Aston University

Some pages of this thesis may have been removed for copyright restrictions.

If you have discovered material in Aston Research Explorer which is unlawful e.g. breaches copyright, (either yours or that of a third party) or any other law, including but not limited to those relating to patent, trademark, confidentiality, data protection, obscenity, defamation, libel, then please read our Takedown policy and contact the service immediately (openaccess@aston.ac.uk)

Engineering Improvements in the Quality Production of Boiled Sweets

M.P.Corcoran 1982

The Department of Interdisciplinary Higher Degrees.
The Univerity of Aston in Birmingham

A Thesis submitted for the award of Doctor of Philosophy

SUMMARY

This thesis describes the procedures developed to control the quality of centred boiled sweet production at the TREBOR factory at Chesterfield.

The current Quality Control theory and documentation of existing sweet process lines is examined and used as a basis to assess the problems and possibilities of implementing techniques in this application.

Initial statistical analyses of the range of centres produced and common defects are shown. From these analyses came a confirmation that the Quality Control organisation was essentially limited by the low level of process knowledge and technology and the high level of skill required to operate the current process.

Based on this analysis of the problem areas the major necessary improvements were then investigated and corrections implemented. These were the design of the rope sizing equipment, and the establishing of control and monitoring functions within the process.

A mechanism for rope sizing was then built, a larger and improved centre pipe was designed and installed, and these together with a photodiode camera system to monitor rope size and reject waste has resolved the problems not resolved by the original quality control system.

The results have been, a greater understanding of the way in which Quality Control organisations work in practice, and ways in which a high speed continuous and multivariable process can be altered to facilitate more effective control to enhance the product.

TREBOR have gained a manufacturing process line which is improved because of a clear increase in the understanding of the old process, and the modifications necessary to include features for the maintenance of better quality during production. Some of the operators' high skill requirement has been replaced with better designed equipment and in-process monitoring.

QUALITY CONTROL
ENGINEERING ANALYSIS
PROCESS DESIGN
PROCESS COMMISSIONING

MICHAEL CORCORAN
1982

CONTENTS

CONTENTS (contd.)

CONTENTS (contd.)

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (contd.)

LIST OF ILLUSTRATIONS (contd.)

LIST OF TABLES

LIST OF TABLES (contd.)

INTRODUCTION

This thesis describes the solution of a quality control problem experienced by TREBOR during the manufacture of boiled centred sweets.

This was outlined by the technical director as a persistent failure of the production departments, throughout the group, to manufacture uniform centred sweets containing a level of centre meeting the required standard.

Particular emphasis was laid upon the practical results required from the research. TREBOR would not be satisfied with a research period ending in a series of recommendations. Consequently, this thesis covers not only the research into the basic problem nature, but also the practical implementation of the procedures to effect remedies.

It was seen as particularly important that the process had to be changed in either its design features or its mode of operation. The choice between the two was left open.

The limitations placed on the method of research were significant; there was no pilot plant available, all test work to be carried out on existing plant and the resulting product was, as far as possible to be saleable. A further complication arose when, shortly after the start of research, the sales of the product experienced a major boom period.

There was considerable support for the research at factory level, in that this specific problem had already been the subject of extensive 'in house' development. As a result, there were already a wide number of differing views regarding the cause of the problem. Although these views were largely unsubstantiated and could not be supported by objective repeatable tests they were strongly held and, at times, particular lines of enquiry met with some personal opposition. However, the general attitude at factory level was to support the research activity.

The first part of the thesis examines the basic requirements for effective quality control. An analysis is made of the size and scale of the problem and this is examined to establish whether currently available techniques can be applied. A review of the literature and published information is then reported to highlight the current level of knowledge concerning this process and its design features.

The research then examines the various theories put forward by the operators and process developers in order to produce tried and tested problems which are likely to be major causes, and to separate out those theories which have little basis in fact, or cannot be substantiated. This is done on the basis of an engineering analysis, since the main points illustrated by the product analysis were specifically concerned with poor level control of the centre contents and poor control of the alignment of centres within the sweets.

The major problem causes were identified to be in the rope forming process and the dimensions of the [illegible] used to add the centre material.

The latter part of the thesis deals with the redesign of these elements and the commissioning of prototypes.

A photo-diode camera system was designed and installed to monitor rope size and to reject sweets having major variations in size prior to wrapping.

A new method of rope forming is described and was designed using technology transferred from the steel industry. Its performance enables smooth continuous production, and at the same time substantially reduces waste, labour content, skill requirements and improves finished product quality. A new large diameter, tapered centre pipe was designed and installed resulting in greater control of the range of centre content material.

A pressure sensing device was installed to give information on the flow of centre material, it indicated variations of flow-rate and some of the possible causes. This was later adapted to give a continuous record, and also to reject batches of solid sweets which should have contained centre material.

Each of the elements represents an improvement on its own merits, collectively they represent the complete solution of the original quality control problem.

The results of the research are not only measured in tangible benefits to the TREBOR manufacturing departments, but can also be measured in the increased knowledge of the technology of the existing process.

The limitations of using statistical techniques of quality control are shown, and the importance of using engineering analysis as part of quality control theory is shown to be paramount.

The transference of major sections of readily available technology from the steel industry to the confectionery industry represents a fundamental contribution to the solution of this problem and illustrates how similar technologies may be relevant in seemingly unrelated industries.

The particular value of the research carried out is best examined as a concept of solving industrial problems using engineering analysis and technology transference. The result is the use of existing techniques and technologies, but altering their application to suit the particular problem and industry.

THE PROBLEM SPECIFICATION

THE QUALITY PROBLEM AT TREBOR

The Problem Specification

The problem as specified by TREBOR was a consistent failure by their production departments to produce centred and non-centred sweets meeting the agreed Quality Specification.

Substantial quantities of sweets are involved. The Chesterfield factory produces over 10,000 tonnes of boiled sweets per year.

The process line on which the sweets are manufactured is laid out as follows :

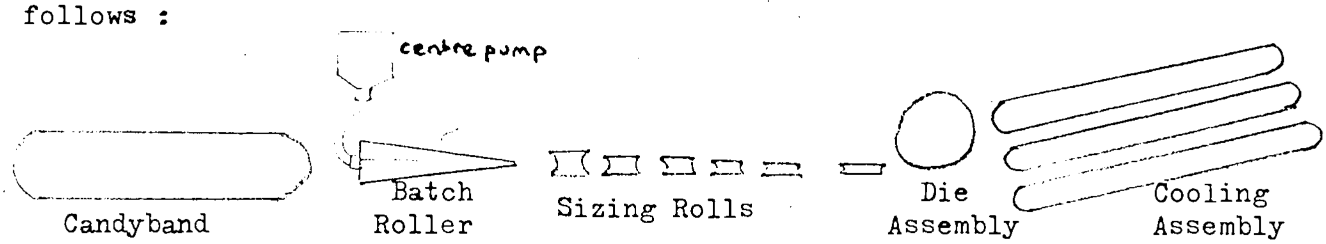


FIG. 1 - SCHEMATIC DIAGRAM OF THE MANUFACTURING PROCESS

The Candyband is a moving steel band which acts as a heat exchange unit to transport the molten sugar from the cookers to the forming process, removing heat continuously.

The batch roller is a conical cavity which receives the sugar in the form of a strip and proceeds to blend this into a conical rotating mass.

The prefeed rollers draw the narrow tip of the rotating sugar mass into the sizing roll assembly which then rolls and draws the sugar into a narrow rope to be fed into the die assembly.

The Die assembly is a wheel type structure containing 40 plunger type dies which cut and form the sugar rope into a series of soft sweets.

These are then ejected onto fast moving belts which take the formed sweets into the cooling area.

The cooled, firm, sweets are then either weighed and packed into jars or passed on to a packaging department where they are mechanically wrapped in wax paper.

The Original Problem Specification came from the Technical Director and was supported with extensive evidence from the Quality Control organisation. The nature of the problem was that in none of the sweets designed to contain a centre was the level of centre content up to the specified quality standard. This was seen as a major problem and the terms of reference were, that this situation was to be changed, such that, the required centre content was maintained within each sweet uniformly.

Potential solutions were to be examined varying from alterations of the production and Quality departmental organisations, to alterations in aspects of process design or running. The choice was to be left open in order not to restrict the scope of research.

Initial Limitations

Whilst there was considerable support for the research, it was also evident that the research was to be carried out with a number of limitations.

Firstly, the scope of research was left open, but there was considerable emphasis on the practical impacts of the work.

Secondly, there was considerable pressure on the production department, originating from both the Marketing Department and Research and Development, to improve the quality of the product immediately.

Finally, because of the particular nature of the process, it was made clear by the production department that although experimentation and test would be accommodated, high volumes of waste were unacceptable. There was no 'pilot plant' available and as a result all test work would be carried out on standard process lines, the product produced would have to be saleable.

Collectively, these limitations emphasised the need for a well thought out research investigation. The most immediate danger would be that an improperly designed solution would be rushed into effect, the resulting consequences of failure would be immediately apparent and could have destroyed the credibility of later stages.

THE HISTORY OF THE DEVELOPMENT OF CURRENT QUALITY CONTROL THEORY

The development of the current statistically based quality control techniques can be traced over the past 80 years in the form of a draft –

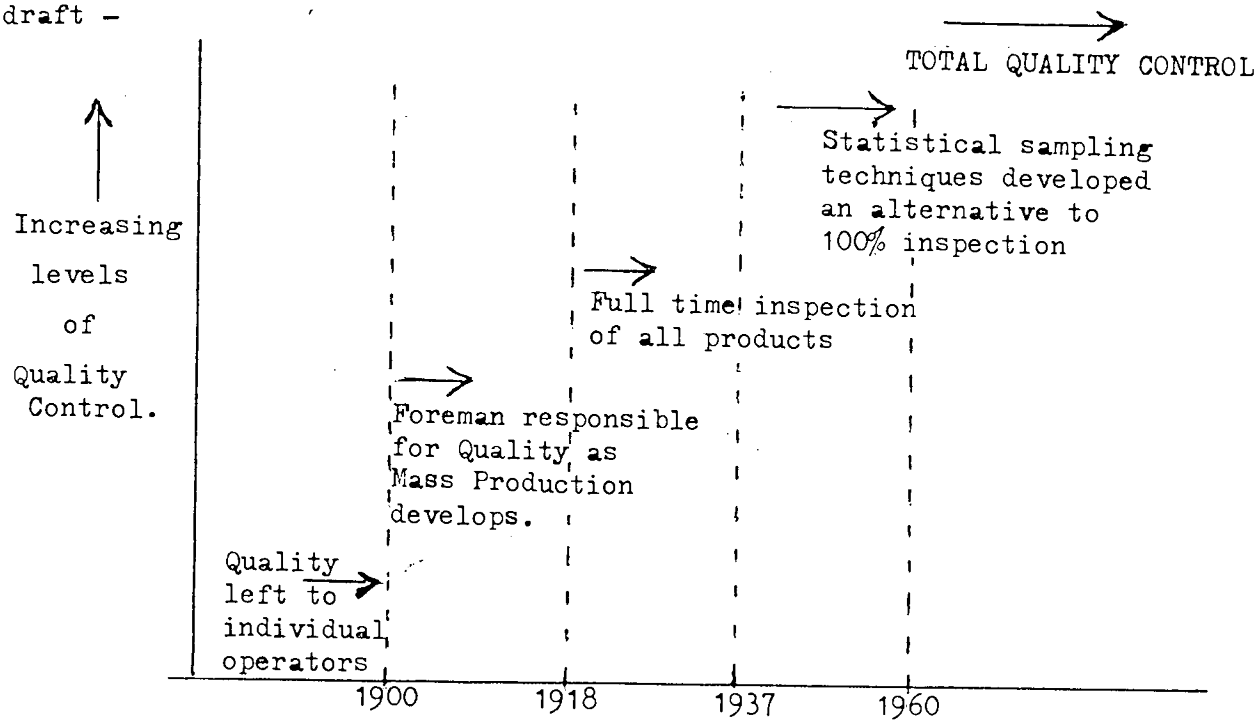


FIG. 2 – THE HISTORICAL DEVELOPMENT OF QUALITY CONTROL

This chart developed by Feigenbaum[1] is a clear illustration of the historical development. TOTAL QUALITY control he outlines as a concept for 1960 development and he defines as:-

> 'an effective system for integrating quality development, quality maintenace, and quality improvement efforts of the various groups in an organisation so as to enable production and service at the most economical levels which allow for full customer satisfaction..'

Despite this view, many quality organisations within industry rely heavily on the pre 1960 statistical techniques and those developed since for multivariate analysis.

The implicit assumption of current quality control theory as outlined by JURAN[2] is that processes are controlled to an extent where higher levels are always available, but at a higher premium.

The major role identified for quality control organisations is that of monitoring the production operation, identifying the magnitude and range of defects and isolating the problem areas responisble for the greatest number of defects.

The responsibility then falls on the management structure to either ensure that the process is operated in such a way as to minimise the defects, or to change the problem areas so that the process can be operated smoothly with the minimum level of defects.

For the Quality Organisation to operate effectively the process and planning of its operation must contain several major elements.

JURAN[2] lists these as follows:-

- Choice of machines, processes and tools capable of holding tolerances.
- Choice of instruments of accuracy adequate to control the process.
- Provision of adequate manufacturing information.
- Planning of process Quality Controls.
- Selection and training of production personnel.

The process must be designed in such a way that, according to JURAN[2] -

- Operators must be aware of what they are <u>supposed</u> to be doing. (Specification)
- They must be aware of what they <u>are</u> doing. (Feedback)
- They must have the means for regulating the operation of the process. (Control)

If all of these elements are present, then effective quality control is possible.

If one or more is absent then it is the role of the quality organisation to identify which areas need resources from the management (because of the statistical analysis) and/or liaison with engineering process technologists.

In order to be able to carry out their function there must be a high level of process knowledge <u>and</u> process control.

Many of the case studies used to illustrate Quality Control techniques are based in industries and processes which contain substantial numbers of discreet elements, operations and processes. Typical industries quoted include the assembly of electrical components and mechanical sub-assemblies.

Machining operations are also particularly useful, since it is possible to examine aspects of quality on a 'before' and 'after' basis. In this way, the statistical analysis of the source of defects and measurements of error are particularly easy to identify.

In continuous process industries, several operations may be carried out before it is possible to examine a part produced product in which quality deviation may be occurring. JURAN[2] recommends continuous sampling and analysis to build up a picture of quality variations and possible causes.

With the growth of automation within the food and petrochemical industries, continuous sampling may result in the production of major volumes of product before correction can be applied, and in some cases the amounts can be unmanageable.

In areas of development where labour intensive and skilled operations are to be automated there may be a low level of process knowledge which further complicates the statistical analysis.

In automated or semi-automated continuous processes where multi-variable reactions are occurring, and part finished continuous sampling is not possible, then statistical quality control techniques are of little value.

It is proposed to examine how effective control can be established in such a process as exists in the food industry, or more specifically, the confectionery industry.

The particular process concerned contains all of the elements which make conventional statistical quality control most difficult to apply.

It is a continuous high speed multivariable high skill process which has no effective quality control, and about which there is little process knowledge.

THE EXISTING QUALITY CONTROL ORGANISATION

AND ITS PERFORMANCE

The factory at Chesterfield produces over 200 tonnes of confectionery per week. Of this, over 60% is high boiled, much of this 60% is also centred product.

The regularly tested aspects, measured by the Quality Organisation are as follows:-

- Count per ½ Kilo
- Shape
- Size
- Colour
- Level of Centre

Taking each in turn:

<u>Count per ½ Kilo</u> is a simple numerical way of checking whether the sweets are of correct weight. This is to stop "give-away", since many sweets that are roll-wrapped are not sold by weight, but by count i.e. 10 sweets/roll. Oversize sweets lead inevitably to loss of profit margins.

<u>Shape</u> -is a visual inspection to ensure that the sweet is correctly formed. Mis-shapes, as the term implies, are easy to detect.

<u>Size Inspection</u>- is carried out by placing the sweets in a copper tube end-to-end to see if 10,12, or more sweets are to standard.

FIG. 3 - <u>A SWEET SIZE GAUGE</u>

i.e.

Fixed Distance of open tube

If they fit they are the correct size, provided the number of sweets match the size of gauge.

This test is not really able to detect size variation until it reaches major proportions, since both this and count per ½ kilo will fail to detect combinations in a sample of small and large sweets, since the effects of 'underweight/overweight','undersize/oversize' tend to balance each other out.

Colour Inspection is very arbitrary, and subjective. Whilst the colour 'standard' samples may be held in Quality Control, major variations occur from this on the process line. Fading is quite common, and the main purpose of this test is to detect major colour variations within the sample, or drastic variations from standard e.g. black or brown sherbet lemons, or white coffee crunch.

Level of Centre - tests consist of - breaking the centred sweets open with a heavy metal object, and by visual subjective examination deciding whether there is sufficient to leave the process unaltered and the work unimpounded.

QUALITY CONTROL PERFORMANCE

The first studies on the high-boil process lines showed that the Quality structure was in continual conflict with both the process workers and the management structure. These disagreements arose because of the readily identifiable faults in the product, specifically:-

- low centre levels
- poor shape
- poor size
- high variations in count/½ kilo

In fact, on almost every level of quality inspection, the existing Quality Control structure was duty-bound to reject the product at regular intervals. This established directly that the product was defective. Quality, by agreed standards was poor and deteriorating. Conflict between Quality Control and Production was continual, and heated. The regularity of occurrence meant that significant volumes were involved, and also that the problem was real. The Quality Control records showed the gradual deterioration over years quite clearly:-

TABLE 1 - ACHIEVED QUALITY LEVELS

Number of weekly passes against standard 100% throughout the year	1972	1973	1974	1975	1976	1977
above 90%	13	34	1	-	-	-
" 80%	39	18	17	3	-	-
" 70%	-	-	32	42	47	19
below 70%	-	-	2	7	5	33
TOTAL	52	52	52	52	52	52

In the department producing the high boil centred sweets there are four process lines. These are Uniplast lines manufactured by Bosch, this is abbreviated to the notation - UP1, UP2, UP3, UP4, by the Production departments, the number denotes the particular line concerned.

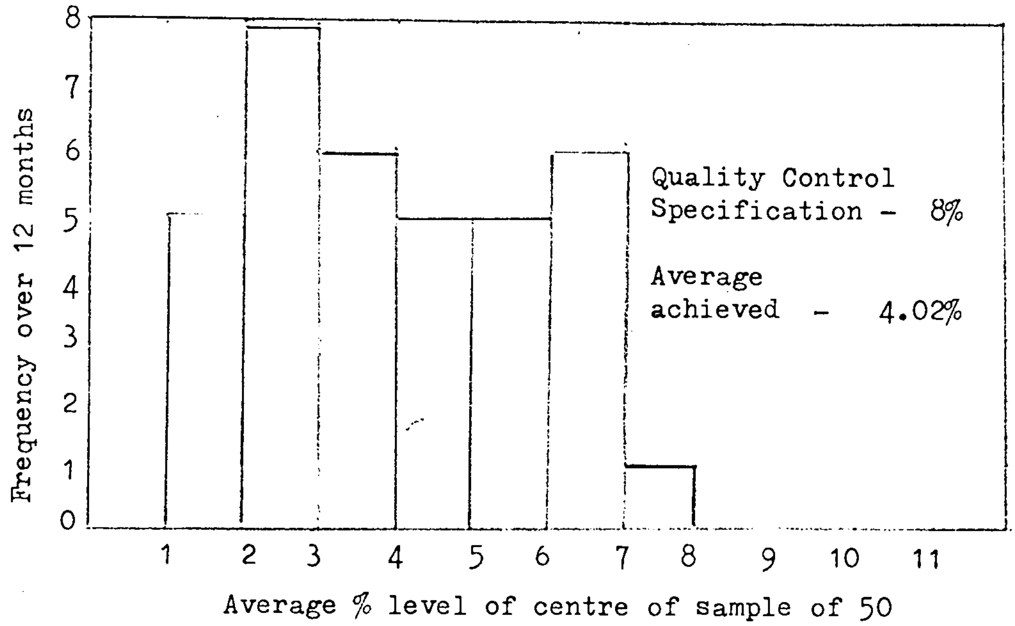
Of the four lines, three are continuously fed with sugar produced on a candyband, (moving steel cooling band). The remaining line UP4, is hand-loaded with hand-cooled and moulded sugar.

The next stage of analysing the performance to specification is to compare the achievements of each process line, to establish whether one particular line exhibits a better result than its neighbour.

The results are shown, compiled in histogram, from the Quality Records held at Chesterfield.

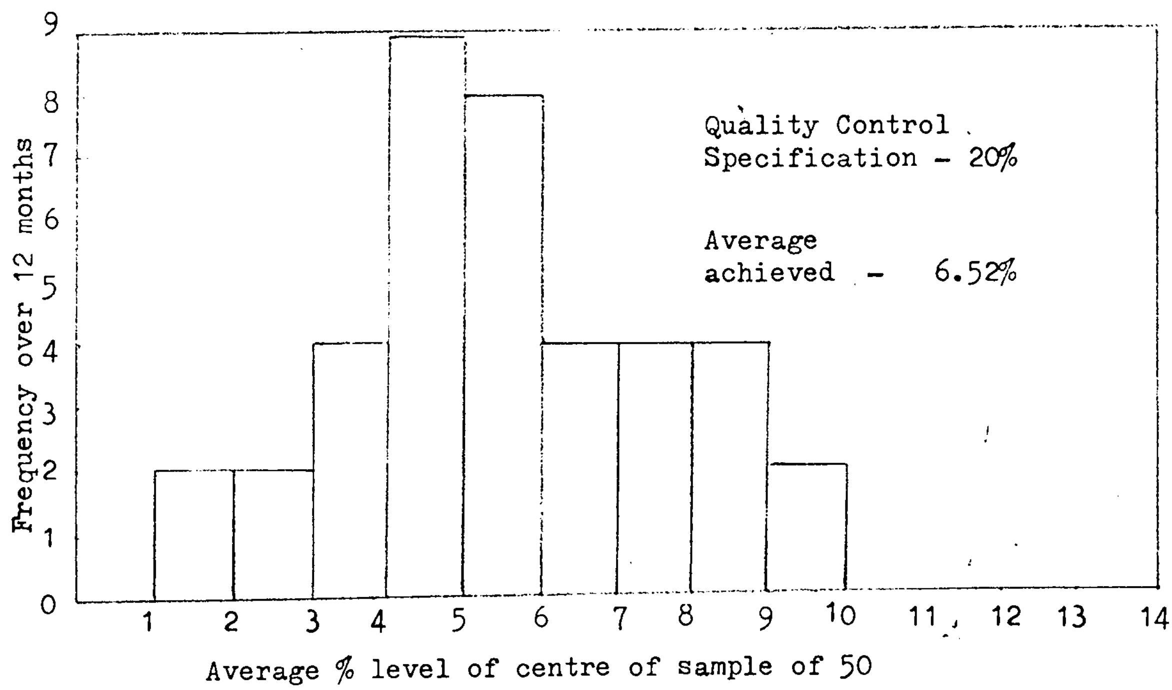
UNIPLAST 1

Sherbet Centres - FIGURE 4

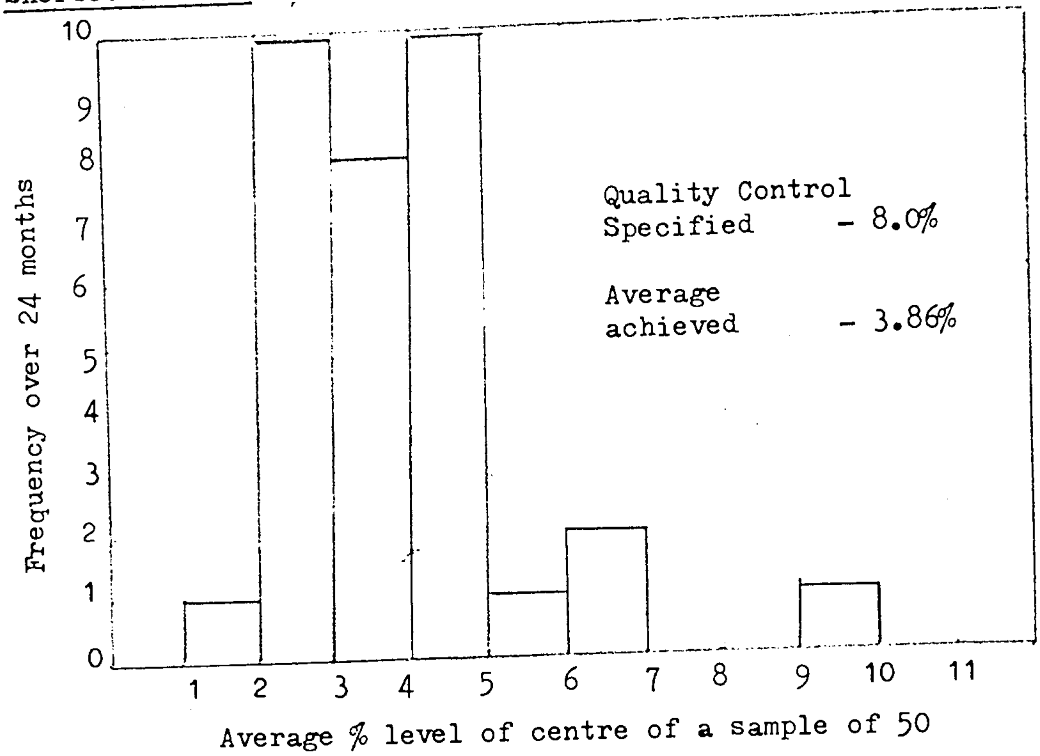


HISTOGRAMS SHOWING THE RANGE OF CENTRE CONTENTS PRODUCED OVER A PERIOD OF MONTHS

Chocolate Centres - FIGURE 5

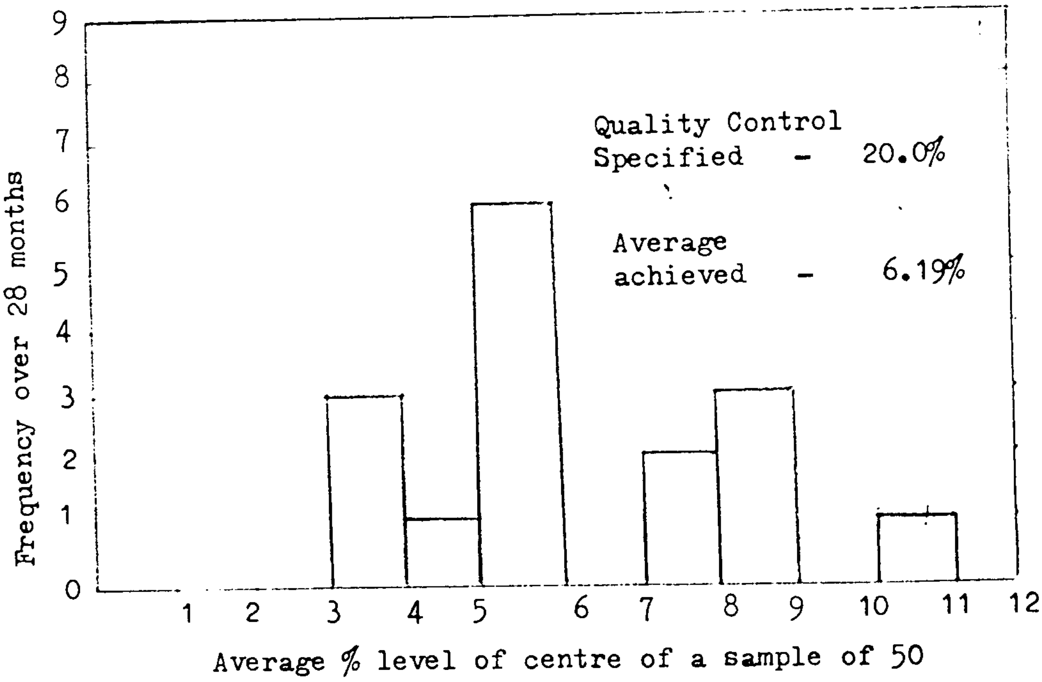


Sherbet Centres - FIGURE 6

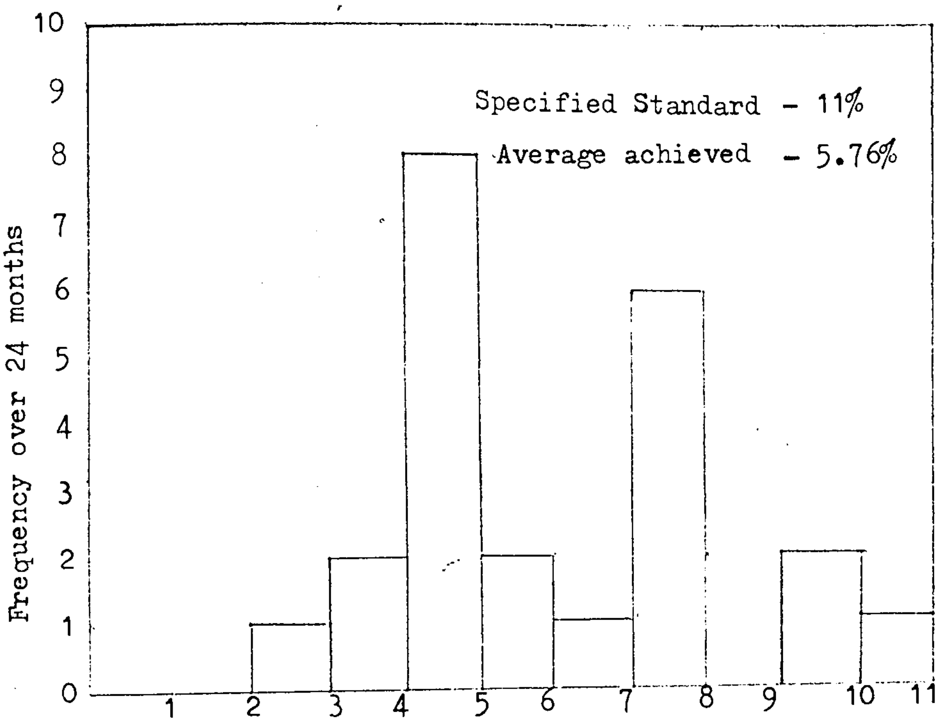


HISTOGRAMS SHOWING THE ACHIEVED RANGE OF CENTRE CONTENTS FOR UNIPLAST 2 OVER A PERIOD OF MONTHS

Chocolate Centres - FIGURE 7



Sherbet Centres - FIGURE 8

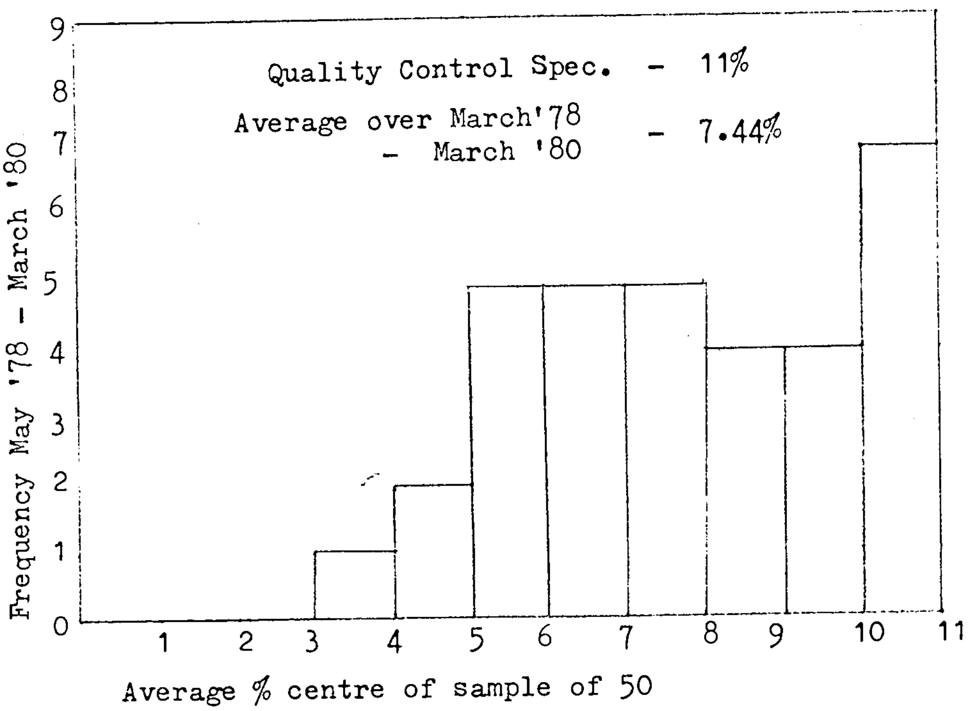


THE ACHIEVED RANGE OF CENTRE CONTENTS FOR UNIPLAST 3

Chocolate centres are not made on this machine, largely because of inconvenience. The end of its process line is not connected to the wrapping departments, since it is largely confined to jam, and sherbet centre manufactures. The choice is entirely due to its location within the factory.

