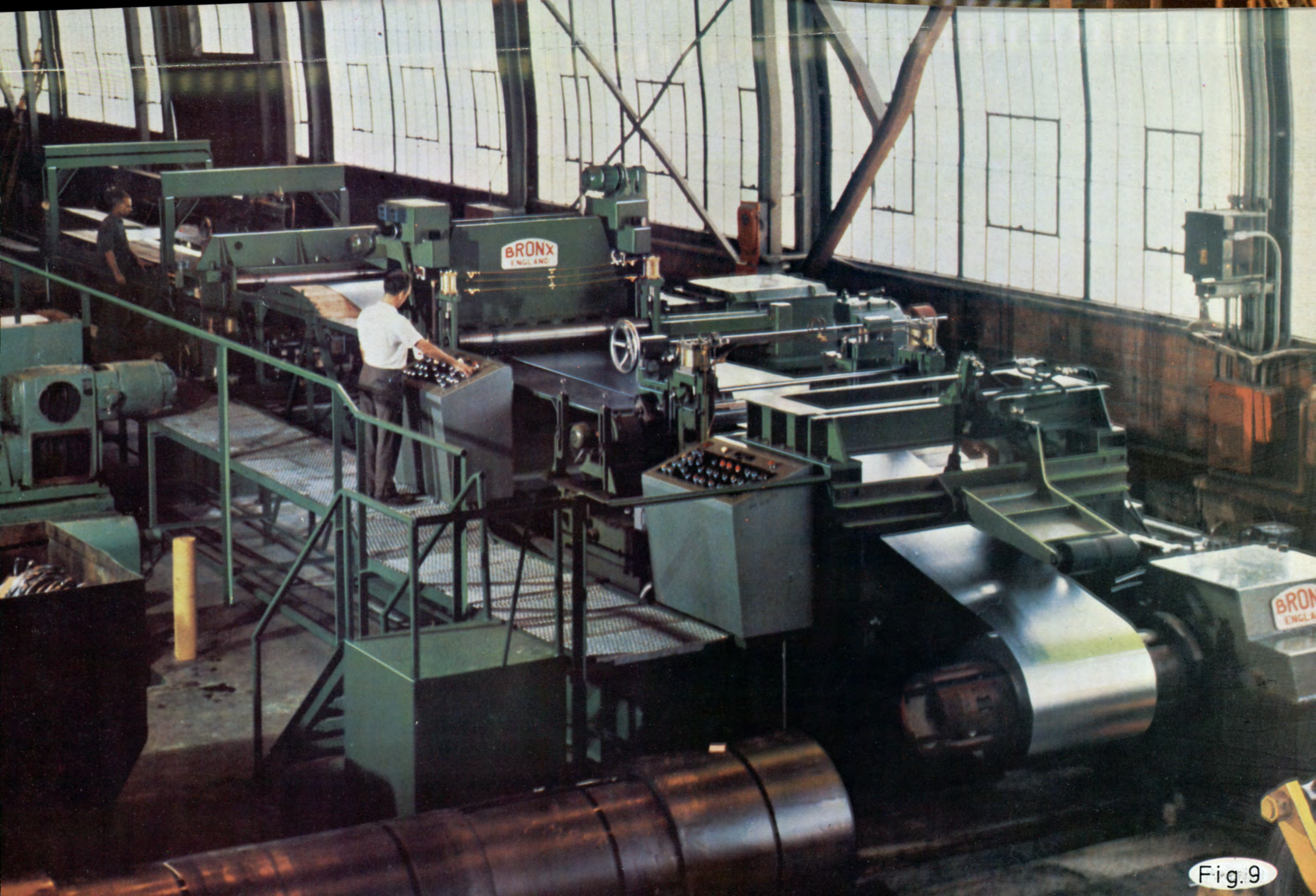
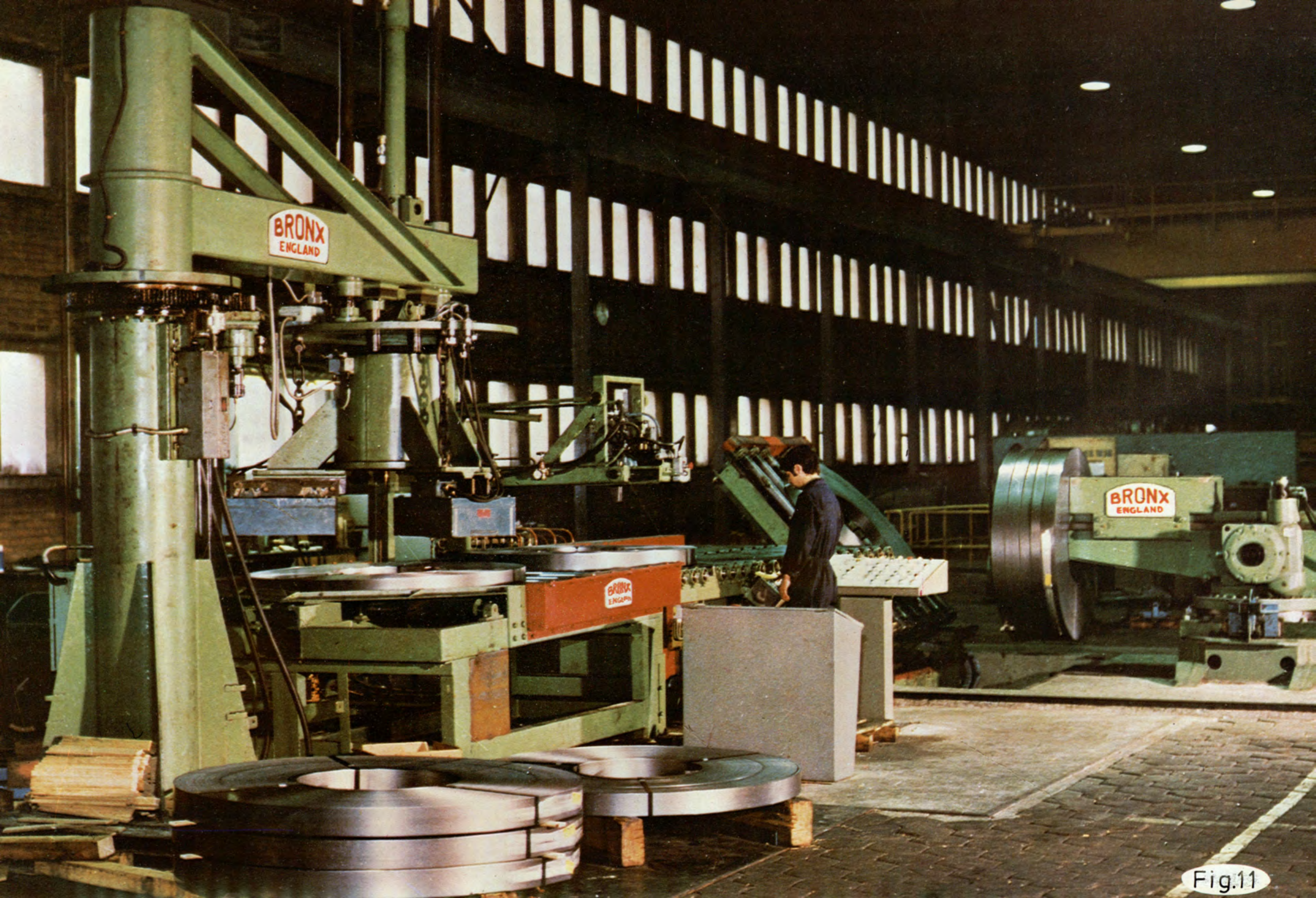


