THE INTRODUCTION OF GROUP TECHNOLOGY VIA CODING TECHNIQUES; A CASE STUDY

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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.

"There is skill in presenting change so that it
is seen as an opportunity rather than a threat."

G. A. B. Edwards, & G. M. Fazakerley
M.T.D.R. U.M.I.S.T. 1973

SUMMARY

The introduction of Group Technology in an established batch-production company using coding techniques is described in detail and the writer examines the 'present state of the art' along with the particular considerations developed in a typical case study. The 'Overall System Approach' is endorsed but recognition is given to a practical, though necessarily limited, introduction.

The application of classification and coding techniques is described, and the use of conventional and special code types in the creation of improved information retrieval is discussed along with the creation of associated conventions. The need for unique component codes is highlighted and the design of such systems described.

Selected component types are endorsed as offering greatest potential for the initial implementation and the practical intepretation and application of the Opitz Code is detailed. Rotational components are shown to offer the greatest potential for the introduction at the company involved and the code families established are critically analysed in the design of production groupings.

The translation of basic code families into production families, and hence machine loads, is described in the design and structure of machine groups or cells.

The principal parameters and restrictions of this work are defined and the limited introduction of Group Technology in a particular production area is reported. The practical aspects of introducing a 'pilot line' are described along with an evaluation of the resulting introduction.

The value of the Opitz Code as an aid to production is critically examined with rotational components, reference being made to practical code intepretations, and its fundamental accuracy with non-rotational components is contrasted with Production Flow Analysis.

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Report 11th October, 1973.

FOREWORD

In the Production Engineering Industry, the innovation of improved philosophies is often considered not for the refinement of operative systems, but, as a last resort in desperate situations.

The introduction of Group Technology as a "Saving Grace" in an out-of-control situation does not ensure success. Indeed, it would require courageous vision on the part of those in control to promote Group Technology to fruition.

Group Technology is still considered by many to be "just another variety reduction system." The recent growth of successful applications (Ferodo, Mercer,) has shown Group Technology to be both fundamental in concept and a sound basis for any truly objective approach to engineering production management.

The radical nature of this concept necessitates the full acceptance, approval and involvement of management. Few companies applying Group Technology have introduced it as an overall concept and such limited commitments merely generate reserve about its value.

Group Technology is not a new technique; its successful introduction and growth in Russia since the 1920's has been well documented (1., 2.,).

Since the early 1960's a handful of British companies (as above) have introduced and developed Group Technology techniques and the works of (Thornley, Connolly.) are well known in both academic and industrial circles.

The introduction of this new technology has fostered a host of consultant organisations and specialists preaching the 'gospel of Group Technology', yet, remaining academically entrenched away from the practical realities associated with the introduction of change, they write only about the "end of the rainbow".

In the main Group Technology has been exhalted in coding techniques, and, in fact, with coding and coding attributes being the early academic approaches, Group Technology is seen by many as an interesting study on workpiece statistics. (3, 44, 40.

Many firms have considered Group Technology but, "the verifications of coding and coding techniques have dissuaded many, although no company appears prepared to implement Group Technology in a total sense in one step". (4) Ferodo remain one of the few companies to demonstrate the overall approach.

If the basic motivation behind the decision to implement Group Technology is analysed it is found to be commercial, the possible social aspects being regarded as secondary. (5) Papers concerning the few successful British applications have shown this to be so. (6. Fig. (1)).

Recent works (7, 39) have illustrated some of the "teething troubles" to be surmounted but as yet, no account has been made of an **arduous** introduction.

INTRODUCTION

As modern techniques bring change to the industrial scene with advanced technologies and sophisticated automation, it is widely believed that industry is becoming increasingly committed to mass production. Intrinsically the reverse is formed, with the trend towards increased variety and Merchant writes of 75% of the American metal working industry being devoted to the batch production of orders of 50 pieces or less. (11)

Although the general approach to batch production has seen little change since the Industrial Revolution, with production shops steadfastly preserving the functional layout, the devotion to flexibility and maximum plant utilisation caters little for increased component variety. In the conventional batch production shop few changes are seen since 1780 at the Soho Foundry in Birmingham. Machines are still grouped according to types and functions. Typical examples are the separate grouping of lathes, milling machines, drilling machines, etc. Therefore the path of a component through such a production arrangement becomes extremely complex and tedious without some approach to systematic rationalisation. (Fig. (2)).

Similarly, considering modern products, inspection reveals that they basically comprise conventional components, Parts such as bushes, screws, collars and pins still predominate, yet the methods of producing these components have changed very little. Without resorting to advanced techniques, the efficiency of production can be improved by a systematic analysis of the manufacturing function.

CONVENTIONAL PRODUCTION METHODS -
MACHINE LAYOUT AND ITS DISADVANTAGES

In a typical batch production shop the system of manufacture includes a variety of machine types. Shop layout depicts these machines grouped according to type and function and, as shown in Fig. (2), the inter-machine movement of work in progress can be extremely arduous and time consuming. Most work has to pass, in batches, through several, if not every, production unit before completion. Each machine is manned and to achieve satisfactory levels of both machine and labour utilisation there must be a constant stream of work.

In order to maintain maximum utilisation of both machines and labour the sizes of component batches are usually increased above the required amount. Such increases in batch sizes (E.B.Q. (12)) are brought about to counteract the costs of work-in-progress and duplicated tooling. Serious financial side-effects of enlarged production quantities are manifested in increased inventory costs with stock and work-in-progress as work is held anticipating future orders. Therefore, stock items not immediately required for sale tend to occupy manufacturing facilities to the detriment of orders required to meet the demands of the market. Accurate market and sales forcasting are essential for the anticipation of such demands and, with increasing emphasis on sales, production industries depend heavily on these techniques. It has been stated (13):

"There is a serious lack of appreciation throughout the country of the importance of good delivery."

With high levels of work-in-progress and finished stocks, production functions are slow to respond to changes in demand; the wheels of production are too slow.

Where many complex components have to be machined in large quantities the probability of meeting delivery dates is very low. Under such conditions the high utilisation of plant and short manufacturing times are in conflict and delivery dates are often made "tongue-in-cheek." Although the use of computerisation can improve production control fields, as may armies of "progress vigilanties", their use in this field is often specific. Contingencies have to be provided for such temperamental variables as absenteeism, machine breakdowns and scrap. Computerised Production Control does involve the balance of inventory costs and raw material input, but, what is required is a more general approach to the production function.

Group Technology offers this type of control; "Group Technology (or parts family manufacture) is a method of achieving some degree of mass production in batch production industries. Large batches (families of similar components) are formed from small batches of identical components by grouping them in accordance with those features which determine their manufacturing methods, with a reduction in setting time and increased productivity". (14).

This new approach to production is applicable to those companies which cannot make use of the flow-line principle. The method is, however, similar to the flow-line principle in a number of ways, and, although flow-line production considers;

a) Continuous demand for the product.

and b) Standardisation.

with Group Technology it is necessary to think in terms of component parts rather than completed products. "Product thinking" is replaced by "component thinking"; "With Group Technology the first requirement for the implementor is that he must ignore product-thinking". (15).

In shop loading there must be a recognised distinction between demand for products and demand for components. With the former, attention is directed to the marketed product and, with the latter, to the series of components which make up the finished unit. It is with the latter at the heart of production, that Group Technology offers positive benefits.

For the introduction of Group Technology the similarity of production operations and sequences must be considered. "Group Technology is a technique which enables the benefits of large batch production to be extended to the manufacture of small and medium batches". (7). Group Technology deals with a wide variety of engineering products having infrequent or non-continuous demand. The firm to which Group Technology is advantageous is one which has many different components. The technique enables the formulation of large batches of work from small batches of similar components. This similarity is based on a number of particular parameters involving features which influence component manufacture.

In the light of the urgent need to improve productivity in British industry, Group Technology offers a practical, yet far reaching, solution. "For properly understood and applied Group Technology can achieve substantial increases in productivity for industry, particularly where the production is on a one-off or small batch basis". (17)

The successful implementation and continued progress of Group Technology will depend a great deal on continued management involvement, from director level downwards. "A necessary requirement for success is the support of somebody in a high position (e.g. a director) who is interested in the success of the project". (7).

This work concerns an application of Group Technology at the Birmingham Switchgear company of George Ellison Limited. The company has an overloaded batch production shop of typical functional layout with its customary problems. The momentum for Group Technology is maintained by the company Managing Director and both management and Trade Unions are aware of the need for production improvements.

OBJECTS OF THIS WORK

1. To show how advantages can be gained from a limited introduction of Group Technology.
2. To illustrate how the growth and acceptance of Group Technology philosophy in a company requires full management involvement.
3. To demonstrate the practical application of Group Technology with two pilot lines.
4. To evaluate the accuracy of the Opitz Code for practical component grouping and develop contrasts with purely production analyses.

SCOPE OF THE INVESTIGATION

UNIVERSITY LINK WITH INDUSTRY

George Ellison Limited approached the University of Aston in Birmingham in July, 1972 when the application of Group Technology to its Switchgear manufacturing concern was considered.

The author who had previous experience of Group Technology applications both in industry and at U.M.I.S.T. (18), was employed to introduce Group Technology using coding techniques. It is this link which has demonstrated the growing union between the university and industry to their mutual benefit.

The terms of reference of the project were quite broad; "Introduce Group Technology to the Switchgear Machine Shop," although a degree of revision was to follow which created parameters for the introduction of a pilot line (see later).

BRIEF BACKGROUND OF THE ELLISON ORGANISATION

George Ellison Limited enjoys a long standing reputation for its wide range of high quality Switchgear products. Ellison Switchgear is sold around the world and includes both medium and high voltage equipment capable of carrying up to 3,000 amps. A synopsis of the Ellison range of equipment is to be found in the appendix. (1) (See Fig. 3)

In 1898 George Ellison opened a Swtichgear factory in Paris which was to be transferred to Birmingham in 1906. The present works commenced production in Perry Barr in 1916 and continued to manufacture switchgear as part of the Ellison Holdings Company until 1st October, 1973, when the switchgear company became a separate private concern.

The Evered and Company, hospital equipment manufacturers of Smethwick, joined the switchgear factory in 1966 to share the site and production facilites. This concern was absorbed by the Advanced Engineering Division of the British Oxygen Company Limited on 1st October, 1973, but remains on the same site (although now to all intents and purposes, being a separate concern.) (See Fig. 4).

MANUFACTURING FACILITIES

The Ellison production shop provides both light and medium machining facilities and displays machines grouped on the traditionally functional basis. Machines are grouped according to type, with duplication not only of machine types and installations, but also of all their associated tooling.

The main maching sections are;

a) Turning
b) Drilling
c) Milling
d) Light Press
e) Heavy Press

To be included also are;

f) Brazing
g) Welding and Fabrication
h) Sub-Assembly
i) Final-Assembly and test

Clearly, this list does not include auxiliary, but important, facilities such as;

a) Heat treatment
b) Painting and Epoxy powder coating
c) Plating
d) Tool room

A layout of the factory showing the Machine Shop is to be found in Fig. (5).

A review of the plant list reveals old equipment still in use in the machine shop and the obvious duplication of machines. Duplication proliferates around the tooling associated with machining sections suggesting scope for rationalisation.

The low present-day cost of the majority of the old machines suggests reasons for the degree of tolleration of under-utilisation.

The largest machining section is that of turning (Fig. 5) and it is principally to this section and its auxiliary secondary machining facilities that the principles of Group Technology offered major benefit. As will be shown later approximately 65% of machined components were found to be rotational, by design and large component categories can be easily grouped with few complex machining requirements.

PRESENT MANUFACTURING DIFFICULTIES

The loading of the Switchgear machine shop is based on a planned assembly schedule of four weeks. Such an assembly-based machining programme disrupts the manufacturing cycle and is counter-productive restricting batch quantities over a diverse range of simple components, creating high proportions of machine-setting time. Also, at the start of the excercise company policy did not permit the manufacture of buffer stocks nor did the high frequency of machine setting changes allow for extended batch machining. It was therefore difficult to economically or punctually produce component batches whose sizes were related to single assembly programmes and, further, to justify the use of automatic machines.

As shown in Fig. (5 & 6) the turning section (which performs a major proportion of primary machining operations) has a large number of automatic and semi-automatic capstan lathes. These machines require long setting operations in conventional shop practice and therefore large batch quantities are essential for economical production. Batch sizes in the Switchgear machine shop are restricted and so without some form of component and tooling rationalisation, the ratio of setting time to run time is very high. Thus, machines are constantly awaiting re-setting and their effective output low. A typical example of component batch quantities selected for production on Ward 2A capstan lathes during a single production cycle is shown in Fig. (7).

Group Technology was seen as a means of reducing setting times and creating a responsive shop which would accommodate high frequency, small batch production.

"The setting up of the machine tools for production can be standardised for the whole group and the sequence of manufacture is so arranged that the changeover from one component to the next requires the minimum of adjustments." (19)

PLANNING AND MACHINE TIMES

As batch sizes were reduced and stop-gap measures became the norm in the congested machine shop, many jobs were re-routed on a "knife and fork" basis. The staff involved with planning had been dramatically reduced in recent years and there was no active Work Study functions; re-planning and the monitoring of production times being difficult. As a result operation planning details were almost totally unreliable and the control of production was continually lost to the shop supervision. Any new components were planned along the traditional functional-shop lines including the additional associated allowances using synthetic time estimates. Such times did not cater for disruptive small batch production nor ad hoc changes in machine type. Often components planned for production on such machines as B.S.A. single spindle automatics were machined on capstan lathes when their batch sizes were very low.

The reduction in setting times and the effective increase in batch sizes can result from the application of Group Technology to batch production; "a family of components can be constructed to accommodate a costly piece of equipment and thereby increase the utilisation of that piece of equipment". (7) In this way the disruptive element of high frequency, small batch production would be dramatically reduced and components allied to machines best suited for their grouped production.

LABOUR RELATIONS

In the machine shop there is a large proportion of semi-skilled and female operators. A review of the machined component types associated with Swtichgear was undertaken and revealed that components were mainly of low complexity obviating semi-skilled operatives for their manufacture. The reduction in batch sizes to the order of jobbing quantities resulted in many turned components being transfered from automatic machines to the Capstan section. This section was therefore heavily loaded with simple components requiring frequent machine 'breakdowns'.

The operators are paid at a fixed rate, although a few years earlier an incentive scheme was in operation. With the current high level of non-productive time for re-setting the shop floor operators could not be expected to accept an incentive scheme. Nevertheless, with the frequent disruptions associated with the jobbing production of dissimilar components, job satisfaction was non-existent.

Much has been written on the subject of worker motivation and job enrichment (20, 21, 22) and it is simple to comprehend the reasons behind recent strikes at the Ellison factory. There is a constant mistrust between management and shop floor workers basically due to their respective attitudes and lack of liaison. This was typified by the initial reaction of the Trade Union Shop Convener, who, when introduced to the author proclaimed: "we're not having Group Technology here!"

There was an urgent need for the benefits [illegible] Group Technology could bring both to production performance and the morale of the operators, whose resistance was met at the very mention of change. (23)

The scope of the investigation could be quickly resolved into terms of a typical functionally orientated small-batch and jobbing machine shop overwrought by typical production and human problems created by its very existance.

Group Technology was known to have its "grass roots" embedded in such a typical situation and the problem was not what remedy to apply but how to apply it. The introduction of Group Technology needed to be gradually phased into selected areas where it would give early benefit and its propaganda required control so that it could be seen as an opportunity rather than a threat. (21)

CONSIDERATIONS FOR THE INTRODUCTION OF GROUP TECHNOLOGY AT GEORGE ELLISON LIMITED

George Ellison Limited was becoming increasingly aware of their failure to meet customer delivery dates. Initial observations showed a traditional-type machine shop with high levels of work in progress and its associated problems.

The machine shop always appeared to be overloaded, yet, had low output. With shop loading based on monthly assembly schedules, hold ups were frequent and the name Ellison became a synonym for delivery unreliability.

It is of some interest to note that the Managing Director of George Ellison Limited revealed his interest in Group Technology some time before the Group Technology Centre, at Brimpton, near Reading, was established.

Aware of the benefits which Group Technology could bring to his ailing company, the Managing Director used his long connections with P.E.R.A to introduce his staff to the principles of Group Technology by way of a pre-arranged course of lectures.

It seems that, at that time, P.E.R.A. had not 'graduated' beyond the technique of "Sequence Technology" and it was not until the Group Technology Centre organised seminars on Group Technology that the Managing Director could begin to crystalise his intuition.

A team of three production engineers, including the writer, attended a four-day seminar at the Group Technology Centre on 31st July, 1972.

MANAGEMENT MOTIVATION TO APPLY GROUP TECHNOLOGY

Group Technology is seen by many as a technique which gives advantages to production on the shop floor. Such limited understanding often results in company interest being biased towards the production aspects. See Fig, (1).

In this way initial company interest in Group Technology tends to be economically motivated, though not necessarily from a lack of understanding of its full potential. The detailed analysis of production data, often for the first time in a company's operation, reveals many onomalies, promoting much thought towards beneficial future exercises. "It is at this stage that the original decision to implement (Group Technology) often becomes clouded over or forgotten". (4)

To date only one company (Serck Audco (16)) has introduced Group Technology purely to alleviate poor customer relations.

At George Ellison Limited the creation of a current information source has given immediate advantages, although the wider aspects of Group Technology and particularly those of social change (33) are particularly important to this company.

The practical application of Group Technology was focused on the production shop and its machining quota, via coding techniques. As machined component production was the panacea of all output restrictions this area was considered to be the root cause of manufacturing problems. There was a need for a rationalised approach to the high frequency production of small batches (Fig. (7)) sample batch), and the then current lull in company sales (Fig. (8)) provided an excellent opportunity for the introduction of Group Technology. Such a phased introduction was commenced as a prelude to the future increase in sales (Fig. (8).

An important secondary factor connected with parts manufacture was the growing disenchantment of the shop labour. The high proportion of setting changes associated with small batch quantities provided little job satisfaction, and the worsening labour relations were of great concern to management. The contribution which Group Technology offered to employee morale was therefore a serious consideration.

EXPANSION OF THE INVESTIGATION WITH THE ADDITION OF HOSPITAL EQUIPMENT MACHINED COMPONENTS

At the start of the project both Switchgear and Hospital Equipment components were machined in the same shop, albeit in separate batches. During the initial reviewal of machined components it was realised, by those responsible for the exercise, that Hospital Equipment machined components were mainly rotational. These rotational components were, in the main, extremely simple in design and production requirements. Although few in number, their annual requirements were such that they constituted considerable machine loadings.

It was to be shown later in the coding exercise that when Hospital Equipment simple rotational component families were compared with identical code families of Switchgear components on an annual usage basis, they formulated comparable machine loadings. (Fig. 9)

When initially considering the application of Group Technology the presence of Hospital Equipment components in the Switchgear machine shop and the effect that they would have in the design of machining cells was not considered. This was perhaps a result of "product thinking" as opposed to the "component thinking" which grouping philosophy necessitates.

"Product thinking" in the company is as much a problem today as it was at the start of the exercise, and this will be discussed more fully later.

The production management was approached with the proposed combination of Hospital Equipment and Switchgear machined components in the coding analysis, and, after some opposition, the scope of the investigation was enlarged.

INTER-DIVISIONAL RELATIONS

Since the Hospital Equipment Division joined the company in 1966 their machining requirements have grown considerably. Earlier light machine loads which had benefited the switchgear machine shop by increasing their machine utilisation had now grown into heavy demands on available capacity.

Hospital Equipment Division turning requirements were fulfilled on an amicable sub-contract basis by the Switchgear machine shop,. The increasing machining requirements resulting from a growth in Switchgear sales reduced the free machining capacity available. Thus, overload situations developed with spare machine capacity held at a premium, and a division of loyalties developed.

The machine shop supervision, who were essentially "Ellison men", found it difficult to justify their Switchgear work backlogs and so inevitably, the blame was placed on the Hospital Equipment Division. The growth of this new division was particularly beneficial to the Ellison Company in a period of low Switchgear sales, but was being frustrated by the very concern it was aiding.

Loyal Ellison employees began to make their accusations and the growing split in loyalties caused some discomfort. The main division depended, to an increasing degree, on Ellison facilities.

Relations deteriorated to the eventual extent that certain machines in the Ellison shop were donated to the new division. The tube manufacturing facilities were, in the main, the property of the new division, but, it was the general machining such as turning, milling and drilling which were in demand. Therefore two automatic capstan lathes were to become expressly available for Hospital Equipment manufacture.

Later in the exercise, these two machines were to be used to give some of the benefits of Group Technology, and this will be discussed later.

GENERAL CONSIDERATIONS FOR THE INTRODUCTION OF GROUP TECHNOLOGY

All companies have their own established organisational structures, methods and procedures, and personnel, and when considering the introduction of any new system or concept these factors must be duly considered. There will be a general reluctance to accept new methods and ideas, and the introduction of Group Technology will influence many areas (Fig. (10)). Initial reactions of companies to the concept of Group Technology reflect a general level of incomplete understanding, the technique often being intepreted as one of variety reduction. Many firms claim to have their own "systems" but investigation often shows these to be inefficient or non-existent. The scope of this work and specific considerations for the introduction of Group Technology at George Ellison Limited have been discussed earlier, and the more detailed strategy (for such an introduction) will now be examined.

Generally, there are four main areas for consideration;

1. The generation of enthusiasm and understanding of Group Technology among both managerial and shop floor personnel.
2. The type of introduction; whether overall changeover or gradual adaption is considered.
3. The phasing of the introduction.
4. The need for careful scheduling and budgeting to minimise the disruptive effects of the changeover.

1. SELLING GROUP TECHNOLOGY TO THE COMPLETE ORGANISATION

It cannot be over-emphasized that without the total understanding and involvement of both top management and the shop floor the introduction of Group Technology cannot be successful. It is often difficult to persuade management of the need for their overall involvement because "old schools of thought" often prevail basically as a result of the management structure. For this reason the introduction of Group Technology is probably best performed by specialist management consultants. The links of authority will otherwise be disjointed without the understanding and committment of top management, and only small localised benefits will result. The practical benefits to be gained from the introduction of Group Technology are immediately apparent to production control departments and shop floor supervision and it is the experience of the writer that such practical enthusiasm is often frustrated by restricted managerial involvement. The benefits to be gained on the production side are consistently clear with remarkable savings in setting times (40 - 80% (25)), reductions in work-in-progress (72 - 92% 26), simplifications in tooling, the economic requisitioning of raw materials and a more contented work force.

On the shop floor the advantages of Group Technology are more readily accepted than with upper management, because the benefits to the workers are much more apparent and positive. In the selling of Group Technology to upper management three considerations have to be made;

a) Group Technology will not be readily accepted by upper management unless its introduction can be planned and budgeted in detail.

b) The more practical types of manager with shop experience can be disuaded from involvement in Group Technology because of the sophisticated classification and coding systems it employs.

c) The initial introduction should be carefully monitored with results and discussions held with upper management to enable them to understand the practical aspects of Group Technology.

2. LATERAL AND OVERALL TYPES OF INTRODUCTION

There are basically two approached to the introduction of Group Technology. Lateral introduction involves the progressive development of small groups within a production shop. Such groups act as trial or demonstration areas and are allowed to evolve adding further groups, one after the other. This is a simple and practical method of introduction with the resulting benefits being clear to both management and labour. Although this method of introduction offers a simplified approach with limited investment and tremendous potential, its very limitation within a company structure can restrict its success. In the writer's experience this type of limited, lateral introduction can create conflicts between rival production departments. A simple Group Technology trial cell initiated in a machine shop will devèlop an increased work flow reflecting improved but isolated efficiency to the detrement of neighbouring sections. Such machining sections would become short of work to the degree that their operations cannot maintain bonuses on production output. The lateral introduction of Group Technology is preferred by companies who cannot tollerate the disruptive side-effects associated with the introduction of new techniques and who see the need for a practical example.

The overall type of introduction, on the other hand, approaches the problem of introduction on a broader basis. It considers the introduction of Group Technology as a total approach encompassing the entire manufacturing facilities. Such an overall type of introduction comprises wide programmes of component classification, standardization, machine grouping, tooling development and grouping of labour. Although the overall type of introduction considers the entire production facilities and component mix it does not pre-suppose the establishment of separate machine cells for the entire component range. Non-standard components predominate in all situations and these would be grouped (probably to a functional jobbing section) so as to cause minimum disruption to the bulk of the component machining. The main problems opposing the success of an overall-type introduction involve the complicated introduction of changes in production control , costing, marketing, purchasing and stock control. Such changes in overall company policy and management systems require careful co-ordination and planning within a stable firm, and it is perhaps on this basis that the more gradual lateral-type of introduction can be advantageous. (Fig. 11)).

On the practical side, work in production at the time of such a radical changeover will present a much greater problem with the overall type of introduction. This important factor is the main opponent to this type of introduction, few companies being in a position to jeopardise output. From an analysis of 150 companies considering the implementation of Group Technology (4) no company was prepared to implement Group Technology in a total sense in one step. Conversly, the introduction of pilot lines on a lateral introduction basis can accentuate production bottlenecks through the imbalance of unchanged machining sections (7).

THE SEQUENCE OF THE INTRODUCTION

"There are conflicting views about the sequence in which the change to Group Technology should be introduced", (27). Summarising the changes involved the overall-type of introduction will be considered as this will reflect an optimum situation whether derived from a lateral or overall-type introduction. (Fig. (11)).

a) COMPONENT REVIEW

Before any systematic classification and rationalisation of the component range can commence a review of the particular component statistics should be made. Such a review will aid the refinement of classification codes to suit the particular requirement for such variables as component types (general groups), size ranges, materials, machine capacities, etc. This will improve the accuracy of the classification system to suit the particular needs. When a suitable, particular classification system has been developed the analysis of the entire component range may commence;

(i) CLASSIFICATION AND CODING

The classification system developed is practically applied either over particular component ranges (i.e. related to a specific product) or the whole product spectrum.

(ii) VARIETY REDUCTION

The grouping of component code descriptions often reveals surprising degrees of duplication by design. The code can be quickly adapted for design retrieval in a drawing office to offer substantial savings via reductions in component duplication.

(iii) VALUE ANALYSIS

The development of value analysis is associated with the previous case of variety reduction. Where the degree of component duplication offers scope for rationalisation of production methods the coding exercise offers potential for value analysis. For example, large numbers of almost identical turned pins may be produced on a special purpose machine or perhaps be manufactured by cold heading. This type of exercise becomes a practicable proposition via a component coding exercise.

(iv) SIMPLIFICATION AND STANDARDISATION

Extending the use of the component classification system, the grouping of parts within a framework of design/production features enables the improved control of their production. The formation of production groups for specific component families simplifies the control of the production function and can lead to the standardization of methods and procedures for specific component/production groups.

b) THE GROUPING OF PRODUCTION FUNCTIONS

The results of the component review, via coding analyses, and associated rationalizations stimulate the progressive change of the production functions with a view to;

(i) The planning of machine re-arrangement into production groups for specific component families.

(ii) The development of plans for the layout of such re-arranged groups.

(iii) The introduction of changes in machine shop layout including the purchase of additional machines and equipment where necessary.

(iv) Simplifying into departmental communications along with improved control in line with the responsive production performance.

c) TECHNOLOGICAL DEVELOPMENT

(i) The design and installation of specialised tooling families within each component family.

(ii) The development of pre-set tooling.

(iii) The simplification of setting with rapid tool change attachments.

(iv) The development of in-process gauges and measuring equipment.

(v) The installation of transfer machinery and material handling aids.

(vi) The development of specialised machines particularly suited to the simplified production groupings with the more explicit specification of new machines.

(vii) The full evolution to automated batch production as the ultimate development.

d) RENOVATION OF MANAGEMENT SYSTEMS BY OVERALL SIMPLIFICATION

Group Technology brings a co-ordinated approach to batch production and simplifications to the management functions.

(1) PRODUCTION ENGINEERING AND CONTROL

The introduction of Group Technology contributes three main advantages to the control of production;

(i) Reduced machine setting times.

(ii) Resultant increasing in machine time/capacity.

(iii) Reduced tooling investment.

Using these improvements effectively, preferred production schedules can be designed to optimize output with standard machine loading sequences. Such improved production control can adopt single-cycle ordering procedures. The traditional multi-cycle ordering technique requires each part to be produced in standard order quantities, with intervals between orders attered to balance output. High stock levels and inventory costs are developed from the use of Economical Batch Quantities (12) to offset the disruptive nature of the multi-cycle ordering technique.

Single-cycle ordering involves the ordering of components at fixed intervals in quantities which are adjusted to comply with the immediate production needs. This type of ordering is used with Group Technology to enable the use of sequential scheduling techniques. In this way the available machine time can be optimised and Gantt Charts used to effectively load machines and machine groups.

(2) SCRAP RATES AND QUALITY CONTROL

Product flow routes are specifically controlled using Group Technology with components allocated to machine groups expressly designed for their production. The use of group layouts containing all the necessary facilities and equipment for specific component manufacture, can return reduced scrap rates. This effective increase in quality results from the simplification of tasks, the use of specialised tooling, and the increased awareness and understanding of the operator towards the production demands. The outlets of each group may be visited by a "travelling inspector" (28) for the random inspection of products.

The overall improvement in control, with production groups autonomously co-ordinated, offers scope for statistical quality control. The very fact that components can be associated with specific groups and individual or groups of operators is a basis for the improvement in quality and alround control. Even if the scrap rate is not reduced, savings will occur because of reduced manufacturing costs, ie., reduced investment in each part (29).

Summarising, an increase in the level of quality can only arise if the producer (be it a single operator or a group) wants to do the job properly. (30). Quality control 'at the point of production can only be achieved by the producer, never by the patrol inspector.

(3) PURCHASING

Capital movement is directly related to both market research (sales) and production demands (saleable products). The application of Group Technology leads to reductions in the investments in raw material and supplies, and, with the associated reductions in work-in-progress, accurate assessments can be made of inventary levels to minimise costs.

Production groups, their machines and associated tooling are related to specific component groupings and therefore their tooling and equipment requirements can be accurately determined, with subsequent savings and the avoidance of duplication.

(4) ACCOUNTING

The change to group layout improves the detailed knowledge of both production requirements (raw materials, tooling consumables, etc.) and component/product demand. There is a great reduction in the amount of documentation required to control material flow with Group Technology, and Fig. (12) compares paper work typically used in both Group Technology and functional layouts. Such simplifications in documentation incorporate reductions in administrative personnel and indirect labour, greatly simplifying accounting. Costs are easily attributed to components and products because each production group becomes a cost centre. Therefore costs are simply based on finished component output per group, per cycle.

(5) LABOUR REQUIREMENTS

With the adoption of Group Technology specific labour requirements; manning, skill levels, supervision, etc., can be accurately established. Generally, the skill levels required with the more simple machines used in group layouts tend to be lower. It must be remembered, though, that skilled labour remains essential for the more complex machinery and setting operations. Although most of the work in Group Technology "cells" can often be rationalised to a semi-skilled nature, to operate efficiently the labour must be flexible. In keeping with their corporate spirit the labour must deploy themselves flexibly and their full understanding and involvement in the concept and practical working of Group Technology is essential.

Indeed it might be agreed that such work organisation is necessary, (in this case with skilled operators), if workers are to be compensated for their otherwise diminished work role. (31)

The application of Group Technology principles to a production environment involves the examination of both the production processes and their work content; the group labour is considered an integral composite in cell design. The close evaluation and development in cell work content enables the accurate specification of labour requirements, and this gives advantages in personnel selection.

Differentials in operator skill levels are an additional consideration and the labour requirements for group working are also sociologically important. The behaviour of working groups has been well covered, (22, 32,), as have their roles in Group Technology cells, (21, 33, 35).. It is perhaps more important to recognise that the introduction of some form of functional group working will generally lead to the enrichment of the job, which in turn, requires individuals to become proficient in the execution of a greater variety of both direct and indirect tasks, (34).

The requirements of group labour to develop their work content for improved cell performance precludes the involvement of Trade Unions, who see technological change as a cross upon which they never intend to be crucified. (35). To alleviate potential difficulties and maintain a contented work force there is a need to pass on some of the benefits of Group Technology to the workers in the form of improved remuneration.

(6) GROUP PAYMENT AND WAGE SYSTEMS

Within a Group Technology group or cell the production facilities are related to specific component types or families, and to fulfill the output levels required, the labour force, its rate of production and wage levels must be accurately predicted. The particular choice of labour is very important to the success of the cell and the group should be balanced with each member being seen by the others to be contributing to the overall output. (36)

It is not the purpose of this section to expand an inter-group relativities and pay structures, but the ability of working groups to control output must be appreciated in considerations regarding wage systems. It has been proposed (36) that for an initial introductory period (perhaps for weeks) the average earnings of group workers should be guaranteed. A group-related wage system could then commence if requested by the operators. On the other hand, resistance to change is the panacea of shop-floor evolution, and it may be necessary to use persuation in the form of higher pay. The development of a payment system involving a standard monthly wage plus bonuses, determined from output quantity and quality, has been developed around the characteristics of group workings, (37).

(7) STOCK CONTROL AND STORES

Group Technology drammatically reduces levels of stock and work-in-progress. The improved response of the production function enables stock levels to be reduced, with associated savings in inventory carrying costs.

This improved conversion rate of raw material into finished stock automatically reduces work-in-progress. Fig. (13) illustrates typical reductions in material throughput times, with less investment in stocks, The reductions in work-in-progress offer the improved utilisation of floor space, (normally choked with unfinished stock), reduced investment in handling and storage, (usable floor space might be costed at $50p/ft^2/annum$), and a better working environment. Sufficient space need only be provided for the output of a single production cycle.

(8) MARKETING AND THE USE OF FORECASTING TECHNIQUES

The adoption of single-cycle ordering techniques, practicable with Group Technology, enables production to quickly respond to changes in market demand. Frequent market or sales forecasts provide a more accurate basis for production variations, allied with output permutations, than multi-cycle ordering can offer. These forecasts can be translated into production requirements with allowances estimated against existing stocks, (both of raw material and finished components).

Such short term forecasts are accurate, and, being on a transient theme, enable adjustments for variations between actual and forecast sales to be easily made. Such variations will not change the character of conventionally machined components, but the particular quantities upon which machine and cell loadings are based. The same types of conventional component categories are universally perpetuated, that is, simple parts such as bushes, screws, pins, etc., (a design recognition which formulated the Opitz Code). The introduction of rationalised production methods for such component types, although often similar, are fundamentally affected by actual component demand. It is on this theme that the importance of short term forecasts is applied and the design of production families must consider flexibility as an essential requirement. Market knowledge and forecasting techniques are an imperative requirement for the success of Group Technology, imparting flexibility with responsive delivery performance and reduced production costs.

(9) DESIGN AND THE FUTURE ROLE OF THE DRAWING OFFICE

Good design must always envisage production and its associated problems. Such a production orientation should consider materials, machine tooling and ease of manufacture. In this way design would be influenced by the production facilities available and would envisage not only the creation of new components but also the tooling and production aids for their manufacture. The design of production aids falls into three main groups;

(i) The design of improved tooling to simplify set-up changes and reduce non-productive machine times.

(ii) The design of tooling families based on associated component groupings.

(iii) The design of production aids such as handling equipment, improved in-process gauging, and ultimately, special-purpose machines.

With Group Technology, design becomes component orientated and involves the rationalisation of existing designs using Value Analysis. The initial review of components and the establishment of a code data base improves design retrieval and fosters variety reduction exercises. With this, the act of examining components, machines, tooling, operator skills, market demand and system of organisation is very significant and affects component design and subsequently product design. (38) (Fig. 14).

(10) PRODUCTION PLANNING

The introduction of Group Technology inspires new confidence in delivery commitments, because production planning becomes reliable. Group Technology, in practice, provides accurate control over production throughput times with sequential machine loading on pre-tooled, pre-planned operations. The primary phases of such overall statagies evolve at the classification stage, whereupon the basic components are associated with their respective groups or families. The grouping of components with similar production features enables the logical development of similar machining or operation times. This is because with similar components, small dimensional differences represent little or no change in machining time. Therefore grouped components may either be allocated group times (based on average throughput times with several machining operations) or standardised allowed times. (Fig. (15)).

Production bottle-necks are avoided with machine groups permanently set-up with all their necessary tooling and raw material requirements for specific production requirements and accurate control is restored to the planning function.

4. THE STRATEGY AND CONTROL OF THE INTRODUCTION

As the introduction of Group Technology will radically change the existing production and control functions in a company, the changeover should be phased into a number of clearly defined projects. Every company has its own established functions and procedures, and the influence of such a revolutionary approach must not totally disrupt the work flow in the interim period. Therefore, introductory projects must be carefully planned and budgeted to maintain positive progress and maximum rate of increase on the investment.

At George Ellison Limited the introduction was initiated with the analysis of turned (or more exactly, rotational) components from the main product lines. This exercise, which contributed practical advantages to the "intangible benefits" proclaimed, will now be described.

THE CODING EXERCISE

On July 31st 1972 the author, accompanied by an Aston undergraduate and an Ellison Chief Production Planning Engineer, attended a 4-day seminar at the Group Technology Centre,[±] near Reading. The seminar covered an introduction to the Opitz Code and demonstrations on its use in the introduction of Group Technology. Tutorial sessions were held on practical workpiece coding and a representative range of Ellison drawings was used for coding and for the assessment of an overall size range code.

The Group Technology Centre was to remain on a contract basis with George Ellison Limited to provide a computerised code sorting facility and technical assistance with the introduction of Group Technology. The continued involvement of the Group Technology Centre will be discussed in the following sections.

[±] The Group Technology Centre was a Department within the United Kingdom Atomic Energy Authority formed in 1968 to assist industry with the application of Group Technology.

THE OPITZ CLASSIFICATION SYSTEM

The system was developed in Germany to help the development of new machine tools. The original classification system established data on workpiece statistics. The present system as eddited by MacConnell (Fig. 16,17) has been developed using workpiece statistics and comprises 5 primary and 4 secondary digits. The Opitz Code used at George Ellison Limited included an additional supplementary code digit to enable the improved recording of component dimensions in two principal axes. (Fig. 18)

The primary code is basically geometric in design and groups components by a logical shape association describing significant features in order of complexity and implying production methods or requirements. The supplementary code provides information on primary dimensions, materials, initial form of materials and accuracy. This last description afforded by the code is optional but can be used to identify components requiring a more specialised process such as grinding. The particular threshold above which accuracy becomes particular will vary from one application to the next but in general shop practice, significant levels in accuracy worthy of coding are above ± 0.005 inch. This accuracy digit may therefore aid the appropriate matching of machine ability to component facilities. Fixed digital significance predominates in certain areas of the code with individual digits describing shape elements pertinent to all component classes, positions within the digits having corresponding intepretation.

The Opitz Code is simple to memorise, being particularly concise and accurate with conventional components. With experience code and shape association become almost automatic and high rates of coding are possible after an initial learning period. (Fig.19,20).

CODE CONVENTIONS AND INFORMATION RETRIEVAL

A series of conventions (for the use and intepretation of the Opitz Code) were proposed (Fig. 21,27) along with plans to enable the coded information to become a reliable data base. "Any actual coding system must be designed to fit the requirements for the particular undertaking." (39)

A typical example of where the use of a convention was found to be essential was in the coding of turned components having screw-threads. An undercut at the end of the thread can either be ignored or coded as a "functional groove". In the latter case a different digital significance would result. (40) (Fig. 23).

In this way the primary code digits become a reliable intepretation of workpiece statistics and the continued adherance to such conventions results in the growth of distinct component families. (P. 61)

Similarly, workpiece dimensions can result in confusion in the code digits. This confusion is derived from the descriptions given to components by draughtsmen. Turned component categories such as bushes, collars, spacers, sleeves, etc., are typical examples of functionally-orientated descriptions for the same component types. The Opitz Code shows the production significance of digital representation by describing such components similarly. Optiz also uses his 1st primary digit to group on Aspect Ratio ($\frac{L}{D}$) with rotational components, and this is discussed in other work (41).

The Opitz Code is particularly well suited to rotational component categories and this may well be explained by the fact that it was first used in Germany for the development of new machine tools. The Opitz Code descriptions for non-rotational components are less precise, mainly becuase rotational components have a basic fixed parameter (i.e. they are circular in section and machined around the main shape axis). Therefore conventions must be used with the code either in the form of additional digits related to the main code, or additional intepretation by means of the supplementary digits.

A particular example is the convention adapted to differentiate between the drawing descriptions of bar, strip, plate and sheet. See Fig. (24). With this convention the basic raw material form contributes to the overall description.

INFORMATION RETRIEVAL

The Opitz Code information comprised 10 digits and each code number related to a 6-figure works component number. Additional digital information was thought necessary because:-

1. The simple retrieval of basic code information, ie. Fortran Coding Forms and punched cards, was required for correction purposes.
2. The company had no computerised information retrieval system and, thereforemany future uses and applications were envisaged for the code information.
3. Each punched card had 80 columns of which only 16 carried code and component number information.

Digits were added to each code number in columns signifying:-

1. Fortran Code Sheet number (for good housekeeping).
2. Type of equipment, i.e. Switchgear or Hospital Equipment.

This left a remaining 53 punched card columns un-used. Additional information could be added at a later date relating to:-

1. Component usage.
2. Batch size.
3. Batch frequency.

4. Machining Operation types.

5. Setting times.

6. Machining times.

7. Plant or Group location and identification.

8. Manufacturing Route.

9. Raw material reference.

10. Costs.

11. Total manufacturing time.

12. Product or assembly description.

13. Other pertinent information.

STARTING POINT IN THE CODING EXERCISE

It cannot be over emphasized that some early benefit from Group Technology was required on the shop floor. The coding of component drawings serves not only as a means of production data retrieval but also as a reviewal of the current work throughput. The drawing office has an immense file of approximately 560,000 drawings, some 250,000 of which are in photograph form. Only approximately 7,000 of these drawings represent current switchgear machined component production although it is company policy to supply spares for all their products, including obsolete equipment.

It was said, by those who viewed Group Technology as purely a coding exercise, that the coding should commence with drawing number 1!

Enormous potential could be seen in the future extension and use of coding techniques but as current production difficulties had created the need for Group Technology the coding exercise was directed towards the current machined components. The main areas of usage for machined components, and particularly rotational items, were in the "F.S." range of Circuit Breakers. This range formed the main-stay of the switchgear component production.

USE OF THE OPITZ CODE FOR ROTATIONAL COMPONENTS

The use of the Opitz Code at the siminar held at the Group Technology Centre had centred around turned components. As discussed earlier the Opitz Code was particularly well suited to the coding of turned components and it was in this component spectrum where those responsible for the exercise saw most benefit. It was at this stage, therefore, that the decision was made to concentrate the coding exercise and the introduction of Group Technology onto turned components. This component category was to also include components of a rotational nature and the basis for this decision was:-

1. The Opitz Code is well suited for the classification of rotational components with geometrical and production features having accurate digital significance.
2. A high proportion of machined components are in this rotational category (to be later shown as 65%).
3. These rotational components mostly occupy small size ranges conducive to simplified grouping and realistic machine loads.
4. The Opitz Coding of rotational components is not difficult and high rates of coding were thought possible.
5. The turning section was the focal point of the machine shop with machines conveniently placed for the creation of simple groups.
6. Owing to the dis-harmony in the machine shop at that time, labour relations would not favour a radical changeover to cellular manufacture. Therefore a gradual introduction on the "pilot line" theme offered greatest potential.

SYSTEMATIC INFORMATION RETRIEVAL

The panacea of progress with the coding exercise has been the information retrieval. "The first pre-requisite for applying Group Technology is a knowledge of the components to be machined". (7).

The writer and his coding assistant (an Aston undergraduate) were new to the company and had no knowledge of the product structure. Although this was an advantage for grouping philosophy (7), encouraging component rather than product thinking, it hindered the coding exercise. Owing to the lack of a computerised retrieval facility a manual study of component parts was necessary using the Drawing Office Master Material Sheets to determine:-

a) Associated product identity.

b) Commonality of usage in the product range.

c) Requisitional status (made in or brought out).

Drawing Office Master Material Sheets list major assemblies, sub-assemblies and minor assemblies separtely, with their relative components in order of assembly importance and in non-numerical order. It required an inordinate amount of tedious manual cross reference to select rotational components from written descriptions. The systematic study of Material Sheets involved the deletion of selected component numbers and the requisitioning of the required drawings. A print off each component drawing was thought necessary because:- (See Figs. 28 and 29).

1. The Opitz Code reference was to be added.
2. The Production Engineering Department could not permit the removal of their drawings.
3. The component drawings would be required later in the exercise.

4. A complete set of component drawings filed in Opitz Code order would be useful for reference purposes and to highlight other uses of the coding exercise.

Such was the difficulty in establishing and maintaining a steady supply of component drawings without duplication that the rate of component coding was slow. For some time the writer was fully occupied in acquiring drawings for the coding analyst but the creation of an accurate code data base was thought to be of paramount importance. (Fig.(20))

"It is important that the classification and coding systems in use in any factory are sound in basic conception and are applied to the optimum degree so that they may contribute to, rather than reduce the overall efficiency. (40)

CODING PRACTICE

Before the first drawing was coded a thorough assessment was made of:-

1. How the code data should be presented.
2. The necessary steps required to prevent needless duplication and to hasten drawing information retrieval.
3. In the ways the code may be used as a basis for the addition of information pertinent to production elements.

This assessment was carefully made in the knowledge that no similar information retrieval system existed in the company, and followed Middle's assessment, (39)

"Any actual coding system must be designed to fit the requirements for the particular undertaking."

CODING OF DRAWINGS

Firstly, it was considered that the Opitz Code number should be added to the component drawings. For this purpose a rubber stamp was designed and the number written onto the stamp print in a convenient drawing location. See Fig. (25). In this way a convention in presentation was assured with clear identification for retrieval purposes.

CODING STATEMENTS

Secondly, the code and component numbers were to be written on a Fortan Coding Statement. The Group Technology Centre had suggested their standard statement type (Fig. 26) but this was not considered to be entirely suitable, and a new statement (Fig. 27) was designed which would satisfy control requirements and supplement present information. It was considered that this data would complement a future production control system. Fig. (30) shows future statement type.

The additional data concerning set-up and machining times was not added to the coding statements at this point because:-

a) This would greatly extend the coding exercise.

b) The planning details were often inaccurate.

c) This pre-supposed that production methods and times would remain unchanged after the implementation of Group Technology.

USE OF COMPONENT GUIDE CARDS

Thirdly, a convenient feed-back of production information was considered useful in the Production Engineering Department. Component Guide Cards (Fig. 7) were employed for this purpose, carrying planning details in note form. For each component drawing to be coded its relevant Guide Card was extracted and the Opitz Code added to aid information retrieval and avoid the unnecessary duplication of coding.

The Group Technology Centre provided a facility for the processing of code data and the Fortran Coding Statements were regularly submitted, as the exercise progressed. Computer print-outs containing listings in Opitz Code and component number order were obtained and used to demonstrate the practical value of the coding exercise.

PROGRESS WITH THE CODING EXERCISE

After an initial learning period the rate of coding rotational components increased steadily towards the 200 drawings per day figure quoted by MacConnell (42) By September, 1972 all the identified rotational components in the "F.S." range of switchgear equipment had been coded and were grouped into Opitz Code families. (Fig. (31) shows typical Switchgear rotational components coded.

The potential which Group Technology offered a beleaguered functional machine shop, with a rationalised approach to grouped component production, was high-lighted by the early Opitz Code listings. This code information transformed the then current melee of rotational component manufacture into sensible groups of manageable variance. Large families of simple, almost identical, components placed emphasis on duplicated design and the original decision to implement Group Technology became clouded over or forgotten. (4).

The directive was given, by those responsible for the project, to enlarge the scope of the coding exercise with a view to:-

1. Increasing the size of the data bank to form a useful retrieval facility.

2. Enabling larger areas of the component range to be reviewed whilst an additional coding analyst was employed. (An Aston undergraduate was temporarily engaged for the coding exercise).

3. Giving scope for the introduction of Group Technology over a wider range of machined components.

This increased coding range was to present difficulties which retarded the rate of coding, reduced the code accuracy and delayed the introduction of some early benefits. Those responsible for the coding exercise were aware that:-

a) Increasing the scope of the exercise involved the coding of non-rotational components.

b) Non-rotational components were not as accurately described by the Opitz Code.

c) Non-rotational components were not considered to require immediate analysis (except for certain specific groups, to be developed in the next chapter).

d) With the more complex components the rate of coding would be considerably reduced.

The coding exercise continued with the "F.S." range of switchgear; the series of auxiliary coding conventions becoming increasingly used to identify components manufactured on a sub-contract basis. The rate of coding was reduced to around 50% of the previous norm. (See Fig. (20)

HOSPITAL EQUIPMENT MACHINED COMPONENTS

After two months the coding exercise was expanded to include the machined components of Hospital Equipment Division manufacture. Attention was drawn to the rotational component categories because:-

1. The Opitz Code accurately described rotational components.

2. These rotational components were machined in the Switchgear machine shop.
3. Being a new concern, almost all the drawings were current, and of good standard.
4. All the drawings were well filed, making retrieval simple.
5. Previous experience has shown that high rates of coding were possible with simple retrieval components and the increased size of the code data would complement both the exercise and grouping potential.

METHOD OF APPROACH TO CODING

The retrieval of relevant component drawings for coding contrasted sharply with the duration and thoroughness of the Switchgear component analysis. All the drawings were readily attainable and, after discussions with the Drawing Office supervision concerning the rapid development of an accurate code file, and the need for reliable information the exercise commenced on different lines to the previous application.

1. Drawings were taken in block from the Drawing Office and coded.
2. No reference was made to the Material Sheets to determine component status.
3. The Opitz Code number was written onto the master drawings.
4. A coding convention was used to signify basic component identity.
5. The Opitz Code description was recorded for each component and a listing in code order computed.

This total approach to the coding of component drawings furthered the progress of the coding exercise but developed uncertainty with its accuracy;

a) Drawings absent from the file at the time of coding were not included, and when the code was used later in the project such omissions became apparent.

b) The Drawing Office Master Material Sheets were not used and therefore component characters were not known, that is whether made in, bought out, related assembly, or discontinued. When the components were later analysed for grouped production mamy such shortcomings were discovered.

c) Adding the Opitz Code to the master drawing instead of a drawing print created the disadvantage that if the component was later modified the code thereon may be made inaccurate.

d) Components designed for special customers' orders and not normally produced, were coded with the conventional components with no additional reference.

The coding of rotational components was completed in less than two days, indicating the speed of coding possible with simple parts. (Figs. 20 and 32).

EXTENSION TO INCLUDE HOSPITAL EQUIPMENT TUBES

Rotational component drawings were coded with such rapidity that the scope of the exercise was enlarged. Hospital equipment tubes could be technically described as 'rotational components' with the Opitz Code. The supplementary digits of the code classify tubular components, but, although basic overall dimensions are described with the code, tube gauge is not.

A typical plain straight tube would have the following Opitz Classification:-

20100 - 13 - 230 Fig. (33 and 38)

Although this code gives a good general component description, there are many variations in tube gauge within each diameter range specified by code size digits.

The coding exercise was extended to include all straight tubular components, without modification to the code, and a larger percentage of Hospital Equipment Division components became tenable to the exercise.

With the completion of the coding of straight tubes, again with comparative speed, the exercise was further extended to include the remaining tube-like components which were formed around their main shape axes.

As mentioned earlier in this section, the Opitz Code was less accurate in the classification and description of non-rotational components. Formed tubular components could be generally categorised with the Opitz primary grouping:

77--- (Fig. (34)

i.e. Long component with a formed main shape axis.

SQUARE - SECTION TUBES - CODE CONVENTION

Both straight and formed square-section tubes underwent identical production processes to the circular section tubes. The Opitz Code satisfactorily described circular section tubes in basic geometry and production features and it was thought contrary to grouping principles to widely differentiate between these two types of tube section, by code. Therefore, the same Opitz Code description was used for all square-section tubes with an additional code prefix, "S".

Therefore previous circular section tube codes such as;

20100 - 13 - 230 (Fig. 33)

would become;

S20100 - 13 - 230 (Fig. 35)

for square section tubes.

NON-ROTATIONAL COMPONENT CATEGORIES

A small percentage of the Hospital Equipment Division machined components occupied non-rotational component categories in the Opitz Code. These components were satisfactorily coded to terminate the coding exercise for the Hospital Equipment Division. No other remaining components were thought to be described in any way suitable for the application of grouping techniques, using the Opitz system. It was envisaged that the remaining un-coded components (and their Switchgear Division counter-parts) would be classified and coded when a suitable, specially designed code was available.

The Group Technology Centre was consulted and engaged for the design of such a code, and this will be described in the following chapter.

TERMINATION OF THE CODING EXERCISE

On the completion of the coding analysis for Hospital Equipment Division machined components the exercise with the Switchgear components was resumed.

Material Sheets were obtained for all the remaining equipment in current production (e.g. Fuse Switches, Universal Mechanism Boxes, High Tension equipment, and all the associated cabinets). The systematic approach to the retrieval of codable components described for rotational groups was continued for all the remaining non-rotational component categories. These categories included specific non-rotational components unique to switchgear manufacture, such as Contacts. For the purpose of accurate classification and adaptation into the grouping philosophy, a special code was designed specifically for the Ellison range of Contacts and this will be described in the following chapter.

Other specific component groupings perculiar to the manufacture of Switchgear included levers and lever-type components. Again the design of a special code was thought necessary and a code for levers was designed and will also be described in the following chapter.

Another student from the University of Aston in Birmingham joined the company during the completion of the coding exercise. Mr. J. Alexander was to study the use and suitability of the Opitz Code (41) in this practical application and assisted in the completion of the coding exercise.

The coding exercise was satisfactorily completed in December, 1972 after almost 5 months duration and the relevant statistics on code information are shown in (p 113).

The progress and details appertaining to the coding exercise are to be discussed.

MAINTENANCE OF CODE DATA

Although the main coding exercise had been satisfactorily arrested the newly formed code data base was not to become dormant. It was considered that the code data could continue as a component retrieval service for the drawing and design departments but must remain current.

For this purpose the drawing offices and production planning departments were approached for the notification of;

1. New components
2. Modifications to existing components
3. Deletions

The accuracy of the code data remains dependent upon such notifications.

DESIGN AND USE OF SPECIAL CODES.

In the application of classification systems in Group Technology, variety reduction or design retrieval systems, the choice of code type is not of prime importance. It is the use to which the code is applied and the respect of associated conventions that denotes success. Much of the earlier work on Group Technology has been devoted to the more widely published classification schemes (43,44) and, more recently, papers have reviewed the codes currently available (2) for the description of component/machining characteristics. Other codes such as Brisch (17) are tailor made to their applications, and the design and development considerations for industrial classification systems have been well covered. (45).

Burbidge (46) writes; "Because there is such a wide variation between the items handled by different companies, a universal classification is impossible, and each system has to be designed to suit the user."

It is with unconventional component categories that care needs to be taken to ensure that a universal-type code is not incorrectly applied. Conceived from an analysis of machined component statistics (2) the Opitz system offers advantages for the coding of conventionally machined components (especially rotational), but its suitability is restricted with non-standard workpieces. Involved in the use of the Opitz Code at George Ellison Limited, the writer experienced the temptation to apply the code to workpieces - which did not belong to the categories defined by the code or contained non-standard features outside the classification range. In many cases, with the adoption of conventions, the application of the Opitz Code was satisfactory, but with certain component categories the description offered was loose and unsuitable.