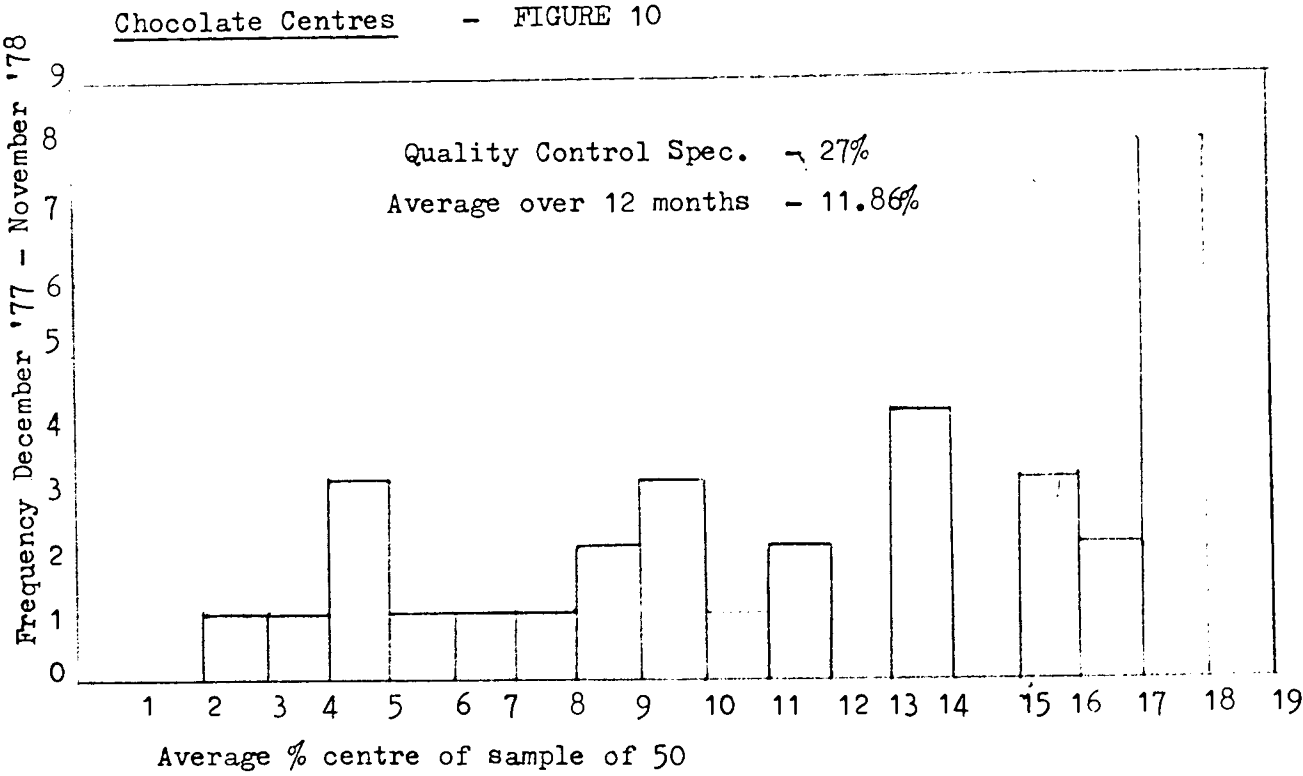
UNIPLAST 4 (Machine)

Sherbet Centres - FIGURE 9



THE ACHIEVED RANGE OF CENTRE CONTENTS OVER A PERIOD OF TIME FOR UNIPLAST 4

Chocolate Centres - FIGURE 10

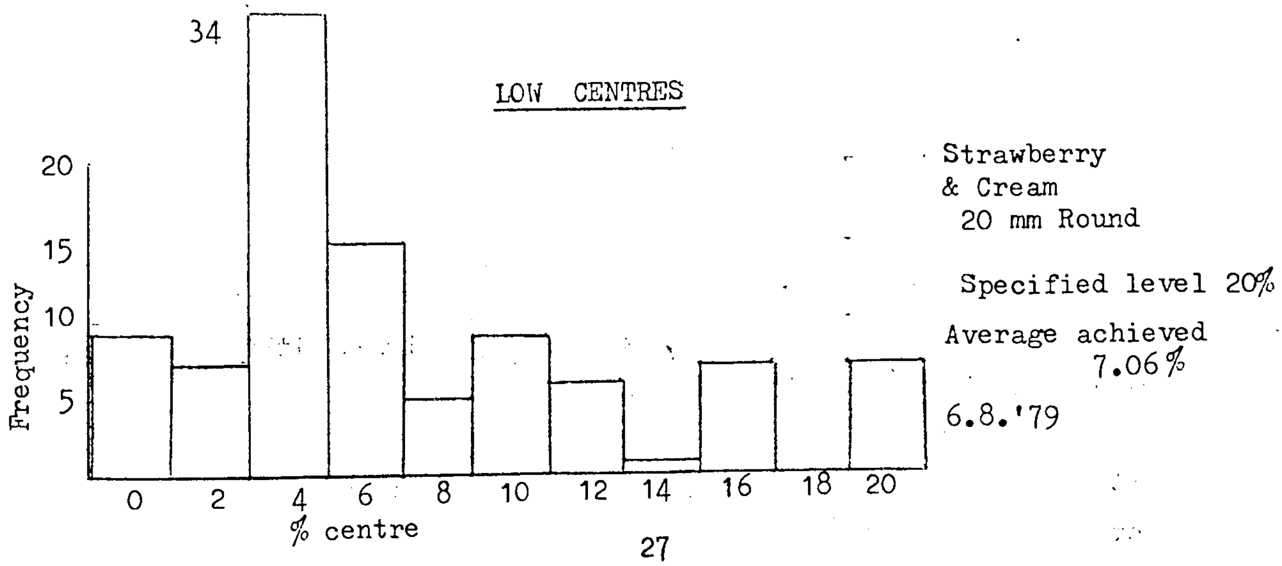


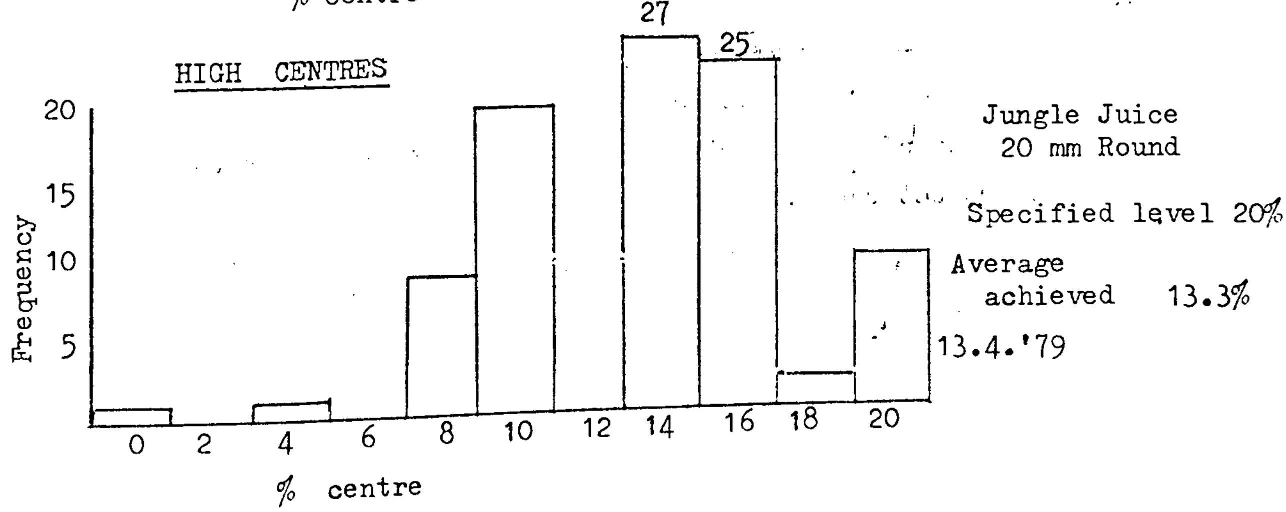
It is clear from these histograms that no particular process line produces a significantly better level of centre on either the chocolate or sherbet centred product. The range of centre levels produced is wide in all machine lines.

Analysis of the spread does not reveal any particular repeatability or even a GAUSSIAN distribution. In fact, the really noticeable feature of the distributions is their randomness.

The randomness of centre content is also reflected, in exactly the same way, in individual sampling. The diagrams below show the distribution of contents in 2 samples of 100 sweets from one batch. The variations are made over the sample average.
The actual average level can be increased or decreased by adjusting the centre pump speed, but the wide range does not alter.

FIG. 11 - THE FREQUENCY DISTRIBUTION OF CENTRE CONTENTS ACCORDING TO PUMP SPEED





Increasing the level of pumping does not guarantee that solid or low centred sweets are not produced. Equally, reducing the level of pumping does not ensure that dangerously large centres are not contained within the distribution.

These wide ranges illustrates how there has been a lack of control of the level of centres in all sweets.

Centre Alignment

The alignment of centres within the sugar case was also found to have marked variations. This showed itself on the production line in situations where, even though the average level of centre was low, the sweets were breaking during the handling and packaging process.

The explanation behind this effect is one of applied stress and the ability of the case to withstand it. A sweets' maximum impact resistance is a direct function of its minimum case wall thickness. As a result, a badly aligned centre with a thick case wall on one side and a thin case wall on the other has the same properties as a large centred sweet with the same equivalent thin case wall uniformly aligned.

Of the sweets examined, almost all were badly aligned within the case, varying only in the magnitude of misalignment.

Apart from sporadic or peculiar defects, it emerged that -

- poor alignment
- poor level control

were the cause of the majority of defects examinable for the whole product range.

REASONS WHY THE DEFECTIVE PRODUCT IS MANUFACTURED

To fully understand why the current situation exists, it is necessary to examine the process operation and performance in more detail, and it is best illustrated in the form of a flow diagram of the whole manufacturing process :-

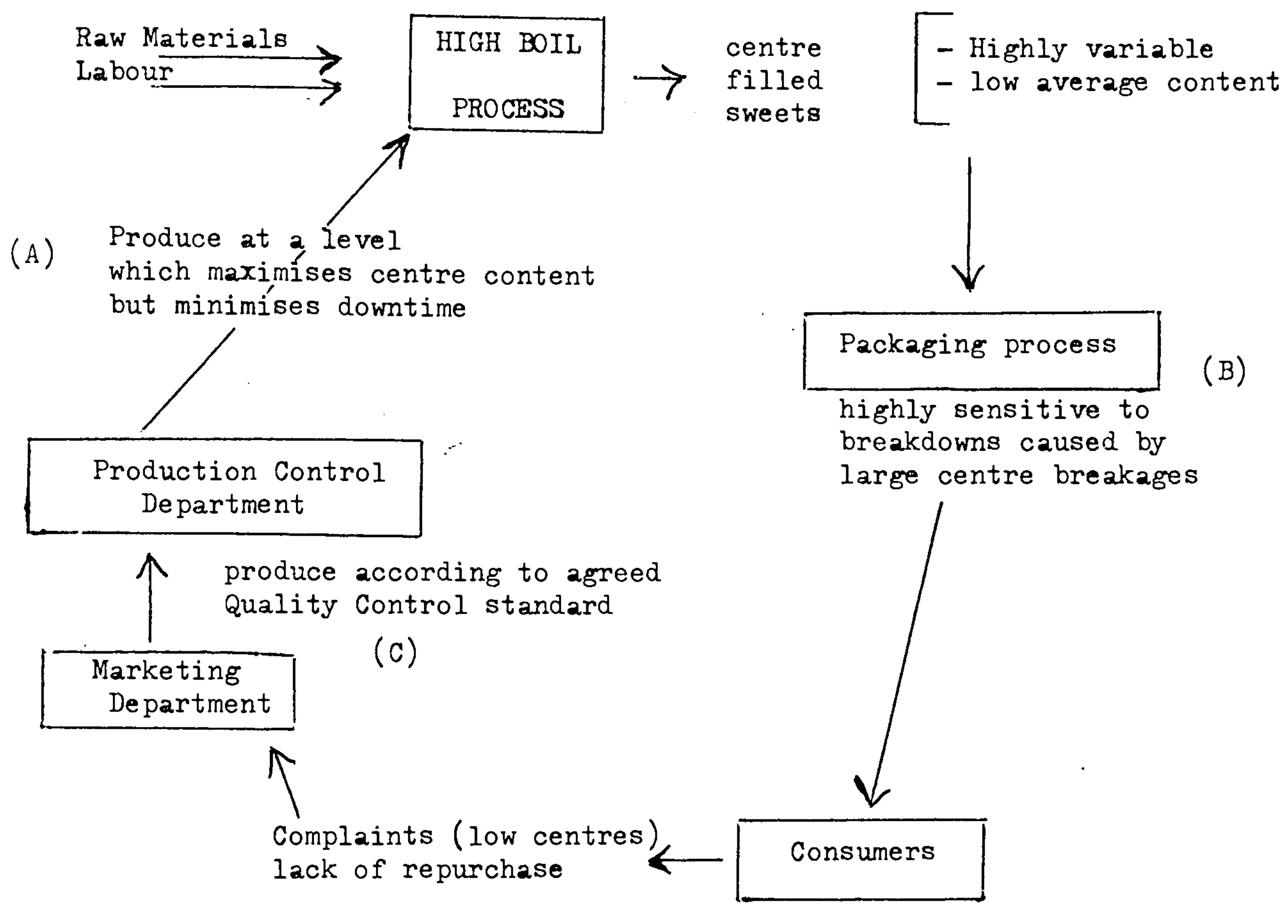
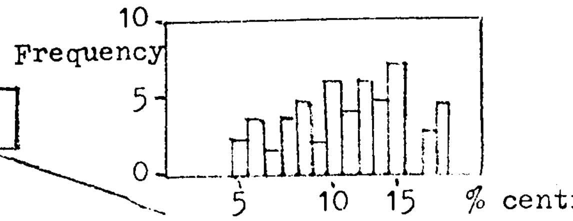


FIG. 12 – THE CONFLICTING DEMANDS ON THE MANUFACTURING PROCESS

The conflicting demands (A) (B) and (C) place the manufacturing department in an impossible situation. With current procedures unchanged, to produce sweets of required quality standard leads to problems in packaging, manufacture high waste levels, and major delays. These points are further illustrated in the following two diagrams:

OPTION 1

Typical Spread



PRODUCE HIGH CENTRES

Sweets break in wrapping and cooling

High Wastage

Increase in sorting and inspection

Clean down all assemblies. Use extra staff for sorting and cleaning.

Time/labour shortages, high wastage production not met. Adverse reaction through management structure.

Sweets burst in Die Assembly

Loss of £2000/hr in volume

Sugar build-up on tables

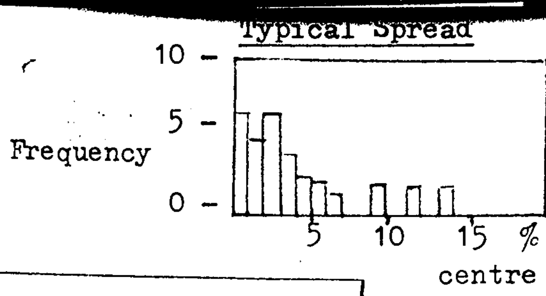
Run machine at higher RPM

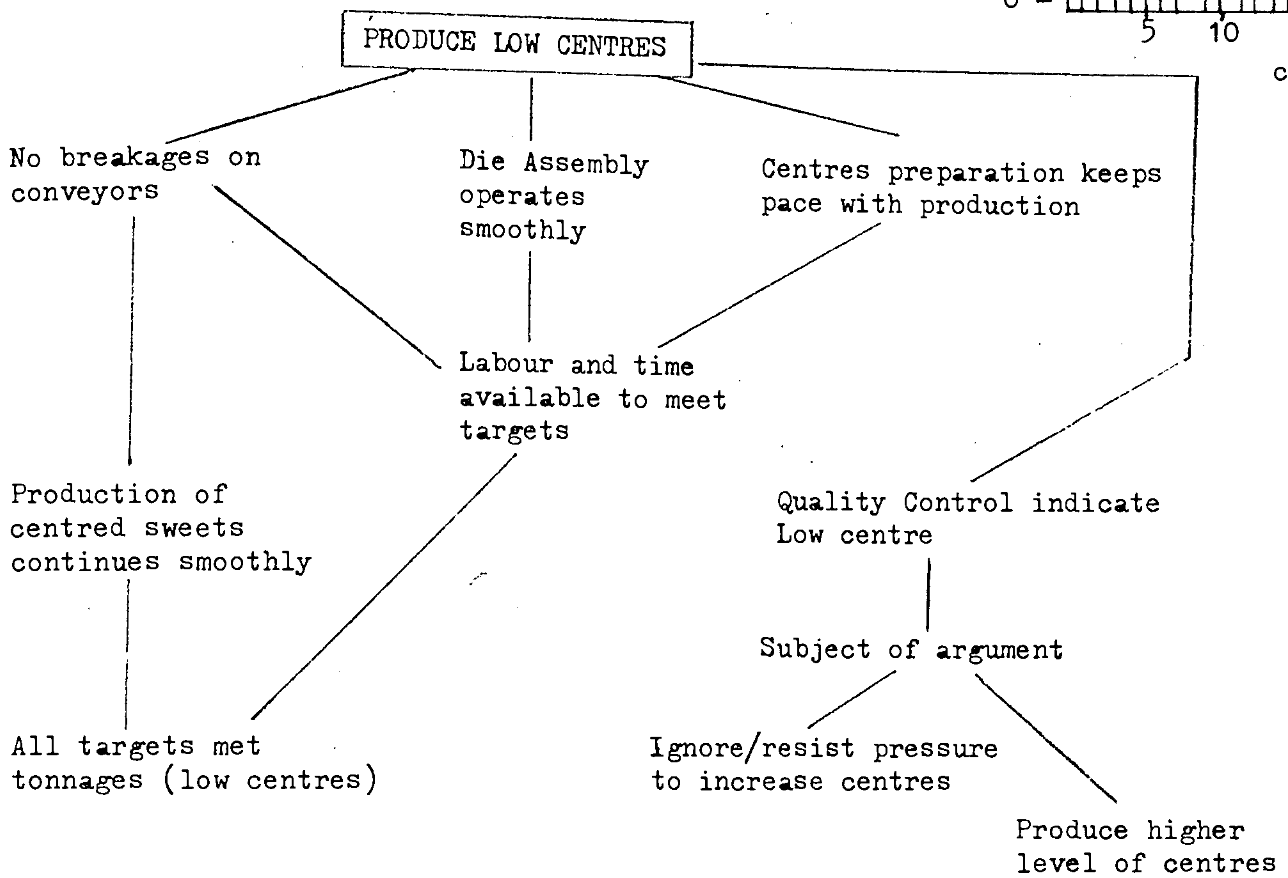
Turn down centre level to reduce break risk at higher RPM.

Outcome : - Produce lower centres to solve short-term problems.

FIG. 13 - THE EFFECTS OF ATTEMPTING TO PRODUCE A HIGH LEVEL OF CENTRE

OPTION 2





Outcome:- Sales decline - Market Research carried out - Is the fault of low centres or a seasonal/structural trend?

FIG. 14 - THE EFFECTS OF RUNNING A LOW AVERAGE CENTRE LEVEL

The most likely result of these two considerations is for the process to be run at the lowest acceptable level of centre, since this will create least problems.

The flow charts clearly show that to produce high centres creates immediate problems, and to switch to lower levels of centre immediately removes those problems and enables smooth continuous production.

IMPORTANT NOTE

It should be made clear at this stage that the process operating at present produces a range from solid to high centred sweets during any production run. The process is run at the lowest risk level, i.e. with the least chance of a caseburst or with the level of centre which gives the smoothest production runs.

In measured terms, this means that the average level of centre achieved varies between 10 - 40% of the level specified in the quality standards.

Level is the target, the spread of centres in any sample is still high, ranging from SOLID → 20% centres. But attempting to run the process at a higher average dramatically increases the risk of a caseburst and its consequences.

Moreover, it has been clearly shown in the diagrams that the effects and reaction to the problems arising from producing high centres are immediate, whereas the reaction to low centres will be extensively delayed.

The effect of failing to produce a uniform product which meets the specified standard is perceived by the marketing department to be an increasingly short product sales life. This is especially true of roll-wrapped 20mm round centred sweets. The product life-cycles show classic signs of early sales growth after launch which builds up to a peak and falls away rapidly. The expected matureation of sales does not occur and the interval between launch and cancellation of products has shortened, from 3 years in the early '70's to less than eighteen months.

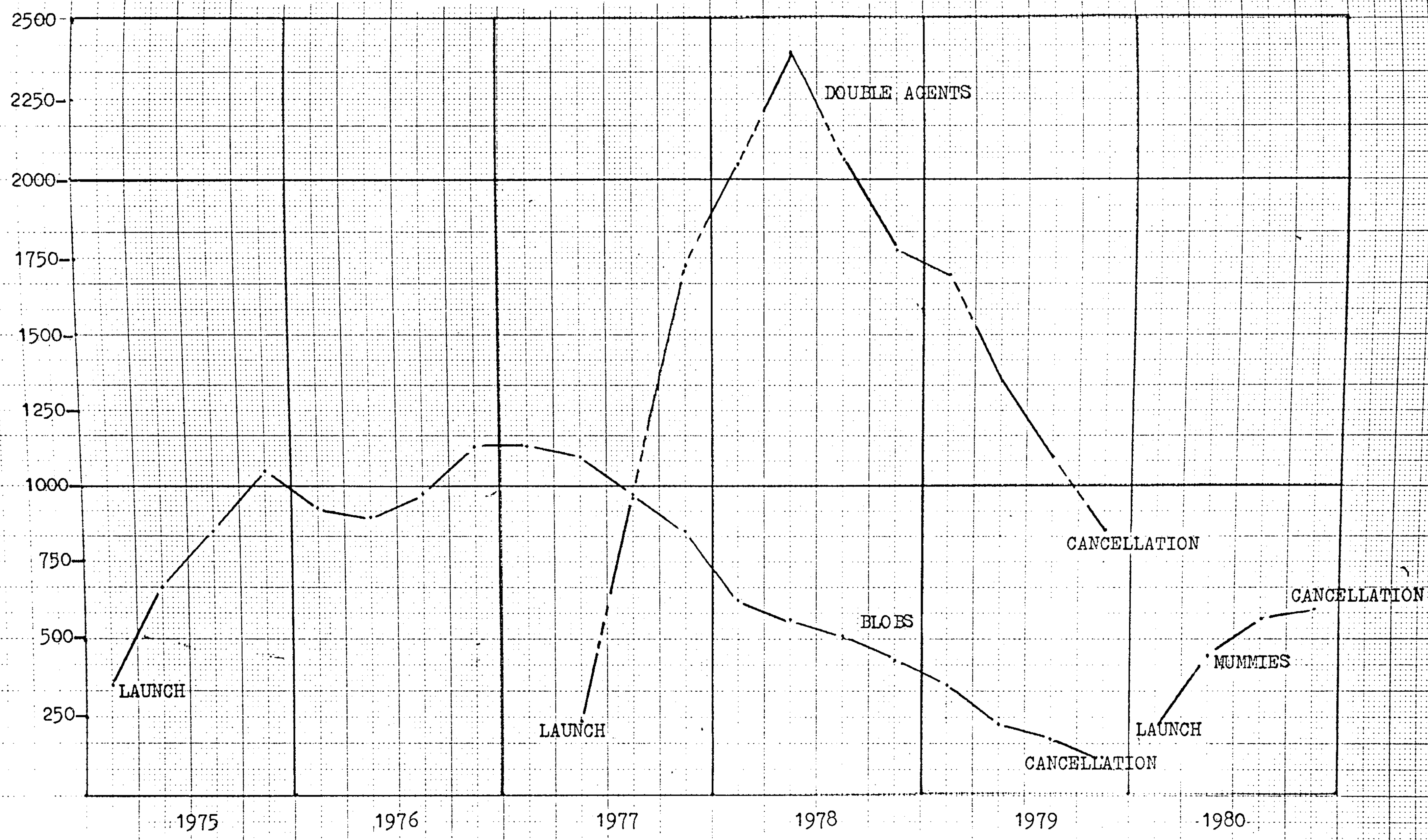


FIG. 15 – THE SALES PATTERN OF CENTRED 20mm ROUND SWEETS 1975 – 80

STANDARD QUALITY CONTROL

REMEDIES FOR THIS SITUATION

Feigenbaum[1] describes Quality Control as a continuous process consisting of four major steps :-

(a) Setting the quality standards.
(b) Appraising conformance to the standards.
(c) Acting when the standards are exceeded.
(d) Planning for improvements in the standards.

In the first case, the quality standards have been set in this situation, the decision on acceptable quality has been made and therefore cannot be considered arbitrary.

The second stage, appraisal, is done continuously, and it is quite clear that over the past decade the implicit terms of the standards have never been achieved.

The third stage, corrective action, assumes a level of knowledge and control which is not present in this case. If an adequate level of control was already available, then under certain conditions the quality specification would have been achieved at some point, even if only sporadically. This has not been the situation over the past decade.

The final requirement assumes that the previous three have been met, when in fact, only the first has been carried out.

JURAN[2] lists the following table as a guide for products which fall outside quality specifications:-

	Process meets specification	Process does not meet specification
Process inherently capable of holding tolerances	No action	Re-average process Reduce excessive variability Relax tolerances
Process inherently incapable of holding tolerances		Relax tolerances Change Process Suffer and sort

FIG. 16 – JURAN's RECOMMENDED ACTIONS FOR ACHIEVING QUALITY BY PROCESS CHANGES.

The conclusion to be drawn from this would be to change the process or to relax the quality specification. This first course, has been tried repeatedly by TREBOR, the major problem has been the complete lack of published objective data on how the existing process works. No change of process tried in the period 1970 – '76 resulted in quality specification being achieved.

The second alternative, to relax the specification, is considered unacceptable by TREBOR.

JURAN[2] also lists a method of determining process capability:-

(1) List the specified tolerances.

(2) Determine the average.

(3) Measure the natural or inherent variability of the process, (the instantaneous degree of reproduceability).

(4) Measure the actual variability of the process over a period of time.

(5) Establish the cause of differences between (3) and (4).

QUESTION	ANSWER
Does the process meet the tolerances?	Compare (1) (2) (4)
Can the process meet the tolerances by recentreing ?	(1) (2) (4)
Is the process incapable of meeting the tolerances ?	(1) (3)
Is it economically feasible to reduce variation so as to increase conformity to tolerances ?	(5)

As the histograms showed earlier, the average achieved level of centre was approximately 40% of the specified centre level. The specified centre level had never been achieved, and the variation over a period of time, ranging from 18 months to 3 years, showed no discernible pattern of reproduceability.

In terms of Quality Control applications to complex continuous multi-variable processes such as this, virtually all three major texts are in agreement that this is the type of area for future development in Q.C. techniques.

JURAN[2] gives a general advisory diagram for building quality into a system, but again the basic assumption is, that there is sufficient background knowledge on the operation and control of the process to implement corrective action.

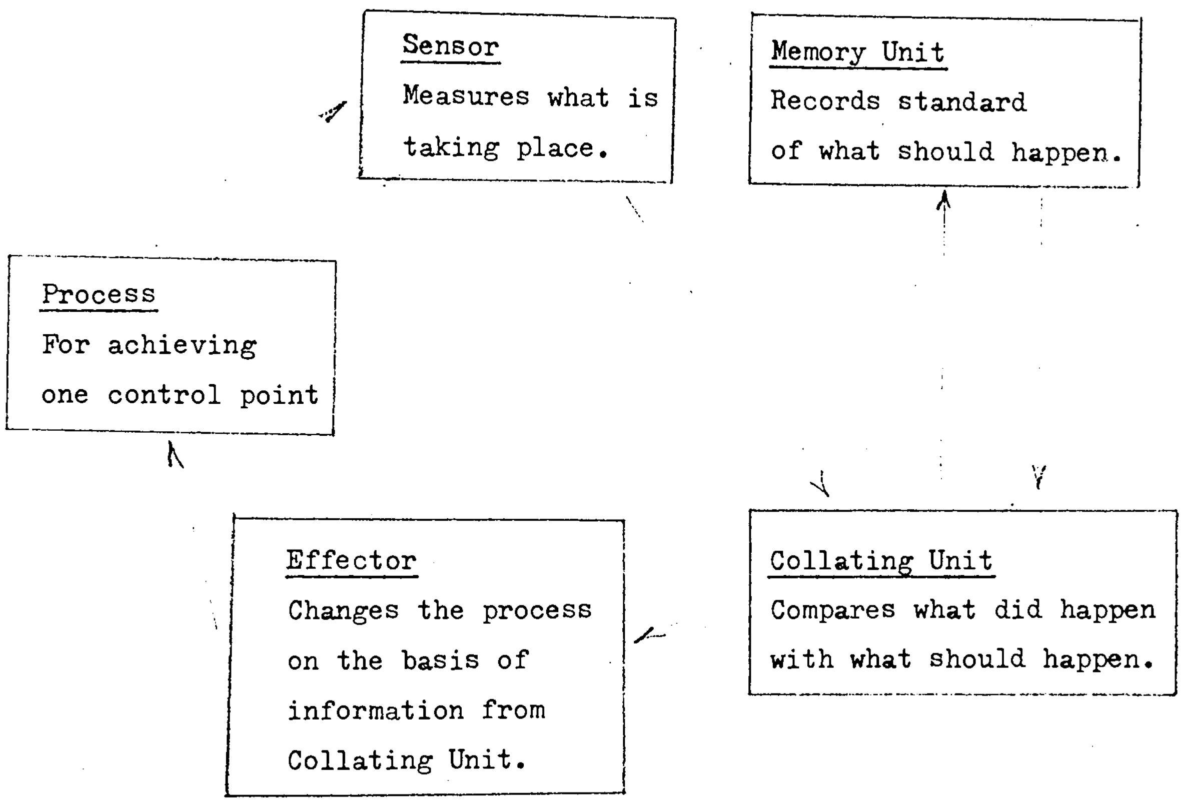


FIG. 17 - JURAN'S QUALITY SYSTEM FOR CONTINUOUS PROCESS CONTROL

Niebel & Baldwin[3] go into more detail in their description of the particular problems of continuous processes and high speed processes, in relation to necessary levels of quality. An example is quoted of a high speed assembly plant fed by a track, bringing washers at a rate of 1440 per hr. Even if only 1% of the product is defective, this represents 14 machine stops every hour, or, 1 every 4 minutes where the defective washer has to be removed from the jammed track.

In the TREBOR situation 5,000 sweets per minute are manufactured, feeding 12 packing machines. One defective high centre or badly aligned case causing a breakage will shut-down one of the machines. Since they are all fed from the same track, 12 well placed high centres could shut-down the entire packing process for over 5 minutes. To safeguard the production of high centres the process must be capable of over 99.8% accuracy, otherwise the risk of major stoppages will be alarmingly high.

Niebel & Baldwin[3] outline two further interesting points:-

> 'The detailed development of an analysis may demand, particularly on complex processes, comprehensive knowledge of the related process technology.
>
> 'Active participation in special studies may therefore be required from plant process specialists and technologists'.

The comprehensive knowledge and its availability will be the subject of the next section.

The active participation in quality control design by specialists and technologists is echoed by Feigenbaum[1]:-

> 'Quality control is an aid to, not a substitute for, the good engineering designs, good manufacturing methods and conscientious inspection activity'

In a case study used by JURAN[2] in the steel industry, the absence of effective process knowledge and control is also seen to be fundamental :

> 'Despite the inroads made by science in the 20th Century, certain phases of the processes are still considered by many to be more of an art than science. The highly developed know-how of a blast furnace operator, the great skill of the open hearth or electric furnaceman, and the seeming intuition of the Bessemer blower are not to be learned from books, but are acquired by many years of intimate experience'

The picture that emerges from all of these texts is the inadequate knowledge of how to apply quality control techniques to continuous processes. In all cases emphasis is made of the need for extensive process behavioural knowledge.

Moreover, it is accepted that there is a limitation on the use of statistical techniques on a 'closed process' where complex multivariable reactions are taking place.

The TREBOR problem presents an ideal illustration of all of these aspects:-

- continuous process
- high speed process
- very low defect tolerance
- process incapable of meeting specification

The need here is for an application of techniques and analyses outside the quality control function, and at the same time also provides a unique case-study for taking Feigenbaum's[1] concept of 'TOTAL QUALITY CONTROL' and establishing its relevance and possible benefits.

THE EXISTING KNOWLEDGE

OF PROCESS DESIGN

Several factors complicate a review of the literature in this field. Firstly, confectionery has been, and still is, regarded as a high skill industry.

Secondly, the term confectionery covers most sugar confections ranging from chocolate to cream cakes.

Thirdly and most fundamental, the low technical level of published information available. Books are published which attempt to cover and update confectionery knowledge, once every 20 years.

The earliest references go back as far as Egyptian Hieroglyphics, but for the purpose of this research, the earliest reference used is :-

1903 -'The Technology of Sugar'
Author: J. Geddes Mc. Intosh [4]
Lecturer at the Agricultural Polytechnic,
Regent Street

Most of the information in the text concerns sugar refining and extraction of sucrose from either beet or sugar cane.

There is however, a useful section on the properties of control of sugar syrup boiling in a vacuum and the diagram of the sugar cooker shown of 'Howards vacuum pan' shows the principle of cooker still in use today at TREBOR, Chesterfield, and used widely throughout the industry.

A further useful point in this reference is the detailed description of the methods by which 'good' sugar is determined, the so called thread point of sugar.

> "If the thumb and forefinger be gently parted, the sugar will form into fine threads"

Sugar in this state is then deemed to be at working point.

The next useful reference is a book published in 1923.

'The manufacture of Confectionery'

Author: Robert Whymper [5]

This deals more directly with sugar manufacture and listed are the basic essentials for sweet making:-

Stoves - Coke or Gas

Large Steam Pans for melting

Sugar boilers (Howard type)

Hot and Cold metal tables

Drop Rollers

There is no mention of sizing rollers as are currently used, but two items worthy of note are contained in the book:-

1. Photograph of a hot table (page 17)
   (identical to those in current (1980) use.

2. Photograph of the embryonic batch roller (page 21)
   (which is not fundamentally different to those in use today).

The rest of the text pages 94 - 221 deal almost exclusively with recipes for sweet confection types.

The next relevant reference is published in 1928:

'The Science and Practice of Confectionery'

Author: Dr. D. Ellis [6]

This book again tries to cover the entire range from chocolate to cakes, referring to 'sweetmeats' rather than sweets, and the thumb and forefinger tests are described in detail to establish 'good sugar'. Batch rollers are shown rolling the sugar to a rope which then passes into a drop-roller system.

Most of the texts examined continued in this style, however, some useful points in 1952 which indicate the situation :-

'A Text book on Candymaking'

Author : A.E. Leighton [7]

Some of the passages in the book are worth quoting in full, and from the Introduction :-

'The so-called 'Old Timers'..... are retiring from the business, who is to take their places with enough knowledge and experience to carry on when we do not have properly constituted courses to teach the art ?.....'

This passage illustrates two elements, firstly, that in the period 1920 - 50, any developments were carried out by a group of people within the Industry who were not being replaced.

Secondly, the use of the word 'art' illustrates the way in which the development was viewed, not as a scientific, methodical use of technology on which there was a firm basis of knowledge, but reliant on confectionery expertise.

The second passage comes from the Conclusion :-

'The growth in size and operations of commercial plants, together with the consequent spreading of specialisation, places each worker in a niche, from which he is seldom allowed to emerge... and thereby become a craftsman..
... The availability of apprenticeship opportunities, patterned after European systems, which served our old time candymakers so well, is negligible'.

Here again the image of craft and skill and of one generation passing on hidden or secret skills by word of mouth, is put forward.

Whilst these two passages illustrate this, they also echo a sense of tragedy at the loss of skills and knowledge.

It is also important to note that these statements come from the U.S.A. and their Number One confectionery developer. Two other points are:-

- The U.S.A. in 1952 was the strongest world economic power.
- Much of the equipment in use at TREBOR in Chesterfield, was purchased in the period 1955 - 60.

The rest of the book again tries to cover the entire range of confectionery, however, several points are relevant to boiled sweet manufacture -

(Page 9) A photograph of a 'Berks. Mixer' illustrating an automatic method of mixing colour and flavour into molten sugar.

This same machine, in a slightly modified form, but using the same principle is in operation at TREBOR, referred to as the BRUNO mixer.

(Page 11) Shows a continuous vacuum cooker as an innovation, these are still in use at Chesterfield.

(Page 17) Shows a Batch roller exactly the same as the 1923 model shown in 'Whymper's' book.

So between 1923 - 52 little fundamental development had taken place.

Between 1952 - 80 the only further development at TREBOR with the addition of independently driven, integral pre-feed rollers.

The next reference was published in 1956 in the U.K.

'Chocolate and Confectionery'
Author: C. Trevor Williams[8]

This work follows closely on the pattern of trying to cover the entire field, but some useful illustrations are shown:-

<u>Fig. 43 Page 39</u>

A standard confectionery line for high boil sweets

This shows a scroll type centre filler attached to a standard batch roller feeding a rostoplast cut and form die.

Also included is one of the earliest pictures of sizing rollers shown on FIG. 41. The sizing rolls shown are 3 fixed gear roll pairs attached to the batch roller exit, these in turn feed a final pre-feed pair at the die entry.

The section covering high boil sweets refers to recipes for hard candies and is almost entirely exclusively to devoted recipes.

A sense of complacency in the sizing roll design and machine performance is evident:-

> 'Under close control, hard candies lend themselves admirably to mass production, and the modern plant available for continuous operation has reached a very high degree of mechanical efficiency'

It must be pointed out that, at that period of time, maximum speeds of operation were in the range of 500 kg per hour.

The pace of development, in tonnage terms, changed little in the next 12 years. This emerges in:

'The History of Baker Perkins' (1968)
Author: Augustus Muir[9]

In this book, describing the achievements of the leading U.K. confectionery machine manufacturer, a photograph is shown of a candyband. This is noted as a major innovation, which at that time, it was:

> '....... one operator can supervise two candymaker plants that between them turn out a ton of sweets per hour'

The current tonnage performance of TREBOR's candybands is 1.2 tonnes each, per hour. The individual design is almost identical to that shown in 1968.

The next reference which contained some of the most useful information is:-

'Chocolate, Cocoa & Confectionery Science & Technology' (1970)
Author: B.W. Minifie,[10]

In a text over 600 pages in length, the author attempts to cover high boiled sugar in 4 pages including photographs and charts.

Again, the text contains recipes and attempts to cover the entire confectionery range.

No mention is made of sizing rollers although much of the 4 page high boil section lists the workings of the micro film cooker. This unit, tried by TREBOR, although successful, could not cook to the required tonnage, and so was replaced.