Fig. 9



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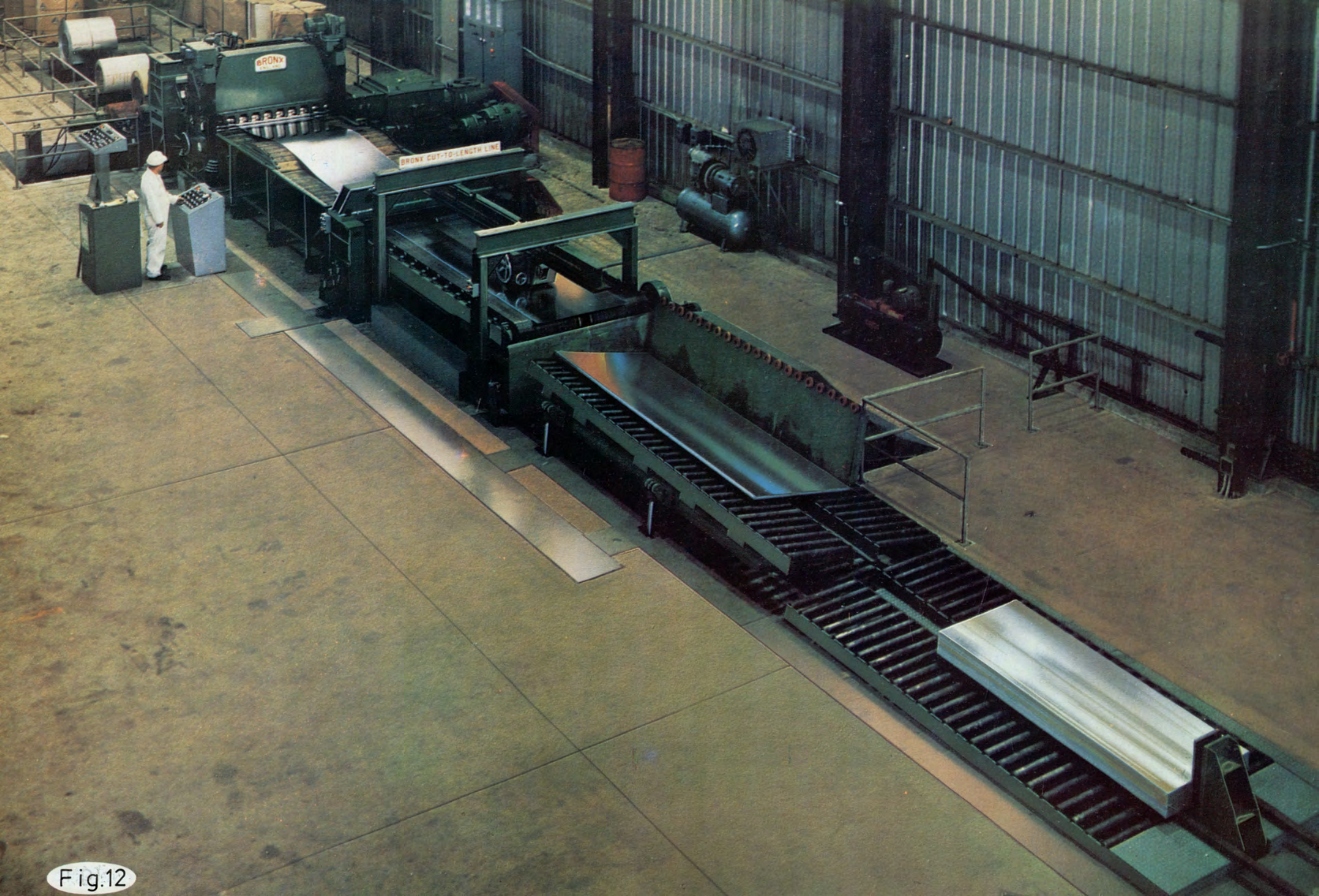

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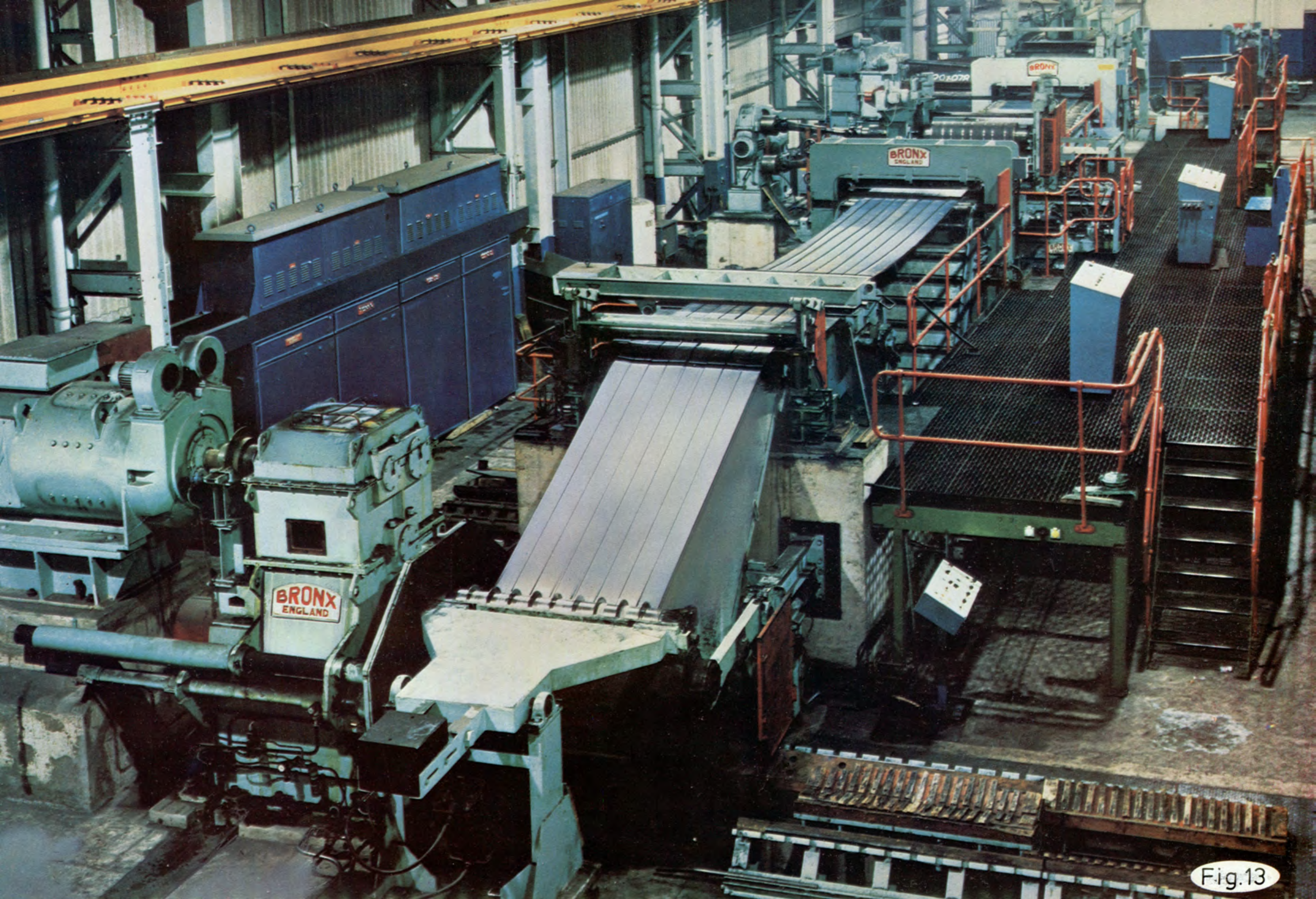