COMPONENTS FOUND UNSUITABLE FOR OPITZ

At George Ellison Limited three main component categories were found unsuitable for the Opitz Code;

a) Contacts and contact-like.

b) Levers and lever-like.

c) Sheet-metal work.

FACTORS INFLUENCING CODE DESIGN

Capacity within the Opitz Classification System

The Opitz system was found to offer a simple, accurate and reliable data base for conventional workpiece statistics. Two of the three component categories (i.e. contacts and levers) offered secondary machining features as covered by the mutually exclusive terminology used in Opitz, (i.e. plane surface and auxiliary hole production). Also, the interpretation of the Opitz Code by MacConnell (43) contained two dormant primary digits, 5 and 9 (Fig. 17). These two digits were made available for the types of development considered, and digit '5' was considered satisfactory for the basic identification of these two component types.

Primary digit '9' was reserved for the description of extreme component complexities or for those components not satisfactorily described in any way by the Opitz Code. Sheet-metal components were to be given this separate digital significance (Fig. 17), and did not use the other Opitz classifications.

Using codes of the same length and form, having identical secondary feature digital relations, the contact and lever codes were compatible with the Opitz Code and shared its avantageous features.

CONSTANT CODE SIZE

The geometrical/production characteristics of the two codes occupy 5 digits, as with the Opitz Code, and to eliminate coding errors the supplementary digits were also made common. (Fig. 36).

DIGITAL SIGNIFICANCE

Both the contact and lever codes were designed to be compatible with the Opitz Code, sharing 4th and 5th digit relations for Opitz component geometric classes digits 6, 7 and 8. Having initial component class digit '5' the various geometrical shape elements were described by the 2nd and 3rd code digits. (See Fig. (37)).

COMMON TERMINOLOGY

Basic "contact" and "lever" (component) types were simply identified by means of the 2nd code digit, and their associated shape elements described with individual elements within the 3rd digit. The simple division and description of classes was logical and similar to the Opitz Code for digits 4 and 5, and having common supplementary terminology. The new codes were simple to introduce and easily understood by production engineering laymen.

CLASS DESCRIPTION

The entire ranges of "contact" and "lever-type" components were reviewed to aid their logical association and grouping into similar categories. Basic shapes and shape associations were categorised on a logical theme with increases in digit number corresponding to increasing complexity. (See Fig. (37)).

UNIQUE CODE IDENTITY

The aim of the special codes was not to give an item or product a unique number (39) but was directed towards production improvements and particular cost savings (contacts are copper materials).

Unique identity was given by component number; associated identity, grouping design and production features to a common end, was given by the code.

If a unique identity was to be allocated to each item (using contacts as an example) (Fig. (37)) there would be insufficient capacity within the Opitz-type code, thus necessitating the use of a large code to the detrement of the previously common terminology.

a) THE CONTACT CODE.

A review of all contacts and contact-like components was made to investigate the potential for natural grouping or shape associations.

Component retrieval was based on the following considerations;

1. Description or name "contact".
2. Association with the purpose of a "contact".
3. Auxiliary components used with contacts.
4. Copper material.
5. Components similar to contacts ("contact-like"), being of non-ferrous material.

With reference to the Drawing Office Material Sheets all drawings relevant to this analysis were examined and categorised according to;

1. Contact type;
    - a) Section metal (Fig. 37).
    - b) Formed shape (Fig. 37).

c) Cast or forged heavy sections (Fig. 37).

d) Brazed assemblies (Fig. 37).

2. Geometrical characteristics.

3. Auxiliary machining features.

The Contact Code was designed on the basis of these categories and the inter-relationship of the code descriptions and digit numbers within the Opitz Code are shown in Fig. (36).

CONTACT CODE USE AND THE DEFINITION OF CONTACT-LIKE COMPONENTS

Closely following the same drawing retrieval methods used for the main coding exercise, (Fig. 29) contacts associated with the present switchgear production were quickly identified for coding. Categorising the drawings by way of the code-shape identification, speedy progress was made and a portion of the collated code data is shown in Fig. (38). The code was simple to interpret and high rates of coding were possible.

The main contact groupings were found to be digits 5.0. and 5.2. (see Fig. 37) and the code descriptions were found to closely reflect the planned production operations. A typical example of how the Contact Code accuractely interpreted production operations was with the section-metal types, 50--- see Fig. (39). These contacts were sawn, milled and drilled as implied by the code, and, the production of the smaller types (Fig. 40) was to some extent specialised. A small section of the machine shop had been developed for this purpose and included drilling and tapping arrangements, but excluded the initial sawing operation. Recently, with the use of the code, three small contact-type components were reviewed in the design of rotary indexing tables for improved production in this small machining section. These indexing tables were to locate components for drilling and tapping (one table each contact "family") and incorporated pneumatic component ejection (see Fig. 40).

Some of the section-metal and formed contact categories (502-- and 511-- (Fig. (37)) included standard workpiece geometry (Fig 41). With conventional component types occuring within a specialised category the basic rules for the component search required close observation (Fig. 29). Workpiece classification and coding techniques using the conventional Opitz Code showed large families of conventional components (both ferrous and non-ferrous) which appeared similar to "contact-like" components in both geometry and production requirements. Typical examples were component parts required for the brazed assembly of large moving contacts (Fig . 41). Coded individually, the separate components were given completely different identities to the assembled contact (Fig. 41). The correct interpretation of the code was vital to the successful grouping exercise for contact manufacture and four basic considerations eminated:

1. The components would require a related production sequence to enable contact production to be successfully scheduled.
2. Conventional component types would converge for the brazing assembly operation.
3. Contact-like components were of copper material requiring special machine cutters.
4. The grouped production of contacts and contact-like components was essential for improved production performance with reduced cost of work in progress (copper) and associated costs.

CONTINUATION OF THE CONTACT EXERCISE

The "families" of contact and contact-like components were available in tabular form by September 1972. The further detailed analysis of this information for the purpose of improving contact manufacture was then suspended.

In June 1973 this area of activity was re-commenced with a view to the formation of a production 'cell' for types 52--- and 53--- contacts

The grouping exercise was to be performed by an engineer inexperienced in the practical application of Group Technology and the writer was asked to monitor the progress made. There was a continued lack of appreciation of the terminology; "contact" and "contact-like", in the scope of the component review. Further to this, the grouped production of types '52' and '53' contacts did not consider the machining of the constituent components thereof and in one case ommited 92% of a certain component family.

Despite the continued involvement of the writer this limited approach prevailed with the addition of dissimilar components on the basis of planned manufacturing methods. The reasons for this decision were documented as:-

1. These dissimilar contacts were planned for the same machine tool and this machine was required for other contacts which formed the main loading of the machine group.
2. This machine, a vertical milling machine, was the only one of its type available and would otherwise have surplus capacity.
3. The dissimilar contacts had tooling which was designed specifically for this vertical miller.

The exercise continued without the use of the established code data on the basic lines of a Production Flow Analysis (47). This analysis did not attempt to question the existing manufacturing methods and succeeded in the design of a small functional layout which attempted to reduce material movement.

The relative values of component coding and production flow analysis are dicussed (**128**) and analysed in the formation of "tooling families" in later sections, (**61**).

The Contact Code was designed around a specific range of unusual component shape features, and contacts were unique to switchgear production. Many of the larger contacts, though, comprised components having conventional shape features which were brazed together on assembly. In basic form, therefore, the only association between constituent elements and final assembly was material (**copper**). It was therefore important to associate such conventional components with the assembly (**contact**) by means of the special code. Equally important, though, was the need to positively differentiate between those components pertinent to contact manufacture and those which were not, although having common material (**copper**).

CONNECTIONS

Naturally switchgear manufacture includes a large variety of copper electrical connections. These connections would normally have been included in the coding exercise and would be accommodated by code description 511--/--/72- (raw material form classed as strip convention). Connections were manufactured in a special G.T. cell (Fig.(42)) developed in 1970. This cell essentially comprises a power press and a press-brake section for the blanking, piercing shearing and forming of copper strip. Auxiliary facilities, such as those for hand-press work, light and medium drilling, and the racking of associated raw material, complete a compact manufacturing unit. (Fig. 43) All copper connections are produced in this cell and this component grouping was not considered in the coding exercise.

b) THE LEVER CODE

Similar in design to the Contact Code (P.50) the Lever Code was developed from an analysis of the lever and lever-like associated components perculiar to production of switchgear.

The retrieval of relevant component drawings for the application of the special code was based on the following parometers:-

1. Description or name 'lever'.
2. Association with, or acting for, the purpose of a 'lever'.
3. Components similar to levers both in design and operation, having one or more principal areas of rotation.

The Drawing Office Material Sheets were again used to select all the relevant drawings for each type of switchgear, and component drawings were categorised for coding according to:-

1. Lever type;
    a) Fabricated types.
    b) Cast, forged or moulded types.
2. Geometrical characteristics.
3. Auxiliary machining features.

Similar in layout to the Contact Code, the Lever Code was designed on the basis of these 3 categories and the code illustrates the associated digit/component relationships. (Fig. 36).

LEVER CODE USE AND THE DEFINITION OF LEVER-LIKE COMPONENTS

During the main coding exercise many components which were now identified as belonging to a lever 'family' were coded under a standard Opitz grouping. This grouping - component class digit "7" - (Fig.(17)) was considered imprecise, and, to improve component drawing retrieval, a convention was stipulated to categorise all such components. Thus, although the standard Opitz Code did not provide satisfactory descriptions of component identity, its use with a convention did provide an approximate grouping for future analysis.

The use of an inaccurate, but general, Opitz description - class 7 - (Fig. 17) grouped all components occupying every family of "lever class" components as one "family". Although this grouping was broad the relevant production information for the group i.e. plane surface machining and auxiliary drilled holes, - digits 4 and 5 - (Fig. 16) was accurately described by the Opitz Code. The design of the Lever Code promoted the more accurate grouping of lever-associated families, but used the same production information as Opitz. With these types of component families where the number of primary shape variations could approach infinity, the secondary machining features were often the only machining required. It was therefore likely that a Production Flow Analysis of such components would yield similar (if not improved) benefits as the special codes.

A secondary advantage of specialised codes in the variety reduction and design retrieval fields was quite apparent.

The selection and identification of lever-like components involved similar techniques as used for contact-like components. Experience in the design and use of coding techniques stimulated the logical interpretation of important component features. Many components classified as "Lever-like were found to have no such association either by name or in use, but were geometrically similar, having one or more primary axes of rotation from an evaluation of basic design. (Fig. 45 and 46).

THE SHEETMETAL CODE

During the initial stages of the coding exercise some component categories were found to be either vaguely described with, or entirely unsuitable for, the Opitz Code. The Opitz Code was suitable for machined components (39) and could not be accurately applied to the following workpiece categories;

a) Sheetmetal.

b) Formed rotational and non-rotational components.

c) Tubes and tube-work.

The review of these component categories was not considered at the start of the coding exercise (Page No. 35) and, with the unsuitability of the Opitz Code, the Group Technology Centre was approached for the design of a code to meet the above requirements.

The code comprised 14 digits, 6 geometrical, 5 supplementary and 3 forming classifications. (See Fig.(47)).

The component classes were divided into 3 main groups:-

1. Components whose main shape was flat.
2. Three dimensional components where the bending was parallel to the edges of the main shape.
3. Other three dimensional components.

A fourth class division concerned formed components which were circular in section, being particularly well suited to formed tube-work. One component class digit '9' remained vacant to enable the future classification of specific component categories. (See Fig.(47)).

Excepting primary class digit 8 the sheetmetal code was fundamentally of Polycode design, and comprised 14 digits.

Component class digit 8 described components formed from circular section material and was particularly suited for the description of formed tubular components. (Fig. (48)). The sheetmetal code was abbreviated for use at George Ellison's with the deletion of the forming code and the formed height digit. (Fig. (49)). Another more specific digit was then added to this abbreviated code to describe the jointing process types used. (Fig. (49)). The final code used comprised 12 digits, the first digit '9' identified the code type for mechanical sorting procedures. The initial supplementary code was also modified and adapted to meet the specific (raw material), requirements. (Fig. (49)).

THE PRACTICAL APPLICATION OF THE SHEETMETAL CODE,

ITS ADVANTAGES AND DISADVANTAGES

The code, as used, comprised 12 digits. Being entirely dissimilar to the Opitz and Opitz-based codes, the introduction of this code to the coding exercise reduced coding rates and imposed difficulties with data sorting and presentation. The original design of the Coding Forms (Fig. 26) did not envisage the Sheetmetal Code and a code location had to be considered so as not to reduce to utilisation of data capacity.

Being of polycode-type the sheetmetal code did not offer inter-related shape/code sequences as with Opitz and the code was therefore difficult to memorise.

The formed component code descriptions were usefully accurate although the 6th digit (Fig. (47)) did not relate to the means of hole production (i.e. punched or drilled?). This was thought to be an unfortunate draw back necessitating the further analysis of related planning details.

Component class digit 8 offered an improved description with formed tubing, having three primary digits (2, 3 and 4 Fig. (48)) relating to tubes. The supplementary code (Fig. (49)) enabled the more exact description of the raw material, particularly tube gauge to be made.

The Sheetmetal Code was used to describe a limited range of formed components (Fig. (47)) before the coding exercise was terminated, and its improved descriptive accuracy offset usage difficulties.

COMPARISON OF SHEETMETAL AND OPITZ CODE FOR SPECIFIC COMPONENT TYPES

The Opitz Code had been used for the classification of certain formed component ranges such as tubes, tubework, and some presswork. Opitz offered fair geometrical descriptions for straight tubes with auxiliary reference in the supplementary code. (Fig. (17)). Similarly, with rectangular or square section straight tubes, the use of a letter 'S' preceding the geometric code offered satisfactory alpha-numeric descriptions, (Fig.33, 35). With formed tubular components Opitz did not provide details pertinent to forming geometry and therefore a coding convention was required to enable the future accurate interpretation of this Opitz adaption. In the main, this code adaption relied on the Opitz supplementary code digit for tubes (Fig. (34)). With pressed or formed non-tubular components the Opitz Code was again adapted to provide a coding convention. Such adaptions provided code descriptions for auxiliary machining features such as holes and slots (Fig. (17)). Tubes and sheet materials were specified in terms of gauge. The Opitz supplementary code described major external dimensions only and was therefore unsuitable. Thus with the introduction of this new code, tube components were classified by two dissimilar codes.

The Sheetmetal Code offered more precise geometrical descriptions which did not rely on supplementary code information for their accuracy. Components could be grouped according to formed shape and auxiliary features such as cut-outs and holes were well described, although the means of auxilliary feature production required further interpretation. A major advantage over the Opitz Code was in raw material description. The code included material gauges or thicknesses based on a detailed component survey.

SUMMARY

When the coding exercise was directed towards component categories which were not satisfactorily described with the Opitz Code, attempts were made to convert the code data. The Opitz adaptions which provided the two special codes for Contacts and Lever components were both satisfactory and compatible with the parent code type (Fig. (16)). The Opitz Code was in no way suitable for the accurate description of sheetmetal-type components and offered only partial description with tubes. The unsuitable components which were coded with Opitz can be identified, although only with vague accuracy, as a result of the conventions and ingenuity of the adapted codes used. In this way components which were not precisely classified were grouped for future identification and analysis. When such a review is made these components can be re-coded with the purpose-designed Sheetmetal Code.

FAMILY FORMATION FROM CODE DATA

The coding exercise commenced with rotational components selected from the current range of circuit breakers. The component review was then extended to include similar machined components from the entire switchgear and hospital equipment manufacturing programmes. The scope of the component search became increasingly diverse as the exercise progressed and in December, 1972 the project was re-aligned to the further analysis of rotational component families. The coding exercise(s) had shown that rotational components offered the greatest potential for the application of Group Technology, as;

1. Rotational components were found to include approximately 65 per cent of all machining.
2. The turning section was the largest functionally arranged machining area.
3. As such the turning section illustrated production difficulties for which Group Technology offered proven remedies.
4. The introduction of a simple but effective pilot group or 'Cell' would demonstrate the advantages of Group Technology and help to generate enthusiasm and greater understanding in the company.
5. The Opitz Code profered accurate component descriptions enabling the accurate formation of practicable component groupings.

CODE ANALYSIS

The coding exercise had provided a data base which tabulated the classifications of some 5,000 components. Punched cards were produced for each of the code descriptions and tabulated listings in both Opitz classification and component stock number sequences were provided by the Group Technology Centre. Some 2,000 of the conventional components coded could be seen to occupy rotational categories and the visual examination of these component code numbers illustrated their overall basic simplicity. Large blocks of identical code descriptions were seen to reflect the typical component categories of collars, bushes, pins and screws (basic code equivalents, 00100, 10100, 10000 and 12000 respectively Fig.(51) all within the small code size categories.

The largest rotational grouping was for bush and bush-type components and showed clear divisions between ferous and non-ferrous materials, - per cent of which being in the 00 - 20 code size category. This block of Opitz Code descriptions formed the basis for the first component family, grouping components which were identical or similar by code description. The code description related these components by geometric shape features and size, and by the machining operations required. The ability of the code to accurately imply component and production feature similarity was suspect and will be discussed in the following section.

1st COMPONENT FAMILY

The Group Technology Centre suggested that the 10100 series code group could act as a basis for family formation and defined a component family (42) as "a collection of component parts with a high similarity and work content to support the establishment of a group of machines to manufacture them."

Using the bush family (10100) as a base, similar component groups could be developed on a code description basis, all within similar code size ranges. Such an enlarged component family was developed using 10100 as a base code (see Fig.(50)) and the level of sub-family addition was decided on the basis of;

1. A realistic work loading for primary machining operations.

2. The degree of component dissimilarity, which could be tolerated in the creation of 'families' for grouped production.

3. Group structure and secondary machining operations.

1. PRIMARY MACHINE UTILISATION

Traditional philosophy maintains that the maximum utilisation of machines is of prime importance in shop loading. In batch production industry machine utilisation includes all periods during which the machine is engaged, including setting times. If the machine utilisation is broken down into productive and non-productive elements, the proportion of the available time when metal is actually being cut is far below the 100 per cent goal desired for maximum utilisation. In the Switchgear turning section productivity is low when compared with the machining potential, yet, so-called machine utilisation is high. This normally requires a re-design in the definition of utilisation to relate effective utilisation to productive capacity. (48

An application of Group Technology at English Electric (Siddlers) established permanently set-up machine groups allocated to component families. A 75 per cent increase in productivity resulting from an elimination of set-up time was established, although the overall utilisation was slightly reduced.

At Ellison's the Opitz listing of machined component families showed larger quantities of identical or similar components, for example bush-types, than other families. (Fig.(51)). Therefore, defining the primary machining operation as that which forms the primary feature characteristics of the components, this operation will load the primary machines of some families more than others. (See Figs. 52 and 53).

DEFINITION OF THE PRIMARY MACHINE FOR ROTATIONAL COMPONENT GROUPS

The layout of a group of machines for the purpose of cellular manufacture must, from basic principles, be developed around similar components, or more exactly, components having similar production requirements. Rotational components have an additional advantage, by design, in that not only are their production requirements similar but also their geometry. The similarity of production features is judged on the basis of primary shape description and therefore, if components are grouped initially by such features, they will constitute machine loadings which dictate the design of the production group. The primary machine for a rotational component cell is therefore that machine which creates the primary shape features of the component family.

This primary machine will feed any secondary machines associated with it and will have the highest level of utilisation. Although co-ordinated with other machines to form a production cell or "synthetic machine" the primary machine or process will not necessarily be the "key" machine ((39)).

Some component families, for example Family 1, contained large groups of similar components having no secondary machining features. For these components the primary machine will be the only machine required for complete component manufacture. The primary machine would perform as a single machine cell ((50)) and provide a highly efficient manufacturing unit.

In the formation of manufacturing groups the gross under-utilisation of critical machines is to be expected if large reductions in setting time are to be gained by grouping. ((7)). But the numbers of components within some families having no auxiliary features, by code, were such that family formation for single-machine cells provided insufficient work content.

2. FAMILY GROUPING AND MACHINE UTILISATION

A more detailed analysis of the 24 component families was undertaken to translate the number of similar code numbers in each family into tangible machine loads. The 24 groups of code number associations (Fig.(51)) were correlated into machine loadings using annual component usage quantities. It was realised that due to the reduced production output concordent with switchgear sales at the time of the analysis the 1972 usage quantities could create some unusually low family loadings, but there was a need to convert the more academic coding information into production practicalities. There was insufficient time in the exercise to indulge in component requirement forecasts as these must be related to finished products and there was no available computerised parts explosion. It was therefore accepted that the 1972 usage quantities could be used provided that;

a) A forecast factor was used in addition to the usage quantities.

b) The degree of component family combination did not reduce the flexibility required in cellular production.

Component quantities in each family, and in each code size range, were collated to establish their machinery requirements. At the start of the exercise (P.9) it was accepted that the existing planning records were of insufficient accuracy to offer reliable machinery information. Also, the introduction of Group Technology obviated the acceptance of change. Components in each code family were selected at random and reference was made to their planned allowed machining times. Using representative mean machining times the sum total loadings for primary machining operations were calculated. (See Fig.52,53). This basic information relating discrete component families to machine loadings used existing operation times to demonstrate the simplicity of grouping concepts and re-orientate production problems into perspective.

3. GROUP STRUCTURE AND SECONDARY MACHINING OPERATIONS

From the analysis of rotational component families (Fig. (51)) the Opitz Code was used to identify those components requiring secondary machining operations, this was established using the 4th and 5th digits of the code (Fig.(17)). These code digits describe auxiliary features of components and, in so doing, imply production operations. (See Figs. 58 and 59). Using the code, components requiring secondary machining operations were identified and the following table shows the relatively light machining requirements.

Components requiring drilling operation(s)	20%
Components requiring milling operation(s)	10%
Components requiring both milling and drilling operation(s)	4%
Total	34%

This analysis showed that no individual component family contained sufficient numbers of components requiring auxiliary machining operations to fully utilise grouped secondary facilities. The merits of primary machine utilisation have been discussed earlier and, although on a code family basis some primary machines may not be heavily loaded, secondary machining requirements were ridiculously low. Earlier work ((55)) has referred to rotational component group structure in terms of a turn - mill - drill layout, but, this analysis of typical conventional components demonstrates unsatisfactory levels of utilisation for some primary and all secondary machines if groups are strictly related to code families. Secondary machines may be less important, from a utilisation aspect, than primary machines but expensive plant may be involved, such as milling machines.

By comparison, light-drilling machines involve smaller investment risks and a greater level of under-utilisation may be possible depending on the number of similar machines required for other areas of production.

Using simple component families as a base, production groups were collated to investigate the possibilities of:-

a) Designing production families on the basis of maximum utilisation of primary machines, with low utilisation of secondary machines.

b) Separating families by code into primary operation only and mixed operation groups.

c) Designing production families to provide good utilisation of primary machines by allowing a degree of component dissimilarity, and sharing grouped secondary machining facilities.

SUMMARY AND THE "IDEAL" FAMILY

From the early analysis of rotational component codes shown in Figs. 51, 52 &53) the insufficient quantities of similar components in certain families demonstrated that the design of production units or cells based on single families was not possible. The 'ideal' practice of one component family (on a code basis) having its own production facilities could be only partially maintained with the largest component family (bush-type components Fig. (51)). This particular family included size ranges which extend beyond the capacity of any single lathe. Therefore, although the design of production cells based purely on single code families offered the optimum in Group Technology it was considered unacceptable because;-

i. The high degree of under-utilisation of capital equipment could not be tolerated.

ii. There were insufficient machines available to provide separate production facilities for each code family of components.

iii. The introduction of Group Technology on a cell - per - component - family basis would create problems which would initiate unwanted propaganda to the detriment of the exercise.

It was envisaged, at this stage, that a limited number of production cells could be quickly established to successfully produce combined families of compatible components. Such cells would specialise in the efficient production of the simple, large families of pin and bush-type components, that is "nuissance value" items (51). Not all components or families of components could be accommodated using this approach, nor was it thought that all rotational components would fall into practicable groups. There would always be a need for a jobbing section which would have the capacity to;

a) Machine "difficult" components not compatible with any cell.

b) Serve as extra capacity in emergencies.

c) Machine component "sub-orders" involving very small quantities (i.e. setter-operator work).

The design of production families and the grouping of associated machined was therefore to follow possibility "C" in the previous section. To enable the accurate intepretation of code number groups each code family of components was reviewed for specific production requirements.

THE USE OF TOOLING ANALYSES IN THE INTEPRETATION OF CODE FAMILIES INTO PRODUCTION REQUIREMENTS

In the coding exercise for Switchgear components prints were obtained for each component drawing, and, after coding, these prints were filed in Opitz Code order. Due to circumstances at the time of coding Hospital Equipment* components no drawing prints were obtained, and these prints were now necessary for tooling analysis purposes. Each code family contained similar, if not almost identical, components from the two divisions and drawings were retrieved en bloc for each code family. The large numbers of almost identical components within the simple base families of bush-type and pin-type components offered potential for variety production and demonstrated the practical aspects and accuracy of the code for design retrieval.

*(P.42)

BASE FAMILIES

Using these simple, large families as a base components were grouped, with the aid of the size range code, to form sequenced production families to the benefit of effective machine utilisation. The Group Technology Centre provided Tooling Analysis Sheets (Fig. 54) for the tabulation of the production requirements of each component. These sheets listed component features in terms of rotational machining operations and served to:-

1. Demonstrate the production and design similarities of components within a code family.
2. Show the advantages of producing all the similar components by the same process on the same machines.
3. List all the tooling and setting adjustments necessary for their grouped production.

Additional information was also entered on the Tooling Analysis Sheets recording component raw material diameters (for collet sizes required) and material index number (for raw material issue). In this way component families were tooled-up for grouped production on a primary operation basis. Components which were similar to the primary grouping but which had features requiring secondary machining operations were also grouped with the parent family on a primary feature basis.

SECONDARY FEATURE PRODUCTION

Component families were grouped initially on code primary features and hence Opitz Code listings grouped, for example, all plain turned bushes in strict code sequence. Thus, all bushes with the same primary code were grouped according to:-

1. Production accuracy (Code digit 10).
2. Material form (Code digit 9).
3. Material type (Code digit 8).
4. Component length (Code digit 7).
5. Component max diameter (Code digit 6).

Sorting of the selected code families could be done using punched cards and a card sorting machine was used to select components in this order. Having identified the required component families with the primary Opitz Code the supplementary code was reviewed for the selection of particular components with the primary code families. Following the sorting list;

1. Components unsuitable due to dimensional accuracy requirements could be identified. Certain components, particularly those with reamed bores or accurate grooves, were not appropriate if generally simple (open tollerance) components were required.

2. To enable the use of semi-automatic chucking only components produced from bar stock were required.

3. In certain code families it could be advantageous to seggregate non-ferrous and ferrous components.

4. Long part lengths would create problems with frequent bar stock replacement, that is, few long components could be turned from standard bar lengths.

5. Relating component families to particular machines, the basic limiting parameter was machine spindle capacity.

On the Optiz Code listing, code families were arranged basically in primary code sequence. Any primary code family was listed initially according to the 5 indices mentioned in sequence order 1 - 5 respectively. Thus, components identical to the base code family on a primary feature basis (for example, plain bushes), but requiring secondary operations such as, for example, auxiliary holes, were widely separated by the code.

10100 - primary code for bush-type components
- numerous supplementary code variations

10103 - identical primary feature bush-type with auxiliary drilled hole
- similar supplementary code variations

Components were grouped on a critical production feature basis, and, sharing this basic feature, components having auxiliary shape elements were grouped on the same basic theme.

Auxiliary machining such as drilling and milling was recorded using separate Tooling Sheets Figs. ((55) and (56)). These analysis sheets recorded drill sizes, cutter types, etc. and included methods of holding such as vice, vee-blocks, dividing head, etc. See Figs. ((55) and (56)). The tabulation of such production details illustrated great potential for the simplification and control of tooling, and the rationalisation of holding devices.

The combination of similar components with and without auxiliary machining features to form a composite component family envolved a group structure naturally based on the primary operation as the "key" operation. This "key" operation would have the highest level of utilisation in the machine group, and would feed auxiliary machines. The relationship of primary to secondary machining operations in synthetic machine groups was seen to be directly related to family composition and the degree of machine under-utilisation which could be tollerated.

GROUP STRUCTURE AND SECONDARY MACHINING OPERATIONS

From the analysis of component machining times (Fig.52&53) it was found that no individual code family correlated on a primary code feature basis (i.e. plain pin or bush), comprised sufficient work content to effectively load the starter machining operations. Product geometry and size ranges showed considerable variety (24 initial code families) and group design strictly on a code family basis would make cells so small as to be virtually unworkable, principally because of the unacceptable utilisation of second operation machines . (52) The design of group structure was therefore considered to be a compromise between practical and economic acceptance, and envisaged performance. On the one hand, a review of the plant list showed typical duplication of functional machining facilities with low present day cash values, and on the other the potential for successful small machine cells which would have lower utilisation than the conventional plant.

This approach involved the re-orientation of the machining facilities for rotational components only, whereas the coding exercise indicated a remaining 35% of machined components could be grouped as non-rotational and specific non-rotational. This did not consider components which were sub-ordered, customer specials, spares or fabrication requirements. Machining facilities were required for these non-rotational component types although rotational components were the prime consideration of the project. Also certain areas of the rotational code families comprised components which were either of high complexity or of sufficient variance with the conventional groupings to necessitate separate manufacture. A separate machining section comprising a functional group of machines was thought to offer most benefit for those non-standard component groupings.

Taking the non-rotational components and the need for a general functional machining group into consideration, there would be a large reduction in the number of machines available for cell formation if separate cells were arranged for rotational components. Of the machines present in the turning section possibly the centre lathes would be the only lathes required in a functional jobbing group, but, a large proportion of the drilling and milling machines would not be available for rotational component cells.

SHARED SECONDARY MACHINING FACILITIES AND A LIMITED INTRODUCTION

The review of the components in each of the 24 code families showed that not only did the majority have simple production requirements but also that each family included components requiring auxiliary machining operations. Thus, the development of production cells on the shop floor suffered two main limitations:

(a) Insufficient component quantities within distinct family groupings to justify single family cells based on primary operations.

(b) Individual auxiliary machining facilities could not be related to each component family.

A solution which offered a compromise between the complete re-orientation of the main machine shop and the limited introduction of Group Technology without additional investment in machines was proposed. Selected simple component families were combined to provide realistic loadings for recognised machines in the turning section, and to justify demand for selected plant for drilling and milling operations.

THE LIMITED INTRODUCTION OF GROUP TECHNOLOGY IN THE MACHINE SHOP

There were two principal opponents to the radical change which the complete introduction of Group Technology would bring to the Ellison machine shop;

1. The financial position of the company at the time of the exercise.
2. Poor labour relations prior to the separation of the two company Divisions and the opposition which would be stimulated.

It was recognised that the company economy and labour force had to be insulated from the effects of change by way of a phased introduction. In December, 1972 scheduling techniques had been successfully applied using the Opitz Code for practical component grouping.

SEQUENTIAL SCHEDULING USING THE OPITZ CODE

Sequential loading schedules were developed for Hospital Equipment simple rotational components using the Opitz Code. An Opitz Code listing of all the Hospital Equipment machined components had been available since the coding exercise, demonstrating the simplicity of the turned component requirements. Two automated Capstan Lathes had been made available especially for Hospital Equipment current component production in the Switchgear machine shop. It was the purpose of the exercise to obtain maximum component output from these two machines:-

Herbert 2D automated Capstan

Accuratool Plug-board Capstan

The direct application of Group Technology principles to these two machines was seen to be a good demonstration of its suitability for jobbing production and as a practical intepretation of the Opitz Code.

COMPONENT - MACHINE MATCHING

The loading of two specific machines automatically fixed certain component parameters;

a. Spindle capacity/max component diameter.

b. Maximum feed strokes/turned component length.

c. Tooling Capacity/component family shape features.

Using the Opitz primary code few rotational components were identified which were either outside the capabilities of these two primary machines or sufficiently complex to propose inter-scheduling problems. Typical code family types collated for these machines are shown:-

OPITZ CODE FAMILY	DESCRIPTION
00100	Collar - type
10000	Pin - type
10100	Bush - type
10200	Tapped bush - type
11000	Turned pin - type
11100	Turned bush - type
13000	Grooved pin - type

These component families were each of sufficient variance to make re-setting necessary within each family when machining. It was therefore decided to adopt Durie's (50) technique of creating sub-families based around fixed component parameters such as collet size and material type.

USE OF OPITZ SUPPLEMENTARY DIGITS TO MATCH MACHINE CAPACITIES

Components within the selected families were grouped using the size and material code digits. Unfortunately, the size code digit range did not accurately compare with the machine capacities.

CODE DIGIT	SIZE RANGE	MACHINE CAPACITY
0	Dia. ≤ 0.8 in.	Accuratool 0.8125 in. max.
1	Dia $> 0.8 \leq 2.0$ in.	Herbert 2D 1.5 in. Max.

Therefore a complete range of component drawings within each diameter range code digit was re-viewed to select those components within the two machines capacities. After this coarse manual sort, the selected components were examined for overall part lengths. Bearing in mind that the two machines relied on continuous feed bar-stock material for their operation there was little point in selecting components which were of such a large part length that a low quantity of finished components could be obtained from each length of bar-stock. If this were the case the machine would require frequent re-stocking as all the components were required in large batch quantities. The part length maximum and the particular supplementary code ranges were:-

MAXIMUM PART LENGTH	OPITZ SUPPLEMENTARY CODE SIZE RANGE
$3\frac{1}{2}$ in.	Digit 2 :- 2 - 4 ins. maximum

COMPONENT SEQUENCING WITHIN SUB-FAMILIES

Having selected components which were within;

a) The machine capacity restrictions

and b) Of low complexity by family type.

the families were re-sequenced into sub-families according to;

1. Collet size
2. Tooling requirements

3. Batch quantities.

At the time of the exercise there were approximately 105 rotational components availabe for analysis, of which 67 or 64% were finally sequenced. By dividing this total requirement according to machine collet size, that is, 0.8125 in. max. and 1.500 in. max. groupings, the final component quantities per machine were;

Accuratool - 41 components
Herbert 2D - 26 components

For each machine the components were sequenced into sub-families whose features could all be accommodated using the 6 capstan stations plus front and rear tool posts. (Fig. (60)). The components in the sub-families were of little family or production feature variance and there was nothing to be gained from maintaining strict family discipline, for example, all pins, all turned pins, all bushes, and so on. It was initially considered to pre-set 6 end stops on a capstan head to complete a range of pins, Fig. ((95)). This application did not optimize component interchangeability because of the close family similarities and therefore the combined sub-families were re-scheduled by collet sizes.

PERFORMANCE

The rotational components considered in this exercise were required in medium to large batch quantities. Their annual requirements ranged from 400 to 17,600 with a weighted average of approximately 4,000. Components were arranged into optimum schedules for each machine and given a schedule reference number;

Accuratool	Herbert 2D
A1/0	H1/0
A2/0	H2/0
A3/0 etc.	H3/0 etc.

The sequence number relation was such that suitable additional components could be inter-posed without disrupting the main sequence:-

A1/0
A2/0
A2/1)
A2/2) New components
A3/0

Unfortunately, the sequential loading exercise was short-lived due to internal difficulties within the machine shop, but demonstrated a highly successful exercise in the creation of two single machine cells. An important by-product of the exercise was the exhuberant acceptance of grouping techniques and terminology by the shop-floor supervision. This was heralded as a major breakthrough in the shop-floor attitudes towards new production methods.

METHOD CHANGES THROUGH COMPONENT GROUPING

A useful revelation stemming from component family grouping was the variance discovered in present production methods.

Of the 41 components grouped for the Accuratool;

25 were planned for the Accuratool.

7 were planned for the Ward 2A Capstan.

7 were planned for the Bimax Saw.

1 was planned for the B. S. A. Auto.

1 was planned for the Herbert 2D.

Of the 26 components grouped for the Herbert 2D;

16 were planned for the Herbert 2D.

7 were planned for the Ward 2A.

2 were planned for the Ward SA.

1 was planned for the B. S. A.

REASONS FOR NON-CONFORMITY IN PLANNING

1. Component batch quantities.
2. Work required for under-utilised machines.
3. New machines.
4. Planning Engineer's preference.

CONCLUSIONS DRAWN FROM THIS LIMITED EXERCISE

Although the practical application of this sequential planning exercise was short-lived it served to demonstrate the usefulness and accuracy of the Opitz Code for rotational components, the potential for further applications directed towards machine interelation and grouping, and sowed the first "Group Technology seed", in successfully surmounting conventional shop practice.

THE EXTENSION OF THE INTRODUCTION IN THE MACHINE SHOP

To further the practical and demonstrative inroads from the sequential planning exercise on the Hospital Equipment Division rotational components, a report was presented to the Managing Director of the Switchgear Division, in July, 1973. This document proposed the phased introduction and growth of these proven techniques and considered the combined manufacture of Switchgear and Hospital Equipment rotational components. From the experience gained with the former exercise specific family combinations were proposed with which certain machines in the turning section could be utilised. The broader family groupings included those components requiring secondary operations and this report proposed that milling and drilling operations be initially performed on shared machines in their existing locations.

ADAPTATION OF THE TURNING SECTION -
REPORT ON PROPOSED IMPLEMENTATION

The proposed implementation detailed the grouping of specific component families to machines in the turning section and demonstrated family formation with Hospital Equipment Division and Switchgear Division turned component family combinations. The report showed how large sections of the machined component requirements could readily benefit from the introduction of Group Technology. It was understood that, at the time of writing, the movement of machines was a prime limiting factor. Significant advantages were shown to be offered through the limited introduction of specific component family combinations to the existing turning section. The component families considered were duplicated in the turning requirements of both divisions and their relative annual usage quantities were described earlier in this work (p.13 and Fig. 9).

The component families and their quantities within each similar type showed that;

1. Both manufacturing divisions produced simple turned components.
2. Hospital Equipment Division turned components were the least complex and occured in fewer code families (Figs. 9 and 32).
3. The turned components from both divisions were compatible for combined production.
4. The addition of similar component families from both Divisions would be mutually complementary.
5. The separate machine loadings constituted by these Hospital Equipment Division components were comparatively light, and did not offer an appropriate level of plant utilisation.
6. The combination of similar component families from the two manufacturing divisions would enable specialised turning "cells" to be implemented.

7. The combination of similar component families would provide sufficient work content to justify the specialised utilisation of separate machines.

DETAILS OF MACHINING REQUIREMENTS

The component families considered were assessed for their machining requirements. A large majority of these families required only a single operation to complete their manufacture. Those components requiring secondary machining operations required facilities for;

1. Second operation turning %
2. Drilling
3. Milling
4. Combinations of milling and drilling

Translating the component families into primary and secondary machining requirements individual machine cells based on specific family groupings were not considered necessary, as outlined in the previous chapter. The report considered family grouping on a 1st operation basis and the design of single machine cells without machine movement.

THE COMBINATION OF SIMILAR COMPONENT FAMILIES FROM BOTH DIVISIONS

It was emphasised in this report that the poor set-up-to-machining ratios apparent in the turning section could be improved with the combination of similar component families from both divisions. As an example component families for the Switchgear Division were equated to primary machine loadings;

Family No.	Code		Ann. Quantity
1	10100		40,130
1a	10200		11,230
3	20100		4,520
5	00100		22,875
		TOTAL	78,750

Equating component families to actual production times this combined family loading correlated to approximately 1300 hours machining time. Also, to give the maximum work content from these Switchgear component families the quantities included;

a) Dissimilar component materials.

b) Components with higher levels of complexity.

To achieve a higher degree of machine and labour utilisation additional dissimilar component families were added;

Family No.	Code		Ann. Quantity
6	11100		25,597
8	21100		99
		TOTAL	25,696

GRAND TOTAL 104,446

This increased family loading offered approximately 1800 hours machining time and resulted in a "composite component" of high complexity, see Fig. .

This complex single - machine - cell loading did not offer a successful introduction of Group Technology.

THE COMBINATION OF SIMILAR COMPONENT FAMILIES FROM BOTH DIVISIONS

The combination of component families from the Switchgear and Hospital Equipment Divisions was proposed. The increases in component quantities created higher machine loadings with simple family design.

Family No.	Code		Increased Ann. Quantity
1	10100		73,000
1a	10200		14,000
3	20100		4,600
5	00100		76,000
		TOTAL	167,600

The enlarged simple family loading correlated to a full years machine requirements. The increased family specialisation offered a more simple "composite component" (Fig.) and the following benefits;

1. Good flexibility between operation changeovers.
2. The ability to simplify scheduling.
3. The design of simple tooling families as no component required turning on its outside diameter.
4. Almost no secondary machining other than secondary turning operations.
5. A reduction in the relative quantities of dissimilar materials simplifying changeover problems.
6. The larger groupings of almost indentical components simplfied production planning; new components within similar family parameters being automatically grouped to the "cell".

IMPLEMENTATION

The report considered the advantages of a limited introduction of Group Technology without machine movement and proposed the immediate implementation of the single machine cell for bush and collar-type turned components. Such an introduction offered relief to the mounting production difficulties and departmental rivalries between the two Divisions.

Unfortunately, the advantages offered to a dual production shop by a limited introduction of Group Technology could not be realised. The

Hospital Equipment Division had resorted to sub-contract component manufacture to fulfill its growing requirements and the re-association of the two divisions manufacture was not possible. For the completion of this study it was therefore proposed to implement Group Technology in the Hospital Equipment Division machined component parts manufacture.

CELL DESIGN - PRIMARY APPLICATIONS

SEPARATE MACHINE SHOP

The increased limitations on the manufacturing facilities available to the Hospital Equipment Division encouraged its management to consider separate machining arrangements. There were two main groups of machined components;

1. Rotational Class; mainly simple turned parts.
2. Tubes and tubework, in the main for welded assembly.

As mentioned earlier in this work, the turned components were previously machined in the Switchgear machine shop, but separate facilities were available, although in need of improvement, for tube production. The machines concerned were poorly positioned with respect to each other and for the co-ordination necessary to maintain useful output. (See Fig. (57)).

The production of tooling aids for the Switchgear machine shop, had been reduced and the Tool Room location moved to smaller premises. The old Tool Room was a large separate building adjacent to the main machine shop and contained de-greasing facilities for Hospital Equipment tube manufacture. The re-location of machining plant in this area was a natural choice not only making Hospital Equipment production more autonomous, but, also separating the two companies manufacture.

MACHINE CELL DESIGN

From the earlier use of the Opitz Code for Hospital Equipment turned items, component mix and machining requirements had already been analysed. There were special sections of the code which classified straight tubes, and coding conventions aided the retrieval of formed types. The existing

MACHINE LOADING VIA FAMILY SELECTION

Although the Ward 1A Capstan Lathe was a reasonably versatile machine certain loading parameters controlled the selection of components for production. To optimise productivity all the rotational components were to be turned from bar stock, using a conventional collet chuck and bar-feed arrangement. Initially, only components which could be finished in one operation were considered because secondary turning operations would restrict output and impose re-scheduling problems. This was just one of many difficulties encountered having a single machine and another Capstan Lathe was thought essential to be viability of the project.

The Optiz Code was initially used to select families of components which, by their code descriptions, suggested production features within the capabilities of this machine, and which could be completed without remounting. When the selected code data was translated into production component drawings the practical accuracy of the code was seen to be limited. (An appreciation of the practical value of the Opitz Code can be found in the following chapter.)

Families of components were selected for this specific machine guided by the following parameters;

1. Material initial form, i.e. bar stock Opitz 9th digit.
2. Maximum diameter, 1 inch maximum for Ward 1A. Opitx 6th digit.
3. Part length, limited to 4 inches maximum. Opitz 7th digit.
4. Feature complexity, Opitz 2nd and 3rd digits.
5. Components whose code features suggested no second turning operation.

CODE GROUPINGS

Potential components were selected from an Opitz Code listing tabulated using the above parameters. As mentioned earlier in this work, Hospital Equipment machined components were mainly of low complexity, and therefore most of the components selected were within the capabilities of the Ward 1A. These code groupings revealed large families of pins and bush-type components but, on closer examination of the actual drawings not all were suitable for grouping. Apart from inaccuracies and inadequacies demonstrated in the Opitz Code, it was mainly the size ranges covered by the supplementary digits which created grouping problems.

The inital digital relationships to component size ranges were;

Digit	Size Range (Diameter and length)
0	$(D \leq 0.8$ in. $(L \leq 0.8$ in.
1	$(0.8 < D \leq 2.0$ in. $(0.8 < D \leq 2.0$ in.
2	$(2.0 < D \leq 4.0$ in. $(2.0 < L \leq 4.0$ in.

As the Ward 1A has a maximum spindle capacity of 1.0 inches the size ranges covered by the code were imprecise for the loading of this machine. Fortunately, there were less than 100 components in the 0.8 to 2.0 inches size range and re-grouping was quickly performed.

PRODUCTION GROUPINGS

The potential offered by the code family groupings was found to be immense for design retrieval but requiring practical intepretation by Production Engineers. The basic logic of grouping was in no way disputed and tremendous value eminated simply from the component review.

The basic limitation was the single Ward 1A Capstan Lathe and the reversal of the now conventional approach to the introduction of Group Technology. (53). The techniques of component family co-ordination were now crystalled to provide particular advantages to a single conventional machine.

The component family/machine parameter observations were such that radical changes were made in basic philosophy because this single machine had to provide high output over a range of component families. Components were combined to form realistic production groupings with consideration given to;

a) Batch Sizes - With a large quantity of differing components required for each production cycle, individual large batches would increase the lead time for other small batch components.

b) Feed Lengths - The Ward 1A had no machine feed and therefore components requiring long Capstan feed strokes, particularly those involving close tolerances, were omitted. Also, components whose part lengths were such that low quantities were obtained per bar length of raw material were removed from families due to their disruptive element.

c) Tooling Requirements - The future use of preset tooling was envisaged with capstan heads provided with sufficient tools to produce a family of components (Fig. 59). But, having only one capstan head, components whose particular tooling requirements exceeded the available capstan capacity (five stations and one end stop) could not be included. (Fig. 60).

d) Material Types - The frequent occurance of dissimilar materials created another factor which would reduce flexibility. There were a number of components within each family grouping which had identical tooling requirements but which were of either; mild steel, brass aluminium or nylon material. The effects of machine clean-downs and tooling changes were balanced against batch sizes and the need for varied output.

e) <u>Collet Sizes</u> - The machining of components within production families would benefit from the closer grouping of common collet sizes. The advantages of component family similarity were balanced against the disruption of frequent collet changes and subsequent bar stock removals.

Respecting these five parameters all the components within the "controlled capacity" of this single Capstan lathe were reveiwed to form a practicable production grouping. Many components ideally suited to grouped production, having almost identical tooling and setting requirements, were omitted because of their very large batch sizes. (11% of the components initially selected for the Ward 1A were required in annual quantities exceeding 5,000). Some of these were found to have annual usages of over 10,000 off, one particular brass turned pin having a requirement of 19,400 off per annum These components demanded automated manufacture and the simple scheduling of component families onto this single machine did not provide sufficient capacity for their addition to the loading.

The resultant component grouping developed for the Ward 1A contained 55% of the initial selection based on Opitz Code families. Scheduling techniques were then applied to these components to compare and evaluate the performance of this single machine cell which was required to produce approximately 60% of all the rotational components.

SEQUENTIAL SCHEDULING WITHIN COMPONENT FAMILIES

Having a single machine and a total of 63 components including 4 basic code family groupings, there were seen to be 2 methods by which performance could be maximised;

a) Code family - based production schedules.

b) Sequential loading by individual component features.

a) CODE FAMILY - BASED PRODUCTION SCHEDULES

It was recognised that with the limitation of a single capstan lathe as primary operation machine for a number of different component families the separate, uninterupted machining of individual groups may be impossible. But, the four basic code groupings each comprised components with a high degree of design and production similarity. A study was therefore made of the tooling changes involved in the streaming of components in the same code families to this single machine.

Components within each code family were identified from the code listing and their drawings retrieved. An analysis of the particular production requirements was then made and recorded using the Tooling Analysis Sheets (Fig. 54, 55, 56). Arranging the components into 4 code families;

FAMILY CODE	DESCRIPTION	NO. OF COMPONENTS	ANNUAL THROUGHPUT
10000 20000 22000	Plain Pins Plain Pins Screwed Pins	26	51,000
11000 21000	Turned Pins	10	29,650
10100 10200 20100 20200 00100	Bushes Tapped Bushes Bushes Tapped Bushes Collars	19	42,600
01100 11100 11200 21100	Turned Collars Turned Bushes Turned Collars with Tapping Turned Bushes	9	7,650
TOTALS		63	131,500

COMPOSITE COMPONENTS

Each code family was arranged into a preferred sequential loading with material type and collet sizes taking precedence. Less than 30% of the components required roller-box turning, but where turned diameters were common the schedule was adjusted to this advantage. Composite components were developed for each code family and the associated tooling noted, See Figs. 58 and 59 .

ANALYSIS OF PERFORMANCE USING CHANGEOVER PENALTY ASSESSMENT

Although the 4 code families were basically simple in production requirements each family required frequent setting changes and comprised dissimilar materials as well as varied collet requirements. All the tooling and capacity details were within the performance of the Ward 1A, but, this was a single machine. The total 63 components from the 4 code families represented an output of 131,500 components per year, and, to develop the essential flexibility, an operation changeover penalty point system was used. An interaction matrix was constructed to evaluate optimum changeovers using the following points system;

CHANGE	MATERIAL	COLLET	R/ BOX	DIE HEAD	DRILL	TAP	END STOP
PENALTY	10	6	4	3	2	2	1

This detailed inspection of each component drawing before the schedule was issued showed many feature similarities beneficial to the formation of composite tooling packages but stressed the disruption of frequent material and collet size changes. Because of the major limitation of having a single primary operation machine, and with a well-defined narrow component requirement, the changeover penalty assessment was re-directed to consider components on a production feature basis only.

b) SEQUENTIAL LOADING BY COMPONENT FEATURES

The previous exercise demonstrated the counter productive effect of maintaining strict code family component production sequence. As the most influential component changeover penalties were seen to be those involving material types and bar/collet sizes, the sequential loading sequence was reformed from practical considerations.

MATERIAL TYPES

There was a total of 5 non-ferrous components in the production family, including 1 from each of the code family groupings. The total number of these components was 5,100 (relating to their annual usages) and, as they represented only 4% of the total machine loading, they necessitated careful accommodation to reduce their disruptive factors, It was therefore decided to re-arrange the loading schedule such that these non-ferrous components could be either;

a) Grouped by material types for production at appropriate interludes in the schedule.

b) Machined at the end of each cycle when machine cleaning is least disruptive.

COLLET SIZES AND THE PRODUCTION SEQUENCE

The maximum combination of primary production features had been limited to a single outside diameter turning operation, plus a single inside diameter drilled hole (with or without screw threads). This limited combination (derived basically from the use of the Opitz Code) enabled all the required tooling to be accommodated within the 6 stations of the machine capstan. (Fig. 60). Thus, the remaining variable concerning component geometry was the overall bar diameter, i.e. collet size.

Re-arranging the component grouping into collet sizes created 11 diameter based families each with composite machining requirements within a single capstan set-up. (Figs. 61). This showed that within the component collet size range there was a clear duplication of code family types, and, if a collet size loading sequence was proposed these families would overlap. This code family duplication accurately revealed production feature similarities and the potential for designing a single capstan tooling arrangement for all the components.

ANALYSIS OF PERFORMANCE USING CHANGEOVER PENALTY ASSESSMENT

Using an identical changeover penalty system to that used for the components within code family groupings (page 95) an identical evaluation of the effects of component sequence was made. For components machined within collet size families there was a reduction in the total point penalty awarded of 27% over the initial code family sequence. By refining the technique accordingly to prevalent production features (common roller box settings or drill sizes, etc.) the total penalty was reduced still further to a 70% of the original sequential pattern.

MACHINE LOADING AND CONTROL

The collet-size based loading schedule offered increased flexibility over the original code family sequenced programme, and, with the single Ward 1A required to machine 63 individual components, was naturally preferred. The manufacturing program was issued on a 4 week cycle and most of the scheduled 63 components were required on every cycle. If a rigid schedule had been maintained for the original code family based loading, with some families having as many as 26 components (page 94), the schedule would have to take precedence and other components be delayed. Therefore the problem would be where to start the schedule and how to accommodate non-scheduled components at short notice.

The second schedule type, based on collet sizes, incorportated greater flexibility due to individual collet/component sequence having greater than 9 individual parts. This schedule also offered preferred sequencing within each collet sized category but, as no "system" can irradicate emergency or "rush" requirements, it was tested to accept random component order. The 63 components were analysed using an interaction matrix, part of which is shown in Fig. (62). This matrix chart evaluated the changeover penalty incurred in machining any one component from the 63, at any time. By the identification of the lowest penalty changes an optimum sequence could be shown through the component mix. An example of such a synthetic component change was;

CHANGE INVOLVED	PENALTY
Material	20
Collet	10
Roller-box setting	6
Die head	3
Drill size	2
End stop	1
	Total 42 Points

The principal advantage of the matrix chart was that the proposed group foreman would use the information to control the component loading for optimum performance. No longer would he have to try to group jobs together from memory to minimise machine idle time because all the components would be co-ordinated on the charted program. When a non-scheduled component is urgently required the foreman can select the optimum stage for its introduction to minimise the disorientation of the schedule.

MACHINE LOADING AND PRODUCTION TIMES

An assessment of the machine time required to produce the component grouping was made from the original planning records. Large reductions in actual job times were not envisaged at this stage because there were few method changes and the condition of the particular machine would not permit the use of carbide tooling. Noteably, there was some variance in the planned machine times, particularly where identical components were previously produced on different machines. A loading was calculated using each component machine time and annual throughput. The total machine time was summated to be approximately 2,000 hours.

REDUCED MACHINE IDLE TIME THROUGH MINIMISED SETTING ADJUSTMENTS

THE COMPOSITE COMPONENT

The small degrees of variance in component production features enabled the design of a single composite component whose tooling requirements could be accommodated in a single capstan arrangement. Fig. (61).

To reduce the limitations imposed by sizes within code families (Fig. 75) the production was scheduled on a collet size and material type basis. Setting changes were therefore minimised to become "adjustments" around a basic setting, for example, end stop changes to accommodate different capstan feed strokes and component part lengths.

The reduced non-productive or idle time resulting from the use of grouping techniques culminated in increased output, and could be expressed in terms of productivity factors. (29).

$$P.F. = \frac{S_1 + M}{S_2 + M}$$

where S is the average set-up time per batch in each case and M is the floor to floor machining time per batch. For the single Ward 1A utilisation the productivity factor for an output based on the forecast annual requirements was 1.3 .

THE NEED FOR ADDITIONAL TURNING CAPACITY

Many components within the code family types selected for the Ward 1A were exluded from the grouping and scheduling exercise beaause;

a) They were above the collet capacity of the machine (i.e. greater than 1 inch diameter).

b) They were required in quantities which obviated specialist manufacture (i.e. automatic or N.C. Lathes).

c) They were of an increased level of complexity which would limit their compatibility with scheduled components, introducing changeover difficulties with additional tooling and setting requirements.