The most useful section of the text is the Appendix or Supplement, Pages 583 - 606. Thirtytwo manufacturers of confectionery machinery are listed and it is useful to note their countries of origin:-

FIG. 18 - THE COUNTRY OF ORIGIN OF NEW CONFECTIONERY MACHINES (1970)

United Kingdom	1	(Baker Perkins)
Denmark	1	
Switzerland	1	
West Germany	22	
U.S.A.	2	
Holland	2	
Italy	1	
France	1	
Australia	1	
	32	

Of these only one manufacturer is listed as providing a significant* development in high boil -

i.e. E.K.S. (Spezial Maschinen GmbH)

This development is the use of an extruder in place of a batch roller. Since the output stock is 40mm diameter, sizing rollers are still necessary to reduce this to the required 16mm diameter.

After 1970, most of the texts continue the same pattern of covering the entire range of confections and treating high boil in 2 - 3 pages.

The two major magazines to cover confectionery for manufacturers are :-

1. Confectionery Production[11]
   Specialised Publications Ltd.
   Grove Road,
   SURBITON.

2. C.C.B.[12]
   International Review for Choc. Conf. & Baking, (English version)

   Published by Verlag Edward Blackman K.G.
   HANOVER

Both these magazines cover new developments in the confectionery sphere. These tend to be in chocolate and packaging. Some indication of the current level of development can be found by examining the equipment offered in the advertisements.

Standard batch rollers and 4 rope size units are illustrated as common-place and no fundamentally different method of drawing and forming high boil sweets is shown*, either in the recent texts 1976 - 80, or in the equipment advertised for sale.

* i.e. other than candymakers, depositors, batch rollers, sizing rolls already listed.

The same situation is true for the two major U.S.A. magazines:-

The Manufacturing Confectioner[13]

Glen Rock Road,
NEW JERSEY.

and

Food Technology[14]
Institute of Food Technologists,
CHICAGO
Illinois.

These are the only significant U.S. food publications, and in the case of the 'Manufacturing Confectioner' the high-boil equipment illustrated is standard, and imported from the United Kingdom.

The Food Research Association (B.F.M.R.A.)

Lists only one report since 1950 that concerns sugar confectionery process developemnt. This is a bulletin, dated 1964.

'New Developments in Processes'[15]

Considering the fact that four years later Baker Perkins were advertising candymakers at 500 kg/hour, this gives an indication of the state of knowledge at the time.

The confectionery industry is not over enthusiastic about research associations e.g. B.F.M.I.R.A. and S.I.R.A.(The Scientific Research Association).

This has become quite evident, not only in discussions at TREBOR, but it is also a point Minifie[10] emphasises in 1970

"The information given to the Research Associations by the larger companies is limited, and is never anything which may affect the profitability of a company in relation to its competitor. The work published by the Associations, therefore, is of limited value and may be out of date in the eyes of the more progressive organisations.

When it comes to the development of new industrial plant and machinery, a lot of this seems to have been done entirely by the machinery manufacturers. Mistakes have been made which could have been avoided if more fundamental knowledge and experimental manufacture had been at their disposal. The machinery manufacturers have to sell their products to keep in business and sometimes the smaller producer of confectionery is persuaded to buy plant which is well beyond requirements, or which is not really suited to his product."

It has been shown in the review of previous writers, back to 1903, that many of the early designs are still in use and remain fundamentally unchanged.

Minifie,[10] in the passage quoted, makes two important points which deserve further mention -

1. "The overall secrecy of the industry and the low value of published information."

In an earlier passage he stresses this point:-

"In the chocolate and confectionery industry, research has, for many years, been kept within the confines of the larger companies and very little has been published other than that related to analytical techniques."

This secrecy also has drawbacks:-

"... some chocolate and confectionery producers have designed and manufactured their own plant because they have not been willing to put all their process information at the disposal of a machinery manufacturer. The result of this is often inefficient and cumbersome plant."

TREBOR definitely follow this course, technical policy states:-

"Trebor neither encourage nor seek publicity in the Technical field."

2. The second point that Minifie makes in his earlier quote is that machinery manufacturers have to sell their products to keep in business. As a result they are not unwilling to sell equipment which is not particularly suited to an application.

They are, however, highly reluctant to change an existing product, or to carry out major developments.

RESUMÉ OF LITERATURE REVIEW

The earliest quoted reference: Geddes Mc. Intosh[4] 1903, is very useful for the basic sugar description i.e. refining from raw cane or beet, but the section dealing with the 'thread point' raises some doubts. In a cottage industry environment, this subjective, highly skilled and time consuming test may have been worthwhile. In the present day with continuous cookers and processes, this type of subjective evaluation has little relevance.

Robert Whympers[5] book in 1923 lists all of the basic production units necessary for confectionery making:

1923		1980 equivalent
Stoves - coke or gas		Oil-fired steam raising boilers
Large steam pans for melting	→	still used
Sugar boilers (Howard type)	→	still used
Hot and cold metal tables	→	still used
Drop Rollers	→	still used in some cases *
The Batch Roller (an innovation)	→	still used

It is not meant to suggest that there are no alternatives or that there have been no developments, but the listing does show that equipment recommended as standard in 1923 is still very firmly entrenched today.

Leighton's[7] book published in the U.S.A. in 1952 confirms this low development picture and at the same time illustrates some interesting points :

1. The Industry regarded confectionery as a major skill.
2. 'Old Timers' were disappearing into retirement and their knowledge; skill and crafts were being lost. This confirms any idea that 1920 - 1950 had seen the Industry stagnate.

* except where the Uniplast or Rostoplast die assemblies are used.

3. Further photographs of equipment still in standard use today -

- the Bruno mixer
- continuous vacuum cooker
- Batch rollers

The book published by C. Trevor Williams[8] in the United Kingdom four years later in 1956 also shows the same elements, but with the addition of an early photograph of sizing rollers. The basic design features shown in this photograph are still retained today.

The next major development was the Baker Perkins candymaker illustrated in 'The History of Baker Perkins'[9] in 1968 as an innovation. The operating tonnages were low, around 500kg. per hour compared to todays speed of 1200kg per hour.

Minifie's[10] book in 1970 is a major comprehensive work of over 600 pages of which 4 are devoted to high boil sugar. Of the 32 firms he lists as involved in manufacturing confectionery equipment, 69% are in West Germany, only 1 firm is listed for the United Kingdom.

The magazines which circulate the trade both in the U.K. and U.S.A. show the predominance of standard batch rollers, rope size units and die assemblies.

The food research association lists only one report covering high boil developments and that was issued 16 years ago.

Minifie[10] illustrates quite clearly in his book the constraints on development caused by the combination of secrecy and unwillingness of the manufacturers to change their products to suit individual needs.

As far as existing knowledge can be discerned, there appears to be very little available, and only then with a minimal technical content.

JURAN,[2] Feigenbaum[1] Niebel & Baldwin[3] all emphasise that effective quality control is only possible where comprehensive knowledge exists.

The only course open in this type of situation is quality monitoring and reporting. Control to make the product match the specification is absent. As a result, the Quality organisation is limited to defect isolation.

As pointed out earlier,* these defects can be classified as either management or operator controllable defects.

In this situation, the choice of producing high centres or low centres is an operator controllable defect. The wide range of product and low defect tolerance of the process is a management controllable defect.

It is at this point that Feigenbaum's concept of TOTAL QUALITY CONTROL emerges as a major consideration. Defect isolation and quality monitoring are not a solution; they are a limited result of the existing process design.

Quality control, he argues, should become an integral part of the design cycle.

Niebel & Baldwin[3] also agree with this, but see the quality improvement programme as requiring the active assistance and participation of process specialists and technologists.

In this situation at TREBOR, these specialists do not exist, as stated already, confectionery skills are considered as an art possessed by a few individuals.

* Page 5

Actual process developments as illustrated in the earlier part of the literature review have been conducted at a low level of 80 years. Published information is scarce because of :-

i. the low level of development in this sphere

ii. the overall secrecy and high commercial value of results.

Minifie[10] confirms this in his book dated 1970 analysing the countries of origin of new developments,* and in his comments on the value of outside research associations.

Much of the equipment at TREBOR was purchased in the 1950 - 60 period when tonnages and process speeds were lower, and the necessary skills to operate the equipment were more readily obtainable.

The equipment available today is little changed from that which was available in 1950.

The problems isolated are specifically, poor alignment of centres within sweets and poor control of the uniformity of centre level.

The objective now must be to build up the level of existing process behaviour knowledge, and to establish the skill-free automatic control network outlined in principle by JURAN[2] who considered it as a necessary future development.

* Page 35

AN ENGINEERING ANALYSIS

OF POSSIBLE PROBLEM AREAS

IN THE CURRENT PROCESS

Whilst this analysis concerns a search for elements capable of causing poor alignment and poor level control, attention is also given to the possible fault areas which the operators and confectioners consider important. This serves a dual function, firstly, it ensures that at the initial stage of analysis, possible unidentified problem areas are not overlooked. Secondly, it carries out the involvement principle outlined by Niebel & Baldwin[3] of consulting and involving process developers and technologists. In this case, at TREBOR, confectioners have had the main influence in the historic development of the process, with the engineering function providing a service role to carry out their recommendations.

The major areas listed by these participants include all of the other potential problem areas that could be responsible for the alignment and control problem. They are:-

1. The consistency of the molten sugar and its important role.

2. The high operating speed of the process.

3. The importance of temperature control of the centre material.

4. The shape of the sweets as a cause of poor performance to standard.

5. The age and maintenance of the process line.

6. The physical dimensions of the centre pipe.

7. The design of the centre pumps for even delivery of the centre material.

8. The attitude of the operators towards running the process and attempting to achieve the specified standards.

Taking each in turn:-

<u>The consistency of the molten sugar as a major contributing cause to the centre variation, and general quality-problem:</u>

The 'sugar' is a 50-50 mix of granulated sugar and liquid glucose which are mixed together and dissolved into a 67% saturate solution at the early stage of manufacture. This 67% saturate liquid is then passed through a vacuum chamber which operates between 8-25" of mercury, and the liquid at this point has been heated to between 125°C - 155°C.

As the syrup leaves the chamber its total moisture content has been reduced from 33% to under 3%. This liquid hot sugar mix is then either pumped or carried to a cooling surface. At this point colours and flavours are added according to specification. The total moisture content should again now not be greater than 3%.

The sugar is then cooled, either by hand-working on a heated or cooled steel table, or alternatively, by pumping the mix directly on to a moving steel cooling band (candyband).

Typical problems which occur during these four stages are:-

- insufficient moisture removal
- graining or violent recrystallisation
- inversion *
- insufficient colour or flavour

* this may not show itself immediately, however, a high level of invert sugar causes the sweet to become sticky and dramatically reduces subsequent shelf-life.

Over the last 80 years the confectionery industry has developed a high level of expertise in sugar dissolving and boiling. This is apparent by the level of published information, the standard designs of cookers and the overall high levels of knowledge on the running performance of the cookers.

Over the same period of time, cooling and working the sugar into finished sweet has remained heavily based around hot tables and batch rollers.

Candymakers first became available in the mid 60's and considerable development work has been carried out by both TREBOR and the equipment suppliers to the industry.

FIG. 19 - TABLE WORKING MOLTEN SUGAR

This involves placing the liquid onto the hot steel table (which is lightly dusted with chalk to prevent adhesion) heated to 75° - $80^{\circ}C$. The sugar is then continually lifted, folded and replaced onto the table until it is deemed to be suitable for loading onto the batch roller.

The continual folding is necessary, due to the poor conductivity of the sugar. The cooling is achieved by taking heat away from the outside surface and then folding this cooled layer in such a way that the cooled outer layer is moved to the centre of the sugar mass:

FIG. 20 - COOLING MANUALLY - THE FOUR STAGES IN SEQUENCE

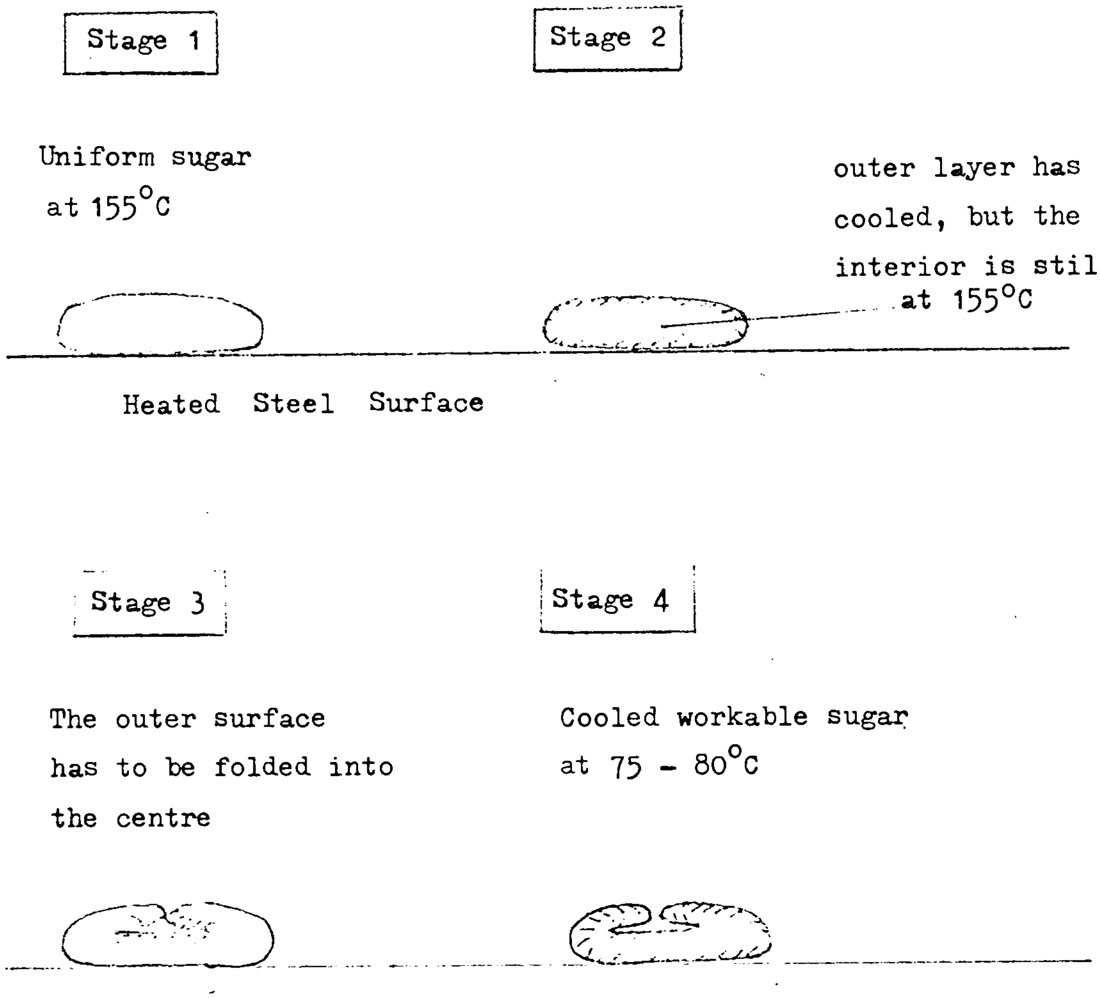
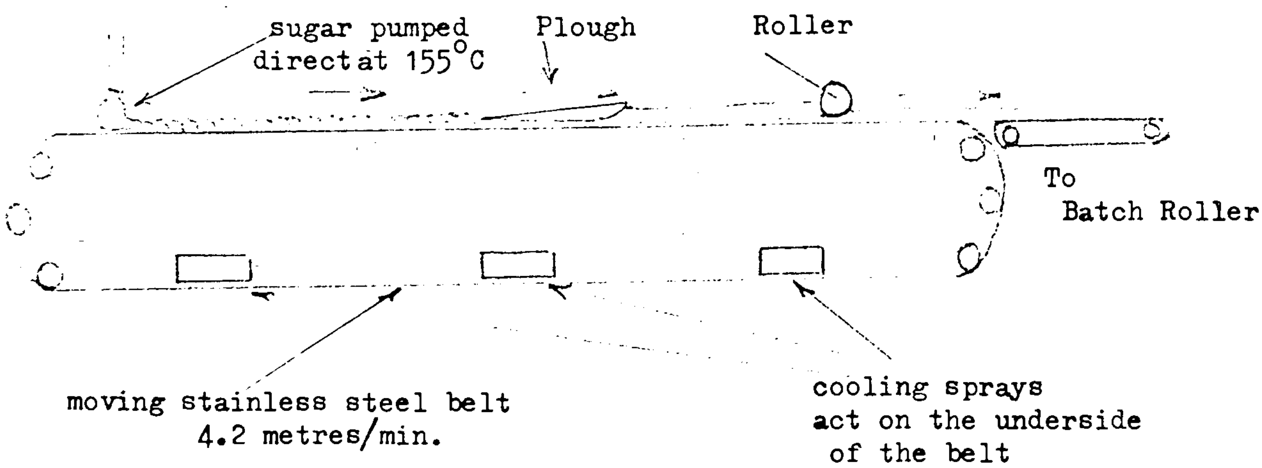


FIG. 20[a] - COOLING BY A CANDYBAND



The same effect is achieved by pumping the sugar at 155°C on to a moving steel band which is continuously cooled by water sprays.

The moulding action is achieved by ploughs which lift the surface film of sugar at its edges and carryout the same folding action as is achieved by hand moulding.

Some basic information about the sugar as it is being worked in these stages, both manually or on a candyband, is contained in two reference articles:

1. The physico - chemical characteristics of boiled sweets and their relationship to structural stability and Keeping Quality.
   J. Kelleher [16]
   B.F.M.I.R.A.
   1963

The major points outlined in this reference, that are relevant here, are:-

(a) Sugar in this molten state, after it is shock cooled is a super cooled liquid or glass. Hence a boiled sweet is completely amorphous and contains no evidence of crystal structure.
This was confirmed by X-ray diffraction studies.

(b) The liquid achieves a glass transition temperature in the same way as a normal inorganic glass, at this point the viscosity reaches 10^{13} poise.

The reference also gives detailed explanations of buffers, emulsifiers, and graining or recrystallisation.

The other reference is:-

2. Vapour pressure Study of Hard Candy.
   W. Duck [17]
   Manuf. Conf. August 1957

In this reference, the Author describes the importance of moisture control on the final sugar. He lists the range 2.6% → 4.7% as the working range for moisture contents of a sugar glucose mix. Above 4.7% moisture and the sugar does not harden into a glass when cooled.

He describes the detection of the glass transition point:

> "It has been found that when specific heat, coefficient of expansion, viscosity and modulus of elasticity of glasses are measured over a range of temperature, there is an abrupt change in the value for each of these at a temperature which is known as the transition point of the glass."

The basis of the practice on sugar consistency at TREBOR was that sugar was being produced in textures that varied continually.

The variation range was described subjectively as between hard or soft sugar.

The majority of those questioned claimed that this variation was the single most important feature.

The concensus of opinion was that once this variation had been removed, all of the major problems associated with the process and the product would be resolved.

Published information about sugar and sugar boiling is extensive. In the early references dating from 1903 listed in the Literature Review, the description of the method of detection of the 'thread point' of sugar is catalogued.

In the later references both W. Duck[17] and J. Kelleher[16] give extensive proof that sugar in this state is, and behaves as, an inorganic glass.

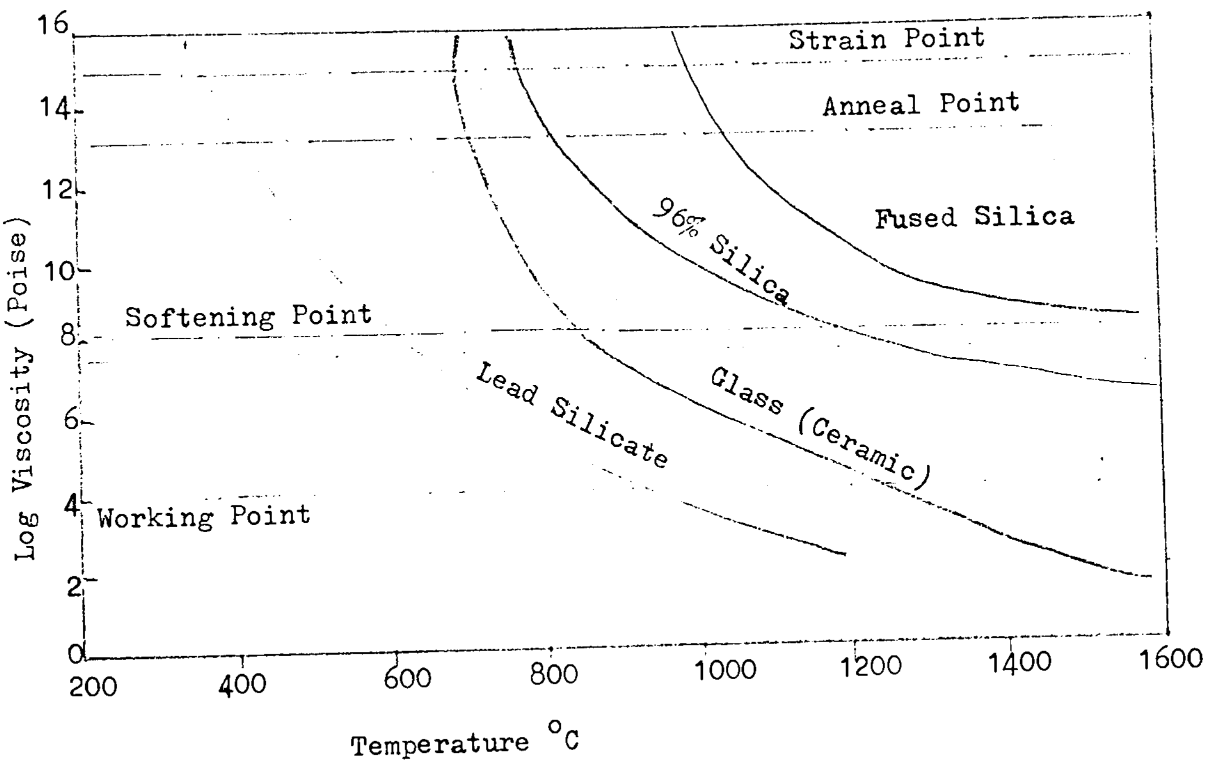
Taking this proof a stage further, a basic text on Glass properties and behaviour -

'Metals, Ceramics and Polymers'[18]

Wyatt Dew. Hughes (1974)

gives a basic viscosity temperature graph covering silica glasses:

FIG. 21 - THE VISCOSITY OF SILICA GLASSES AT DIFFERENT TEMPERATURES



From this graph relating to glasses, it can be seen that, the range between working point and hardening point is considerable 10^4— 10^8 poise.

It is not necessary to compile a similar table for sugar glass over the range 0— 150°C to be able to use this information.

Sugar is cooled from 155°C down to 80°C before it becomes workable.

During the period of forming, every attempt is made to ensure that the temperatures are held constant.

When emerging from the cooling assembly the sweets are approximately 50 - 60°C.

Initial Studies and Observations showed that whilst the sugar was produced on a variety of machines, there were several major patterns of handling which are common:

1. Continual loading and reloading of part-cooled sugar in the event of a problem occurring during rope sizing.

   This happens during a rope break. Sugar is removed from the end of the candybands and placed on holding tables while the blockage is cleared on the rope size unit. It can remain on the holding tables for periods of up to 10 minutes. During this time the sugar is not being worked or hand moulded, and so is deteriorating as it cools.

   When it is reloaded on to the batch roller its material properties are often significantly different to the sugar in the batch roller and the sugar leaving the end of the candyband.

   The volumes involved are considerable and the problem occurrence is frequent.

   This was later quantified:-

   A typical weeks production for 1 process line showed 10% of the time as downtime due to rope breaks and represented approximately 220 minutes of continuous output from the cookers that was off-loaded, part-cooled, then reloaded on to the batch rollers.

   The given output of the cookers is 20 kg/minute and this 220 mins. represented over 4 tonnes of sugar loaded and reloaded.

   The sugar as it is reloaded, is visibly less fluid and significantly 'harder'.

2. Of the four process lines at Chesterfield producing high boil sugar, each cooling method is significantly different, yet the quality of the normal sugar remains uniform.

   In essence, TREBOR make the sugar in a variety of ways and produce a uniform product, yet the problems remain.

3. Even during normal smooth production runs when operators agree that the sugar is 'good' and consistent or that 'hard' consistency sugar is not present; the same problems in product terms arise, i.e. poor alignment and variation in level of centre.

4. When hard sugar is reloaded and mixed with good sugar the same problems occur.

Taking each of the four points together presents a useful picture.

TREBOR and the operators collectively agree that a good consistent sugar is vital to good product. There is no argument against this. However, whether this condition is present or not, the same problems in centre contents remain.

When a variety of different methods and machine designs are present producing uniform and workable sugar, and yet the problems still remain, it cannot be a valid argument that the sugar, or a further alternative method of producing it will resolve those related to centre content.

Furthermore, the Quality records charts show that prior to 1970 the quality situation was significantly better. Post 1970 shows a continual deterioration.

Over the same period the tonnage output of each line was increased by 50%.

Therefore, without entering into a long analysis and specification of the ideal properties of sugar, it is apparent, on the basis of the analysis so far, that hard or soft sugar is unlikely to be the major cause of poor centre control and poor alignment.

The basis of this argument about sugar quality is therefore, one of subjective problem perception.

The operators have perceived that over a 5-10 year period, as the speed has increased, they have continual problems feeding sugar through the rope size units. These problems are apparent by rope breakages.

The same operators are responsible for feeding the sugar manually through a prefeed, and they can also sense, by touch, variations in sugar texture. When this causes problems, they rightly attribute the cause to sugar consistency variations, ie. hard or soft sugar. However, even when the equipment runs smoothly, defective centre contents and alignment are still produced. This is not apparent to the operators, since the feedback is limited, hence they do not perceive any problems when the equipment runs smoothly.

Over the same period, as the speed increases, the operators have seen the product quality decrease, running problems and shutdowns increase. They can attribute an immediate cause to a rope break due to hard sugar, hence they associate the 4 tonnes of reloaded sugar with inconsistent sugar, rather than the particular design of the rolling process.

As a result, they believe the solution of the problem to be the production of consistent sugar.

Marketing perceive the solution of the problem to be the achievement of consistent well aligned centres.

The problem in development terms has therefore, historically, been a search for a method of producing consistent sugar on the assumption that, once this has been done, the problems of centre contents would be resolved.

This view is further strengthened when placed in the context of the literature review, which has shown the industry built around the perceptions of the craft, skills and art of confectionery.

CONCLUSIONS

Hard sugar and soft sugar variations will cause manufacturing problems in terms of running performance and downtime.

The production of, even consistent sugar, on its own, will not resolve the problems of centre position and content. Even - consistent sugar, free of lumps, is produced in a variety of ways, for differing durations of time, yet defective product is still continually produced.

The problems of centre content and alignment are common to all high boil process lines, hence the basic cause, but also to be common to all process lines.

Each process line at Chesterfield produces and cools sugar in significantly different fashions. Hence, variations in sugar consistency, however undesirable, are not the fundamental cause of poor alignment or centre variations.

THE HIGH SPEED OF OPERATION

AS A CONTRIBUTING FACTOR

Over a ten year period, from the late 1960's to the early 70's, the tonnage produced on each line has been increased by 50% measured at an hourly rate.

Over the same period, the measured quality level of the sweets has declined -

TABLE 1 - (Repeated)

No. of weekly passes against standard 100% throughout the year:	1972	1973	1974	1975	1976	1977
above 90%	13	34	1	-	-	-
above 80%	39	18	17	3	-	-
above 70%	-	-	32	42	47	19
below 70%	-	-	2	7	5	33
	52	52	52	52	52	52

These two factors taken together suggest that major elements of the process may be speed-dependent.

Taking each process element in sequence:

1. Cookers

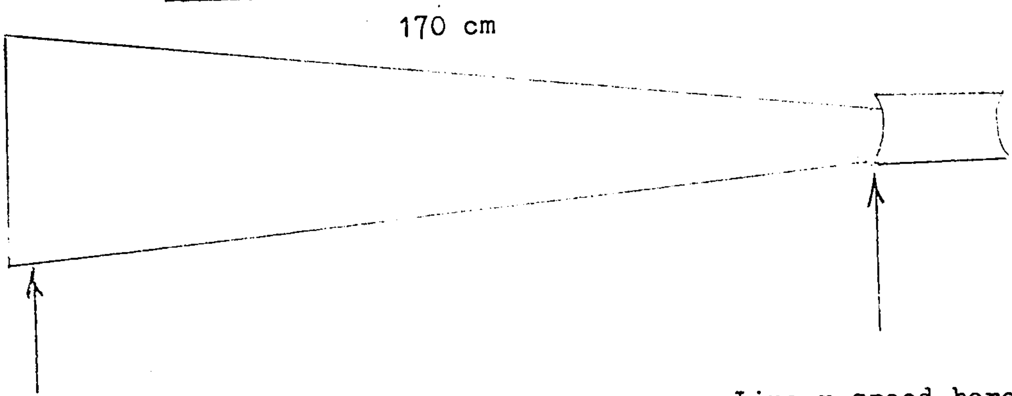
   All the cookers use standard technology and produce syrup at speeds above and below their rating without visible deterioration.

2. Candymaker

   This line cools the sugar and feeds a rope size unit alongside a similar line which is slower and manually cooled, both lines produce sweets with identical faults, i.e. low control of centre level, and poor alignment of centre.

3. Batch Roller

FIG. 22 - THE LINEAR SPEED OF SUGAR AT DIFFERENT POINTS OF THE BATCH-ROLLER



Linear speed here	Linear speed here
@ 800 kg/hour - 0.22 cm	4.12 cm
@ 1200kg/hour - 0.33 cm	6.26 cm

The function of the batch roller is, to blend the sugar mass and form the initial 'stock' or billet at the tip of its cone.

From the speeds shown above, although overall linear speed of the sugar increases eighteen fold from one end to the other, the increase in flow is also linear for the step increase from 800 kg to 1200 kg/hour.

At its widest point the speed is less than 1 cm and 170 cm later, its speed has only increased to just below 7 cm.

The speed of flow of the sugar at these rates is quite controllable and provided the pump and pipe are correctly designed*, control of speed should not present a problem.

* See later in text for analysis of centre pipe and pump designs.

4. Rope Size Units

These consist of 6 pairs of Rollers which reduce the section from 70mm diameter to less than 14mm diameter, at the die entry.

Even at the early stages of observation of the process, at the start of 1977, it was clear that major problems were occurring in this area, over short time periods and frequently.
This was borne out by the two Tables below:-

TABLE 3 - MEASURED DOWNTIME DUE TO ROPE BREAKS

Hour of Day	Monday min.	Product	Tuesday min.	Product	Wednesday min.	Product	Thursday min.	Product
9–10 am	–	Sft.Centre D/Agents	–	Sft.Orange	3	Toffee Apple Blobs	4	Choc.lime D/Agents
10–11	–		2		6		6	
11–12	–		–		–		10	
12–1.0pm	8	Chunks	19	Kopp-Kopps	–		–	Kola Kubes
1–2	8		2		–		7	
2–3	6		2		2		8	
3–4	severe		5		1		–	
4–5	13	Pineapple	5	Chuckles	–	Pear Drops	3	Cough Candy Twist
5–6	17		14		–		4	
6–7	33		16		2		5	
7–8	11		8		2		–	
Total Minutes	96		73		16		43	

The above Table shows the downtime due to rope-breaks when a pile-up or rope neck occurred producing waste, shutdown and inferior product.

The data was collected by means of a chart-recorder linked to an LED cross-section monitor set up to continually recording rope-size.

A similar Table shows the frequency of rope-breaks, over one every hour period during the working day: -

TABLE 4 - ROPE BREAK FREQUENCY OVER THE SAME WEEK

Hour of Day	22 January Monday	Tuesday	Wednesday	25 January Thursday
9–10 am	– *Staw.& Cream Double Agents*	– *Soft Orange*	3 *Toffee Apple Blobs*	4 *Chocolate lime Double Agents*
10–11	–	1	6	2
11–12	–	–	–	6
12–1.0 pm	3	12	–	–
1–2	5 *Chunks*	1 *Kopp-Kopps*	– *Pear Drops*	7 *Kola Kubes*
2–3	5	2	2	7
3–4	severe	1	1	–
4–5	5 *Pineapple*	1 *Chuckles*	–	3 *Cough Candy*
5–6	9	1	–	4
6–7	8	5	2	5
7–8	7	6	2	–
Total Number of Breaks	42	30	16	38

Collating the information for both downtime and frequency of occurrence gives the following:-

TABLE 5 - THE DAILY AVERAGE DURATION OF ROPE BREAKS

	Mon.	Tues.	Weds.	Thurs.
Downtime (Minutes)	96	73	16	43
Number of Breaks	42	31	8	37
Average Duration (Minutes)	2.28	2.35	2.00	1.16

Overall, for the week shown, the total number of rope-breaks was 118, and these caused the machine to shutdown for 228 minutes (10% of time monitored). The average rope-break lasted 1.93 minutes.

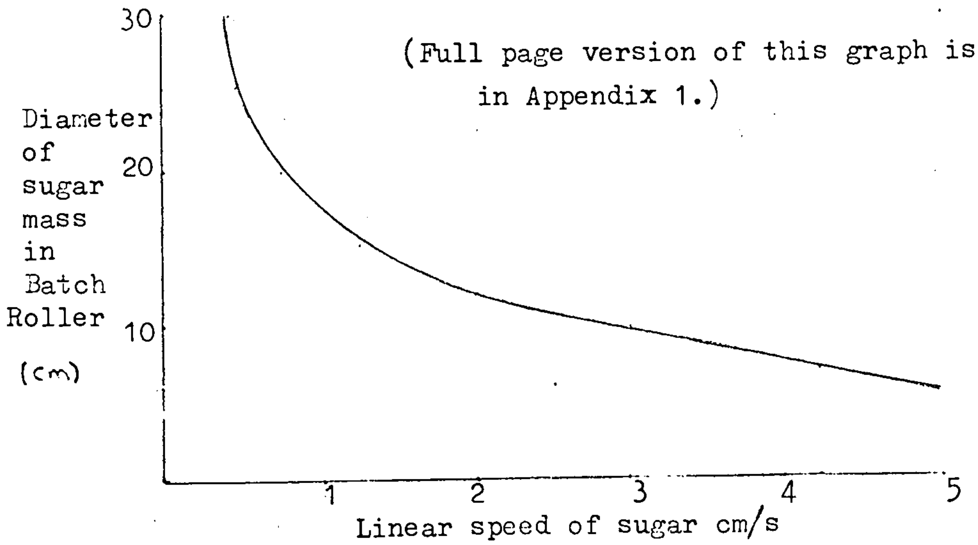
This picture was not untypical. It was in every way an average week. What clearly emerged were the following points:-

- Rope-breaks were occurring frequently (10% of running time lost).
- The average duration was 2 minutes.
- During this time, significant waste, and poor product is produced (228 min. accounted for approx. 4 tonnes waste). Retail value £20,000 for the week examined.
- The rope-breaks were occurring whether the product was centred or solid.
- The breaks were also independent of any particular type of product (Kopp-Kopps or Sherbet Lemons).

Of all the areas examined so far, the major problems, and readily identifiable problems, were occurring at this point.

The effect of speed increase on this unit is illustrated in the following sketch:

FIG. 23 - THE LINEAR SPEED CURVE OF SUGAR IN THE BATCH ROLLER



The rope breaking situation is clearly a major problem area which will benefit from detailed analysis.