Fig.13

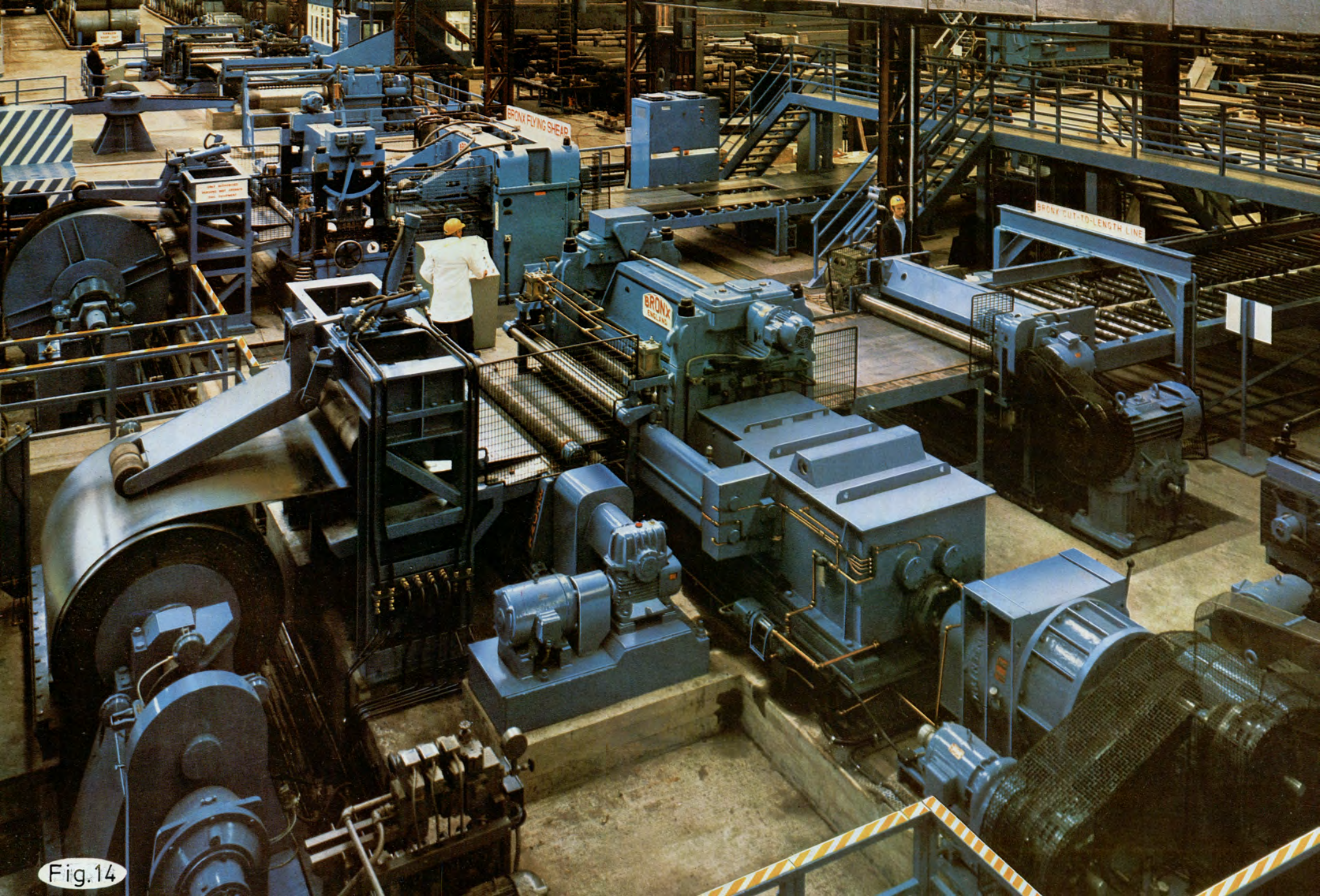
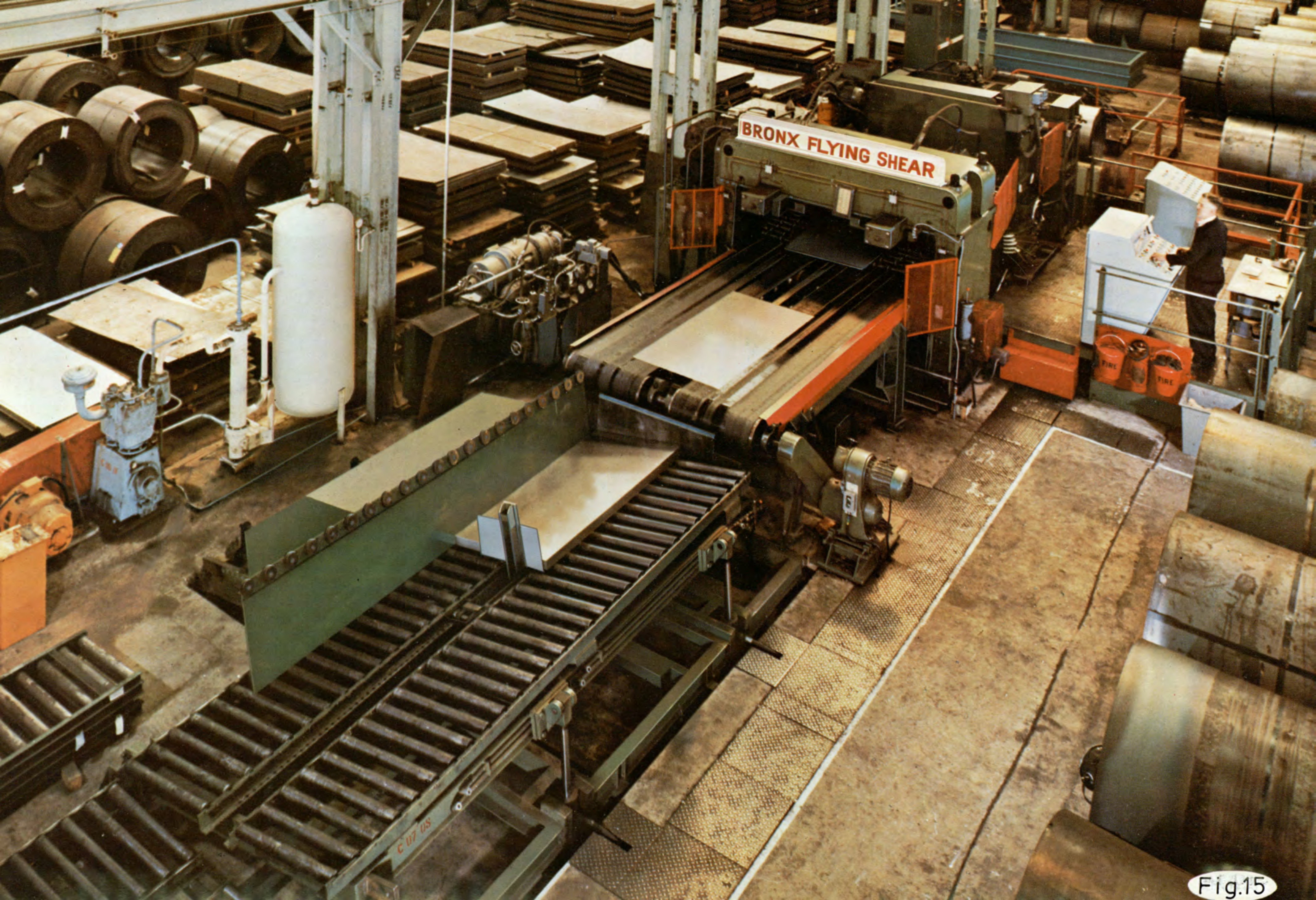


