AUTOMATIC HANDLING OF KNITTED OUTERWEAR GARMENTS

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ABSTRACT

During the finishing of fully-fashioned knitted outerwear garments, these have to go through a complex series of operations that usually involve shrink resisting treatment, grease removal, dyeing and drying. The garments are left inside out as they come from the assembling stage but, when these operations are completed, they have to be turned the right way out, sorted and stacked according to their sizes, ready for the next operation; usually known as "trimming", the garments are steamed or steamed and pressed, with or without a manually inserted metal frame, to impart the desired final shapes to the garments. Finally, necks, buttons and other trims are assembled before the final inspection from where they are bagged and boxed.

Inevitably these operations are labour-intensive. From the operator's point of view they are repetitive, tedious and physically demanding. From the employer's viewpoint, they become also very expensive due to the high usage of human labour.

This research is directed towards the introduction of some degree of mechanization and automation in the sequence whereby the garments are turned, sorted and stacked. After exploring alternative concepts for turning and sizing, one was selected and developed. Later, this concept was incorporated into a system designed to sort and stack the garments automatically.

The human intervention is not completely suppressed, as some operations require vision, intelligence and touch in a way not yet attainable by the rapidly occurring developments in this field. Nevertheless a preliminary economic assessment gives an indication of the ultimate feasibility of full automation for these operations.

The decision was taken to develop the turning/sizing concept to the experimental phase as this was considered to be fundamental to

the proposed innovation. The first steps of the experimentation were very encouraging. Two rigs were designed. The sizing rig measures the width of the garment from waist to armholes in steps of 1 cm under controlled stretch conditions, and feeds such measurements into a microcomputer. By its analysis of these measurements the microcomputer establishes the shape of the garment and is able to select the chest level width to be used for sizing information and quality control. The turning/sizing rig uses the techniques previously developed for sizing and, by means of especially designed mechanisms and long stroke linear actuators, turns the garment inside-out.

CHAPTER 1

INTRODUCTION

1.1 The Objective of the Research

The "Automatic Handling of Knitted Outerwear Garments" means, for the purpose of this work, the automation or semi-automation of a sequence of operations carried out in the knitted garment finishing industry, usually known as "Dyers and Finishers", where the articles, jumpers, sweaters or cardigans, have to go through a complex group of operations in order to have the required degree of finishing for the customer's satisfaction.

During one stage of this "finishing" process, the garments are required to be "Turned" inside out, " Sorted" according to their sizes and "Stacked" into piles of one size. This requires a comprehensive amount of handling operations by a number of operatives which is repetitive, tedious, physically demanding and very expensive.

The purpose of this work is, therefore, to investigate and produce results that can lead to the mechanization of the above mentioned sequence of operations with minimun human intervention, and at a cost that would justify industrial application.

1.2 The Place of this Research within the Textile Manufacturing Context

When looking at the present situation of the textile industry, it is seen as a well mechanized world. This is especially true in the yarn and fabric areas where a wide range of machines is available for almost all the situations. The degree of mechanization is very high and the operator intervention is limited to loading the machines that will work for several hours before needing unloading and reloading. Apart from that, operators are only needed to remedy eventual minor problems.

As far as the machines are concerned, radical advances are not to be expected in this area. However, competition between machinery manufacturers will lead to improvements like increases in speeds, efficiency and versatility by the use of the latest technologies.

On the other hand, when the work is to turn fabrics into garments, in the making-up and finishing areas, this is where the human intervention is more difficult to replace. The work usually requires vision capabilities, intelligence and touch, even if most of the time the work becomes repetitive and boring. Automation has made little penetration in this area because handling fabrics poses special problems different from those of fairly rigid materials.

The subject of introducing automation to the apparel industry has often been raised in the last few years, certainly when envisaging the impact that the present so called technological revolution will have in the development of new equipment and machinery. This is sometimes seen in a futuristic manner[1], where apparel plants are shown as continuos production lines, performing automatic feeding, cutting, sewing, inspection and finishing operations by a new generation of skilful robots, with all the standard features at present associated with these machines, as well as visual and tactile capabilities.

The situation of labour-intensiveness of this sector of the textile industry, makes manufacturers of industrialised countries, with high wage economies, vulnerable to the low labour cost competition. The size of this disadvantage was already enphasized in 1979 by Kurt Salmon Associates[2], stating that the weighted average annual cost of each member of this labour force in the high wage economies was approximately $12 000, while in the main apparel-producing less developed countries (excluding COMECON and China), the average annual cost of each member of the labour force was approximately $2000.

The reasons for investing in research and development aimed at technological advances in this area of the textile industry is, therefore, completely justified, not only as a tool for cost reduction, but also for quality improvement, risk reduction and job enhancement.

CHAPTER 2

EXISTING INDUSTRIAL PROCESSES

2.1 The Knitted Garments Industry

Knitted garments can be considered under the more general heading of "knitwear", which is almost entirely weft knitted. Their common characteristic is to possess an integral welt or rib that is produced automatically during the knitting process rather than being overlocked during subsequent making up operations.

Knitwear manufacturers are mainly vertical. Apart from the yarn, usually purchased from an outside spinner, they knit, cut, make up, and pack often within the same factory. Nevertheless, the dyeing of yarn, garment blanks and unfinished garments is usually carried out by independent dyers. In some cases, there is a grouping of manufacturers, with a large dyer serving the whole group.

Knitted garments can be classified under the following main headings:

1-Cut-and-Sew
2-Fully-Fashioned
3-Half Hose
4-Ladies Hose
5-Underwear

Important to this research is to consider the second group, Fully-Fashined garments. However, for a better understanding of the situation, some attention will be paid to the first heading, Cut-and-Sew garments.

2.2 The "Cut-and-Sew" Process

2.2.1 Production Method

Garment blanks, such as bodies, sleeves, collars and necks, strapping etc, are knitted to length, and as far as possible to width, on circular or flat knitting machines. The pieces come from the machine in "string formation" and have to be separated by pulling out the drawthreads by operatives known as the "drawthreaders".

Automatic drawthreading has been used for some time and this is based on the use of a special drawthead. The operation is combined with the steaming of the fabric prior to cutting and is mainly used for the separation of the trims but is also applied on body pieces. The separation takes place due to the nature of the special drawthread used which melts under steaming action.

The various pieces are then piled, usually in two dozen lots, and then passed to the cutting room where the "cutters" place a pattern over each blank and cut it to shape individually with shears. More recently, semi-automatic machines have appeared on the market to carry out these cutting operations.

The two dozen cut garments are then assembled and passed to the "overlockers" who overlock the blanks together, followed by the necks and other trims. Ancillary making up operations are subsequently carried out where necessary such as: neck linking, buttoning, button holing, application of pockets, hand stitching.

The completed garments are passed to the steaming room where they are steamed and/or pressed and then counted, bagged and boxed.

2.2.2 Knitting Machine Details

Knitwear is produced on "rib" machines, that is, those possessing two sets of latch needles, or "purl" machines, that is, those possessing a double headed latch needle[3]. The machines can be either "flat bed" or "circular". They can be made in various gauges (needles per inch) and all machines are capable of producing welt rib and inserting a drawthread.

Flat machines are slower as they never have more than two feeders and knit at a slower speed as they are reciprocating. Circular machines always have at least 4 feeders and sometimes 6 or 8.

Flat machines can knit exactly to width as the number of needles in operation can be increased or decreased. With circular machines the fabric is produced in tubular form and the width is determined after "opening" by the particular diameter of the machine. Although different diameter machines are available, inevitably it is necessary to cut some fabric to waste.

According to Wray[4], in comparative terms, "there is greater scope for patterning in the flat machines, but the process is slower and therefore less productive". In general, flat machines are used for the heavy gauges. Here loss of speed is less noticeable due to the lower number of stitches per inch produced. The importance of minimizing waste is more important as the garment weighs more. Circular machines are used for fine fabrics where the greater output becomes more important.

2.3 The "Fully-Fashioned" Process

2.3.1 Production Method

The rib welts for cuffs and waist bands (generally 1x1 rib or 2x2 rib) are produced on the 'V' Bed Flat Machine as per cut-and-sew knitwear. These are "run on" to a point bar and then transferred to the Fully-Fashioned Machine. That running-on operation consists upon connecting the rib and plain fabric of a knitted blank on a Cotton's Patent fully-fashioned machine before jersey knitting commences. It is done by means of a topping or transfer bar having grooved points which are spaced to correspond with the gauge of the knitting machine.

The Fully-Fashioned Machine then knits body and sleeve blanks to shape by widening or narrowing the fabric width, which is achieved by increasing or decreasing the number of wales. A characteristic of such fully-fashioned garments are the "fashion marks" which indicate the transference of loops for shaping.

The shaped blanks are "cup seamed" together and on certain styles linked "loop for loop" together. After the dyeing and other finishing operations, that will be described later in more detail, the neck is then cut out and the neck rib attached, usually by linking on "loop for loop".

2.3.2 Knitting Machine Details

Classic fully-fashioned knitwear is produced on Cotton's Patent Straight Bar Machines which work on rather different principles than other types of weft knitting machines. They have only one set of bearded needles which work in unison. The knitting action is achieved from eccentric cams fixed to a shaft running the length of the machine. The machines are made to various lengths and numbers of knitting heads up to a maximum of 16 where 16 garment blanks can be made to shape at once.

2.4 Comparison of the Two Processes

Fully-Fashioned Knitwear is considered to be aesthetically better than Cut-and-Sew, as the garment is made to shape and the edges of the blanks are selvedged which means that they will not run or ladder unless damaged. Linking is also considered superior to overlocking but is expensive, slow and a highly labour and skill demanding operation. There are nevertheless some disadvantages:

As there is only one set of needles on the Cotton's Patent Sraight Bar Machine, rib structures cannot be produced.

Jacquard designs also cannot be produced. However, "lace", "tuck", stripes and "cable designs" can be produced on machines equipped with the appropriate mechanisms[4].

The separate knitting and "running on" of the ribs is an additional operation not necessary with Cut-and-Sew knitwear. Certain of the latest machines are equipped with the facility to produce the rib automatically, but these are very complex and expensive. According to Woodward[5], the economics of these machines is consequently very debatable.

Flat machines with a facility to transfer the ribs to the bars are another alternative to this highly labour-intensive operation. A great contribution to its automation was given by the research carried out in the Department of Mechanical Engineering at Loughborough University of Technology into the handling of knitted garment parts, from where the ART (Automatic Rib Transfer) Conversion Mechanism[6] came to life as the result of the work of the team built up by Professor G.R. Wray[7] and led by his colleagues Dr. R. Vitols and Mr. J.E. Baker. The ART is a novel automatic rib transfer system which has the advantage that it is a relatively inexpensive modification to existing 'V'-bed knitting machines.

2.5 The "Finishing" of Fully-Fashioned Knitted Garments

In order to fully appreciate the research area of this work, a general description is given of the manufacturing process, paying special attention to the finishing sequence.

The garment pieces are knitted to shape by the manufacturer on fully-fashioned machines as described on section 2.3. For the purpose of this thesis, the "manufacturer" is the company or department within the company that knits and assembles the garments. The "finisher" is the company or department within the company that provides the operations that follow for finishing the garment.

After being knitted, the different parts are assembled using operations such as overlocking, cup seaming and linking, to produce a quasi-completed garment. At this stage, the neck and other trims are not usually assembled; the area of the neck is provisionally closed in a sewing machine or simply left opened and the garment is ready to go to the finisher. There are no fixed rules on this procedure, but this method is commonly used on grounds of quality. Experience shows that if the neck and other trims are already fitted at the time of the dyeing operations, some distortion is very likely to take place.