Die Assembly

The action and operation of this unit has been described fully in 'Die Design and the operation of Die Assembly'[19] However, it is interesting to compare the operating speeds as originally used with those actually used.
The designed operating speed recommended by Robert Bosch and all other manufacturers is a maximum of 100 rpm.
The actual operating range at TREBOR is as follows:-

TABLE 6 - THE OPERATING SPEEDS OF THE DIE ASSEMBLY

Product Type	Die Speed	Kg/hour
Sherbet Lemons	90 rpm	1200
Chocolate Lime Quilted Oval	90 rpm	1200
Double Agent 20mm diameter (All types solid and centred)	120-150 rpm	1200
Dotties/Chuckles	150 rpm	1200

Apart from the wear and lubrication problem there seems to be no other factor in this unit which is speed dependent or a likely cause of low centres.

The speed increase is achieved by altering the lubrication of the die plungers. Instead of relying on pure vegetable oil on a drip feed basis, a heavy vegetable oil/fat is thickly smeared over all the moving surfaces of the die assembly, this reduces wear which would otherwise soon cause the shutdown of the process

Cooling Assembly

These are standard units in use throughout the industry. There are temperature problems during hot summers, but their operation is not dependent on the speed of any element. The sweets are cooled for an avearge time of 12 minutes from an input temperature of 70°C down to 50°C, on the sweet surface.

Problems, when they occur on these units, are solely caused by high ambient temperatures, or high levels of misaligned centres. The effect of both, is to congeal the mass of cooling sweets and results in major shutdowns.

To summarise this theory - "The speed of the process is too fast," the major identifiable area in the process which is speed dependent, and giving visible problems is the rope size unit, and size reduction process.

This will be analysed in detail in a later text.

THE IMPORTANCE OF TEMPERATURE CONTROL OF THE CENTRE MATERIAL

This suggested theory was specifically concerned with sherbet centres. The procedure is that the sherbet powder is mixed and heated to approximately body temperature. If this temperature is exceeded the powder begins to fuse into a congealing mass, resembling bitumen. After heating, the sherbet is loaded into insulated containers and transported to the batch roller.

The heating action during the mixing has the effect of driving off moisture, and results in the powder flowing more freely through the scroll feed to the pipe exit in the batch roller.

Since the analysis of the distribution of sherbet centres revealed no major difference to the distribution of chocolate centres produced on the same lines, there was little evidence for the argument that achieving one particular temperature would prevent any chilling of the sugar-case during the forming of the rope.

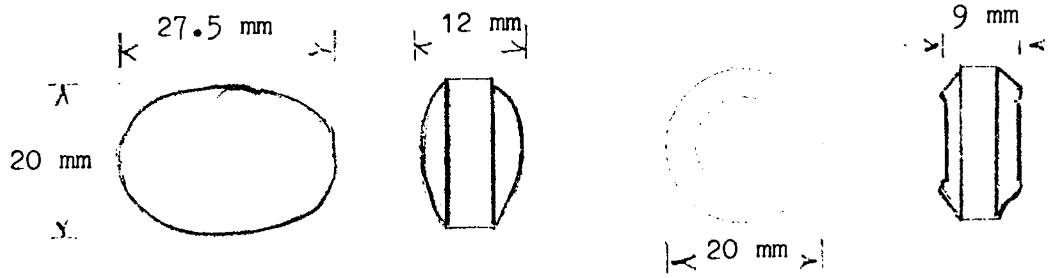
It was accepted that heating the sherbet produced a more free flowing powder, but the distribution of centres under ideal conditions, and over a long period, was exactly the same pattern as that of chocolate, jam and cream centres.

THE SHAPE OF THE SWEETS
AS A CAUSE OF
THE POOR PERFORMANCE TO STANDARD

The basis of this theory concerns the <u>shape</u> of the sweets which contain centred product.

The shape of a sweet is a completely arbitrary choice, e.g. Chocolate limes are manufactured in two forms:

FIG. 24 - SWEET DIE SHAPE VS ACHIEVED CENTRE LEVEL



	27.5 mm Quilted Oval	20 mm Round
Specified Centre level	27%	20%
Typical Achieved	18%	9%

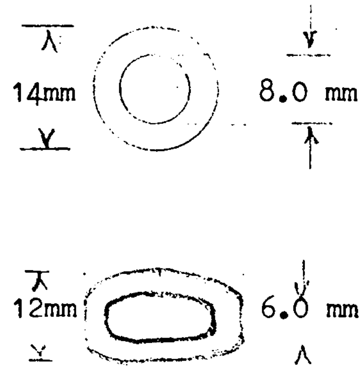
In essence, the difference in the results is due to the movement of both case and centre during compression in the die chamber. This factor emerged in the analysis, and could be attributed to a difference in the design of the two dies.

The comparison is as follows:-

FIG. 25 - QUILTED OVAL (27.5mm Oval) THE LEVEL OF COMPRESSION IN THE DIE CHAMBER

Original rope section

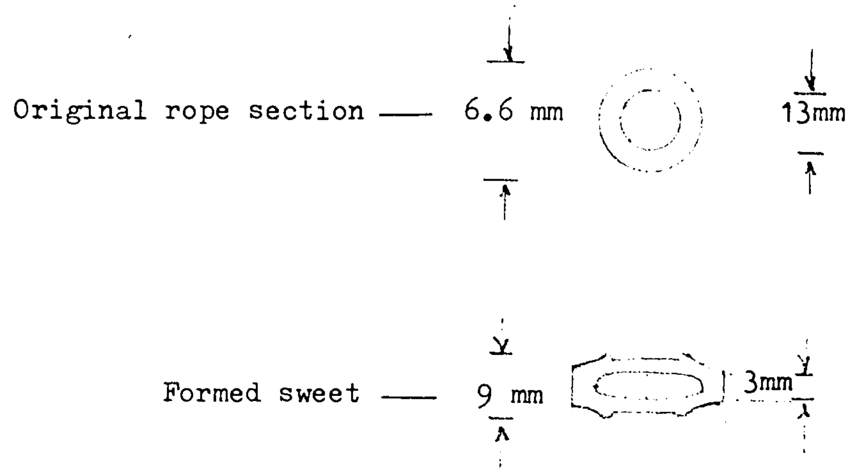
Formed sweet -



Overall compression of rope → 75% of original

LIBRARY

FIG. 26 - 20mm ROUND, THE LEVEL OF COMPRESSION IN THE DIE CHAMBER



Overall compression of rope → 45% or original

This was the only major point to emerge in the analysis of die shape and design, i.e. less compression makes it a safer sweet in a die chamber. Hence operators have found that, for the same level of centres, different die shapes have different risks. Higher levels of compression tend to lead to lower 'safe' levels of centre. Given also that poor control of centre level and poor alignment exist, this problem is magnified still further.

However, one important point arises here which relates to another argument, that 'Quality control specifications are unrealistic'. That is to say, "what level of centre, provided that alignment and level of centre can be controlled, is safe?"

This can be answered on two levels:-

LEVEL 1 - reasoned argument, the BASIC RULES of die design developed in the die design report[19] suggested the following :-

continued/.......

FOR A TOTALLY SAFE DIE

A. original centre height in rope section $<$ final sweet thickness

For a 27% Quilted oval
original centre height = 8.0mm

Final sweet thickness = 12.0mm

Hence, on this basis this die shape is totally safe provided level and alignment is controlled.

B. maximum spread of centre $<$ original rope diameter

Quilted oval
spread of centre = 12.0mm
rope diameter = 14.0mm

∴ again on this second criterion, the Quality control specified level for this die shape is achievable and safe.

LEVEL 2 - measured data. By measuring the case wall thickness of successfully wrapped sweets, using the centre charts, it is possible to calculate a maximum level of centre which, if evenly aligned, would safely pass through all process stages.
This has been done in Year 1 Review,[20] and the figures are as follows:-

TABLE 7 - THEORETICAL ACHIEVABLE LEVELS OF CENTRE FOR EVENLY ALIGNED CENTRES

Product	Specified Standard	Achievable with alignment controlled
Chocolate Lime Double Agent	20%	22%
Double Agent Sherbet	11%	14%
Sherbet Lemon	11%	15%

To Summarise this theory, the choice of sweet shape is arbitrary, and quality control standards are high in comparison to achieved levels. This does not mean that any particular shape is unrealistic to produce, or that the standards should be brought down.

What has been developed here is an analysis of one of the safest shapes - Quilted oval, and also the most risk prone - 20mm Round. Both have exactly the same case/centre material combination, but both are produced with different levels of centre,

e.g.		Standard	Achieved	%
Quilted oval	-	27%	18%	67%
20mm Round	-	20%	9%	45%

in normal production situations, i.e. all other factors remaining constant:-

- operators
- chocolate pipe/pump
- batch roller
- Uniplast die drive
- sizing roller assembly

However, the analysis on a reasoned basis, and on recorded and analysed data, shows that the standards are achievable even with these shapes, provided, alignment and level of centre can be controlled.

All of the other die shapes lie within this range, i.e. safest, Quilted oval, and riskiest, 20mm Round.

THE MAINTENANCE AND AGE
OF THE EQUIPMENT
FORMING THE PROCESS LINE

The development of new equipment and maintenance of existing units presents particular problems in this environment of high volume confectionery production. These are related to:-

1. <u>High capital cost</u>

   A typical production line, of which there are four in Chesterfield, would cost in excess of £750,000 to build from scratch today. Hence, the product it produces must be in demand.

2. <u>High value of product</u>

   When any one of the lines is running at 1200kg/hour this represents a value of product of not less than £4,000/hour. Any development, or interruption of flow caused by development, will have an immediate cost.

3. <u>Low level of time available for maintenance</u>

   As can be seen, much of the equipment is heavy and in situ, and so it can be overhauled only at the week-end. This is because of the legislation concerning <u>food industry</u> environments * and the danger of metal contamination of product.

   As a result the time available for repair-work, other than minor needs, is extremely limited.

Combined together these factors mean that equipment has to be developed around running processes, and once installed on-line, the time available to maintain it will be limited.

If the new or modified equipment breaks down and production cannot continue, the cost is of major proportions.

For example, in product loss alone, one line out of commission for one week would account for over 50 - 60 tonnes lost. This has a potential value of over £200,000.

* Health and Safety at Work Act. 1974

In addition, the labour and services built around the line would also add the further cost of ten to fifteen operators idle.

If repair work is anything more than minor, the scale of costs rises alarmingly in proportion to the lost production.

It is evident that even on a summary analysis the demands on basic process design are enormous.

The age of typical units show:-

Candymakers	-	10 years old
Sizing roll units	-	14 years old
Bunchwrap units	-	25 years old
Uniplast die drives	-	15 years old

Moreover, there is considerable weight to support these views in that the equipment is not in first class condition, but by all possible means is kept operational.

It must be said that although the technology of the process was developed in the late 1940's, much of this equipment has been designed in 'Brunel' fashion. Safety factors in moving parts are high and major breakdowns are rare, e.g. in any calendar year between '76 and '79, one production line has not been out of use for longer than one day.

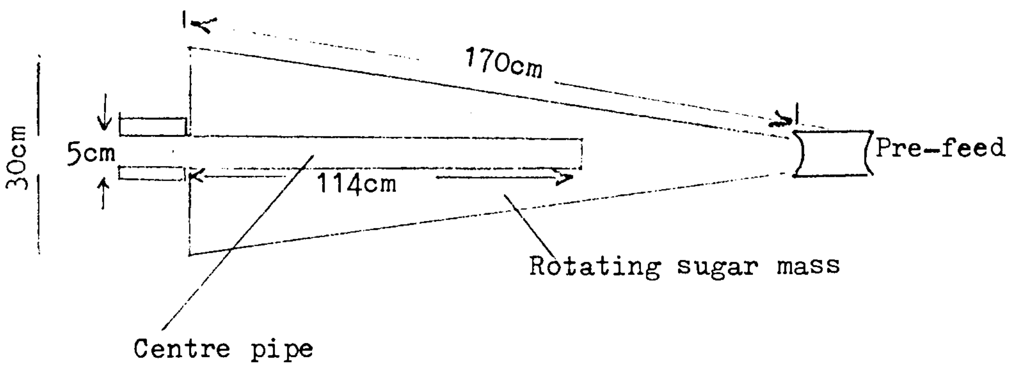
Given the increase in speeds of operation in both rolling and die forming that has occurred over the last 20 years, there is more weight to the argument that the process is beyond design limits than that failures result from poor maintenance.

CENTRE PIPE DESIGN

AND CONTROL

The existing dimensions of centre pipes within the batch roller are identical, regardless of centre type and density:

FIG. 27 - THE DIMENSIONS OF THE CENTRE PIPE RELATIVE TO THE BATCH ROLLER



Exactly the same pipe is used for:-

- jam
- sherbet
- cream
- chocolate

The density range of the materials is significant, varying from $0.8 gm/cm^3$ (for sherbet) to $1.40 gm/cm^3$ (chocolate).

The centre material is moved through the pipe by pump action or via a scroll-type feed in the case of powdered sherbet.

The pipe dimensions are fundamental parameters of the process, yet there is no recorded evidence of how they have been derived.

To achieve the correct level of centre, specified in the standard, it is important to ensure that the flow rate of both sugar and centre material are in balance, i.e. flowing at the same speed and at the correct proportions.

Since the specified standard of centre varies for each centre type and sweet size, it should follow that the dimensions of the correct pipe to achieve the standard should vary accordingly.

This can be illustrated by using a worked example of establishing the rate of flow of chocolate necessary to produce sweets which contain 20% chocolate (by weight) in their finished state.

Worked Example - Chocolate Sweets (Specified Standard 20%)

Knowns

(1) Rate of output of sweets (specified in standards) 1200 kg/hour

(2) Density of chocolate 1.4 gms/cm^3

(3) " " sugar 1.4 gms/cm^3

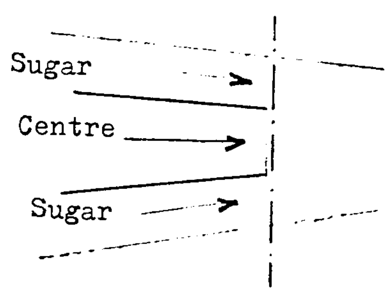
Working - to conform to standard, 20% of the nominal output of 1200 kg/hour should be chocolate.

1200 kg/hour	=	20 kg/minute
20%	=	4 kg/minute
@ 1.4 kg/litre	=	2.86 litres/minute

∴ the rate of delivery of chocolate at the pipe exit should be 2.86 litres/minute to conform to the specified standard.

It is also important that, as this chocolate is delivered to the end of the pipe at this rate it should emerge at the same linear speed as the sugar moving around the end of the pipe.

FIG. 28 DESIGN CONSTRAINT FOR PIPE DIMENSIONS



If this is not the case, one of two conditions prevail.

The first condition - is where the chocolate is emerging from the pipe at a greater rate than the sugar surrounding it, this will inevitably lead to an unstable situation where the centre level exceeds the specification and bursts out of the sugar case at some stage during forming.

The second condition - is where the chocolate is emerging at a slower rate than is necessary to fill the cavity created by the pipe. This is also an unstable situation and will lead to the sugar moving in to fill the cavity past the pipe end, and resulting in sweets lower than specification.

When the chocolate is emerging at the same speed as the sugar, a flow-balance situation exists which provided it is maintained, should not be the source of any instability during later stages of the forming process.

The only limiting factor on the level of centre at this stage of the process is the physical size of the pipe. This can be calculated when the specified standard of centre is known by using the graph of linear speed vs. batch roller dimensions already illustrated on Page 61.

Worked Example - to establish pipe diameter to enable a balanced flow of 20% centre into the batch roller,

i.e. Given - specified flow rate of chocolate 2.86 litres/minute
- existing length of centre pipe 114 cms.

Working - 114 cm down the length of the batch roller gives a diameter of sugar at that point of 16 cm. From graph: Fig. 23 the linear speed at this point is 1.2cm/sec.

Flow rate of chocolate = 47.6 cm^3/sec.

Using these two factors together, the necessary cross sectional area of the pipe to deliver the required volume at the specified rate can be calculated i.e.

$$\frac{47.6\ cm^3}{1.2} = \text{Area } cm^2$$

$$= 39.7\ cm^2$$

Since the pipe must be circular to enable sugar to rotate around it, the diameter can be calculated from:-

$$\pi R^2 = 39.7 \text{ cm}^2$$

$$R = \frac{39.7}{\pi}$$

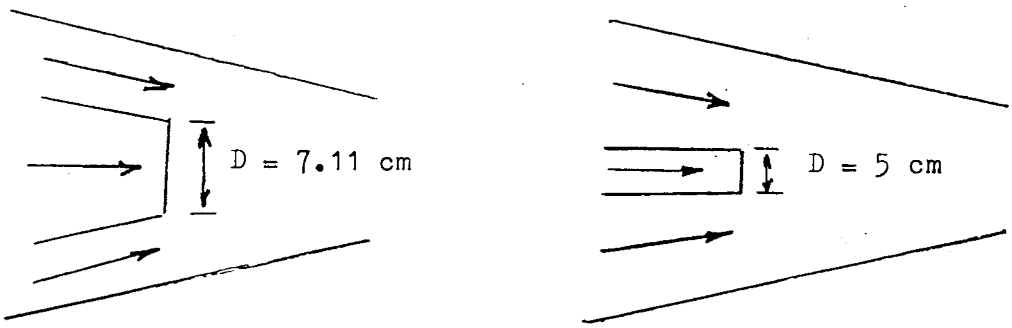
$$= 3.556 \text{ cm}$$

$$D = 2R = 7.11 \text{ cm}$$

Comparing the existing diameter with 'ideal' flow balance diameters:

FIG. 29 - <u>COMPARISON OF IDEAL PIPE DIMENSIONS AGAINST THE EXISTING PIPE</u>

<u>IDEAL</u> | <u>Existing</u>



Cross section area of pipe end = 39.7 cm^2

Cross section area of pipe end = 19.64 cm^2

<u>If the Analysis</u> is then taken a stage further, if the existing pipe was to be in a state of <u>flow balance</u>, then the chocolate would be emerging at 1.2 cm which gives a delivery volume of:-

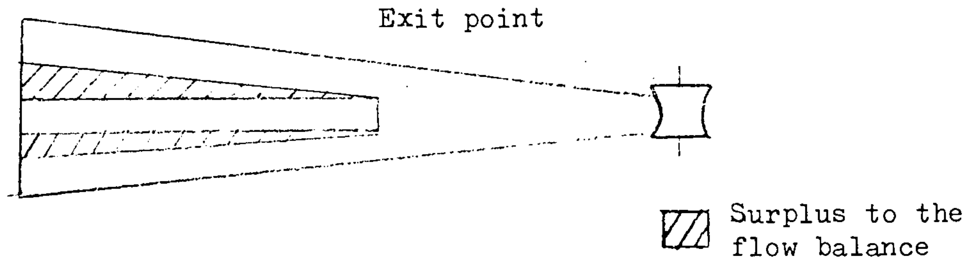
$$1.2 \text{ cm}^1 \times 19.64 \text{ cm}^2 = \underline{23.57 \text{ cm}^3 \text{ chocolate}}$$

This represents: 84.86 litres or 118.79 kg chocolate per hour. At a nominal tonnage of sweets at 1200 kg/hour this gives 9.8% centre in a flow balance situation.

Reference to the Quality Control records shown earlier, confirms that for Chocolate Double Agents, the highest tonnage centred sweet, the average achieved level of centre over the past three years is 10%. In other words, at present, consciously or otherwise, the operators are running the process in a 'flow balance' situation, or below.

In addition, a further easily recognised defect of the existing pipe is its lack of taper:

FIG. 30 - THE EFFECT OF USING A NON-TAPERED PIPE



which means that as the sugar flows over the pipe exit point, all of the sugar surplus to the flow balance situation causes a pressure buildup at the exit point. This complicates still further the maintenance of flow balance.

As a result of these calculations a new centre pipe was designed and constructed and its performance is evaluated on Page 132.

CENTRE PUMP DESIGN AND CONTROL

One of the first conclusions to be drawn by all concerned in the historical running of the line was, that variability in the amount of centre from one sweet to another was directly caused by the pump and its failures.

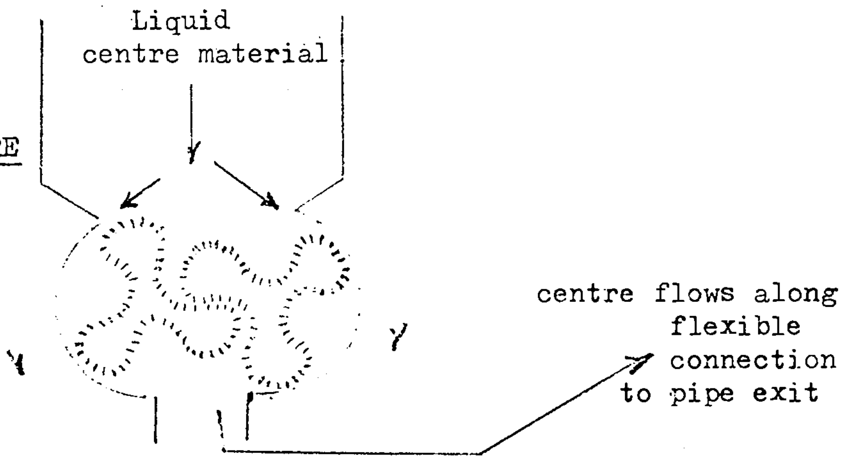
As a result, over the past decade a large variety of pumps have been tried without any major improvement.

Liquid Pumps - The best choice in this field has proved to be a particular design of gear pump.

The action is illustrated in the sketch below:-

FIG. 31

THE ACTION OF THE CURRENT LIQUID CENTRE PUMP



These are capable of delivering, extremely accurately a controlled flow of centre liquid.

Powder feeds

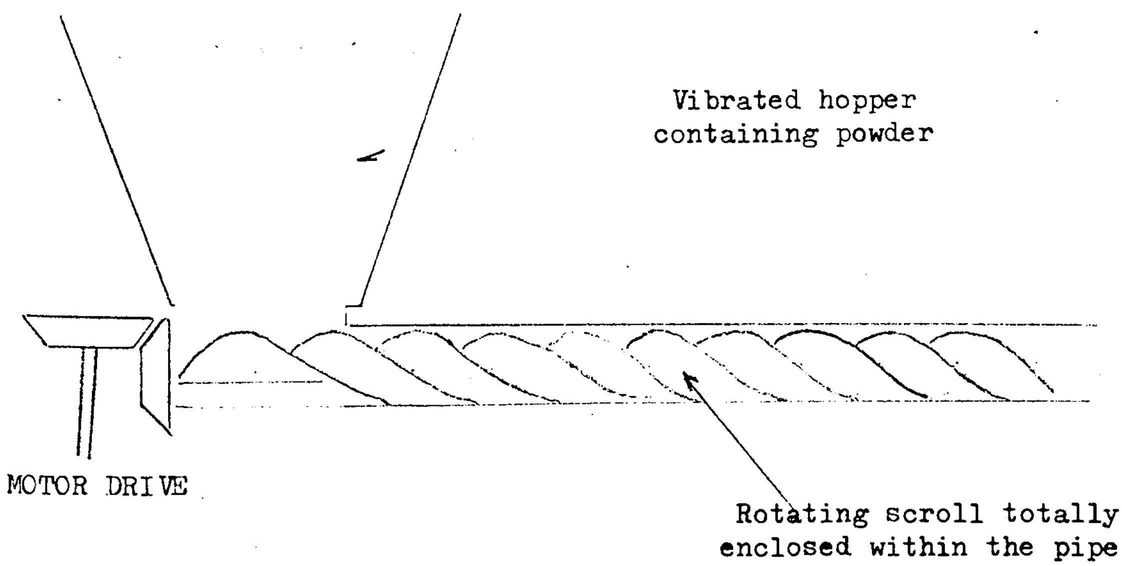


FIG. 32 - THE ACTION OF THE CURRENT POWDER FEED UNIT

The feeding of sherbet and peanut powder is done by means of a totally enclosed scroll rotating inside a pipe having the same dimensions as the existing arbitrary centre pipe.

With both powder and liquid pumps, much has been claimed about the orifice dimensions leading to the pump action chamber.

Whilst a wide 'throat' or orifice will lead to the material reaching the chamber easily, a narrow orifice will have the reverse effect. There has to be some point at which this reaches an optimum, and from that point on, any increase will have less and less effect on the pump efficiency.

An Important Point to note here is that this line of development had been investigated before the start of the project. Considerable resource had been, and continues to be devoted to this area with limited success.

During the period of this project when the problems were being specified, a new hydraulic-drive sherbet pump was installed, unfortunately with no benefit. Since then, a new choclate pump has been designed and tried, again with no improvement.

Over all the areas examined so far, the pipe design and the sizing roll reduction had both shown major defects. The pumps scroll feed and liquid pumps, both dealing with vastly different materials had shown exactly the same problems, variation in centre content and poor alignment.

Considering the data, we have an extensive development programme on pump design which was costly, and yielded little. Also product which exhibited exactly the same flows despite totally different material types (powder and liquid) and totally different pump designs (scrolls and gear pumps).

The conclusion drawn was that the product defects were being caused by elements common to both activities.

This did not include the pumps themselves, as the variations had been widely tested.

It remained to investigate:-

- pipe design
- pipe alignment
- sizing roll design
- die design

as a cure for the problems. Only then would it be reasonable to look again at the pump as a remote contributing feature.

OPERATOR ATTITUDES

The basis of this theory is that the operators purposely run the process and centre level at a point which results in the easiest working routine. It suggests that they are unwilling to attempt to run the process so that the specified centre content can be achieved.

A number of points established so far conflict with this suggestion.

The analysis of centre pipe dimensions has shown that the flow balance at the pipe exit experiences major problems of pressure when it is attempted to increase the achieved level of centre addition above 40% of the specified standard.

The historical records kept of the achieved level of centre have shown this to be varying around 40% of the specified standard.

These two points collectively emphasise that there is a physical limit on the achievable level of centre without major disruption, requiring unspecifiable levels of skill to exceed it.

The flowcharts showing the options of producing high centres or low centres reinforce this point:

To attempt to produce a high level of centre produces immediate problems of waste, breakdowns, and skill, in both the high boil department and subsequent packaging departments. To produce low average levels of centre ensures that these problems are considerably reduced.

For the operators to deliberately run the process at a low level of centre, when major levels of centre could be achieved, is to blame the operator attitude as a sole cause and ignores the fundamentals established already, i.e. an absence of adequate control, and a lack of a method of specifying to the operators how to produce high levels of centres, with no major problems and on the existing equipment.

The conclusion to be drawn is that the operators do run the process at a level which produces 40% of the specified centre content because of physical design limits of the current process and an absence of adequate control to overcome these limits.

It cannot therefore be acceptable to blame the operators' attitudes as a cause for failure to achieve the specified standard.

RESUMÉ OF THE ENGINEERING ANALYSIS OF POSSIBLE PROBLEM AREAS IN THE CURRENT PROCESS

RESUMÉ

The analysis of the manufacturing procedure and the behaviour of the major elements in it has revealed some fundamental design areas which need attention. At the same time other areas, to which considerable resource has been allocated in the past, are shown to have no significant effect.

The quality of the molten sugar produced, both on the candy-makers and manually, needs to be reasonably uniform, but is not responsible for the major defects outlined in the analysis of product.

The speed of the process appears to be of fundamental importance to the efficient operation of the rope sizing and sweet forming process. This is borne out by the analysis of the frequent breakdowns of the rope forming equipment. In the past, and at present, considerable skill has been necessary to operate this unit, and although high levels of skill are necessary, they are not always available. As a result, the product quality fluctuates considerably according to the available skill. Even when the best operators are available the product does not meet the standards required.

The rope forming operation must therefore be completely redesigned to improve its performance, and more essentially, to provide accurate adequate control of size reduction in the continuous process.

The dimensions of the centre pipe also reveal a lack of flow balance necessary to ensure even delivery of the centre material at the pipe exit.

The physical action of both pumps and scrolls do not indicate any lack of capacity to carry out their function. This is borne out by a comparison of the defects of sherbet and chocolate centred sweets, scroll feed is used for sherbet powder and a gear pump is used for liquid chocolate. They are quite different in principle, yet the product defects are identical, i.e. poor alignment of centre material within the case, and low control of centre level.

The other major elements analysed were:-

- Temperature control of centre material
- Shape of sweets
- Maintenance and age of equipment.

Each of these has an effect on one particular type of product, yet all of the product defects are common. This tends to discount these areas in terms of their possible contribution to major quality variation.

Finally, operator attitudes do not appear to be a major cause of the problems simply because of the fundamental design limits established in the process so far, i.e. centre pipe dimensions and poor difficult control of the rope size using the current roller configuration arrangement.

The next stage must be to look at the established problem areas with the object of improving their operation, to provide effective control of their operation and hence the quality of product.

THE RE-DESIGNED ELEMENTS

IN THE PROCESS

INTRODUCTION

The installation and testing of prototypes designed to overcome the problems outlined covers four specific areas:

1. The testing and design of a purpose built system to monitor rope size variations.

2. The construction of a new mechanism for rope forming capable of maintaining the alignment of centre material, and performing this function reliably over an extensive period free from the current high breakdown and waste frequencies.

3. The testing and evaluation of a larger dimensioned tapered pipe, conforming to the design principles outlined.

4. The commissioning of a centre pressure monitor in order to give an accurate indication of the rate of flow and variations of centre material during rope forming.

Each of these new elements is described as a separate entity. Specification is given as to how the design features were chosen and modified during commissioning. At the end of the descriptive sections relating to performance, there is a separate quantification of the benefits of each element.

ROPE SIZE MONITORING

Rope size monitoring became the first objective in attempting to control the process. This was fundamental for several reasons.

Firstly, until the rope size variation had been established and documented, it would not be possible to establish the effectiveness of any alterations in the process.

Secondly, this monitoring will show the effects of alterations in normal running parameters with the existing four rope size unit, and also those due to fundamental changes in rope size design.

The search for an accurate method of monitoring rope size was carried out also with a view to monitoring centre position within the rope. This was not possible, as will be explained later, but the end result was the purchase of a tailored photo-diode camera system which achieved the major requirements of outside dimension monitoring.

The systems and techniques examined were as follows:

- Infra-red monitoring via a thermovision system
- Ultrasonic thickness measurement
- Pneumatic gauging
- Photo-diode measurement

Each of the systems were investigated on the grounds of cost, availability, size, and its ability to exist in the instrument - hazardous environment in which it would have to perform.

The system eventually chosen would also have to satisfy the major constraint outlined in the research approach i.e. being the first major purchase and it had to work to such an extent that there was an effect on production and no short term requirements would be met. If it did not work, the credibility of the entire project would become suspect in the eyes of the firm and this could inhibit subsequent capital expenditure.

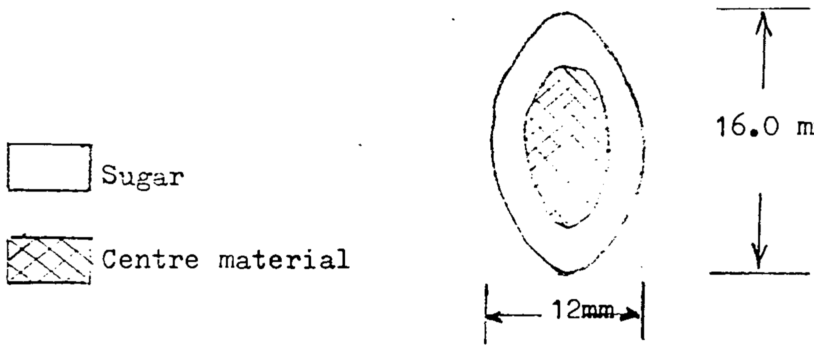
Taking the basic product specification , which laid out the requirements of the system the one chosen would have to be:-

- compact
- durable
- generate useful monitoring information
- cost effective

Taking each of the systems examined in turn:-

<u>The Infra-red Camera System</u> - was an Aga Thermovision system. This consisted of a camera head trained on the object (the rope) from which an infra-red thermographic analysis of the surface radiation was displayed on a screen.
The problem inherent here was that the centre was contained within the rope of the following dimensions:-

FIG. 33 - THE DIMENSIONS OF THE SUGAR ROPE CONTAINING A CENTRE FOR 20mm ROUND SWEETS



The case wall according to Quality control standards would never be less than 3.0 mm thick.

Sugar is a very poor conductor of heat, and hence, the thermovision system would give only a surface picture. The position and alignment of the centre would be invisible to the infra-red scanner except when the centre was about to burst out of the case, by which time the situation would have deteriorated beyond useful control.

In addition, the cost of the system was £20,000 per camera. Two would be needed and since the value of the information they generated would be limited, £40,000 under the circumstances was too high to be feasible.

These systems are primarily useful in detecting heat losses in buildings, medical analysis, and thermographic analysis of uniform materials in industrial processes. In the majority of cases in the confectionery environment, the temperature differential between the case and the centre, is not so great as would tend to show up, even at the surface level.

Ultra-sonic thickness measurement - the cost per unit c. £2,500 looked promising, but the system failed on several fundamental pre-requisites:

- The sensing head needed to be in firm contact with the monitored rope. This is not possible, since any surface contact would have to be with a soft rope moving at 1.76m/s past the monitoring point.

- The analysis of the information from the head required materials to be of significant differences in density. This is found in its most common applications, steel vs. air, in hull thickness measurements in the ship repair business. Another example is, bone and muscle and fluid in the maternity application of Ultra-Sound.

  This density difference does not exist in the confectionery application. The sugar case varies in density in the range of 1.1 - 1.5gm/cm^3 according to the amount of air diffusion during cooling. The centre materials vary between 0.8gm/cm^3 for sherbet to 1.5gm/cm^3 for chocolate.

  The density differential between case and centre would not show up even if a firm contact could be established.

As a result Ultra-sonics were not chosen.

Pneumatic Gauging - was rejected on several points. The size of the units made them unacceptable. The need for physical contact with the rope also discounted the units on principle. Finally, the hazardous, dust laden atmosphere worked against these units being chosen.

Photo-Diode Camera Systems - consist of a camera head, a processor and display. The units examined were available from two firms in competition :

- Herbet Sigma Limited
- Integrated Photomatrix Limited

Herbet Sigma Ltd. were marketing and selling a Reticon * Linescan system, whereas, Integrated Photomatrix Ltd. were manufacturing to their own design.

Since the system chosen would have to be partially tailored to meet TREBOR requirements, Integrated Photomatrix Ltd. looked the superior of the two systems. In addition the latter system was also capable of distinguishing centre position in a transparent rope.

Whilst this system did not fully meet with the initial specification, it offered a number of distinct advantages:

- Continuous read-out of rope dimensions at the operating point.
- Generation of Alarm Signals for operators to register oversize and undersize rope.
- Actual Rejection of Undersize rope.
- Continuous Graphing of the rope size and variations.
- Low cost, £7500/unit.

The principle of operation and units involved of the photodiode system are explained and illustrated in Year 1 Review. Briefly the system consists of a camera head, a light source, and a processor .

* Under licence from U.S.A.

The Camera System was also very compact, and since the camera head could be used remote from the processor, this meant that the space taken up at the monitoring point could be kept to a minimum.