Fig.14



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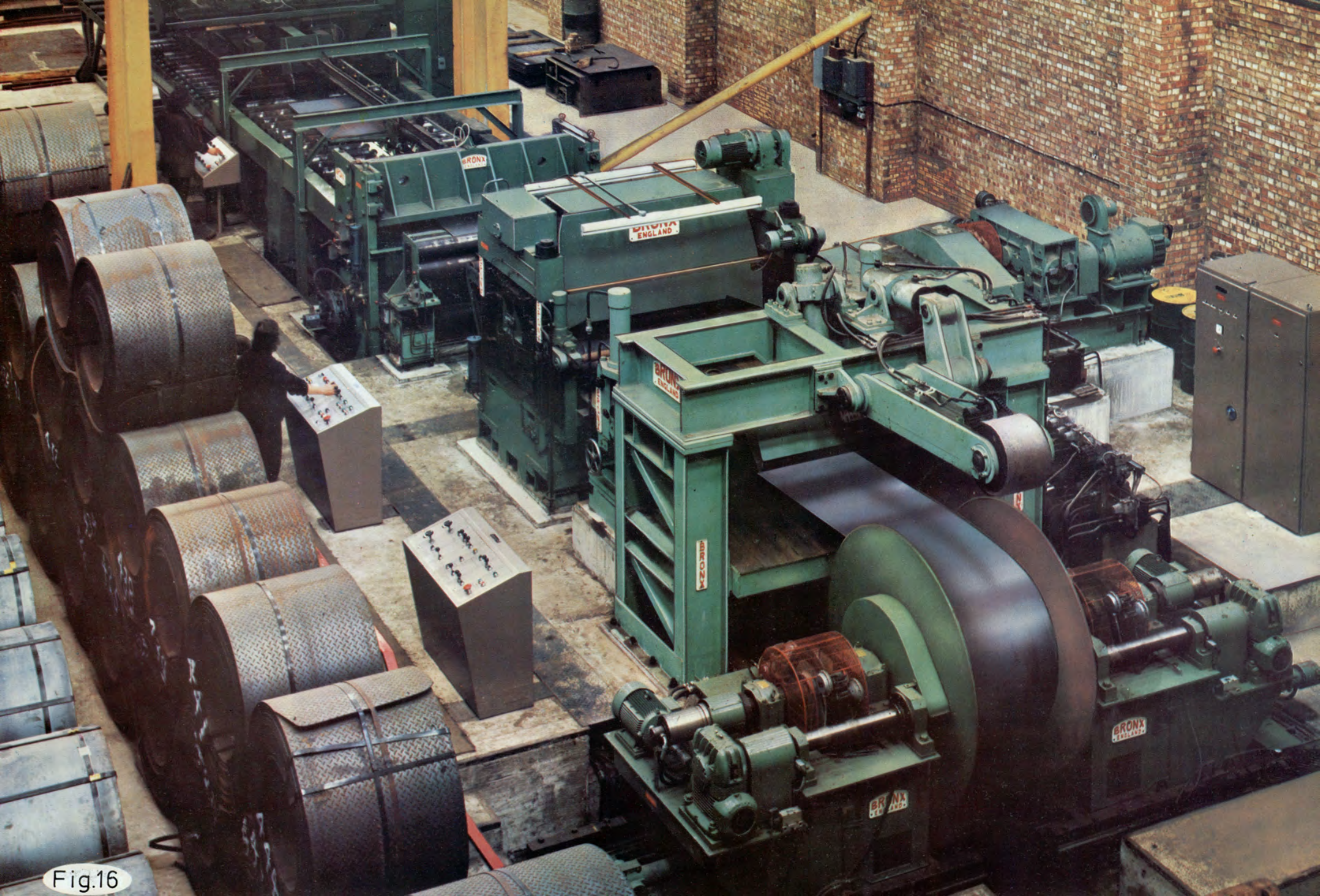
BRONX
BRONX ENGLAND
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BRONX
BRONX ENGLAND
BRONX ENGLAND
Fig.16