As a result of the assembling process, the garments reach this stage with the wrong side out, having their seams to the outside. They are left in this condition, bagged according to size and sent to the "finisher" for dyeing and finishing. To understand the "finishing" procedure, the process in use at "Stevensons (Dyers) Ltd" of Ambergate near Derby, a Company specialised in dyeing and finishing of yarns and garments, is taken as an example.

The flowchart shown in Fig. 2.1 sets out the sequence of operations. The garments, from one particular customer, are

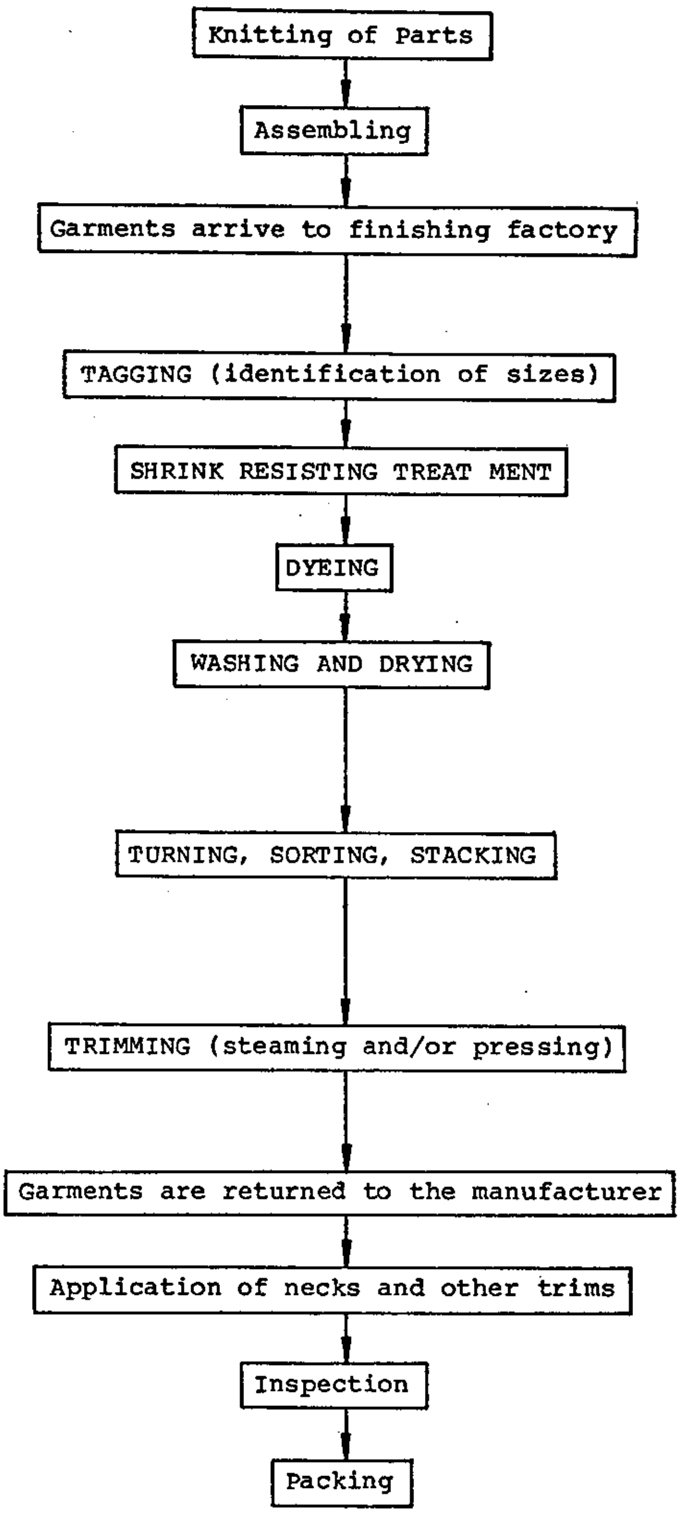


Fig. 2.1 - Flowchart for fully-fashioned knitted garments processing

delivered to the warehouse of the finishing factory either in bundles, carton boxes or polythene bags, the sizes being separated but not individually identified. The finishing process may involve operations like shrink resisting treatment, grease removal, dyeing, drying, turning, sorting and trimming.

To start, the garments are individually identified according to size. This "tagging" operation is carried out by attaching, to a point on the waist of the garment, a tag of coloured thread which will not be affected by the dyeing process. This is done by operators working on benches or on a slow moving conveyor. For economic reasons, colour coding is always kept to a minimun in every batch; hence, the size with the largest number of garments is always uncoded. In consequence there is no special colour for a special size and the relationship between tag colour and size is valid only for one particular batch and is specified on the production sheet.

The garments are sent for shrink resisting treatment and are then dyed. Different sizes are dyed in the same vat simultaneously because a customer naturally wants his order to be entirely dyed to the same shade. During these operations the garments are left in the inside out condition to prevent damage to the outside and to achieve the best results in colour quality.

After dyeing, the garments are washed and dried, using conventional washing, hydro-extraction and heated tumble-drying machines. They are next taken on large trolleys to the "turning" room.

In the turning room the garments are individually taken from the trolley by the operator who manually turns the garment using his or her arms and hands. The operator then straightens the garment and, according to the coloured tags, sorts and stacks into piles, each pile of one size, ready for "trimming". These stacks are usually made on the sides of the trolley to minimise the amount and amplitude of operator movements.

In the " trimming" room, the garments are again individually grasped by the operator from the stacks using one hand,whilst the other hand takes hold of a metal frame. The frame is inserted within the garment which is subsequently adjusted to a correct position on the frame and then placed upon a steaming table. By the action of a foot lever, steam is emitted through holes which "sets" the yarn so that the garment takes up the shape of the frame. Extraction of the excess steam and passage of cold air complete the setting of the fabric. In some cases, for a more permanent finishing, the frame is removed from the garment which is straightened on the table that revolves while the fabric is subjected to heavy pressure for a pre-determined cycle time. When these operations are completed, the garments are stacked flat, one on top of the other, on a table at one side of the work station. Apart from minor adjustments to the shape and dimensions of the garment, the "trimming" operation gives the garment the attractive appearance important to the customer.

This completes the "finishing" sequence. The garments are then returned to the manufacturer for fitting of necks and other trims. They are finally inspected for faults and packed.

The above description corresponds to the main stream of the production at Stevensons Ltd. Nevertheless there are variations to this process, not only within this Company but also at other smaller companies within the trade. Some of these variations, based on field observations by the author when visiting garment finishing factories are:

1- Some garments are not completely dried after dyeing. On grounds of better results, garments of some fibres are left in a slightly wet condition for trimming. This means that they have to be turned in a wet state. In some cases, as much as 10% of the production has to be processed in this condition;

2- Sometimes garments arrive at the finishing factory with the right side out. In this case they have to be turned twice, with one extra turning operation at the beginning of the process;

3- The situation may also occur where garments arriving inside out from the manufacturer are to be processed with the right side out. Hence one simple turning operation is required in the beginning of the process complemented by a simple sorting operation in the end;

4- Some manufacturers do their own tagging. Garments were seen with the neck closed using sewing thread of different colours to identify the sizes;

5- In some circumstances a particular batch of garments can be of only one size. When this situation arises, no tagging is necessary;

6- In some companies, the turning operation is independent of the sorting operation. The garments are simply turned by one operator and later sorted and stacked by another operator.

CHAPTER 3

SUMMARY OF RELEVANT PREVIOUS APPROACHES TO THE PROBLEM AND LITERATURE SURVEY

3.1 Manual Turning Assisted by "Arms with Poles"

3.1.1 Vertical Arms

As seen in section 2.5, the turning of knitted garments is carried out manually. An alternative to entirely manual turning is the use of a device that is basically a pair of vertical bars with "poles" at the top ends. The two bars are widthwise adjustable to accommodate differences in garment size. The working procedure is shown in Fig. 3.1, and is as follows:

1. The operator places the garment over the arms and pulls the waist down until the shoulders are touching the poles;

2. The operator pushes the neck of the garment down by hand until the sleeves are completely over the arms and the cuffs are clearing the poles;

3. The poles hold the cuffs while the operator pulls the garment up, off the arms, holding the waist. The turning of the garment is completed. Next it is sorted and stacked according to the colour tag code as per manual turning;

This method is basically manual and it is only used in two situations:

a) Turning of wet garments which, because of their condition, are unpleasant to handle.

b) Turning of very small garments which, because of their small dimensions, are difficult to manipulate and could be distorted by the size of the operator's arms.

3.1.2 Horizontal Arms

This is a device similar to the one referred to in the previous section, but the two arms are substantially horizontal as shown in Fig. 3.2.

The turning procedure is also very similar to the one with vertical arms. However, there is one major difference that explains the reason why the arms are longer than in the vertical mounting. The operator first loads a number of garments on the bars, using the same procedure as described on the first two steps of vertical arms. When the apparatus is filled with garments, the operator then turns and unloads all of them at once, with a procedure similar to the third step of vertical arms, adapted to the horizontal situation.

3.1.3 Conclusions

Turning with the aid of "arms with poles" is basically a manual operation. There is no contribution towards automation and the situation remains labour-intensive. Its application is restricted to wet or very small garments and under normal circumstances the operators prefer not to use them. They also reduce productivity; according to the Industry, the rate for manual turning is between 340 to 360 garments per hour, while the use of "arms with poles" slows the operation down to about 300 garments per hour.

3.2 The Use of Suction

The use of suction, as a method of turning garments, has long been applied in the manufacturing process of socks. These are usually short closed tubular shaped knitted garments, as, by the time the turning is carried out, the toe has already been closed.

The situation is quite different with outerwear knitted garments. These have a much larger surface which, allied with the natural porosity of the fabric, as well as the holes of the sleeves and sometimes the neck, makes the efficient use of suction very difficult.

3.2.1 The "Turn-o-Matic"

In 1967 Singer Sewing Machine Company was appointed agents for the American "Turn-o-Matic", made by J.L. Gilbert, Inc.[8] which is said to "turn garments automatically and at the same time remove all loose threads, thereby saving time and inspections costs. The Turn-o-Matic creates a powerful suction. The garment to be turned is offered up to an appropriate adaptor. A 5 hp motor creates sufficient vacuum to turn any garment right side out..."

Horrocks[9] gives a comprehensive description of the apparatus, reports on the tests carried out, and concludes that suction is an inappropriate method to turn knitted outerwear garments, especially those with "open" stuctures where the air simply flows through the loose knitting, and the friction between the fabric restricts the flow of the material. He carried out tests with a Turn-o-Matic purchased by Stevensons Ltd and loaned to the University for trials. Horrocks suggested several modifications to improve its performance but concluded that the Turn-o-Matic is inherently slow. The machine could only turn consistently close knit garments by virtue of its method of working. The fact that the use of the Turn-o-Matic has been abandoned is a confirmation of its poor performance.

3.2.2 Other Suction Devices

Another device based on the use of suction was reported in 1974 by Franke[10] in the German magazine "Textiltechnik". The device is said to be a "recently developed pneumatic machine for turning sports jerseys inside out". Its absolute similarity with the Turn-o-Matic exempts the author from any further comment.