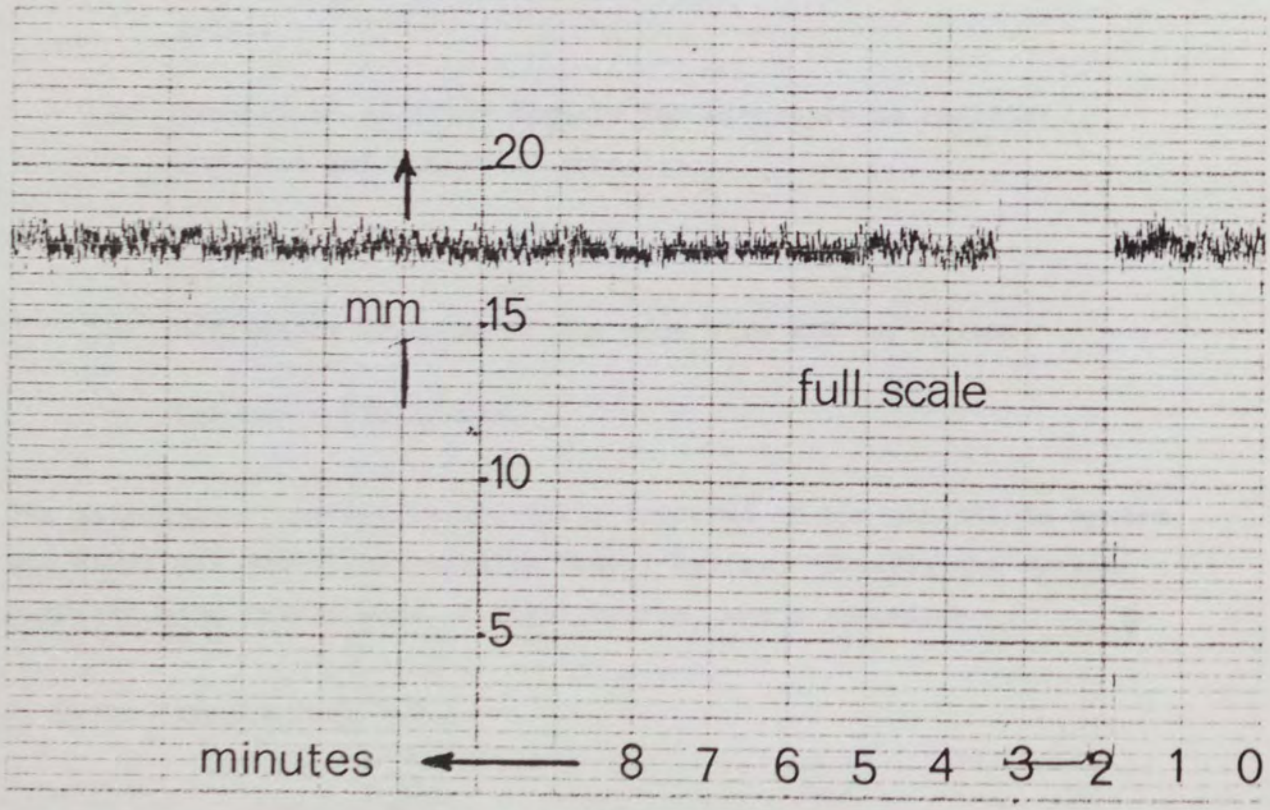
As a result of these advantages, the photodiode system was chosen and purchased.

The order was placed in March 1978 and the camera received in December 1978.

FIG. 34 CAMERA PROCESSOR CONSOLE

Anotated Diagram shown opposite

The photograph shows the prototype camera processor. The chart showing size variation can be seen emerging from the recorder. For presentation purposes the chart traces in the following pages (Figs. 37 - 39) have been photographically reduced, the main aim being to show trends developing i.e. stable and unstable rope forming. Since these occur over extensive time periods, to show them fully to scale would greatly increase their length without adding to clarity. As an aid one sample trace is shown below:



ROPE SIZE MONITORING

The Commissioning Period

The physical appearance of the system is as follows:

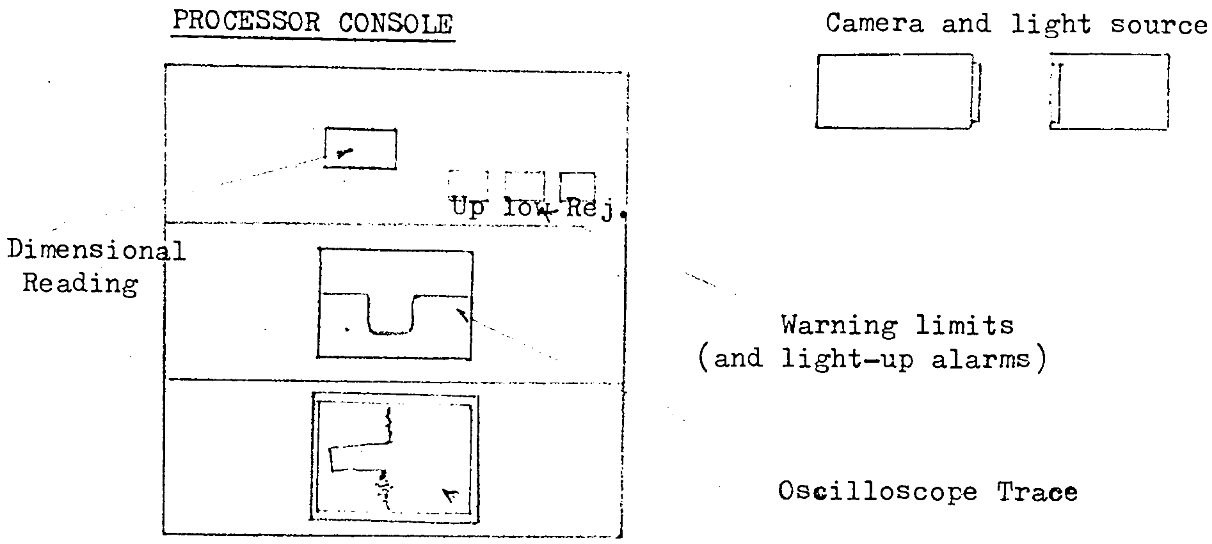


FIG. 35 - THE ELEMENTS OF THE PHOTODIODE CAMERA SYSTEM

The warning limits acted on 3 levels:

1. Upper Limit - when the size of the rope exceeds the set limit an audio alarm alerts the operator and a light flashes to signify the cause.

2. Lower Limit - acts in exactly the same way, but indicates that the rope size is too low.

3. Reject Limit - this is activated when the rope dimension is so low that major defects are occurring causing unusable sweets.

The Reject Limit action was derived from the Upper and Lower limits, and it also initiated a relay attached to a reject mechanism which removed the sweets from the cooling belts into waste tins.

All three warning limits can be set on any dimension between 0 - 25.6 mm. This is sufficient to cover every possible rope size.

The normal working levels are:-

Upper Limit	-	17.0 mm
Lower Limit	-	15.5 mm
Reject Limit	-	15.0 mm

The normal size for the sugar rope on the most common rope (20 mm round sweets) is in the range 15.8 -- 16.2 mm.

Envisaged Operation of the Rope Size Monitor (Prior to Installation)

The rope size variations were occurring in several forms which were detectable prior to the installation of this system.

1. Complete breaks - were due to a 'pile-up' on the rollers. The rope necked down and broke completely.

2. Rope Necks -(of major proportions) - where the rope momentarily 'necked' or thinned-down dramatically in the space between the last sizing roll pair and the die pre-feed. This is detectable on a 90cm stainless chute referred to as 'the rope bridge.'

Both of these size variations, operators attributed to poor sugar causing feeding problems.

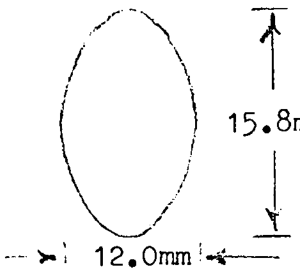
The envisaged operation of the camera system was that the build-up to complete breaks would be alerted to the operators by the audio alarms, so that they could take corrective action. In addition, the waste sweets produced, in both complete breaks and rope necks, would be removed from the system enabling good size control of the sweets manufactured for despatch packaging.

Problems Encountered During Commissioning

1. Actual Rope Shape

The rope has the dimensions shown below:-

FIG. 36 - DIMENSIONS OF A SOLID ROPE FOR 20mm ROUND SWEETS



As this emerges from the last roll pair and runs past the monitor point, it is in a highly unstable situation of movement. Under some circumstances the rope is under tension and remains upright, at other times the rope is slack and tends to fall over. As a result the control system functions capably when the rope is under tension, but when the rope becomes slack and falls over, the camera system 'sees' the 12.0mm width as height and carries out the reject sequence.

Solution

A rope stabilising chute was developed to ensure that the rope could not fall on its side at the monitor point. The result is that the camera system measures and rejects only on true size variation.

2. <u>Break Frequency</u>

Breaking on a standard four rope size unit occurs frequently throughout the running time, as the Table below shows:

TABLE 5 - (Repeated)

	Mon.	Tues.	Weds.	Thurs.
Downtime (minutes)	96	73	16	43
No. of Breaks	42	31	8	37
Average Duration (minutes)	2.28	2.35	2.00	1.16

This is repeated from Page 60 where the data is given in more complete form, including products and hour of the day. No particular product, or time of day appear responsible for an increase or decrease in downtime.

A more important factor is certainly the level of skill used in setting up the parameters of running, and also the skill available to make sure these parameters remain stable.

Each rope-break produces approximately 7lb of waste sugar removed from the process which is not immediately re-usable and must be transported to a separate section of the factory for reclamation.

For the week shown, the reject volumes would be:-

TABLE 8 - DAILY REJECT VOLUMES TRAPPED BY THE CAMERA SYSTEM

Monday	Tuesday	Wednesday	Thursday	TOTAL
130 kg	98 kg	25 kg	117 kg	370 kg

So the direct effect on the production department here, is that the rope monitoring system would trap 370kg of waste sugar inside the department. This is not only visible and needs to be removed, but it also causes friction between production control and the departmental staff.

The effect on the subsequent wrapping department is more major. One or two defective sweets can cause a roll of 12 sweets to be scrapped. So against the 370 kg. removed prior to wrapping, must be balanced, a volume of potential reject work in wrapping of six times the amount rejected, i.e. 2.2 tonnes/week @ £5,000 tonne retail.
Balanced against a purchase price of £7,500, the weekly saving more than justifies the capital outlay.

An exercise was then carried out to quantify, in cash terms, the value of running this rope monitoring system. This is shown in detail on Page 109.

3. Neck frequency - Necking of the rope was also occurring regularly, and could not be registered by human eyesight.

The problem in this situation is that a rope neck is not a complete stop in the rolling process, and hence, prior to the installation of the camera system, went largely unnoticed.

However, operators and production control soon began to notice the high volumes of work trapped by the reject system, entirely atrributed to rope necks.

Complicating factors

The waste is removed approximately 9 seconds after it emerges from the dies, prior to entry onto the main, slow moving, wide cooling belts.

Due to the fact that there is a time delay involved here, a dual timing system had to be evolved:

	Action Rope Break
Timer 1 (Delay On)	count 9 seconds and activate reject system
Timer 2 (Delay Off)	when reject condition no longer viewed by camera, commence counting 9 seconds, and de-activate reject system.

This has formed the basis of a crude timing system.

Problems occur when the process is speeded up, e.g. 100 die rpm → 150 rpm. This significantly alters the necessary time delays, and hence, if these remain unchanged good product is rejected earlier, and at the end of sequence bad product is left in the system or vice versa.

When the operators view this situation, they immediately call into question the entire system of rejection. Hence, it is a full-time occupation to alter the timing sequences at each speed alteration of the process.

The Solution - is a simple implementation of a microprocessor to use a memory system of alteration of time delays and reject operations.

This has been designed and is due to be implemented shortly.

4. Noise Levels

The noise levels are in excess of 95 dB and occasionally, over 110 dB.

Commercially available audio alarms in this range exist only in the hearing 'pain threshold'. As a result, operators who have either suffered hearing damage or managed to filter out excessive noise, are unable to distinguish audio alarms at an acceptable dB level. On the same basis pain threshold audio alarms are unacceptable and illegal when they operate as frequently as a rope break or neck, occurs.

As a result, until the general level of noise in the environment is reduced, and until the work routine assumes a less frantic pace, audio alarm systems used in conjunction are not practicable.

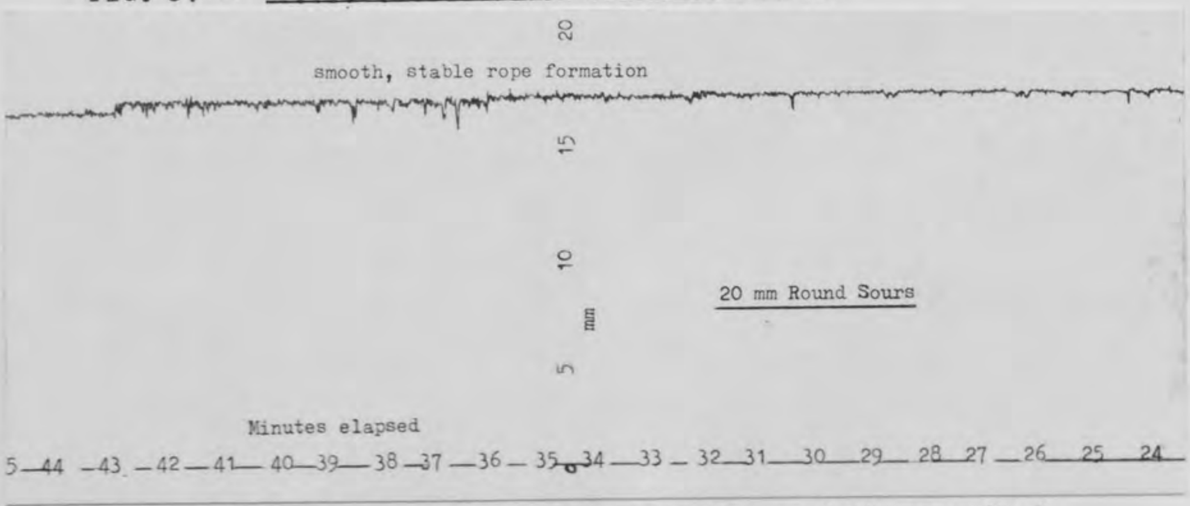
5. Operator Co-operation and Skill levels

The use of a chart recorder is highly valuable in, not only recording break and neck frequency, but also in setting the speed parameter of the process.

It has been found that a narrow trace on the chart indicates stable size of rope, and hence, sweets. A wider lateral trace indicates much higher variation in the parameter set-up of the process.

The reaction to this is varied. Several operators use the breadth of the lateral trace,

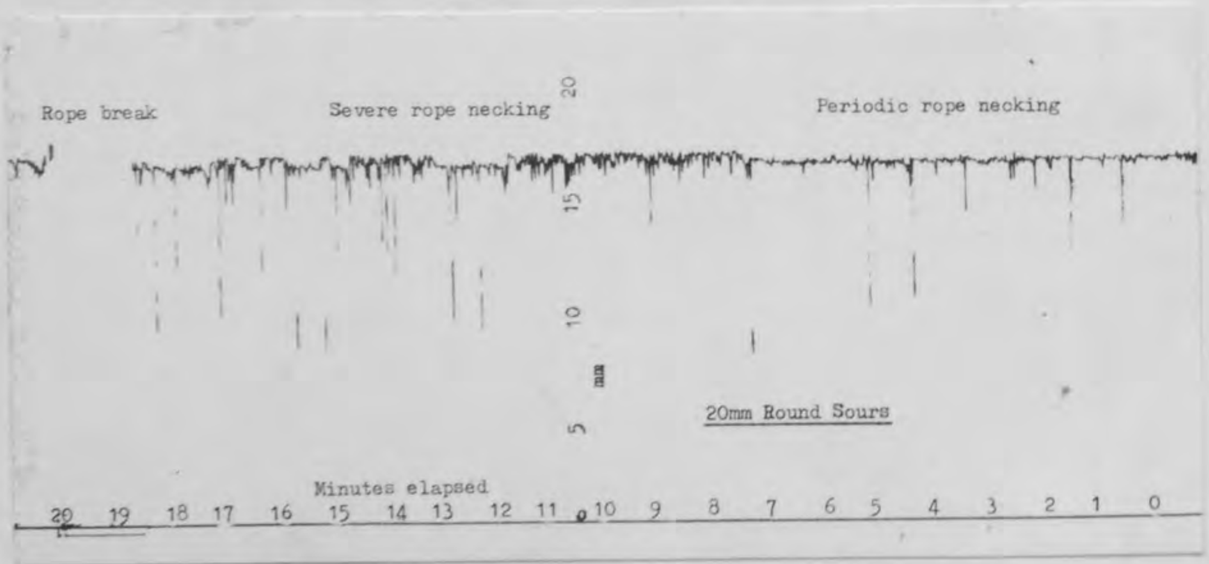
FIG. 37 - CHART TRACE OF STABLE ROPE FORMING



as an aid to setting the speed parameters of the pre-feed, rope size unit, and die assembly.

It also acts to indicate an unstable situation developing e.g.

FIG. 38 - CHART TRACE OF AN UNSTABLE CONDITION DEVELOPING



6. Problems of Control Feedback

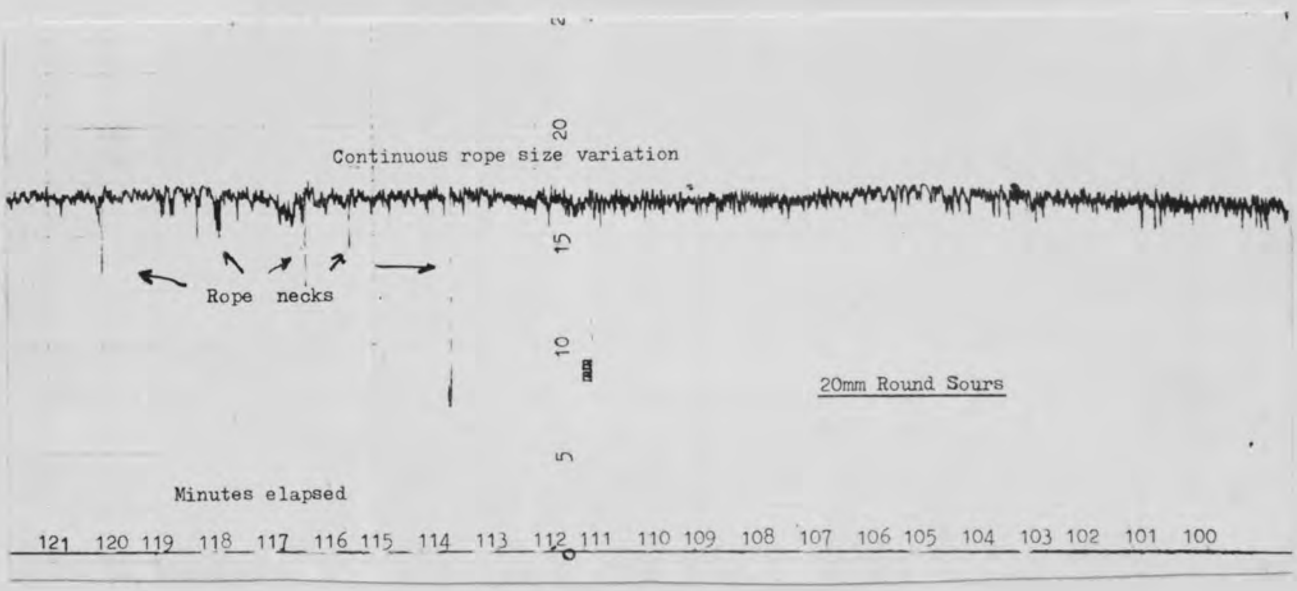
Once an instability has been established, considerable skill is required to correct it. The current poor design of the four rope size unit and the entire forming process, vastly increases the workload to carry out the necessary corrections to the process.

When this is done, with the requisite skill and effort the end result, is a much improved product and easier subsequent wrapping. However, because the demands are made to a department which does not directly benefit, the operators are understandably unwilling and resistant to making that effort.

This calls into question whether the level of skill required is too great, and also more fundamentally, is it reasonable to make mass produced sweets with a process requiring high levels of skill.

An alternative approach is to re-design the rolling and forming process to operate with the minimum of skill and effort so that it remains as stable as possible once set in operation.

FIG.39 - CHART TRACE OF UNSTABLE ROPE FORMING



Benefits of the Photodiode Rope Monitoring System

The benefits are:-

- Rejection of waste product before it enters the wrapping department.

- Continuous record of size variation and running performance of sizing equipment.

- Indication of stability of the set parameters, i.e. pre-feed speed, rope size speed and die speed, e.g. a narrow chart trace indicates good rope size, a wide trace indicates the opposite.

  Both situations are undetectable by eye without the help of instrumentation.

- Indication of instability. When the parameters are incorrectly set, or fluctuating, the continuous chart record gives an indication of instability,

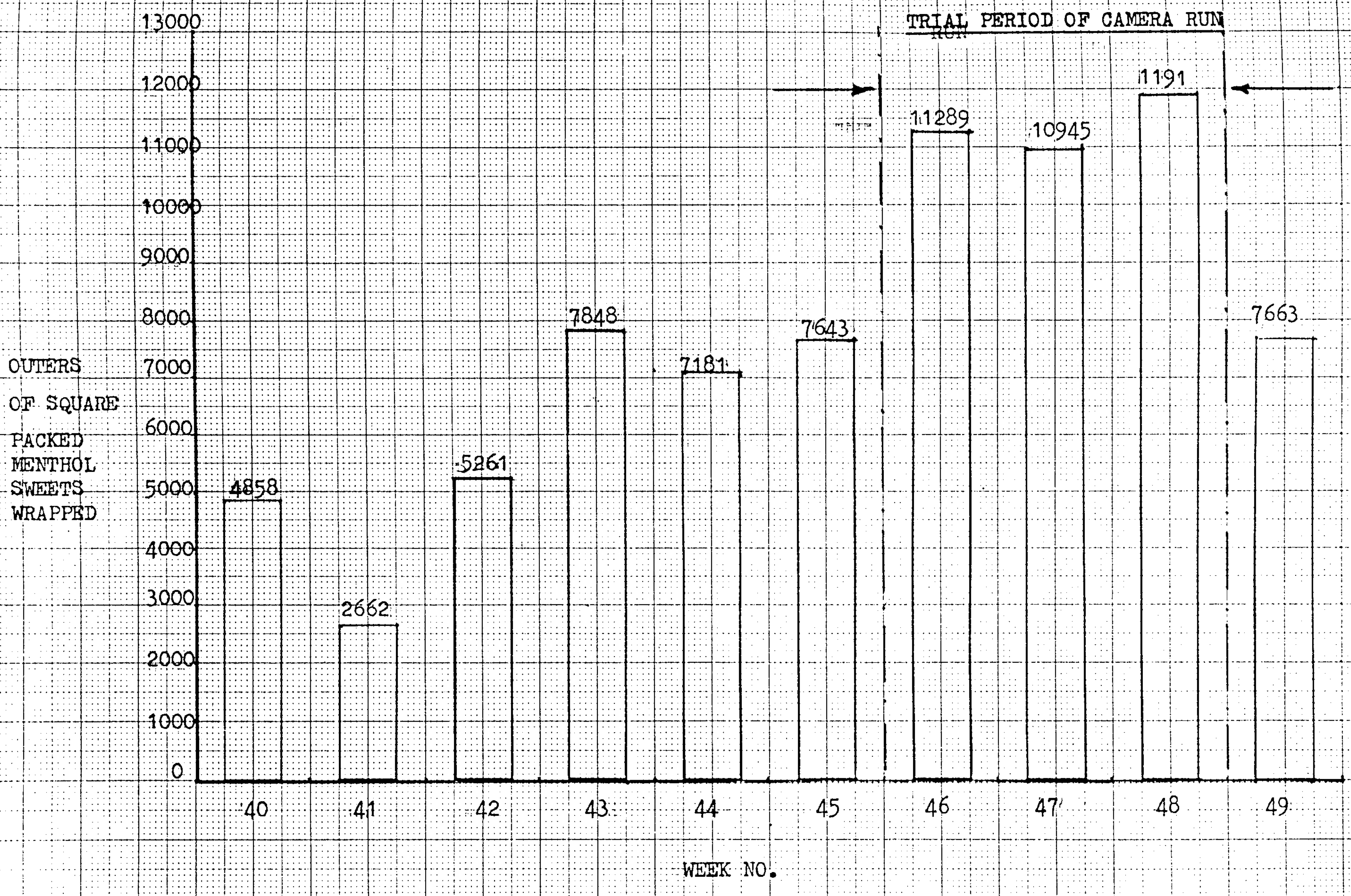


FIG. 40 – THE INCREASES IN WRAPPED TONNAGES DIRECTLY ATRRIBUTABLE TO THE USE OF THE CAMERA SYSTEM

ROPE SIZE UNIT DESIGN

The background to this area is outlined fully in earlier sections and reports. However, it is useful to briefly examine the stages of analysis which pointed to the problem areas in this unit.

1. Historical Development

Rope size units at Trebor are in excess of 25 years old. Their design is common to the rest of the confectionery industry. It is fair to state that their design has evolved from a process of trial and error rather than any particular scientific principle.

As the breakdown analysis has shown in previous sections, these units are heavily skill dependent, labour intensive, and frequently the cause of shutdowns during normal running.

Similar units are advertised in the confectionery journals[11-14] and no major alternative principle is available for achieving the same result.

2. Initial Analysis

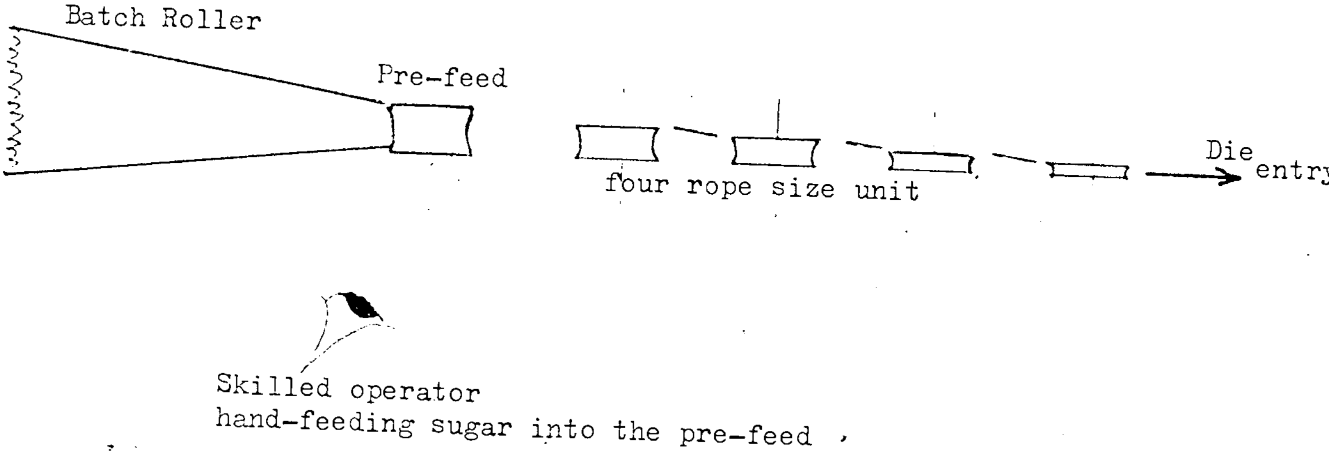
It was quite apparent from preliminary observations that these units were frequently blocking and stopping. The operators attributed this to the variation in sugar consistency.

Analysis had shown the centre volume and alignment to be varying considerably. Again the operators blamed the sugar consistency as the cause.

The initial analysis was taken up viewing a unit which, despite frequent breakdowns and poor alignment of centre had existed in line for over 25 years, and according to the operators was not the source of any problems. In their view the problems were caused earlier in the process and the performance was determined by set-up control.

Basic Design Features

FIG. 41 - THE BASIC DESIGN FEATURES OF THE FOUR ROPE SIZE UNIT



Normal Operating Mode

Once the batch roller is full of sugar the operator draws out the end into a 'rat-tail'. This is then fed into the pre-feed, guided into the rope sizer, and through each pair individually. As it emerges from the last pair on the four rope size unit it is then fed along the rope bridge and guided by hand into the die pre-feed. From this point on, the epicyclic cutters cut and form the rope into sections, they are then compressed between two plungers into a die chamber and ejected on to a cooling belt. This action takes place within one rotation of the die assembly. There are normally 40 pairs of dies operating on one die ring. The die assembly is normally rotating at 90-120 rpm to give a constant speed output of 1200kg/hour.

Initially Observed Problem Features

1. Skill level in feeding sugar from the batch roller into the pre-feed

   This is an arduous task and prone to frequent failure. When this occurrs the entire feeding sequence, i.e. 'rat-tailing' must be repeated.

Problems occur here with such regularity that the operators are unable to leave the pre-feed location whilst the machine is running, and due to the manual nature of feeding, the operators' hands must be continuously in contact with the sugar at the pre-feed entry. Despite protective gloves, skilled feeders' hands and fingers are burned by the end of a week's production. The burning has the appearance of heavily reddening skin, especially the thumbs, which over a long period of time loses touch sense, and results in swelling.

In a similar way to the ambient noise levels, the heat burning of the hands has over the last 25 years, become an accepted feature of the job.

2. <u>Heavily Studded and Roughed Roller Surfaces</u>

To enhance the grip of the rollers on the sugar surface, they are heavily ribbed and spiked, this has the effect of puncturing the outside skin of the sugar rope and limiting the achievable level of centre in a rope as a result.

3. <u>Heavy Overall Skill level</u> in feeding throughout the process.

Due to the fact that the sugar must be hand-fed between each roll pair, it is frequently necessary for two operators to be present to restart the machine after each breakdown.

4. High Waste Level

The department with four process lines produces waste averaging 10% of all product produced. This represents an average of 15 tonnes per week of waste sugar.

The true cost of the waste can be measured in several ways, i.e.

Retail value of 15 tonnes at £5,000/tonne
+ Energy consumed to heat 15 tonnes
+ Energy consumed in removing and disposing
+ Cost of labour and overheads to make 15 tonnes weekly.

On the first level, the lost retail value is over £75,000 per week, even when looking at the cost of raw material:-

15 tonnes sugar at £500/tonne	-	£7,500
Waste value at £30/tonne (animal feed)	-	£ 450

Ignoring the energy wasted in production and disposal, also the labour and overheads, the overall waste figures become:-

TABLE 9* - THE THEORETICAL LOSS DUE TO THE POOR PERFORMANCE OF THE FOUR ROPE SIZE UNIT

lost retail value/week	-	£ 75,000
lost raw material/week	-	£ 7,500
TOTAL Weekly Loss	-	£ 82,500
ANNUAL Loss		£ 4,290,000

These figures do not represent an actuarial evaluation. They are included to show the magnitude of the financial implications.

5. Low Level of Achievable Centre

Poor product quality documented earlier at approximately 40% of the specified standard shows the current design and operation of these units contain a number of undesirable and high cost faults.

Detailed Analysis of Rope Sizing Design

Two questions must be asked of the existing design at this stage:-

1. What is the function of the existing rope size unit?
2. Is it carrying this out? If not, why not?

The function of the rope size unit is to:-

(a) Draw out the sugar evenly into a rope which can be cut into regular consistent shapes in the dies. The end result must satisfy Quality Control specifications.

(b) To add centre to the rope of a different material, which must be at a controlled level and evenly aligned within the rope.

The rope size must be capable of carrying out both of these functions with the minimum of:-

- waste
- skill
- labour

and at the required speed (1200kg/hour).

If the rope size is capable of carrying out its function and meeting the requirements placed on it, then the answer to the centre problems must lie elsewhere in the process.

Initially, in the rope size monitoring experiments, it can be seen clearly that the rope diameter is varying extensively. Breakdowns are common and levels of waste are high.

It is necessary to examine the detail design of the rope size unit to see if it conforms to known and accepted practice or scientific principles.

The standard 'rolling handbook' which covers basic scientific theory is:-

'Roll-PASS DESIGN'[21]

United Steel (1960)

Whilst this work refers to steel rolling, the problems covered are almost identical.

In the confectionery industry, the running of this unit is subject to:-

- underfeeding
- overfeeding
- complete breaks
- pile-up situations

All of these situations are found in steel rolling.
The consequences in the steel industry of these problems are far more significant and as a result considerable research has been carried out into roll design and running parameters.

In the event of a sugar pile-up, the machine is shutdown, the sugar is cleaned away and the process restarts within minutes.

In the steel industry, when a stock piles up at a roller entry, the material is at 1100°C and cools rapidly. It is almost impossible to remove from the rolling mill and hence the entire mill is damaged and needs refurbishing.

Since the consequences are less catastrophic, the confectionery industry, with cheap labour and raw materials, has for over 25 years accepted that breaks are frequent.

The steel industry, working to much closer tolerances and higher volumes, has had necessity to develop the theory to enable smooth and continuous running of its rolling process. The volumes involved give an indication of the comparison.

The Chesterfield, Trebor Factory, produces 200 tonnes/week of sugar sweets on four process lines, with an average waste level of 10%.

The B.S.C. Rolling Mill at Roundwood, in Rotherham, will produce 6,000 tonnes of rolled steel rod bar with an average waste level of less than 1.5%.

General Parameters In Sizing Roll Design

With the greater accuracy, design and wealth of theory available concerning rolling for steel, it is useful to conduct the analysis of the four rope size unit with the same parameters as found in steel rolling practice.

The most basic design parameters listed in 'Sizing Roll Practice and Design' are:-

- Reduction of area between roll passes.
- Coefficient of friction of material and roll surfaces.
- Lack of inter-stand tension.
- Angle of contact of material on roll surface during rolling.

Explaining each briefly:-

Reduction of Area - is the amount by which the cross-sectional area of the entry stock is reduced when it emerges from the roll pair exit, e.g.

If the entry C.S.A. is 70 cm^2
and the exit C.S.A. is 50 cm^2

the Reduction of Area is 29%

Normal practice is that the reduction should be kept to a maximum of 30%, in exceptional circumstances this can go as high as 45%, but rarely above.

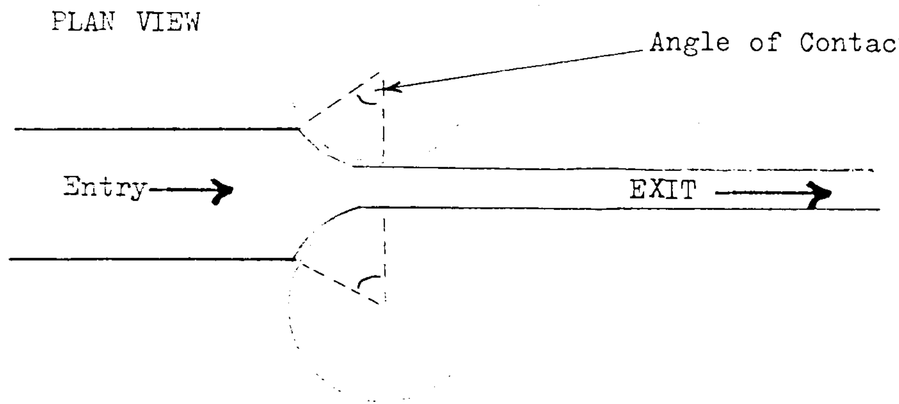
Coefficient of friction - relates to the level of natural grip between the roll surface and the material being rolled.

Lack of Inter-Stand tension - is a major principle. Any tension between successive roll pairs leads to the material 'necking' out unevenly. This is an uncontrolled effective reduction and introduces major instabilities into the rolling system.

As a result, all pairs are designed for constant volume flow, i.e. the volume of material exiting a roll pair is exactly matched to the cross sectional area and speed of the next entry roll pair.

Angle of Contact - this relates to the angular segment of the roll surface which is in contact with the material during rolling:-

FIG. 42 - THE DERIVATION OF THE ANGLE OF CONTACT



In most roll pass designs the angle of contact is kept in the range 21-25°.

Looking at the confectionery four rope size unit reveals that most of these fundamentals are being broken in some fashion.

Reduction of Area

Looking at each roll-pair:-

TABLE 10 - THE REDUCTION OF AREA CARRIED OUT BY EACH ROLL -PAIR OF THE FOUR ROPE SIZE UNIT

		C.S.A.		Reduction
Pre-feed		$38cm^2$	$- 11.4cm^2$	70%
Rope Pair	1	11.4	- 7.0	38%
"	2	7.0	- 4.5	35%
"	3	4.5	- 3.8	15%
"	4	3.8	- 2.2	41%
Die Feed		2.2	- 1.7	25%

The first indication of a possible problem area is the massive reduction at the pre-feed - 70%. It is here that the skilled feeder must maintain constant attention.

Coefficient of Friction

The pre-feed and rope pairs 1 and 2 are heavily roughed with grooves and spikes. Despite this, talcum powder has to be applied heavily on the sugar surface at the pre-feed entry. Without this the system soon becomes unstable and slippage occurrs, causing major feeding problems.