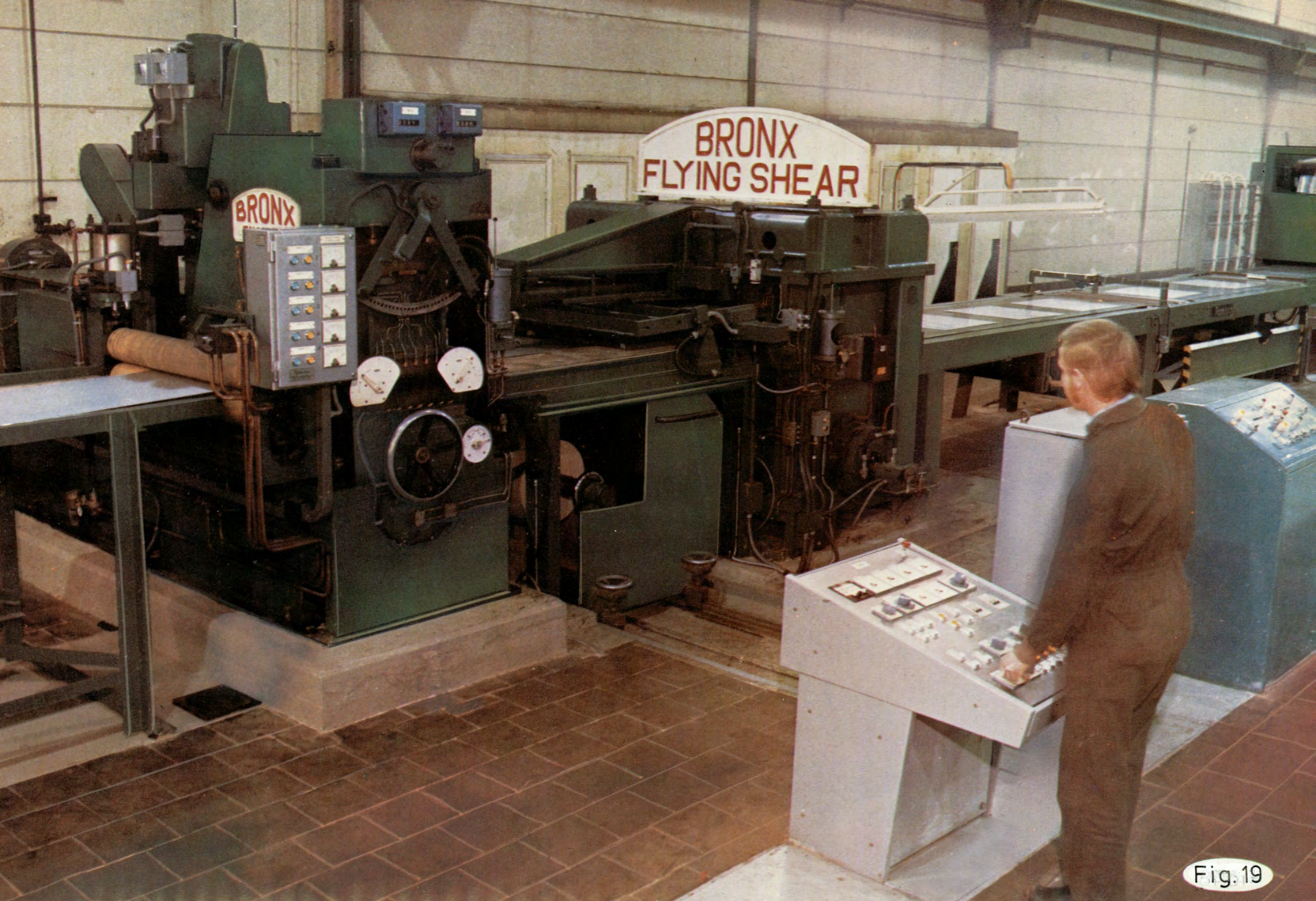


Fig. 19

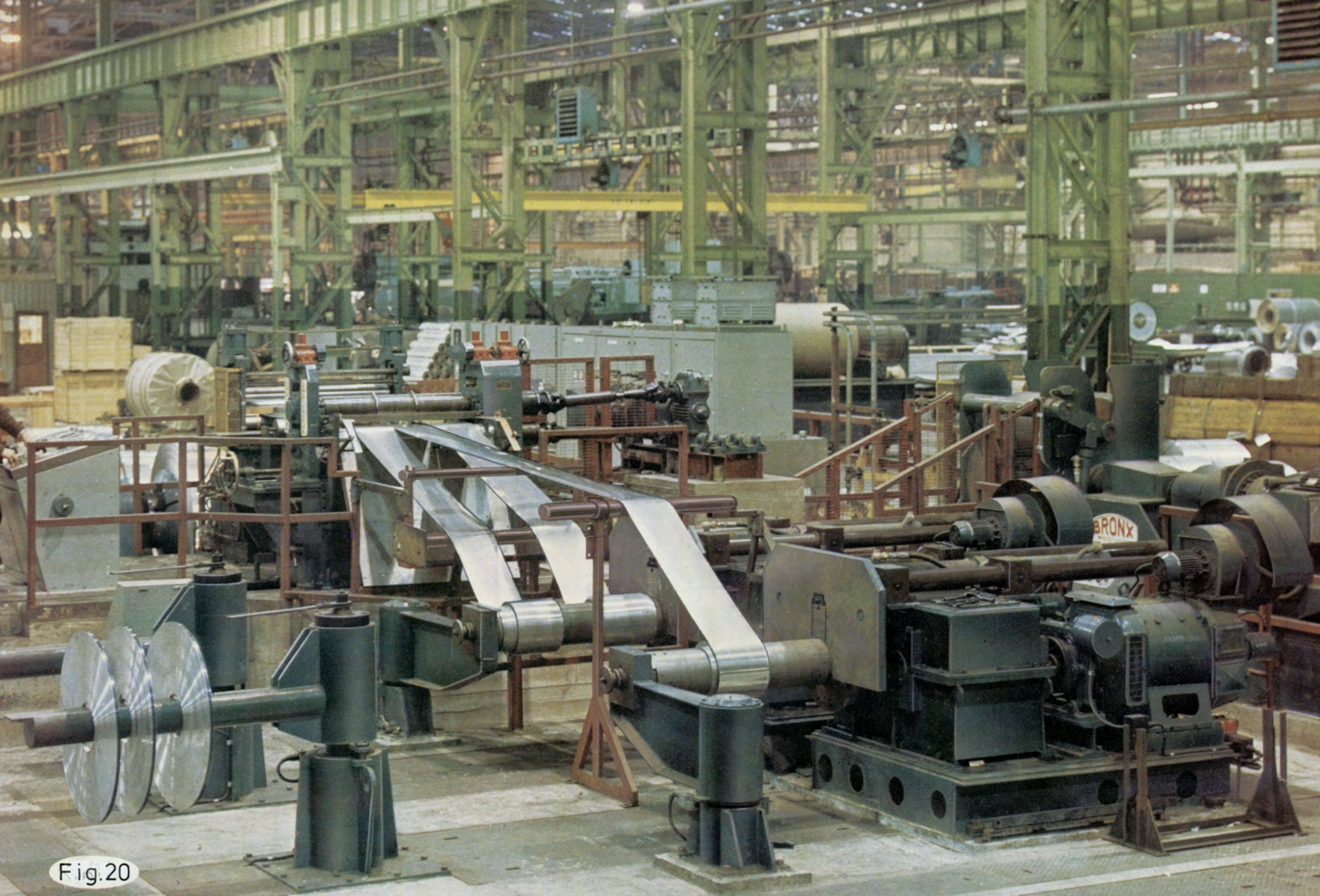


Fig.20