During the initial literature search, two patents were found on the topic of turning garments by means of suction. Sunbrand Corporation claimed an "Improved Article Turning Apparatus"[11] which "relates to an improved pneumatic apparatus for everting articles formed of flexible sheet material such as textile articles". The same Sunbrand Corporation claimed a "Garment Turning Assembly"[12] which is said to be particularly intended for use with the turning apparatus described and claimed in the previously mentioned patent. The former patent describes the apparatus, its mode of working and use with different textile articles. The latter describes an adaptor for the purpose of turning sweaters and the like. The careful examination of these two patents revealed that the claimed apparatus works on the same principle as the Turn-o-Matic. Therefore, it is possible to state that the Turn-o-Matic was the commercial application of these patents.

3.2.3 Conclusions

Suction as a method of turning outerwear knitted garments has been attempted without major success. The Turn-o-Matic not only had a poor performance, but it did not introduce any degree of automation. The operation remained basically manual and labour-intensive, and the tagging operation was again the method for size identification. In those cases where the device was able to turn the garment, some of the hard work could be taken from the operator, but the practice at Stevensons Ltd revealed that experienced operators were faster using manual turning.

3.3 The Inspecting/Turning Devices

3.3.1 General Description

A number of devices have been found during the literature search, which are intended for use in the final inspection of the garments as described in section 2.5. Some of these devices can also be used for turning, in which case the garments are left inside out until the last inspection. This procedure has, however, a restricted use.

Earlier in 1969, Hall[13] of Hall Textiles (Mansfield) Limited, patented an invention which "relates to an apparatus for use in examining garments to detect any faults therein which may have occurred during manufacture". Another objective is "to provide means enabling an inside-out garment to be turned right side out as it is removed from the apparatus after examination". The apparatus comprises two substantially vertically disposed tubes, open at their upper ends and mounted on a rotatable platform. The garment is then placed over the tubes and examined. The distance between the tubes can be adjusted to cater for garments of various sizes. The apparatus also produces a flow of air down the tubes at required times to hold parts of the garment adjacent to the ends of the tubes, enabling the garment to be turned as it is removed from the apparatus. The tubes are provided with a transparent cover incorporating a light to facilitate the examination of the garment.

The apparatus has later been altered by its inventor and the new arrangements patented[14, 15] but the working principle remained the same. The device has been produced and marketed under the initial trade name of "Garmatic". At present, the device is still in production under licence by another manufacturer using the trade name of "Super-lite 2-garment examining and turning machine".

A similar device has been marketed by L.I.F. Machine Co.[16] under the trade name of "Specto-flip". The complete similarity of its working principle with the one previously described, exempts the author from further comment.

3.3.2 Conclusions

The inspecting or inspecting/turning devices are mainly designed for the final inspection of garments. Those provided with turning facilities are in fact an aid to manual turning, without introducing any degree of automation. The turning operation is carried out in a very similar mode to the one used with "vertical arms with poles" described in section 3.3.1, remaining, therefore, essentially manual and labour-intensive. Tagging of the garments is once again the method for size identification.

3.4 The Contribution of Loughborough Final Year Student Projects

3.4.1 M. Horrocks, 1977/78

Horrocks[9] was the first of a series of final year students who, at the Department of Mechanical Engineering of Loughborough University of Technology, investigated the feasibility of automatic garment turning and sorting, under the supervision of Professor G.R. Wray.

After an initial literature search, he carried out tests on the "Turn-o-Matic", loaned to the University by Stevensons Ltd. His conclusions on the performance of this suction device have already been mentioned in section 3.2.1.

His work led to a concept that presents some similarities with the manual turning assisted by "arms with poles" described in section 3.3.1. Horrocks designed an apparatus that was built and tested in the following year. Fig. 3.3 is a photographic view of the apparatus.

3.4.2 I. Wilkie, 1978/79 and H. Lau, 1979/80

Wilkie[17] started his work by testing Horrocks apparatus which he found to have many conceptual faults. Wilkie then took the decision to find a fresh approach to the problem. The result of his work is a concept based again on the use of "arms with poles" but working in a rotary manner. A 3-times scaled-down model was designed, built and later tested with babies garments. The rotating method of operation was revealed to be space saving, but the basic principle of the concept did not promise a successful outcome. No provision was made to prevent the arms from going into the garment shoulders; the clamping method was inefficient; no attention was given to sizing.

Lau[18] then took over the project and immediately looked into the mechanization of Wilkie's model, rather then making any serious attempt to assess the validity of the concept or putting forward any alternative methods of actuation. The resultant apparatus shown in Fig. 3.4, does not represent, therefore, any real evolution of Wilkie's concept.

3.4.3 M. Spooner, 1980/81

Spooner[19] critically analysed the results of the previous projects and then decided on a new approach. His work has not passed from the sketch stage, but his final concept represents a considerable effort to arrive at a feasible solution. A brief description of his concept is given in section 4.4; (Fig. 4.7 represents a schematic side elevation).

3.4.4 S. Bridge, 1981/82

By the time Bridge[20] started his work on the topic, the author was also initiating his investigations. Bridge's concept is, therefore, the result of discussions he had with the author during the initial exploratory phase. For that reason, Bridge's concept is just a more elaborated stage of the author's concept No.4 that can be seen in section 4.4 and is illustrated in Fig. 4.12.

3.4.5 Conclusions

This brief look at the final year student projects has shown a determination to find a solution for the turning of garments; however, little attention has been directed towards the automatic sizing and sorting. The author is conscious that the very limited time available to undergraduates has certainly been a factor in the restricted outcome of their work.

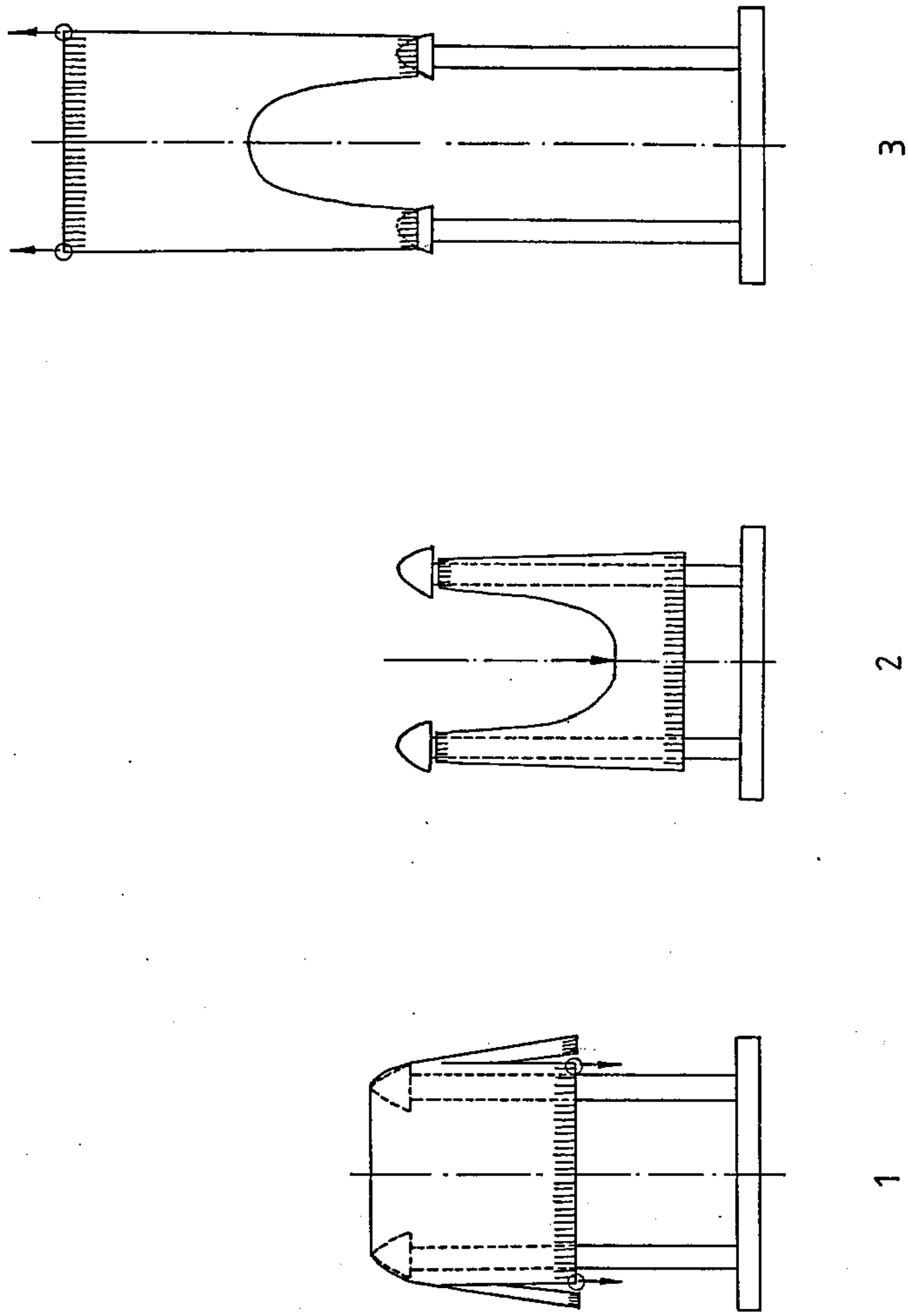


Fig. 3.1 Manual turning using vertical "arms" with "poles".

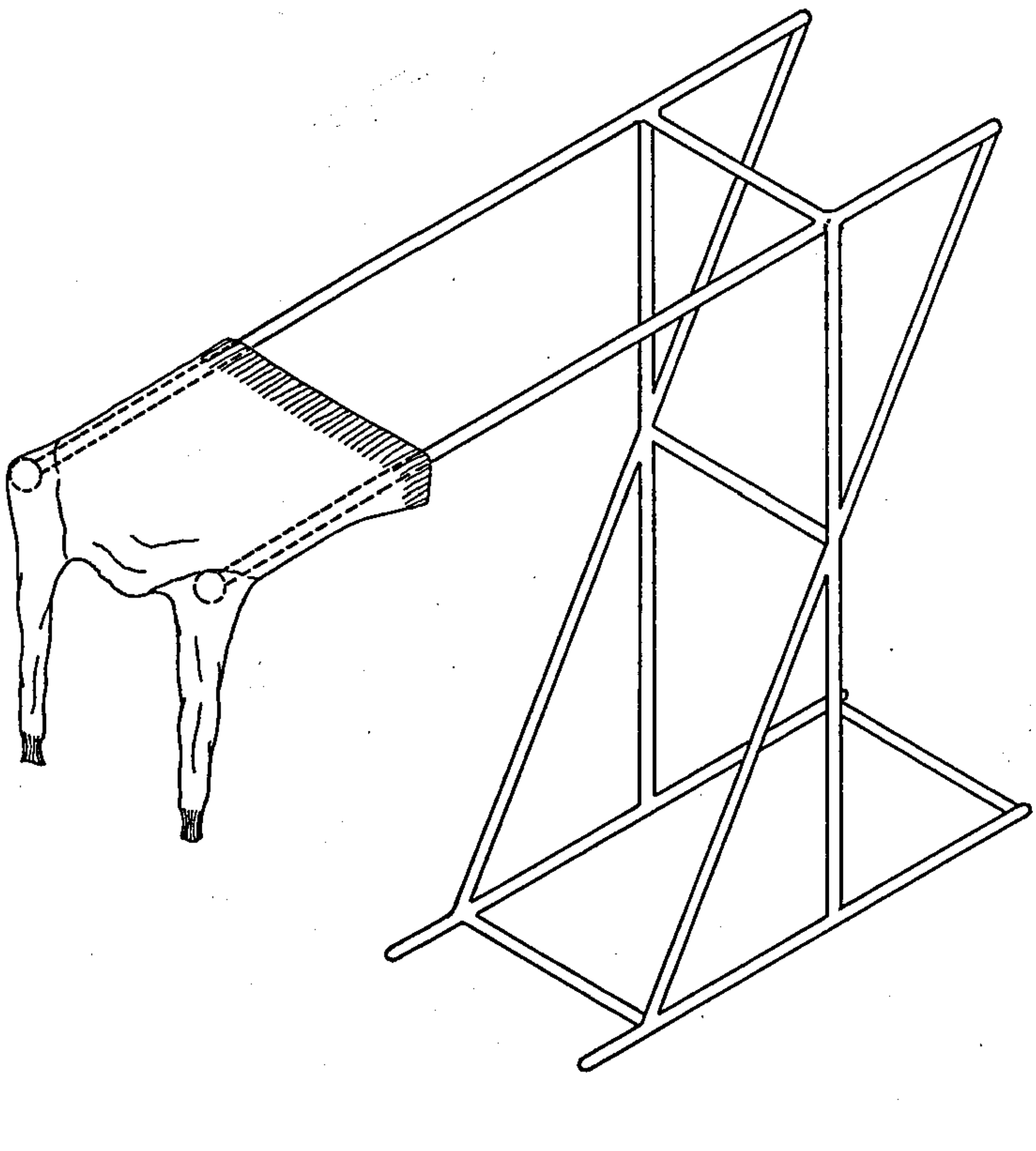


Fig. 3.2 Manual turning using horizontal "arms" with "poles".