Of the 40% of these components 17 (equivalent to 16% of the total) were to be selected for sub-contract turning. At the time of this exercise a Ward 3A capstan lathe became available and the addition of this machine to form a production group was proposed.

COMPONENT FAMILY PRODUCTION ON THE WARD 3A

This machine was required to supplement the output of the Ward 1A by;

a) Machining selected components outside the capacity parameters of the Ward 1A.

b) Acting as a second operation turning facility for components machined on the Ward 1A.

c) Supplying overload or relief capacity to the Ward 1A.

A total of 25 components were streamed to this machine, many of which belonging to identical code families produced on the Ward 1A. Most of these components were above the maximum bar diameter which could be turned on the Ward 1A and the remaining few of part lengths which excluded them for reasons of low component quantities per bar length.

CODE FAMILY SIMILARITIES

WARD 1A	WARD 3A
Maximum diameter 1 inch	Diameters 1 inch 1.5 inches
00100	00100
01100	01100
10100	10100
11100	11100
20100	20100
10000	
20000	
11000	
21000	
22000	
10200	
11200	
21100	
Total Ann. Quantities 131,500	38,450
Estimated loading (hours)2,000	1,300 hours

COMPONENTS REMAINING OUTSIDE SCHEDULING PARAMETERS

There remained a residual 16% of the rotational components which were not included in the work schedules for the two primary machines. Most of these components were within the dimensional capacities of these two machines but were excluded for reasons related to the initial selection parameters. Those components excluded solely due to their high requirement quantities, but which were essentially within the scheduling and tooling requirements, of the Ward 1A, could be accommodated in small batches to relieve temporary shortages. Otherwise, the strict scheduling parameters were to be maintained to maximise output and typical components categorically excluded are shown in Fig. (63).

INTER - MACHINE SCHEDULING

The most important function of this second lathe was to provide a co-ordinated second operation capacity for components machined primarily on the Ward 1A. Approximately 10% of the components selected for the first machine required second turning operations. These components belonged primarily to the bush-type 'family' and the second operation involved de-burringthe reverse end of the bores. (Fig. 64). The necessity for this second operation was investigated and it was found that burrs on the component bores were a result of the part-off operation. Although the degree of burring could be reduced by controlling the machine cross-slide during the parting operation, a second operation would remain essential on those components requiring burr-removal for improved assembly purposes.

The components primarily assigned to this Ward 3A constituted approximately 65% of its operative capacity (based on annual component usages). There was insufficient scope for successful grouping within the individual component families, again mainly due to the frequent disruptions caused by collet and material changes within code families. Only 5 (20%) of the components required roller-box turning and a compromise could be found between code family and production family based loadings to permit improved jobbing production with random component selection. The remaining capacity would be used to provide the second operation function in connection to the Ward 1A.

CO-ORDINATION ON COMPONENT PARAMETERS

The first operation machining of the 25 bar stock components assigned to the Ward 3A was insufficient to fully load the machine, and the utilisation of the remaining capacity to perform second operations on Ward 1A components was proposed. Such second operations involved remounting components and, as this machine was also fitted with a collet chuck, there were distinct advantages to be gained in co-ordinating bar/collet sizes, where possible. The de-burring operations could be performed without using the capstan head, which would remain tooled for the Ward 3A loading. 35% of the Ward 3A components also required second operations of similar types to those from the Ward 1A.

MACHINE LOADING AND FLEXIBILITY

The total work content for the Ward 3A involved both bar feed and chucking components.

BAR FEED	CHUCKING
25 components 38,450-off per year 1300 hours approximate loading	15 remounted components 31,250-off per year 300 hours approximate loading

Although the machine time required for de-burring operations was very small the large numbers of components were to be accommodated within the remaining capacity. It was proposed to co-ordinate the two machines manufacture to enable components to pass from one machine to the next for completion without interuption. Those components (25) specifically selected for the Ward 3A were to be secondary in priority to the machining of components from the Ward 1A. Having available capacity the Ward 3A would be sufficiently flexible to operate in phase with the Ward 1A and a mini-flow line production would result. Inter-operator liaison would permit related work transfer between the two machines and the Ward 3A would provide overload capacity. This would enable schedules to be maintained on the Ward 1A and with both machines operating in unison work transfer would be simplified.

SECONDARY MACHINES IN THE TURNING GROUP

To complete an autonomous production group secondary machines were necessary. Of the primary operation components completed on the two capstan lathes 15% required milling or drilling operations. The total production involved 35,500 components per annum, 27,600 of which (77%) required only a drilling operation. The total production requirements for these two machining operations was very light and the secondary features of limited variance (Figs. 65 and 66). Single milling and drilling machines were allocated to the group;

1 - Adcock and Shipley Horizontal Mill.

1 - Pollard 4 - Spindle drill.

Turned components requiring milling	8,800
Turned components requiring drilling	47,450

(quantities from 1973/74 piece forecast)

LABOUR REQUIREMENT AND SCHEDULING

Components requiring milling and drilling operations could be simply accommodated by the two machines. The production features were of low complexity and milling fixtures and drilling jigs were available. All components requiring such secondary machining operations must have first been turned and would be despatched from the two primary machines. The total work content was within the capabilities of 1 operative and he would be responsible for both the milling and drilling operations. Scheduling was not required within these machining operations other than by operator discretion as the components were similar, required in low quantities and short machine times.

A composite job instruction card was considered for all components manufactured in the group. Fig. (67). This card listed all the operations performed in the group and, for any particular component, unnecessary operations were deleted. The movement of work in progress through the group was to be the responsbility of the operators and teamwork was to prevail.

TURNING GROUP LAYOUT

The arrangement of the machines in this group was designed to promote successful cellular manufacture. (Fig. 68). The two capstan lathes were provided with bar-feed tubes and positioned side by side to enable the simple transfer of components for second operation turning. The milling and drilling machines were positioned in close proximity to the two primary machines and completed a small manufacturing unit.

To promote the successful performance of the group, racking was to be provided by the two lathes for bar stock, and tooling racks containing all necessary tools, jigs, fixtures, etc., located by their associated machines. Ample temporary storage space was provided for work in progress and the movement of this work would be performed by the operators. Cutter grinding facilities were also to be provided in the group to reduce losses in production due to tooling problems.

GROUP LABOUR

A total of 3 setter-operators would man the group and have responsibility for production and work movement. The machines were so positioned to provide a good working environment and help generate the teamwork necessary for successful working. A foreman was to have control over this and the tube production group.

THE TUBE GROUP

The production of tubes and tube-work was to be improved with a specialised manufacturing group located in the new machine shop. This group (fig. 69) was to comprise existing tube production machines and equipment in addition to new machines, and was to provide separate line facilities for straight and formed tubes. The original coding analysis included tube components and showed;

Straight tubes	150,650
Straight tubes with mitre cut	4,750
Straight tubes with drilled holes	60,600
Straight tubes with saddle milling	134,000
Total straight tubes	350,000
Formed tubes	37,400
Formed tubes with drilled holes	10,100
Formed tubes with saddle milling	9,100
Total formed tubes	56,600
Straight rods	4,600
Straight rods with drilled holes	10,800
Straight rods with saddle milling	4,400
Total rods	19,300
Total Annual Throughput	472,000

(quantities taken from 1972/73 piece forecast)

See Figs. (33 & 34)

GROUP STRUCTURE - THE TWO LINES

Tube production was divided into two component groupings; straight and formed tubes. As shown in the throughput figures, rods were included in the groupings, by type, because they required no rotational machining and could share the grouped production arrangments.

Each production line would incorporate sawing, the two existing saws being used for the straight tube group and a new automatic feed saw for the formed tube group. The two saws for the straight tube group included a swivel head saw for mitring. The necessity for this saw in the straight tube group was realised from the results of the coding exercise. The automatic feed saw was assigned to the formed tube group and was necessary to provide the inreased output requirements, and to allow the other two manually operated saws to specialise in straight and mitred tube production. Fig.(69). The two existing saws were overloaded with the production requirements and it was thought that the new saw would enable not only the removal of the overload but also reduce the need for purchasing tubing in ready cut lengths.

SECONDARY MACHINING - DE-BURRING

From the analysis of existing tube production it was found that, after the initial sawing operation, all tubes were de-burred before proceding to following operations. This de-burring was particularly important with cut tubes for bending, because a mandrel has to be inserted into the tube prior to bending. Also, many tubes were mounted into drilling fixtures and, there again, burr removal was found to be essential. Therefore de-burring facilities were located by the saws of both groups. (Fig. 69).

SADDLE-MILLING

Over 30% of all tubes required a saddle-milling operation and most of these (91%) were in the straight tube group. For this reason the single milling machine head adapted for the saddle-milling operation was positioned in the straight tube group. The remaining 9% of the tubes requiring this operation would share the saddling machine before returning to the formed tube group.

The saddle-milling operation was the slowest machining operation and, as this was a shared facility, it was regarded as the "key" machine.

DRILLING

Both groups were provided with drilling facilities to ensure independence of machining capacities. The formed tube group contained a single spindle and a special purpose drill. The special purpose machine, having a pneumatic multi-drilling arrangment, was designed specifically for the single plane drilling of series of identical holes. (Fig. 71). The straight tube group had one single-spindle drill.

The drilling machines used were essentially those used in the previous tube production set-up. The very large quantities of both formed and straight tubes requiring drilling operations (70,700/annum) were equivalent to 86% of the total annual tube throughput. This did not include the quantities of rods also requiring drilling (10,800/annum). The resulting heavy loading on the drilling machines was eased with the ability of the two parallel production groups to share common facilities. The degree of work sharing was to undergo careful control to avoid the unnecessary build-up of work in progress.

ADDITIONAL PRODUCTION AIDS

To promote the successful throughput of tubes additional facilities were provided for the storage and maintainance of tooling by the machines. Each machine was provided with all the tools and equipment necessary for its machining commitments and uncut tube storage racks were located by the saws. Because of the long lengths of tubing (over 15 feet) to be located alongside the formed tube group saw a special purpose work table was designed. This table incorporated roller conveyors and was able to pivot from the saw to feed the bending machine. (Fig. 69).

At the end of the straight tube group an inspection bench was provided alongside the finished tube marshalling area. (Fig. 69). This bench held a small fly-press for the rectification of distorted tubes, as well as sundry hand tools for the removal of remaining burrs. Completed tubes were to be given temporary storage alongside this bench prior to transit to epoxy powder coating and assembly the main shop.

COMPONENT SCHEDULING AND LABOUR INTERACTION

The two parallel tube groups were, by design, mini-flow lines. The machines in each group were positioned to improve work movement and enable work-in-progress to be quickly dissolved. Small marshalling areas were provided by each machine and it was to be a duty of the group operators to maintain the work flow. After sawing, all tubes were de-burred and, with the straight tubes having the larger demand, a special tube de-burring machine was located behind the saws. (Fig. 70).

A total of 9 operators were to man the two tube groups, certain machines such as the saws (3) and bending machine (1) required full-time supervision. These three saw operators were responsible for the daily loading of their machines with tube stock and an additional exercise for improved facility layout determined optimum stock locations to minimise material movements. (Fig. 72). The output of these three operators was to dictate the loadings of the individual secondary machines and 5 operators were deployed on the machining and scheduling of the work throughput. The saddling operation was performed in the straight tube group and, as some amount of sharing was necessary, one operator remained with the milling machine whilst the remaining 4 operators were flexibly deployed. This operator was then responsible for work movement between the groups. All the operators were responsible for the de-burring operations necessary on tubes cut by the saws before performing the subsequent operations, and convenient areas were made available for work marshalling.

TOOLING LOCATIONS

From an analysis of the production requirements for tube manufacture detailed records were made of operations, cutter or tool types and sizes, and workpiece clamping (jigs and fixtures). The tooling sheets (Figs. 55 & 56) used for the secondary machining of turned components were applied to this task. The results of this analysis were used to assign all the particular tooling requirements to machines in the groups. There was a degree of duplication, particularly of drill sizes, but this was considered essential for machine and group independence. Jigs and fixtures were to be located alongside machines and carry clear identifications.

MANUFACTURING INSTRUCTIONS AND CONTROL

As the production of all tubes followed a simple, often duplicated, pattern a revision of the existing job cards was considered. The tube group catered for a maximum of 5 machining operation types:-

1. Sawing
2. Mitring
3. Bending
4. Saddle Milling
5. Drilling

As shown earlier (page 106) a total of 42% of the group throughput required a single sawing operation, 17.3% drilling, 31.3% saddling and 12% bending. A simplified job card containing all these operation types was proposed and the particular operation sequence for each component could be ticked off. (Fig. 67). Component drawings were to be stored with the group and it was thought that with future production familiarity job cards would be superceded by a simple order ticket. (Fig. 73).

INTER-MACHINE SCHEDULING

The degrees of tube component similarity both in design features and production requirements offered great flexibility to the component throughput. Tooling changes to accommodate the component variety for the machining operations were so simple that scheduling could be self-imposed. Work queuing would be minimised and controlled at the longest and most critical operation, saddle milling.

The operators necessary for the successful operation of the tube group were already established as a working group in the original tube production shop. The success of the team as a manufacturing unit would reflect in the labour's acceptance of the new principles applied in improving production performance and their working environment.

THE IMPLEMENTATION OF THE PRODUCTION GROUPS

The details appertaining to the implementation of the proposed groups were completed by October 1973 and their entire acceptance and approval was proffered at director level. The only machine awaiting movement into the shop was the second Capstan Lathe for the turning group (a Ward 3A was proposed). The writer was asked to apply his detailed component knowledge (from the application of the Opitz Code) to the selection of such a machine. The purchase of a particular Capstan Lathe was then proposed.

A useful by-product of the coding exercise was the use of coded component dimensions for the assessment of raw material requirements and component/raw material commonalities. Racking was purpose designed for the storage of selected raw materials and positioned in relation to the manufacturing groups. A loading bay was constructed to feed the raw material storage facilities. (Fig. 72).

In addition to the outstanding machine tool required to complete the turning group, certain other factors, some specifically relating to labour shortages, have delayed the full implementation of the proposed production groups.

The decision to implement was iminent at the time of writing.

THE PRACTICAL APPLICATION OF THE OPITZ CODE AND ITS SUITABILITY FOR COMPONENT GROUPING

The Opitz Code as a means of component identification and grouping has been associated with Group Technology for many years, (2, 3, 44). For this work it is considered unnecessary to compare and contrast Opitz with the many other classification systems as this has been well covered. (1, 2, 44). This chapter critically examines the value of the Opitz Code in a practical application and makes reference to earlier work perpetrated under the writer's direction by Mr. J. A. Alexander,[I] (41)

(A) ROTATIONAL COMPONENT GROUPING

The Opitz Code successfully describes and groups rotational components by design and production features. Such descriptive accuracy is clearly aided by the basic design parameter of such component types and this constitutes a third geometric shape axis. Code-component similarity is sufficiently precise (with conventional component types) that the code could replace the actual component drawing and accurate component descriptions could be verbally communicated. Indeed, earlier sections in this work (P69) show the range of rotational components at George Ellison Limited to mainly comprise simple conventional types

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[I] Mr. J. A. Alexander was a final year undergraduate student at the University of Aston in Birmingham seconded to the writer to study the practical implementation of the Opitz Code.

Exceptions to this include individually mounted or "chucking" components and components turned from hexagonal bar.

COMPONENTS PRODUCED FROM HEXAGONAL BAR

Alexander's work (41) makes reference to the production similarities of components turned from round and hexagonal bar and notes their wide separation in the Opitz Code, (Fig. (74)). This annomally cannot be over emphasized with large groups of essentially similar components, (turned from round bar), appearing on the Opitz Code, (for specific rotational components) the second and third primary code digits do not provide shape element descriptions equivalent in accuracy to those given to conventional rotational components. External and internal shape elements are described with only one digit, (Fig. (17)). Therefore, simple turned components with hexagonal (or even square) section material are poorly described when compared with their conventional counter-parts. (Fig. 74)).

From a design viewpoint the separation by code of standard rotational components from those with "deviations" is important, but, in the Opitz Code, the ninth digit (in the supplementary code) provides this significance, (Figs. (17) and (18)). Therefore conventionally machined components made from round and hexagonal bar can be described with the same geometric code and individually indentified with this ninth code digit, (Fig. (18)). The standard supplementary code does not separate hexagonal bar from other polyagonal sections (digit '2' used in either case) and this could be revised. Also, a point which will be critically examined later in this section is the validity of the code size ranges. Special collets are used for hexagonal bar stock and a specific size range code appertaining to A/F dimensions would provide accurate collation on bar stock sizes.

COMPONENT FEATURE INTERPRETATION AND CODING FOR PRODUCTION USE

Previous sections in this work have emphasized the need for strict conventions in the intepretation of the Opitz Code, (P.31). For this reason it can be argued that those responsible for the coding exercise should preferably have practical shop experience. Enlarging on Alexander's work (41) a component may be assigned to particular code families by way of a feature other than the principle feature of that component. Typical examples such as machined grooves and under-cuts have been well portrayed (54), but there are other examples which, in the writer's opinion, should be noted.

Figure (75) shows an example of a rotational component which, technically, falls into an Opitz category; "stepped to both ends with no shape elements". This description implies that the component requires re-mounting for a second turning operation, when, in fact, the short shoulder can be turned from a front tool part prior to the part-off operation. The component therefore belongs to the much greater family of components which are stepped or turned to one end, (Fig. (51)).

Figure (76) illustrates a possible gross code placement error. If the extended, non-standard chanfer is mis-coded as a "functional taper" this simple turned component is widely mis-placed in the Opitz Code. Such a code description implies the use of taper-turning attachments, or, compound slide, whereas the short "taper" can be successfully machined with a form tool. Figure (77) shows another example of this annomally.

Certain other simple component types can be proffered incomplete, though technically accurate, code descriptions. One example used in Alexander's work is the plain stud screwed on both ends, (Fig. (78)). Figure (79 & 80) shows components with the same code description but differing fundamentally from the component in Fig. (78) because they can be finish-turned in one operation. Similar discrepancies arise with grooved pins, (Fig. (81, 82, 83 i.e. does the code describe more than one groove feature?

Other examples of where the Opitz Code can supply erroneous rotational component descriptions, and where such descriptions can be improved with the practical intepretation of codeable features, are shown in Figs. (84, 85, 86).

The base feature acting as a reference in the code descriptive relations is a smooth or plain outside diameter. Such a simple feature type is described by the code digit '0' (Fig. (17)) and successive increases in numerical value denote increasingly complex features. Digit '0' implies an unmachined outside diameter or a rotational component, thus implying that the outside diameter is the raw material bar size. Such a component class can consider simplified tooling, without turning attachments, for family production.

It was during the development of tooling families from basic code families that this annomally was fully appreciated. Alexander's work considers components with a smooth outside diameter (41) although an additional notation would isolate the componet types under consideration. Particular advantages could be seen with the large code families of bush-type components (41) where capstan heads could accommodate a range of drills and boring bars only where such a family included no turning.

Other coding annomalies soon became apparent during the further development of tooling families from code families. A typical example of the importance of production engineering experience when coding is shown in Figure (87). This simple screw component is produced on a B.S.A. automatic capstan lathe and this machine produces the head slot as the final operation. The component is coded with Opitz, as having a slot as an auxiliary machining feature and this terminology generally applies to subsequent milling operations. Fig. 88 shows other perculiar code intepretations.

CODE SIZE RANGES - THE SUPPLEMENTARY CODE

Earlier mention was made in this work(P114) to the choice and suitability of size ranges used in the coding exercise. The size range used in the Opitz Code was an incremental size range progression adapted from British Standard Preferred Numbers, and was promoted by the Group Technology Centre. Within the 10 code digits available, the size range covered dimensions less than or equal to 0.8 inches up to dimensions greater than 80.0 inches, Fig. (18).

Considering the Opitz Code, its size range increments and the entire product structure at George Ellison Limited, the size range used does encompass all dimensions. Components included in this large dimensional range vary from small turned pins to large sections of steelwork. For the purpose of coding rotational component types, at the start of the exercise, this code size range was very imprecise. Over 95% of the rotational components were found to have diameters within the size range covered by the first two code digits, Fig. (89).

MACHINE CAPACITIES

The existing turning section on the shop floor comprised a large range of machines covering a limited variety of spindle capacities.

QUANTITY	MACHINE TYPE	SPINDLE CAPACITY
1	Ward 1A Capstan Lathe	1.00 inches
6	Ward 2A Capstan Lathe	1.25 inches
3	Ward 3A Capstan Lathe	1.50 inches
1	Ward 7	1.75 inches
1	Ward 7 D.S.	2.00 inches
3	Accuratool Plugboard Capstan	0.8125 inches
4	Herbert 2D Auto Capstan	1.50 inches
1	B.S.A. 48 Auto	0.50 inches
1	B.S.A. 68	0.75 inches
1	B.S.A. 88	1.00 inches
1	B.S.A. 98	1.125 inches
1	B.S.A.138	1.625 inches
1	B.S.A.168	2.00 inches

Three centre lathes were also available in the shop but these are not included because of their roles as jobbing machines.

Comparing the Opitz Code size ranges with the machine capacities reveals a poor relationship, with the bulk of the turning requirements occupying the 0.8 to 2.0 inch diameter range. Thus, taking a typical large component family such as the bush-types, (Opitz Code 10100, Figs. (17) and (51)), an additional reveiw of component diameters must be performed before the parts families can be translated into practicable machine loadings. The only code size range digit of practical use is digit '0' (diameter less than or equal to, o.8 inches (Fig. (18)) but this is only suitable with one machine, the Accuratool.

Earlier in this work (P. 19) the need for preliminary component sampling was stressed in order that basic reviewal parameters (via coding) may be determined. In this study the improved relationship of code size range increments to machine capacities would have provided a more reliable basis for machine loading with primary operations. A considerable amount of additional analysis was required to re-group rotational component families to enable the summation of actual machine loadings.

THE ACCURACY AND VALUE OF THE OPITZ CODE FOR ROTATIONAL COMPONENT GROUPING

The Opitz Code was found to offer accurate component description and grouping but requires careful intepretation and modification (via specific conventions) for production use.

(B) NON-ROTATIONAL COMPONENT GROUPING

Three component class digits describe non-rotational components in the Opitz Code, (Fig. (17)). An additional (5th) primary digit is available for specific component categories. Each of the component class digits describes basic component geometry with respect to three co-ordinate axis dimension ratios, (Fig. (90)). The Supplementary code includes two digits for principal component dimensions (i.e. 'A' and 'B' axes), therefore such geometric ratios contribute a general third dimension ('C' axis). Additional description of the overall shape of the non-rotational component categories is given by the second geometric digit, a separate descriptive range applying to each component class, (Fig. (17)). The two geometric digits attempt to offer basic shape feature descriptions seemingly providing an initial, primarily design orientated, classification grouping. It would appear, therefore, that more emphasis is centred around design retrieval applications and less capacity is available in the code to describe production features.

The production features on non-rotational components principally involve secondary machining operations. With rotational components the basic workpiece geometry implies turning operations and primary shape features are machined to create a classification identity, whereas with non-rotational components the primary shape is not changed by machining. Typical machining operations for non-rotational components involve the milling and drilling of auxiliary shape features, (Figs. (91) and (92)).

ROTATIONAL SURFACE MACHINING ON NON-ROTATIONAL COMPONENTS

The non-rotational component classification structure uses identical 3rd, 4th and 5th digital relations with all three component classes, Fig. (17). The third digit in each case described components with a principal bore, or having rotational surface machining. During the coding exercise this particular digital relationship for bored features was rarely used and care was needed to avoid certain ambiguities when applying the Opitz Code. For example, with lever-type components, where there are principal bore features (Fig. (46)) plus other auxiliary holes, the code intepratation is meaningful. Certain other lever or link-type components create some ambiguity in code intepretation when minor holes become the principal operative features, Fig (45)

Many such components where classified as "Levers" under a unique classification code designed during the coding exercise, (P.55).

FORMED COMPONENTS

The fifth digit in the geometric code included the description of formed components, Fig. (16). This code digit offers an imprecise notation for components which have formed auxiliary shape features, e.g. edge forming on a flat plate. This descriptive range of this fifth geometric digit is common for all non-rotational components.

Some difficulty with code application was encountered with long (type 7) components where the principal geometric features were bent or formed. A typical formed component such as an angle bracket (Fig. (93)) can only be principally described with the Opitz geometric digit 7. This code description allowed for bending in the main shape axis, but formed geometric elements were also described in the 5th digit, with or without auxiliary holes, Fig. (17). Therefore the code description for such components was found to be rather imprecise and particularly so with components formed along more than one principal shape axis.

In the coding exercise the complete unsuitability of the Opitz Code for sheetmetal components was discussed more fully, the value of the code in the grouping of non-rotational components for production will now be described.

NON-ROTATIONAL COMPONENT FEATURE INTERPRETATION AND CODING FOR PRODUCTION

The detailed analysis of the Opitz Code listing for non-rotational component code families showed that approximately 80% of the components had auxiliary features, by code.

CODE FAMILY TYPE	COMPONENTS WITH AUXILIARY HOLES	COMPONENTS WITH MILLED FEATURES	DRILLING AND MILLING
Contact Code 5	69	5	57
6	270	25	37
7	215	33	83
8	169	19	72
TOTAL QUANTITIES	723	82	249
% OF TOTAL	54%	6%	18.5%

21.5% of non-rotational components had no auxilary features, by code.

The evidence found from the code analysis supported earlier experience in the coding exercise that non-rotational components (without major forming operations) were not principally changed by machining. That is, overall geometry remained unchanged and machining was principally confined to the production of auxiliary features such as holes, slots and mounting faces.

THE VALUE OF THE NON-ROTATIONAL CODE IN THE FORMATION OF PRODUCTION GROUPS

The prime importance of this code application at George Ellison Limited was for the review and processing of component information to improve production. Such non-rotational components typically required the machining of detail features, e. g. milled slots and location faces, small drilled holes. There was no gear-cutting performed in the machine shop. Component family formation was seen to be naturally biased toward such secondary feature production and controlling parameters were seen as;

(a) Overall size for location and machine capacity requirements

(b) The combination of such auxiliary machining features.

(c) Material and material form.

The variance in non-rotational workpiece geometry was such that detailed code descriptions served only to augment component drawings and did not offer practicable production groupings. The review of the Opitz Code listing showed duplicate auxiliary machining requirements in all three primary class groupings. Although little non-rotational component grouping had been performed at this stage of the introduction it could be seen that such components were easily grouped by overall shape and size, formulating practical groupings related to machine capacities. It was therefore considered that for a selected group of machines components could be identified primarily on overall size with subsequent considerations for material and material initial form, e.g. all brass castings within specific dimensional parameters requiring drilling, or milling and drilling operations. Therefore, basically, all such components could be initially identified by their supplementary code digits

The existing punched cards for coded components could be quickly machine-sorted on the particular code digits relating to material, material form and dimensions, (Fig. (16 & 96).

PRODUCTION REQUIREMENTS AND TOOLING SHEETS

The Tooling Analysis Sheets used in the analysis of auxiliary machining operations with rotational components (Figs.(55) &(56))could be adapted for such non-rotational component groups. These documents carry details of workpiece clamping, cutter sizes, etc., and are well suited to the grouped analysis of production flow.

PRODUCTION FLOW ANALYSIS AND MODIFICATIONS TO THE OPITZ CODE

Although at the time of writing no production groups for non-rotational components (other than the Hospital Equipment tube group) had been initiated, certain projects concerning specific non-rotational component families (contacts) were under consideration. Experience with the coding exercise and, later, the intepretation of code families into production groupings, enabled the practical merits of the Opitz Code to be crystalled.

Earlier mention was made of the design and production uses of the Opitz Code with rotational components and certain conventions were developed for its practical intepretation. With non-rotational components the suitability of the code for production use was found to be limited. The detailed analysis of the associated production operations demonstrated that, for the components concerned, only the last two Opitz geometrical code digits were implicated. (Fig. (16)). Many such non-rotational components required successive milling and drilling operations and their code intepretations offered no indication of the production sequences involved. (Fig. (91)).

It was realised that because of such detailed production requirements (implicit in the components) the Opitz Code for non-rotational parts provided only general groupings which, even when manipulated using supplementary digits and specific conventions, required additional analysis of the production flow. (Fig. (91) illustrates a typical example).

It was considered that although the Opitz Code did provide a means of non-rotational component grouping, its emphasis was seen to lie upon design considerations. It was realised that the practical application of Group Technology to non-rotational components required the use of coding techniques with the analysis of production routing. The importance of the classification code for such components was in the identification of component groups based on similar production features and certain modifications to the Opitz Code would improve its suitability.

A modified code was seen as having the Opitz 3rd, 4th and 5th geometric digits with three dimensional code digits plus particular notations describing production flow routes.

FUTURE WORK

Great potential was seen in the two pilot groups implemented both for improved production performance and as an example to the rest of the company. It was considered that when the two groups were fully operational a new programme of work involving the monitoring of the groups' performance and the continued introduction of additional applications could be commissioned. Particular details of this future work are listed;

1. The monitoring of group performance with particular attention to the previously planned job times and the use of accurate synthetic times.
2. The effects of certain changes in manufacturing techniques and the resulting machining performance with respect to reductions in job times, setting, work-in-progress and raw material stock levels.
3. The study of group control; the ability of the operators to schedule their own work, supervision levels and the use of simplified works ordering.
4. The extension of the introduction with pilot lines developing in the Switchgear machine shop. At the time of writing one such pilot introduction under consideration was for the production of large electrical contacts. Provisional estimates of the planned performance envisaged savings of 64% in setting times, 28% in machine times, 75% in lead times and approximately £1,400 per annum in work-in-progress.
5. The phased introduction of turning cells in the main machine shop and the effects of component family combination upon group flexibility.

6. During the completion of this work the Opitz Code was added, in a modified form to the Item Master File of the Company's manufacturing programme. The value of this adapted code in the formation of practical production groupings could be judged along with the development of improved component identification.

DISCUSSION

A reflection can now be made of the previous sections and the modus apparandi of this application discussed to assess the effectiveness of this work.

The scope offered for Group Technology at George Ellison Limited was prodigious. The company was typically engrossed with the evils of high frequency, small batch production in an utterly conventional functional shop. Earlier sections in this work considered both the general aspects of Group Technology and particular considerations for its successful introduction at this company. Although the project was limited by the time and finances available the proposed introduction of two pilot cells in the Hospital Equipment Division served as a catalyst for the whole company.

OPENING APPROACH TO THE COMPONENT DATA RETRIEVAL

The project commenced with the application of the Opitz Code to simple rotationally machined components and although allied to the teachings of the Group Technology Centre, remained largely of academic interest until the code was practically applied. It was with this application that certain misgivings of the codes used and direction mittegated were realised. The value of the codes and code data will be discussed.

Initial observations of the particular production "animal" directed the coding exercise towards rotational components and the value of this decision was to be proven later in the project. The importance of "component thinking" in preference to "product thinking" was continually proven in later stages of the exercise but knowledge of the product structure was essential for the direction of the coding exercise. It was during this coding exercise that, after purposeful initiation, the project lost both direction and momentum.

THE ADDITION OF SIMILAR COMPONENTS - COMPONENT THINKING

The approach to the retrieval of drawings for coding the Hospital Equipment Division components did not follow a systematic course. The factors of time and internal managerial difficulties dictated a rapid extension of the coding exercise and, as a result, the accuracy of the code information suffered. These particular component drawings were readily available and of low complexity and it was found that initial pre-sorting of these drawings into basic "type" families led to enormous improvements in coding speed and accuracy. The initial exclusion of the Hospital Equipment Division machined components from the exercise was a typical example of "product thinking" and the later correction of this imbalance demonstrated the mutual compatibility of the two divisions' machining. Working as a small project team within an established managerial structure presented pragmatic difficulties which pre-empted the need for initial management awareness and education.

Coding rules and conventions were created at the start of the coding exercise which were to be of great value in component family formation although they were to some extent negated by the later developments within the company.

EXPANSION OF THE CODING EXERCISE

The expansion of the coding exercise to include non-rotational and, later, non-machined components was an attempt to bring some control over the production function. Although this led to the recognition of certain unique component groups and the development of special classification codes, it delayed the progress of the introduction with rotational components. The basic code data for rotational components used in the current range of circuit breakers was complete within three months but practical component grouping did not commence until some six months later.

The complete Opitz Code (including supplementary digits) was used as recommended by the Group Technology Centre and other digits were added to improve formation retrieval.

It was anticipated that as the company did not have a computerised product structure facility at the time of coding additional information may have wider applications in the future.

The coding exercise progressed with planned expansion through the current range of switchgear products using the Drawing Office records and progress systematically recorded to avoid unnecessary duplication. This involved clerical duties which, although vital to the success of the exercise, hindered the rate of coding. It was found that, with the limited staff available (2 persons), a greater proportion of time was spent in drawing retrieval and other clerical duties than in the actual practice of coding. Although the lack of computerised information retrieval may not be evident in many similar applications, the need for the detailed planning of the coding exercise establishing staff levels required, documentation and information format must be recognised.

ADDITIONAL CODE DATA AND SPECIAL CODES

The original coding sheets recommended by the Group Technology Centre were designed to include specific planning information regarding production methods, setting times, machine times and batch quanitites. None of this additional information was compiled during the coding exercise because;

a) The production planning records were incomplete and often inaccurate.

b) The adoption of grouping philosophy implied that both methods and job times would be expected to change.

c) Until the application became established the determination of batch sizes could not be made and it was considered that "period batch" techniques would be advantageous.

d) The additional demands on staff and time scales could not be accommodated.

Plans were made, with the re-design of this coding document, for the future addition of some of the above information.

UNIVERSAL SUITABILITY OF OPITZ

The expansion of the coding exercise to include non-rotational components unnecessarily delayed the introduction of turning cells in the machine shop and it was approximately five months before the coding exercise was terminated. Excepting the family of contact and contact-type components, the Opitz Code data for non-rotational components remained largely un-used at the time of writing. It was while applying the Opitz Code to non-rotational components that certain natural component groups evolved such as "contacts" and "contact-type", "lever" and "lever-like", for which the Opitz Code was found to be unsatisfactory. The suitability of universal classification systems has been contested in previous work (3, 36, 27) and this application proved the need for special codes for unique component groups. (The practical value and accuracy of the Opitz Code in this application will be discussed later). In the use of classification systems it was found that particular codes each have their merits but that the success of an application depended on the development and strict observance of coding conventions.

Sheetmetal components, and, particularly, those of a formed nature were found to be completely unsuitable for description by the Opitz Code. Hence, a third special code (the Sheetmetal Code) was developed.

With some conventional machined components the Opitz Code offered poor, ambiguous descriptions. It was with such components that familiarity with the Opitz Code often allowed poor primary classifications to be dependant on the supplementary code for their relevance.

SPECIAL CODE COMPATIBILITY

The design of the special codes was biased for their compatibility with the Opitz Code and showed similar design and production attributes. It was with non-rotational components that the principal shape features were less important from a machining aspect because only the secondary production features dictated family grouping and this will be discussed later. The Contact Code was used for both design/component retrieval and production grouping for the formation of a "Contact Cell" and was found to be very successful in this application. At the time of writing this code was used in the design of production families for contact manufacture.

The range of circuit breakers manufactured by this company contain a large variety of lever and link-type mechanical assemblies. Many of the lever-type components were either cast or forged and were not satisfactorily described by the Opitz Code. The "Lever Code" was specially designed around this family of levers and offered primary shape descriptions with two digits. Because these components required secondary machining operations (and also minor drilling on assembly), such as the milling of bosses and the drilling of cotter-pin holes, these features were described with three primary code digits in the Lever Code. Although the practical implementation of this code for production awaits future developments this code data remains a useful aid to design retrieval and a good example of specialist code design.

The third special code was developed for sheetmetal components. The Opitz Code was found in no way satisfactory for these component types, particularly those involving multiple forming operations. The Opitz Supplementary Code included descriptions for sheet material but gave no indication of sheet gauge, an important factor with sheetmetal. The Sheetmetal code provided a useful improvement on the Opitz Code for sheetmetal components although its principal disadvantage was incompatibility with Opitz. Being of an entirely separate design and having 12 digits in all, this code was difficult to use as those involved in the coding exercise were accustomed to the 10-digit Opitz format. On the otherhand, the Contact and Lever Codes were designed to be compatible with the Opitz Code and they were quickly absorbed into the coding exercise. An experienced coding analyst became familiar with particular code types and it was considered that a change in this accustomed code "language" reduced both the rate and accuracy of coding.

The use of these three additional codes proved this to be a valid consideration and it was concluded that a successful coding exercise must follow a rational and systematic course. Coding accuracy and speed was found to be improved if the range of component drawings was pre-sorted into simple families before coding such as; simple rotational groups and others, specific rotational, simple non-rotational, etc.

EVOLUTION IN COMPONENT THINKING THROUGH CODE FAMILIARITY

Experience with the coding of conventional component types has shown that not only is the Opitz Code simple to apply, but that those using the code were able to communicate mental component descriptions and particular production features by code number! This evolution in "component thinking", through experience with coding, demonstrated tremendous potential for design and drawing office applications. The code could be used for component retrieval against basic sketch designs and, at George Ellison Limited, cursary examinations of the code listings revealed scope for rationalisation within a large family of bush-type components. With this particular family it was perhaps unfortunate that the Opitz Code could not describe bare dimensions, although from a production aspect this was of less importance.

Summarising for the coding exercise, the approach to component classification and coding was initiated in a controlled, systematic manner, over a selected component area. Many allowances were made for the existing information sources and an attempt was made to improve the existing component data retrieval. The expansion of this coding exercise to include machined components from the Hospital Equipment Division was a logical development which led to the promotion of two production groups later in the exercise, although, the approach to coding contrasted sharply with the thoroughness of the switchgear exercise.

REDUCED CODING PROGRESS AND RESULTANT COMPANY ATTITUDES

After a successful initiation the value of the code information prompted the further expansion of the exercise to include all machined components within the company's manufacture. This expansion was to include many special and unique component groups and although this did promote the design of certain interesting, special codes, it retarded progress with practical benefits in the machine shop. Also, with the wider, less systematic use of the Opitz Code to include formed and other non-machined components, the very accuracy of the code data was jeopardised.

With little tangible benefits resulting from a project which commenced some five months earlier, a general false impression was conceived throughout the company that Group Technology was primarily concerned with component design rationalisation, being, at this stage, merely a "paper exercise". This general misapprehension and, in some cases, rejection of the Group Technology concept soundly endorsed the need for wider management teaching.

PRACTICAL APPLICATIONS OF CODE DATA

With the completion of the main coding exercise the project was re-alligned to its original course and rotational component code families were analysed for the design of production groups. From this exercise the practical value of the Opitz Code was judged and the anomalies of code intepretation were recorded. The Opitz Code Listing of all the rotational components provided a clear indication of the large simple component families and the generally low level of complexity of the turned components. Broken down into basic code families the turning requirements appeared to contradict shop-floor opinions of its complexity.

The bush-type component code family was selected as the first for analysis and although this demonstrated the clear benefits of grouped production it introduced problem areas relating to code structure and intepretation for practical machine loading. The tooling analysis determined practicable production families for capston lathes which eventually comprised component families widely separated by the code and far removed from "pure" code families. The initial calculations of machine capacity against family loadings revealed major planning anomolies. Many job times for essentially indentical components suffered wide variations, being individually calculated for different machines selected primarily on batch sizes. This anomally alone demonstrated the advantages of grouped production and effective machine loads were calculated using synthetic times.

Initially establishing strict code family groupings it was found that effective machine utilisation would become unacceptably low under optimum loading conditions. Certain families showed potential for single-machine-cell production but almost all the code families contained components requiring secondary machining operations (milling and drilling). It was realised that if a network of group layouts was introduced such that each group was equipped with secondary machining facilities, then certain key machines would have unacceptably low levels of utilisation. It has been suggested (7) that increased investment is necessary in such situations but although this would provide theoretically optimum group structure it would require an unacceptable level of over capitalisation.

Experience with the practical problems involved led to the development of particular solutions involving the phased introduction of production groups designed principally around the primary machines and having shared secondary facilities. This type of solution offered a compromise which, due to the component mix and machines available, was a practical proposition. The exercise on component family formation did conclude, however, that there would also be the need for a separate jobbing type section for components and work not accepted within the grouped structure.

The first practical implementation of Group Technology on the shop floor was with the rotational components of the Hospital Equipment Division. Although this implementation catered for 65% of all the rotational components analysed, it demonstrated some practical limitations of the Opitz Code. Having only two lathes available a new parameter was introduced; bar size or component maximum diameter. Thus there was a maximum spindle diameter for each machine and optimum performance was dominated by collet sizes and material types. Thus, although the final analysis was production - orientated and broken away from basic code families, it was the value of the original code information which lead to this development. Although the exercise demonstrated the practical "art of Group Technology" it was a limited introduction within an unchanged shop environment and needed constant surveillance for its continued success.

PRACTICAL CONTRAINTS

Originally, the large code families of simple pin-type and bush-type components apparent in both of the company divisions manufacture, were considered for the initial introduction of pilot cells. A large proportions of all the rotational components were of these familiar "nuisance-value" types and simple, single-machine cells within the unchanged turning section were considered for their production. A major constraint limiting the adoption of this introduction was the possible loss of productive capacity at a time of large work back-logs (over 20,000 machine hours) although this form of introduction ultimately offered increases in effective machine capacity through the rapid absorbtion of simple work, it was not commissioned.

This proposed introduction demonstrated the logical combination of dissimilar code families, using the supplementary code descriptions, to sequentially load components onto selected machines. Lewis's (16) work on family combination compared with flexibility of performance was a major consideration in the selection of suitable work schedules. No single "pure" code family provided sufficient work content to justify the development of individual unit machine cells or groups. Each code family comprised components over a wide range of bar stock diameters and no single lathe could be satisfactorily loaded. Therefore, if code families (for example a bush-type family) were to be considered in isolation it would necessitate the duplication of the same production group structure with ridiculous levels of machine under-utilisation, but offer "ideal" flexibility and performance. (Fig. (94)).

Clearly, a compromise solution had to be found and this lay with the intepretation of the code families for production. The coding exercise had placed rotational component production into practical perspective; the major component families were basically simple but each over-lapped its neighbour both in dimensional range and production feature elements. The turning section mainly comprised manual operation and plug-board capstan lathes and, with these machines, the main factors influencing work throughput were found to be component material types and collet sizes. Figs. (7) and (89) illustrate the high frequency small batch production and the collet size variance).

From this analysis, production families were developed from the code family collation and the original size range code for rotational components was completely reranged to provide a concise relation with machine capacities. This exercise would not have been necessary had a thorough pre-code component analysis been performed.

THE PILOT CELLS

The establishement of two production cells in the Hospital Equipment Division machine shop offered tremendous potential for the future growth of Group Technology throughout the company. The provision of a vacant annex to the main shop allowed the careful design of group layouts and machine placement without the need to move existing plant. The two groups introduced offered excellent performance and preliminary observations proved complete operator acceptance.

Of the two groups the turning cell offered the more 'classical" introduction with a typical turn-mill-drill production arrangement. The group for tube production was, essentially an improved combination of existing facilities with added refinements for secondary operations and to aid work flow. At the time of writing this group was undergoing provisional operation prior to scheduled working and initial operator reactions were very favourable. The development of the turning group was to act as a shop window to demonstrate the principles and advantages of Group Technology to the main machine shop and the company as a whole. The limited machine selection enforced an interesting adaption of the code data which was used to develop production groupings by family combination.

Sequential scheduling of production families within collet size ranges offered potential for pre-set capstan-head tooling and both "code family" and collet family" techniques were compared. It was this development which emphasised the unsuitability of the size range code used. With simple turned components there appeared to be little value in maintaining strict code family relations if the principal production requirements (tooling, etc.) were within the capacity of a single pre-set tooling head. The importance of collet size with capstan work reitterated Craven's (52) findings and the improvement of the Opitz Code was recommended to reduce the need for detailed production analyses.

The popular theory that component family production leads to automatic reductions in machine setting times was found to be falicious when the families involved high frequency, small quantity batches over a range of collet sizes and this application demonstrates a practical solution. Due to the overall low complexity of most of the rotational component families, future developments were seen to envisage production groups related to machines set to certain collet sizes. This would, however, have led to duplications of operations and tooling across the groups, although to some extent this was already common practice.

The final outcome was seen to depend to a large extent on component demand because this would dictate the level of family combination and hence flexibility of performance for any one machine or group, although batch size should not pre-determine group structure.

Random chucking components were not included in this work because these components were considered to be detrimental to simple family formation if combined with components produced from bar stock.

A separate jobbing section offered a simple solution for these components and would also absorb random short-order work and overloads from the main cells.

CELL LOADING AND OPERATOR SKILL LEVELS

The factor of minimum batch quantity levels pre-determined with traditional machine loading techniques was found to have certain significant affects on cell loading. The current machine shop practise was for female capstan operators to machine the larger batches of simple components and the few setter-operators to complete the low quantity orders. It was quickly appreciated that each production family would comprise a diverse range of order quantities and despite the aspects of simplified setting concordent with grouped production there would always be a degree of setting changeover. Thus, it was considered that with the introduction of Group Technology operator skill levels must increase to enable autonomous operator involvement in performing simple setting adjustments.

ASSESSMENT OF OPITZ FOR PRODUCTION

Although the introduction of Group Technology at this company has principally involved turned parts, the initial coding exercise included non-rotational components and this led to the development of some unique classification systems. These unique codes demonstrated the simplicity of logical component grouping and the formation of coding conventions throughout the exercise emphasised the practical nature of this investigation.

The value of the Opitz Code with rotational components has been high-lighted along with some typical examples of its accuracy, but the suitability of the code for non-rotational components was found to be greatly reduced. With non-rotational components the primary code digits attempted to provide geometric descriptions in the same manner as for rotational components. The code was found to be inadequate in this respect because the basic shape of such components was largely unchanged by the production processes, i.e. a cast component or a rectangular billet. In contrast, with rotational components the actual primary shape features were production features and therefore implied the operations involved to form their basic geometry.

The production operations on non-rotational components were primarily concerned with the machining of auxiliary holes and slots, locating surfaces, etc. The Opitz Code described such operations quite well but these features were only covered by the last two primary code digits. Thus the value of the Opitz Code in this application was principally dependant on only two digits, although rotational surface machining descriptions offered by the code may be of greater benefit in other applications.

Therefore the Opitz Code for non-rotational components appeared to offer both design retrieval and production information, but, failed to provide either with great accuracy. In a practical application there appeared to be little value in identifying basic "flat type" long type and block type groups each requiring identical auxiliary production operations. The code was thought to require improvements with respect to an expansion of such auxiliary feature production and the addition of a third dimensional size digit. Revised groupings would then contain three-dimensional size parameters and this could be directly related to machine capacities and rationalised workpiece clamping arrangements.

MANAGEMENT UNDERSTANDING OF GROUP TECHNOLOGY

Finally the growth of Group Technology in the company as a whole can be discussed. The personnel and human problems of introducing Group Technology at this company must reflect a classic case of misapprehension. The basic reasons for its primary consideration at this company follow MacConnell's (6) findings although little progress has been made with the development of Group Technology philosophy throughout the company before this pilot introduction. The exercise has been viewed by many as a minor project and little understanding of its value has perpetuated beyond the walls of the production engineering department.

The time scale and staff employed for the coding exercise must be a factor in this case and the value of the code is seen by many to be entrenched in component analysis for variety reduction. Although the coding exercise did show the potential for such developments the introduction was primarily directed at component production.

Gradually, with the successes o minor applications the value of Group Technology is becoming more widely accepted.

To a large degree the introduction of new techniques in an established environment will always be opposed with human problems; problems of change, and individual personalities can play a major role here. It has been said (7) that the introduction of Group Technology requires the backing of a forceful senior personality in the company concerned. Although this was principally fulfilled by the company Managing Director the project suffered as a result of inadequate wider management teaching and involvement.

The coding exercise alone exposed tremendous potential for variety reduction within large, simple component families. Many components had seen little such analysis since 1916 when the company was founded in Birmingham. Minor exercises on design retrieval and variety reduction using the code information have enjoyed 100% success rate, but major development along these lines was seen to be secondary in importance to the production application of the code.

The use of Group Technology in the selection and sequential scheduling of component families to specific machines (earlier hospital equipment exercises and the more recent pilot groups) has generated more enthusiasm on the shop floor than in some management areas, mainly through their differences in practical involvement. During the completion of this work there has been an upsurge in interest in Group Technology from Director level downwards and the recent addition of a component grouping index on the company's computer information heralds the future growth of this work.

CONCLUSIONS

1. Group Technology offers a solution to the customary problems of batch production industry.
2. The introduction of Group Technology into a practical situation must be carefully planned and budgeted, for without such control its success will be limited.
3. Prior to the use of component analyses, both the means of component production and a representative sample of the component range require examination.
4. For this investigation such analysis was incomplete and the accuracy of the component statistics was limited.
5. The scale and timing of the introduction must consider the particular situation and be directed to give maximum benefit.
6. The radical nature of Group Technology requires the financial, production and labour resources of a company to absorb change.
7. The initial introduction of pilot groups or cells before the wider introduction of Group Technology is a necessary but practical demonstration for the whole company.
8. The use of a suitable classfication and coding system must be directed to those component areas which offer greatest potential for analysis and be modified to suit the particular application with respect to;
    (a) practical coding conventions for production feature intepretation.
    (b) code data presentation and information retrieval.
9. Initially, for this analysis, rotational components and the turning section were primarily considered and the final component data endorsed the value of this decision.
10. The coding exercise must consider;
    (a) Systematic retrieval of relevant component drawings.
    (b) The training of coding analysts.

(c) The strict intepretation of coding conventions.

(d) The recording and presentation of component codes and other relevant data.

11. No standard classification system will accurately describe every workpiece, particular conventions and, in some cases, special codes must be considered.

12. Conventional codes must not be applied to non-conventional components and when the code description offered to a standard comonent lacks accuracy or is ambiguous, strict coding conventions must be established.

13. Special or unique component groups are identified from the component review and special codes can be developed for their classification. The design of special codes should consider;

(a) Practical code value, for production, design retrieval or a combination of uses.

(b) Logical component feature grouping and intepretation.

(c) Code structure and format for compatibility with the main code data.

14. A reliable code data base can be a powerful management tool.

15. The initial introduction in the machine shop can be successfully performed with pilot groups or cells designed to manufacture large families of simple components. At the company concerned such families comprised bush and pin-type components and tubes.

16. The design of a pilot group must consider primary feature production and effectively utilize primary machines. Group structure and associated component mix are directly related to primary machine production.

17. Secondary feature machining within a group will lead to high levels of machine under-utilisation, and pure cell design can involve high

levels of over-capitalisation.

18. Dissimilar component families have to be combined to effectively load primary machines and the level of family addition must be balanced with the envisaged performance flexibility.

19. The classification and coding exercise reveals component categories which are unsuitable for family grouping or are outside particular group parameters. A separate jobbing-type section is necessary for such component production.

20. The Opitz Code puts simple component production into practical perspective and immediate advantages are apparent in the separate analysis of simple component families.

21. The Opitz Code families are not necessarily obvious production families, each component must be individually assessed for tooling requirements before family combination and such pertinent details may, in fact, lead to the development of production families by sub-family addition.

22. The level of sub-family combination for any one primary machine or group will depend on;

    (a) The machine capacity available or which must be used.

    (b) The composite component complexity and the desired level of flexibility.

    (c) Simple code family size in relation to machine time.

    (d) The physical parameters of the particular machine or group.

23. Within a limited range of component code families a machine loading schedule may group components according to the practical constraints of the given machine.

24. When producing high frequency, small batch components on a Capstan Lathe, collet size and material type are the most important scheduling parameters and production sequences may bear little relation to strict

code families with simple irst-operation - finish turned components.

25. An important production feature of capstan lathe components not described by the Opitz Code is whether the component can be produced from bar-stock or is of a "chucking-type". These two basic component types should not be combined.

26. Machine loads can be quickly estimated using synthetic times based on code family type because within simple rotational component families there is little difference from one component to the next.

27. Production by family type on a capstan lathe can increase setting times.

28. However simple the family combination is designed, there will always be some setting changes necessary and therefore operator skill levels need to rise.

29. The Opitz Code provides accurate design and production descriptions for rotational components because with such components the primary design features are production features and turning is the principal process.

30. Non-rotational components are poorly described for production with the Opitz Code as there is no such simple relationship between primary shape features and machining operations.

31. Classification and coding techniques attempt to rationalise component machining by describing component identities which are related to post-production design features. For simple rotational components the Opitz Code successfully replaces the need for further detailed production analyses, but, non-rotational components require P.F.A. techniques which cannot be condensed into a simple code.

32. The practical aspects of Group Technology need to be demonstrated to the shop supervision if they are to accept and enforce the changes involved.

33. The "Human Problem" is the greatest opponent to the successful introduction of change.

34. For its success the introduction of Group Technology must be backed by and involve a senior personality in the company concerned.

35. To overcome personal problems a planned schedule of introducing lectures must be organised to increase company awareness of the changes required and improve general levels of understanding of Group Technology Principles.

36. Following the introduction of component family production via classification and coding, new and different components become logically assigned to natural production groups without further classification. Such evolution offers scope for simplified works ordering.

37. Once the seed of Group Technology has given practical 'fruit' its value and future development are widely recognised within the company concerned.

APPENDIX I

THE ELLISON RANGE OF SWITCHGEAR PRODUCTS

APPENDIX I

THE ELLISON RANGE OF PRODUCTS

HIGH VOLTAGE

11 KV Oil-break Circuit Breakers 400A, 1200 A.

11 KV Oil-Switch 400A.

MEDIUM VOLTAGE

Packaged Substations - with Cast Resin Encapsulated Class 'C' Insulated or Pyroclar Filled Transformers.

Air-break Switchboards incorporating:

Air-break Circuit-Breakers

Moulded Case Circuit Breakers

Fuse Switches

Motor Control Gear

Fuse/MCB Distribution Boards

Airbreak Circuit Breakers, 800A, 1600 A, 2400A, 3000A

Fuse Switches, 60A, 150A, 200A, 300A, 400A, 600A, 800A

Automatic Power Factor Correction Equipment

Oil-Break Circuit Breakers, 800A, 1600A, 2400A.

LAMBAR Busbar Trunking 300A, 500A, 800A.

LAMBAR Rising Mains 300A, 500A, 800A.

ANCILLARY PRODUCTS

Heavy Duty Push Button Stations, Limit Switches Etc.

APPENDIX III

PROPOSALS FOR THE INTRODUCTION OF GROUP TECHNOLOGY
INTO
THE HOSPITAL EQUIPMENT DIVISION
OF

GEORGE ELLISON LIMITED
PERRY BARR
BIRMINGHAM

Report presented to George Ellison Limited
on
11th October, 1973

SUMMARY (APPENDIX)

Group Technology is to be introduced to the Hospital Equipment Division machine shop with the aim of improving the production efficiency and output.

At the present time all turned components are manufactured on a sub-contract basis and the proposed techniques will enable 84% of such components to be manufactured within the Division.

The manufacture is difficult and inefficient with the present facilities and with Grouping techniques will undergo a complete revision.