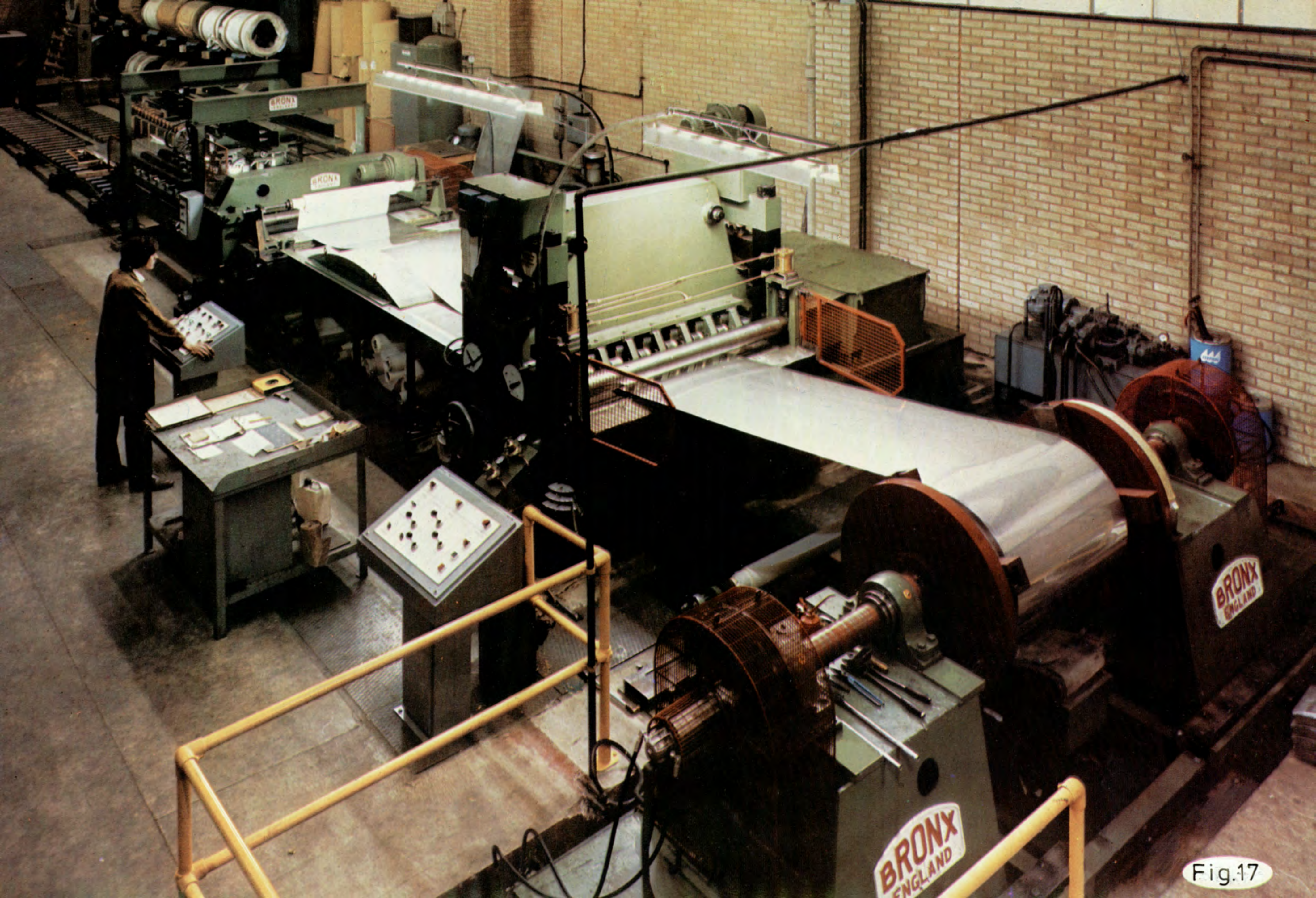


Fig.17

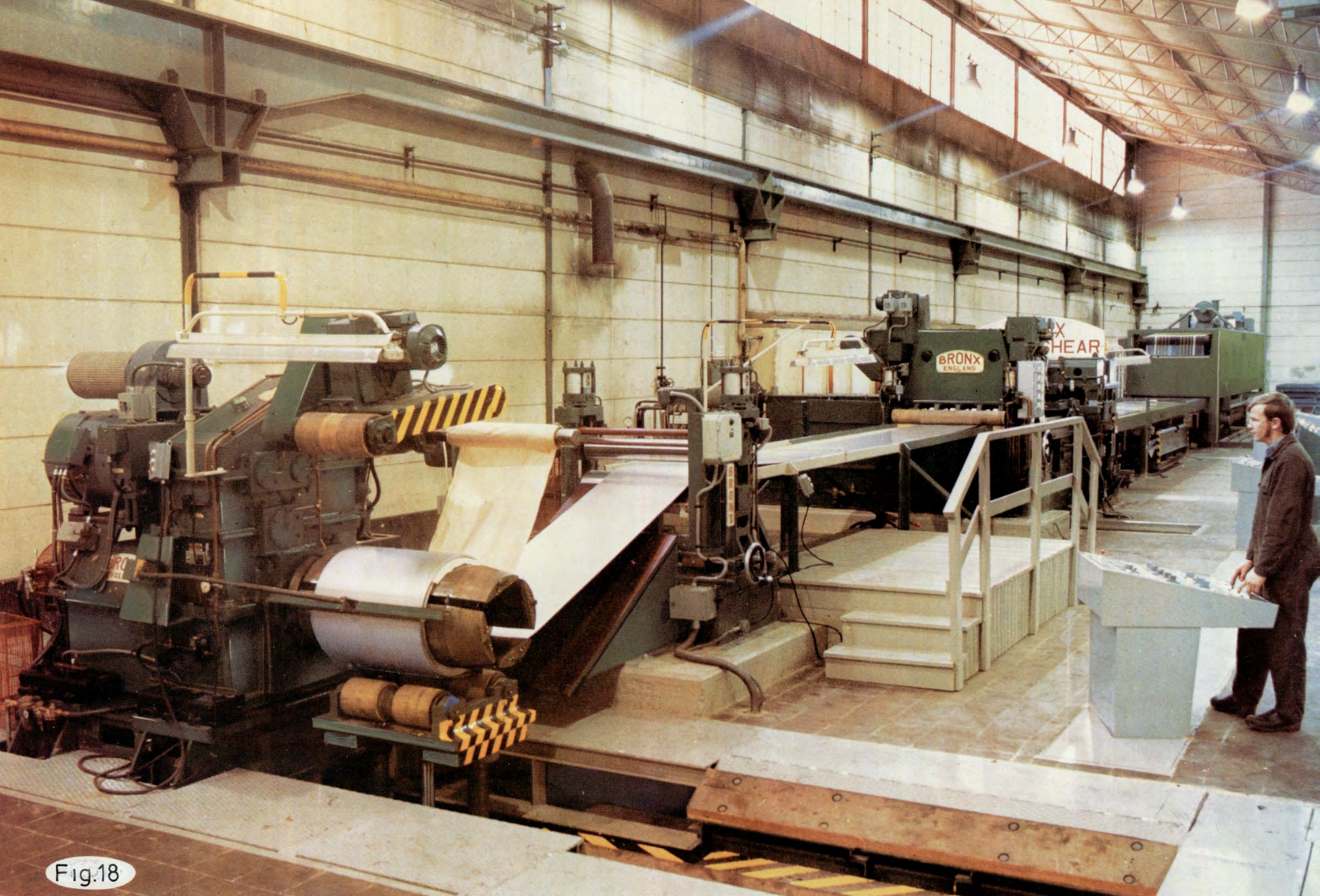


Fig.18