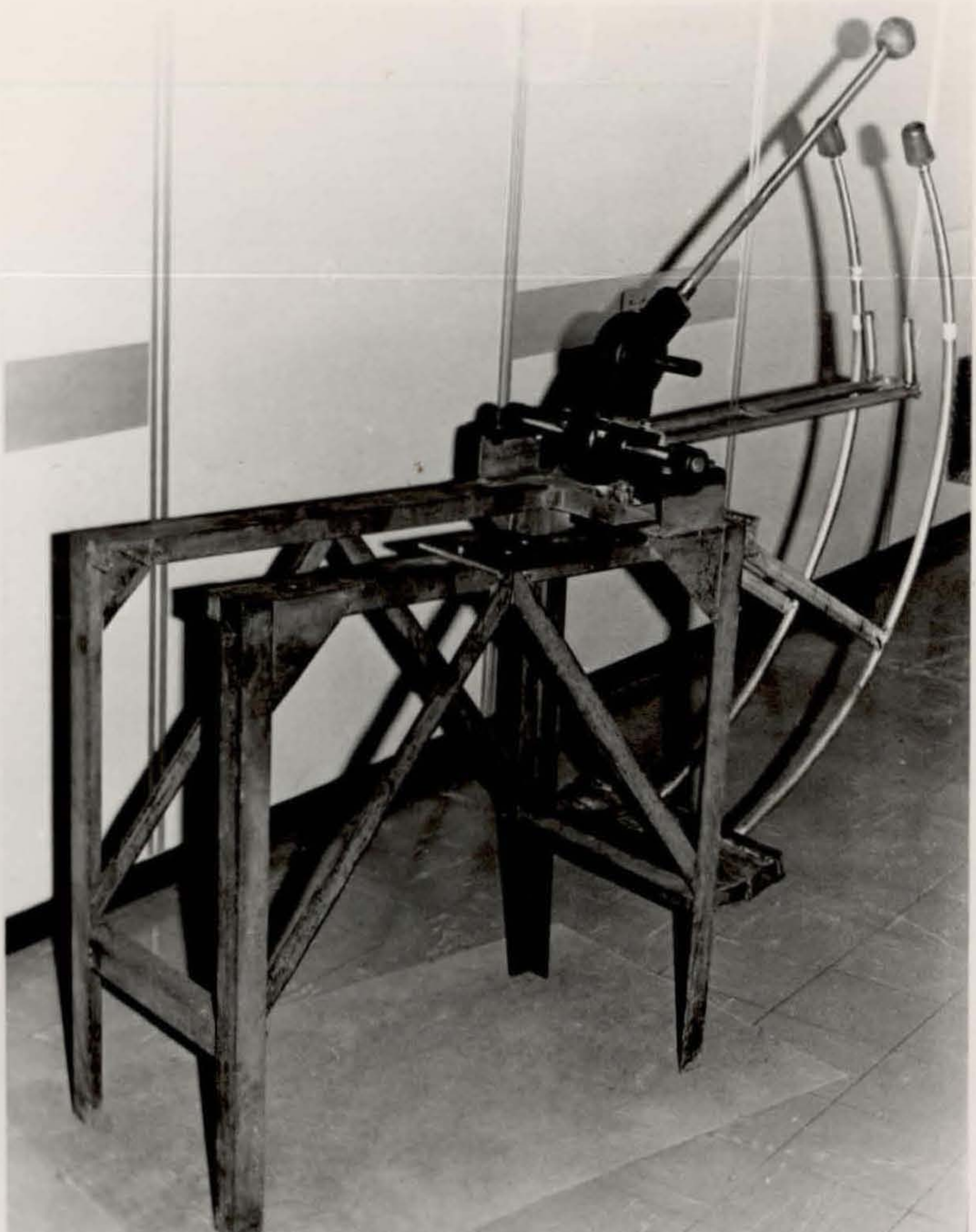


Fig. 3.3 Horrocks apparatus.

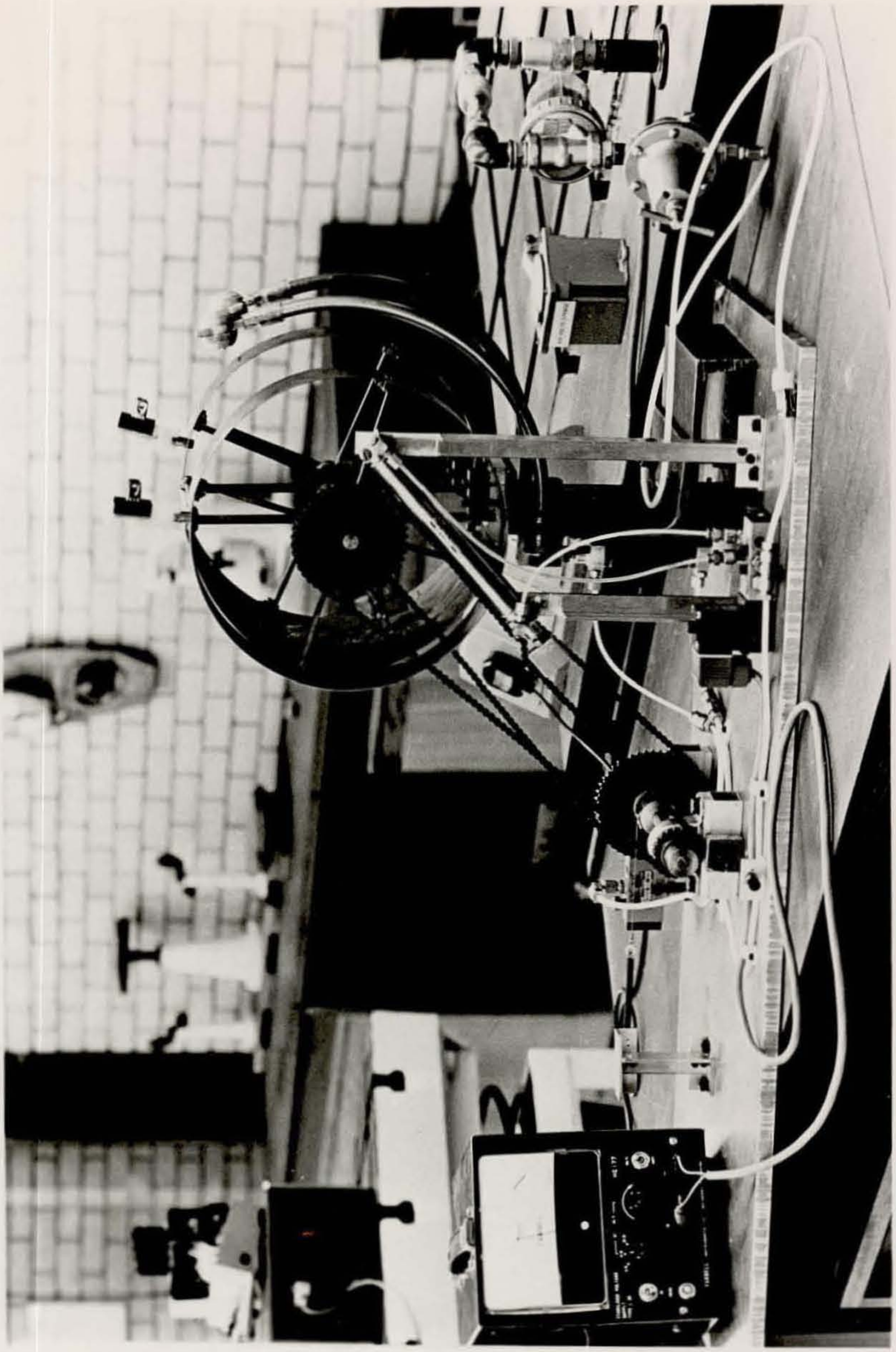


Fig. 3.4 Wilkie/Lau apparatus.

CHAPTER 4

FEASIBILITY STUDY

4.1 Methodology and Assessment of the Problem

After understanding the present industrial process, and summarizing the previous approaches in the area of turning and sorting of garments, it is possible to visualize the problem and make useful contributions to its solution. If a serious and scientifically planned approach is desired, the methodology to be used must be established in order to identify and solve the problems in the correct sequence.

According to Gupta[21], the first step in the design process is the "realization of the need". From the description of the present industrial process, this question becomes evident. The fact that a company, Stevensons (Dyers), approached Loughborough University of Technology looking for a solution, is the recognition of the problem. The present methods adopted for turning, sorting and stacking of knitted garments are mainly manual. This makes the job unpleasant as it is repetitive and tedious as well as costly because it is labour-intensive. However one could always ask the following questions:

Does the problem really exist?

Could it be eliminated by a redefinition and change of the present methods?

Could garments be manufactured the right side out?

Could production be organized so that only one size reaches the finishing department at once?

All these questions have passed through the author's mind but, after mu ch thought and some discussions with technical staff of different companies within the trade, the problem was accepted.

The flowchart of Fig. 4.1 summarizes the main lines of the methodology, setting out a number of steps through which the research is directed.

4.2 Problem Definition

Once the problem has been recognized, it is useful to establish a preliminary statement of the need to determine its nature and its validity. The problem is therefore to turn, sort and stack knitted outerwear garments to cover the upper part of the human body. Each of these aspects will now be analysed in more detail.

4.2.1 Turning

The turning operation consists of reversing the fabric of the garment, essentially made up of tubular shapes, in order to exchange the inside with the outside. This definition is very vague but at this stage one cannot go any further without starting to propose solutions. To clarify the definition, a decision has to be taken about the means used for turning. To accomplish the turning of the garments, two distinct methods can be devised for consideration: suction and mechanical means.

Suction as a method of turning knitted garments has been considered in section 3.2 with unfavourable conclusions.

Excluding suction, the only other way devised for turning garments is to use mechanical methods. By analogy with the manual operation, it is necessary:

i) to enter the inside of the body of the garment and find the sleeves;

ii) to go through the inside of the sleeves and hold the cuffs; and

iii)to pull the cuffs and the sleeves through the inside of the garment, until both sleeves and body are reversed.