This report details the proposed introduction and efficiency improvements which will ensue with an autonomous machining section.

INTRODUCTION

A code analysis of George Ellison Switchgear and Hospital Equipment Division component drawings has been finalised and the Opitz Code data made available.

Original plans were to include machined components from these two divisions in a Group Technology exercise.

In view of the recent re-organisation within the company it has been decided to concentrate the activities of Group Technology in the Hospital Equipment Section. Proposals are therefore put forward in this report for the setting up of Machining Cells to deal with turned and tube-type components.

Managements approval is now sought to implement these proposals and so improve the throughput of the component manufacture.

PROPOSALS

TURNING GROUP

The turning group will manufacture those components of a rotational nature.

The machining facilities to be provided are shown on the layout, and the inter-machine relation will promote the advantages associated with cellular production.

The majority of components fall within the capacity parameters of the Ward 1A Capstan Lathe. The components selected for this machine create a 2,000 hour load (i.e. one normal year). The hourly loading is based on planned allowed times and does not consider the advantages of component grouping and scheduling, which will reduce non-productive machine time.

59% of rotational components will be machined on the Ward 1A. A further 25. of these components will be machined on the Ward 3A Capstan Lahte. Most of these components are outside the capacity of the Ward 1A or are not considered suitable due to their machining and scheduling parameters. The remaining 16% are, for the time being, to remain sub-contracted for a number of reasons:-

- (i) They are outside the capacities of the two primary machines.
- (ii) They are required in quantities which obviate specialist manufacture.
- (iii) They are of a degree of complexity which would restrict simplified component scheduling and introduce additional tooling.

The Ward 3A is not fully loaded with its quota of components and will provide a "second operation" machining facility for components from the Ward 1A.

Any remaining machining time on this machine can be used as an emergency or back-up facility.

The secondary machine facilities are so arranged in relation to the primary machines as to create the necessary environment for successful cellular manufacture.

SECONDARY MACHINES IN TURNING GROUP

15% of primary operation components require milling or drilling operations.

These 15% represent 35,500 components and 27,600 of these require only a drilling operation.

Due to the relatively light loadings on the drilling and milling facilities, it is suggested that one man will operate both machines.

ADDITIONAL FACILITIES

In addition to the primary and secondary machining facilities cutter grinding and storage areas will be provided for tooling maintainance, but a discussion is required with regards to the manpower for this function. The section will have storage facilities necessary for tools in its component groups, and the foreman for the section will be responsible for the upkeep of the equipment. In this way machining time will be maximised.

Jigs and fixtures will be stored by their appropriate milling and drilling machines and have clear identification.

Racking will be provided by the Capstan Lathes for bar stock. These racks can be supplied with the daily requirements from the raw material stores situated at the end of the shop.

Small work-in-progress areas will be made available by each machine with ease of access to enable inter-machine movement.

TUBE GROUPS

All tube work will be manufactured in two parallel machine groups.

One machine group will specialise on tubes which load the bending machine, and will include additional machining facilities to cater for saddling and drilling operations.

The other group of machines will manufacture straight tubes and will have similar secondary machining facilities.

A new automatic feed saw will supply the bent tube group and supplement the two saws in the straight tube group as required.

Details of throughput will be found at the end of this appendix.

SECONDARY MACHINES

Both groups will have de-burring facilities in close proximity to the saws.

The bent tube group will have a single-spindle and a special-purpose drilling machine.

The straight tube group will have a single-spindle drilling machine and a milling machine for saddle-milling, the latter facility being shared between the two groups.

Where duplicate secondary machining facilities exist a degree of sharing can be tollerated, provided the work load from either section is not excessive.

ADDITIONAL FACILITES

As with the turning group, provision will be made for the racking of associated tooling by machines. Each machine, therefore, will have all the necessary tools for its component groups. The maintainance of tools will be provided by the same personnel who provide the service for the turning section.

The saws will have material racking and small work-in-progress areas will be made available by each machine.

A special-purpose work table incorporated will roller conveyors is to be provided adjacent to the saw in the bent tube group. The table will enable the transfer of long cut lengths of tube from the saw to the bending machine.

A small hand press for rectifying distorted tubes will be mounted on a work bench at the end of the straight tube group.

SCHEDULING OF WORK

With the provision of grouped machining facilities and the adoption of common tooling techniques the scheduling of work is greatly simplified.

TURNING GROUP

Only scheduled components of the family will enter this group and then only in the order sequence determined at the planning stage.

The primary machining operation is of the greatest importance and detailed schedules have been developed to maximise tooling commonality and minimise machine setting-time.

For the successful operation of the group the schedule for the first operation must be allowed to work.

Component requirements, of course, may change the constituents of the schedule but sufficient flexibility has been incorporated in the system to deal with modifications.

Once a schedule has been issued and work commenced other work must not be introduced but must be allocated to the next schedule and if necessary the next schedule modified accordingly.

Separate schedules will be used for the Ward 1A and Ward 3A although in some cases the latter machine will form part of the manufacturing facility of the first group and therefore, the schedule must take this into account.

The secondary machines of the turning group are lightly loaded and will be operated by one man who will perform the various operations as the work load and schedule demand.

LABOUR

The facility layout in both the turning group and the tube groups improves working conditions both from a practical and sociological view-point. All workers will be encouraged to increase their skill patterns.

TURNING GROUP

The two Capstan Lathes will each require a full-time setter-operator.

These two operatives must be conversant with both machines and will need to balance their outputs when second operation turning is required. However, the balancing operations will be incorporated to some extent in the schedule pattern.

They will work in harmony with the secondary machinist and be able to assist during absenteeism.

The group foreman will ensure that tooling and tooling requirements are fulfilled, and that the planned schedule is worked in the order laid down.

The inter-machine movement of work-in-progress will be the responsibility of the operatives who will work as a team.

TUBE GROUPS

A total of 9 operatives will man the two parallel tube groups.

Certain machines such as the saws (3) and bending machine (1) will each have one full-time operative.

Other secondary machines will require a high degree of flexibility of labour.

Again, work movement is simplified by the improved inter-relation of machines.

Basically each group will have sufficient facilities for the total machining of its tube types. However, the bent tube group does not have facilities for saddle milling and so components requiring saddle milling have to visit the other tube group.

Having 5 operators available for the secondary machining functions of both groups it is suggested that 1 operator be assigned to the milling operation and be responsible for this transfer of work.

APPENDIX 3

Details of annual component throughputs

Tube Groups

Straight tubes	150,650
Straight tubes with mitre cut	4,750
Straight tubes with drilled holes	60,600
Straight tubes with saddle milling	134,000
Total straight tubes	350,000

Formed tubes	37,400
Formed tubes with drilled holes	10,100
Formed tubes with saddle milling	9,100
Total formed tubes	56,600

Rods	4,600
Rods with drilled holes	10,800
Rods with saddle milling	4,400
Total rods	19,800

Total Annual Throughput = 472,000

(quantities from 1972/73 piece forecast)

Turning Group

Ward 1A = 131,500 ≡ 59% requirements

Ward 3A = 41,800 ≡ 25% requirements

Turned components requiring drilling = 47,450

Turned components requiring milling = 8,800

(quantities from 1973/74 piece forecast)

Total Annual Throughput = 173,300

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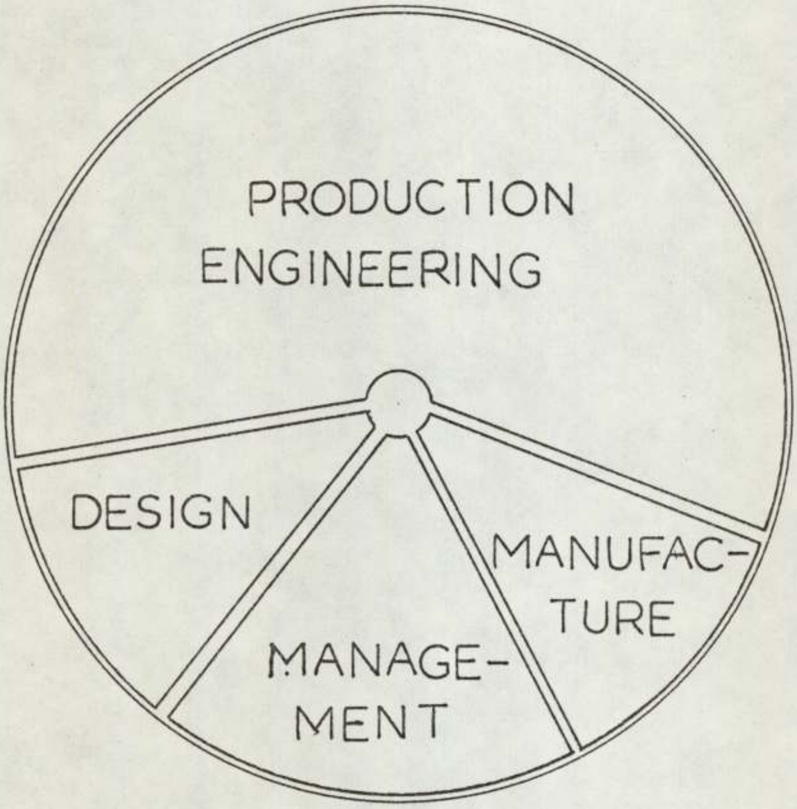
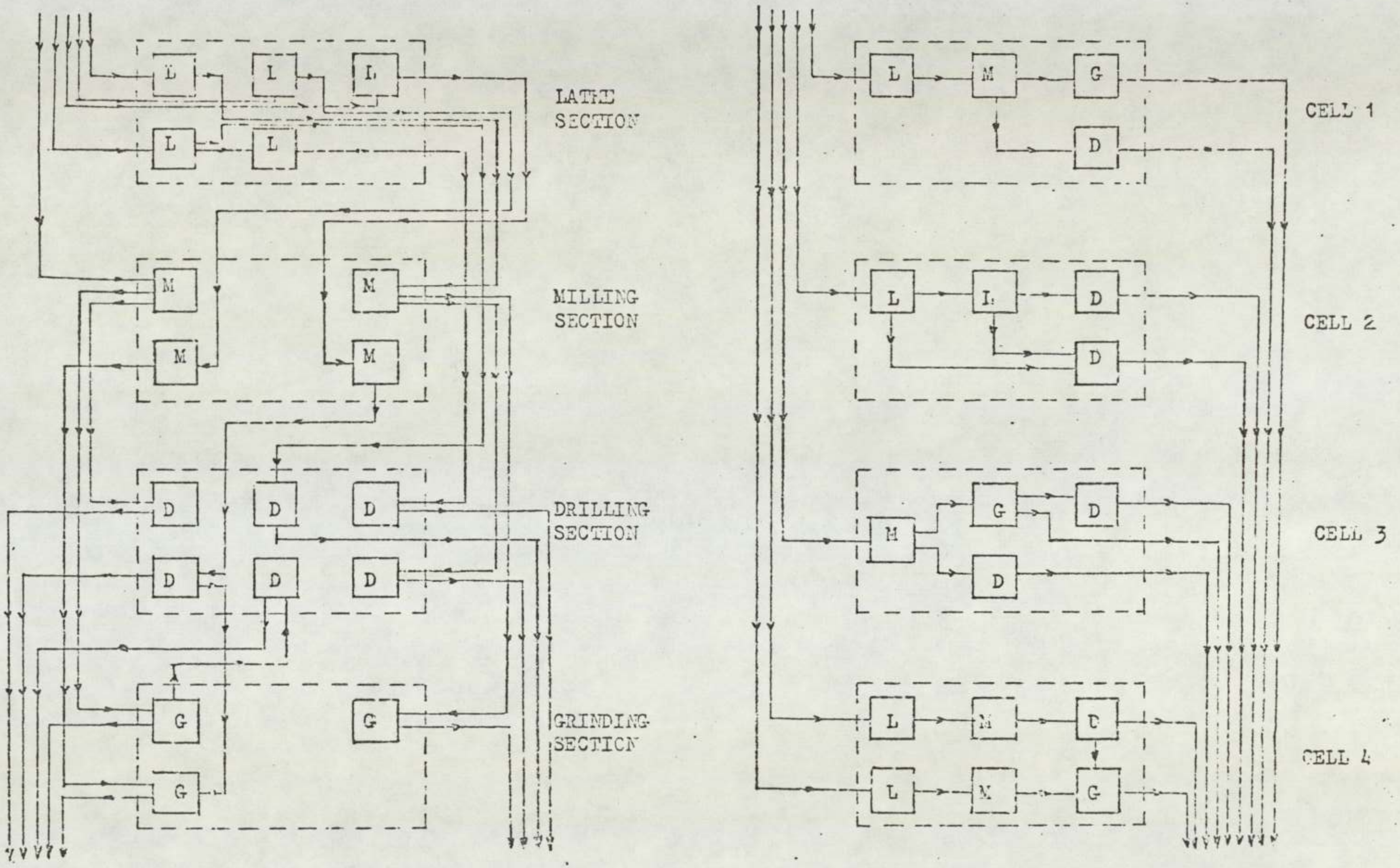
FIG 1



WHY DO COMPANIES IMPLEMENT GT— ANALYSIS OF THE MAIN AREAS WHERE SOLUTIONS TO PROBLEMS ARE SOUGHT

(AFTER BENNETT)



a. Functional layout - complex work flow and high volume of work-in-progress

b. Group technology layout - simple work flow and low volume of work-in-progress

FIG 2 Types of machine layout (identical capacity)

(after Lewis)

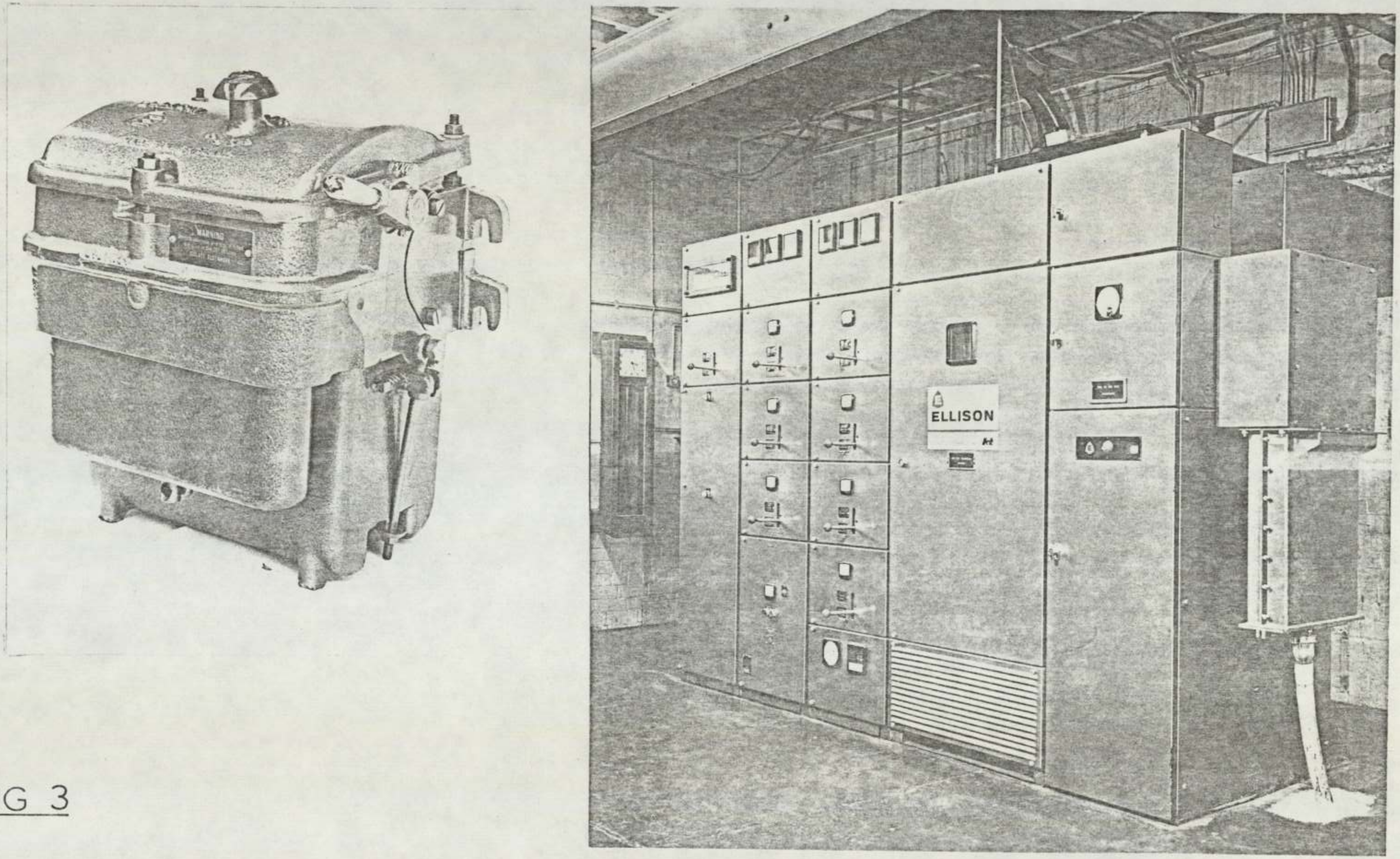
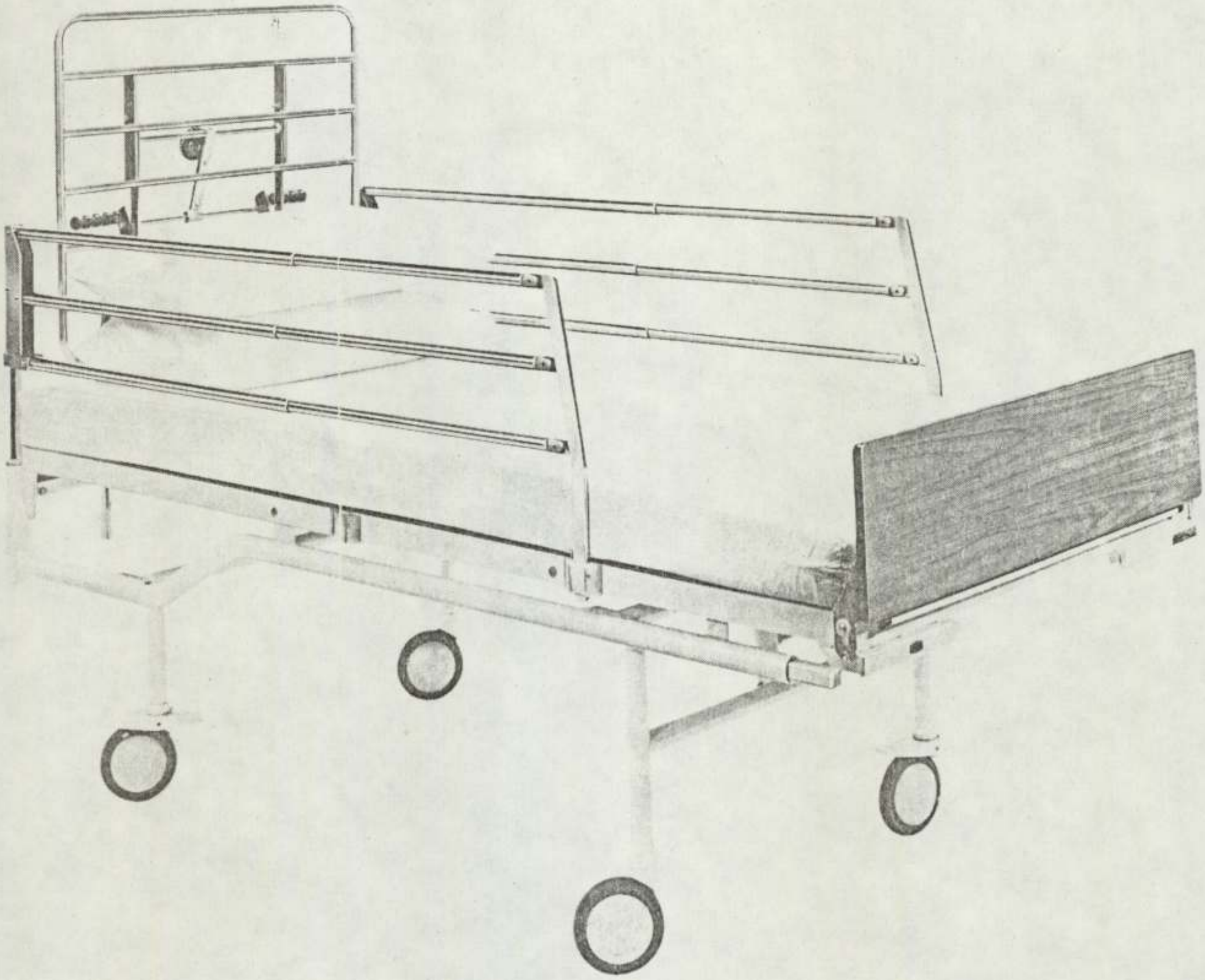


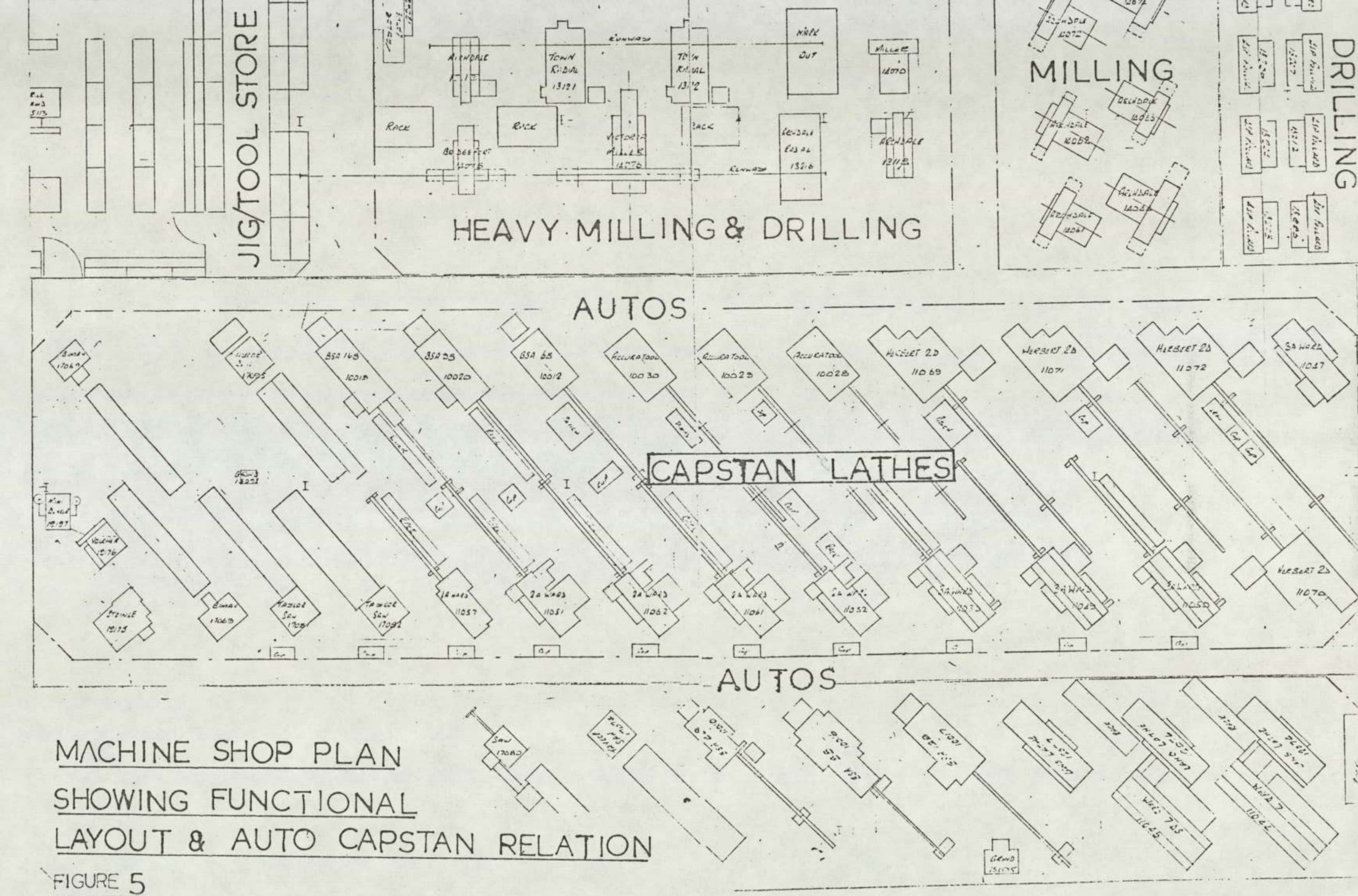
FIG 3

EXAMPLES OF SWITCHGEAR PRODUCTS LEFT A CIRCUIT BREAKER AND RIGHT A COMPLETE SUB—STATION



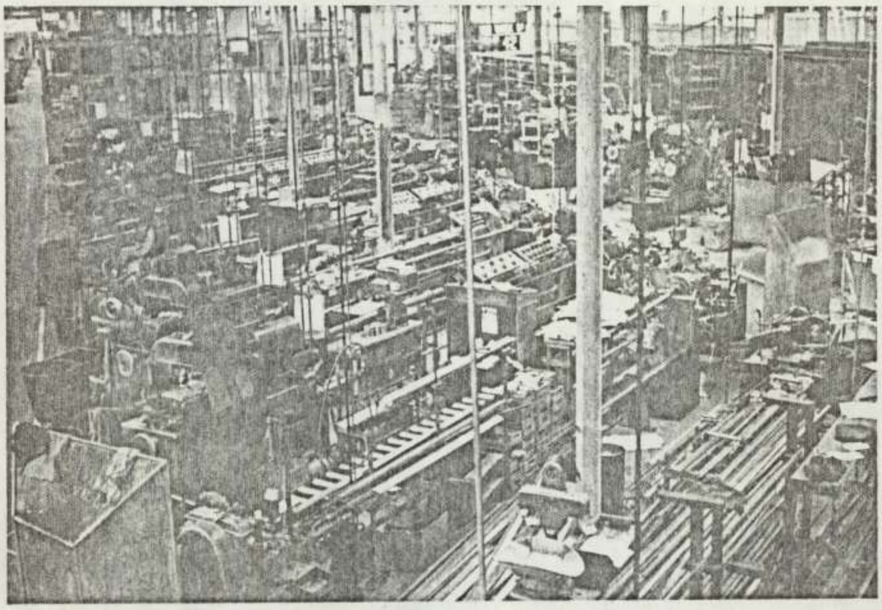
A TYPICAL EXAMPLE OF AN ELLISON HOSPITAL BED

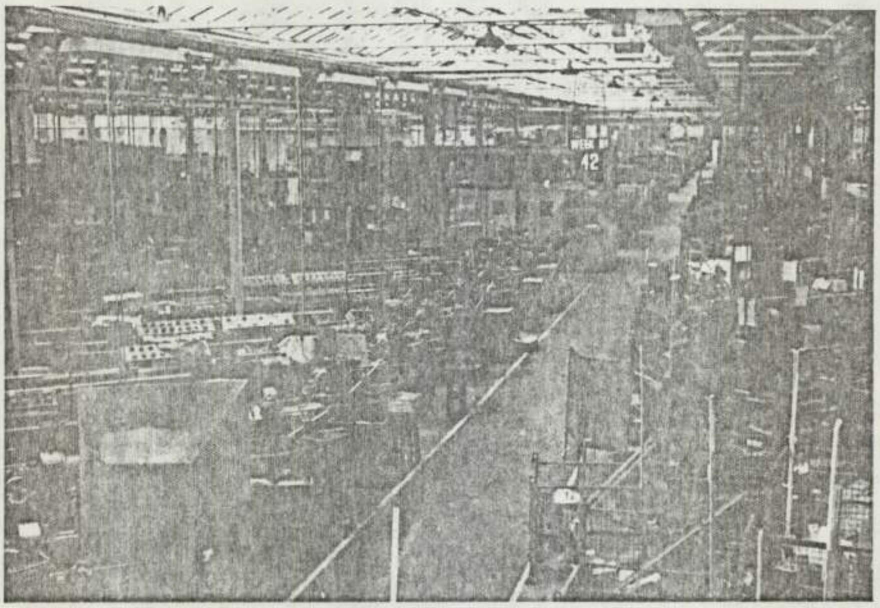
FIG 4



MACHINE SHOP PLAN
SHOWING FUNCTIONAL
LAYOUT & AUTO CAPSTAN RELATION

FIGURE 5





TURNING SECTION SHOWING

CAPSTAN — AUTO LAYOUT

FIG 6

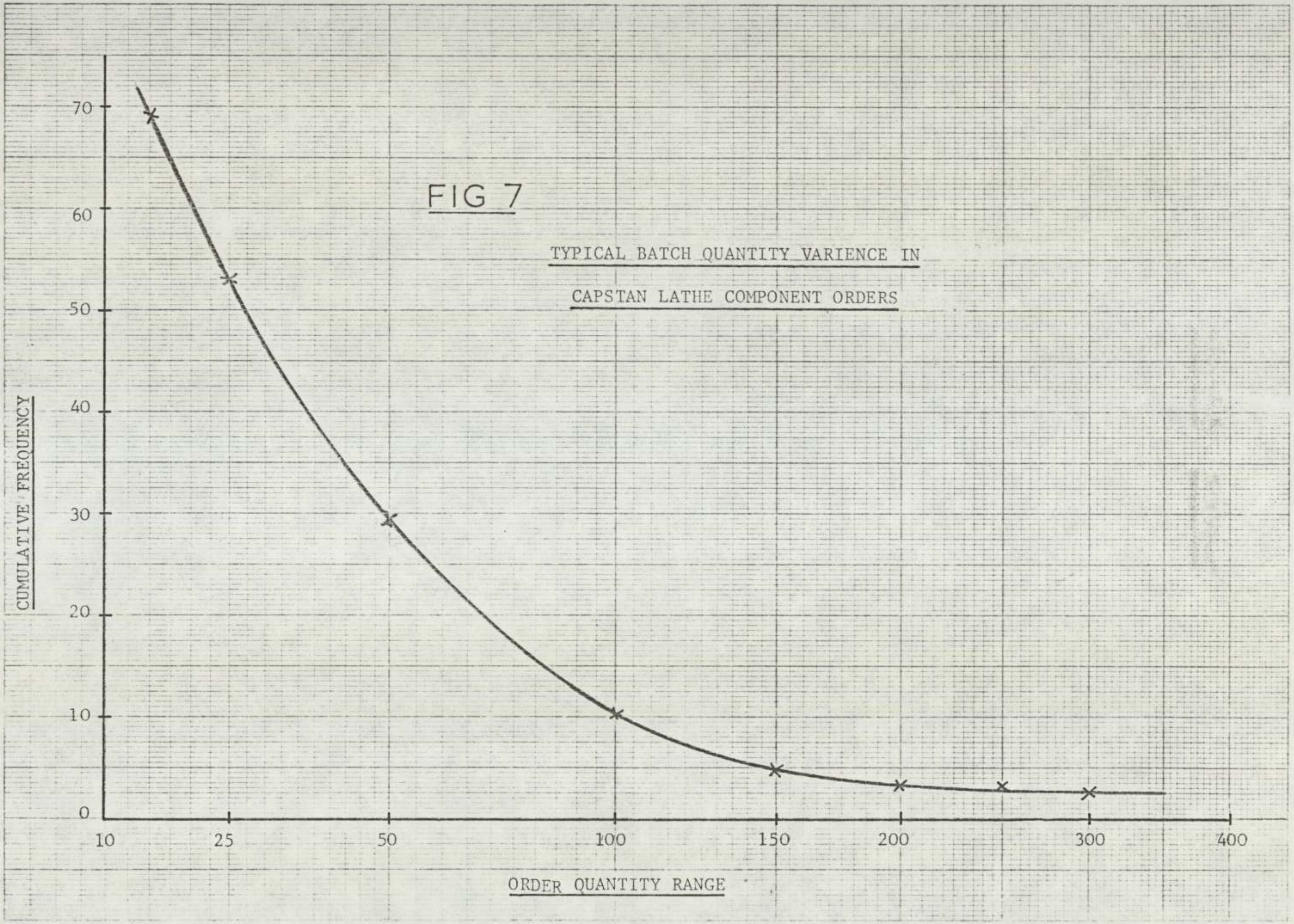


FIG 7

TYPICAL BATCH QUANTITY VARIENCE IN

CAPSTAN LATHE COMPONENT ORDERS

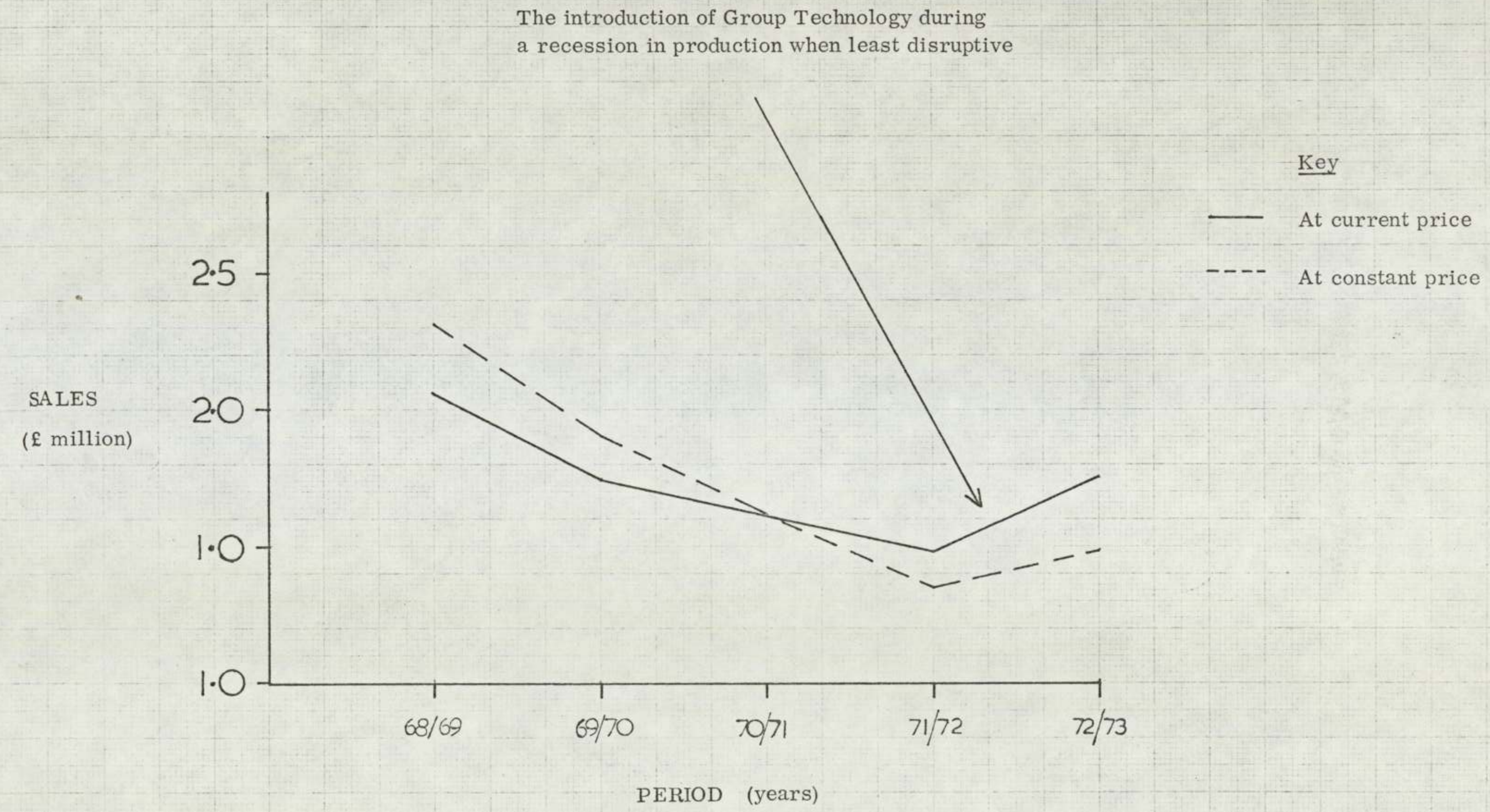


Figure 8

THE TIMING OF THE INTRODUCTION OF G.T. AT GEORGE ELLISON LIMITED

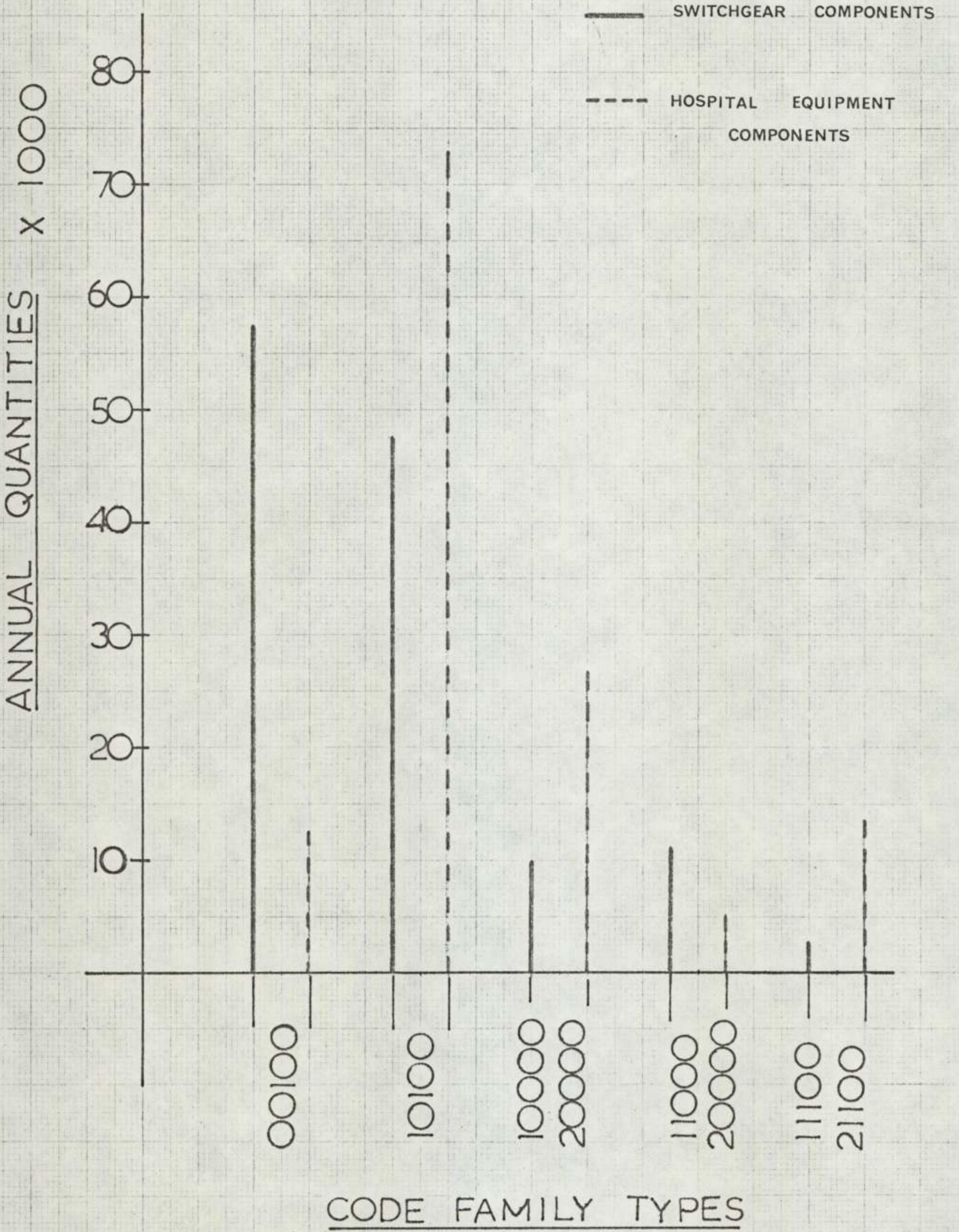
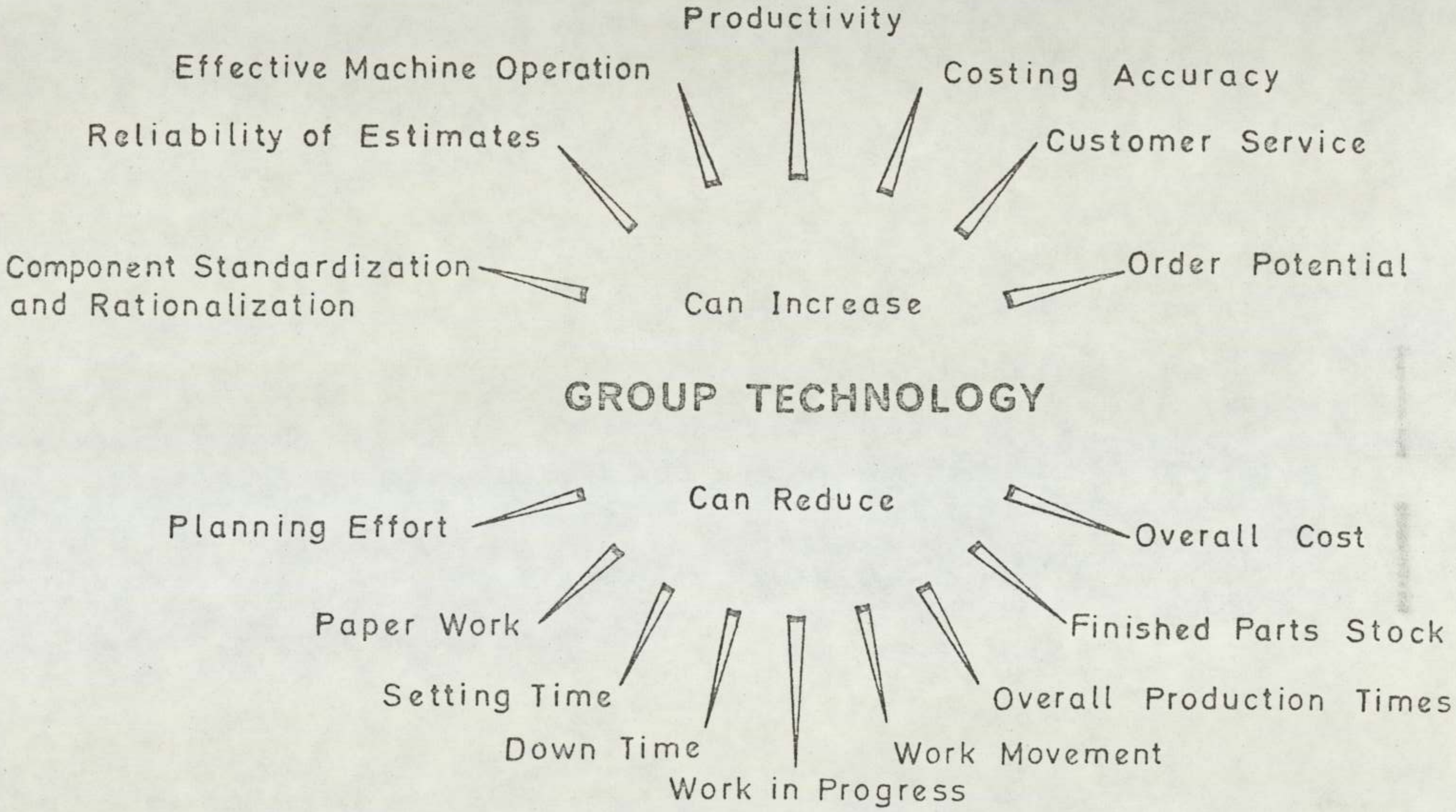


FIG 9

COMPARATIVE COMPONENT QUANTITIES IN IDENTICAL CODE FAMILIES OF BOTH DIVISIONS' PRODUCTION

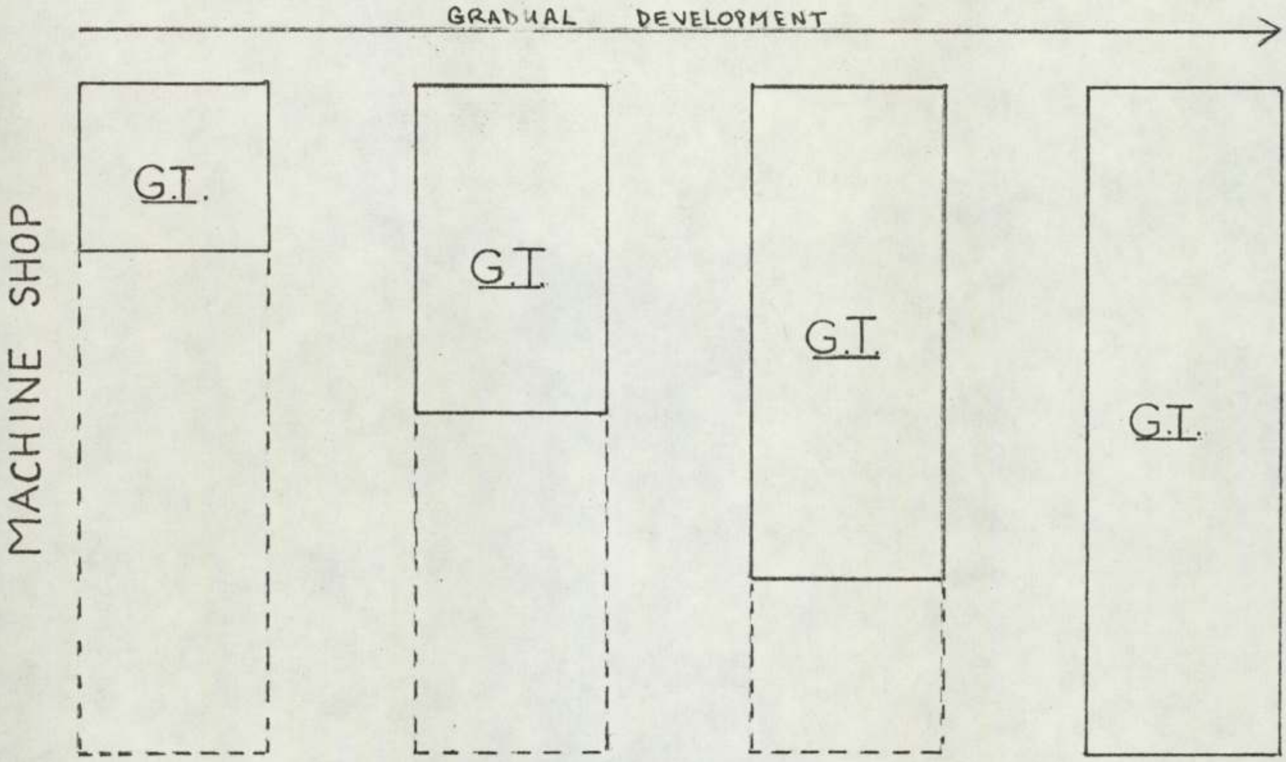


GENERAL ACHIEVEMENTS OF GROUP TECHNOLOGY

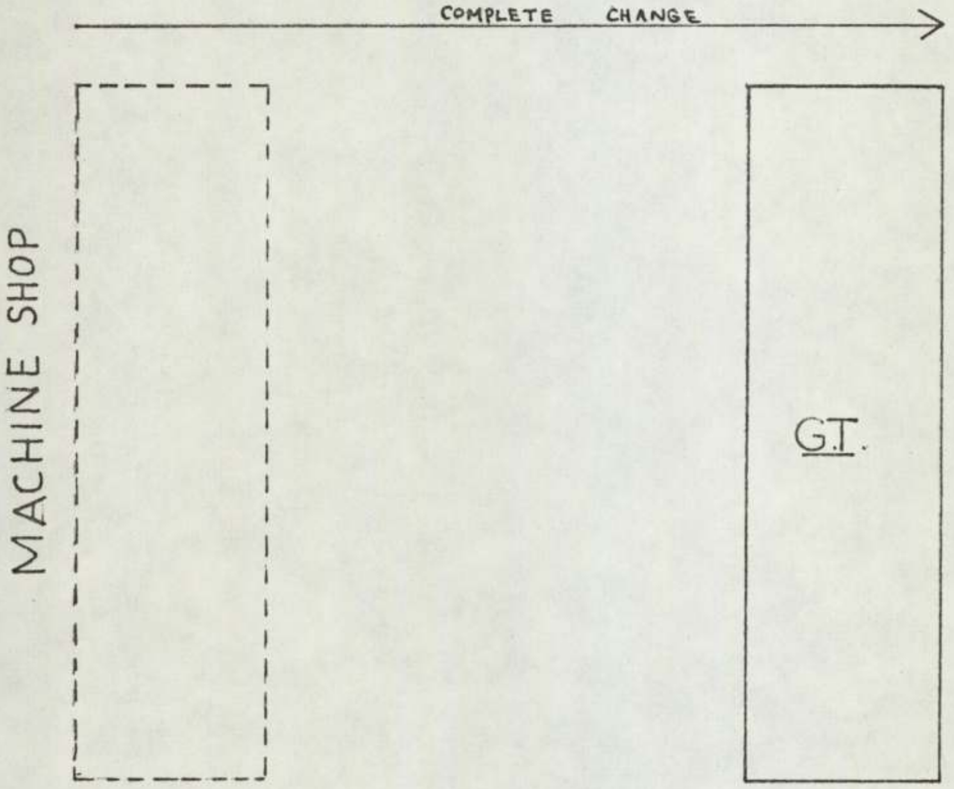
Fig. 10

(AFTER R. H. Thornley)

HORIZONTAL INTRODUCTION



VERTICAL INTRODUCTION



TYPES OF INTRODUCTION

(SCHEMATIC)

FIG 11

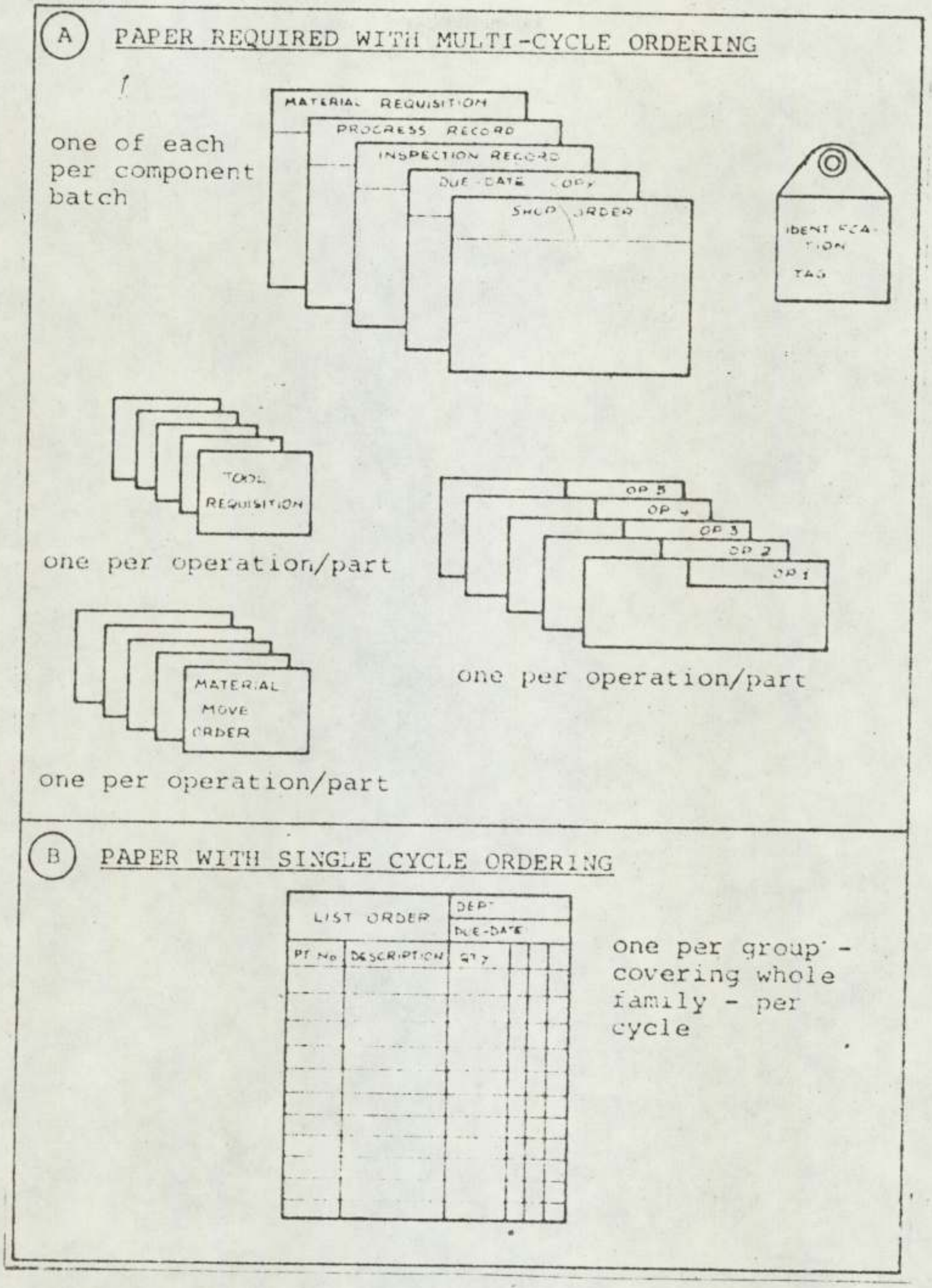
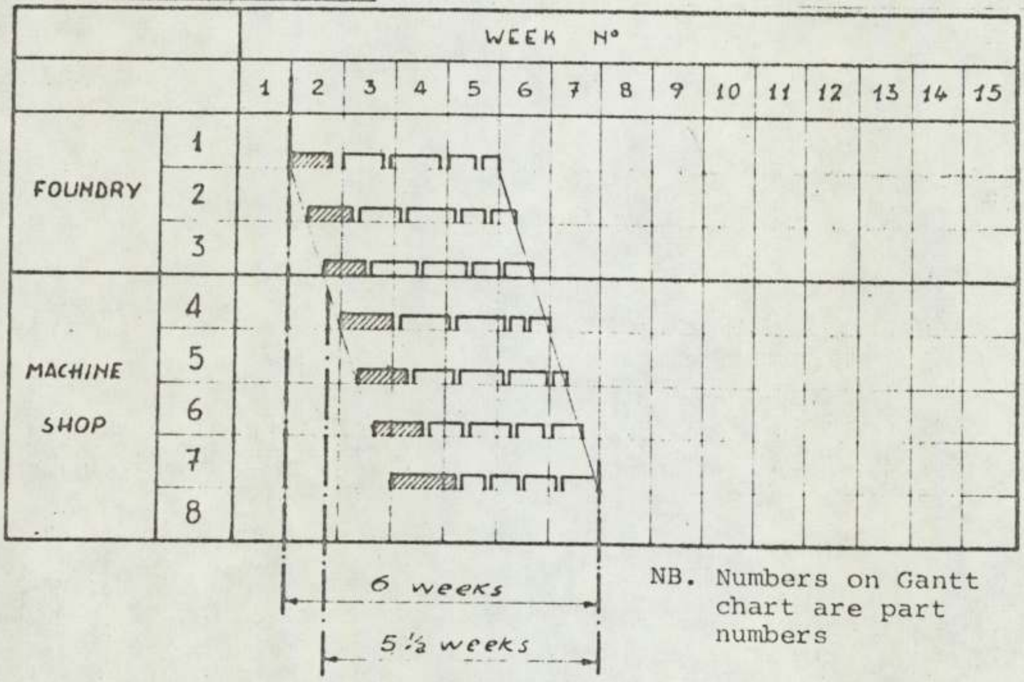