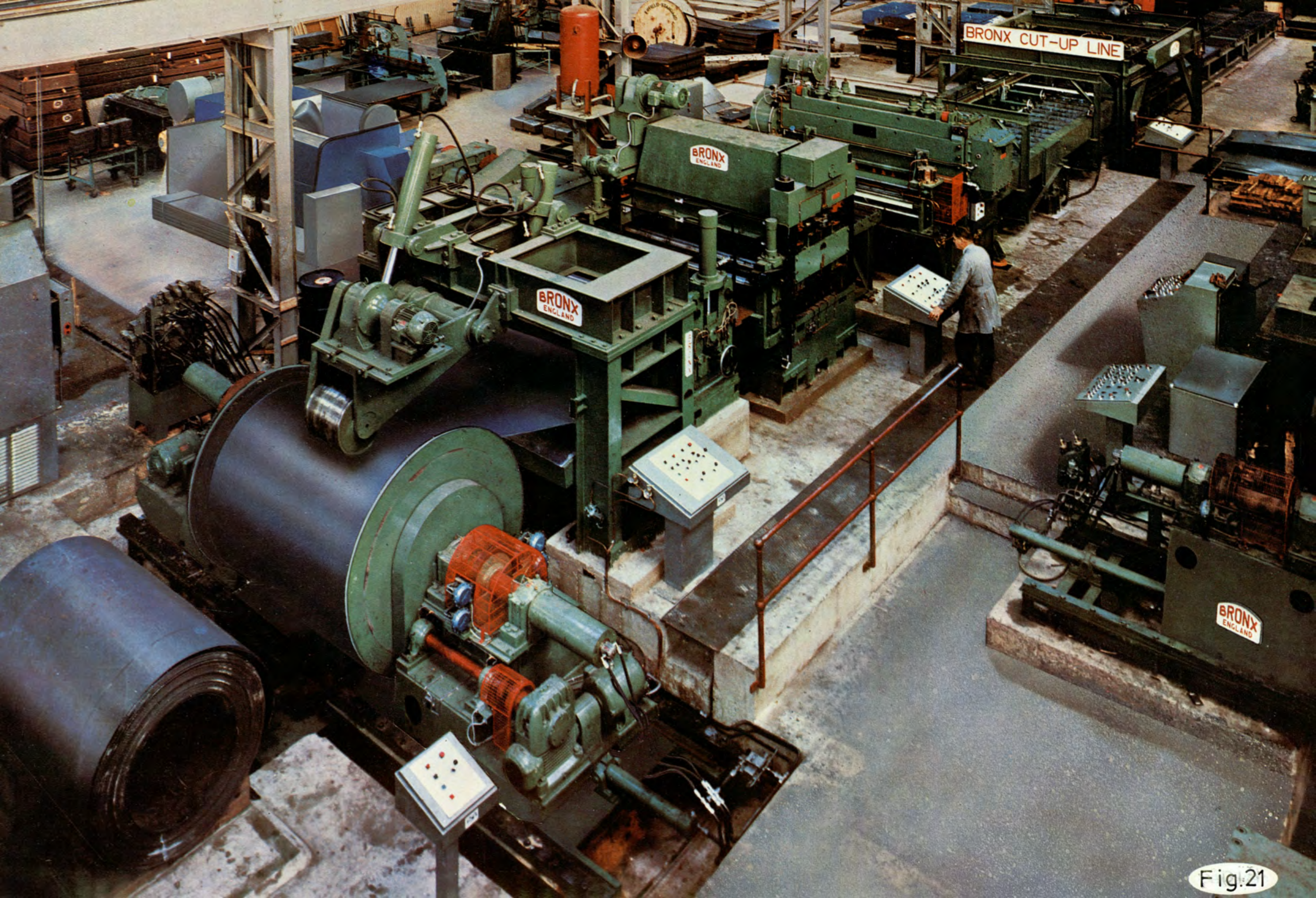
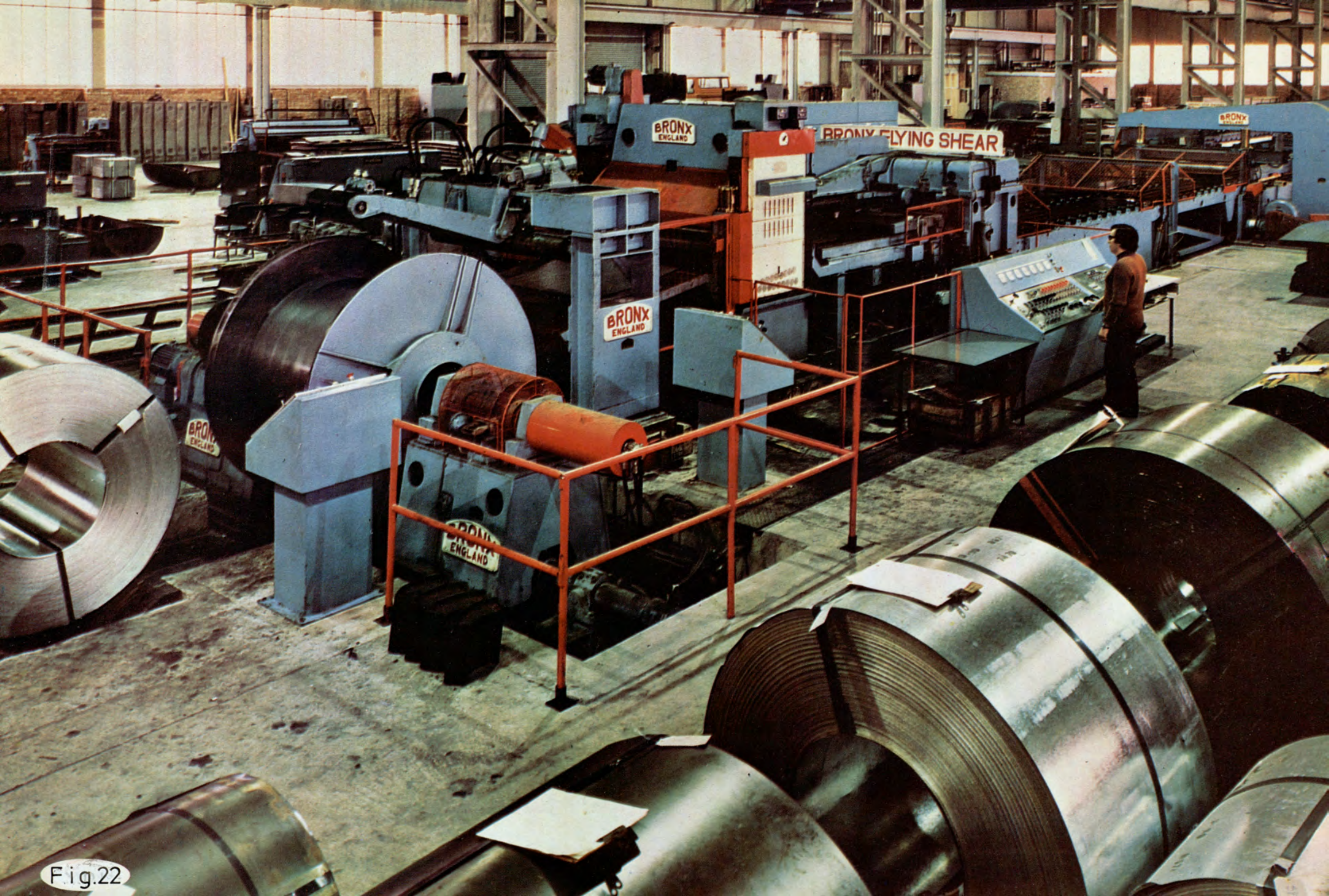
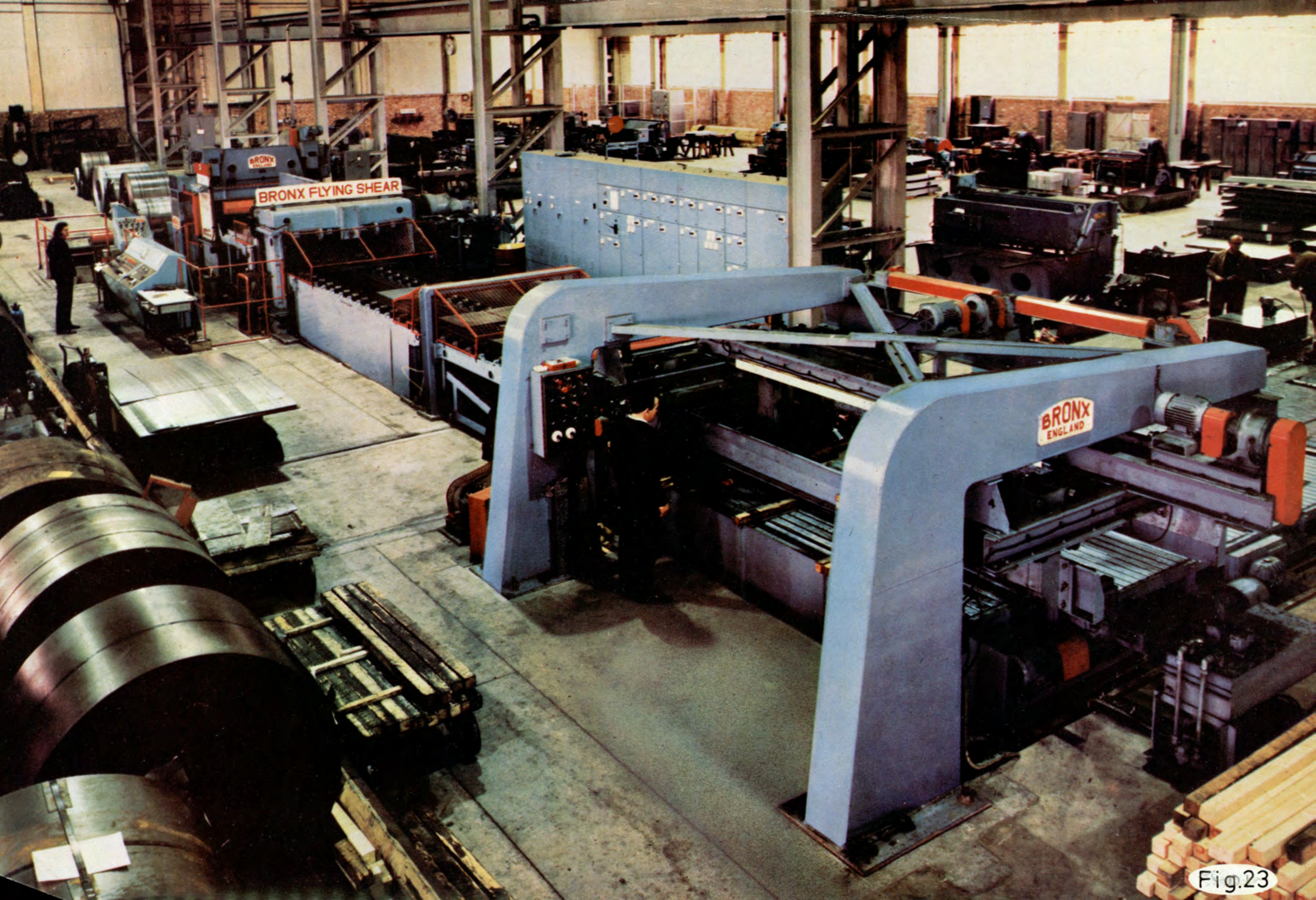