At this divergent and creative phase, all possible solutions must be left open until decisions are taken at later stages. Nevertheless it is necessary to define in which position or positions the garment must be presented to the turning system. In Fig. 4.2 five different possibilities are represented.

a) Garment held by the waist near the two opposite seams with sleeves and body hanging down. The waist will assume a rectangular hole when seen from above.

b) Garment held by the cuffs with the body hanging down.

c) Garment in its "natural position" as on the human body. To achieve this position some kind of support is necessary, such as two substantially parallel vertical bars.

d) Garment on an horizontal flat surface, held by the waist as in a), so that the waist assumes a rectangular hole.

e) Garment on an horizontal flat surface as in d), but held by the cuffs.

In a first evaluation, positions b) and e) are of very little use. Positions a), c) and d) are likely to be applicable whatever turning system is selected.

4.2.2 Sorting

The sorting operation is the act of separating the garments according to size. In the author's approach to the problem, a decision has been taken to first work towards the automatic sorting of the garments based on physical measurements. It is then necessary to identify which garment dimensions are characteristic of one particular size and look for ways of measuring them.

To do this, a number of "size charts" was obtained and their dimensions examined. The two parameters, from which some relationship with the size could be expected, are the "chest width" and "length". According to the size chart of Fig. 4.3, these are dimensions A and B. The "chest width" is taken 2.5 cm (1 inch) below the armhole and the "length" is taken from the shoulder at the neck join to waist. This is not imposed by any standard procedure but follows the traditional methods of each particular manufacturer or customer requirements. For example, it is common to see the chest width to be measured at 1 or 2 cm below the armhole. For the same sort of garment, size charts are however very similar within the trade.

Analysing this information, the natural conclusion is that "length" is not a good sizing parameter. In Fig. 4.4 it can be seen that in the same size chart, different sizes are designed to have exactly the same length. On the other hand, the examination of the chest width/size relationship in Fig. 4.5, shows this parameter as a sizing characteristic. However, plotting size-chest width together for different styles as seen in Fig. 4.6, the important conclusion is that the measurement across the chest of the garment is only characteristic of one particular size when compared within the same style and material.

It must however be borne in mind that the size chart dimensions are the desired final measurements taken with the garment relaxed on a flat surface, neither stretched nor wrinkled. On the other hand, at the time of the "TSS" (turning, sorting, stacking) operations, the garments are certainly not in the best condition to be measured in that way. The previous operations, like dyeing and tumble drying, leave the garments in a wrinkled state that makes it difficult to take measurements using conventional methods.

It is not the aim of this work to go deeply into the complex subject of sizing garments, but it is important to generally understand what are the criteria used to establish the size of garments, especially those concerned with this work.

According to French[22], "sizing has three principal aspects: a) the relationship between one dimension and another in a particular garment; b) the size of the intervals by which one garment is larger than the next smaller garment; c) what the size shall be called, so as to identify it."

The situation differs from one country to another and sometimes within the same country. In the UK for example, men's knitted garments are sized according to the chest circumference measurement; theoretically, one garment labelled 38 should measure 38/2 = 19 in across the chest. The men's most common range of sizes is 34, 36, 38, 40, 42, 44. For women's the sizes are labelled with code numbers 10, 12, 14, 16, 18, 20, which corresponds approximately to bust circumferences of 32, 34, 36, 38, 40, 42 inches. Nevertheless one must bear in mind the difficulties in taking these measurements. The usual procedure is to put the garment flat upon a table and use a conventional tape measure. In this case, allowance for human errors is necessary (positioning of the tape measure, amount of stretch given to the garment when trying to put it flat, and possible differences in the degree of fabric relaxation). This is to say that the degree of reliability of conventional measurements taken on flexible articles is very small.

Recently some work has been directed towards sizing standardization. According to French[22], the most significant proposal is that the size designation of garments should be the body measurements which the garment was made to fit. This is in accordance with the International Standards, where it can be seen, for example in ISO 3636-1977 (E)-" Size designation of clothes- Men's and boy's outerwear garments"[23]: "The size designation system is based on body and not on garment measurements. Choice of garment measurements is normally left to the designer and the manufacturer who are concerned with style, cut and other fashion elements, and who must make due allowance for garments normally beneath a specific outer garment". According to this standard, on knitwear garments for covering the upper or the whole of the body, the "chest girth" is the control dimension.

The advantage of this system is emphasized by Boughey[24] of the Textile Department of the British Standards Institution when she says: "the manufacturer was free to design the style and fit of his garment according to his own wishes but by using the size code he informed the consumer what size person his garment was intended to fit. This system was soon adopted by major retailers and within a short time the women of the United Kingdon became accustomed to buying their clothes according to the size code numbers. ... At first the reader may think that a manufacturer could be given a little more advice on the cutting of his garments, but fashion changes so quickly and two garments labelled with a particular size code may have quite different dimensions as one is intended to be a tight fit and the other a very lose fit. The size code number still applies regardless of the fashion or type of garment. This means that a fashion-conscious woman need not be concerned with garment measurements but can buy a garment labelled with her size code in the knowledge that it will fit her as intended by the designer. This type of reassurance is even more important in shops where no trying-on facilities are provided".

On the construction of the garment itself the different dimensions and shapes are achieved according to the technique being used. As seen in sections 2.2 and 2.3, "cut-and-sew" garments are shaped and consequently sized when the different parts are cut. On the other hand, "fully-fashioned" garments are shaped during the knitting process by means of varying the the number of needles in action in the knitting width.

To summarize, the problem of sorting knitted garments is first of all the one of measuring them. The control dimension is the chest width. The conditions for the chest width to be measured must be defined in order to measure it automatically and that the results can be compared without accounting for human errors. At this stage, a measurement taken after applying a predefined stretching force is suggested and the results must be compared within garments of the same style and material.

4.2.3 Stacking

The stacking operation consists of straightening the fabric of the garments and laying them one on top of the other, in piles, each pile being of garments of the same size.

It is important to emphasize that the stacking operation does not need a high degree of accuracy. The garments are considerably wrinkled at this stage and the only purpose of stacking is to facilitate and speed up the next finishing operation, the steaming and/or pressing of the garments, usually known as the "trimming operation", already described in section 2.5.

4.3 Requirements and constraints

Having defined the problem, the preliminary requirements are summarized in table 4.1, under technical, ergonomic and aesthetic points of view.

After discussions with personnel in the dyeing and finishing industry, it was possible to formulate the following constraints:

1. To consider long sleeved garments only as this covers the major part of the production.

2. To consider adult sizes only. The most common adult sizes according to the UK labelling system are:

   Male sizes: 34 36 38 40 42 44

   Female sizes: 10 12 14 16 18 20

3. To consider different textile materials in both natural and man-made fibres, which will have different properties such as elasticity and friction.

4. To consider garments made from fabrics with "open" and "close" knitted structures.

5. The garments are in a pre-finished state, which means closed necks, no "trims", and in case of cardigans, front not opened.

6. Some batches are left slightly wet for the "trimming" operation.

7. Each batch of garments is always the same style and material.

4.4 Generation of Alternative Concepts for Turning and Sizing

Having defined the problem and summarized the requirements, the creative phase was initiated in order to generate ideas and concepts. As there are three main problems to solve (turn, sort and stack), a decision was necessary to whether the problems should be considered separately, as a whole, or try to associate any two of them. The decision was not easy to take and the generated concepts reflect the situation. At first the author considered the turning problem only but, as the work developed, it was found that the turning and sizing should be associated as should be the sorting and the stacking.

A distinction between sizing and sorting is required. The first is the act of recognizing the size of the garment. The second is the act of separating them.

The following concepts are proposed for turning or turning and sizing only. In order to use the evaluation method suggested by Pugh[25, 26], all the concepts are in a schematic form, more or less to the same degree of detail.

CONCEPT No.1 (Fig. 4.7)

This concept was introduced by Spooner[19]. The author decided to include it here, because it has been the most elaborated proposal, though it has never passed from the sketch stage. The main components are:

1. A pair of stationary circular curved parallel "arms" with "poles" on the arm ends;

2. A "clamp" in reciprocating rotary movement;

3. A reciprocating rotary "flap/flinger";

To describe its mode of operation, use has been made of the following description given by Spooner in an "improved turning machine flowchart":

"1. Operator loads jumper onto clamps former.

2. Operator closes guard which automatically starts the machine. Clamp closes and clamp frame starts rotating clockwise.

3. Clamp frame stops when jumper shoulders close microswitches on turning arms. The flinger/flap then rotates into place.

4. The clamp frame is now allowed to rotate freely as the flap pushes the jumper neck down.

5. Flap frame stops when cuffs pass microswitches. Flap/flinger rotates out of the way while clamp frame moves anticlockwise.

6. Flinger/ flap rotates back down when clamps have passed under it and flap frame starts to move anticlockwise at same speed as clamp frame.

7. Clamp frame stops at its start position and flap frame continues to rotate until cuffs come off the rollers and them flings the jumper off."

The sizing method proposed in this concept is not completely clear. After analysing data on dimensions of a sample of garments taken by the "tape measure method", Spooner concluded that sizing could not be carried out by measuring the chest of the garment. A suggestion is made for sizing based on measurements of body length, body/arm length and distance from neck to cuffs. The final conclusion is that, "at the present time it seems that the machine decodable tagging of jumpers to identify their sizes is the most practicable proposition."

CONCEPT No.2 (Fig. 4.8)

Suction as a method of turning knitted garments has already been discussed in Chapter 3. The weakness of the principle has been pointed out but it was decided to include it here under a new arrangement for comparison with other methods. The main components are:

1. A stationary "turning assembly"[12] as shown in Fig. 4.9, with two holes to suck the sleeves;

2. A widthwise adjustable "clamp" in reciprocating linear movement;

Alternatively, the "clamp" could be stationary and the "turning assembly" have a reciprocating linear movement. A third solution with both being able to move in order to reduce their stroke, and then, optimizing the cycle. The mode of operation is as follows:

1. Operator picks up a garment, selects the waist and loads it in the correct position on the clamp which, initially adjusted to receive the minimum waist width, will expand at the operator's instruction (foot switch), to hold the garment in position.

2. The clamp moves upwards, "dressing" the garment on the outside of the turning assembly. This movement will stop when the assembly is touching the neck and shoulders of the garment.

3. When the clamp and garment are stationary, the suction is activated and the sleeves are sucked through the holes of the assembly.

4. When the reversing of the sleeves is completed, the clamp moves to the starting position with suction still on, and the garment is turned inside out.

The shape and size of the "turning assembly" should be selected very carefully so that it can accommodate all different models and adult sizes of garments. This is likely to be difficult as it can be seen that the cross-section must be designed for the smallest size and the length to completely "dress" the largest size. The question then is whether this "turning assembly" remains efficient when turning large size garments, where it is clear that a large gap will appear between the garment and the walls of the "turning assembly".

Automatic sizing has never been attempted with any suction device and the first impression is that it is likely to be impracticable. If the upwards movement of the clamp is automatically stopped by a signal from the pressure of the fabric of the neck and shoulders area on the corresponding area of the "turning assembly, it would be possible to measure the linear displacement of the clamp and this would probably be proportional to the length of the garment. Unfortunately, "length" is not a characteristic sizing parameter.

CONCEPT No.3 (Fig. 4.10)

This concept is a return to the principle of using mechanical means. The main components are:

1. A pair of vertically mounted parallel straight "arms" with "poles" in the arm ends, in reciprocating linear movement.

2. A "lift neck device" in reciprocating linear movement.

3. A widthwise adjustable stationary "clamp".

Mode of operation:

1. Loading of the garment on clamp as in concept no.2.

2.The arms move downwards until poles touch the shoulders. This is detected by microswitches incorporated in the arm ends; the signal is used to start the lift neck device moving upwards which will stop near the waist level.