Figure 12 - Paper Work Needed to Control Material Flow

(after Burbidge)

Ⓐ MINIMUM THROUGHPUT TIME WITH SAME LOADING SEQUENCE IN BOTH DEPARTMENTS



NB. Numbers on Gantt chart are part numbers

Ⓑ LONG THROUGHPUT TIME WITH DIFFERENT LOADING SEQUENCES

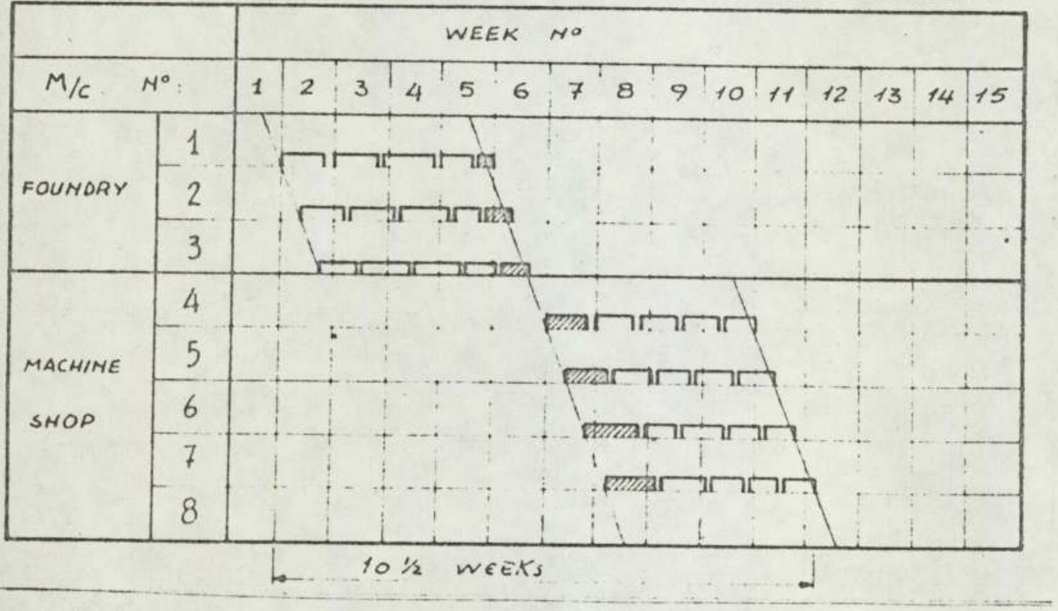
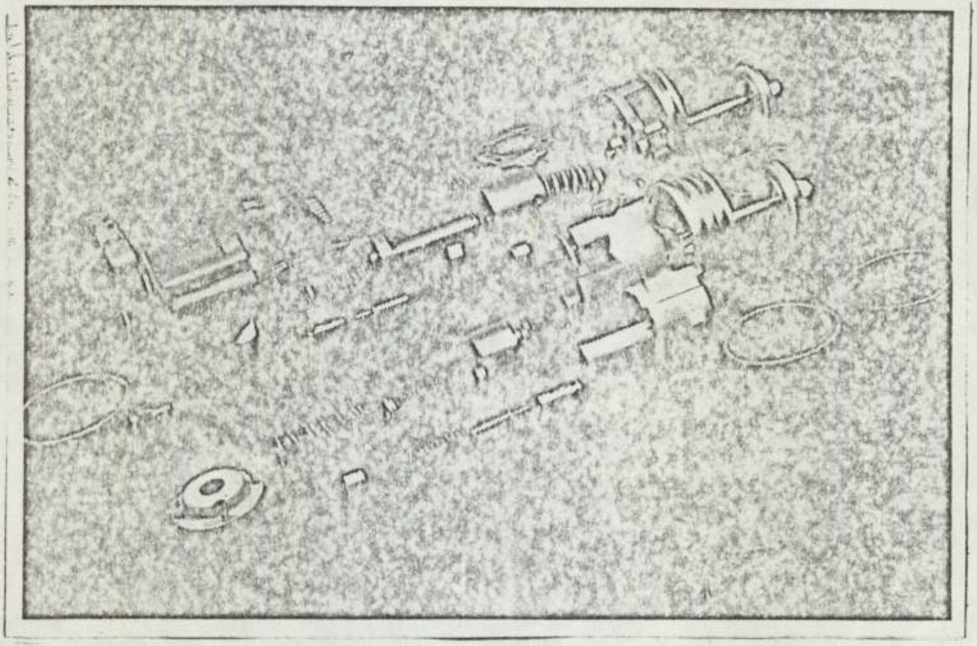


Figure 13 - Elimination of Inter-Process Stores

(after Burbidge)

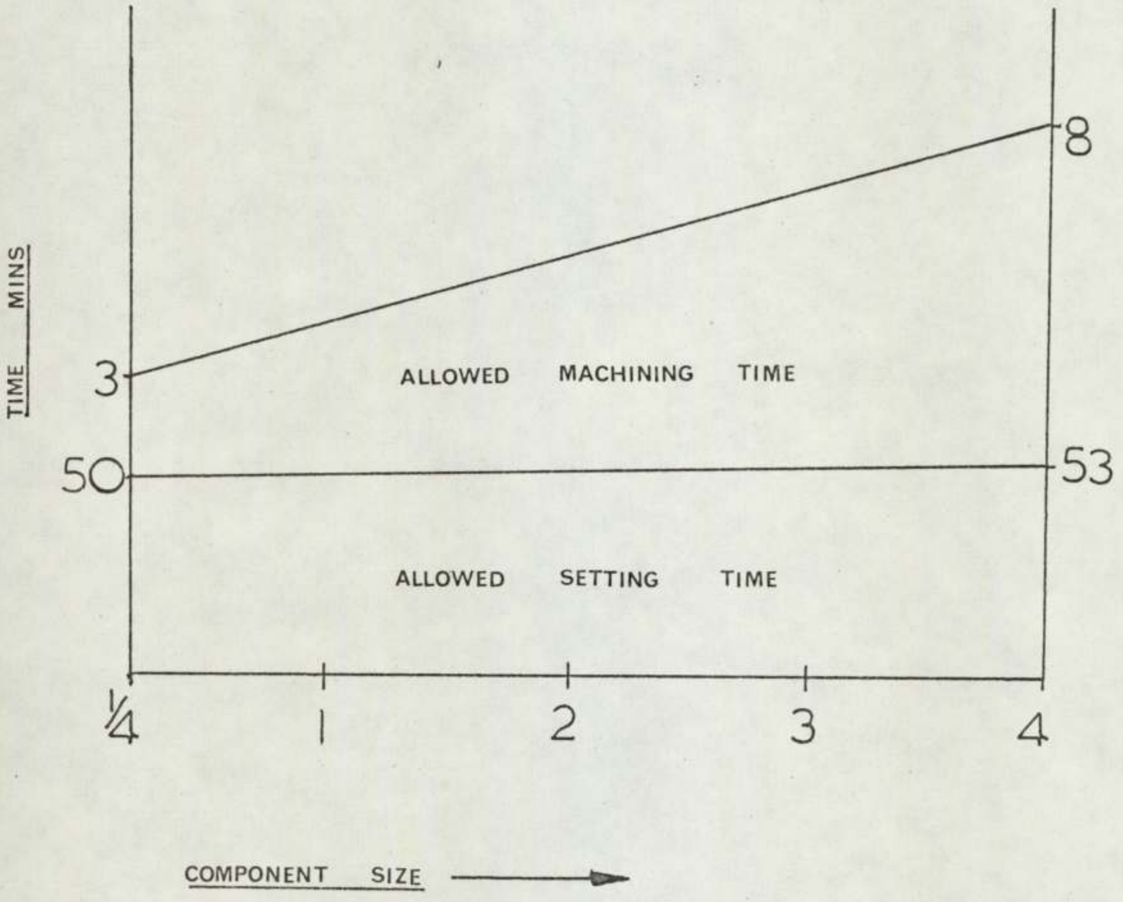
FIG 14



DESIGN RATIONALISATION WITH G.T. — PARTS FOR COMPRESSORS BEFORE (TOP) AND AFTER REDESIGN FOR CELL PRODUCTION.

(AFTER EDWARDS)

FIGURE 15



STANDARDISED ALLOWED TIMES FOR TURNED COMPONENT FAMILY

(after MacConnell)

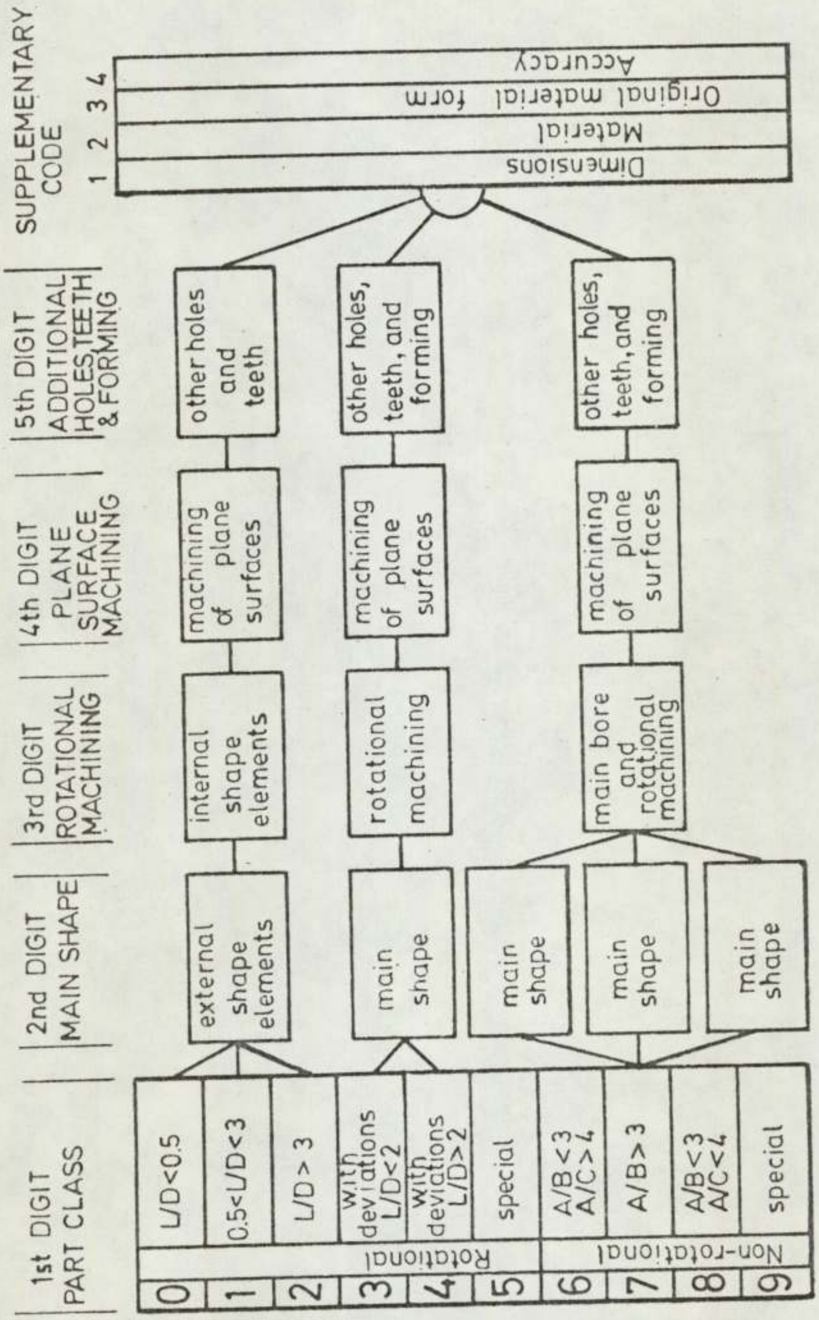


Fig.16 BASIC STRUCTURE OF THE OPITZ CLASSIFICATION SYSTEM

FIG 17

GEOMETRICAL CODE

	1st Digit		2nd Digit		3rd Digit		4th Digit	5th Digit	
	Component Class		External Shape, external shape elements		Internal Shape, internal shape elements		Plane Surface Machining	Auxiliary Hole(s) and Gear Teeth	
0	Rotational Components	$\frac{L}{D} < 0.5$		Smooth, no shape elements		Without through bore or blind hole	No surface machining	no gear teeth	No auxiliary hole(s)
1		$0.5 < \frac{L}{D} < 3$	Stepped to one End or smooth	no shape elements	Smooth or Stepped to one End	no shape elements	External plane surface and/or surface curved in one direction		axial hole(s) not related by a drilling pattern
2		$\frac{L}{D} \geqslant 3$		with screwthread		with screwthread	External plane surfaces related to one another by graduation around a circle		axial holes related by a drilling pattern
3	[redacted]			with functional groove		with functional groove	External groove and/or slot		radial hole(s) not related by a drilling pattern
4	[redacted]		Stepped to both Ends (Multiple increases)	no shape elements	Stepped to both Ends (Multiple increases)	no shape elements	External spline and/or Polygon		holes axial and/or radial and/or in other directions, not related
5	[redacted]			with screwthread		with screwthread	External plane surface and/or slot and/or groove, spline		holes axial, and/or radial and/in other directions related by drilling pattern
6	[redacted]			with functional groove		with functional groove	Internal plane surface and/or groove	with gear teeth	spur gear teeth
7	[redacted]			functional taper		functional taper	Internal Spline and/or Polygon		bevel gear teeth
8	[redacted]			Operating thread		Operating thread	External and Internal splines and/or slot and/or groove		other gear teeth
9	[redacted]			Others (> 10 functional diameters)		Others (> 10 functional diameters)	others		others

FIG 17

GEOMETRICAL CODE

1st Digit

		Component Class
	Rotational Components	
3		$\frac{L}{D} \leqslant 2$ with deviation
4		$\frac{L}{D} > 2$ with deviation
5		Specific Rotational Components
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]

2nd Digit

		Overall Shape
0	Around one Axis No Segments	Hexagonal bar
1		Square or other regular Polygonal section
2		Symmetrical cross-section producing no unbalance
3		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		Rotational Components with two or more parallel axes
8		Rotational Components with intersecting axes
9		HEMISPHERICAL Others SURFACES

3rd Digit

		Rotational Machining
0		No rotational machining
1	External Shape	machined
2		with screwthread(s)
3	Internal Shape	smooth
4		Stepped towards one or both ends (Multiple increases)
5		with screwthreads
6	Ext. and Int. Shape	machined
7		screwthread(s)
8		External Shape Elements
9		Other Shape Elements

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 Spline and/or slot and/or groove
9	Other

5th Digit

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

GEOMETRICAL CODE

1st Digit		2nd Digit			3rd Digit	4th Digit	5th Digit
Component Class		Overall Shape					
		0	Plane	Rectangular			
		1		Rectangular, with one deviation (Right Angle or Triangular)			
		2		Rectangular, with angular deviations			
		3		Rectangular with circular deviation			
		4		Any flat shape other than 0 to 3			
		5	Flat components, rectangular or right angled with small deviations due to casting, welding, forming				
6	Flat Components $\frac{A}{B} \leq 3, \frac{A}{C} \geq 4$	6	Flat Components, 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				

GEOMETRICAL CODE

1st Digit

		Component Class
	Non-rotational Components	
7		Long components $\frac{A}{B} > 3$

[redacted]

2nd Digit

			Overall Shape
0	Shape Axis—Straight	Uniform Cross-Section	Rectangular
1			Rectangular with one deviation (Right Angle or Triangular)
2			Any cross-section other than 0 and 1
3		Varying Cross-Section	Rectangular
4			Rectangular with one deviation (Right Angle or Triangular)
5			Any cross-section other than 3 and 4
6	Shape Axis Curved (bent)		Rectangular, angular and other cross-sections
7			Formed Component
8			Formed Component with deviations in the main axis
9			others

3rd Digit

	Principal bore, rotational surface machining
0	No rotational machining or bore(s)
1	One principal bore, smooth
2	One principal bore stepped to one or both ends
3	One principal bore with shape elements
4	Two principal bores, parallel
5	Several principal bores, parallel
6	Several principal bores, other than parallel
7	Machined annular surfaces, annular grooves
8	7 + principal bore(s)
9	Others

4th Digit

	Plane Surface Machining
0	No Surface Machining
1	Functional Chamfers (e.g. welding prep.)
2	One plane surface
3	Stepped plane surfaces
4	Stepped plane surfaces at right angles, inclined and/or opposite
5	Groove and/or Slot
6	Groove and/or Slot and 4
7	Curved Surface
8	Guide Surfaces
9	Others

5th Digit

			Auxiliary hole(s) Forming, Gear Teeth
0			No auxiliary holes, gear teeth and forming
1	No gear teeth, no forming		Holes drilled in one direction only
2			Holes drilled in more than one direction
3		related by a drilling pattern	Holes drilled in one direction only
4			Holes drilled in more than one direction
5	Forming, no Gear Teeth		Formed, no auxiliary holes
6			Formed, with auxiliary holes
7			Gear teeth, no auxiliary hole(s)
8			Gear teeth, with auxiliary hole(s)
9			Others

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

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

	MATERIAL
0	Cast Iron
1	Modular graphitic cast iron and malleable cast iron
2	Steel $\leqslant$ 26.5 tonf/in^2 Not heat treated
3	Steel $>$ 26.5 tonf/in^2 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

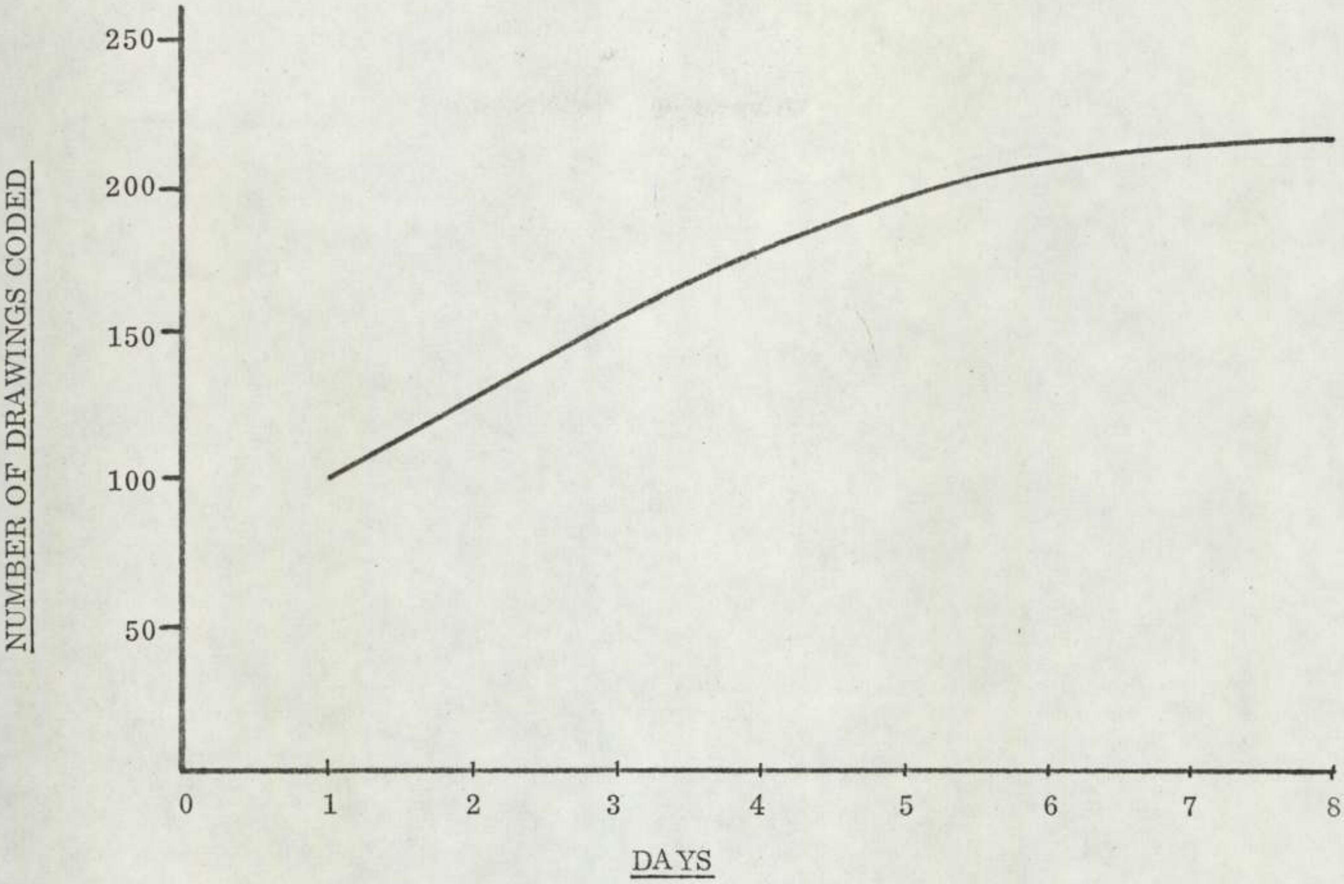
	INITIAL FORM
0	Round Bar, black
1	Round Bar, bright drawn
2	Bar-triangular, square, hexagonal, others
3	Tubing
4	Angle, U-, T-, and similar sections
5	Sheet
6	Plate and Slabs
7	Cast or forged Components
8	Welded Assembly
9	Pre-machined Components

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)

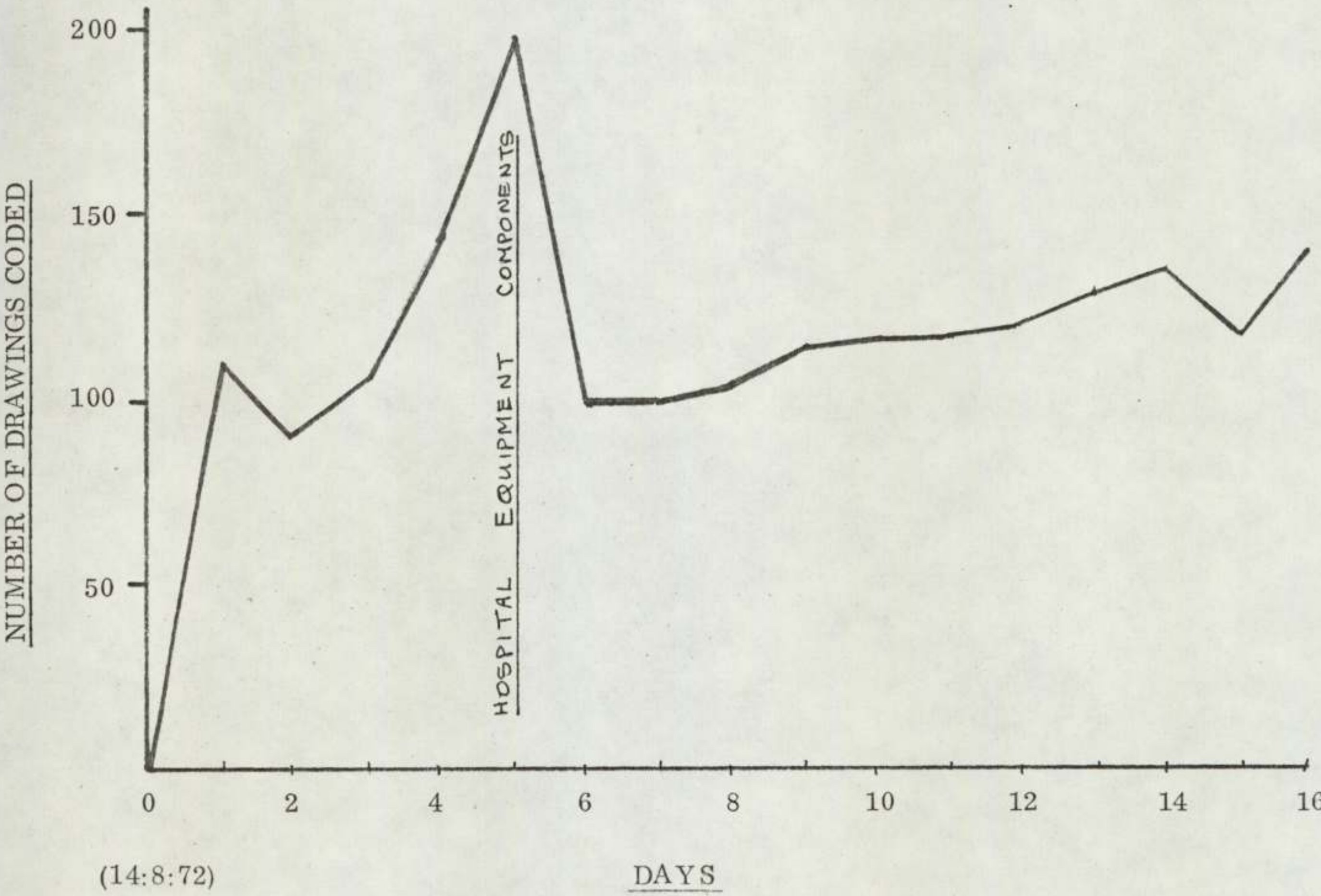
FIG 18 SUPPLEMENTARY CODE

FIGURE : 19 TYPICAL LEARNING CURVE FOR OPITZ CLASSIFICATION



(After MacConnell)

FIGURE : 20 PROGRESS WITH CODING AT GEORGE ELLISONS LIMITED



(14:8:72)

ADDITIONAL CODE INFORMATION

PRODUCT TYPE	CODE
Switchgear Equipment made in	1
Bought out	2
Hospital Equipment made in	3
Bought out	4
Tufnol	5

CODE SHEET COLUMN 68 ↑

FIG : 21

FORMING SUPPLEMENTARY CODE

USED WITH SHEET METAL CLASSIFICATION

JOINTING PROCESS	CODE
None	0
Spot Weld	1
Projection Weld	2
Gas Weld	3
Braze	4
Arc Weld	5
CO_2 Weld	6
Induction Weld	7
Rivet	8
Combinations	9

FIG : 22

CODE - 12000 NOT 13000

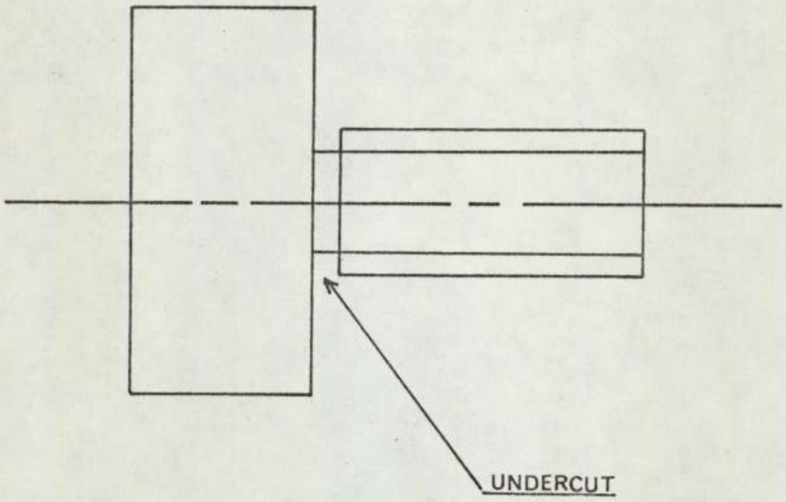


FIG 23

PPACTICAL INTERPRETATION OF THE OPITZ CODE

(AFTER HAWORTH)

CONVENTIONS FOR THIN SECTIONS

PLATE

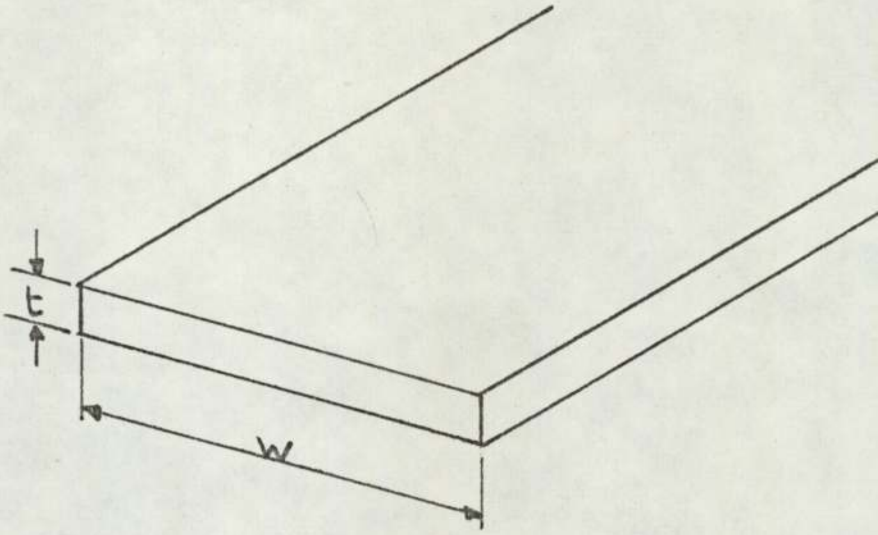
$t \geq \frac{1}{4}$ in

$W > 10t$

SHEET

$t < \frac{1}{4}$ in

$W > 10t$



BAR

$t > \frac{1}{4}$ in

$W \leq 10t$

STRIP

$t \leq \frac{1}{4}$ in

$W \leq 10t$

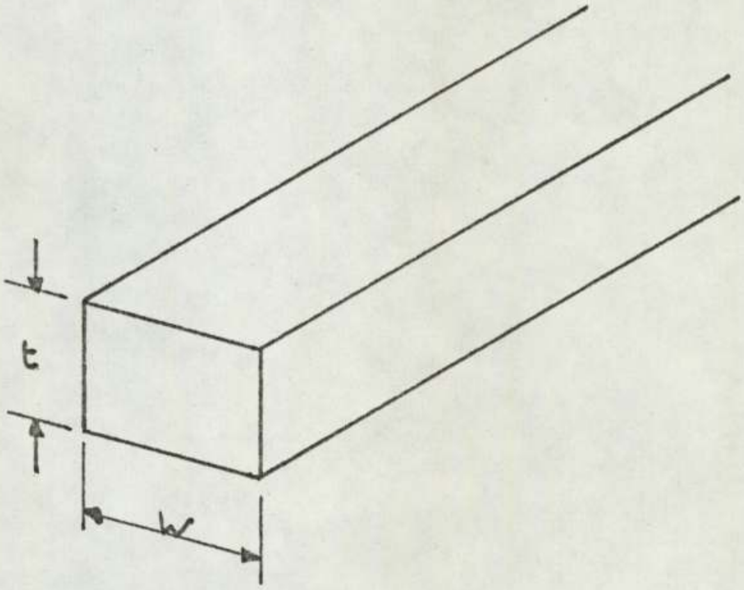
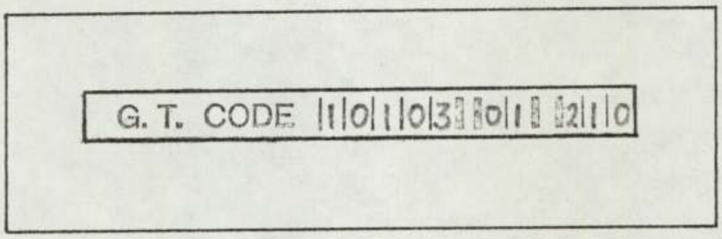


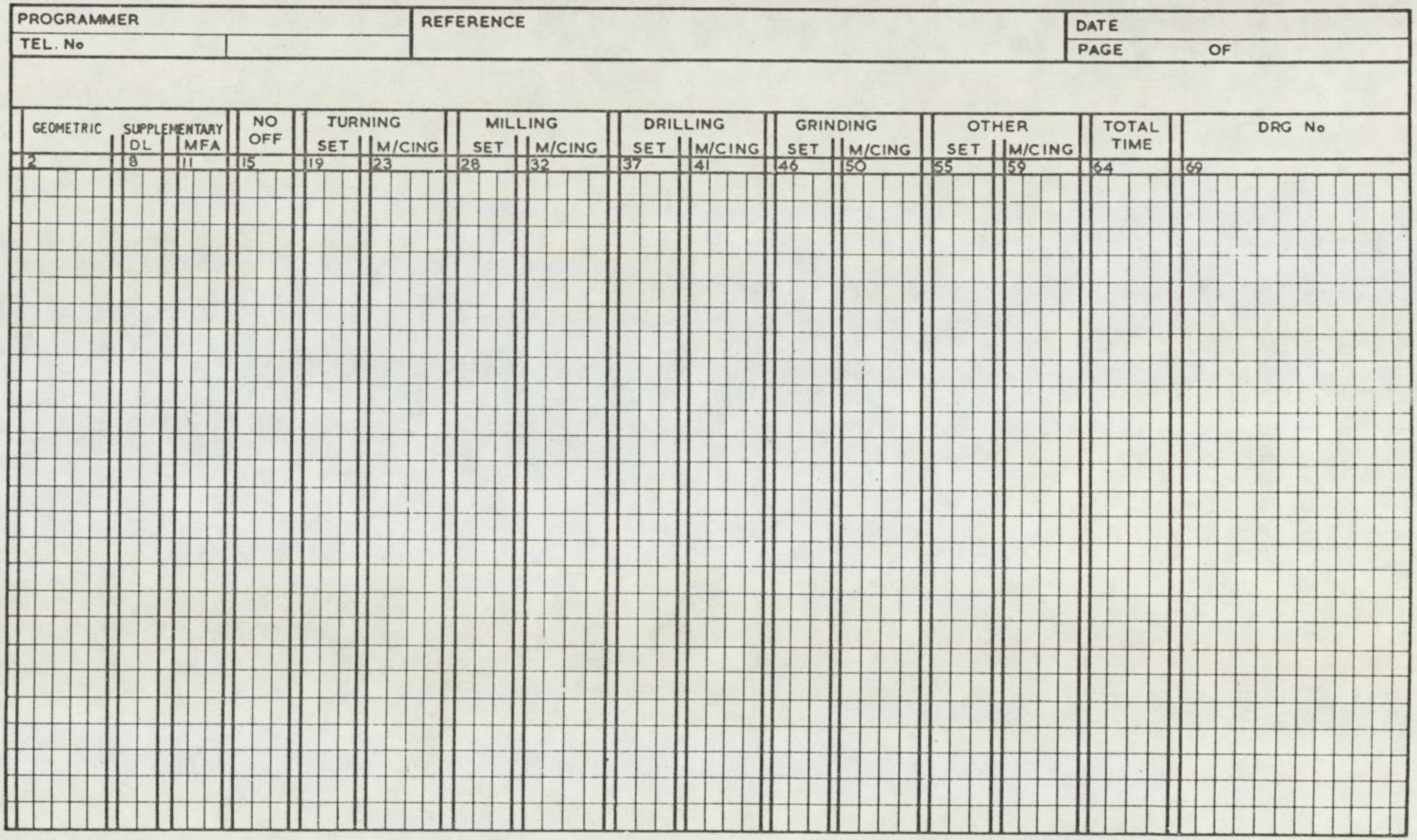
FIG 24

FIG 25



STAMP USED IN

CODING EXERCISE



PROGRAMMER
TEL. No
REFERENCE
DATE
PAGE OF

GEOMETRIC	SUPPLEMENTARY		NO OFF	TURNING		MILLING		DRILLING		GRINDING		OTHER		TOTAL TIME	DRG No
	DL	MFA		SET	M/CING	SET	M/CING	SET	M/CING	SET	M/CING	SET	M/CING		
2	8	11	15	19	23	28	32	37	41	46	50	55	59	64	69

FIGURE 26. CODING FORM FOR COMPONENT ANALYSIS

A.W.R.E. Fortran Coding Form

Programmer J.D.D. Bldg. Ext.
Program ROTATIONAL COMPONENTS
Date Page of
Remarks EXAMPLE OF DATA PRESENTATION

Statem't Nº | Serial Nº

```
 10001 00 210                                                      1  20725    51
 10003 00 210                                                      1   9200    51
 10100 01 210                                                      1 308891    51
 10201 01 710                                                      1 308751    51
 00103 10 810                                                      3 220520    51
 11100 11 211                                                      1 307704    51
```

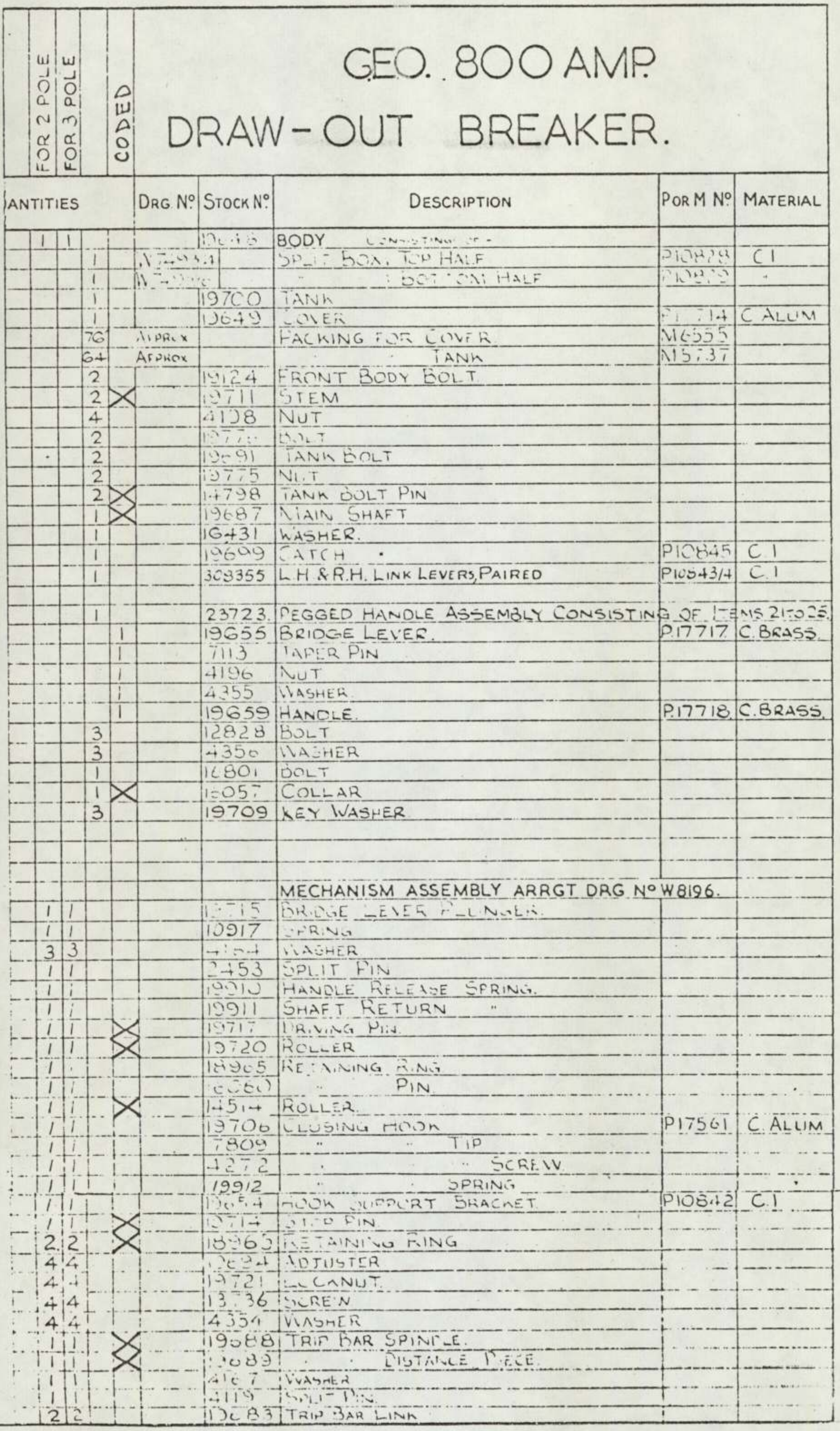
Opitz Code

Component Identity

Stock Number

Code Sheet Reference

FIG 27 EXAMPLE OF DATA PRESENTATION FOR CODED ROTATIONAL COMPONENTS



GEO. 800 AMP.

DRAW-OUT BREAKER.

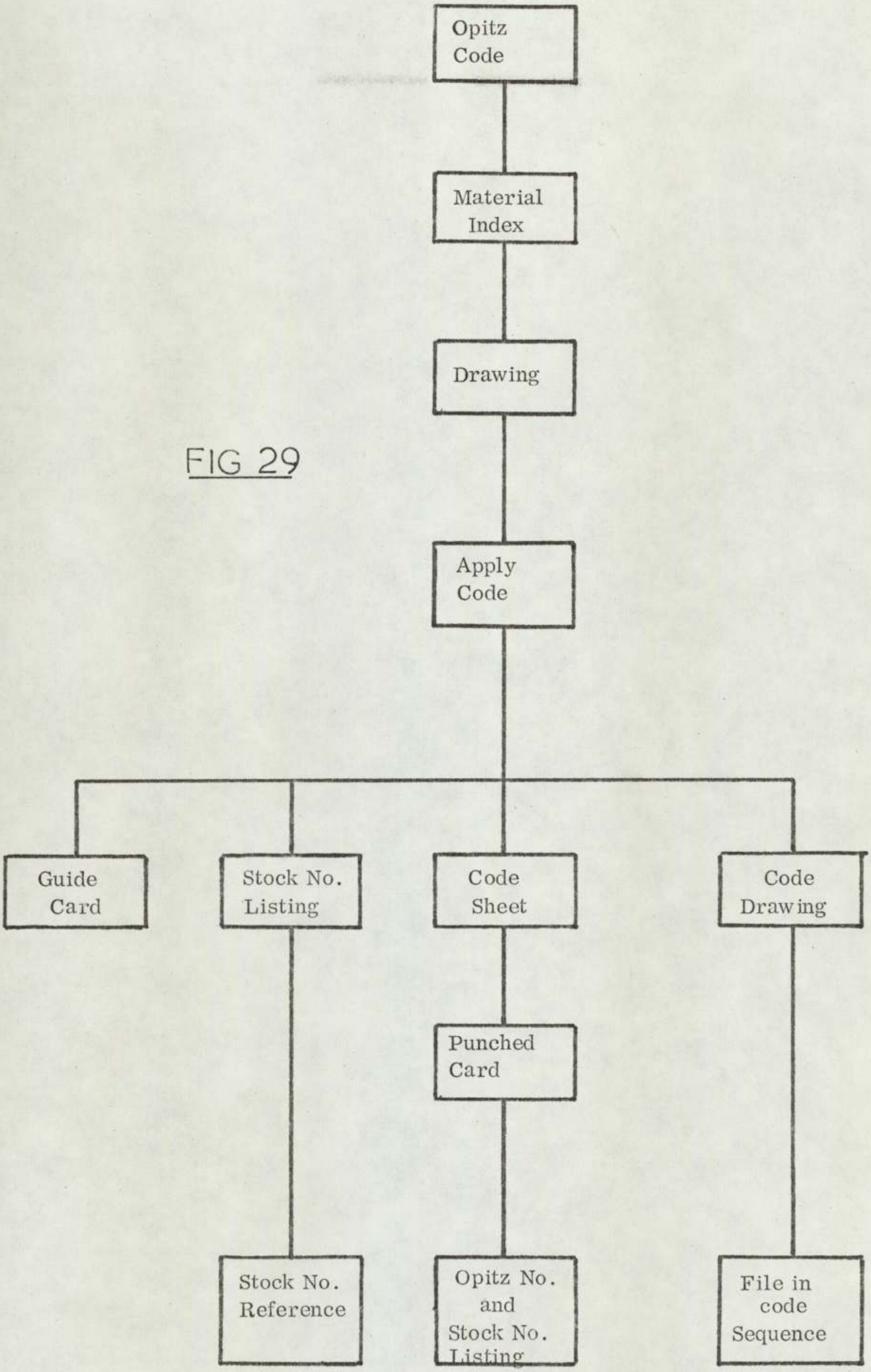
ANTITIES	FOR 2 POLE	FOR 3 POLE		CODED	DRG. Nº	STOCK Nº	DESCRIPTION	P OR M Nº	MATERIAL
	1	1				19646	BODY CONSISTING OF -		
			1		N7493/4		SPLIT BOX, TOP HALF	P10828	C.I
			1		[illegible]		" " BOTTOM HALF	P10829	"
			1			19700	TANK		
			1			19649	COVER	P17714	C. ALUM
			76		APPROX		PACKING FOR COVER	M6555	
			64		APPROX		" " TANK	M5737	
			2			19124	FRONT BODY BOLT		
			2	X		19711	STEM		
			4			4108	NUT		
			2			[illegible]	BOLT		
			2			19691	TANK BOLT		
			2			19775	NUT		
			2	X		14798	TANK BOLT PIN		
			1	X		19687	MAIN SHAFT		
			1			16431	WASHER.		
			1			19699	CATCH	P10845	C.I
			1			308355	L.H & R.H. LINK LEVERS, PAIRED	P10843/4	C.I
			1			23723.	PEGGED HANDLE ASSEMBLY CONSISTING OF ITEMS 21 TO 25.		
				1		19655	BRIDGE LEVER.	P.17717	C. BRASS.
				1		7113	TAPER PIN		
				1		4196	NUT		
				1		4355	WASHER.		
				1		19659	HANDLE.	P.17718.	C. BRASS.
			3			12828	BOLT		
			3			4356	WASHER		
			1			16801	BOLT		
			1	X		16057	COLLAR		
			3			19709	KEY WASHER		
							MECHANISM ASSEMBLY ARRGT DRG Nº W8196.		
	1	1				19715	BRIDGE LEVER PLUNGER.		
	1	1				10917	SPRING		
	3	3				4154	WASHER		
	1	1				2453	SPLIT PIN		
	1	1				19910	HANDLE RELEASE SPRING.		
	1	1				19911	SHAFT RETURN "		
	1	1		X		19717	DRIVING PIN.		
	1	1		X		19720	ROLLER		
	1					18965	RETAINING RING		
	1	1				16060	" PIN.		
	1	1		X		14514	ROLLER.		
	1	1				19706	CLOSING HOOK	P17561	C. ALUM
	1	1				7809	" " TIP		
	1	1				4272	" " SCREW.		
	1	1				19912	" " SPRING		
	1	1				19654	HOOK SUPPORT BRACKET.	P10842	C.I
	1	1		X		19714	STOP PIN.		
	2	2		X		18963	RETAINING RING		
	4	4				19684	ADJUSTER		
	4	4				19721	LOCANUT.		
	4	4				13736	SCREW		
	4	4				4354	WASHER		
	1	1		X		19588	TRIP BAR SPINDLE.		
	1	1		X		19589	" " DISTANCE PIECE.		
	1	1				4167	WASHER		
	1	1				4119	SPLIT PIN.		
	2	2				19683	TRIP BAR LINK		

EXAMPLE OF ROTATIONAL COMPONENT IDENTIFICATION
FROM A MATERIAL SHEET

FIGURE 28

IGURE : 29 SEQUENCE OF DATA REVIEWAL IN CODING EXERCISE

FIG 29



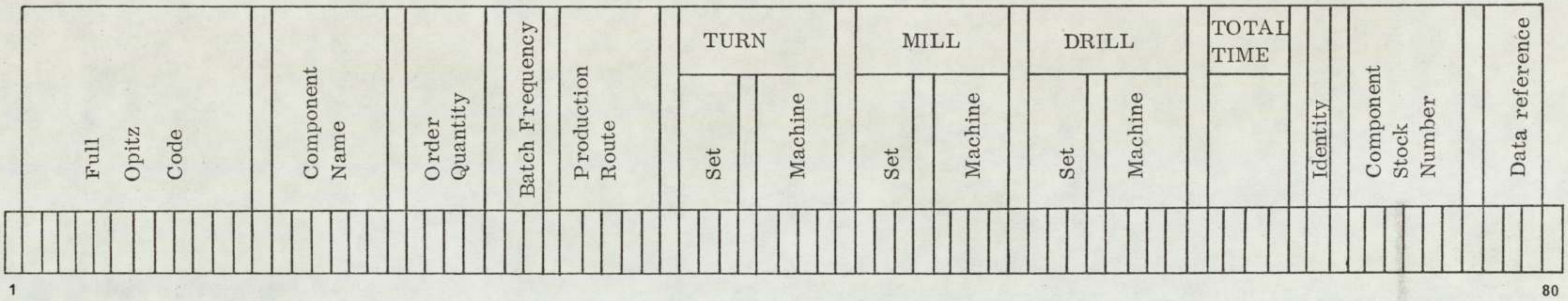
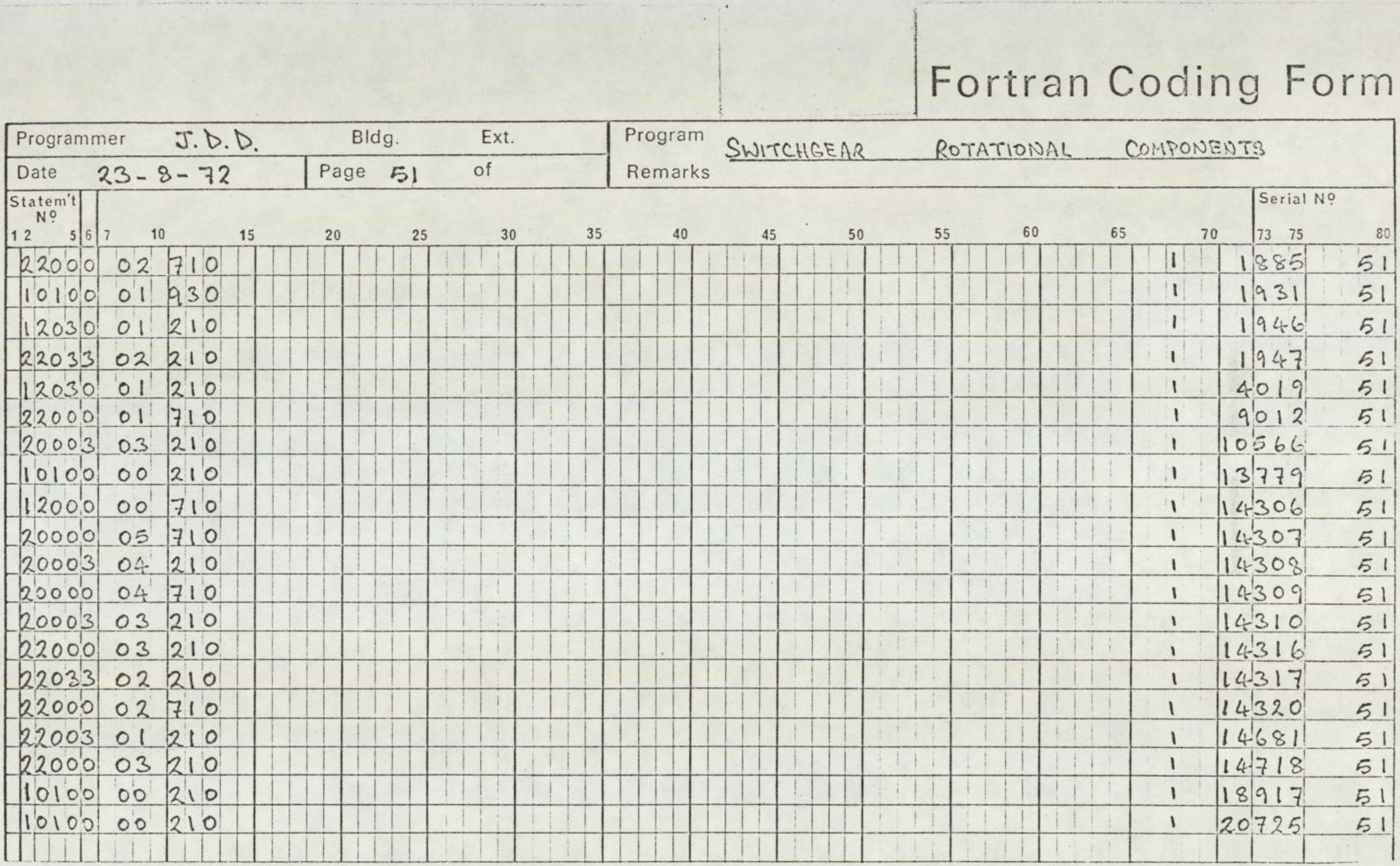


Figure 30

FUTURE EXTENSION IN THE USE OF OPITZ CODE DATA TO INCLUDE PARTICULAR OPERATION TIMES FOR MACHINED COMPONENTS



Fortran Coding Form

Programmer J.D.D. Bldg. Ext.

Date 23-8-72 Page 51 of

Program SWITCHGEAR ROTATIONAL COMPONENTS

Remarks

Statem't Nº	7–8	10–12		Serial Nº	
22000	02	710	1	1885	51
10100	01	930	1	1931	51
12030	01	210	1	1946	51
22033	02	210	1	1947	51
12030	01	210	1	4019	51
22000	01	710	1	9012	51
20003	03	210	1	10566	51
10100	00	210	1	13779	51
12000	00	710	1	14306	51
20000	05	710	1	14307	51
20003	04	210	1	14308	51
20000	04	710	1	14309	51
20003	03	210	1	14310	51
22000	03	210	1	14316	51
22033	02	210	1	14317	51
22000	02	710	1	14320	51
22003	01	210	1	14681	51
22000	03	210	1	14718	51
10100	00	210	1	18917	51
10100	00	210	1	20725	51

FIGURE 31 EXAMPLE OF CODE DATA PRESENTATION FOR SWITCHGEAR COMPONENTS

Fortran Coding Form

Programmer J.D.D. Bldg. Ext.

Date Page 41 of

Program

Remarks HOSPITAL EQUIPMENT ROTATIONAL COMPONENTS

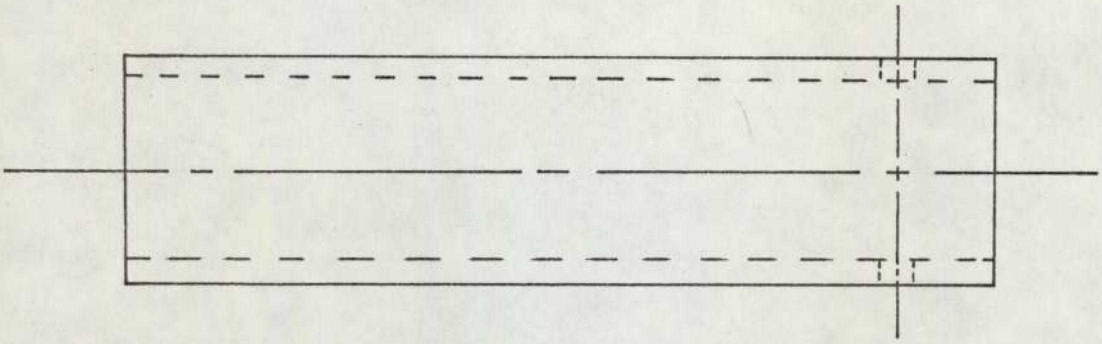
FIG 32

Statem't Nº 1 2 5	7	10	70	Serial Nº 73 75	80
20103	17	230	3 220	602	41
11033	11	816	3 220	603	41
10100	01	910	4 220	604	41
20103	17	230	3 220	605	41
10203	12	210	3 220	606	41
21103	17	280	3 220	607	41
20103	17	230	4 220	608	41
10100	00	210	3 220	609	41
25000	06	280	4 220	610	41
20103	17	230	3 220	611	41
20103	17	230	3 220	613	41
20103	16	230	3 220	617	41
11100	11	812	3 220	618	41
11000	11	810	3 220	619	41
20000	01	210	3 220	620	41
20000	01	210	3 220	621	41
20110	17	230	4 220	658	41
20110	02	230	4 220	662	41
22003	05	211	3 220	664	41
22003	05	211	3 220	665	41

FIGURE 32 EXAMPLE OF LOW CODE COMPLEXITY WITH HOSPITAL EQUIPMENT ROTATIONAL COMPONENTS.