Interstand Tension - is present between all roll pairs. This is apparent by the necessity of 'rat-tail' feeding. It is not possible to start the system by allowing the sugar to feed at its own pace through each roll pair. This is confirmed by the volume flow figures:-

TABLE 11 - INTER-STAND VOLUME FLOW OF THE FOUR ROPE SIZE UNIT

	Mass flow kg/min.	
Pre-feed	20	- variable speed
Roll Pair 1	20.0	- Fixed Gear Ratio
" 2	19.3	- Fixed Gear Ratio
" 3	24.4	- Fixed Gear Ratio
" 4	21.6	- Fixed Gear Ratio
Die feed	20.0	- variable speed

Even if the pre-feed and rope size pair 1 are balanced, because of the fixed gearing between pairs 1-4, faults occur in the volume flow.

The result is both tension and compression existing between roll pairs. Too much leeway is therefore allowed, for the material to draw-out at an uneven rate.

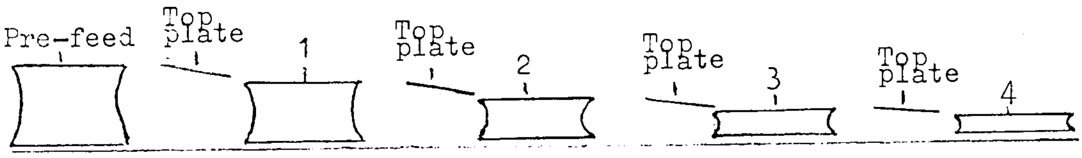
Due to this reliance on the basic properties of the material to be drawn evenly, too much emphasis is placed on the system producing 'good' material, compensating for a badly designed rolling system.

The four rope size unit is not, as it stands, a rolling system, but a combination unit which uses rolling and drawing, both of which are relatively uncontrolled and demand 'good sugar' to work effectively.

Angle of Contact - assumes that the stock is presented to the roll entry for even reduction by both rolls in the pair. This does not occur in the four rope size unit.

The Schematic diagram below illustrates this, in part:-

FIG. 43 - SIDE VIEW OF THE FOUR ROPE SIZE UNIT



Each of the roll pairs are on the same base line. The effect of this is to squash the top of the rope under a top-plate, and to cause pressure at the base of the rope, flattening it out. Were it not for the tension that exists in the system, it would be incapable of feeding or continuous running. Due to the tension in the system, too much emphasis is placed on the basic material properties.

The combination of tension, uneven height reduction, uneven and unbalanced reduction of areas, leads to major disruptions in flow.

Assuming a centred rope entered the pre-feed evenly aligned and that the sugar properties were ideal, the effect of the flow disruptions shown above would almost inevitably cause the case to be worked unevenly, and the centre position and the amount within the rope would be altered significantly throughout the run.

Calculation of angles of contact on a four rope unit therefore, have little relevance because of the presence of these disruptive factors.

Summary of the Analysis of the Four Rope Size Unit

Each of the rolling fundamentals listed in the Steel references, i.e.

- coefficient of friction
- reduction of area
- lack of tension
- angle of contact

are broken and distorted in the design of the Four Rope Size Unit.

The reductions are too large. The friction coefficients are also too large in a failing attempt to compensate for this.

Tension exists heavily in the system, without it, it could not operate, with it, it places too great a load on producing consistent sugar.

The level of contact between the working surfaces of the rollers and the sugar is strongly out of balance and alignment.

The resulting effects of these design failings are that the rope size system will only operate with:-

- high skill and attention
- a narrow range of sugar quality
- a high level of variation in size
- frequent breakdown

Each of these has been confirmed in the analysis and observation of the running process.

/continued......

In addition, the effect on centre content of any rope is to:-

- limit the amount possible in a rope (recorded at 40% spec. standard).
- vary the amount within different sections of rope (as the sugar is rolled and drawn unevenly, this must redistribute the amounts of centre present in any particular length of rope).
- alter the alignment of the centre within the rope (because of both tension and flow disruption.

The end result is, that the design features of the Four Rope Size Unit make up the major problem area of the major isloated defects in the sweets produced, i.e.

- badly aligned centres
- variation in centre content.

The New Rope Size Design

Once the operation of the existing rope size unit was analysed and the problems identified it became apparent that there was no way of making the necessary modifications to improve its performance. The underlying reasons for this conclusion were (1) theoretical and (2) practical:

(1) The reduction in rope area through the rolls is not smooth. Correcting the pre-feed reduction of 70% would need two more pairs of rollers, and in addition the succeeding pairs would have to be modified in size and speed.

(2) The machines themselves, originally designed in 1940 and with only small changes since then, are heavily constructed, so that it is extremely difficult to make even minor alterations. To introduce the additional roll pairs would involve more work than creating a new unit.

It was obvious that these roll sizers had not been "designed" in accordance with best roll practice parameters and procedures. Since the greatest experience in this field lay in the metal working industries, it was decided to approach British Steel for discussion concerning a new rope size unit design.

Whilst they were unable to help directly, they were able to suggest one of their outside consultants, Dr. Lancaster, who of Bradford University, could become involved.

The decision to take this course of action rather than to develop the ideal roll profiles 'in-house' for TREBOR was taken because the task represented a relatively routine design exercise for an expert. He required only to know some of the basic properties of the sugar which had already been established, and that his roll profiles should provide for a reduction from 38 cm^2 to 1.6cm^2 at a given flow rate.

After carrying out some routine viscosity tests on cooling sugar, Dr. Lancaster produced two reports - 22, 23. In the first was the viscosity profile of rolling sugar. In the second were the recommended roll profiles.

The New Profiles for Rope Forming

The comparison between the new profiles and those in existence on the current process is shown opposite in FIG. 44

In terms of reduction of area between passes the comparison is as follows:

EXISTING PROFILES
Reduction of area

Initial cross-section 38 cm^2

Batch roller Pre-feed	11.4 cm^2	70%
1	7.0 "	38%
2	4.5 "	35%
3	3.8 "	15%
4	2.2 "	41%
Die	1.34 cm^2	40%

NEW PROFILES
Reduction of area

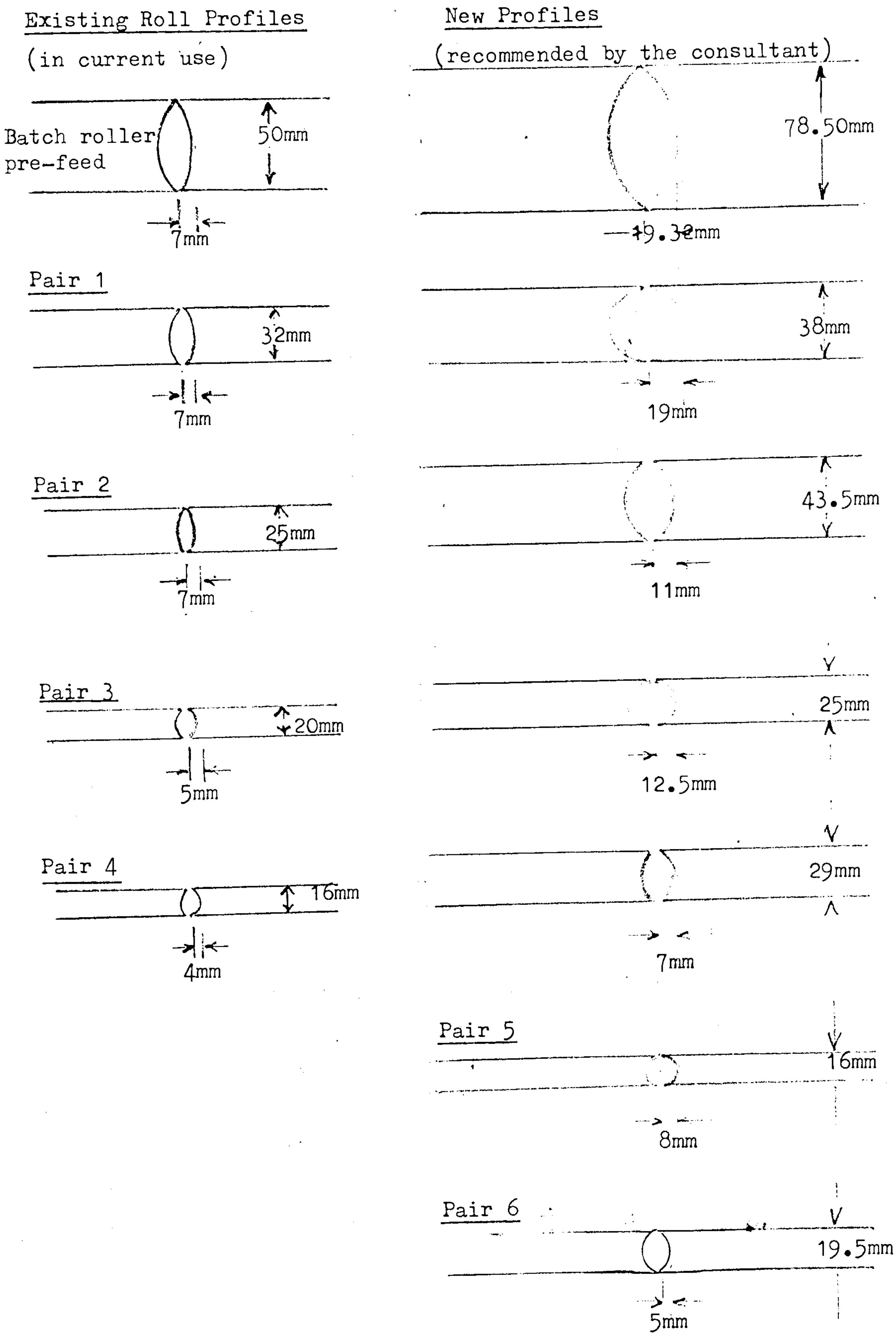
Initial cross-section 38 cm^2

Batch roller Pre-feed	21.2 cm^2	45%
1	11.6 "	45%
2	7.0 "	39%
3	4.8 "	32%
4	3.0 "	37%
5	2.0 "	32%
6	1.3 "	36%
Die	-	-

TABLE 12 - THE COMPARISON OF AREA REDUCTIONS CARRIED OUT BY EXISTING PROFILES AND THOSE RECOMMENDED BY THE CONSULTANT

The main feature of the comparison is the lower reduction carried out at the initial feed-pair at the batch roller cone tip. 45% for the new profiles compared with 70% for the existing profiles.

FIG. 44 - DIMENSION COMPARISON OF THE EXISTING PROFILES AND THOSE RECOMMENDED BY THE CONSULTANT



The new design resulted in a considerable easing of maintaining the feed of sugar into the rope-forming unit, and this aspect was to become of major importance during later stages of the trials.

The new profiles were designed on a basis of constant volume-flow, and the figures provided by Dr. Lancaster illustrate this:-

TABLE 13 - THE INTERSTAND VOLUME-FLOW OF THE NEW PROFILES

Roll Pair	Theoretical Volume-Flow
Pre-feed	20.00 kg/min
Pair 1	19.99 "
" 2	19.99 "
" 3	20.01 "
" 4	20.01 "
" 5	19.99 "
" 6	20.01 "

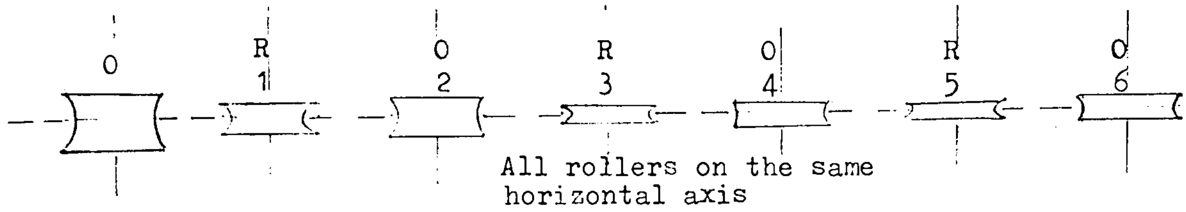
On a basis of comparing roll profiles in isolation, the new roll profiles represented a significant improvement in terms of:-

- constant volume-flow
- balanced reduction of area.

Construction of a Drive Unit for the New Profiles

A suitable drive unit was already available for the new rollers, it could be made to accept six pairs of rollers. It differed only slightly in its features from a four rope size unit. The modifications were quite substantial, but not impossible in this case. The major requirement in the design was that the base plates of the drive unit had provision for adjustment so that the axis of the roll profiles could be set exactly in line.

FIG. 45 - OPERATING SEQUENCE AND LAYOUT OF THE NEW PROFILES



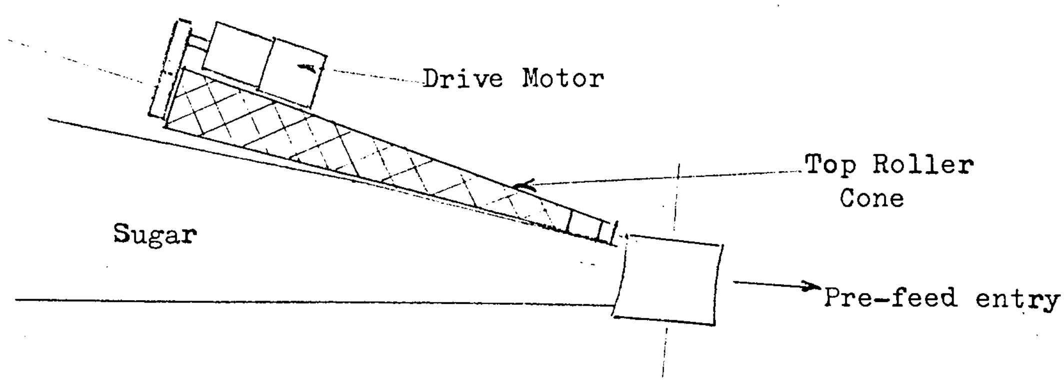
R = Round

O = Oval

In addition to providing the roll profiles, the consultant emphasised the need to control the last portion of the cone-tip of the sugar in the batch roller. Any variations at this point would not be corrected by the rolling system, since this relied on a constant supply volume.

This consideration was taken into account by the design and construction of a small set of top rollers which could be lowered into place to contact the surface of the sugar rotating in the batch roller. Alternatively, they could be lifted out of position so that an operator could return to hand-feeding, should this become necessary.

FIG. 46 THE TOP ROLLER DESIGN



In addition to providing extra control of the entry stock into the new roll profiles, the top rollers provided an "environmental" advantage, in that the operators no longer had to continually handle the hot sugar, so they did not suffer with heat blistered hands which has been a common problem with feeder operatives.

The final design requirement was a suitable method of rotating the rope between the roll pairs. It was necessary because of the pass sequence chosen by the consultant i.e. oval → round → oval. This pass sequence was chosen because a round → round sequence would require a larger number of roll pairs. The only other alternative, diamond → diamond was not suitable for this application.

The method of rotating the stock through 90° was developed over a period of three months, and the ultimate solution was compact deflector plates which deflect the forward motion of the rope at the top and base of the oval section.

Initial Commissioning (March 1980 - August 1980)

In Dr. Lancaster's second report PRL 2, along with the profiles, was the recommendation that the roll surfaces should be roughened to provide an adequate grip to maintain uniform flow. The requirement had to be left unspecified in precise terms and the eventual choice was to be chosen at the commissioning stage.

The initial trials were carried out in an area remote from the main production line. Small samples of molten sugar were passed through the system from the batch roller pre-feed to the sixth pair of rollers on the rope forming unit. No sweets were produced during this period, the purpose of the trials was solely to establish the correct levels of roll surface roughening, the geometry of the turning plate and the top roller design.

Once these small scale trials were completed, the first production trials on the six rope size unit were carried out during August/September 1980. The mode of operation during the trials was to temporarily move a batch roller and the six rope size unit until they were at a suitable angle to commence operation. Sugar was then transferred by hand from the end of a candyband to the batch roller some distance away.

One immediate concern in the trials involved sweet size. All four process lines were heavily programmed, and the line that was available for the trials because of its location, was programmed to make larger sweets i.e. sherbet lemons, cough candy twist. This situation was met by removing the last pair of rollers on the six rope unit so that a rope of 16mm diameter round section was led into the dies, (the final reduction in size was not used).

Happily this resulted in continual production, and moreover, the most successful qualities were achieved when large sherbet sweets were made which contained centre levels averaging 11% compared to a normal 7% (Page 14) using a four rope size unit.

Once these results were known, support was available to plan for the installation of the new drive unit permanently in line UP2. This line made both large and small sweets, but concentrated on rolls (small 20mm round sweets).

Installation of the new drive unit was completed in late May 1981.

In the intervening period, between late September 1980 and early May 1981, short batch trials were made producing samples of high-centred, well-aligned sweets. This was most useful in testing that the new profiles could resolve the problems of poor alignment, and also if the mechanical properties of well-aligned centres differed from those of randomly aligned centres.

Full Production Trials May 1981

The new drive unit was installed on-line in mid May 1981, and a significantly different method of operation was chosen due to new circumstances. In previous trials the machine was run as an experimental unit with the operators not involved in the setting of parameters or the running of the equipment. The new circumstances were that, with the drive unit installed directly in the production line it would not be possible to carry out any planned level of experimentation other than that necessary to get the line started up and maintain smooth running. As a result, the operators became responsible for the setting and alteration of the parameters prior to, and during running.

After some initial and major training problems caused only by lack of familiarity with the new control layout, the operators began to develop a high level of ability in running the machine.
The achieved centre levels reflected this:

TABLE 14 - JAM CENTRE CONTENTS 20 MAY 1981

Jam 20mm round - Specified centre content 15%

Estimated average of ten sweets	16%	10.4%	16%	18.4%	17.8%
Time of day (pm)	1.17	2.01	2.22	3.18	3.41

TABLE 15 - JAM CENTRE CONTENTS 21st. MAY 1981

Jam 20mm round - Specified centre content 15%

Estimated average of ten sweets	13.5%	14.4%	15%	14%	11.2%	18%	18%	13.5%
Time of day (am)	8.06	8.32	8.55	10.06	10.48	11.20	11.25	1.32pm

TABLE 16 - SHERBET CENTRE CONTENTS 20th MAY 1981

Sherbet 20mm round - Specified content 8%

Normal level 3.86%

Estimated average of ten sweets	6.9%	9.2%	6.2%	10.2%	11.6%
Time of day (am)	8.07	8.40	9.43	10.10	11.07

The above figures taken directly from quality control records gave an immediate indication of the improvement in meeting specified centre content.

The attitude of the operators in co-operating to maintain the highest levels dispelled the theory that there was a conspiracy amongst them to choose the easiest routine. They were pleased to use equipment capable of making a better quality product.

Some limited tests on centre alignment showed that there was a marked improvement with the new unit, and from previous experience this was a major contributory factor to the smooth running of the line.

This feature had a secondary advantage in the wrapping department where the high level centres were handled without major disruption. Previously, high level centres had caused stoppages when breakages occurred. The even alignment gave rise to better mechanical properties.

These immediate observations were confirmed and are reported later for the subsequent production runs of the new unit.

The Variable Speed Motor Trials

Following this week of successful production trials it was decided to add the facility of the variable speed motor on the sixth pair of rollers. Dr. Lancaster's original terms of reference had been to design roll profiles suitable to manufacture small 20mm round sweets. To make larger sweets it was necessary to remove the sixth pair of rollers from the drive unit and to feed in the profile emerging from the fifth pair i.e. 16mm diameter round section into the dies on the same production line.

This produced a satisfactory product, but was thought to be unacceptable because of the risk of damage or loss of the rollers and ancilliary fittings.

From a theoretical viewpoint it appeared possible to achieve the same result, without necessarily removing the sixth pair of rollers, but by varying their speed to meet changed size requirements.

Throughout the period June to mid July, the drive unit was run in this modified condition, with an 0.75kw variable speed, frequency controlled A.C. motor installed to drive the sixth pair. Unfortunately, major difficulties arose and these could not be overcome quickly:-

1. The variable speed motor was unable to reach operating speed as quickly as the preceeding 5 pairs of rollers. This resulted in frequent blockages at the sixth pair entry. Despite the addition of a pause delay of one second between the drives this feature continued to give problems on an intermittent basis, and too frequently to be acceptable.

2. In the production situation, the operators had the main responsibility for speed changes and the introduction of this extra speed setting proved too confusing at this stage. This confusion resulted in frequent maladjustment and resulting breakdowns.

As a result of these problems it was decided to return the drive unit to its original condition of direct gearing of all six pairs of rollers.

Production Trials on Direct Gearing - July 1981 onwards

Following these events the operators felt less confident about running the six rope size unit on all product types, including centred work. As a result, the early stages of the next phase of trials was carried out on solid sweets, the purpose being to fully commission the new unit by removing as many of the small problems as possible.

The identifiable developments made in this phase of trials was as follows:-

1. The Level of Roughing of the Roll Surfaces

During previous experimental runs, the level of roughing that had proved adequate, was insufficient for break-free long-term production. This was gradually increased in stages to its present level where the first three pairs of profiles are roughed to a level of 1.5mm deep cuts with a frequency of 120 cuts per roll circumference. The succeeding three pairs are milled to 0.5mm with a cut frequency of 170 cuts per circumference. This has proved ample to provide smooth feeding and running without pile-ups caused by slippage.

2. Sugar Under Roll Surfaces

Periodically the running parameters were set incorrectly, resulting in overfilling of the rolling system. The effects were that sugar was forced underneath the rollers and began to cool, rapidly forming a bond between the rollers and base plates. The result was a rapid overloading of the drive motor and eventual shut-down of the system.

The problem was overcome by cutting 2 mm deep grooves in the base plate:

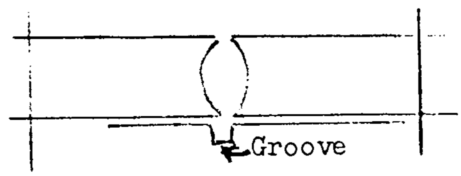


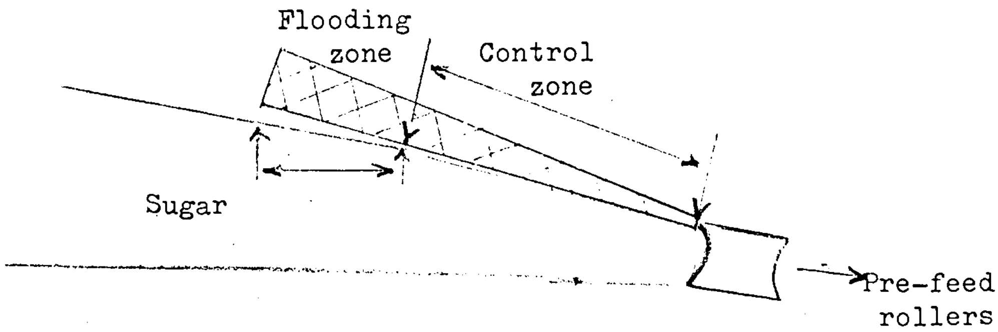
FIG. 47 THE POSITION OF THE GROOVE CUT IN THE BASE PLATE TO COMPENSATE FOR OVER-FILLING

This modification allowed the surplus sugar through, without overloading the drive motor.

3. Adjustment of the Top Rollers

The main purpose of the top rollers is to provide a level of adequate and continuous control of the amount of sugar flowing towards the pre-feed rollers. This control can be varied by adjustment of the level of contact of the top roller cones with the surface of the moving sugar at the pre-feed entry. A wide range of adjustments were tried and the eventual result is shown below:-

FIG. 48 - THE CORRECT SETTING OF THE TOP ROLLERS



The setting of the top rollers provided the final control in the feed to the pre-feed rollers. Its clearance and angle relative to the batch-roller provided the adjustment to compensate for variations in the viscosity of the sugar.

The control zone - is the final portion of the rollers prior to the entry of the sugar into the pre-feed. In practice this forms the front third of the length of the top roller cones.

The flooding zone - is that portion of the sugar cone tip, which although physically under the top rollers is not in contact with the rotating surface.

The control zone provides the accurate physical restraint, ensuring that a smooth flow of molten sugar is presented to the pre-feed rollers. Variations of the sugar viscosity over short or long time periods result in changes of the level of **sugar** in the flooding zone only.

As the commissioning problems were resolved, the performance of the six rope unit, run by the operators in normal production situations improved rapidly. The extent of the improvement was shown by recorded data from the monitoring camera system.

The information is collated in the form of a list of times of uninterrupted production between rope breaks, tabulated for successive production runs on one product type.

TABLE 17 - EXAMPLE OF ROPE BREAK INTERVAL TIMES

Product Type - XXXXXXX

Rope Break	Rope Break Interval (Minutes)
1	10
2	15
3	3
4	65
5	10
6	3
TOTAL	106

In the above example six rope breaks are recorded. The total is then the time for which the machine operated smoothly producing sweets. Looking at the information in more detail, the first rope break occurred 10 minutes after start-up, the second rope break occurred 15 minutes later, the third break occurred 3 minutes later and the fourth occurred 65 minutes after the third and so on. The down-time at the breaks is not listed, but re-start was in fact noticeably quicker.

TABLE 18/overleaf..............

TABLE 18 - ROPE BREAK INTERVAL TIME FOR PEAR-DROPS

Date - Rope Break	3.7.81	6.7.81	14.7.81	4.8.81
1	4	2	17	69
2	1	8	9	59
3	4	12	4	14
4	1	12	15	14
5	1	6	19	24
6	4	21	20	35
7	5	21	36	215
8	1	5	10	
9	17	43	20	
10	5	25	20	
11	2	12	13	
12	4	4	29	
13	10	8	23	
14	13	20	235	
15	17	3		
16	37	5		
17	8	15		
18	13	5		
19	32	5		
20	5	8		
21	194	16		
		5		
		2		
		19		
		10		
		52		
		6		
		330		

The figures relate to periods of continuous running between rope breaks.

The totals relate to the total running time of the machine.

TABLE 19 - ROPE BREAK INTERVAL TIME FOR COUGH CANDY TWIST

Date -	13.7.81	15.7.81	20.7.81	1.9.81
Rope Break				
1	2	36	65	8
2	18	36	17	26
3	9	9	18	20
4	5	20	52	24
5	18	5	30	5
6	11	5	24	8
7	7	35	206	33
8	16	21		38
9	9	1		18
10	6	2		28
11	11	8		208
12	22	24		
13	6	202		
14	12			
15	13			
16	12			
	177			

TABLE 20/overleaf.......

TABLE 20 - ROPE BREAK INTERVAL TIME FOR THE MANUFACTURE OF PINEAPPLE-CHUNKS

Date -	16.7.81			17.7.81
Rope Break	am	pm	evening	
1	10	5	6	7
2	5	8	3	11
3	3	5	36	213
4	10	5	2	231
5	5	8	4	
6	3	7	2	
7	10	24	4	
8	2	8	6	
9	3	2	32	
10	3	2	10	
11	10	4	4	
12	6	12	6	
13	4	8	14	
14	3	12	16	
15	16	8	16	
16	5	7	40	
17	4	20	211	
18	4	20		
19	12	6		
20	111	4		
		20		
		185		

The figures relate to the period of continuous running between rope breaks.

TABLE 21 – ROPE BREAK INTERVAL TIMES FOR SOLID ROLL WRAPPED SWEETS (20mm round and menthol square pack)

	Sour Apple	Sours-Mixed	C/Candy Rolls	Menthol	Menthol
Date –	15.7.81	22.7.81	2.9.81	1.9.81	1.9.81
Rope Break					
1	18	12	3	4	172
2	5	20	164	10	32
3	20	5	60	6	16
4	6	24	227	32	220
5	12	16		60	
6	9	32		26	
7	13	50		4	
8	17	20		52	
9	16	179		4	
10	34			208	
11	5				
12	3				
13	18				
14	17				
	193				

The information shown in these tables gives a picture of the rapidly improving situation for each product type. As each new product type was tried on the new machine, the number of rope breaks became fewer and un-interrupted running times were longer as the operators gained experience.

It is necessary only to compare the number of rope breaks in an early run with those on later runs for similar production lines.

TABLE 22 - POST COMMISSIONING PERFORMANCE OF THE SIX ROPE UNIT ON SOLID WORK

Product	Number of Breaks First Run		Number of Breaks Last recorded Run	
Pear-drops	21	(194 minutes)	6	(215 minutes)
Cough-candy	16	177 "	10	208 "
Pineapple chunks	19	111 "	3	231 "
Solid rolls 20mm	14	193 "	3	227 "
Menthol (square)	9	208 "	3	220 "

The minutes indicate the total running time.

One part to note is that very little experimentation was carried out the period this information covers when the operators alone were responsible for the setting of parameters and changes during running. This is especially important since the analysis of the performance of all current machines is based upon normal running by the operators. It could be argued that - if the new rope size unit had been run under experimental conditions then the resulting information on performance could have been artificial.

Comparison of the Operational Behaviour of the Six Rope Size Unit With That of a Conventional Four Rope Size Unit

The operating procedure of the six rope size unit is less skill dependent than that of the four rope size unit.

The start-up procedure on the four rope unit involves 'rat-tailing' the tip of the sugar in the batch roller cone and feeding this by hand between each roll-pair until the sugar rope emerges from the last pair and can be fed into the die assemby.

The start-up procedure for the six rope unit can be done either with 'rat-tailing' or butt-end feeding, and this is very much a matter of operator preference. Once the sugar has entered the first two pairs of rollers it can then be allowed to feed itself through each successive pair into the dies. Occasionally it is necessary to hand-feed the sugar into the dies when a minor pile-up occurs, but personal observation indicates that this is largely dependent on the confidence and skill of the operator.

The major difference between working the two types of rope size unit can be observed soon after the machines have been started. The four rope unit requires the operator to be continually in attendance, hand-feeding sugar from the batch roller into the pre-feed rollers and continually raising and lowering the angle of the batch roller to prevent flooding or starvation at the pre-feed.

On the other hand, once the six rope unit is started and the top rollers lowered into place, the operator is then free to move around the general location of the machine. The operator's role has thus been changed from one of continual adjustment and decision making to one of machine-minder. It remains a function of the operator to raise or lower the batch roller periodically, but this attention is required much less frequently. On a four rope unit, this raising and lowering is an integral part of the feeding skill and the adjustment is needed every five minutes or so. On the six rope size unit the times vary between thirty and sixty minutes. Because of the action of the top rollers, it is only necessary for the operators to <u>raise</u> the batch roller angle by increments. The purpose of lowering the batch roller when used with a conventional four rope unit is to prevent the sugar flooding the narrow pre-feed aperture. The control and flooding zones of the top rollers prevent this occurring on the new profiles, and there is less chance of this happening because of the large pre-feed aperture.

The increased stability of the new unit is such, that it has been possible to re-activate the alarm lights and audible warnings fitted to the camera system. These had proved to have limited value when monitoring a four rope unit because of the poor performance and continual breakdowns of the system, the alarm lights and audible warnings were operating with such a high frequency that they had become unacceptable.

The six rope unit, as the table have shown, * operates for long periods with the operator in the role of machine minder, and this had an effect that the operator's attention was not always drawn to a developing problem being monitored by the camera system. The installation of a large, beacon type warning light and a supressed alarm klaxon, now ensures that the operators can move away from the rope forming unit for longer periods and perform other tasks, a situation that cannot arise with the four rope unit.

The new situation is shown in the following photographs:-

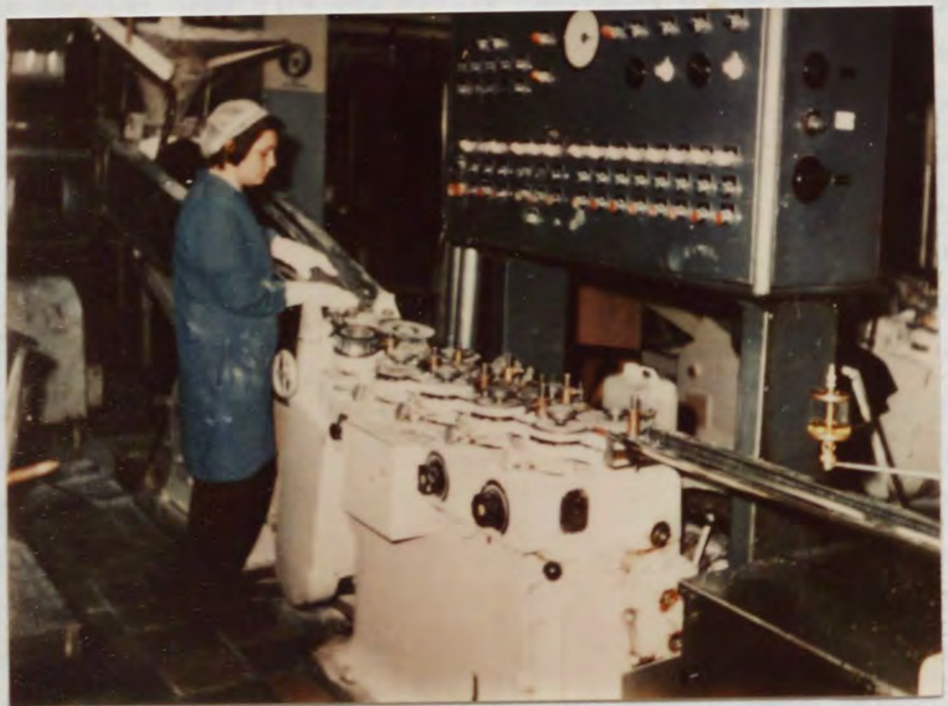


FIG. 49 - THE EXISTING FOUR ROPE SIZE UNIT

This shows the operator in attendance as an integral part of the rope forming operation, hand-feeding the sugar into the pre-feed and continually altering the angel of the batch roller to prevent flooding or starvation:-

FIG. 50 - THE SIX ROPE SIZE UNIT

The top rollers can be seen carrying out their function of controlled feeding. The camera processor console is at the rear of the batch roller, giving a continual indication of rope size and variations. The operator's role is shown to be more passive, i.e. that of machine minder. The rope forming process is continuing without her active intervention.

FIG. 51 - THE SIX ROPE SIZE UNIT OPERATING WITHOUT AN OPERATOR IN ATTENDANCE

Figure 51 shows the six rope size unit operating without an operator in attendance. Whilst this is currently possible in some situations, it is not directly desirable, since routine problems may develop in other immediate areas of the process which would benefit from early corrective action. The main purpose of this photograph is to show that the operator has been released to carry-out less skill dependent tasks, secure in the knowledge that should a fault develop in the rope forming, her attention would be drawn to it quickly.

The Performance of the Six Rope Unit In Centre Manufacture

This is the final area of consideration in the performance of the new roll profiles and design features.

As the results showed in the trials carried out in May 1981, a high level of centre is achievable on the new system even with the operators in control of the vital parameters. The production runs in September 1981 have confirmed these findings.