3. Arms continue downward movement and the cuffs are captured by the poles.

4. Arms and lift neck device return to their original positions with the garment turned inside out.

Alternatively, the clamp could share the stroke with the turning arms to reduce the cycle time.

Automatic sizing could only be based on garment length, by measuring the displacement of the arms until they automatically stop at the shoulders. However, this is not a reliable sizing method as seen in section 4.2.2.

CONCEPT No.4 (Fig. 4.11)

One of the main problems with the previous concepts is the size of the whole turning station. This concept is an attempt to reduce space. Again the rotary layout is the preferable solution as Wilkie[17] and Spooner[19] concluded. The main components are:

1. A pair of circular curved parallel "arms" with "poles" in reciprocating rotary movement.

2. A stationary widthwise adjustable "clamp".

3. A reciprocating rotary "lift neck device".

Mode of operation:

1. Loading of the garment on clamp as in concept no. 2.

2. G1, N1 and A1 stand for garment, lift neck device and arms at starting position. The arms rotate and move through the inside of the garment (A2,G2) until they stop

when the poles contact the shoulders, by means of a microswitch in the arm ends.

3. This signal is used to engage the lift neck device (N) from N1 to N2, which causes the arms to go through the sleeves and the cuffs to be captured by the poles (G3).

4. Arms and lift neck device return to their starting positions, with the garment turned inside out (G4).

Once again, automatic sizing could only be based on garment length, by measuring the angular displacement of the arms from the starting position until they automatically stop when poles contact shoulders.

CONCEPT No.5 (Fig. 4.12)

Using "arms" with "poles" as the main turning fixture is once again used. This exploratory concept resulted from the realization of the problems encountered when using parallel arms in both straight and circular curved shapes, where the distance between them is kept constant. This concept has been the first move to carry out the turning of the garment without going straight into the garment shoulders. The main components are:

1. A pair of circular shaped "arms" with "poles", in reciprocating rotary movement in the plane of the garment.

2. A stationary widthwise adjustable "clamp".

3. A "lift neck device" in reciprocating linear movement.

Mode of operation:

1. Loading of the garment on the clamp as in concept no.2.

2. The turning arms rotate downwards and move through the inside of the garment. At a certain point, because of the circular geometry, this movement is also outwards in order to find the armholes and so the sleeves. Eventually, the movement of the arms will be stopped when the pressure of the poles against the garment actuates a microswitch.

3. This signal also engages the lift neck device (N), which will move the neck of the garment towards the waist, helping to "dress" the sleeves, and the cuffs to be captured by the poles.

4. Both arms and lift neck device return to the starting position, completing the turning of the garment.

The main problem with this concept is illustrated in Fig. 4.12. Different sizes will have the armholes at different levels, and so a different path of the turning arms is required according to size. In the figure, two garments of different sizes and shapes are illustrated to scale in order to emphasize this situation. The other problem is that no automatic sizing is envisaged in this concept.

CONCEPT No.6 (Fig. 4.13)

The problems with the control of the outwards movement of the arms, resultant from the fixed geometry of the previous concept, gave the inspiration to the present one. Here, the distance between the turning arms is not constant, because their path is not constrained by a fixed geometry. The main components are:

1. A pair of substantially straight "turning arms" with "poles" in reciprocating linear movement. The arms are pivoted so that they can move symmetrically outwards in the same plane.

2. A widthwise adjustable "clamp" in reciprocating linear movement.

3. A "lift neck device" in reciprocating linear movement.

Mode of operation:

1. Loading of the garment on clamp as in concept no. 2.

2. The arms, are initially parallel, so that the distance between them is well below the waist width of the smallest adult garment.

3. The arms start moving downwards. When the poles have passed the waist level, they also move outwards, establishing contact with the inside of the garment. This outward movement eventually stops when the stretching force provided by the arms is balanced by the fabric resistance.

4. The arms continue to move downwards, the poles following the seams.

5. Eventually the poles will reach the armholes where the fabric resistance collapses. At this moment the poles move rapidly outwards to start their movement through the sleeves. At the same time, a signal is generated to start the lift neck device upwards movement. The distance between the poles immediately before this position is recorded and transformed into a sizing/sorting signal.

7. The arms continue to move downwards to capture the cuffs with the poles.

8. Arms and lift neck device return to their original positions and simultaneously the clamp starts to move downwards completing the turning of the garment.

9. The clamp returns to its starting position holding the already turned and sized garment.

Alternatively, the clamp could stay stationary during the turning sequence. This would be a simplification in terms of the amount of movements and moving parts, but the full stroke of the arms would be increased quite considerably, almost doubled.

CONCEPT No.7 (Fig. 4.14)

This concept is based on a rather different principle and the garment is positioned according to Fig. 4.2 c). The main components are:

1. A widthwise adjustable "mannequin" with two substantially vertical "arms" incorporating end grippers in reciprocating linear movement.

2. Two widthwise adjustable "clamps" that follow the sideways movement of the "mannequin" arms and can move vertically in reciprocating linear movement, independent of the mannequin.

Mode of operation:

1. The operator picks up a garment and "dresses" its body on the mannequin that is initially adjusted to accommodate the smallest size.

2. The two halves of the mannequin move symmetrically sideways, slightly stretching the body of the garment. The sizing is based on the amount of this sideways movement which is recorded and transformed into a sizing/sorting signal.

3. An audible or visual signal is emitted to inform the operator that he or she can now "dress" the sleeves, which is accomplished by pressing down the neck of the

garment by hand. Alternatively, this could be carried out automatically by a conveniently placed "push neck device".

4. Two clamps, one at each side of the mannequin, automatically grip the waist at two opposite points and the mannequin is released so that the two halves can move inwards loosening the garment.

5. Then the clamps move upwards and, at the same time, the mannequin moves downwards, turning the garment inside out. The cuffs are held by one fixed clip in each end of the mannequin arm and released in the final stages of the turning operation.

The position of the waist of the garment when it is "dressed" on the mannequin is dependent on the size, which will make operation 4 more difficult to carry out. The distance between the floor and the top of the mannequin is about 2 metres. This would dictate the need for the operator to work on a stand well above the floor, or the machine to be located in a lower place relatively to the floor.

The basic principle is similar to the "manual turning assisted by arms with poles", as well as the inspection or inspection/turning devices already described in chapter 3.

4.5 Evaluation, Comparison and Selection

In order to evaluate the different concepts, use is made of a method introduced by Pugh[25, 26]. The criteria used on the evaluation are only related to turning and sizing; they are:

1. Ability for turning;

2. Ability for sizing;

3. Ability to process the required range of sizes;

4. Operator's intervention;

5. Complexity (number of operations);

Succinctly, the basic rules and procedure are as follows:

1. Establish a number of embryonic solutions to the problem and produce them in sketch form to the same level of detail.

2. A concept comparison and evaluation matrix is established which compares the general concepts, one with the other, against the criteria for evaluation.

3. Ensure that the comparison of the different concepts is valid, that is, that all are to the same basis and at the same general level.

4. Criteria against which the concepts will be evaluated are chosen. These must be based upon the detailed requirements of the product specification and so must be established before solution generation commences.

5. A datum is chosen with which all the other concepts will be compared. An existing design forms a useful first datum choice.

6. In considering each concept/criteria against the chosen datum, the following legend should be used: + (plus) meaning better than, less than, less prone to, easier than, etc. relative to the datum; - (minus) meaning worse than, more expensive than, more difficult to develope than, more complex than, more prone to, harder than, etc. relative to the datum; "s" meaning same as datum.

7. Having selected a datum, an initial comparison of the other concepts is made using (6); this establishes a score pattern in terms of the number of +, -, and s's achieved relative to the datum.

8. Assess the individual concept scores.

9. If a strong concept does not emerge, change the datum and re-assess the score pattern.

10. If one particular concept persists, change the datum and repeat. If the result remains the same, let the emergent strong concept assume the role of datum, re-run the matrix and again assess the results.

Table 4.2 shows the evaluation chart for the seven proposed concepts. Initially, the suction concept has been chosen as datum. It is not an existing concept as such, but part of it has had industrial application on the Turn-o-Matic. The first evaluation has shown a tendency for concept No.6 to emerge. The evaluation chart is then repeated, the datum being concept No.1, the Spooner's approach[19]. Again concept No.6 emerges. Finally, the evaluation chart is repeated with concept No.6 as datum. Once again it shows superiority over the others, confirming the previous evaluations. Having reached this stage, this still embryonic concept will be developed towards a more elaborated solution.

4.6 Development of the Selected Concept for Turning and Sizing

4.6.1 Introduction

Concept No.6 is the starting point for the research of a mechanical system able to automatically turn and size long sleeved garments. This turning/sizing station is made up of three fundamental components:

1. The "Clamp", which is the component responsible for holding the garment while being in the machine. It will hold the garment by the waist at two opposite locations near the seams, so that it will be hanging down, the waist assuming the shape of a rectangular hole, the beginning of the tubular part forming the body of the garment.

The author cannot envisage the possibility of using automatic loading; therefore the clamp must be loaded by an operator. Automatic loading would mean that another part of the machine would be able to "look" into the container where the garments are lying in a tangled state, pick one and only one, select the waist and load it in the correct position on clamp. Even if the garments were stacked, this would present a great problem for a more "intelligent" machine, probably a situation for a new generation of robotic devices.

In order to be able to hold different sized garments, the clamp has to have the facility to adjust itself sideways to accommodate from the smallest to the largest waist size.

The clamp will be mounted on a frame that will be able to move linearly and vertically as explained when introducing concept no.6.

2. The "Turning Arms", which are basically a pair of bars with a more protruding element in one of their ends that for simplicity, have been named "poles". These two bars are pivoted so that they can swing symmetrically outwards. The starting position is when they are parallel to each other, and by swinging outwards, the distance between the "poles" can be varied. The whole frame where the "arms" are mounted can move linearly and vertically.

The function of these two "arms" is to imitate what the operators do when they carry out manual turning. They put their arms through the inside of the garment, look for the sleeves, hold the cuffs with their hands and then reverse the procedure, turning the garment. The two "poles" in the arm ends will perform as the hands of the operator, holding the cuffs after getting through the sleeves. The poles must have the ability to hold the cuffs but must be smooth enough when entering the garment, establishing contact with the fabric and moving through the tubular shaped sleeves. During this part of the operation they are required to act as guides for the "arms", breaking through as smoothly as possible.

In this particular aspect, Spooner[19] carried out a good study into the most suitable shapes, exploring both the sliding and the rolling actuation. His final product, solid aluminium rollers with rounded corners, mounted on needle bearings (Fig 4.15), has been used by the author as the basis for this very important element. For reasons of weight reduction and cleanliness, the aluminium has been replaced by nylon.

3. The "Lift Neck Device" which has two functions. The first can be understood by the analysis of Fig.4.16. In Fig. 4.16 a) a garment is represented as on a clamp, ready for turning. Also represented, are the possible trajectories of the "rollers", even when the arms move outwards to search for the armholes. Whatever is the situation, the rollers always go towards the garment shoulders because of the particular shape assumed by the sleeves near the armholes, as shown in detail in Fig. 4.17. As a consequence, the arms will get trapped, stretching the garment, possibly beyond repair, or at least, pulling the waist off the clamp.

Fig. 4.16 b) shows what happens if the garment is lifted at the neck immediately after the rollers have gone into the armholes. There it can be seen how the sleeves unfold themselves assuming an almost perfect tubular shape, in line with the trajectory of the arms.