CODE CONVENTIONS FOR TUBES

FIG 33

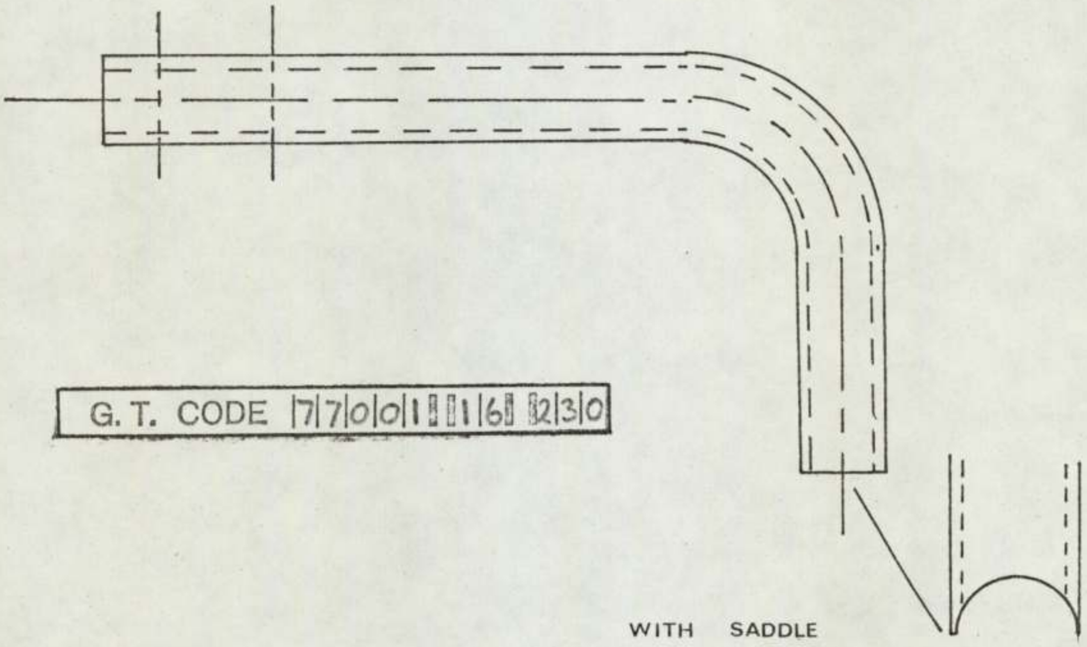


G. T. CODE 20103 14 230

↑ TUBE

FOPMED TUBE

FIG 34



G. T. CODE 77001 16 230

WITH SADDLE

MILLING GT CODE 77071

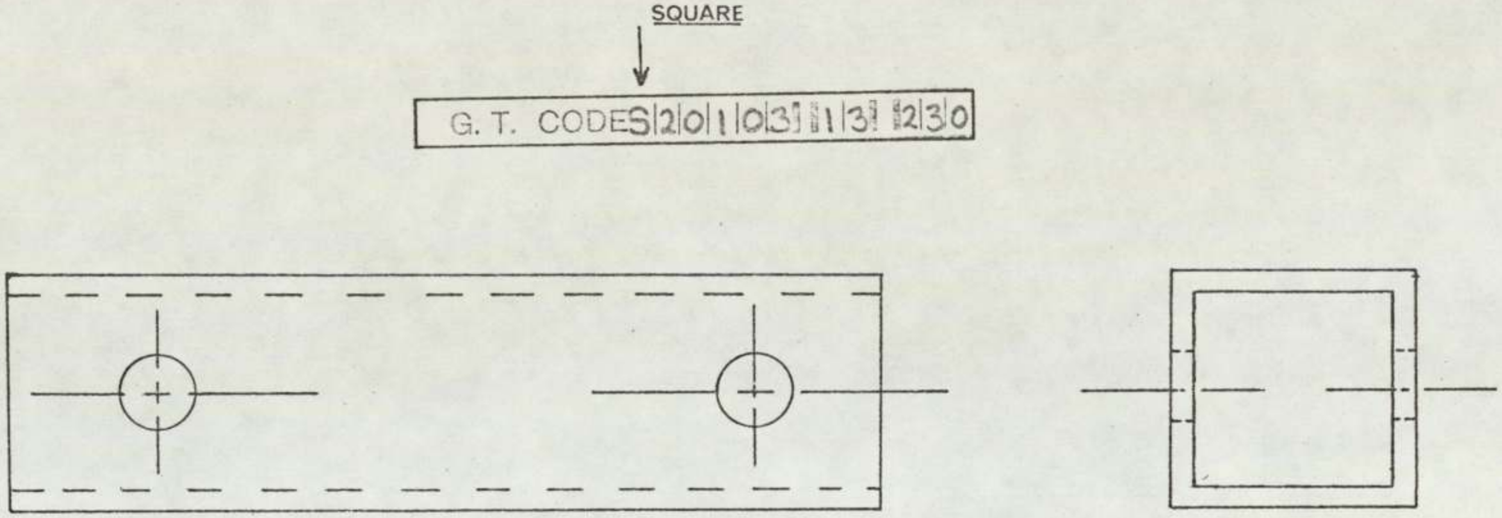


FIG 35

PARTICULAR CODING CONVENTIONS

FOR SQUARE TUBE

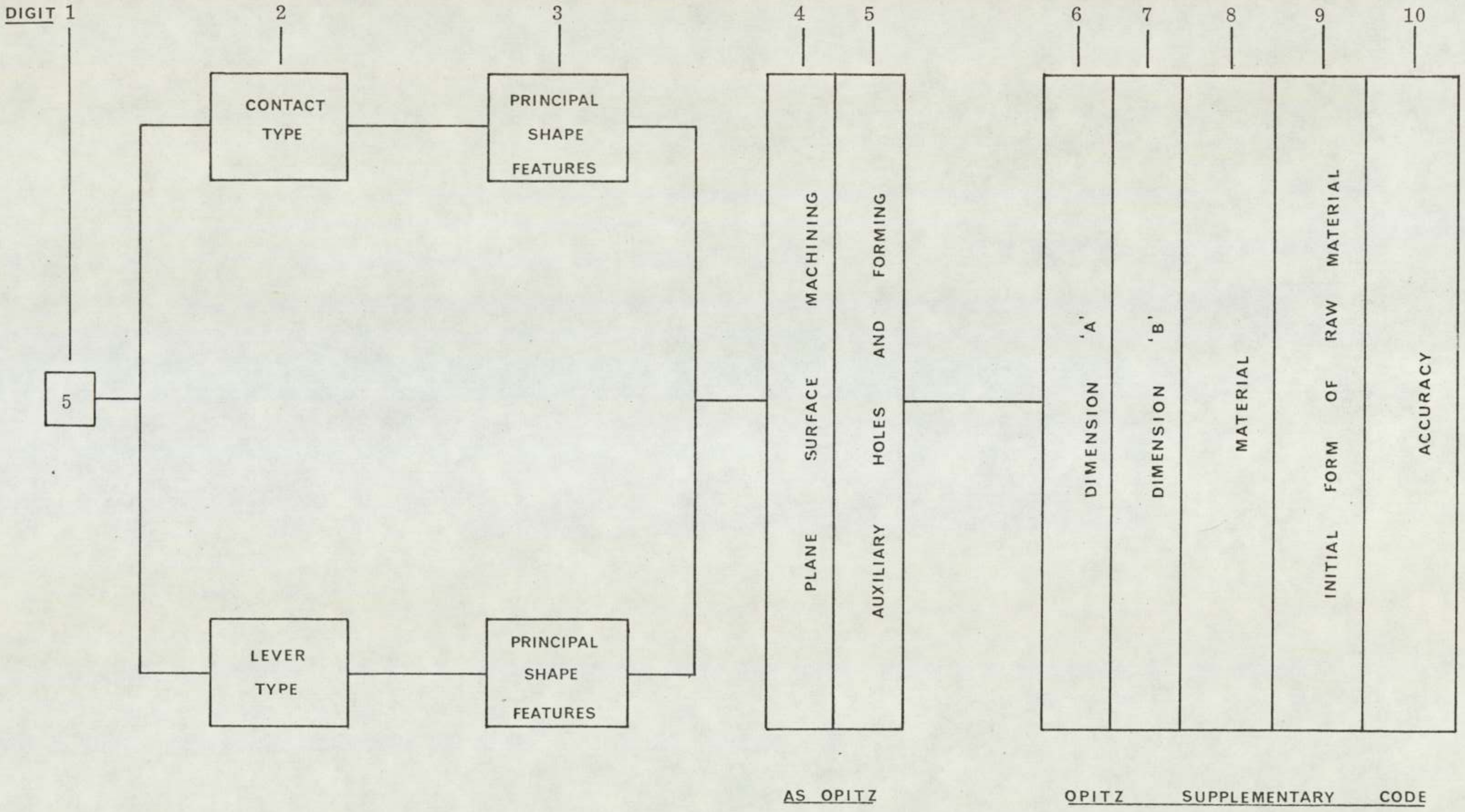


FIG 36 CLASSIFICATION STRUCTURE FOR CONTACT AND LEVER CODES

SECTION METAL

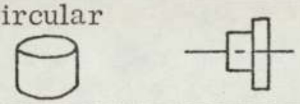
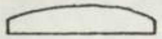
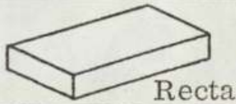
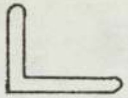
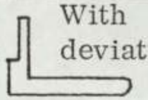
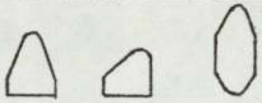
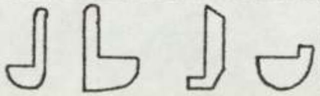
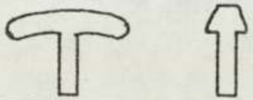
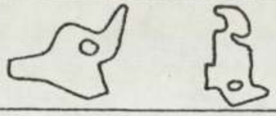
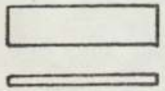
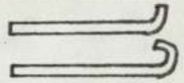
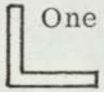
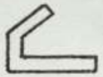
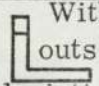
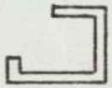
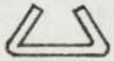
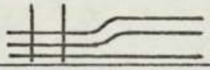
igit	1	Contact Index	2	Contact Type	3	Main Shape	4	Plane Surface Machining	5			Auxiliary Holes & Forming
		5	0	Section Metal	0	Circular 	0	No Surface Machining	0			No Auxiliary Holes or Forming
				[redacted]	1	Arc Tips 	1	Functional Chamfers (e.g. Brazing preparation)	1	NO FORMING		Holes drilled in one direction only
					2	 Rectangular	2	One Plane Surface	2			Holes drilled in more than one direction
					3		3	Stepped Plane Surfaces	3		Drilling pattern	Holes drilled in one direction only
					4	 With deviations	4	Stepped plane surfaces inclined and/or opposite	4			Holes drilled in more than one direction
					5		5	Groove and/or slot	5	With Forming		Forming no Auxiliary holes
					6		6	Groove and/or slot and 4	6			Forming with Auxiliary holes
					7		7	Curved surface	7			
					8		8	Guide Surfaces	8			
					9	Others 	9	Others	9			Others

FIG 37

CLASSIFICATION CODE FOR CONTACTS & CONTACT - LIKE COMPONENTS

2		3		4	Plane Surface Machining	5	Auxiliary Holes & Forming	
		0	 Circular Disc-type	0	No Surface Machining	0	No Auxiliary Holes or Forming	
1	Formed	1	 Flat Strip	1	Functional Chamfers (e.g. Brazing preparation)	1	NO FORMING	Holes drilled in one direction only
[redacted]	[redacted]	2	 Bent along 1 axis	2	One Plane Surface	2		Holes drilled in more than one direction
[redacted]	[redacted]	3	 Curved & segmented arcs	3	Stepped Plane Surfaces	3	Drilling pattern	Holes drilled in one direction only
[redacted]	[redacted]	4	 One bend or 	4	Stepped plane surfaces inclined and/or opposite	4		Holes drilled in more than one direction
		5	  With cut-outs and other deviations	5	Groove and/or slot	5	With Forming	Forming no Auxiliary holes
		6	 More than 1 bend 	6	Groove and/or slot and 4	6		Forming with Auxiliary holes
		7	Laminated connections 	7	Curved surface	7		
		8	Braids & Flexes	8	Guide Surfaces	8		
		9	Others	9	Others	9	Others	

2	Contact Type	3	Main Shape	4	Plane Surface Machining	5	Auxiliary Holes & Forming		
		0	Round Shank	0	No Surface Machining	0	No Auxiliary Holes or Forming		
2	Cast or Forged	1	Rectangular Shank	1	Functional Chamfers (e.g. Brazing preparation)	1	NO FORMING		Holes drilled in one direction only
2	CAST OR FORGED	2	Other cast or forged sections	2	One Plane Surface	2			Holes drilled in more than one direction
		3	Formed + Section Metal and/or Tips	3	Stepped Plane Surfaces	3		Drilling pattern	Holes drilled in one direction only
3	Brazed Assemblies	4	Cast and/or Forged + Section Metal Tips	4	Stepped plane surfaces inclined and/or opposite	4			Holes drilled in more than one directio
		5	Cast and/or Forged + Formed sections	5	Groove and/or slot	5	With Forming		Forming no Auxiliary holes
		6	Cast/Forged + Formed Sections + Tips	6	Groove and/or slot and 4	6			Forming with Auxiliary holes
		7	Section + Section with/without Tips	7	Curved surface	7			
		8	Formed + Formed with riveting	8	Guide Surfaces	8			
		9	Others	9	Others	9	Others		

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 TUFNOL

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 37 SUPPLEMENTARY CODE

FIG 38

```
20103 18 230
20103 18 230
20105 14 230
20105 17 230
20105 18 230
20110 00 230
20110 02 230
20110 02 230
20110 02 230
20110 03 230
20110 03 230
20110 03 230
20110 05 230
20110 05 230
20110 05 230
20110 05 230
20110 06 230
20110 06 230
20113 06 230
20113 06 230
20113 14 230
20113 17 230
```

```
3 220699    42
3 220704    42
3 220421   180
3 220280    36
3 220273    36
3 220469    39
3 205472    26
3 220662    41
3 220700    42
3 205598    31
3 220294    37
3 220798    43
3 205533    29
3 220315    37
3 220496    40
3 220801    43
3 205324    28
3 220881    43
3 220390    38
3 220799    43
3 220533    46
3 220413    46
```

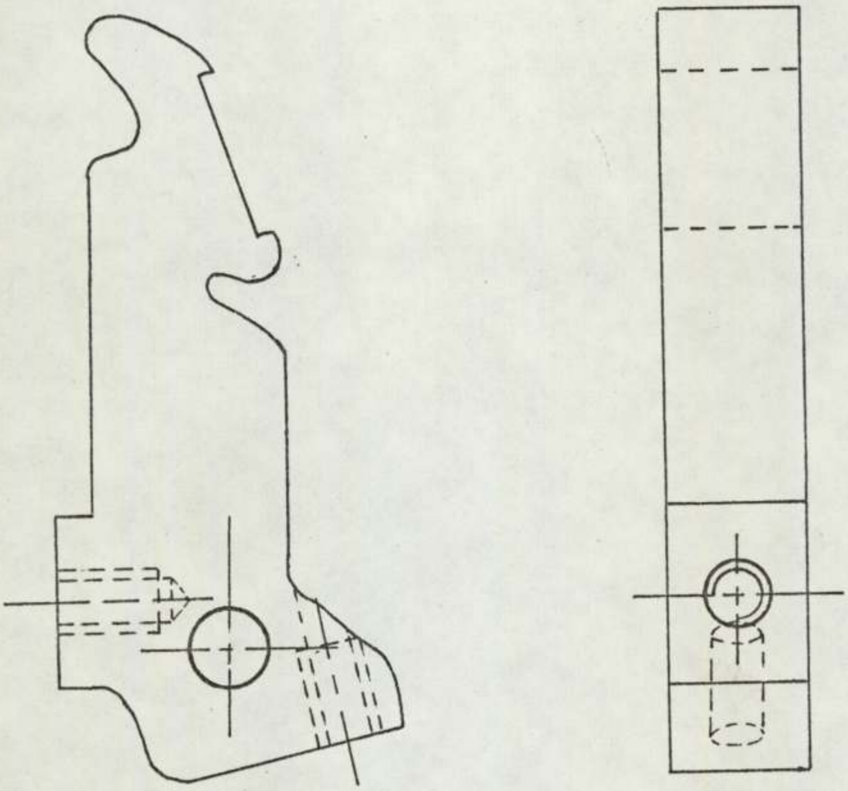
SAMPLE CODE LISTING FOR TUBES

```
50261 31 720
50261 32 720
50274 31 720
50301 21 720
50301 21 720
50301 21 720
50301 21 720
50341 22 720
50442 22 720
50442 22 720
50501 00 720
50501 00 720
50501 00 720
50501 10 720
50501 10 720
50501 10 720
50501 11 720
50501 11 720
50501 41 720
50501 41 720
50502 21 720
50502 21 720
50502 21 720
50502 31 720
```

```
1 332798    56
1 336432    56
1 020977    54
1 021920    54
1 021921    54
1 021923    54
1 310961    56
1 305654    56
1 021940    54
1 021941    54
1 000608   128
1 000609   128
1 000693    59
1 014337   128
1 000700    59
1 306704    56
1 019387    54
1 015620    53
1 012456    55
1 013813    55
1 019677   128
1 019678   128
1 306703    56
1 019679    54
```

SAMPLE CODE LISTING FOR CONTACTS

FIG 39



MOVING CONTACT— CODE 50852

MILLED SLOT

HOLES DRILLED IN MORE THAN
ONE DIRECTION

PRODUCTION FEATURE INTERPRETATION

WITH THE CONTACT CODE

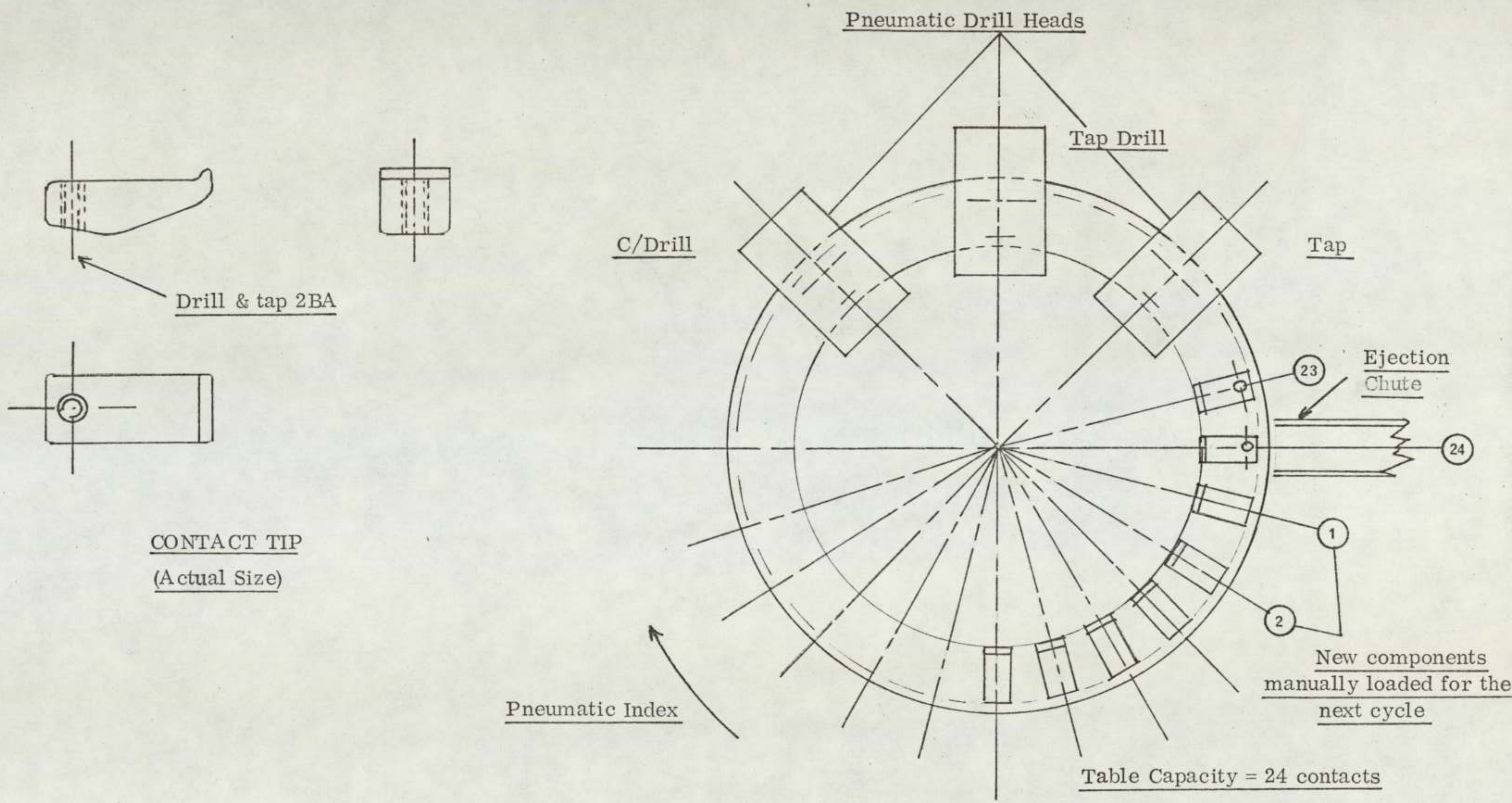
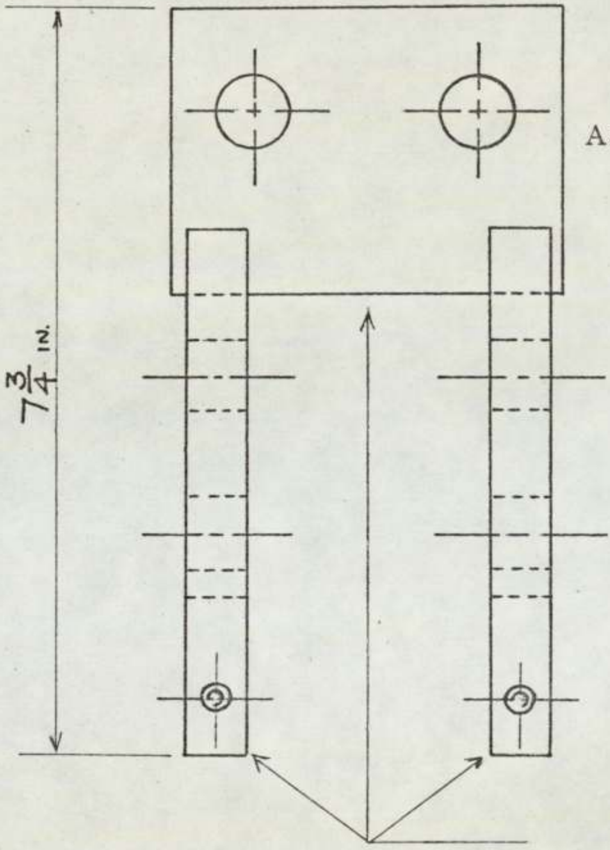


FIG 40

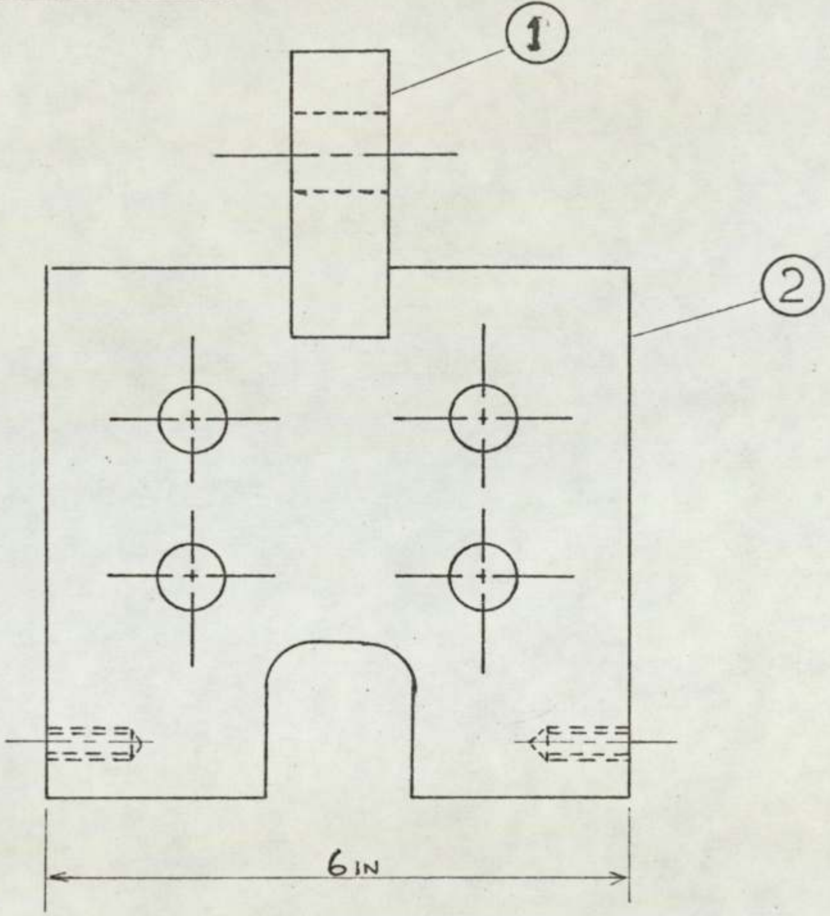
SPECIAL CONTACT DRILL WITH PNEUMATIC ROTARY INDEXING TABLE

ISOLATING JAW CARRIER FOR 3000 AMP AIR BREAKER



Code (1)	50253
Code (2)	50254
Assembly Code	53752

Brazed assembly of 3 rectangular plates



TYPICAL ASSEMBLY OF CONTACT-TYPE COMPONENT

Figure 41

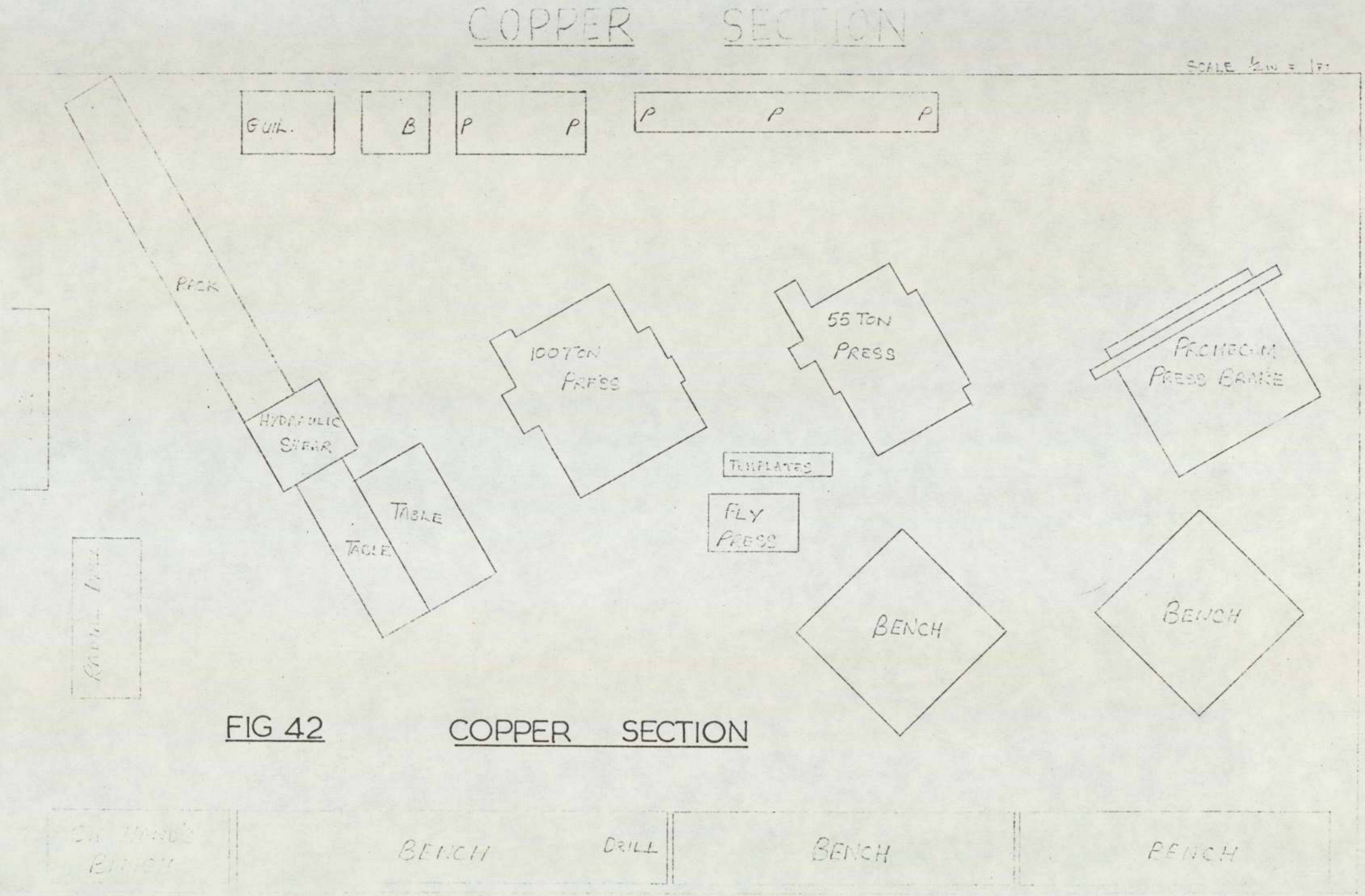
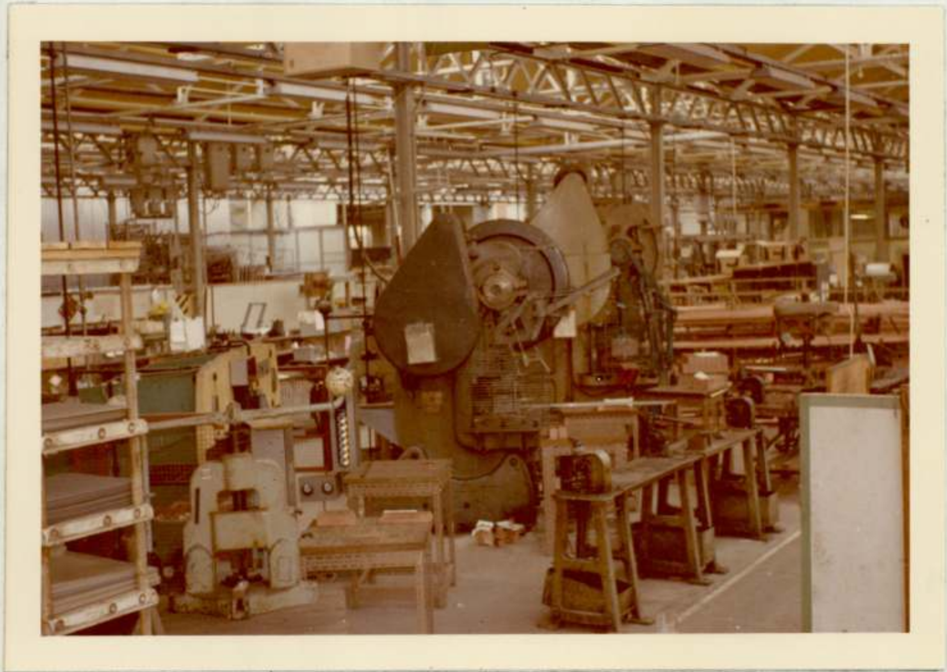


FIG 42 COPPER SECTION

FIG 43



VIEW OF COPPER CELL SHOWING

FLY – PRESS , HYDRAULIC SHEAR

AND 100 TON PRESS

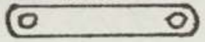
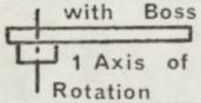
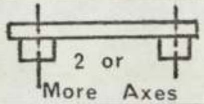
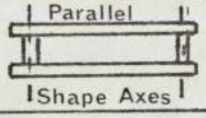
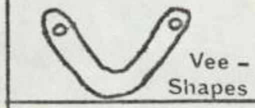
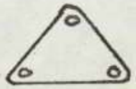
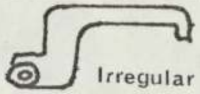
1	CODE INDEX	2	LEVER TYPES	3	MAIN SHAPE		4	Plane Surface Machining	5	Auxiliary Holes & Forming		
	5	0	FOR THE CONTACT CODE	0	STRAIGHT SHAPE AXIS	Plate  RECTANGULAR	0	No Surface Machining	0			No Auxiliary Holes or Forming
		1	—\\—	1		 with Boss 1 Axis of Rotation	1	Functional Chamfers (e.g. Brazing preparation)	1	NO FORMING		Holes drilled in one direction only
		2	—\\—	2		 2 or More Axes	2	One Plane Surface	2			Holes drilled in more than one direction
	LEVER CODE SHARES COMMON STRUCTURE WITH CONTACT CODE	3	—\\—	3		 Parallel Shape Axes	3	Stepped Plane Surfaces	3		Drilling pattern	Holes drilled in one direction only
		4	FABRICATED LEVERS	4		Others with a Straight Shape Axis	4	Stepped plane surfaces inclined and/or opposite	4			Holes drilled in more than one direction
		[redacted]	[redacted]	5	FORMED SHAPE AXIS	 Plate	5	Groove and/or slot	5	With Forming		Forming no Auxiliary holes
		6	FUTURE DEVELOPMENT	6		 Vee - Shapes	6	Groove and/or slot and 4	6			Forming with Auxiliary holes
		7	—\\—	7			7	Curved surface	7			
		8	—\\—	8		 Irregular	8	Guide Surfaces	8			
		9	—\\—	9		OTHERS	9	Others	9			Others

FIG 44

THE LEVER CODE

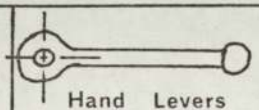
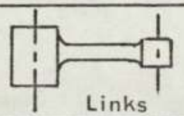
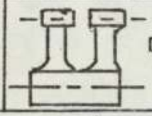
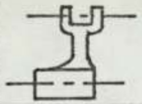
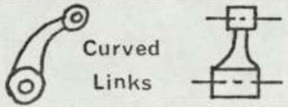
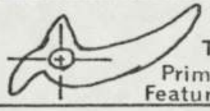
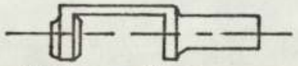
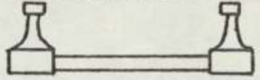
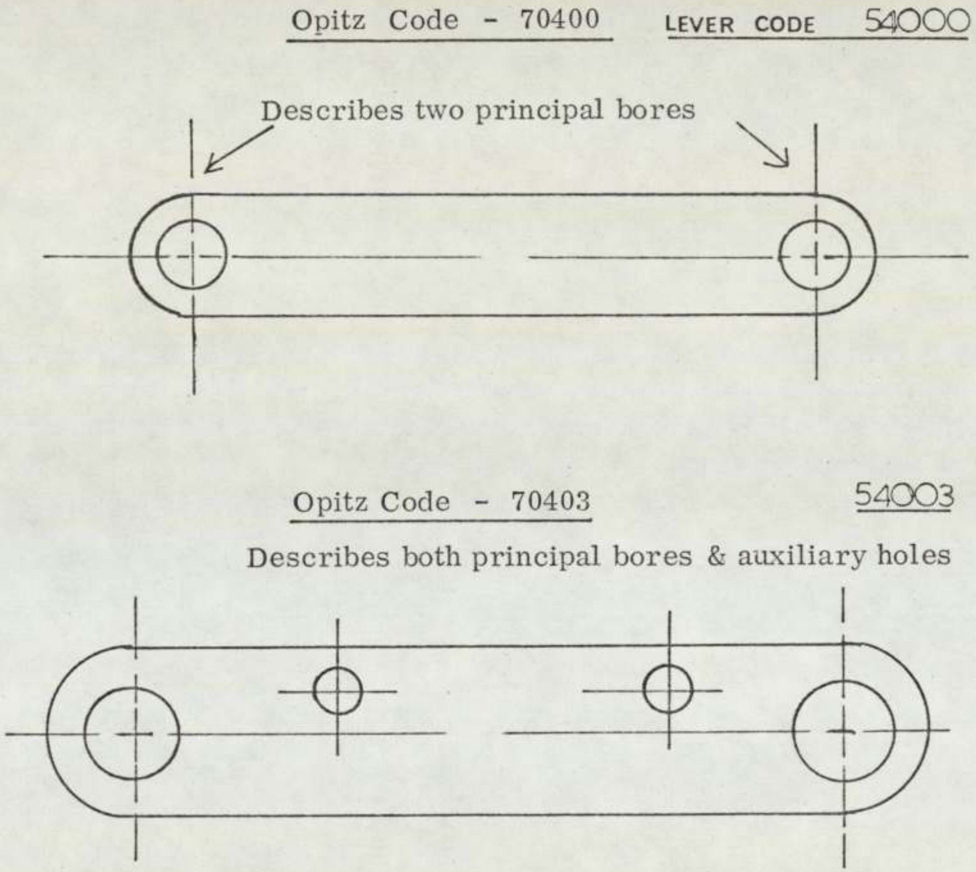
	LEVER TYPES			MAIN SHAPE	4	Plane Surface Machining	5			Auxiliary Holes & Forming
		0	AXIS	 Hand Levers	0	No Surface Machining	0			No Auxiliary Holes or Forming
		1	STRAIGHT	 Links	1	Functional Chamfers (e.g. Brazing preparation)	1	NO FORMING		Holes drilled in one direction only
		2	WITH	 Double Links	2	One Plane Surface	2			Holes drilled in more than one direction
		3		 Spyder Types	3	Stepped Plane Surfaces	3		Drilling pattern	Holes drilled in one direction only
		4		 Lever Arms with Forks	4	Stepped plane surfaces inclined and/or opposite	4			Holes drilled in more than one direction
5	CAST & FORGED TYPES	5		 Curved Links	5	Groove and/or slot	5	With Forming		Forming no Auxiliary holes
		6		 Cam Type Primary Features	6	Groove and/or slot and 4	6			Forming with Auxiliary holes
		7		 Bridge Types	7	Curved surface	7			
		8		 Lever Assemblies	8	Guide Surfaces	8			
		9		OTHERS	9	Others	9			Others

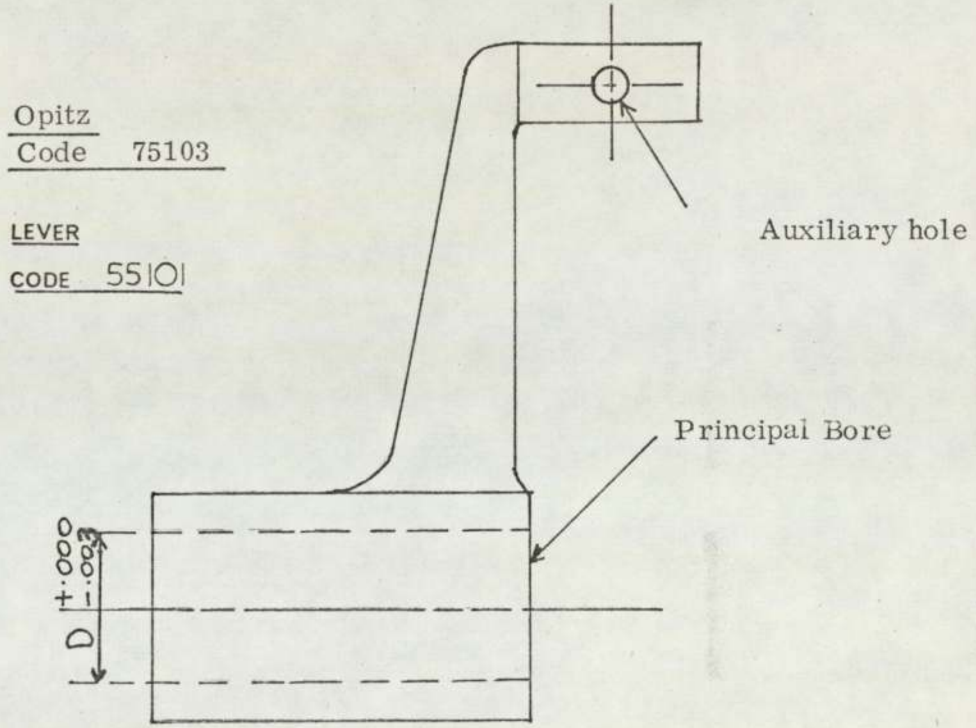
FIG 44

THE LEVER CODE



Such link-type components can present difficulties in strict code feature interpretation when hole features are produced by similar methods and have equal importance.

FIG 45



Such level-type components comprise both secondary holes and obvious principal bores.

The large variety of such levers led to the design of a special code.

FIG 46

LEVER TYPES

TYPICAL EXAMPLES OF PRIMARY AND SECONDARY HOLE FEATURES

DIGIT

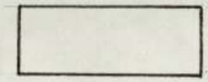
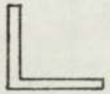
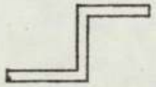
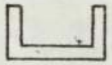
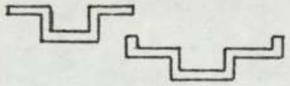
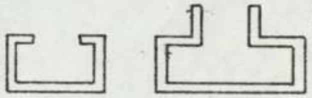
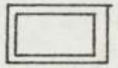
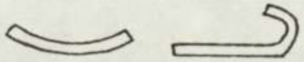
1	COMPONENT CLASS			2	FORMED CROSS SECTION 'A'	3	SECTION 'B'	4	MAIN SHAPE	5	DEVIATIONS FROM MAIN SHAPE		6	ANCILLIARY FEATURES
0	FLAT		SYMMETRY A and B AXES	0		0	CLASSIFICATION AS FOR CROSS SECTION 'A'	0	SQUARE	0	NONE		0	NONE
1			SYMMETRY ONE AXIS ONLY	1		1		1	RECTANGULAR	1	CORNER	RECTANGULAR AND/OR ANGULAR	1	HOLES WITH OR WITHOUT CONNECTING GEOMETRY
2			NO SYMMETRY	2		2		2	ANGULAR	2		ROUND	2	SLOTS
3	THREE DIMENSIONAL COMPONENTS BENDING/FORMING PARALLEL TO EDGES	SYMMETRY IN DEVELOPMENT	SYMMETRY IN BENDING	3		3		3	WEDGE SHAPED	3	CUT-OUTS	RECTANGULAR	3	HOLES AND SLOTS
4			NO SYMMETRY IN BENDING	4		4		4	TRIANGULAR	4		ANGULAR	4	LUGS
5		NO SYMMETRY IN DEVELOPMENT	SYMMETRY IN BENDING	5		5		5	TRUSS OR ROOF SHAPED	5		ROUND	5	LOUVRES
6			NO SYMMETRY IN BENDING	6		6		6	TRAPEZOIDAL	6		RECTANGULAR AND/OR ANGULAR AND/OR ROUND	6	FORMED OR ROLLED GROOVES
7	OTHER THREE DIMENSIONAL COMPONENTS			7		7		7	WITH CIRCULAR PORTION	7	INTERNAL CUT-OUTS	RECTANGULAR AND/OR ANGULAR	7	3 and 4 or 5
8	CIRCULAR OR SEGMENT OF A CIRCLE			8		8		8	IRREGULAR SHAPE WITH MULTIPLE CUT-OUTS	8		ROUND	8	3 and 6
9	SECTIONS			9		9		9	OTHERS	9	OTHERS		9	OTHERS

FIGURE 47 THE SHEETMETAL CLASSIFICATION CODE

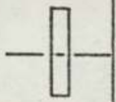
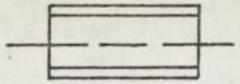
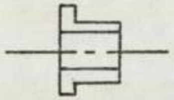
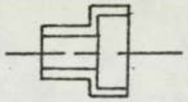
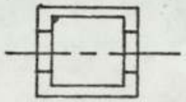
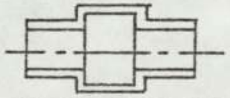
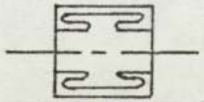
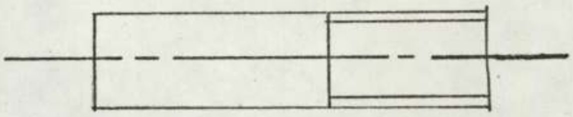
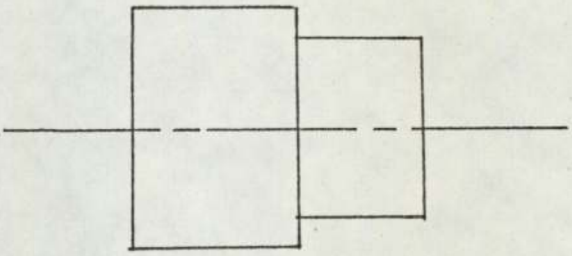
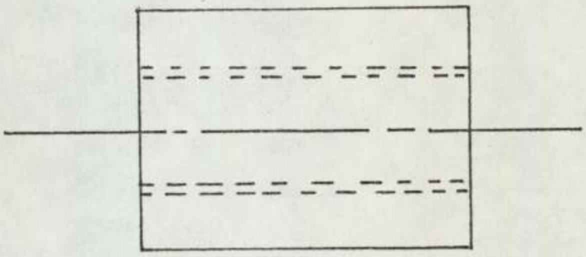
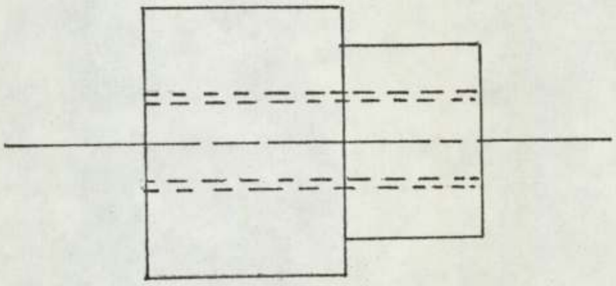
COMPONENT CLASS		FORMED CROSS SECTION				MAIN SHAPE			DEVIATIONS FROM MAIN SHAPE		ANCILLIARY FEATURES	
		'A'			'B'							
		0	UNIFORM CROSS SECTION		0	0	CIRCULAR $\frac{L}{D} \leq 1$	PLAIN DISC	0	NONE	0	NONE
		1			1	1		FORMED CROSS SECTION	1	RECTANGULAR	1	HOLES (WITH OR WITHOUT CONNECTING GEOMETRY)
		2			2	2		OTHERS	2	ANGULAR	2	SLOTS
		3			3	3	TUBULAR $\frac{L}{D} > 1$	PLAIN TUBE	3	ROUND	3	HOLES AND SLOTS
		4			4	4		CONICAL	4	1 and/or 2 and/or 3	4	LUGS
		5			5	5		WITH CURVED AXIS	5	RECTANGULAR	5	LOUVRES
		6			6	6		3 and/or 4 and/or 5	6	ANGULAR	6	FORMED OR ROLLED GROOVES
		7		OTHERS	7	7	SEGMENT	SEGMENT OF A DISC	7	ROUND	7	3 and/or 4 and/or 5
8	CIRCULAR OR SEGMENT OF A CIRCLE	8	VARYING CROSS SECTION		8	8		SEGMENT OF A TUBE	8	5 and/or 6 and/or 7	8	3 and 6
		9	OTHERS		9	9		STIRRUP SHAPE CLAMPING RINGS	9	OTHERS	9	OTHERS

FIG 48 THE SHEETMETAL CLASSIFICATION CODE COMPONENT CLASS '8'

MATERIAL		THICKNESS			DIMENSION 'A'		DIMENSION 'B'	JOINTING PROCESS	
0	MILD STEEL	0	GAUGE	≤ 22	0	≤ 1.0 in	0	SIZE CLASSIFICATION AS FOR DIMENSION 'A'	0	NO WELDING OR BRAZING
1	STAINLESS STEELS	1		≤ 16	1	> 1.0 ≤ 2.0	1		1	SPOT WELDING
2	ALUMINIUM AND ALLOYS	2		≤ 14	2	> 2.0 ≤ 4.0	2		2	PROJECTION WELDING
3	COPPER	3		≤ 12	3	> 4.0 ≤ 6.0	3		3	GAS WELDING
4	BRASS	4		≤ 10	4	> 6.0 ≤ 10.0	4		4	BRAZING
5	NON-FERROUS	5	≤	$\frac{6.35\text{ mm}}{0.25\text{ in}}$	5	> 10.0 ≤ 16.0	5		5	ARC WELDING
6	TUFNOL	6	≤	$\frac{9.52\text{ mm}}{0.375\text{ in}}$	6	> 16.0 ≤ 25.0	6		6	CO_2 WELDING
7	PLASTICS	7	≤	$\frac{12.70\text{ mm}}{0.50\text{ in}}$	7	> 25.0 ≤ 40.0	7		7	INDUCTION WELDING
8	NEBAR ETC	8	>	$\frac{12.70\text{ mm}}{0.50\text{ in}}$	8	> 40.0 ≤ 80.0	8		8	RIVET
9	OTHERS	9	OTHERS		9	> 80.0	9		9	OTHERS

SHEETMETAL SUPPLEMENTARY CODE

FIGURE 49

CODE FAMILIES	COMPOSITE COMPONENTS
10000 20000 22000	
11000 21000	
00100 10100 10200 20100 20200	
01100 11100 11200 21100	

CODE FAMILIES AND ASSOCIATED COMPOSITE COMPONENTS

FIGURE 50

COMPONENT FAMILIES FROM OPITZ CODE DATA
SIZE RANGE KEY
DIAMETER RANGE 0 to 0.8 in.
DIAMETER RANGE 0.8 to 2 in.
ANNUAL QUANTITY 000'S
80
70
60
50
40
30
20
10
1
10100
2
10000
3
20120
4
20000
5
00100
6
11100
7
21000
8
21100
9
12000
10
13000
11
01000
12
02000
13
03000
14
22000
15
22200
16
23000
17
24000
18
25000
19
26000
20
NON STANDARD WITH OPERATING THREADS
21
29000
22
30000
23
40000
24
SQUARE SECTION
31/41 - 000

FIG 51

FIGURE : 52 CODE FAMILY RELATION TO MACHINE LOADING (1st Operation Only)

SIZE RANGE 0.8 - 2.0 IN DIAMETER

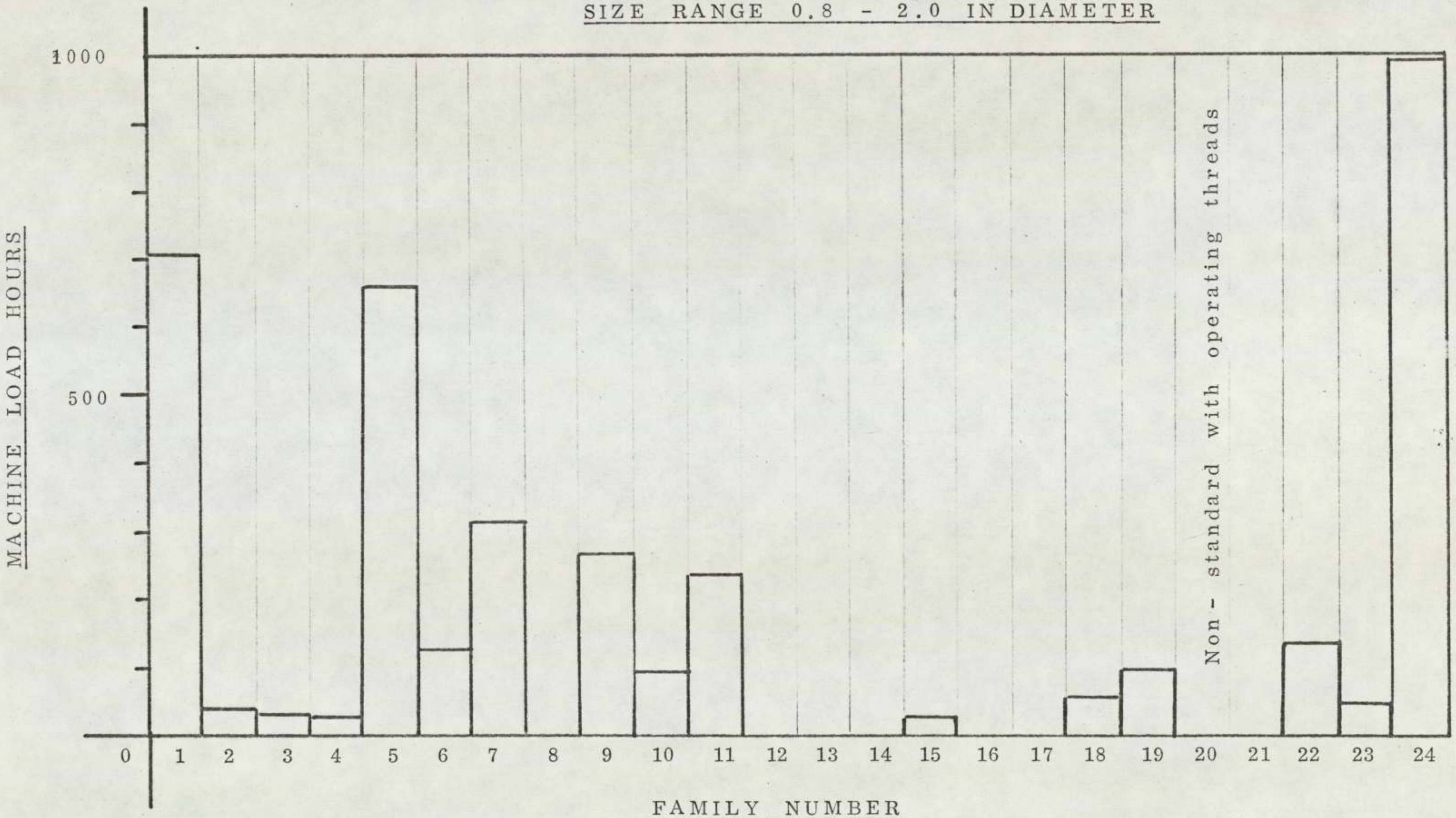


FIG 52

FIGURE : 53 CODE FAMILY RELATION TO MACHINE LOADING (1st Operation Only)