TABLE 23 - CHOCOLATE CENTRE CONTENT LEVELS PRODUCED USING THE SIX ROPE UNIT

Product	Date									
Chocolate 20mm round roll wrapped sweets.	7.9.81	Time of Day(am)	8.15	8.57.	9.00	9.45	10.08	10.50	10.55	11.
		Average % centre	13.4%	10.6	-	18.1	17.5	-	16.2	15.6
	23.9.81	Time of Day(am)	8.03	8.15	9.55	10.32	11.03	11.23		
		Average % centre	-	13.4	14.1	15.0	15.0	17.1		
	28.9.81	Time of Day(pm)	1.10	1.37	1.58	2.22	3.03	3.18	3.42	
		Average % centre	14.2	18.6	14.8	11.6	15.6	12.6	14.7	

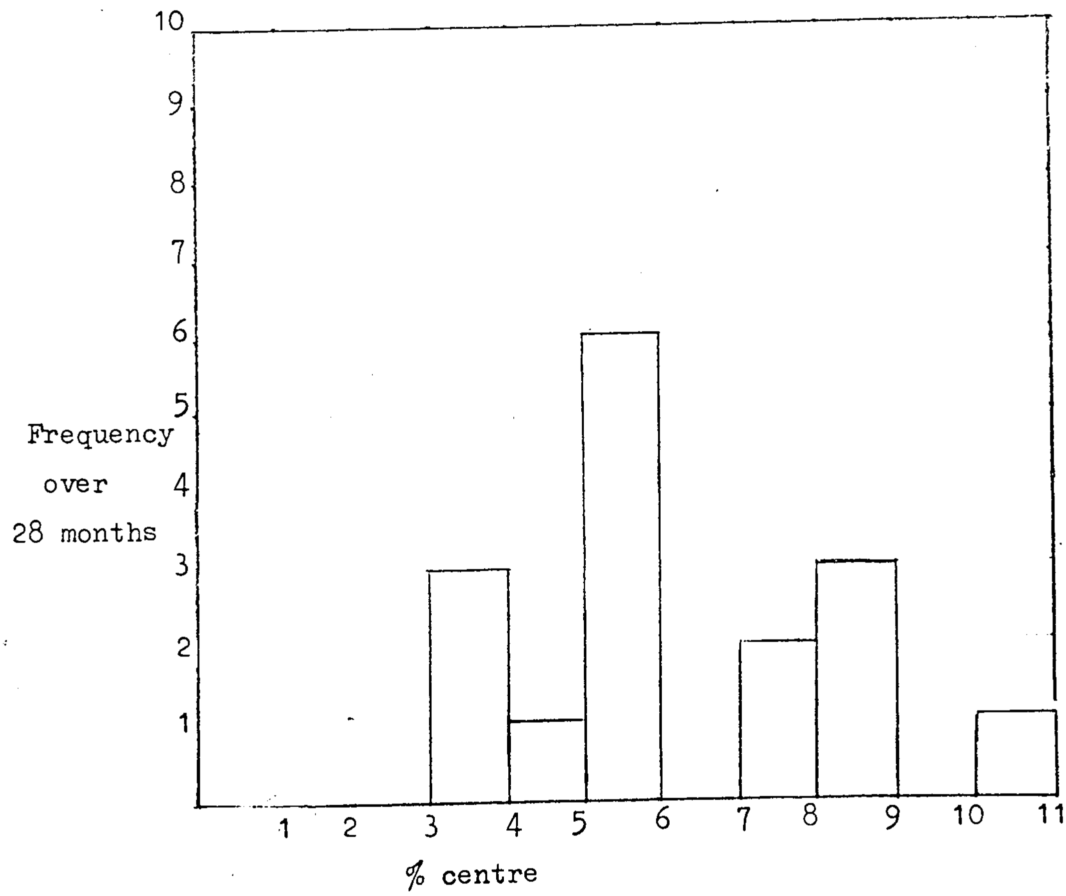
Whilst these figures show a variation in the level of centre contained in a sample, the average level of centre contents is significantly higher than those achieved in normal running on the same product line using a four rope size unit.

The figures in TABLE 23 are directly transposed from the records made by the quality control staff. The product in question was manufactured with the machine parameters set by the operators and throughout the period of running, the bunch-wrapping departments continued to function normally.

The average level of chocolate centre contained in the same sweets produced on a four rope size unit linked to the same production line (UP2) is shown below:-

TABLE 7 (Repeated from Page 12)

The average achieved level of chocolate centres produced on UP2 using a four rope size unit.



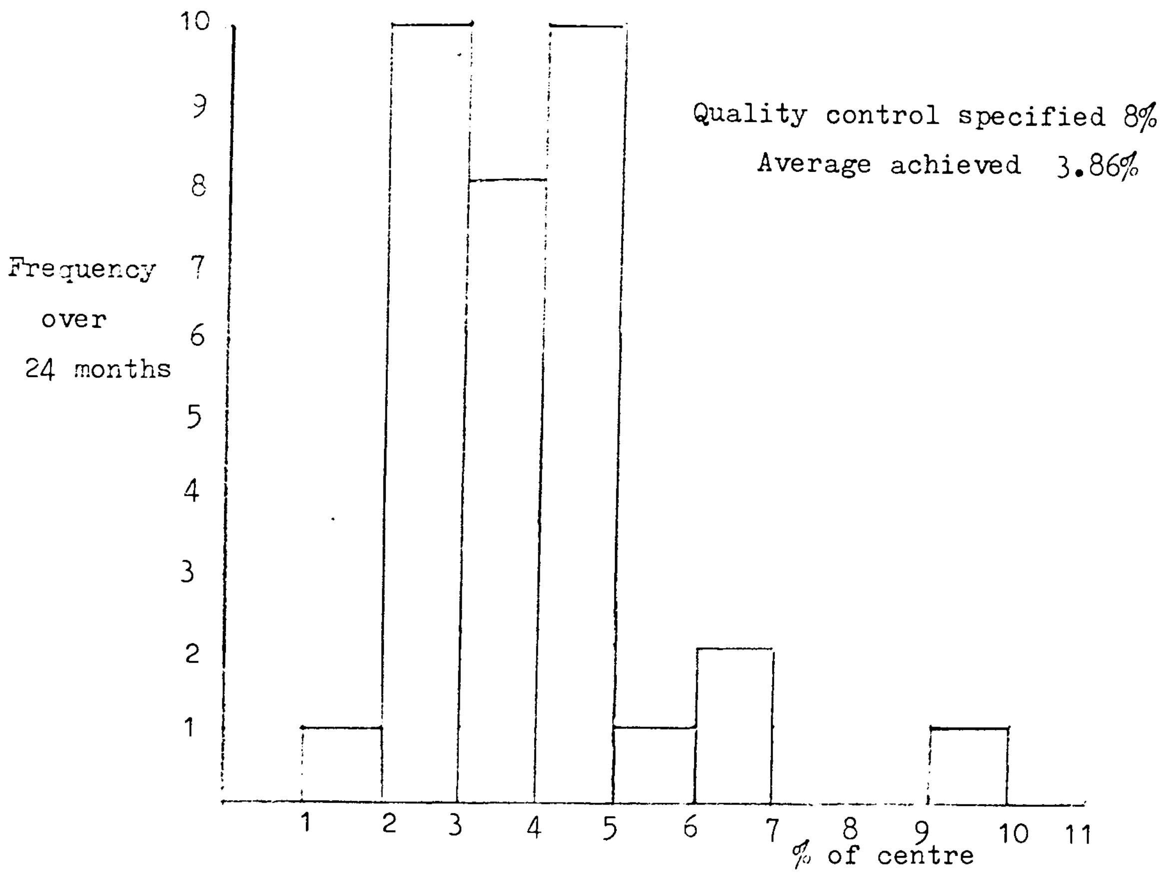
A similar improvement has been recorded for sherbet 20mm round sweets:

TABLE 24 - SHERBET CENTRE CONTENT LEVELS OF SWEETS PRODUCED ON THE SIX ROPE SIZE UNIT

Product	Date						
Sherbet 20mm round roll-wrapped sweets	3.9.81	Time of Day(am)	7.58	8.55	9.35	10.21	10.34
		Average % centre	6.3	4.3	7.7	7.6	5.4
	22.9.81	Time of Day(am)	9.35	10.0	10.30	10.50	
		Average % centre	6.6	8.0	6.8	6.8	

TABLE 6 - (Repeated from Page 12)

THE AVERAGE ACHIEVED LEVEL OF SHERBET CENTRES PRODUCED ON UP2 USING A FOUR ROPE SIZE UNIT



The results from the quality control records also show an improving situation regarding jam centre content levels:

TABLE 25 - JAM CENTRE CONTENT LEVELS OF SWEETS PRODUCED ON THE SIX ROPE SIZE UNIT

Product

Jam 20mm round
roll-wrapped sweets

Date								
	Time of Day (pm)	12.05	1.00	2.13	2.57			
7.9.81	Average % centre	12.2	12.5	15.1	13.0			
28.9.81	Time of Day (am)	8.04	8.10	8.30	8.40	8.52	9.00	9.45
	Average % centre	11.6	17.4	16.0	17.1	13.1	15.8	13.7
28.9.81	Time of Day (am)	10.03	10.10	10.20	10.35	10.39	11.0	11.22
	Average % centre	5.0	-	12.8	10.8	16.4	16.2	13.0
24.9.81	Time of Day (am)	8.07	9.38	10.05	10.22			
	Average % cantre	14.5	16.0	15.9	13.8			

Resumé - Rope Size Unit

Prior to this investigation the parameters of roll profile design and operational speeds had evelved from working experience and accepted practice. Procedures were not recorded and it seemed possible that the designs had been made without real analysis of the process requirements.

Once it was realised that poor performance of the rope size unit was due to design faults, it was necessary to look for the relevant technology to improve the situation. This was not available in the confectionery world, but there were similar processes in use in other industries. After some enquiries it became apparent that the techniques used in steel-rolling were directly relevant to the requirements of this process and moreover their expertise was easily available. It was required that the physical properties of the molten sugar be established and a design format was recommended. and tests initiated to establish whether the same design parameters regarded as major in the steel industry, could resolve the existing problems in the confectionery industry. These parameters were:-

- angle of contact
- level of reduction area between passes
- constant volume flow between passes

The drive unit chosen for the new profiles was fundamentally a conventional confectionery rope size unit with the extra facility to drive six pairs of rollers rather than four. The monitoring of the rollers was also modified to improve the alignment of centres by placing them on the same horizontal axis. In addition it was required to rotate an oval profile through 90° into a round profiled pair of rollers, and a device to do this was incorporated.

After these modifications were carried out, the experiment began to move forward. The initial production trials carried out in August 1980, confirmed that a higher level of centre could be produced under experimental conditions.

Initial production trials in May 1981 proved that high levels of centre content could be achieved which met the specified standard, and in some situations exceeded the standard. In an identical location, the four rope size unit had proved over long periods to be capable of meeting only 40→ 60% of the specified standard.

In terms of break frequency and overall stability, the information from the camera system shows that after initial problems of training, the operators are capable of setting the machine to run for long periods of break-free operation - Tables 18 - 22 illustrate this.

In terms of operative procedure, the role has been changed from one of hand-feeding and continual adjustment with skill, to one of machine minder with occasional interference - Figs. 49 - 51.

The achieved centre content levels shown in Tables 23 - 25 confirm that this situation is improving to a level where the average content of product made on the six rope size unit meets the specified standard. This is not due to better operators as the same personnel are used on both new and old lines, as a result, the conclusion can be drawn that, the experiment of transferring steel-rolling technology for use in the confectionery industry has been successful, and has resulted in major benefits.

PIPE DESIGN TRIALS

Background

As outlined in the pipe design analysis on Page 74 the design and dimensions of the existing centre pipes has been found to be faulty.

The fault lies in the dimensions of both the pipe diameter and outside length and shape for maintenance of a correct flow-balance situation.

The materials passing through these pipes are:-

- peanut
- sherbet
- chocolate
- jam

The dimensions of the existing pipes were all common, and were outlined in the analysis section, i.e.

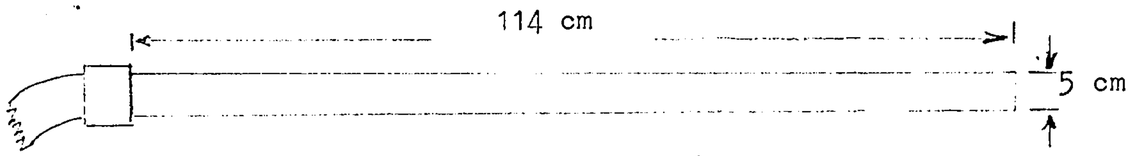


FIG. 52 - EXISTING PIPE DIMENSIONS

After the dimensions for correct flow balance were developed, a pipe, capable of carrying liquid centres was manufactured to the following dimensions:-

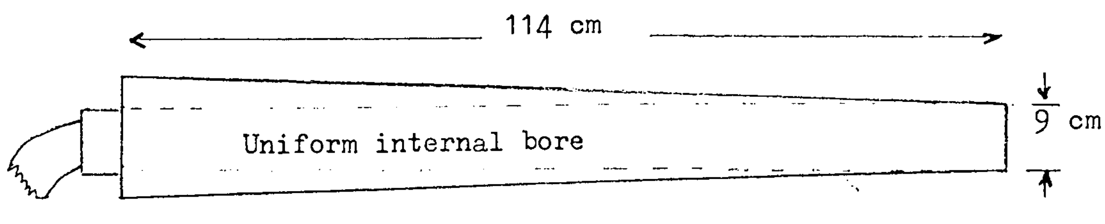


FIG. 53 - THE DIMENSIONS OF THE NEW PIPE DESIGN FOR THE TRIALS

This was then tried out in both chocolate and jam applications.

Results

For both Chocolate and Jam 20 mm round sweets, the specified level of centre is 20% by weight.

In comparing the performance of both existing pipes and the new pipes, it is useful to classify the achieved levels of centres into ranges. This makes the analysis of the data more manageable.

Three ranges were classified:

Range 1	0 - 14%	Product unacceptable, centre too low.
Range 2	15 - 20%	Acceptable product within specification and bunchwrappable, without problems.
Range 3	20% +	Unacceptable. Centre level too high and likely to cause major wrapping problems.

NB:

The results of these comparisons and trials are from product produced on a standard four rope size unit, hence, subject to poor alignment.

The sweets produced were analysed independently by the Quality Control department.

The results were:-

TABLE 26 - RANGE OF CENTRES PRODUCED USING CONVENTIONAL PIPE

Product and Date	Range 1 0-14%	Range 2 15-20%	Range 3 21% +
Mummies, Jam			
26.2.80	52	116	70
3.3.80	92	97	11
4.3.80	28	86	26
13.3.80	28	42	20
21.3.80	46	70	4
Chocolate Fruits			
26.2.80	43	176	37
18.3.80	35	125	-
TOTALS	324 (27%)	712 (59%)	168 (14%)

TABLE 27 - RANGE OF CENTRES PRODUCED USING NEW PIPE

Product and Date	Range 1 0-14%	Range 2 15-20%	Range 3 21% +
Chocolate Limes			
25.2.80	62	118	-
Mummies, Jam			
27.2.80	98	182	-
4.3.80	22	84	34
Chocolate Fruits			
5.3.80	83	53	2
13.3.80	56	101	3
TOTALS	321 (36%)	538 (60%)	39 (4%)

Looking more closely at the percentage of each run in particular ranges gives the following picture:-

TABLE 28 - RANGE OF CENTRES FROM CONVENTIONAL PIPE IN PERCENTAGE TERMS

	Range 1	Range 2	Range 3
Jam	23%	48%	29%
Chocolate	17%	69%	14%
Jam	46%	49%	6%
Jam	20%	61%	19%
Chocolate	22%	78%	-
Jam	31%	47%	22%
Jam	51%	78%	4%
Overall	27%	59%	14%

TABLE 29 - RANGE OF CENTRES FROM NEW PIPE IN PERCENTAGE TERMS

	Range 1	Range 2	Range 3
Chocolate	34%	64%	-
Jam	35%	65%	-
Jam	16%	60%	24%
Chocolate	60%	39%	1%
Chocolate	35%	63%	2%
Overall	36%	60%	4%

NB:

Whilst the conventional pipe gives a good performance in the 15-20% range, it also produces a significantly higher proportion in Range 3 (20% and over) which will be a major limit on the day-to-day running level with normal line operators and normal skills.

The new pipe also gives a good performance in 15 - 20% range, but significantly fewer are produced in the 20% + range, making day-to-day running on the bunch-wraps much safer.

The conclusions that can be drawn from these trials are limited, since both pipes were tried-out on a standard four rope size unit.

However, the picture that emerged was encouraging, i.e.

TABLE 30 - COLLATED TOTALS OF PIPE TRIAL RESULTS

Overall Spread	Range 1 0-14%	Range 2 15-20%	Range 3 20% +
Old pipe	27%	59%	14%
New pipe	36%	60%	4%

Since the new pipe produced fewer sweets in the highest and dangerous range, it was sufficient justification for adopting the newer design.

Commissioning Problems

1. The bigger pipe was substantially heavier than the existing pipe. As a result, a system of fixings had to be designed to balance the weight of the heavy pipe whilst it was in position.

2. Less room for re-loaded sugar. Due to the fact that the four rope size unit was still breaking down with the same frequency, it was still necessary to re-load part-cooled sugar into the batch roller.

   Since there is less room for this sugar, because the pipe is larger, operators are faced with the choice of dangerously overloading the batch roller, or wasting the sugar completely.

   The operator chose the first option, to the point where further and major breakdowns are caused.

This is an inevitable choice, since the poor design of the four rope unit will always necessitate high volumes of reloaded sugar.

NB: This was measured on Page 62 as averaging 228mins. @ 20 kg/min.
i.e. 4.6 tonnes reloaded per batch roll per week.

3. The same skill situation exists on the standard pre-feed, i.e. even if the rope entering the pre-feed is in a state of flow-balance, the massive size reduction (70%), the skill variance of the operators and the flow disruptions are still present.

CONCLUSIONS

On its own, the large pipe still represents an improvement over the existing pipe, since the product produced is superior.

The major problems which cause conflict are still present and hence, until they are removed the operators are reluctant to adopt a more difficult work routine.

As it was the case of the camera system, despite the fact that the product is superior, operators will not change their work routine substantially to benefit subsequent departments at a cost to themselves.

Since the six rope size unit has now removed these problems, the larger pipe has become not only necessary, but also easier to use.

THE CENTRE PRESSURE

MONITORING SYSTEM

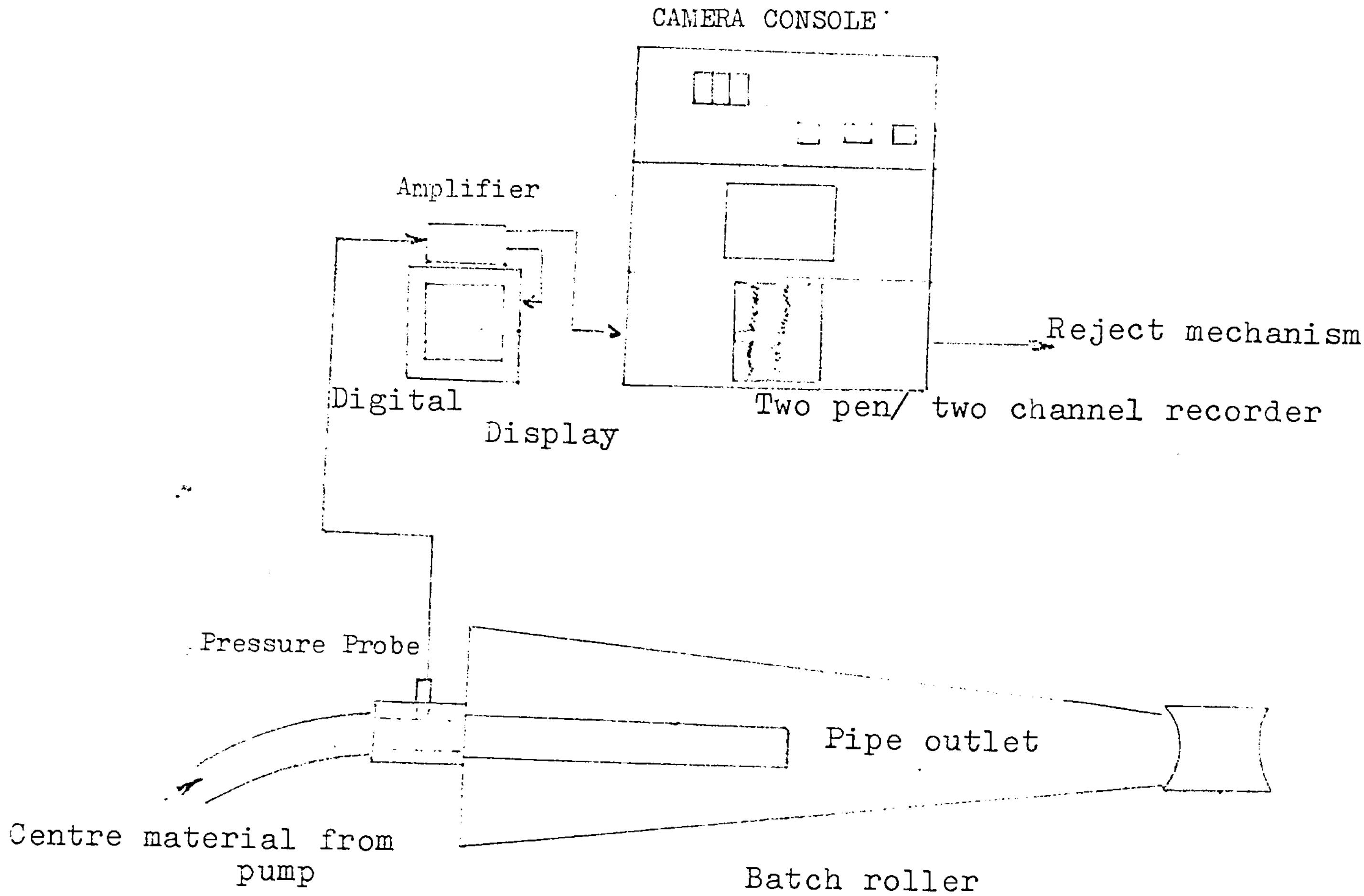


Fig 55(a) Layout and Position of the Centre Pressure Monitoring Equipment

The system consists of:-

- Pressure sensing transducer capable of measuring 1-50 lbf/in^2 to an accuracy of 0.1 lbf/in^2

- Amplifier unit which sends out two signals -

  (1) To a Digital Display of pressure in lbf/in^2

  (2) To a Chart Recorder to register pressure variations over a timebase.

Origin

The system was designed to measure pressure in the larger diameter pipe. The basis behind this was that the larger pipe would operate under a situation of flow balance. As a result, when the flow balance had been attained, pumping at a pressure higher than this point would recreate the former instabilities. The function of the pressure sensor was to give an indication of any build-up. It was envisaged that once the pressure reading changed from zero, the instability of over-pumping above flow balance would be exceeded.

Running Performance

The major point to emerge from first using this system was the good accuracy and performance of the centre pumps.

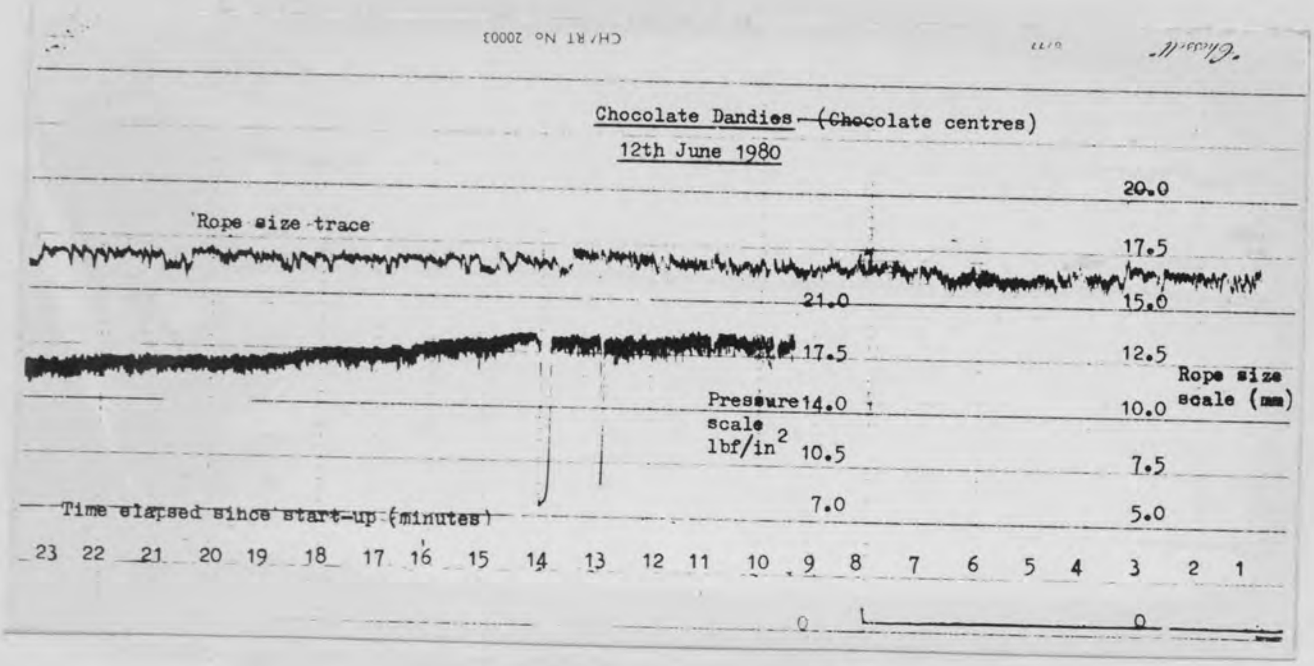
Previous researchers and development personnel had attributed the variation in both amount and alignment of centre to be entirely due to both the centre pipe and effectiveness of the centre pump. These conclusions were never substantiated.

The pressure sensing system was used on both chocolate and jam centres.

The following types of chart traces resulted :

(1) Chocolate centres

FIG. 55 CHART TRACE OF CENTRE PRESSURE AND ROPE SIZE DURING START-UP (CHOCOLATE)



Shown on the trace are several important details:

1. The first nine minutes of start-up are concentrated on getting the rope size unit running. No attempt is made to start pumping centre until this is achieved. As a result, nine minutes of totally solid sweets are in the system and rely on vigilant operators to ensure that they are not wrapped.

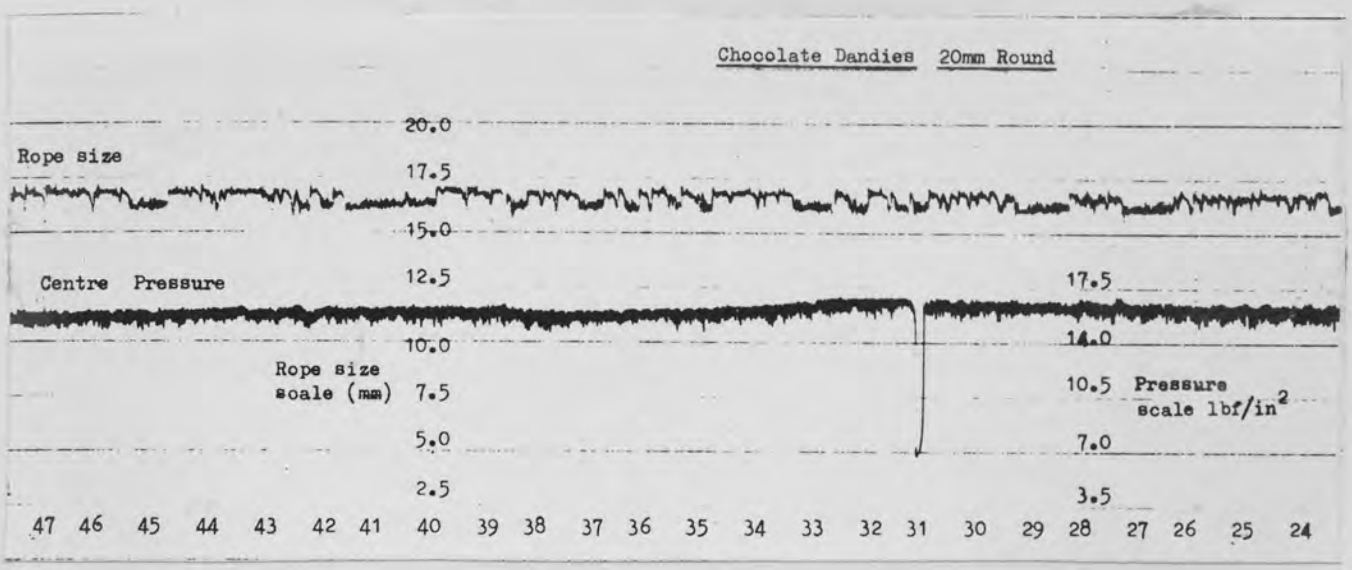
2. Between minute 10 and minute 22 the pressure of the centre material is falling gradually. This is entirely due to thick chocolate in the pipe and pump which has been allowed to cool prior to start-up, and hence, becomes more viscous.

3. Tests at minutes 13 and 14, switching off the pump shows that the return to zero pressure in the pipe is very slow. This shows that with a standard 5cm diameter pipe, the material must be pumped under pressure, confirming the assumptions behind the ideal pipe dimension design (Page 75).

Chocolate centres - same run, Chocolate 20mm Round

12th June 1980

FIG. 56 - CHART TRACE OF CENTRE PRESSURE AND ROPE SIZE DURING NORMAL RUNNING CONDITIONS



4. After start-up, from minute 22 onwards, the performance of the pump, shown by the pressure trace is excellent. The delivery rate and pressure is uniform. The range of variation shown by the width of the trace is $\pm$ 0.3 lbf/in^2

5. The rope size is varying independently and considerably, of the centre pressure.

6. Tests on product produced during this period showed the same level of variation in centre content as found in the product analysis. (Page 15)

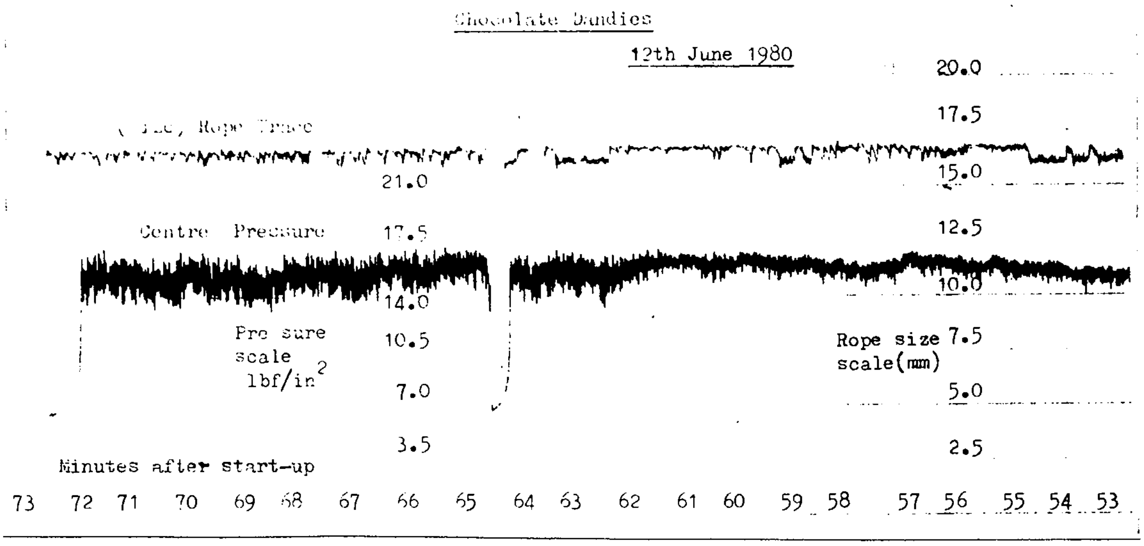
The conclusions that can be drawn from this stage are:

1. The pumps are efficient and no major redesign will resolve the centre problem.

2. The centre content of the sweets is independent of the pump performance, i.e. the pump is delivering the required amount of material at a steady and uniform rate. Redistribution of the centre material is therefore taking place during the rolling process.

In addition to confirming the assumptions of pipe design and pump performance, the pressure monitoring system also detects air inclusion, i.e. the sole cause of hollow sweets.

FIG. 57 - CHART TRACE OF AN INSTABILITY DEVELOPING DURING CHOCOLATE PUMPING



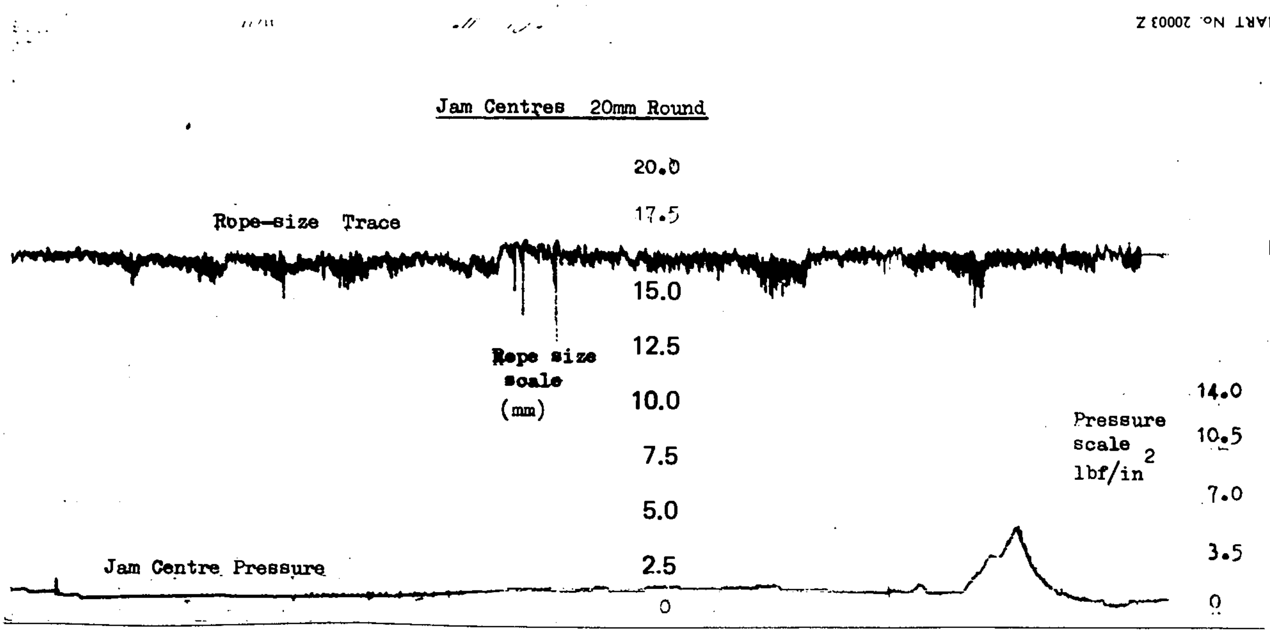
From minute 61 an instability develops. The pump gaskets began to let in air which immediately showed itself on the trace. Sweets examined showed a high level of hollow centres. What is especially important is a comparison between the rope size trace and the centre pressure trace.

No visible sign is shown of any instability on rope size. Since this was the case, the product continued unchecked into cooling and wrapping. The operators running the process by sight and skill were completely unaware that the problem was occurring.

At minute 72 the process was halted in an attempt to check the pump, but it was not until minute 78 that the problem was resolved.

This viscosity variation can be seen in the chart trace:

FIG. 58 – CHART TRACE OF JAM CENTRE PUMPING SHOWING VISCOSITY VARIATIONS AND ROPE SIZE VARIATION



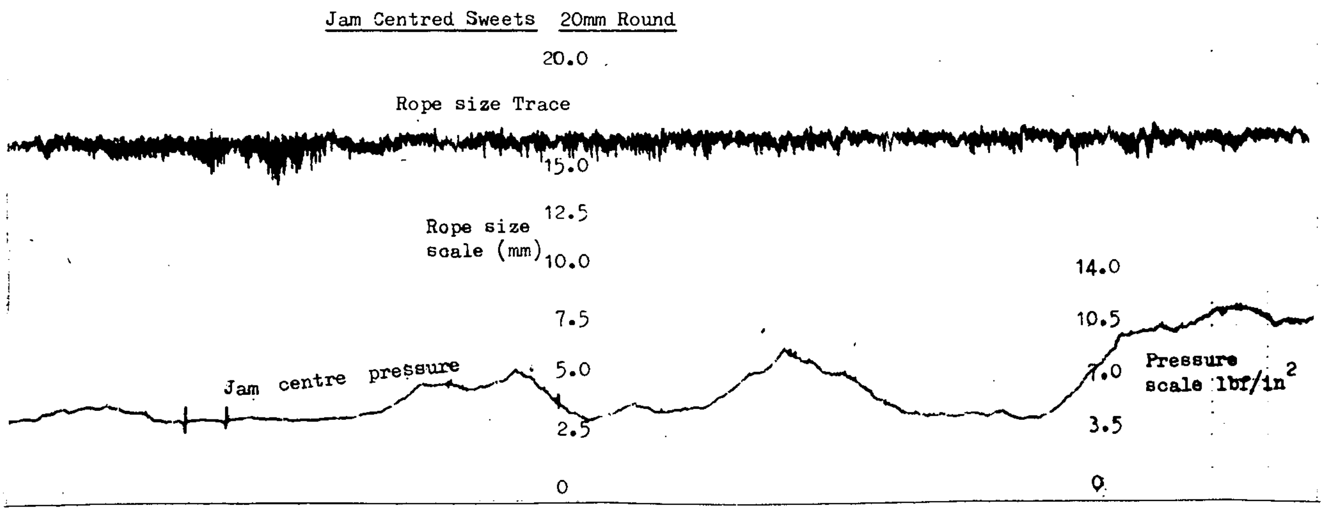
The trace above shows a very low viscosity jam being pumped at 3.0 lbf/in^2 Some points to notice are:

1. The uniformity of the centre pressure.
2. The wide variation in rope size.

The situation is identical to that of chocolate pumping in respect to wide centre content variation in sweets.