The second function of this component is that, by lifting the middle part of the garment by the neck, to a level near the waist, the cuffs are moved upwards, shortening the stroke of the arms required to clear the cuffs with the rollers.

The "lift neck device" plays an essential part on the turning of the garment, but it must be activated immediately after the rollers have passed into the armholes. If it is activated before, the situation represented in Fig. 4.18 will take place, spoiling the operation. The rollers will go into "pockets" just over the armholes, and the system will be jammed, probably damaging the garment, or at least, pulling it off the clamp.

4.6.2 Preliminary Definition of Movements and Dimensions

The sequence of illustrations from Fig. 4.19 to 4.26 show more detailed sketches of the first and most important part of the turning/sizing operation of the selected concept. These sketches are approximately to 1:10 scale, showing a size 44 garment.

Fig. 4.19 shows the garment held by the two grippers of the clamp (C), at the position previously described. The arms (A) and the lift neck device (N) are, as well as the clamp, at the starting positions.

When the operation is started, the arms move downwards with the rollers at their innermost position. After passing the waist level, the element responsible for the swinging movement of the arms is activated, causing the arms to swing outwards and the rollers to establish contact with the inside of the tubular section of the garment body. After a short time, the force (F) exerted by the rollers on the garment, and the fabric resistance (R) will be in equilibrium. This situation is represented in Fig. 4.20. The arms continue their downwards movement, the rollers following the two opposite body seams.

In Fig. 4.21 the arms are moving down and the rollers are at the garment chest level. According to the research carried out on sizing (section 4.2.2), it is assumed that the distance between the two rollers at this position is proportional to the size of the garment.

The arms continue to move downwards, being quite clear that the rollers are about to reach the armholes. This instant is represented in Fig. 4.22. The fabric resistance collapses and the arms accelerate rapidly outwards into the armholes. This fact is then sensed by a system which responds by engaging the lift neck device before the rollers reach the garment shoulders, shown in Fig. 4.23. The result of this important phase is that the arms can move without restriction through the tubular shaped sleeves, while the centre section of the garment is being lifted, as seen in Fig. 4.24. The end of this phase is represented by Fig. 4.25 where the rollers have cleared the cuffs helped by the lift neck device.

Before the arms start moving upwards to reverse the garment, the lift neck device goes back to rest while the arms swing back to their inwards position. The beginning of this phase is shown in Fig.4.26.

When the arms reach their rest position, the rollers will be just over the waist level (see Fig. 4.19). However, the turning of the garment is not yet completed. One method is to move the clamp down and with it, the waist of the garment. This downwards movement of the clamp can be carried out simultaneously with the upwards movement of the arms to reduce the cycle time.

A sample of garments of four different materials covering both natural and man made fibres, men's and women's styles in different sizes was used for assessing the dimensions of the garments the machine must handle. These measurements are recorded in Table 4.3. They were taken with the garments in three different positions: First they were laid flat on a table with the sleeves in a "natural" position; second the garments were measured as though they were on a clamp. In order to save unnecessary collection of data, only the dimensions of the the smallest and largest sizes were recorded. These are dimensions L1, B1, S1, T1. The waist width was measured using two 100 mm wide pads at each side of the waist. W5 and W10 are the waist widths under these circumstances, using a stretching force of 5 N and 10 N respectively; finally the garments were measured from waist to cuffs after lifting the neck to the waist level. This is dimension T2.

The garment shown on these sketches, at the top end of the size range, has approximately 1.1 m from waist to cuffs when hanging on a clamp. In this case, for the cuffs to come off the arms, the clamp must move approximately 1 m downwards, assuming that the initial distance between waist (clamp) level and rollers level is 0.1 m.

The length of the arms can also be visualized. The maximum distance from waist to cuffs when the neck is lifted, as in Fig. 4.25, is 0.9 m (T2 on Table 4.3). Allowing 0.1 m clearance between waist level and arm frame, it is possible to conclude that the arm length must be around 1 m.

The end of the sequence is the return of the clamp to its rest position, still holding the garment by the waist but turned inside out.

4.6.3 The Chest Stretching Experiment

In the previous section 4.6.2, the sizing technique is suggested. It is based on the comparison of the width of the garment at the chest level and under a small stretching force. In order to standardize these measurements so that they can be compared, it is necessary to estimate the stretching force and define the chest level. Fig. 4.27 illustrates the experimental procedure to find the data and the test rig is shown in Fig. 4.28. Table 4.4 summarizes the collected data. The chest width is recorded for each garment using stretching forces from 0.5 N to 2.5 N in steps of 0.5 N. As the experiment progressed, it was decided not to go over 2.5 N as the garments were visually under a considerable stress and in danger of permanent damage.

Figs. 4.29 a), b), c), d) graphically show the results of this experiment for the four sets of garments. The important conclusion is that, within the range of forces used, the chest width of the garment increases almost uniformly for all the sizes. Therefore, if the same stretching force is applied to all the garments of the same material/style, the results can be compared. At this moment, the hypothesis of having to use different forces for different materials is not to be excluded.

4.6.4 The "Concertina Effect" and Alternative Methods to Overcome the Problem

Fig. 4.26 represents the beginning of the reverse stroke of the arms which are moving upwards, bringing the cuffs held by the rollers. The arms themselves are of a smaller diameter than the rollers. As a result of this configuration, the sleeves start bunching around the arms near the rollers. When the moment arises where the rollers have to pass through the rectangular hole of the waist, all the fabric of the sleeves is concentrated like a squeezed concertina, near the rollers. This will result in difficulties to move through the waist and, especially with high friction materials, the need for a large force (F) to pull off the sleeves with a consequent large force on the clamps. The result is the possibility of fabric damage due to excessive stretch. This phenomenon is sketched in Fig. 4.30.

Fig. 4.31 represents three different proposals to overcome this problem. The ideas are based on the simple observation that this "concertina effect" does not take place when a human is undressing a jumper, reversing it at the same time. As the sleeves are relatively tight to the human arm, the fabric "rolls" instead of bunching. The idea is, therefore, to create a configuration that provides low friction when the arms are entering the sleeves, and a volumetric shape with increased friction when the arms are on the reverse stroke.

i) Inflatable arms which are inflated at the beginning of the reverse stroke. Some complexity is present in this design, particularly due to the need to inflate and deflate in synchronization with the turning movements.

ii) Sprung rigid sleeves. In this design, there are two half sleeves on the outside of the arms which will be sprung out by a low force compression spring to provide the arms with a volumetric shape.

iii) Barbed arms. These are made with flexible filaments that will not cause damage to the fabric. The filaments will be placed around the arms at an angle so that they bend towards the arm when entering the sleeves, but will expand volumetrically, filling the sleeves on the reverse stroke.

Based on the simplicity of the "barbed arms", the principle is accepted for eventual use in the final design.

4.6.5 The Swinging Movement of the Arms

In section 4.6.2, the length of the arms was found to be around 1m. Looking again at Table 4.3 (data on garment dimensions), it is possible to decide on the distance between the arms when they are at the innermost position, which corresponds to the distance between the rollers at the same position. Assuming that, when on the clamp, the waist of the garment is stretched using a force of 5 N, the minimum waist width (W5 minimum) is going to determine the distance between the arms at rest. This is done bearing in mind that the arms with the rollers must enter the rectangular shaped waist with enough clearance.

The diameter of the rollers is 40 mm and W5 minimum is 390mm. Leaving 25mm clearance between the outside face of the roller and the clamp as illustrated in Fig. 4.32, the distance between the arms is 390 - 2 x (25 + 20) = 300 mm.

After defining the geometry of the arms at rest, to find the swinging angle it is assumed that the stretching force of 2.5 N is used. Under these conditions, the maximum chest width is 633mm according to Table 4.4 but, after going into the armholes, the rollers must be allowed to move further apart. The distance between the rollers when they are at the extreme outwards position is then taken as 650 mm.

According to Fig. 4.33, and as the angle α is very small, it is permitted to assume that ABC is a right-angled triangle in C. Hence the value of α is given by:

α = arctan 650-300/2/1000
$\alpha = 9.93^{\circ}$
or $\alpha = 10^{\circ}$

Having found the basic geometry of the turning arms, it is now necessary to search for a mechanism to provide the symmetrical swinging movement and corresponding actuator.

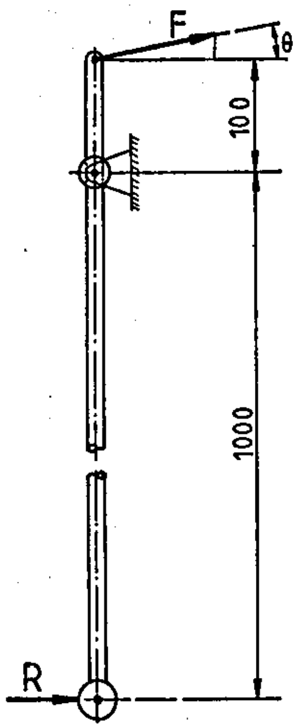
In Fig. 4.34 are proposed three different possible solutions for the swinging mechanism. Design A is the simpliest one but has the inconvenience of having the pivoting points of the arms in a position where they have a right-angle shape. That would mean a junction at the point of maximum bending moment. In both designs B and C, the arms are made of a single straight piece. Therefore there is no junction at the pivoting point. Design B has the disadvantage of having one of the links in linear movement, which is generally considered a poorer solution in comparison with rotary movement. Design C was selected bearing in mind that it represents a valid solution for this problem because the swinging angle is very small.

The dimensions of the different links were found and optimized on a trial and error basis. The final geometry is shown in Fig 4.35, which shows the extreme positions of the arms and swinging mechanism.

4.6.6 Sizing Techniques and Selection of Swinging Movement Actuator

The maximum angle of rotation for the arms is 10°, which is achieved by approximately 34° rotation of the centre crank. The actuator responsible for this movement has to be able to supply the required stretching force at the rollers end. Fig. 4.36 is a diagram of the arms and the swinging mechanism. The actuator is responsible for the torque T applied at the shaft E of the crank DEF. Assuming, for the purpose of these calculations, that a maximum stretching force of 2.5 N is used, it is possible to find the required torque. In these calculations the geometry of the swinging mechanism is based on the graphic study of Fig. 4.35 and is carried out for the two extreme positions.

a) Arms parallel, rollers at inwards position.