SIZE RANGE 0.- 0.8 in DIAMETER

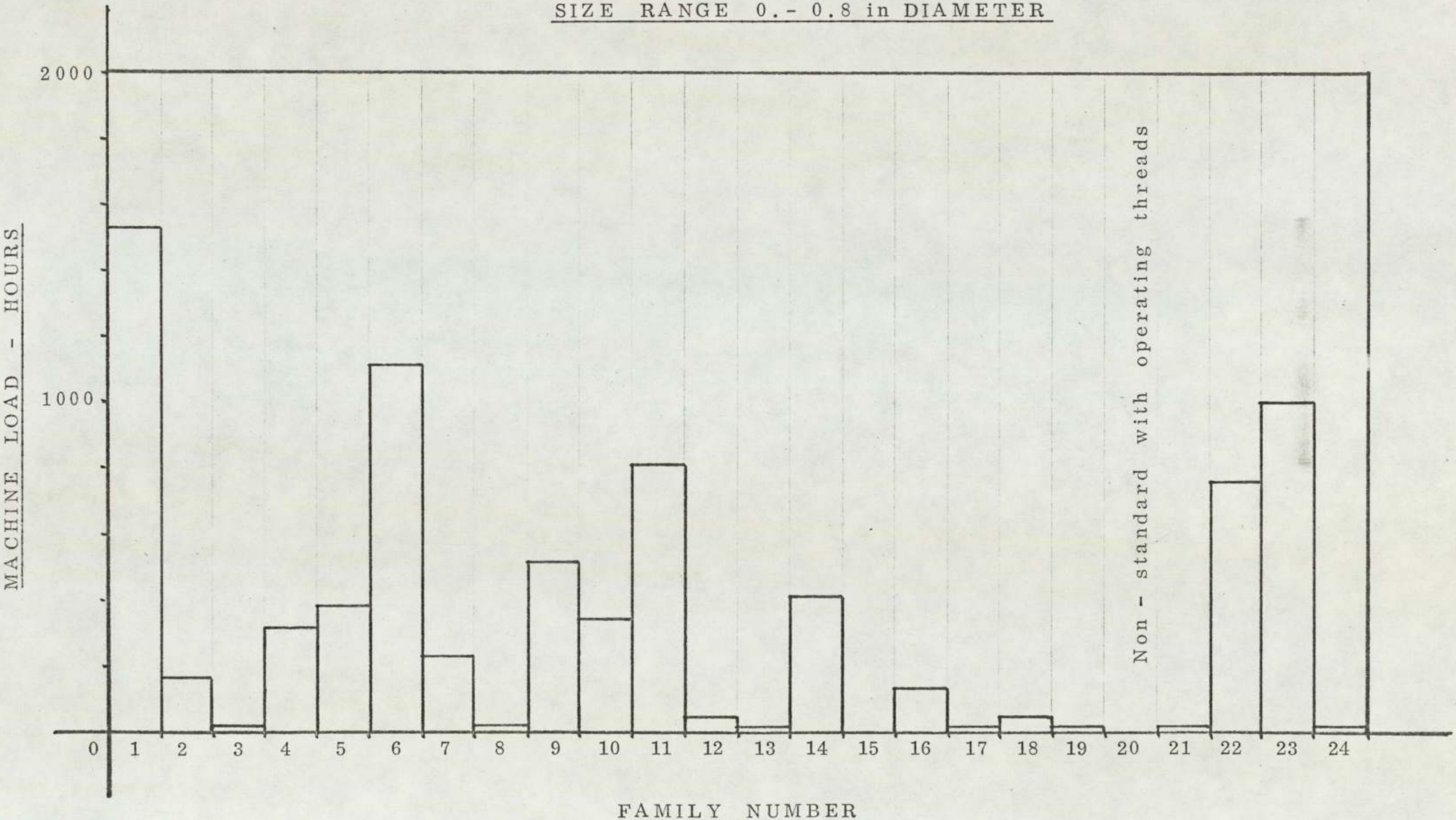
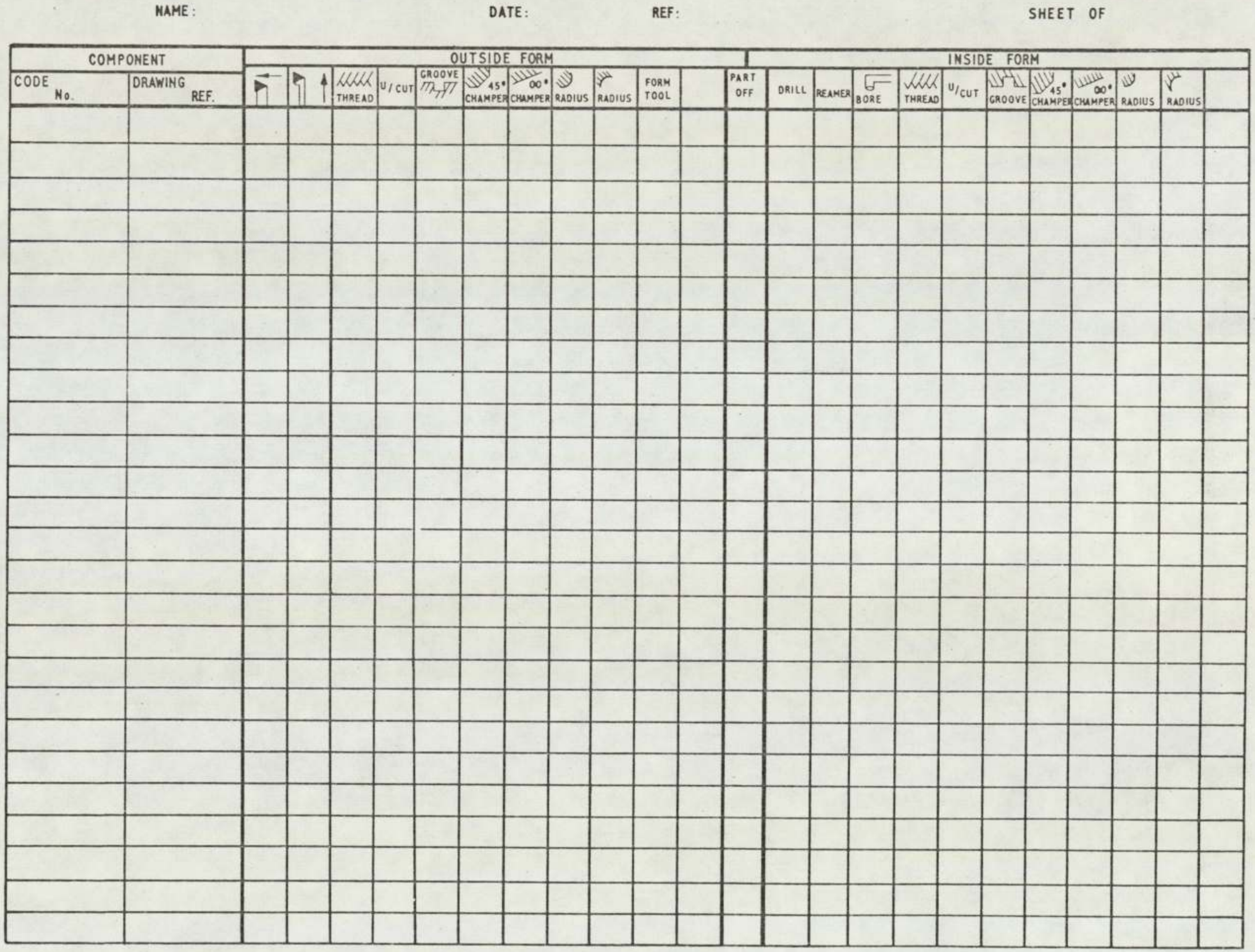


FIG 53

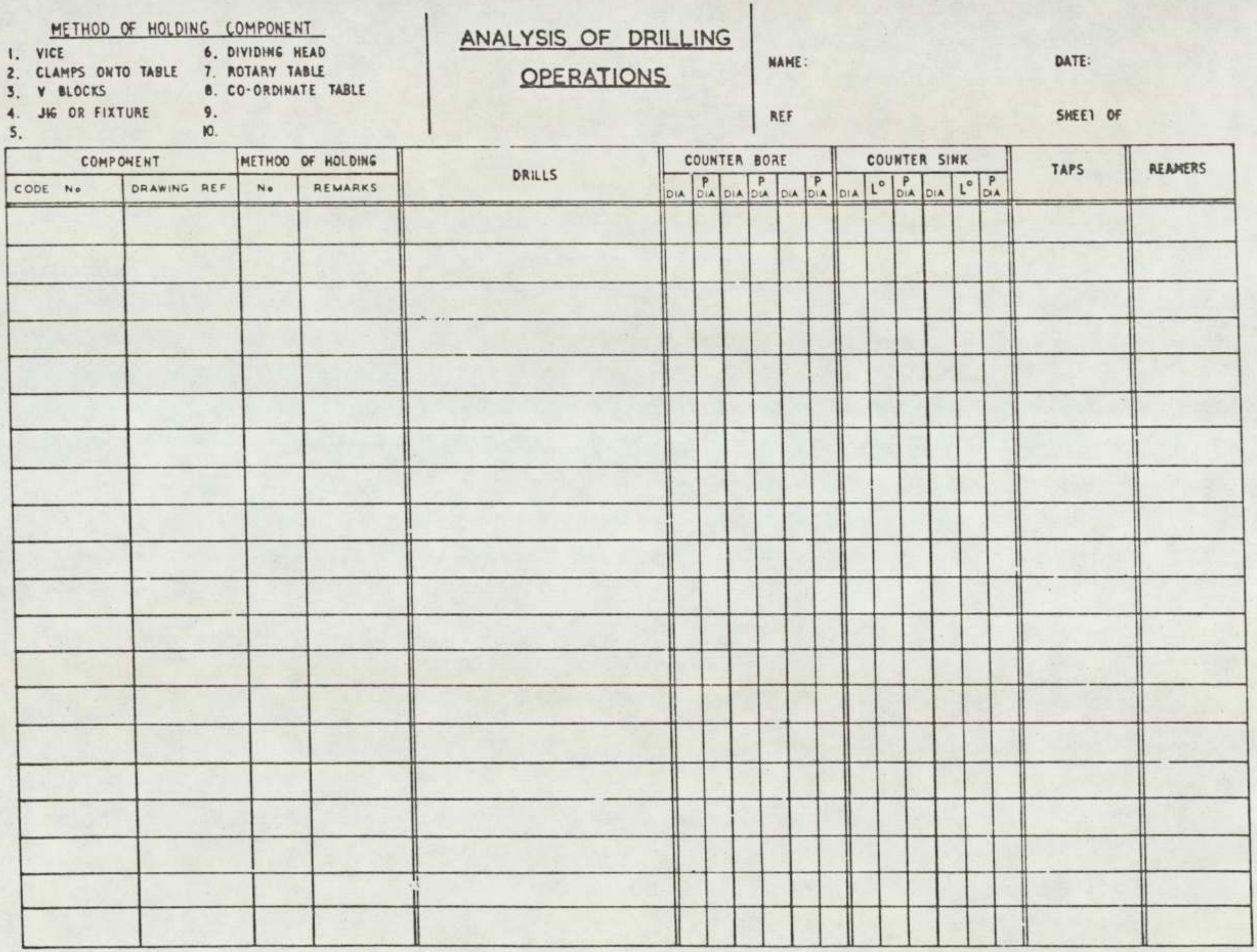


NAME: DATE: REF: SHEET OF

COMPONENT		OUTSIDE FORM												INSIDE FORM										
CODE No.	DRAWING REF.	←	↑	THREAD	U/CUT	GROOVE	45° CHAMFER	00° CHAMFER	RADIUS	RADIUS	FORM TOOL		PART OFF	DRILL	REAMER	BORE	THREAD	U/CUT	GROOVE	45° CHAMFER	00° CHAMFER	RADIUS	RADIUS	

Figure 54 Tooling Analysis Form for turning operations

(AFTER MacCONNELL)



METHOD OF HOLDING COMPONENT

1. VICE
2. CLAMPS ONTO TABLE
3. V BLOCKS
4. JIG OR FIXTURE
5.
6. DIVIDING HEAD
7. ROTARY TABLE
8. CO-ORDINATE TABLE
9.
10.

ANALYSIS OF DRILLING OPERATIONS

NAME:

DATE:

REF

SHEET OF

COMPONENT		METHOD OF HOLDING		DRILLS	COUNTER BORE						COUNTER SINK						TAPS	REAMERS
CODE No	DRAWING REF	No	REMARKS		DIA	P DIA	DIA	P DIA	DIA	P DIA	DIA	L°	P DIA	DIA	L°	P DIA		

FIGURE 55. TOOLING ANALYSIS FORM FOR DRILLING OPERATIONS

(AFTER MacCONNELL)

METHOD OF HOLDING COMPONENT

1. VICE	6. DIVIDING HEAD
2. CLAMPS TO TABLE	7. ROTARY TABLE
3. V BLOCKS	8.
4. FIXTURE	9.
5.	10.

ANALYSIS OF MILLING OPERATIONS

NAME:

DATE:

REF:

SHEET OF

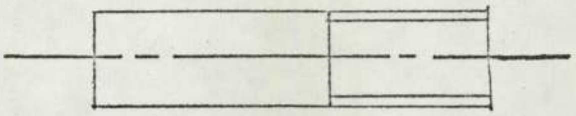
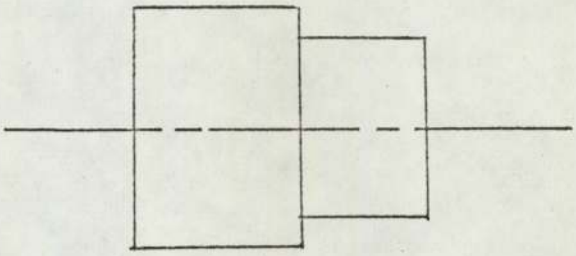
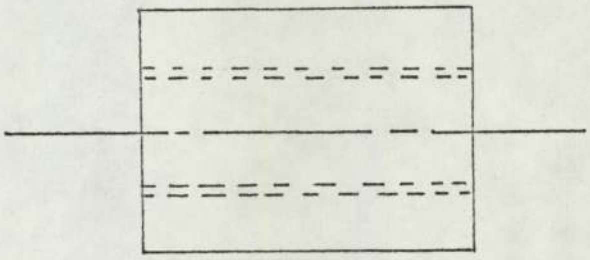
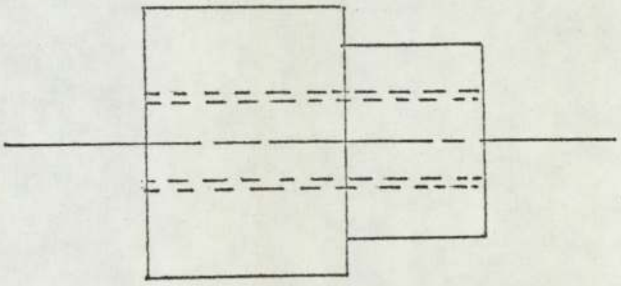
COMPONENT		METHOD OF HOLDING		CUTTER										END MILL				
CODE No.	DRAWING REF	No.	REMARKS	FACING		SIDE & FACE			SLOTTING		OTHER			DIA	LENGTH	TYPE		
				DIA	TYPE	DIA	WIDTH	TYPE	DIA	WIDTH	DIA	WIDTH	TYPE					

FIGURE 56 TOOLING ANALYSIS FORM FOR MILLING OPERATIONS

(AFTER MacCONNELL)

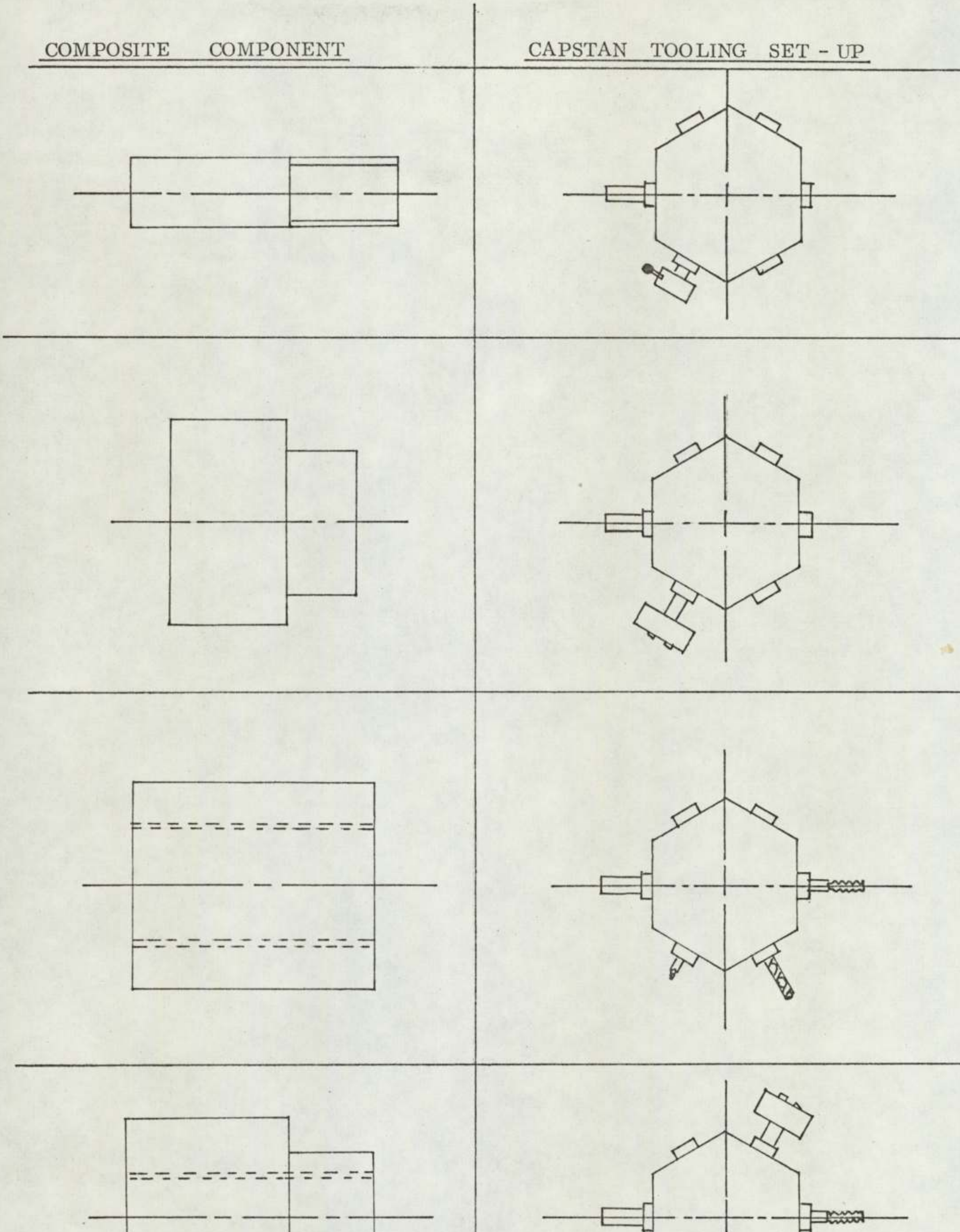
FIG 57

VIEW OF ORIGINAL TUBE PPODUCTION SHOWING (FOREGROUND) SAW AND (REAR) BENDING GEAR. NOTE HIGH LEVEL OF W.I.P. AND CRAMPED LAYOUT.

CODE FAMILIES	COMPOSITE COMPONENTS
10000 20000 22000	
11000 21000	
00100 10100 10200 20100 20200	
01100 11100 11200 21100	

CODE FAMILIES AND ASSOCIATED COMPOSITE COMPONENTS

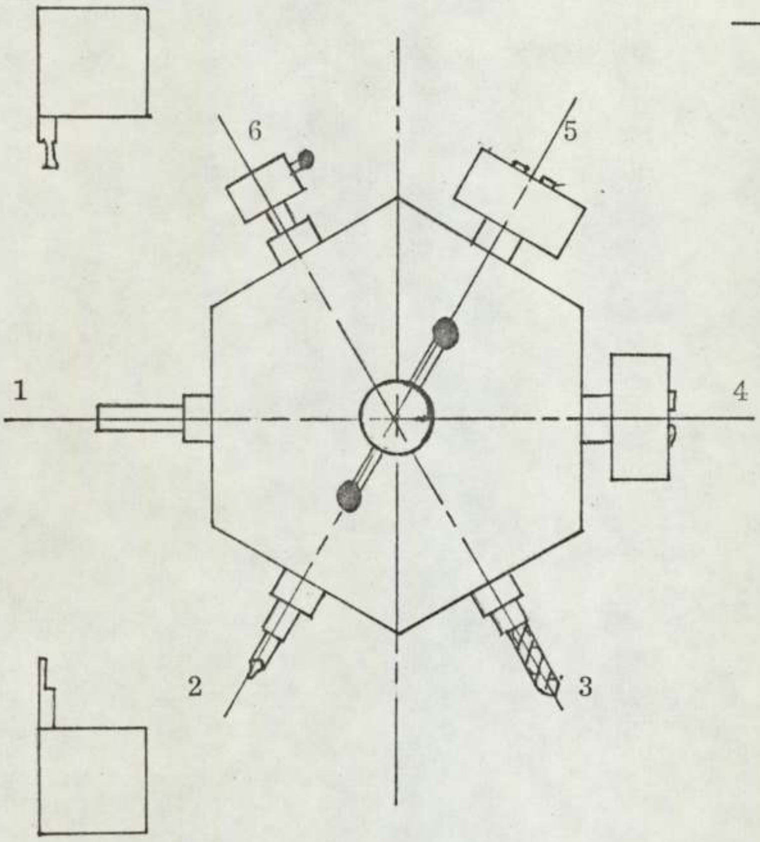
FIGURE 58



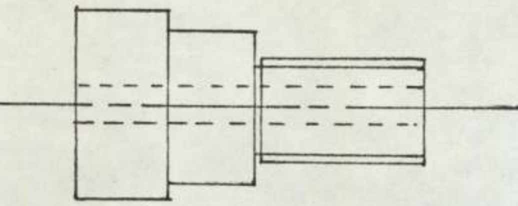
TOOLING PACKAGES FOR INDIVIDUAL CODE FAMILIES

FIGURE 59

Part Tool



Groove Tool



Composite Component with max. combination of features possible with 6 stations.

Turret Pos 'n	Tool Description
* 1	End Stop
2	Centre Drill
+ 3	Drill
+ 4	Roller Box Turn
+ 5	Roller Box Turn
+ 6	Screw

* End Stop can be replaced with swing stop arrangement

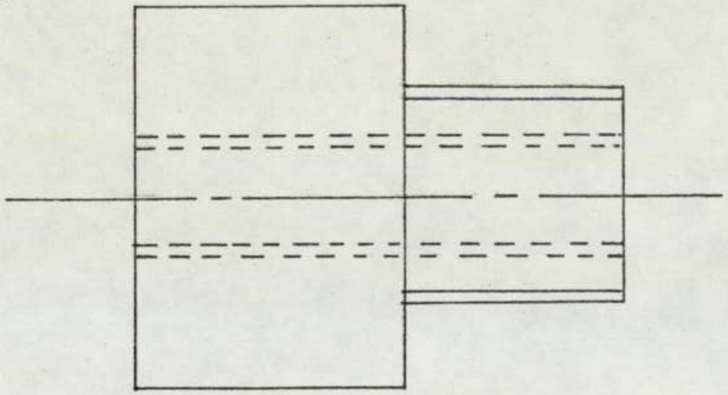
\+ Change to suit requirements

TOOLING COMBINATIONS WITH CAPSTAN HEAD

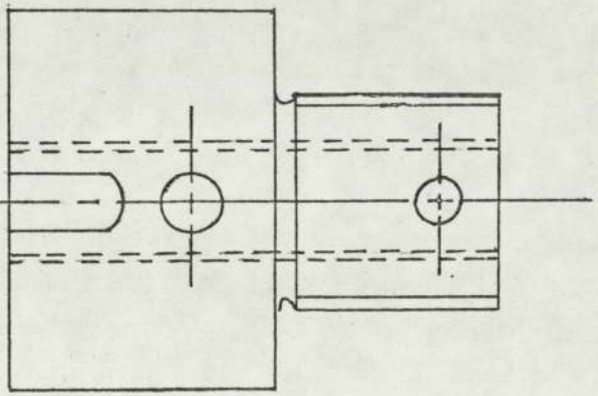
FIGURE 60

FIGURE 6

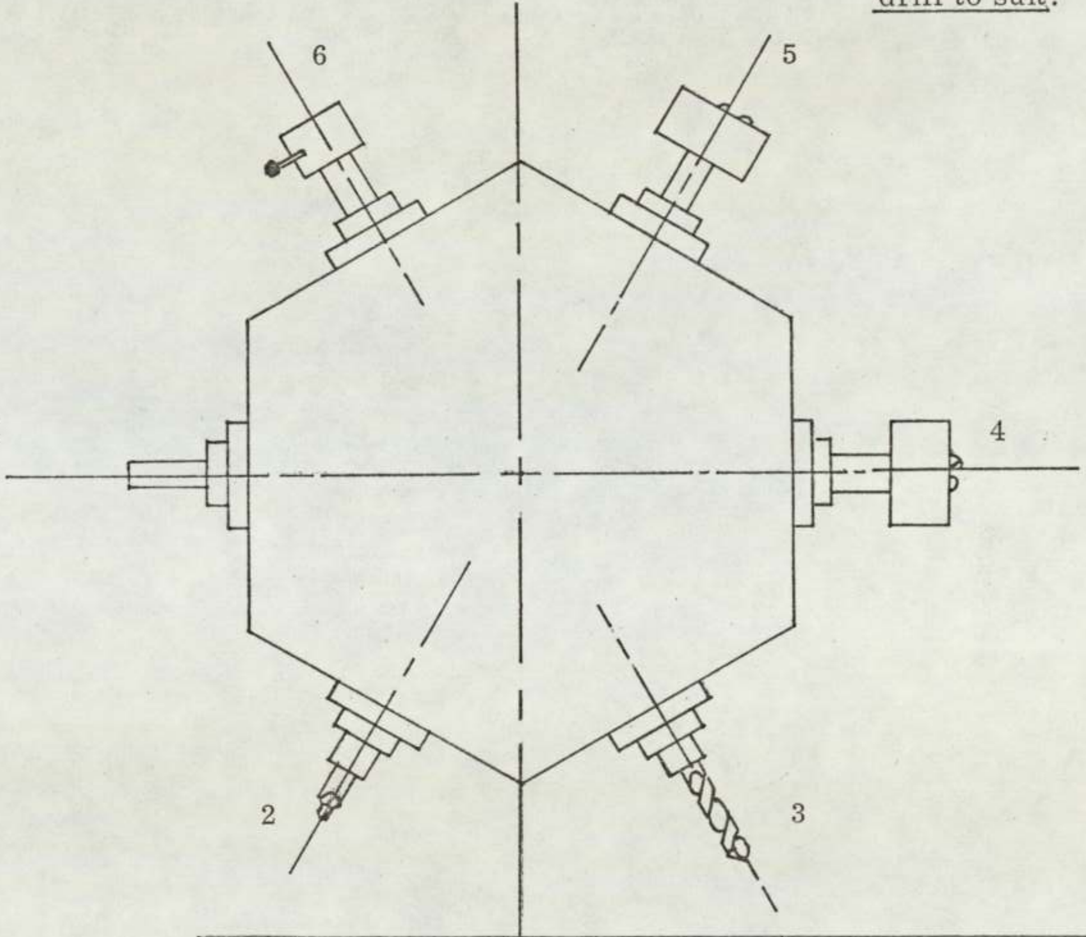
Code Family
Composite
Component



Actual Production
Composite
Component with
Auxiliary Features



+ - Interchange with drill to suit.



Turret Pos'n	Tooling Set-Up	Turret Pos'n	Tooling Set-Up
1	End Stop	4	Rough Turn +
2	Centre Drill	5	Finish Turn +
3	Drill	6	Die Head

COMPOSITE COMPONENT AND TOOLING DERIVED FROM CODE FAMILIES

CHANGE TO

		205016	205017	205022	205029	205101	205131	205135	205138	205162	205169	205264	205268	205514
	205016	X	17	23	11	17	11	37	13	11	11	17	1*	11 *
	205017	11*	X	20	11*	14	11*	38	13	11*	11*	14	11*	11*
	205022	11*	14	X	11*	14	11*	25	13	11*	11*	14	11*	11*
	205029	11*	17	23	X	17	11*	41	13	11*	11*	17	11*	11*
	205101	11*	14	20	11*	X	11*	38	13	11*	11*	14	11*	1*
	205131	11*	17	23	11*	17	X	41	13	11*	11*	17	11*	12
CHANGE FROM	205135	31	34	27*	31	34	31	X	33	31	31	35	31	31
	205138	11*	17	23	12	17	12	41	X	11*	11*	17	11*	11*
	205162	11*	18	24	11*	17	11*	41	13	X	11*	17	11*	12
	205169	11*	17	23	11*	17	11*	41	13	11*	X	17	11*	18
	205264	11	12	17	11	1*	11	33	13	11	11	X	11	2
	205268	1*	17	23	11	17	13	41	13	11	11	17	X	12
	205514	11	17	23	11	7*	11	41	13	11	11	7	11	X

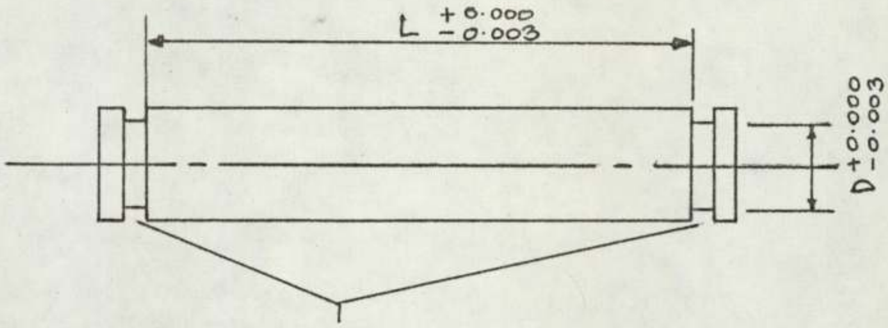
MINIMUM SETTING CHANGES SHOWN *

(Complete chart includes 63 components)

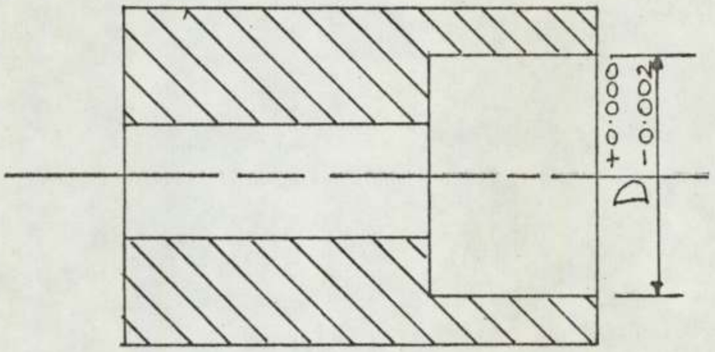
SAMPLE PORTION OF CHANGE OVER INTERACTION MATRIX

FIGURE 62

FIGURE 63

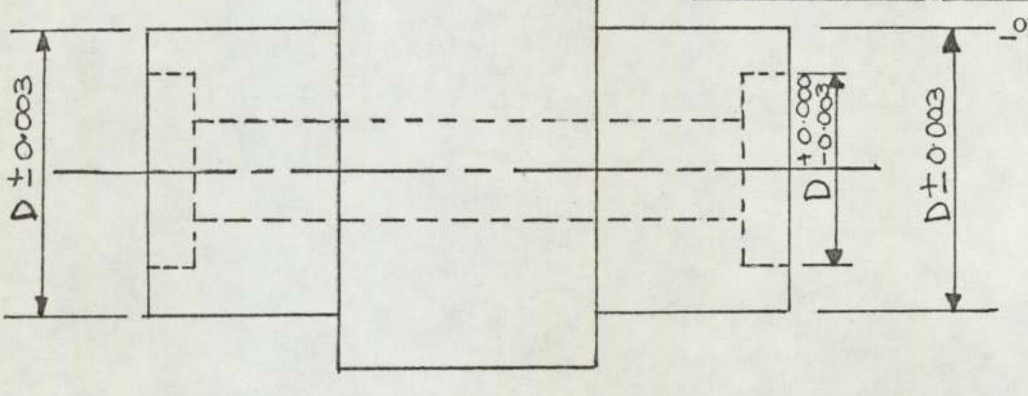


Required Groove Accuracy
Elliminates From Family



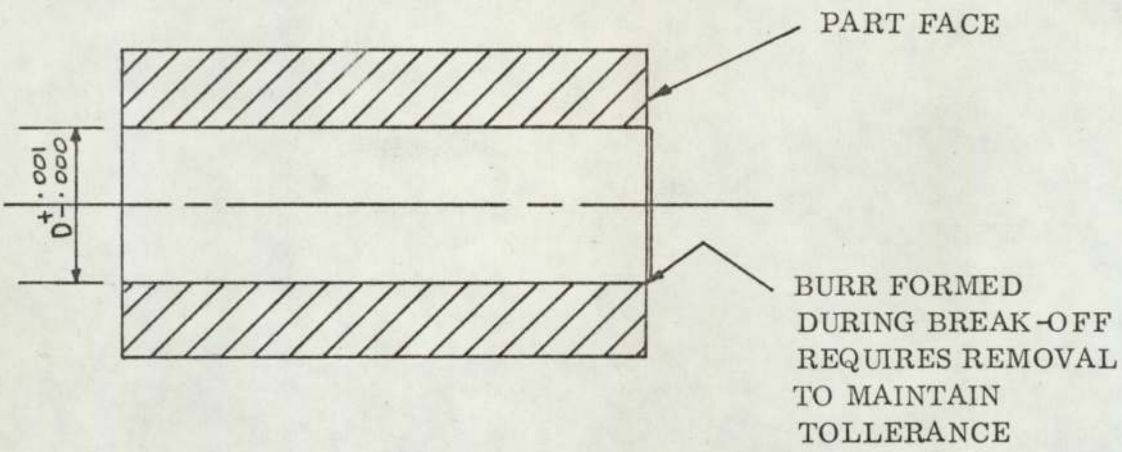
C/Bore Requires Additional Tooling and
Close Tollerance - not suitable for family

Complex components requiring
additional tooling & remount
operation



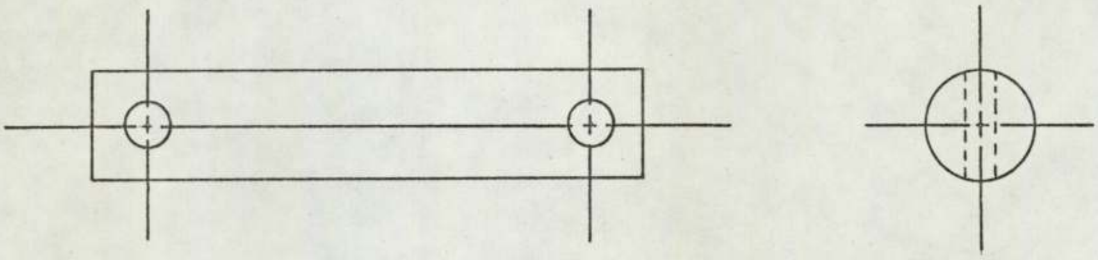
COMPONENTS OMITTED DUE TO PRODUCTION COMPLEXITIES

FIGURE 64



TYPICAL COMPONENT REQUIRING SECOND TURNING OPERATION

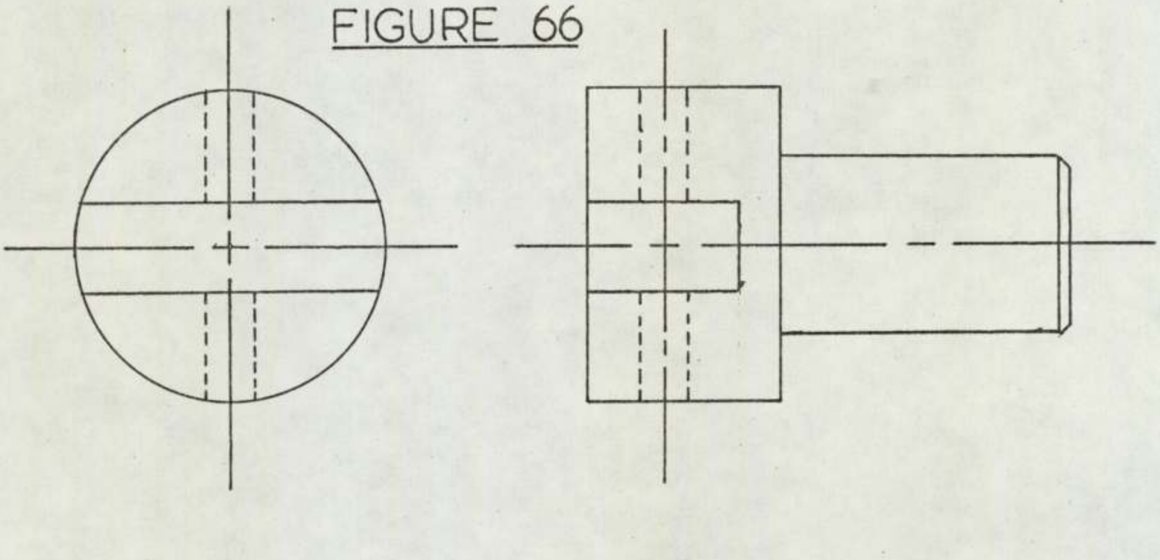
FIGURE 65



TYPICAL COMPONENT REQUIRING DRILLING

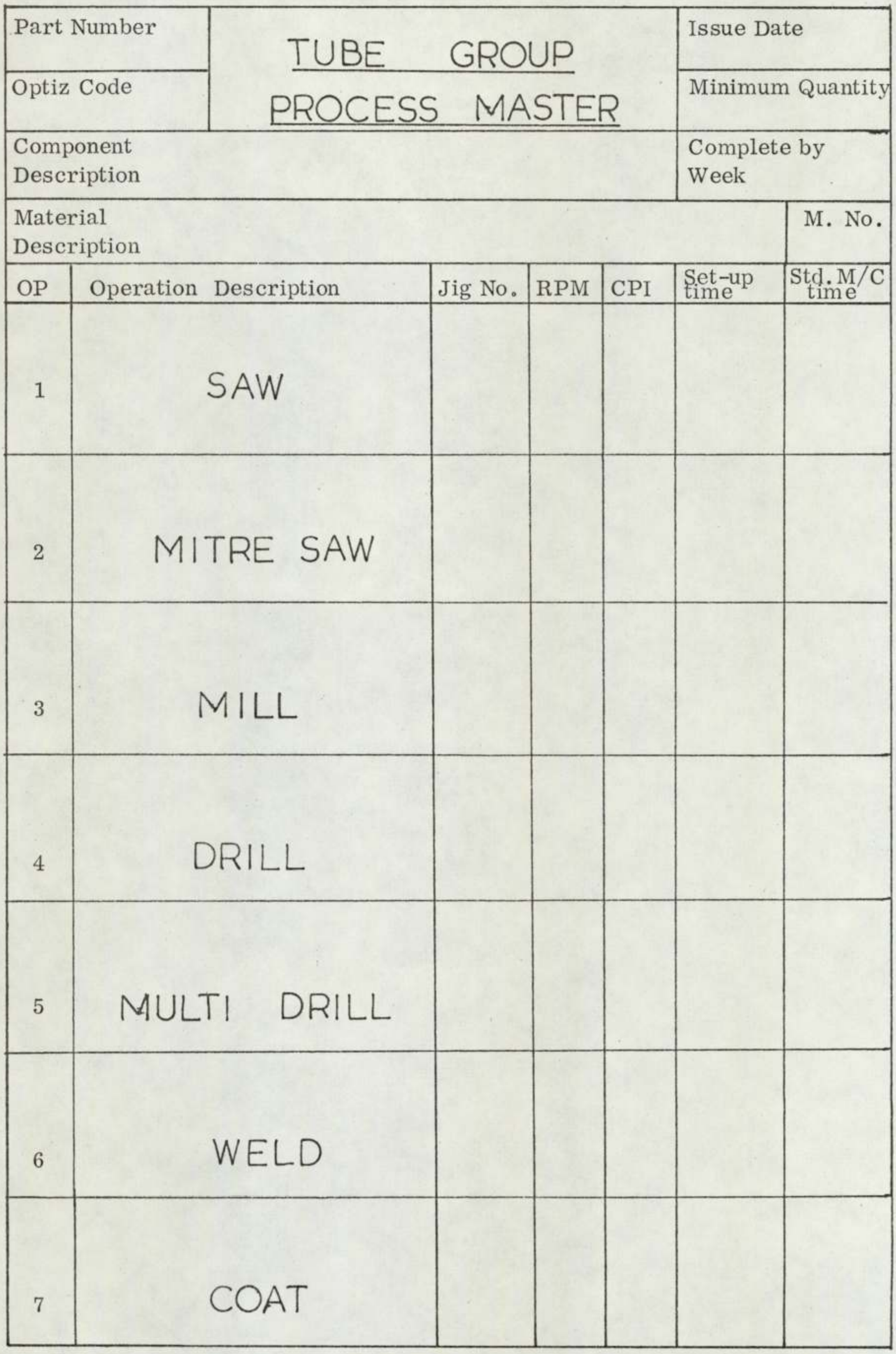
(No components required other than radial drilling operations)

FIGURE 66



TYPICAL COMPONENT REQUIRING MILLING OPERATION

FIGURE 67

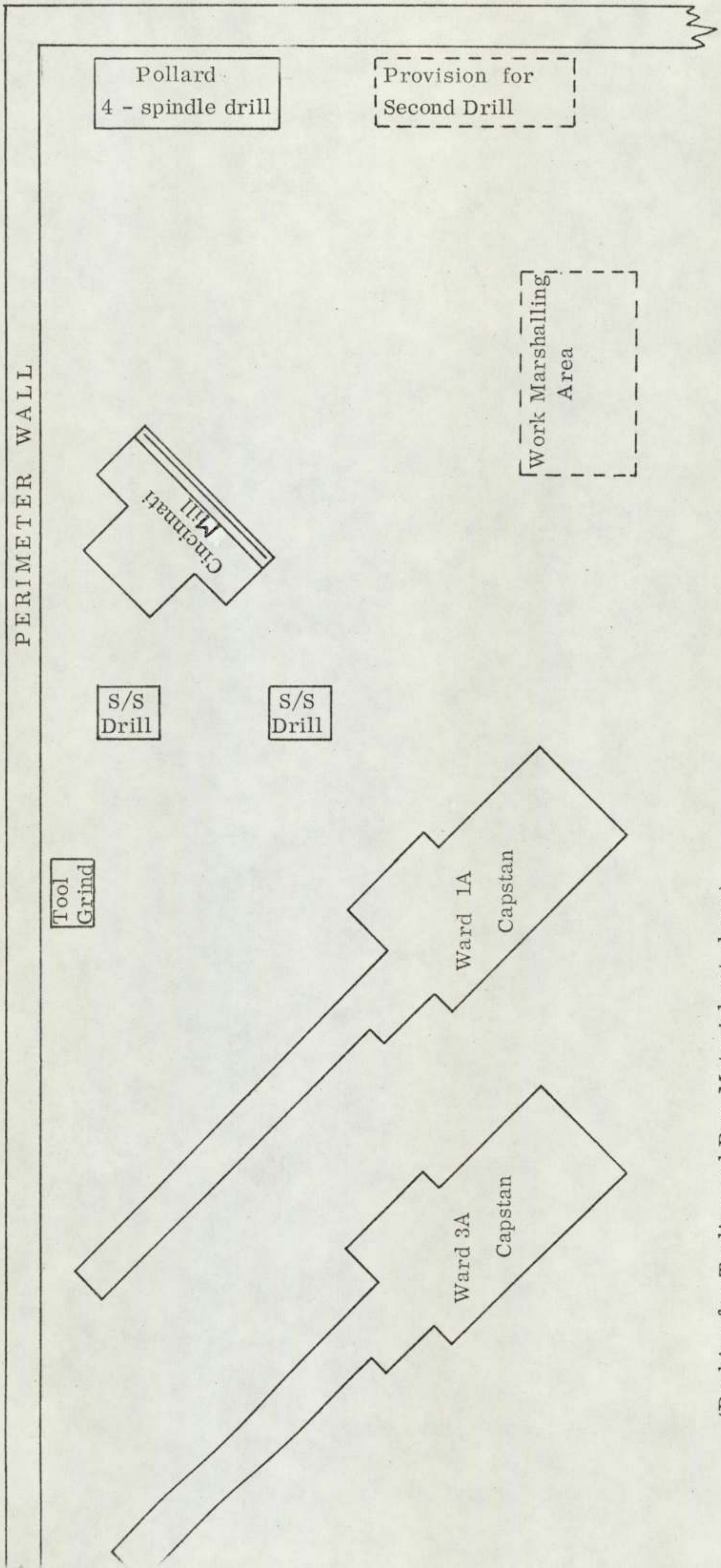


Part Number	TUBE GROUP PROCESS MASTER	Issue Date
Optiz Code		Minimum Quantity
Component Description		Complete by Week
Material Description		M. No.

OP	Operation Description	Jig No.	RPM	CPI	Set-up time	Std. M/C time
1	SAW					
2	MITRE SAW					
3	MILL					
4	DRILL					
5	MULTI DRILL					
6	WELD					
7	COAT					

COMPOSITE JOB CARD FOR TUBE GROUP COMPONENTS

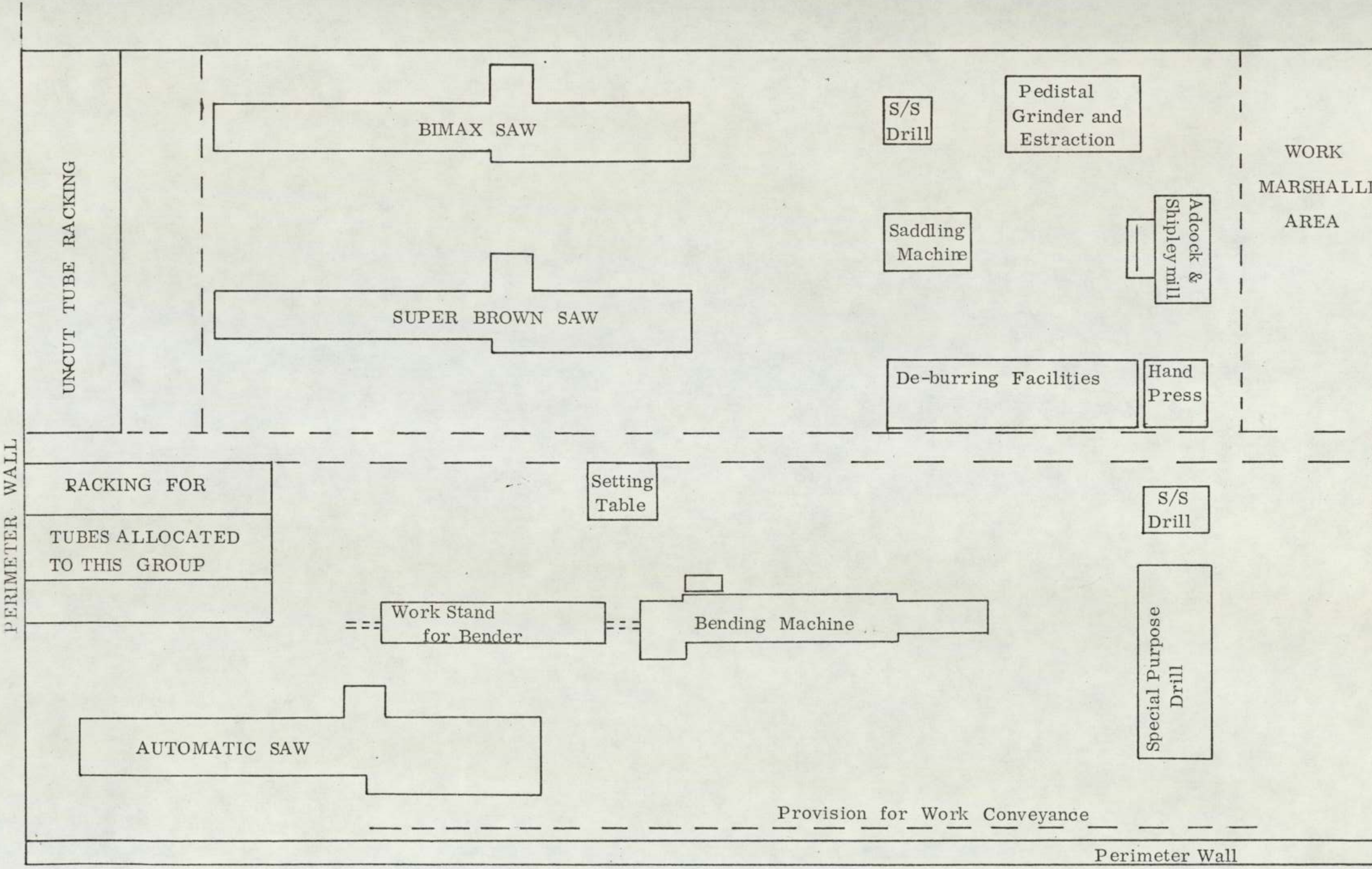
FIGURE 68



(Racking for Tooling and Raw Material not shown)

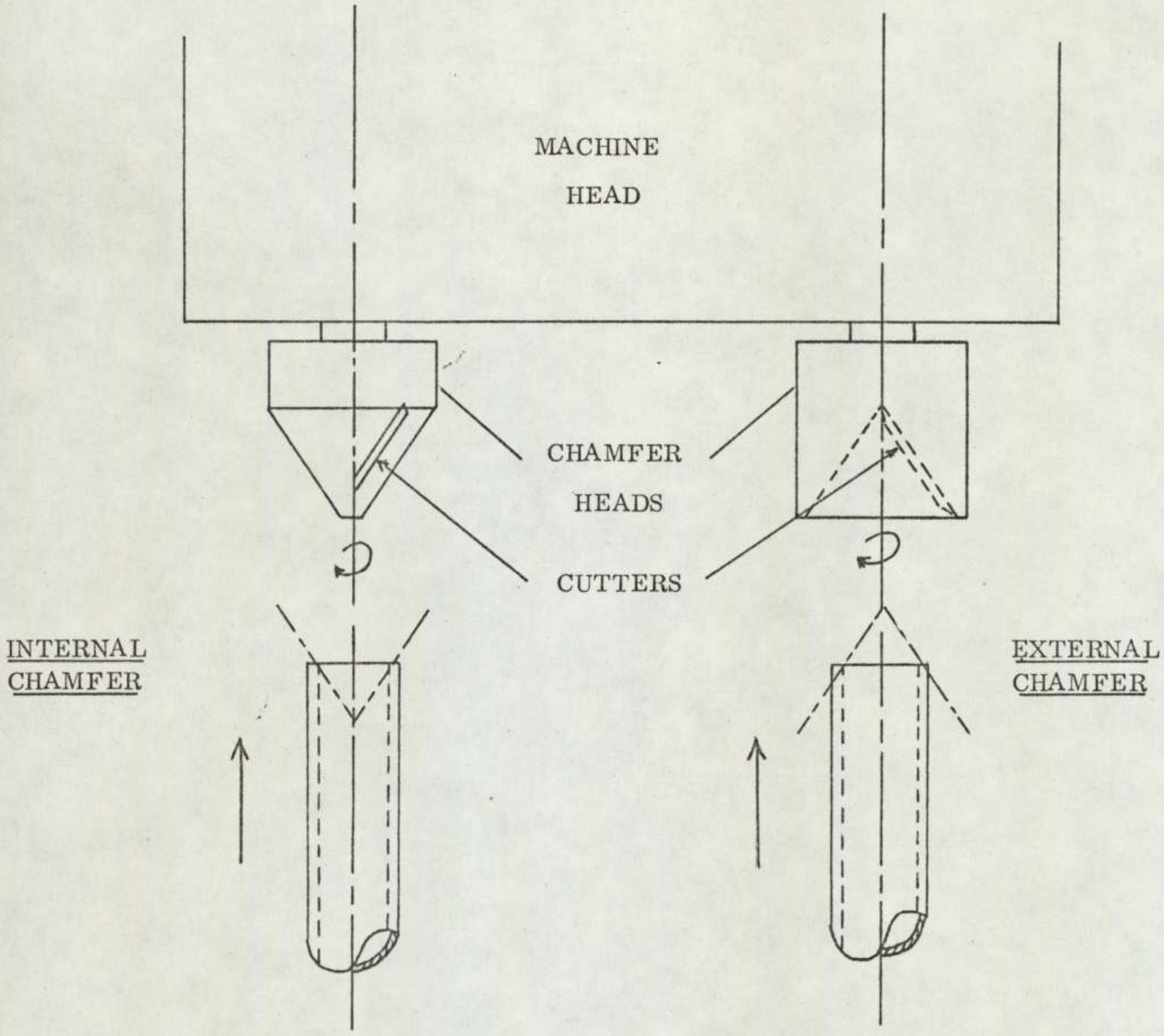
TURNED COMPONENT GROUP LAYOUT

FIGURE 09



TUBE GROUP LAYOUTS

FIGURE 70



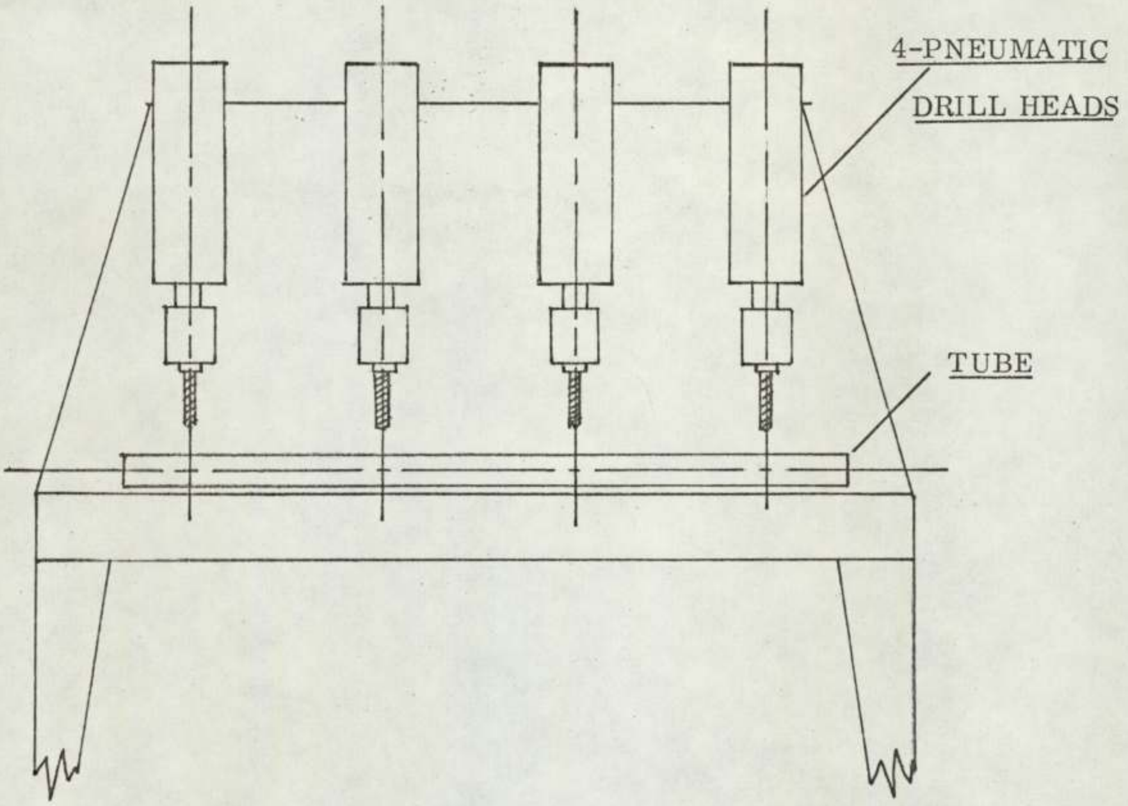
CHAMFER HEADS WILL ACCOMMODATE A WIDE RANGE OF TUBE DIAMETERS.