The uneven, thick material is shown in this trace:-

FIG. 59 - CHART TRACE OF JAM PUMPING DURING NORMAL RUNNING



The production run is exactly the same as the previous trace, the time elapsed is approximately 1 hour.

1. As with chocolate, even with a wide variation in centre viscosity, the rope size trace is relatively unaffected.

2. The changes in jam centre pressure are not instantaneous as they are in air inclusion of chocolate pumping.

3. The pump is maintaining constant speed.

The information presented by mapping the jam centre pressure is still useful. The above case is the worst ever recorded with jam. The normal case is of long periods of uniform pumping and viscosity during which the effects on increasing and decreasing the pump speed are immediately visible.

The advantages of the centre pressure monitor are considerable. With both chocolate and jam, the effect, and magnitude of an increase or decrease in pump speeds are immediately visible.

With chocolate, because of the uniformity of the material, a specific pressure is directly relatable to the average level of centre;

i.e. 15 $lbf/in^2 \rightarrow$ average centre level 18%

With chocolate and jam, the monitor senses the pump being switched off immediately as it happens. This has been linked to a reject system which rejects solid sweets.

As a research tool it has proved that:

a. Despite arguments to the contrary, the pumps are in both cases performing well and are not problematic.

b. The solution to the centre variation is not attributable to pumping, pump design or the maintenance of uniform pressure of centre.

The monitor has shown that over long periods when the centre pressure (and rope size) have been uniform, the centre level has still varied in the usual histogrammic pattern outlined in the early part of the thesis.

The pressure sensing system has now ended its trials and is being designed into the microprocessor based central control system.

S U M M A R Y

SUMMARY

Outlined in the introduction to Quality Control theory are the fundamental pre-requisites for the effective operation of a quality control system:-

- extensive process knowledge
- extensive process control

The basic assumption is, that the required quality level is always available at a price. Deviations and defects will occur from time-to-time and it is the responsibility of the Quality Control organisation to isolate defects, to attribute causes, and to quantify the costs.

Where process control or knowledge is absent, conventional texts advocate relaxing the product specification or changing the process.

The situation at TREBOR is one where a continuous high speed process fails to produce any product which matches the agreed specification, and the required process control and operating knowledge to achieve this, are absent.

Conventional remedies to this situation recommend changing the process. Methods for identifying which parts of the process to change are absent or cannot usefully be applied.

The process is highly skill dependent to operate in its present form, and even when adequate skill is present, acceptable product conforming to specification is not produced.

Fiegenbaum[1] advocates a pattern of continual change of processes where quality control and engineering functions work together closely to meet the existing specification and to continually improve product quality.

An examination of the present state of process design reveals continual breakdowns during normal running, suggesting that major process elements are not operating as they should.

The review of the published literature and current available information reveals a low pace of development over a period of 60 years, with a heavy emphasis on skills of operation.

The situation is not capable of meeting JURAN's three major pre-requisites for effective quality control:-

"If the operators are to be held responsible,

1. They must know what they are supposed to be doing (specification).

2. They must know what they are doing, (feed-back of performance).

3. They must have the means for regulating what they are doing, (control)."

The conventional quality control statistical techniques for fault isolation are not possible here because of continuous, and multivariable nature of the process. Analysis of product is not possible in a part-finished stage, hence all analysis must be carried out on finished product in the final stage of cooled, formed sweets. This analysis is further complicated by the high speed of production - 5,000 per minute, and the time delay between forming and cooling - 8 minutes.

Apart from the sporadic faults, the existing quality monitoring system showed that, within a wide range, the average achieved level of centre was around 40% of the specified level.

Further analysis showed two persistent and common faults of all centred products:-

- poor alignment of centres with the sweets
- poor control of the level of centre.

These two faults were common to all centre case combinations, and as a result, subsequent wrapping processes were severely restricted in the average level of centre that they were capable of handling without major shut-downs and waste.

An analysis was then carried out on all of the major elements of the process whech were capable of contribution to these two faults. This analysis was made in association with the investigation of potential problem areas which the operators considered to be major.

The areas examined for possible causes were:-

1. The consistency of the molten sugar.
2. Operating speed of the process.
3. Centre pipe design dimensions.
4. Centre pump design.
5. Shape and size of the sweets.
6. Temperature control of the centre material.
7. Attitudes of the operators towards the process.
8. Maintenance and age of the process elements.

Each of these areas was analysed in detail and there emerged four major fault areas:-

1. Centre pipe dimensions.
2. Monitoring of the centre flow.
3. Monitoring of the rope size unit.
4. Re-design of the rope size unit to cater for high speed continuous forming.

A larger tapered centre pipe was designed as a result of the analysis of the dimensions of existing pipes. This was intended to match the achievable flow of centre material at the pipe exit in relation to the flow of sugar at that same point. The object was to minimise the pressure problems caused by trying to overpump centre material to compensate for the small pipe orifice. Overpumping, or pumping under pressure was necessary in order to deliver the required flow of centre material to achieve the specified level of centre, independent of whether the rest of the forming system could handle the required centre level.

The centre pressure monitoring system - was designed to measure the level and stability of the pressure of the centre material delivered by the pump to the pipe exit. This unit gave an accurate indication of the stability of the pumps which were found to be well inside the required performance range, and not responsible for major variations in the level and control of centre content.

The rope size monitoring system - achieved by the use of a photodiode camera system and digital output showed that the existing rope forming system was problematic and subject to frequent breakdowns. A reject system was added to the system, activated by either low rope size or low centre pressure which removed the defective sweets prior to entry into the cooling system.

The full picture that emerged using the rope size monitor was of a high skill requirement to achieve consistent rope size, and a high level of maintained attention to ensure that this situation remained stable. In some situations high levels of skill and attention, even though they were present, could not guarantee consistent rope size forming.

Analysis of the rope forming operation - revealed major design flaws. Roll pairs were heavily roughed to compensate for over-large reductions. The guide plates and position of the lateral roll axes were having a fundamental effect on the flow path of the material. This was causing uneven deformation of the rope, independent of other factors leading to poor alignment of the centre within the rope.

The poor matching of volume flow between roll pairs was the result of an arbitrary design which the literature review has shown was the result of a low level of development over 80 years. As the speed of the unit increased, so did the magnitude of errors caused by the design flaw. The reaction within TREBOR was to attempt to increase the skill level available to operate a suspect design.

The design and commissioning of the new rope size equipment was a result of the analysis of the problems of the current unit and comparison with existing knowledge held by the steel industry on general rolling problems and parameters, i.e. reduction of area, constant volume flow, coefficients of friction etc.

The elements of the new process each perform well on their own. The large pipe reduces over-large centres, the pressure monitor gives an indication of centre flow and rejects solid sweets; the rope size monitor assists set-up and control, and rejects small sweets. The new rope size unit considerably "de-skills" the current feeding operation and significantly improves alignment.

When the elements are combined onto one process line, JURAN's basic requirements will have been met, using Feigenbaum's concept of TOTAL Quality Control in practice.

The operators will:-

- know what they should be doing
- be provided with the means to achieve it
- be provided with the control to change it.

The next stages of design, i.e. the combining of the tested, redesigned elements and the automation of their operation is already underway. Once this is complete and linked to a microprocessor based central control system, then the major elements of JURAN's continuous process quality control system will have been established.

The original quality problem experienced by TREBOR can now be resolved. The problem features of poor alignment and poor level control have been shown to originate in the areas outlined. The installation of each of the new process design elements:-

- larger tapered pipe
- pressure monitoring system
- six rope size unit
- photodiode camera system
- reject system

working in association, rather than independently will resolve the original problem features.

The automation of the entire new process line can take place shortly after installation. A microprocessor control unit for the camera system is already under construction, this can be altered to include control programmes for the speed of the six rope size unit, the reject system and the pressure monitoring system.

The basic programme specification will then ensure that the pump is switched on at the correct point, set the speed of the rope forming equipment based on the rope size data provided by the camera system, and reject any sweets which are out of specification, re size and level of centre. The design of the six rope size unit will ensure that the centre material is aligned within the rope and the large pipe will ensure that the correct proportion of centre is added, free of any major pressure problems.

The overall stability of the rope forming equipment, due to its constant volume flow between roll pairs, will minimise the current level of rope breaks substantially reducing waste and labour requirements.

With the new units working within their control range it will then be possible for the quality organisation to specify the level of centre and to supervise the operation of process control to ensure that the standards are met.

D I S C U S S I O N

The initial problem specification was not laid out as a formal statement. Although considerable work had been carried out within TREBOR, there was little documentary evidence of its purpose or its results.

The Technical Director specified the problem by describing the process in general terms and summarising the description with a series of definitive statements:-

'The sweets have little, or no centre'

'This is wrong, we need to correct it'

'We do not understand how the existing process works'

'We need to establish a firm basis of design knowledge'

Following these initial discussions a visit was made to the main factory at Chesterfield to view the problem first hand.

The Works Manager added to the previous statements by introducing the concept of operator training and supervision. Whilst he supported the idea that the process design was suspect, there was also emphasis on the broader aspects of the problem, e.g.

'Is the process being operated at too high a speed?'

'Would greater communication between different operators improve the running of the process?'

'Are the standards in the quality specification too high?'

The main development effort prior to the start of the research had been carried out by teams of development confectioners. As shown in the literature review, the emphasis in this role was on the art and skill necessary to understand and modify the process. As a result, the engineering department acted in a service role on the direction of the development confectioners. Initial discussions on the nature of the problem produced a wealth of ideas as to possible problem areas and causes:-

'The operators are not supervised or motivated enough'

'The sugar varies too much and needs to be improved'

'The consistency of the centres varies too much'

'The standards set by quality are too high'

'The sweets are subjected to too much handling before they are properly cooled'

'The sweets should be left to stand overnight to allow them to cool properly'

'The speed of the process is too high'

'The centre pumps are no good'

These are a selection of the views that were put forward by the development confectioners. They alluded to a wide range of problems and areas which needed greater attention. Many of the arguments were subjective and unquantified and since the engineering department was acting in a service role, their efforts were being directed into a variety of unrelated areas in a diverse fashion. They were attempting to solve undefined problems which were based upon opinion rather than fact.

The first and most important area for action was to define the requirement in an objective manner, factually based, so that capital and resource could be directed immediately to the most major problem areas. This was carried out by examining the quality specifications and comparing it with the performance of the process over a long period of time. There was also a need to separate continuous problems from sporadic problems.

The analysis of the performance showed that, independent of machine type, the overall quality standard had rarely been achieved. This was further illustrated when histograms showed a lack of any pattern of repeatability. The range of centre contents was wide when measured over short or long time periods. Rather than attempting to attribute causes at this stage, this problem aspect was defined as:- POOR CONTROL OF THE LEVEL of centres.

In addition, as the author became more familiar with the process it was evident that process familiarisation revealed continual process shutdowns either in manufacturing or wrapping, caused by sweet breakages. Further examination showed that this was frequently independent of the level of centre and was a direct function of the alignment of the centres within the sweets. As a result the second major continuous problem aspect could be defined:- POOR ALIGNMENT of the centres within the sweets.

These two problem aspects were defined as being common to all case/centre combinations and to each process line. Collectively they encompassed all of the previous specifications of the problem, regardless of source.

Having defined the problem in objective terms, the next stage in the research was to examine each element of the process to establish whether its performance was contributing to the problem as defined.

The way in which this analysis was carried out was to be of fundamental importance to the later stages of the research. It was a major consideration that the operators and developers should feel that their views had been taken into account, and this meant that no particular view or argument could be left out, however unrelated it may have seemed.

Whilst the individuals concerned may not have accepted the objective proof or disproof of their theories, they were accepted by senior and middle levels of the management structure. This was especially important, since co-operation at these levels would determine the availability of capital and resources. The developers and line workers had previously been the major influence in resource and development allocation, so to recommend other areas which conflicted with their views had to be based on something more than opinion. The alternative would be to place senior and middle management in a difficult position of arbitration between unsubstantiated opinion.

The value and importance of this was shown when the design of the rope sizing equipment was called into question during the research. The attitude of the developers was heavily based upon the need to produce consistent sugar, and that once this had been achieved, most other problems would disappear. The qualities and attributes of 'good sugar' were undefined, but both operators and developers agreed that periodically it was produced and the process ran smoothly. Despite this, the quality records showed no single period when the average achieved level of centre was within specification.

The full factual basis behind the rejection of this need for 'good sugar' has been examined earlier, but the data upon which it was rejected was objective. As a result, the senior managers were not placed in the position of arbitrating between opinions, but had a direct choice between <u>fact</u> and <u>opinion</u>.

The remainder of the process elements analysed on an engineering basis were presented in this fashion. On each occasion, the senior and middle levels of management were presented with the same type of choice.

The situation prior to the start of the problem specification and process element analysis was one in which a low level of process knowledge available in published form was complicated by an excessive emphasis on skill as an integral requirement for process operators and developers.

At the end of the problem specification, the problem was properly quantified and dimensioned. It had been changed from a series of loosely defined statements about potential problem areas and causes, to an objective statement of fact. This was now in the form that compared the required level of centre content with that which was actually achieved over long and short time periods.

All process lines had been compared in their performances in manufacturing similar products and the two common problem aspects were then again - poor alignment and poor centres.

At the end of the engineering analysis, the elements of the process which were established in <u>fact</u>, as capable of causing the two major problem features were both outlined, and the necessary changes were put forward:-

- A new larger dimension tapered centre pipe.
- A new mechanism for rope forming.
- Monitoring and control devices for rope size and centre pressure.

Senior and middle management were thus presented with a properly dimensioned and analysed problem and a specification of the modifications to the process necessary to remedy them. Prior to this they had been presented with an array of unconnected problem areas including some which were either continuous or sporadic, and others which were common to all types of sweets. The historical solutions put forward had been based upon:-

- The need for good consistent sugar whose qualities could not be defined.
- The need for consistent accurate pumps, which were again unspecified, but based upon the assumption that the wide variety of existing pumps were unsatisfactory.
- The need for overnight storage areas for large volumes of product.
- Extensive rubber matting to absorb impacts during cooling.
- Higher levels of skill and motivation required in the operators - coupled with "better" supervision.

- A reduction in the specified quality standards to a level which was routinely achievable, rather than a level which was hardly ever attained.

The list could be extended further, but the implication remains clear. If these suggestions had been fully implemented, the attained level of centre would remain unchanged, the skill and labour requirements and associated costs would rise sharply, and finally, the space requirements for the production process would have increased to alarming levels.

The choice open could also be illustrated in comparative approximate cost terms:-

OPTION 1 - To implement the results of the engineering analysis.

TABLE 18 - APPROXIMATE COST OF IMPLEMENTING RESULTS OF RESEARCH PROGRAMME

Item	Cost	
Larger Pipe	£ 500	
New rope forming unit	10,000	
Rope size monitor	7,500	
Centre pressure monitor	2,500	
TOTAL -	£ 20,500	(higher centre level + lower labour content)

OPTION 2 - To implement the recommendations of the confectionery developers.

TABLE 19 - APPROXIMATE COST OF IMPLEMENTING STANDARD SOLUTIONS TO PERCEIVED PROBLEMS

Item	Cost
New candyband	£250,000
New pump	6,000
Overnight storage areas	+ 25% cost per tonne
Rubber matting	500
Higher labour/skil content	+ 10% cost per tonne
TOTAL -	£256,500 + 35% increased cost per tonne

(same centre level + higher labour content)

On a comparative basis, it was more than worthwhile to accept the results of the engineering analysis, and this was substantiated as the new elements were designed and installed.

The Rope Size Monitor - gave instantaneous feedback to the operators on the quality of the sweets being produced, at the initial stage of the process. It showed that the stability of the set parameters during forming was low and continual adjustment was required. It was applied to automatically reject waste, which if passed through, caused major wrapping problems, at an alarming rate. This application showed conclusively that the performance of the current rope size units was poor and unstable.

The Larger Centre Pipe - reduced the top range of variation of centre contents whilst maintaining the acceptable range. The result for the wrapping department was a much higher level of safety during wrapping. The result for the manufacturing department was to change and reduce their circumstances for overloading batch rollers when attempting to clear surplus sugar accumulated during rope breaks. So for the moment the necessity for maintaining production levels placed a limitation on the use of this unit. Until the problems of continual rope breaks had been resolved the use of this pipe during normal production would be limited. This further strengthened the need to alter the method of rope forming.

The Centre Pressure Monitor - revealed that the centre pumps were operating well within the desired performance range and confirmed the results of the engineering analysis. This showed that there was no need for new pumps of alternative design.

The Six Rope Size Unit - proved that once the design parameters during rope forming were adhered to (constant volume flow, reduction of area, etc.) that the whole forming operation could be made more stable, and at the same time reduce labour and skill requirements, improve alignment and the mechanical handling properties of the finished sweets.

Once these elements had been redesigned, and tested, and proved capable of resolving the original problem, it became possible to examine some of the pertinent questions which arose during the course of research.

The first of these is:-

"Why had the problem been allowed to develop at TREBOR, and why was it eventually resolved outside the organisation via its collaboration with the I.H.D. department?"

The answer to the first part of this question can be found by examining the historical development of the process as outlined in the Literature Review. The confectionery industry has, throughout its history, been labour intensive with emphasis on skill and craft. This can be said of the early development of many other industries, e.g. glass making, pottery and china manufacturing. The products made by TREBOR cover a wide range of processes, from chocolate refining to boiled sweet manufacture. Each product within the range may be manufactured in a completely different way. Boiled sweet manufacture represents a large part of the total tonnage manufactured by TREBOR, as pointed out earlier, over 17,000 tonnes are produced annually. In terms of relative size, this makes TREBOR the fourth largest manufacturer of all confectionery in the United Kingdom, but the second largest in terms of boiled sugar sweets. (Rowntree Mackintosh being the largest). The remainder of the U.K. boiled sweet manufacturers are small in relative terms, rarely exceeding £20m annual turnover compared to TREBOR's £120m.

As a result, as pointed out by Minifie[10], much of the process development is carried out under substantial secrecy 'in house'. This secrecy is reflected in the low level of published information available. Its implications are also highlighted by Minifie[10]. Since customers for new equipment are few, and the capital cost is high, manufacturers produce a range of equipment in which design changes slowly and they attempt to meet the requirements of all sweet manufacturers from the smallest to the largest.

The emphasis on skills and craft combined with the level of secrecy, and low levels of change have all reinforced the position of the confectionery developers. It has placed upon them a requirement to be capable of developing the engineering aspects of the process in response to their interpretation of the perceived problems. The increase in speed of operation in the 1965 - '75 period placed the developers in just such a situation. As the speed increased, so did the associated problems of breakdowns in manufacturing and wrapping. Since the overall secrecy, and emphasis on skill had prevailed in the past, their response to the problem was to attempt to increase the levels of skill required in manufacturing and wrapping.

i.e. Their recommendations for more consistent sugar, better supervision and more rubber matting.

When these recommendations were implemented with the installation of alternative candybands, by an engineering department acting in a service role, the problems still remained. The developers' response was not to question their own perception of the problem, but to assume that the correct solution to their <u>perceived</u> problem had not yet been found.

As a result the candybands were modified still further, or complete alternatives built at substantial cost. The problems of breakages and low achieved level still remained.

This cycle continued until there were three successive models at Chesterfield, and another built and installed at the Forest Gate factory. Each was substantially different in design, but none produced significantly different levels of centre, or operated in a way that was free from the continual downtime already documented.

The approach to the I.H.D. department came at the end of the completion of the fourth candyband. The problem specification was, as has already been described, in very indistinct terms.

The solution was brought about by analysis and specification of the problems in such a way that removed isolated or sporadic causes and features. It was achieved as a result of objective test, analysis and redesign, taking into consideration the views of the developers, the manufacturing department, and subsequent wrapping departments.

In this situation, the secrecy and emphasis on skill had reinforced the position of these individuals who were unwilling to question their own perception of a problem. It could be argued that, once the modifications are in full production, if they continue to be protected by the same level of secrecy, they could be reinvented by another manufacturer in several years' time, or that they may already be in existence, but guarded by secrecy in another manufacturer. This is not the case however, since if it were true, large volumes of significantly high consistent centres would be generally on sale within the U.K.

The next important question which has arisen during the research is:-

> 'What part did Quality Control theory play in the solution of the problem, and are there any implications to be drawn?'

The problem, however specified, is based upon a perception of poor quality. Since this is the case, it was useful to examine the way in which conventional quality control theory advocates the problem could be solved.

From the earliest sections of the thesis it can be seen that the inherent assumption is that the required quality is always available at a price. If this is not the case, the recommendation is to lower the quality standards to a level which is routinely available. The alternative is to change the process so that the required quality level can be achieved. In this situation, the final option is the only one which is relevant.

The way of identifying the particular area or areas which require changing is based strongly around statistical sampling of part-finished product. In this case, as has already been described, a statistical type of approach is not usefully applied. As a result, an alternative approach, by an analysis of the engineering elements, which were potential causes, had to be developed.

An important point arises at this stage; the conventional view of quality control, as advocated by the major texts is split between the following roles:-

1. As an enforcement agency which operates to ensure that operators work in such a way that the desired quality product is produced.

2. As a fault identification service to the engineering and management structures to point out areas which require redesign in order to provide the desired level of quality control.

With reference to Fiegenbaum's[1] original view of the development of quality control practices, he sees the first major stage of development when the decision on quality approval is taken out of the hands of individual operators and becomes the responsibility of the work-group foreman. This is then developed through stages to the present day position where most industries have quality control departments as a separate and independent function from the production department.

All of the texts examined, agree that operators should be responsible for producing the required quality as a normal routine, rather than seeing quality control as a function which sorts out defective work.

Quality Control has gradually become a separate function from normal production departments, but to carry out its role effectively requires extensive process knowledge.

The techniques developed as an aid to fault area identification are intended for use by a quality control department which is not essentially an engineering department. The engineering department is seen as acting in a service role upon the recommendations of:-

- Process developers and technologists
- Quality Control
- Production departments

In the TREBOR situation, the problem perception of the process developers was found to be at fault. Quality control was limited to quality monitoring, as there was insufficient process knowledge or control. The engineering department was trying to resolve a variety of diverse and unconnected problems.

The resolution of the problem was brought about by an engineering analysis of the areas considered most likely to be a cause of the defects isolated in the problem specification.

This is an example where statistical analysis on its own, could not resolve the problem. The resolution could not come from extensive process knowledge, since those with the greatest level of knowledge, the process developers, had wrongly perceived the problem. Quality control, using statistical techniques, and the process developers acting separately, or in conjunction, could not resolve the situation. This illustrates the importance of engineering analysis of a correctly specified problem, and reinforces Fiegenbaum's concept of TOTAL QUALITY CONTROL:-

'An effective system for integrating quality development, quality maintenance and quality improvement efforts of the various groups in an organisation......'

A useful point highlighted in this case-study is the limitation of attempting to use statistical analyses of part-finished product.

Useful information can be drawn from this case-study by observing the growth of quality control function as a separate and independent department. As this has occurred, the techniques for examination of product quality have moved from total inspection of all manufactured items towards statistical sampling of representative product.

Defect isolation is an important part of the quality control function, but the techniques that can usefully be applied in continuous processes of the types studied, are of limited value. They are restricted by the inability to examine part-finished production. The trend within industrial design at present is moving towards more continuous operations of this closed type which will further restrict the operation of the quality control organisation. The need, therefore, is to bring more engineering analysis into the process of defect isolation, and have this carried out by the quality control staff.

The nature of the process at present, and the way in which it is being changed, means that unless this path is followed, the function of the quality organisation will be, as in this case, limited to quality monitoring and unable to identify sources of product problems.

The final point to be analysed is the benefit of transferring technology from an unrelated industry, to a situation where its use may provide substantial benefits.

In this case-study, the major important parameters in steel rolling were transferred for use in the confectionery industry. The benefits have proved to be significant. The new rope size unit substantially removes the level of skill and labour required to carry out the sweet forming process. In addition, the improvement in the alignment of centres results in lower waste levels in manufacturing and packaging as well as an overall improvement in the achieved level of centre content.

The benefits of the technological transfer of knowledge have already been detailed, also the reasons why it happened, firstly, as an experiment to introduce established theory used extensively in steel rolling into this area of the confectionery industry where no detailed theoretical knowledge existed. Secondly, having established that the transference could be beneficial, to build upon it with extensive commissioning of new equipment in a production environment. The technology transference was brought about during the course of a multi-disciplinary search of available knowledge for potential solutions to the correctly dimensioned and specified problems.

Areas of future research in this field may now begin to benefit from further technology transference. One possibility is the use of elements of glass manufacturing technology. Since sugar is basically a material in a glass-like state, there could be significant benefits from transferring appropriate process technology, rather than attempting to develop alternatives in the confectionery industry.

The process modifications carried out so far, have enabled the sweet forming process to operate with a wide range of variations in the condition of the molten sugar. The product quality and process operation have benefitted, but the cooling of the sugar remains a subjective process, the understanding of which needs to to be rationalised formally.

The original problem specification has now been resolved and these future areas of work represent refinements and expansions which may be gained via technology transference, as has already been shown to be of particular value.

CONCLUSIONS

The conclusions that can be made as a result of this research cover four areas:

1. <u>The High Boil Sweet Forming Process</u>

   It has been shown that normal running of the existing equipment results in poor control of centre level, complicated by its poor alignment in the formed rope. Further, the major contributory factors have been in the incorrect shape and size of the centre pipes and the rope size units.

   The remedies which are now being proved to be effective in operation are:-
   (listed in the sequence of their implementation)

   1. To monitor rope size in process and then to use this to operate a mechanism which rejects products formed outside set limits.

   2. To install a new design of a larger tapered pipe so that centre material is fed at a controlled and balanced flow rate.

   3. To monitor and record the pressure of the centre material, and so control its level and uniformity.

   4. To link this to the same reject mechanism as above to remove defective sweets.

   5. To design and construct a new six rope size unit, which preserves the alignment of the centre material and eliminates tension and compression in the rope between roll pairs.

2. <u>The Quality Control of the Process</u>

   This has been shown to be limited to a role of quality monitoring because of the low level of knowledge and control of the manufacturing units.

Continued/......

The options open to change this situation, as several major texts have been also shown to be limited due to the peculiar nature of the process. The fact that it is a continuous process producing high volumes of product, with several multivariate parameters capable of simultaneous changes, has shown the limitations of applying current statistical theory. The general uses of statistical quality control theory, based on the attribute analysis of part-finished product has been shown to be of little value in this case.

The concept of deeper involvement by the quality control function in machine and analysis and design has been demonstrated to be of particular value. The notion of 'TOTAL QUALITY CONTROL' as put forward by A.J. Feigenbaum has been used in a practical situation, and it has been illustrated and expanded to show the particular value of engineering analysis as an integral part of establishing effective quality control.

The recommendations of JURAN 'to gain the active involvement of process designers and technologists' has also been shown to be of little value in a case such as this. The process technologists and designers had attempted, over an extensive period of time, to resolve an undimensioned and subjective problem which was the result of a wrongly based perception of the true occurrences.

3. Problem Identification, Specification, and Analysis

It has been illustrated how an industry can be severely limited in its ability to overcome problems by a combination of secrecy, and an over-dependence on skills and crafts. These skills had historically been developed when the industry was small, in relative terms, and was labour intensive. In turn these skills were a necessary compensation for poorly designed equipment and processes. As the demands in terms of quality and volume of production increased, it has been shown that an attempt to increase further the level of skill necessary to run the process is a negative development.

The important consideration was to examine the reasons behind the need for the existing skills and for further increases. In this case-study the reasons lay in an incorrectly identified cause of problems (poor sugar), the way in which it was specified was too loose, and the way in which changes were quantified were not correctly analysed. The solution was brought about by identifying potential problem areas, specifying their nature in such a way that they could be tested for validity and analysing the results of these tests to provide the basis for their resolution.

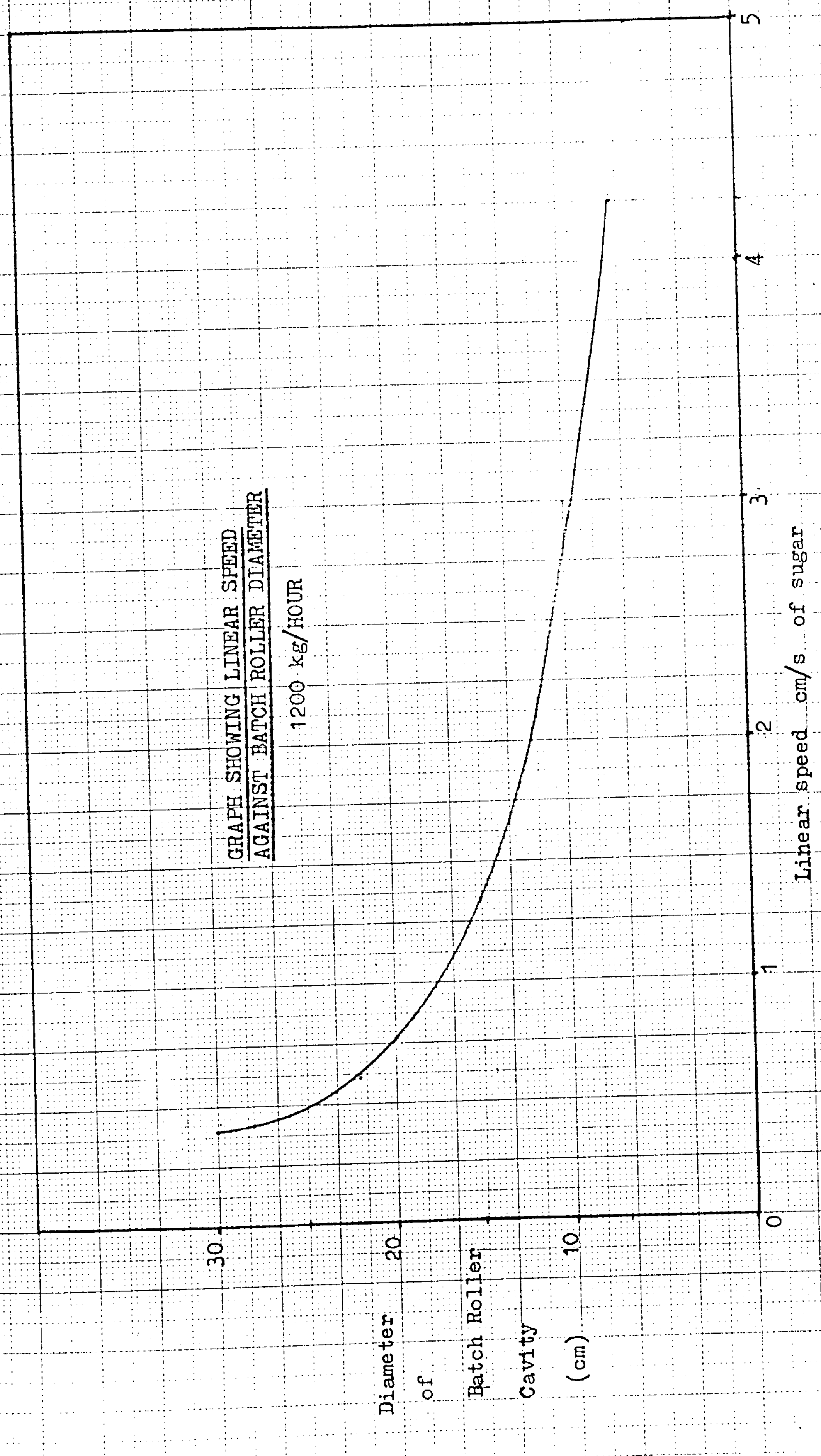
4. The Transference of Technology from Unrelated Industries

In this case, from steel rolling to the confectionery industry has proved to be of particular value in overcoming problems where there is little established knowledge.

Collectively, these conclusions add to the knowledge now held by TREBOR on the operation and design features of the high boil centred sweet process, and have provided an opportunity to test and implement research into the effectiveness of quality control structures and techniques.

APPENDIX 1

Graph of linear speed in relation to batch roller diameter.


GRAPH SHOWING LINEAR SPEED
AGAINST BATCH ROLLER DIAMETER
1200 kg/HOUR
Diameter of Batch Roller Cavity (cm)
30
20
10
0
1
2
3
4
5
Linear speed cm/s of sugar

REFERENCES

	Reference Number
Total Quality Control (Engineering & Management) A.V. Feigenbaum (1961)	1
Quality Control Handbook J.M. Juran (1962)	2
Designing for Production B.W. Niebel, E.N. Baldwin (1963)	3
The Technology of Sugar J. Geddes McIntosh (1903)	4
The Manufacture of Confectionery Robert Whymper (1923)	5
The Science & Practice of Confectionery Dr. D. Ellis (1928)	6
A Textbook on Candymaking A.E. Leighton (1952)	7
Chocolate and Confectionery C. Trevor Williams (1956)	8
The History of Baker Perkins Augustus Muir (1968)	9
Chocolate, Cocoa & Confectionery Science and Technology B.W. Minifie (1970)	10
Confectionery Production (Trade Publication) Specialised Publications Ltd. (1976 - 80) Surbiton	11
C.C.B. (Trade Publication) International Review for Chocolate, Confectionery & Baking V.E. Beckman (1976 - 80) Hanover	12

REFERENCES - continued

	Reference Number
The Manufacturing Confectioner(Trade Publication) Glen Rock Road, New Jersey (1976 - 80)	13
Food Technology (Trade Publication) Institute of Food Technology Illinois (1976 - 80)	14
New Developments In Processes High Boil Sugar Group B.F.M.I.R.A. Leatherhead (1964)	15
The Physico-chemical Characteristics of Boiled Sugar Sweets and their Relationship to Structural Stability and Keeping Quality J. Kelleher - B.F.M.I.R.A. (1963)	16
Vapour Pressure Study of Hard Candy W. Duck & R. Cross Manufacturing Confectioner - August (1957)	17
Metals, Ceramics & Polymers O.H. Wyatt, D. Dew Hughes (1974)	18
Die Design and the Operation of the Die Assembly (Report) M.P. Corcoran (1977) (TREBOR)	19
First Annual Review of Project M.P. Corcoran (1977) (TREBOR)	20
Roll-PASS DESIGN United Steel (1960)	21
Preliminary Consultants Report on Rolling Properties of Sugar Dr. P.R. Lancaster (1978) (TREBOR)	22
Report on Recommended Roll Profiles for Reducing the Cross-Sectional Area of Sugar from 70mm Round to 12.0mm Round Dr. P.R. Lancaster (1979) (TREBOR)	23

FURTHER READING

Apparatus for Moulding Sweetmeats
Patent Spec. 1509619 - October 1975

Sugar and Chocolate Confectionery
Lees & Jackson (1973)

Candy Technology
J.J. Alikonis
Alkem Research Center
Connecticut - U.S.A. (1980)