BRONX CUT-UP LINE
BRONX
ENGLAND
BRONX
ENGLAND
BRONX
ENGLAND

Fig.21


BRONX FLYING SHEAR
BRONX
ENGLAND
BRONX
ENGLAND
BRONX
ENGLAND
BRONX
ENGLAND
BRONX
ENGLAND
Fig.22



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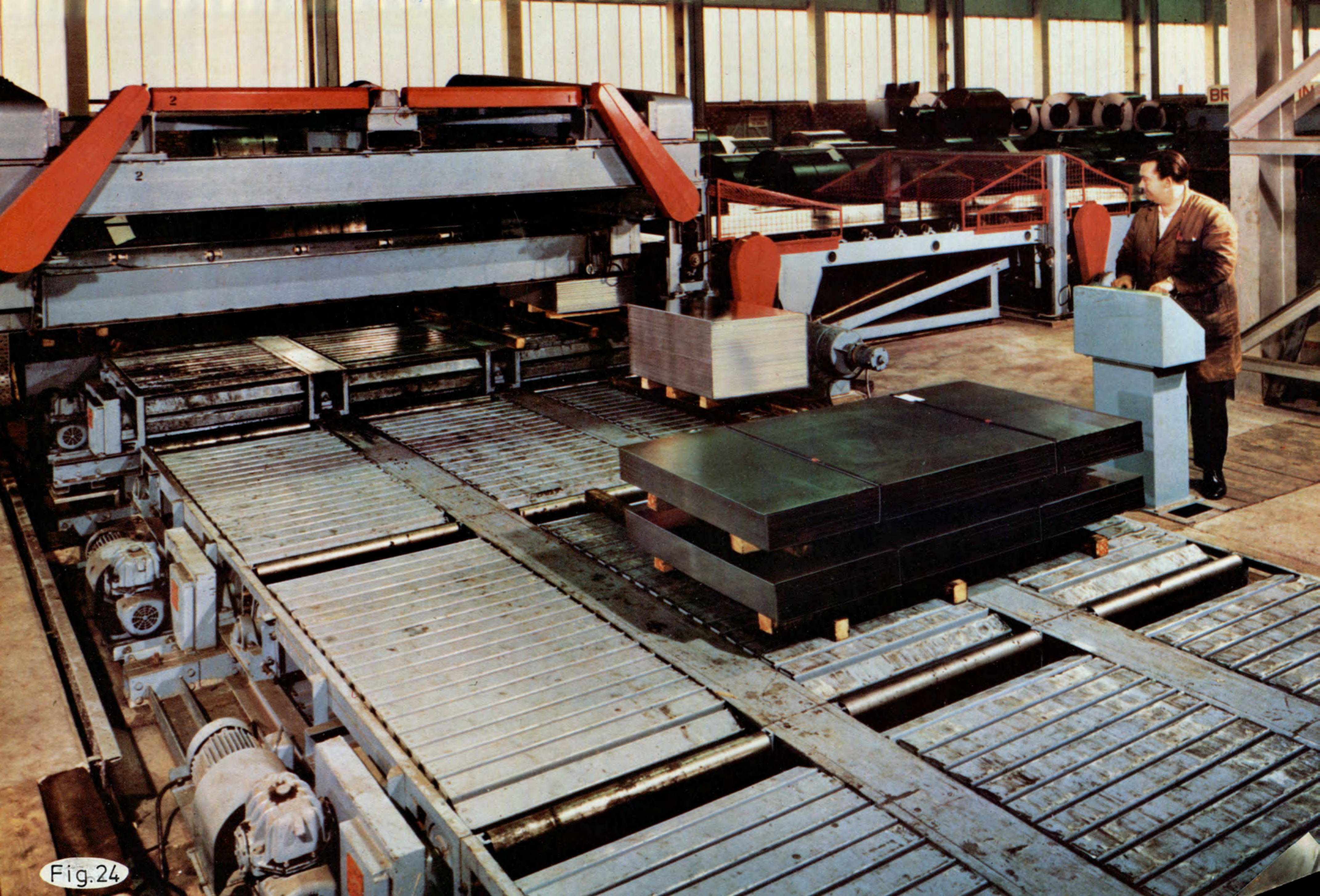

Fig.24