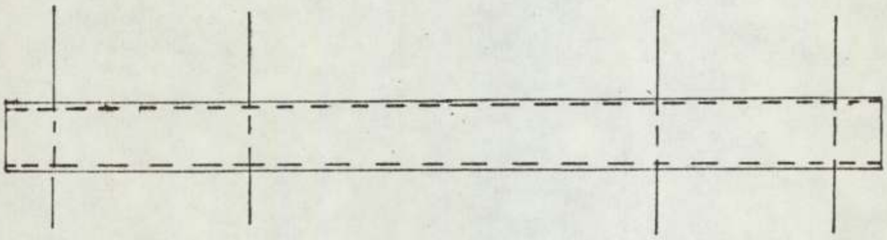
BAR STOCK MAY BE GIVEN EXTERNAL CHAMFERS.

FIG 70

TUBE DE-BURRING MACHINE

FIGURE 71



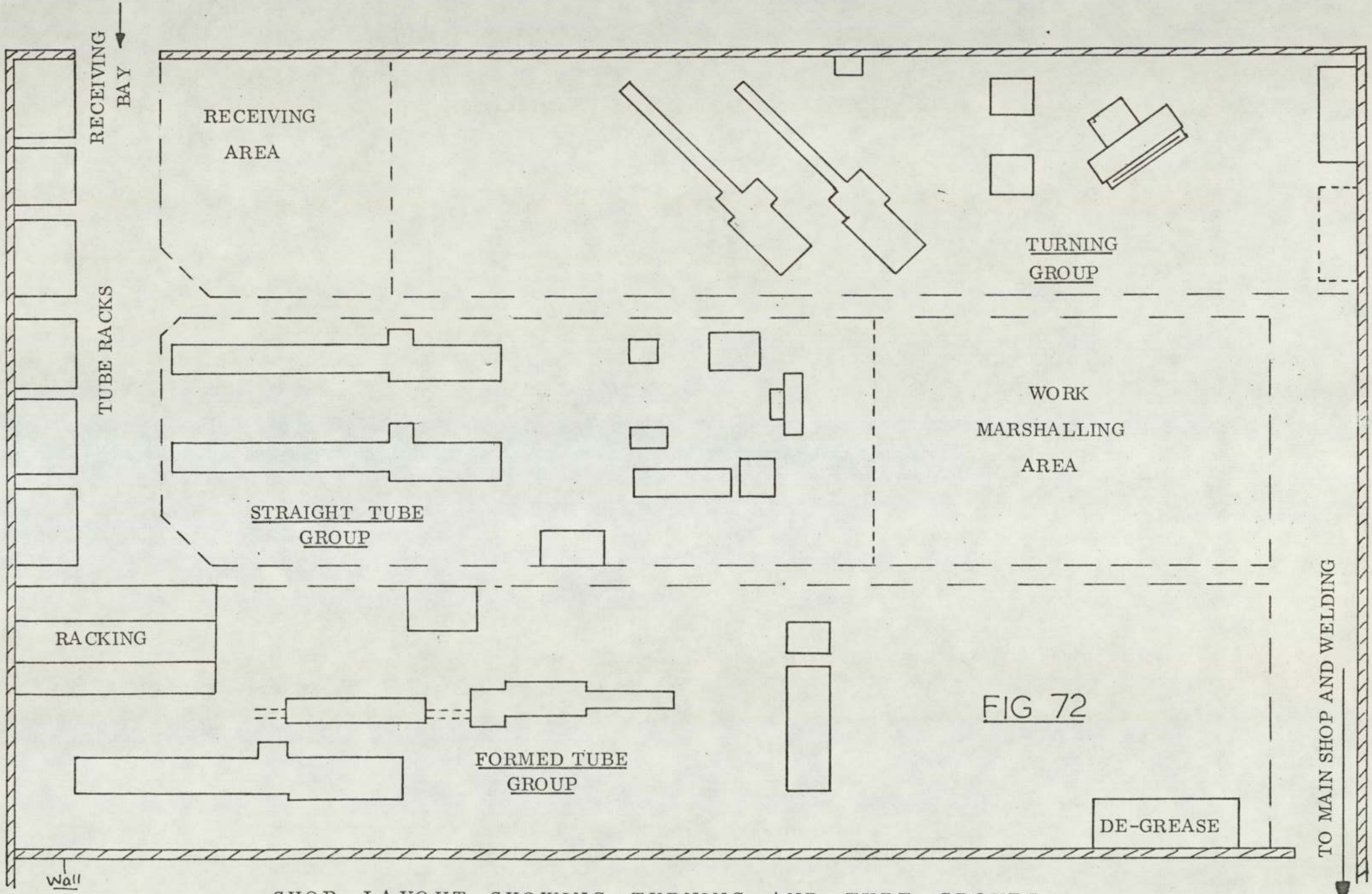


TYPICAL COMPONENT ILLUSTRATING
ADJUSTABLE DRILL HEAD FACILITY

FIG 71

SPECIAL PURPOSE DRILL FOR TUBE COMPONENTS

FIGURE 72

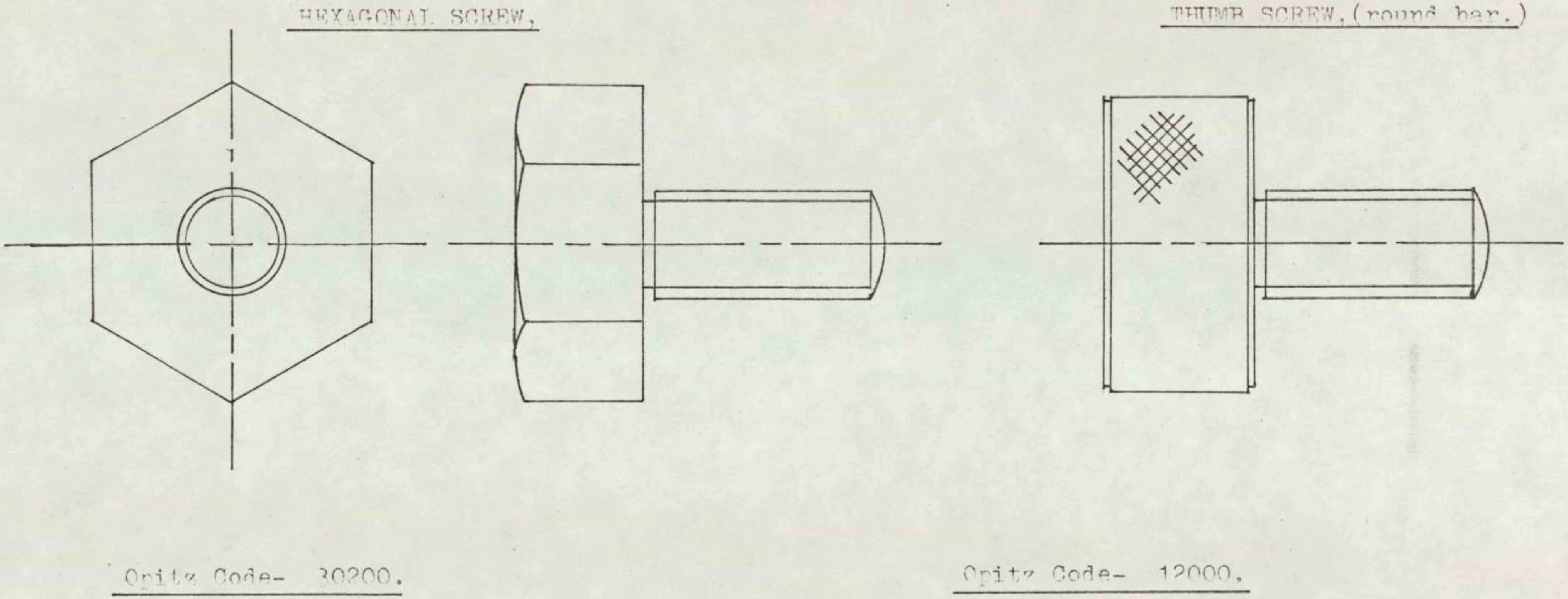


SHOP LAYOUT SHOWING TURNING AND TUBE GROUPS

FIG 73

<table>
<tr><td>GROUP</td><td rowspan="2">JOB
TICKET</td><td>PART N°</td></tr>
<tr><td>STRAIGHT TUBE</td><td>220504</td></tr>
<tr><td>MATERIAL</td><td colspan="2">1⅛ x 14G. MS</td></tr>
<tr><td>QUANTITY</td><td colspan="2">450</td></tr>
<tr><td>REQUIRED</td><td colspan="2">WEEK 33</td></tr>
</table>

SIMPLIFIED MANUFACTURING INSTRUCTIONS
WITH JOB TICKET



HEXAGONAL SCREW,

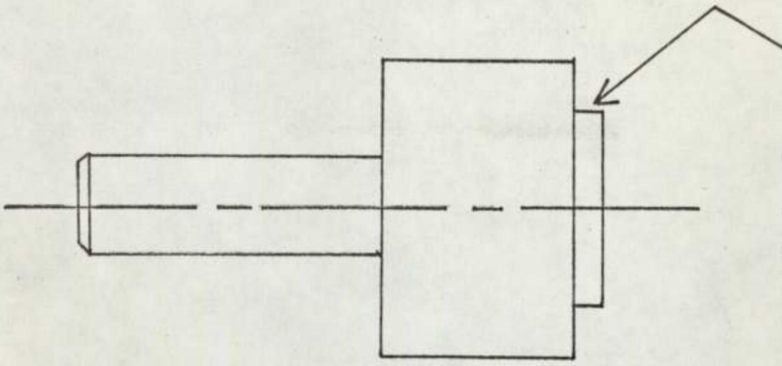
THUMB SCREW, (round bar.)

Opitz Code- 30200.

Opitz Code- 12000.

EXAMPLE OF COMPONENTS WITH IDENTICAL PRODUCTION FEATURES BUT WIDE CODE SEPARATION.

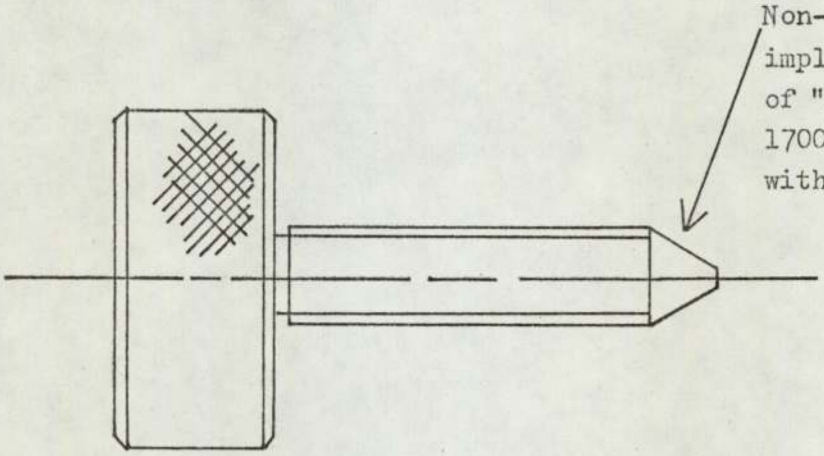
FIGURE 74



Shoulder on back face technically implies an Opitz Code of 14000 but can be machined by front tool post before part-off operation.

OPITZ PRODUCTION CODE - 11000

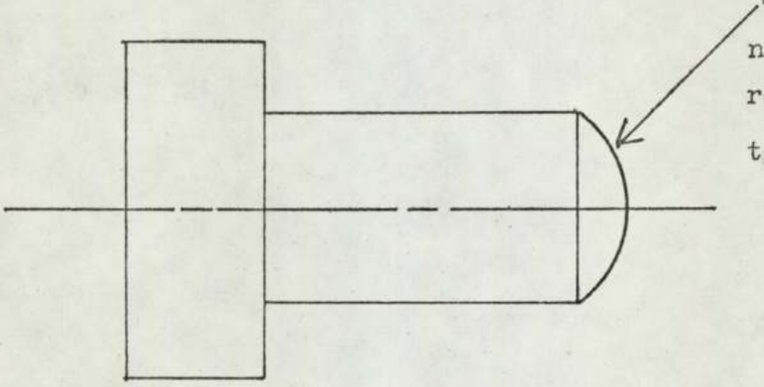
FIGURE 75



Non-standard taper can imply Opitz Code descripti of "Functional/Taper" code 17000, but can be turned with simple form tool.

OPITZ PRODUCTION CODE - 12000

FIGURE 76

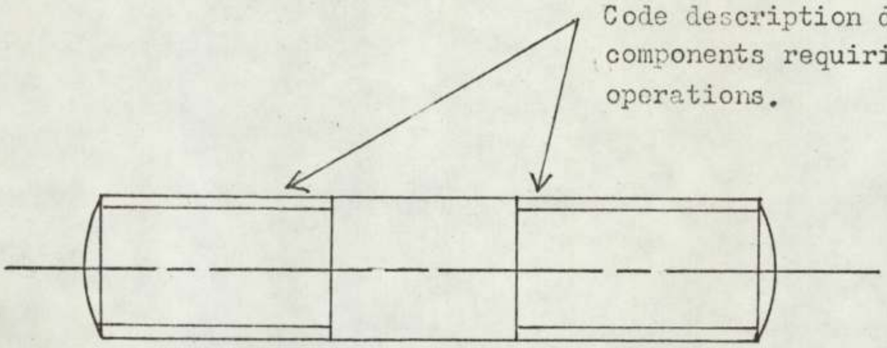


Similarly the radius is not of primary importance, requiring a simple form tool.

OPITZ PRODUCTION CODE - 11000

FIGURE 77

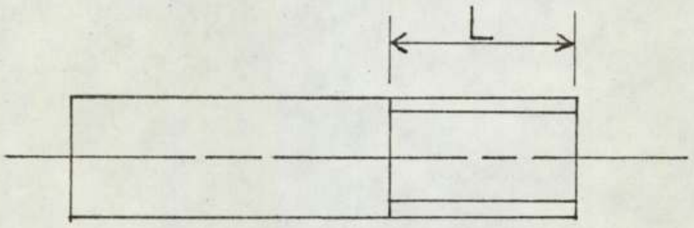
EXAMPLES OF OPITZ CODE INTERPRETATION



Code description does not identify components requiring re-mount operations.

OPITZ CODE - 22000 (after Alexander)

FIGURE 78

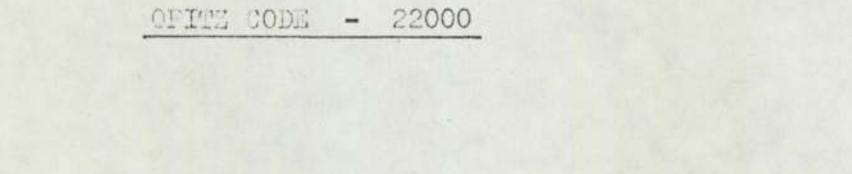


OPITZ CODE - 22000

FIGURE 79

Some Opitz Code description refers to the two screwed components shown in Figs. (78) and (79). Figure (81) shows a similar screw having much longer feed stroke (possible beyond the strokes of certain machines.

The screw shown in figure (80) may be thread-rolled.

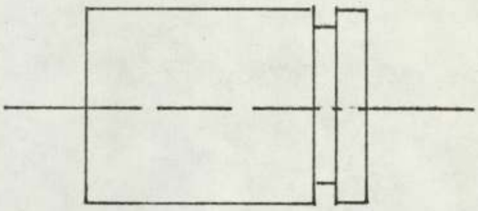


OPITZ CODE - 22000

FIGURE 80

EXAMPLES OF OPITZ CODE INTERPRETATIONS

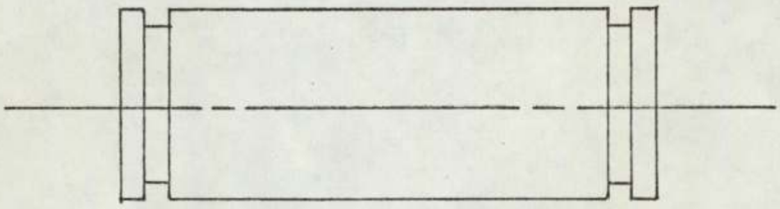
Single groove finish turned in a single operation.



OPITZ CODE - 13000.

FIGURE 81

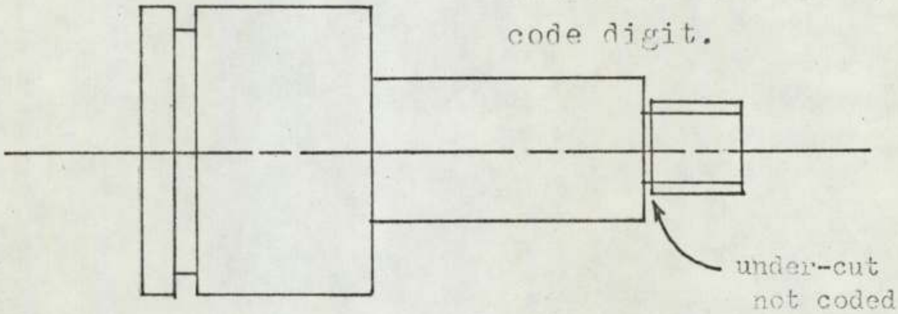
Grooved component with similar code type although both grooves can be turned in a single operation.



OPITZ CODE - 23000.

FIGURE 82

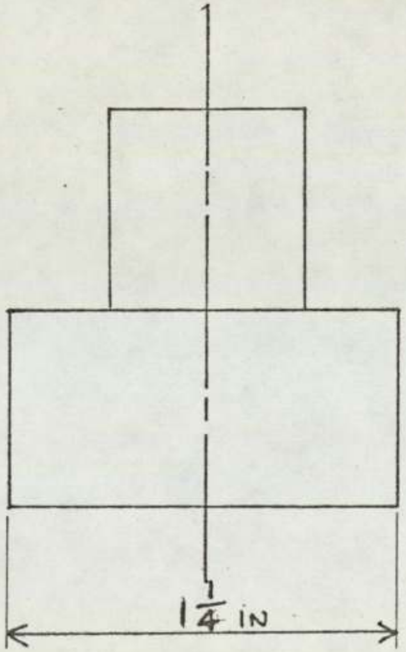
Component with three principal shape features grouped on groove code digit.



OPITZ CODE- 13000.

FIGURE 83

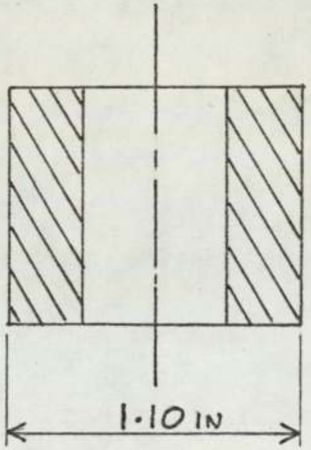
PRACTICAL CODE INTERPRETATIONS.



Single turned dia on standard bar size

OPITZ CODE - 11000

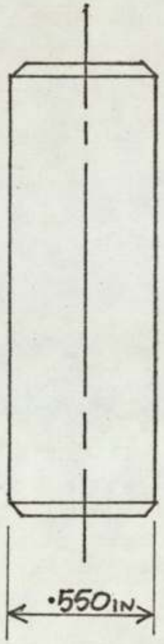
FIG 84



Actually turned on O/D
Bar size = 1⅛in.

10100

FIG 85



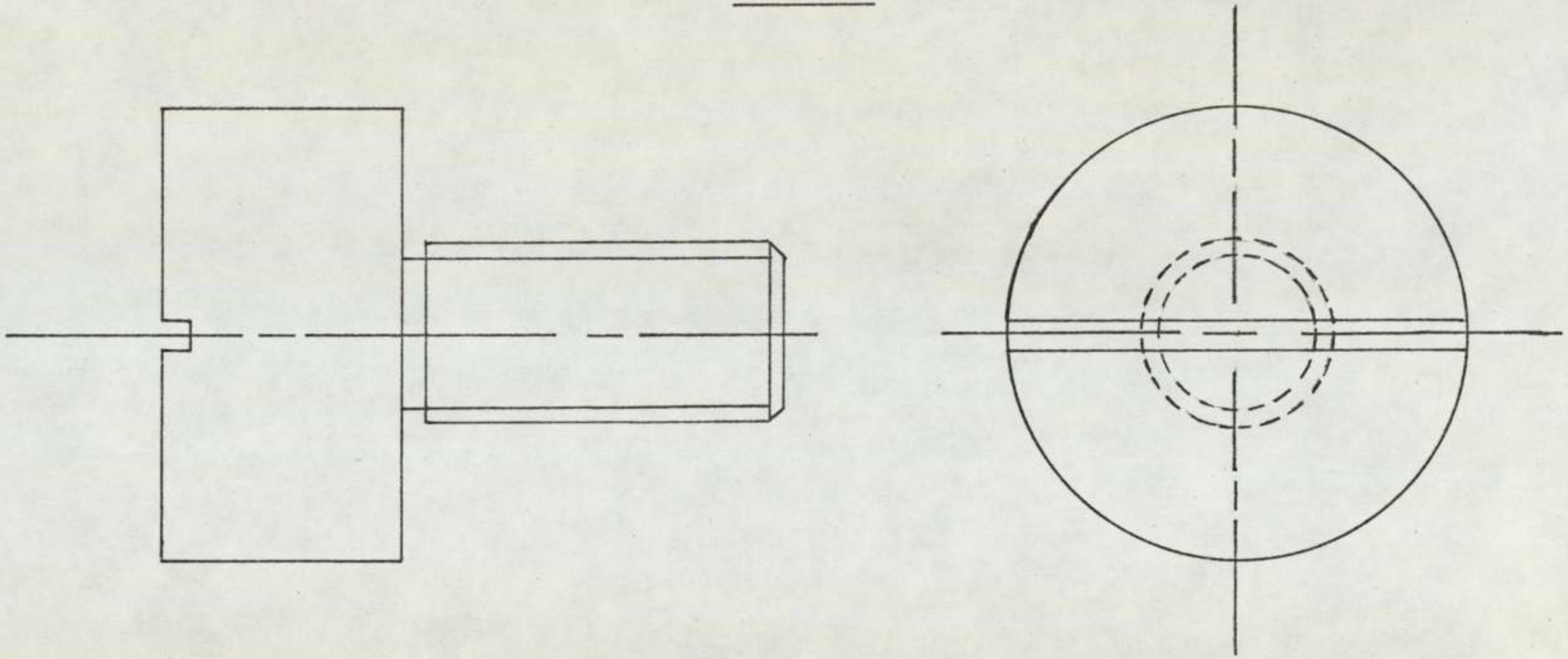
Actually turned on O/D
Bar size 9/16 in

20000

FIG 86

THE PRACTICAL INTERPRETATION OF OPITZ CODE DESCRIPTIONS

FIG 87

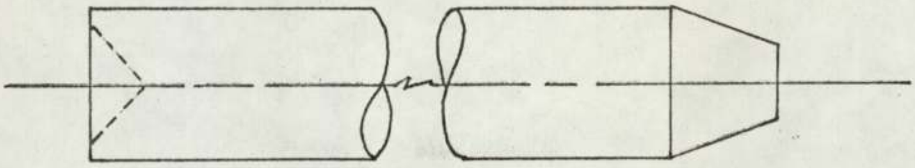


OPITZ CODE - 12030

Component is produced on BSA auto with slotting attachment

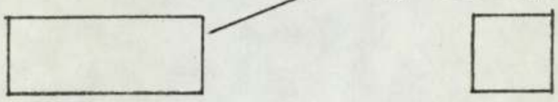
The Opitz Code implies a secondary machined feature.

EXAMPLE OF THE PRACTICAL ACCURACY OF THE OPITZ CODE

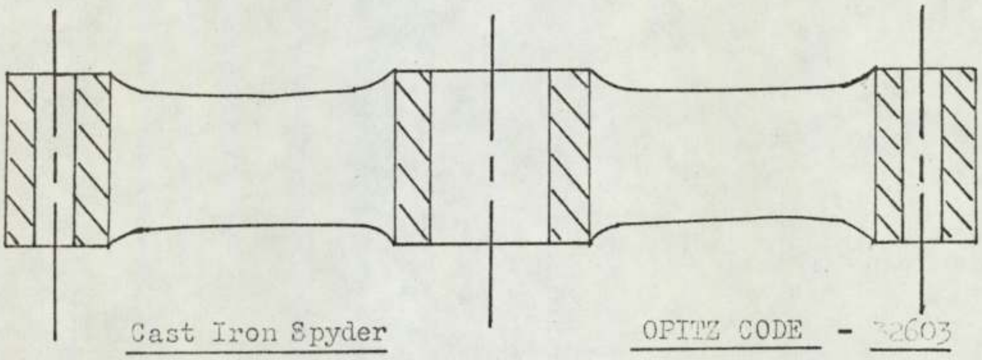


TAPER PIN OPITZ CODE - 27100

Square faces easily machined by turning.

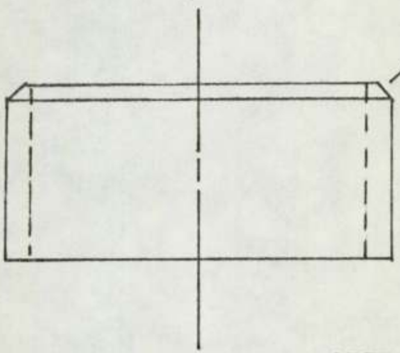


Mild steel block OPITZ CODE - 31000



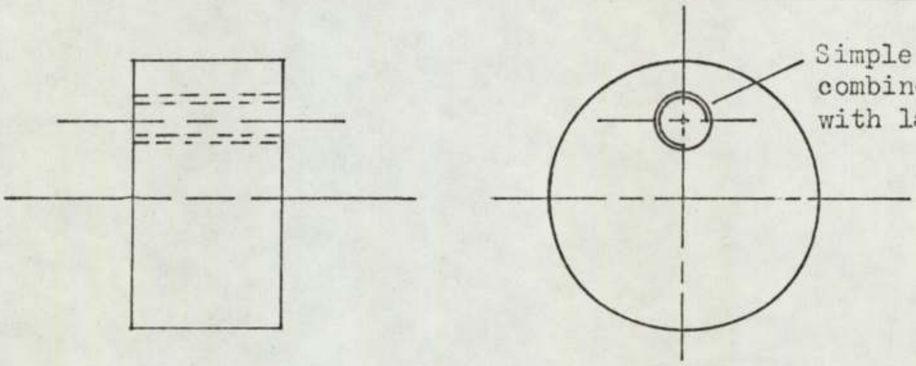
Cast Iron Spyder OPITZ CODE - 32603

Square faces and chamfers best machined by turning.



Mild steel tube OPITZ CODE - 10103

Simple off-set collet combines this componen with large bush famil

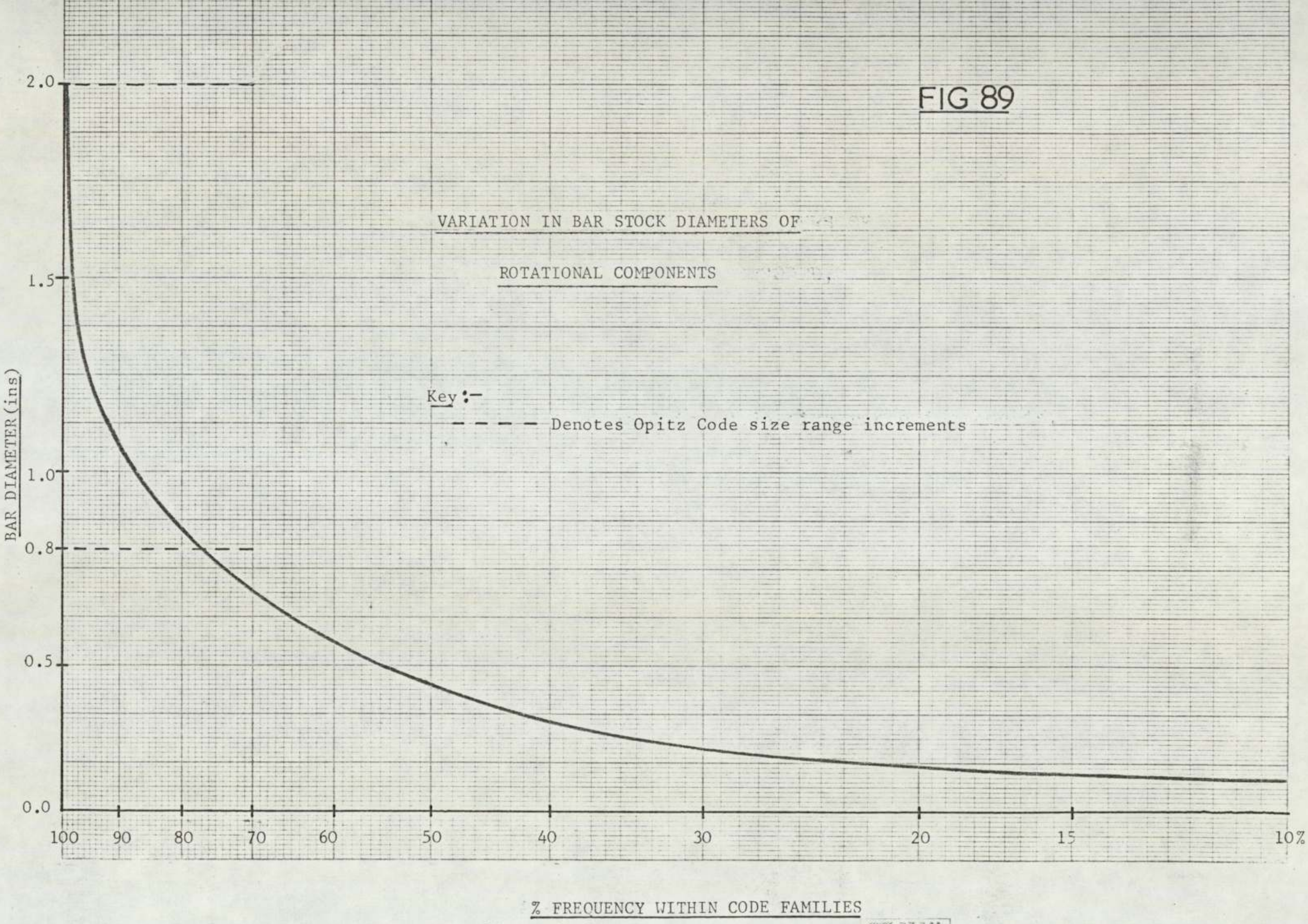


Distance piece OPITZ CODE - 10200

FIG 88

UNUSUAL COMPONENTS CLASSIFIED IN ROTATIONAL GROUPS

FIG 89



VARIATION IN BAR STOCK DIAMETERS OF ROTATIONAL COMPONENTS

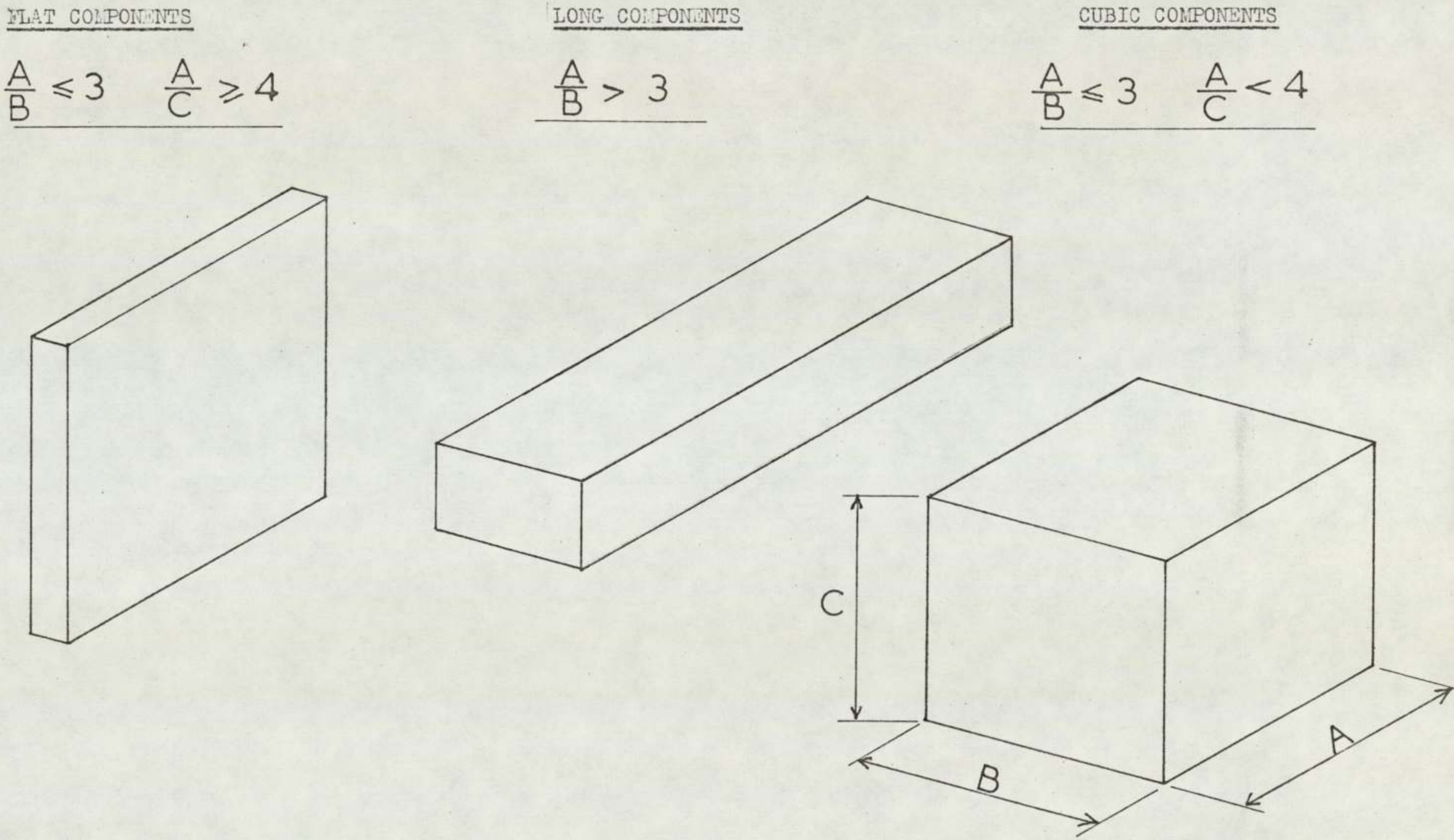
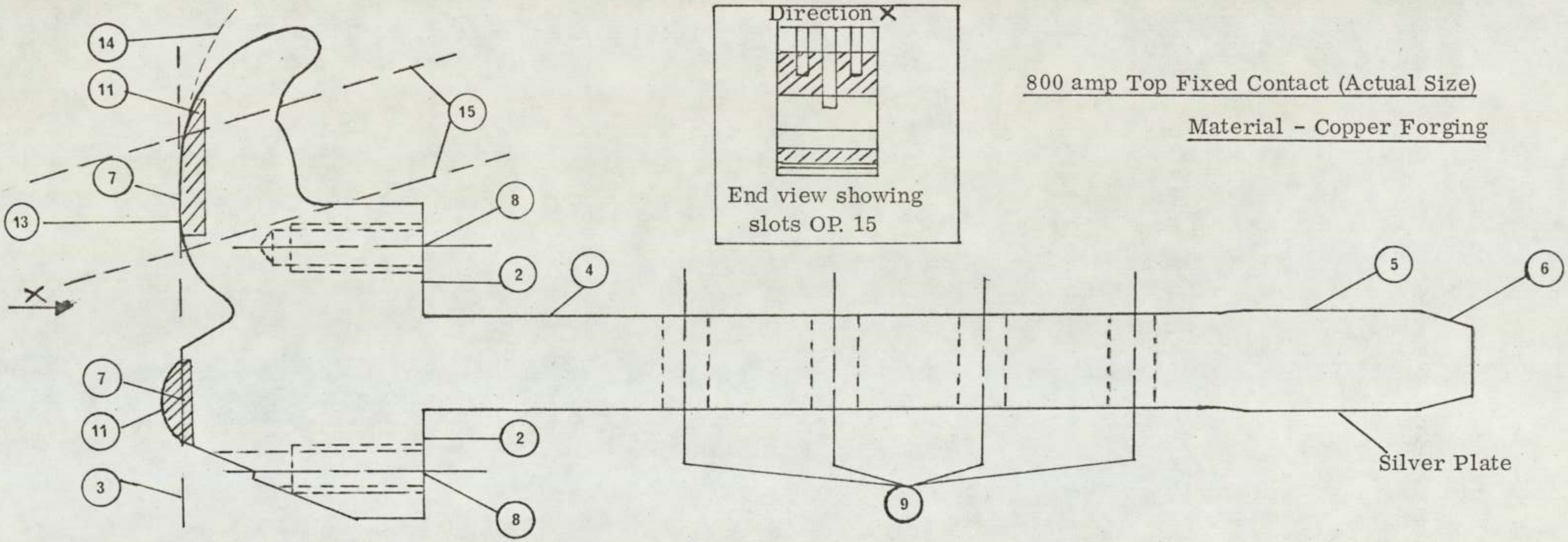


FIG 90

BASIC GEOMETRIC CLASSES FOR NON-ROTATIONAL COMPONENTS


800 amp Top Fixed Contact (Actual Size)

Material - Copper Forging

End view showing slots OP. 15

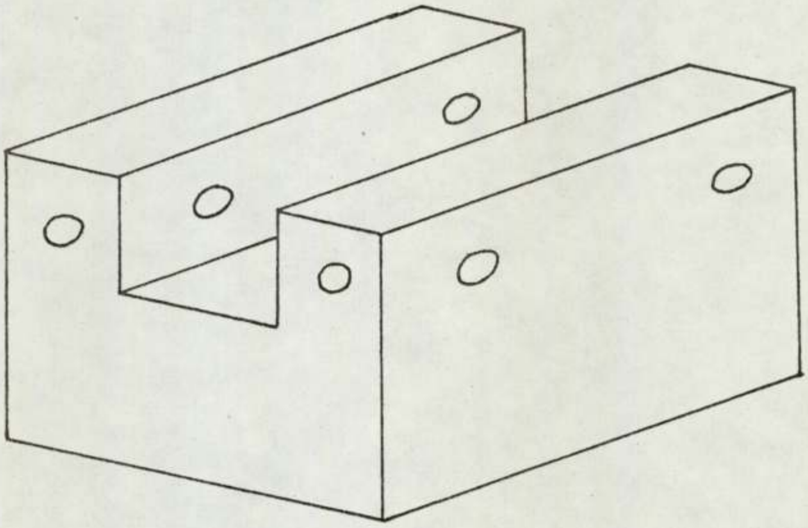
OP No.	1	2	3	4	5	6	7	8	9
Operation Description	Bench Check	Horizontal Mill	Horizontal Mill	Horizontal Mill	Horizontal Mill	Horizontal Mill	Horizontal Mill	Pollard Drill	Pollard Drill

OP No.	10	11	12	13	14	15	16	17	18	19
Operation Description	Inspect	Braze Tips	Linish	Vertical Mill	Horizontal Mill	Horizontal Mill	Linish	Inspect	De - grease	Silver Plate

FIGURE 91

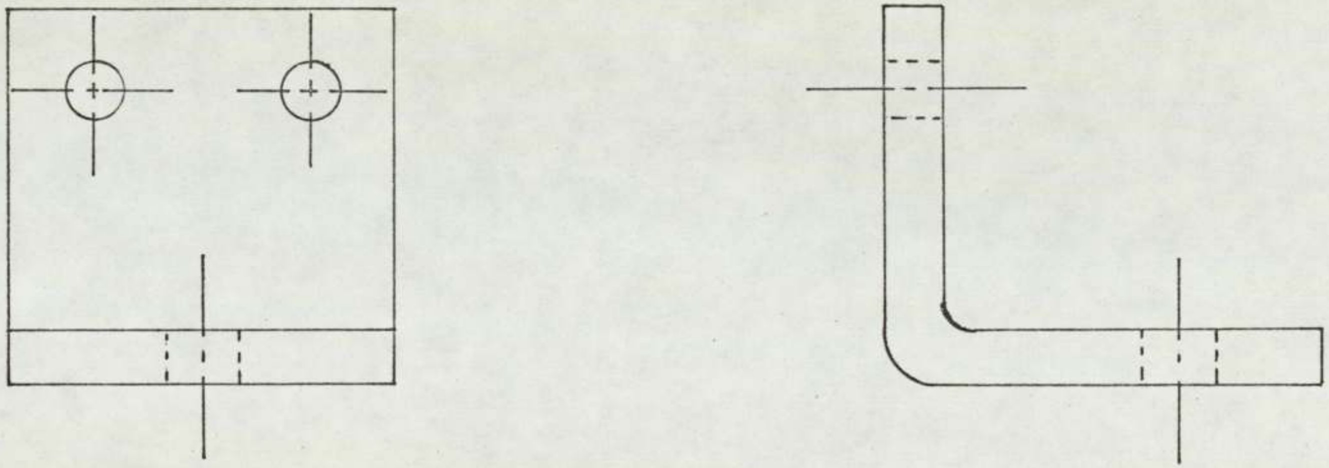
EXAMPLE OF COMPLEX PRODUCTION SEQUENCE WITH NON-ROTATIONAL COMPONENTS

FIG 92



OPITZ CODE - 80052

NON-ROTATIONAL COMPONENT SHOWING SIMPLE AUXILIARY MACHINING FEATURES WHICH DO NOT CHANGE THE PRIMARY IDENTITY.



OPITZ CODE - 71006

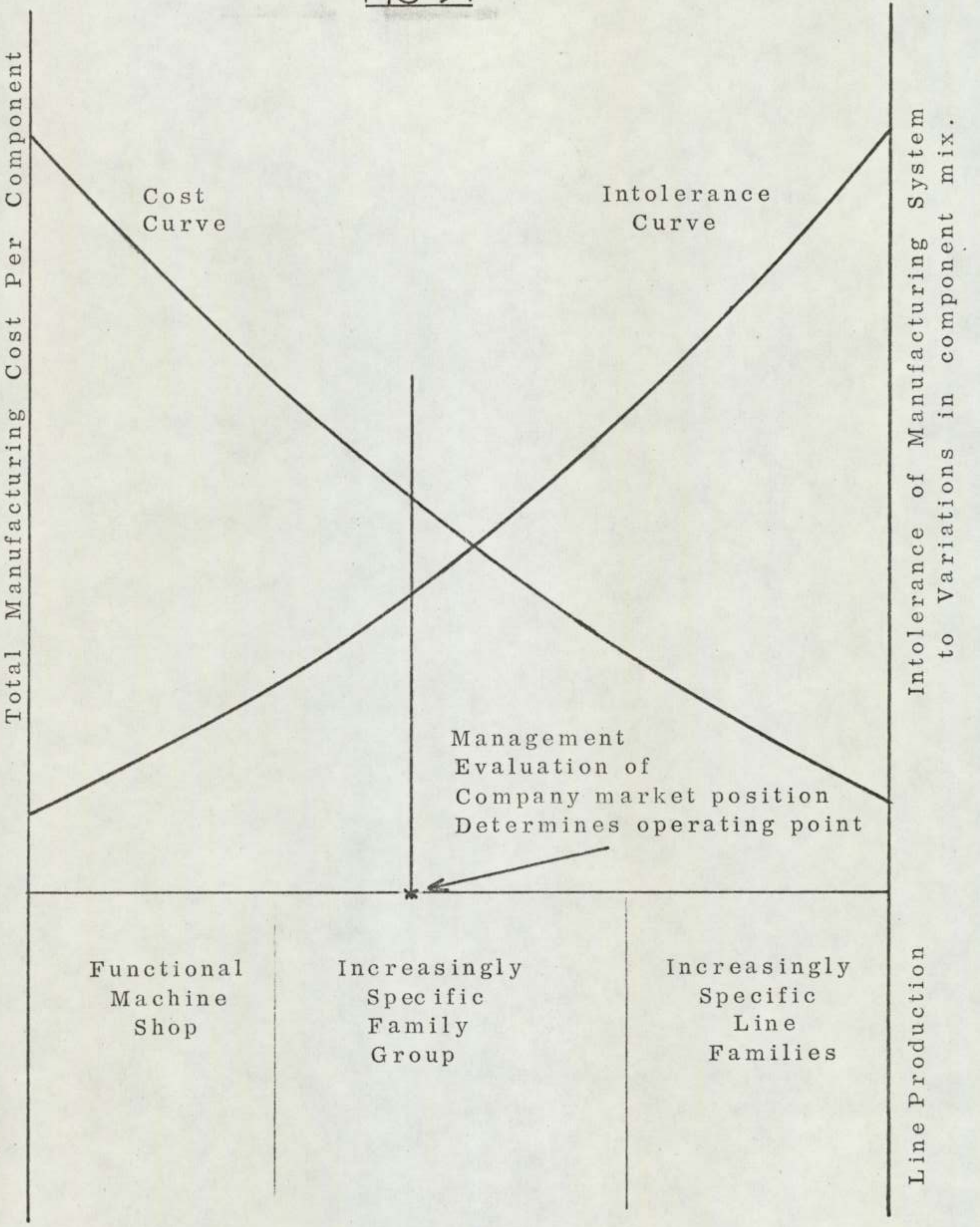
Formed components may only be described under the Opitz primary class digit 7.

Convertions must be adapted for the description of more complex formed components.

FIG 93

TYPICAL SIMPLY FORMED COMPONENT AND IMPRECISE OPITZ DESCRIPTION

FIG 94



RELATIONSHIP BETWEEN GROUPING COST AND FLEXIBILITY

(After Lewis)

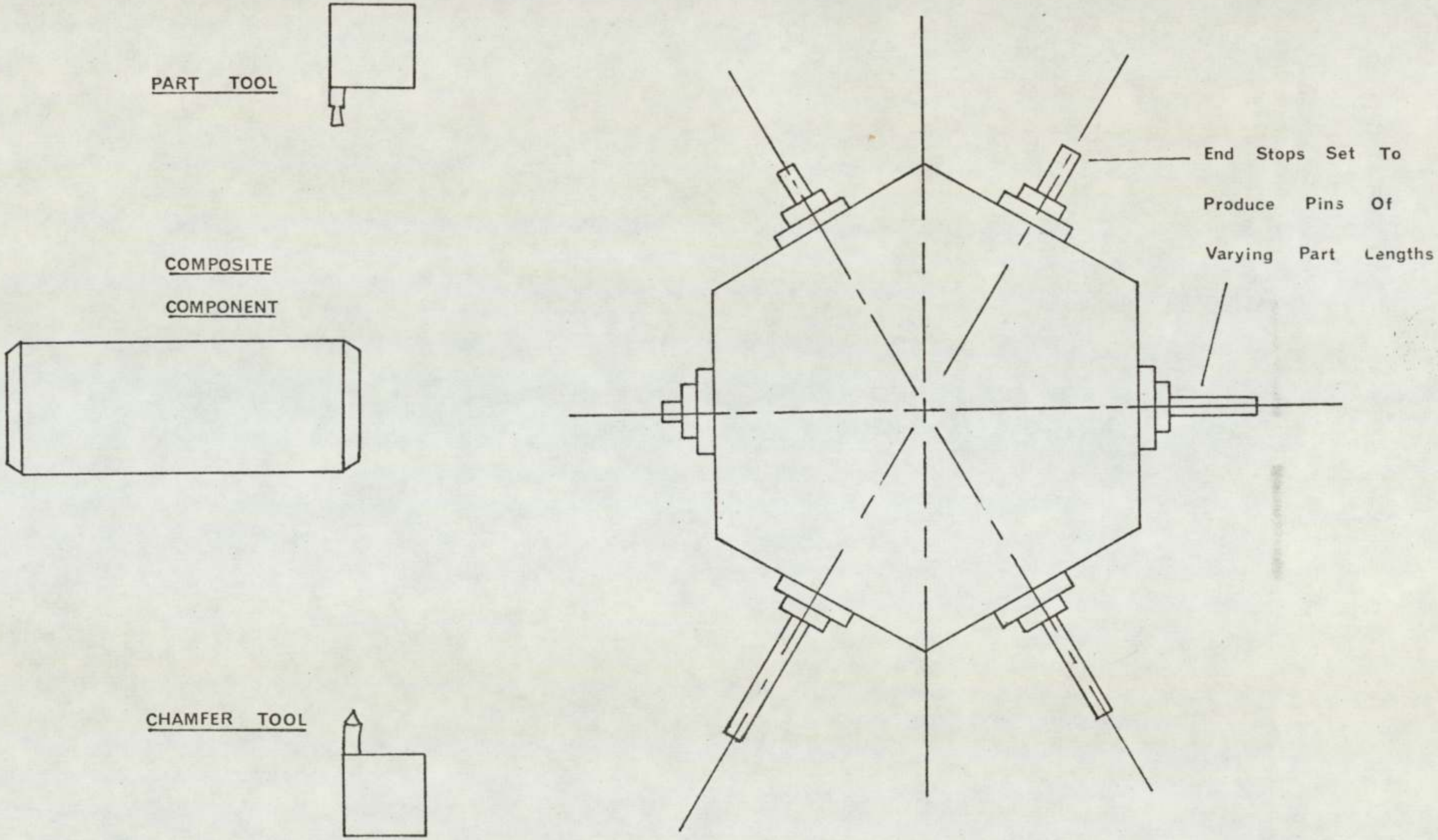
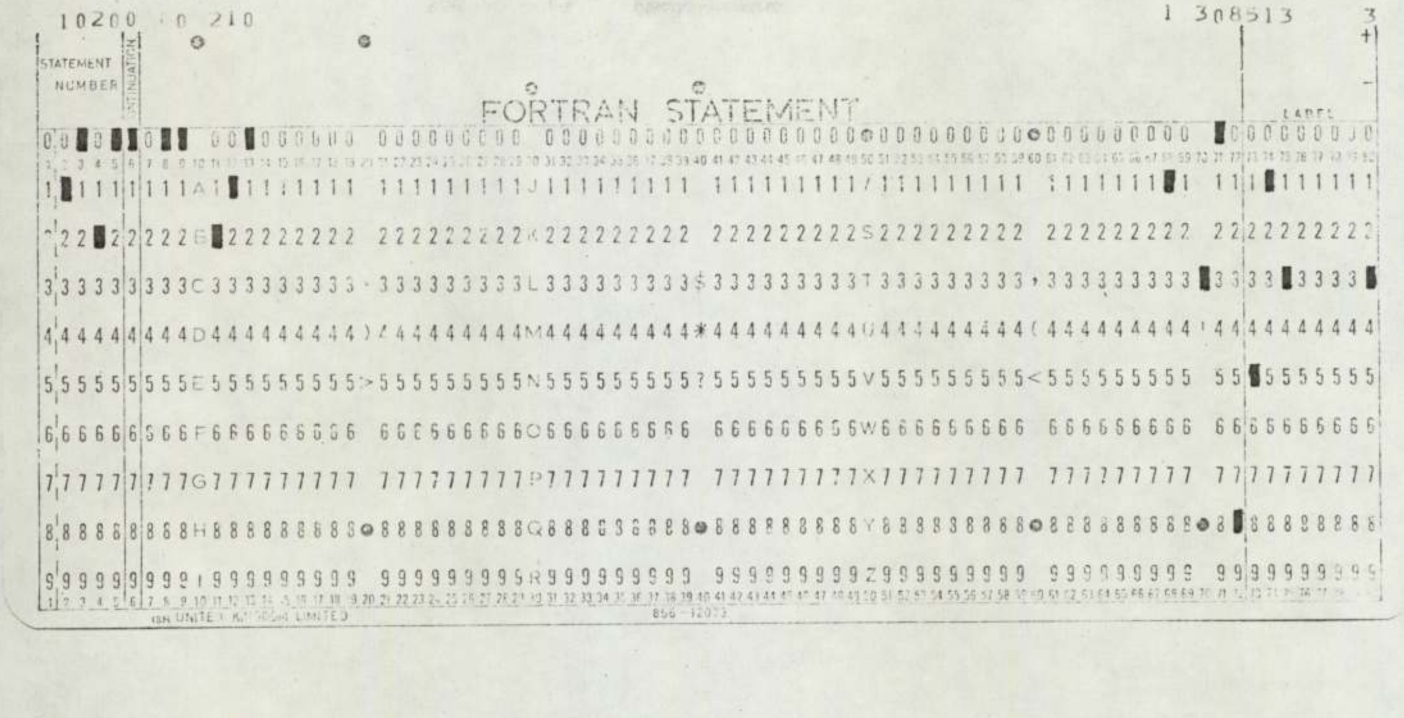
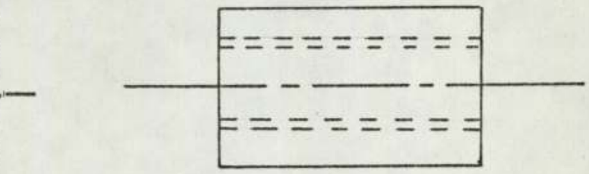


FIG 95

CAPSTAN HEAD SET UP TO PRODUCE SIMPLE PIN FAMILY



```
10130 12 230
10103 01 219
10133 11 217
10133 11 217
10200 00 210
10200 00 210
10200 00 210
10200 00 210
10200 00 210
10200 00 210
10200 00 210
10200 11 711
10203 01 214
10203 12 210
10223 12 219
10233 01 214
10233 11 214
10133 12 318
10400 11 730
10450 44 230
10505 22 211
11000 00 210
11000 00 210
11000 00 210
```



```
3 220896   77
1 310223   52
1 021858    8
1 021958    8
3 205323   28
3 205368   30
3 220158   35
3 220081   34
3 205368   30
3 205323   28
1 308513    3
3 220747   43
1 306488   16
3 220606   41
3 220373   46
1 305582   14
3 220374   46
1 310043   52
1 001882   62
1 320662    1
1 339401   93
3 205291   27
3 205567   31
3 205291   27
```

FIG 96

PUNCHED CARD AND SECTION OF PRINT OUT FOR A PARTICULAR COMPONENT