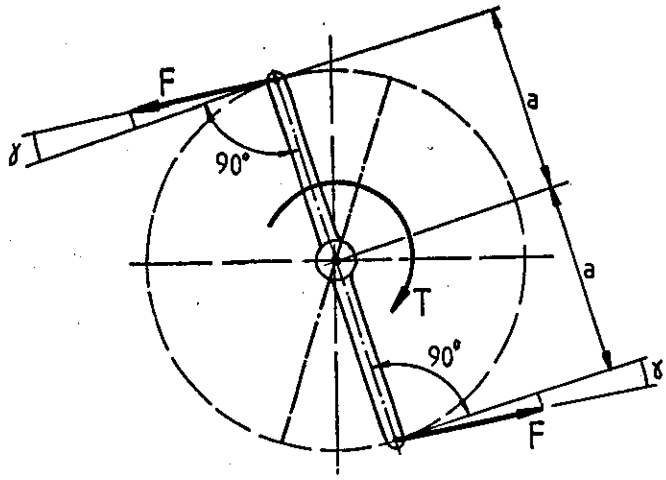
Condition of equilibrium:

$$R \times 1000 = F \times \cos\theta \times 100$$

$$F = 10 \times R/\cos\theta$$

$$\begin{cases} R = 2.5 \text{ N} \\ \theta = 11^\circ \end{cases} \Longrightarrow \quad F = 25.5 \text{ N}$$

For this situation, with a = 0.03 m, the torque is:

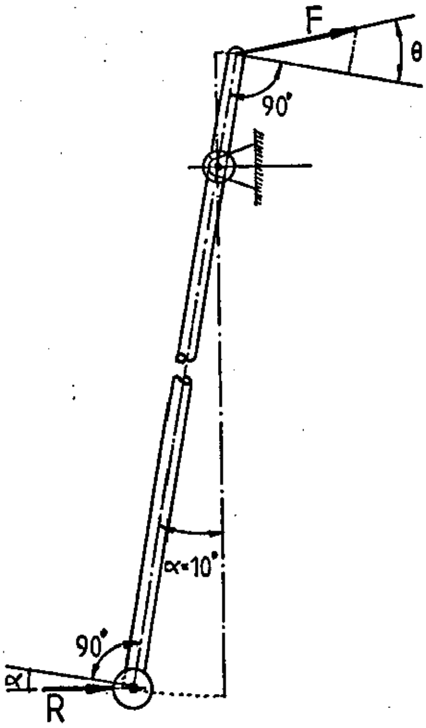


$T = 2 \times F \times \cos \gamma \times a$

For $\gamma = 6^\circ$ and F = 25.5 N the torque is

$T = 2 \times 25.5 \times \cos 6^\circ \times 0.03 = 1.5$ Nm

b) Arms at outwards extreme position.



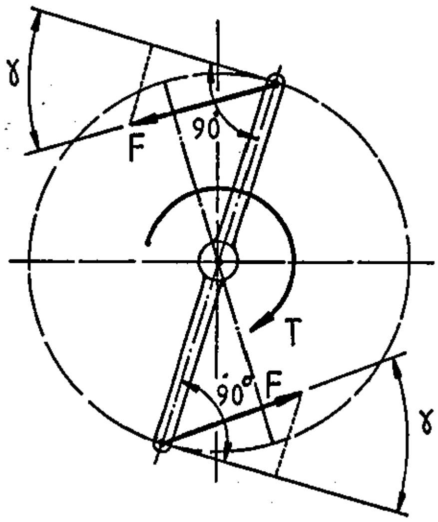
Condition of equilibrium:

$R \times \cos \alpha \times 1000 = F \times \cos \theta \times 100$

$F = 10 \times R \times \cos\alpha / \cos \theta$

$\begin{cases} R = 2.5 \text{ N} \\ \alpha = 10^\circ \\ \theta = 22^\circ \end{cases} \implies F = 26.6 \text{ N}$

For this situation the torque is:



$$T = 2 \times F \times \cos\gamma \times a$$

For $\gamma = 28^\circ$ and F = 26.6 N, the torque is

$$T = 2 \times 26.6 \times \cos 28^\circ \times 0.03 = 1.4 \text{ Nm}$$

These calculations show that, due to the characteristic of the swinging mechanism itself, the relationship, applied torque versus force at the rollers is not perfectly constant but the variation is within an acceptable margin. If the same calculations are carried out with the arms at the inwards position, and a major simplification is made, assuming that the arms and links are at right-angles with each other, then,

$$\begin{aligned} F &= 10 \times R \\ &= 10 \times 2.5 \text{ N} \\ &= 25 \text{ N} \end{aligned}$$

$$\begin{aligned} T &= 2 \times F \times a \\ &= 2 \times 25 \times 0.03 \\ &= 1.5 \text{ Nm} \end{aligned} \qquad (4.1)$$

Hence this simplification is perfectly acceptable.

For driving the swinging movement, several solutions can be put forward:

One being an electric motor (DC servo motor or stepping motor). The driving system could in that case, assume two different shapes:

a) Using a small gearbox to drive the the crankshaft E directly, as is shown in Fig. 4.37.

b) Using a lead or ball-screw and nut, which converts the rotary movement of the screw into linear movement of the nut that is pivoted on the crank. By this arrangement, shown in Fig. 4.38, the nut is able to reciprocate across a 34^{o} sector, pivoted to the crank. In both situations a) and b) it is assumed that the motor is reversible.

Alternatively, an arrangement similar to the previous case b) could be used, with a small double acting pneumatic actuator in place of the motor as is shown in Fig. 4.39.

Using the electric motor in any of the configurations a) or b), the system must incorporate a force sensing device to limit the swinging movement according to the desired stretching force. This could be done by a force transducer designed to sense the force exerted at the rollers and would give the feed-back information to stop the motor when the required stretching force is achieved. Once the equilibrium is reached, the motor would be driving the swinging mechanism so that the rollers would be following the profile of the garment, mantaining the stretching force previously defined for the material being processed.

The amount of rotation of the crank, when the rollers are at the chest level, is then measured and this information used for sizing. If a DC servo motor is used, this measurement could be carried out by means of an angular displacement transducer connected to the crank shaft or driven by it. If a stepping motor is used, the size can be related to the number of steps executed by the motor from the starting position.

The force transducer could be made of strain gauges conveniently positioned near the pivoting point of the arms, where the bending moment due to the force exerted at the rollers is maximum.

The double acting pneumatic actuator offers a much simplier solution over the other two. The force can be controlled by the simple adjustment of the air pressure. The sizing measurements can be taken as with the DC servo motor solution, that is, using an angular displacement transducer connected to or driven by the crank shaft. Based on its simplicity and easy control, this has been the selected design.

The preliminary selection of the pneumatic actuator can now be carried out. Fig. 4.39 shows the geometry of the arms and swinging mechanism. The crank has been extended to the point J where the front clevis pin of the pneumatic actuator is going to drive the crank. Because space and weight are at premium, a short 25 mm stroke was chosen. This dictates the length EJ to be 45 mm. Using the simplification where it is assumed that the links are at right-angles with the crank and arms, the following equations are valid:

$$2 \times F \times 30 = P \times 45$$

$$F = 10 \times R$$

where P is the thrust required from the actuator and R the stretching force at the rollers. Hence,

$$2 \times 10 \times R \times 30 = P \times 45$$

$$P = 13.3\ R$$

The following table gives the values of the required thrust P for different stretching forces R. In the last column, the theoretical value is increased by 20% to account for friction losses.

R (N)	P (N)	P+20% (N)
1.0	13.0	15.6
1.5	19.6	23.5
2.0	26.2	31.4
2.5	32.6	39.1

The following formula is used to select the piston diameter:

$$P = p \times \pi \times d^2 \times 10^{-1}/4$$

where

P = piston thrust (N)
p = working pressure (bar)
d = piston diameter (mm)

The piston diameter is then given by

$$d = [(P \times 40)/(p \times \pi)]^{-2}$$

Considering the maximum thrust of 39 N, and a working pressure of 4 bar, the diameter is d = 11.1 mm. The nearest standard cylinder bore is 12 mm and the final force can be adjusted reducing or increasing the inlet pressure.

4.7 Preliminary Concept of the Whole Process

4.7.1 Introduction

In sections 4.4, 4.5 and 4.6 the turning/sizing concept is generated and developed. The sorting and stacking of the garments is not yet considered under this concept. However, the solution for this sorting/stacking operation is very important for the concept as a whole. Its eventual industrial success will depend on the performance of all required functions, that is, a good turning/sizing machine is of little industrial application if the sorting/stacking operation needs manual intervention.

This section deals with the research and investigation of a system that can be added to the turning/sizing concept to give the full process machine layout.

4.7.2 The Conveying Carousel

While the loading operation, for the reasons pointed out in section 4.6.1, has to be carried out by one operator, the aim is to carry out the unloading operation automatically. That would pose no problems if the garments were simply dropped in a basket or any other sort of container or on to a slow moving conveyor belt; but the requirements ask for a disciplined unloading operation where the garments are sorted and stacked according to size.

Another objective to bear in mind is to cut the operating cycle so that the automatic process can compete in economic terms with the present manual process.

It is the author's opinion that these objectives have been met by the introduction of the "Carousel Concept", illustrated in sketch form in Fig. 4.40. It shows the association of the already known turning/sizing concept with the conveying carousel to give the full process machine layout which is represented in the flowchart of Fig. 4.41. The movements of the different components are numbered in Fig. 4.40 with the exception of movement No.6. They are:

1- Vertical reciprocating movement of the arms.
2- Vertical reciprocating movement of the clamp.
3- Vertical reciprocating movement of the lift neck device.

4- Indexing rotation of the carousel.

5- Horizontal reciprocating movement of the stacker.

6- Swinging movement of the arms (not shown in this sketch).

7- Lift neck device flap rotation.

8- Sideways movement of the clamp pads.

9- Vertical "accommodation" of the stacker.

The carousel is basically a substantially prismatic frame that holds a number of clamps. It is provided with an indexing movement by which the clamps are moved from one station to the next. Using the carousel to convey the garments, all three fundamental operations shown in the above mentioned flowchart, are carried out simultaneously. Under these circumstances, the cycle time of the machine will be determined by the most time consuming of these three operations in conjunction with the carousel indexing rotation.

A simple comparison based on the visualization of these operations, takes the author to the conclusion that the turning/sizing operation is going to be the more time consuming. A preliminary kinematic and dynamic analysis of the turning movements as well as the carousel, will give an indication of the cycle time for the whole operation. This will be carried out later in the chapter.

It is emphasized that, by this carousel concept, the safety of the operator is quite good, as he/she is faraway from dangerous moving parts. In front of him/her, only the indexing movement of the carousel takes place. To make sure that, in a moment of distraction, he/she is not hit by a clamp, a photo-electric sensor conveniently positioned, will immediately stop the carousel if the operator is inside a defined area of danger.

4.7.3 The Loading Operation

This operation takes place in the loading station (L) and is carried out by one operator. He/she picks up a garment from the container and loads it onto the stationary clamp.

At this stage, little attention has been directed towards the clamping system. Suggestions have been made where the clamp is essentially made of two "pads" with the facility to expand sideways. Based on this assumption, the operator has to pick the garment, select the waist and put it in a centralized position, around the two pads. Once this is achieved, he/she will press a foot switch (both his/her hands are holding the garment) that will activate the mechanism responsible for the sideways movement of the two pads of the clamp, until the expanding force is balanced by the fabric resistance. By doing so, the clamp is self adjusted to the width of the garment waist. The friction between the clamp pads and the fabric will sustain the garment in position.

4.7.4 The Turning/Sizing Operation and the Lift Neck Device

Once the loading of the garment has been accomplished, the carousel indexing movement is activated. The garment is conveyed to the next station where the turning and sizing take place and an empty clamp is simultaneously moved to the loading station where another garment is to be loaded.

The turning/sizing operation then starts, following the main lines described in section 4.6. The manufacturer's size charts do not agree on the definition of the chest level. The most common references for the chest level are 2.5 cm (1 inch), 2 cm, or 1 cm which means that the measurement of the chest must be taken at a level 2.5, 2 or 1 centimetres away from the armholes. This is of little importance, providing the situation is standardized for all the garments. In principle, 2 cm away from the armholes is going to be the standard chest level. The sizing technique can now be described as follows:

The arms have entered the garment and swung outwards so that the rollers have established contact with the garment, under a controlled stretch. Once equilibrium is reached, the distance between the rollers, in terms of the position of the swinging mechanism, is recorded at different levels, 1 cm apart. This gives the profile of the body of the garment. Once the rollers have gone into the armholes, this is immediately detected by the system which is instructed to go to its "memory" to get the measurement taken 2 cm before. Under the circumstances this is the chest width of the garment that is relevant for sizing and must now be compared with a standard scale, characteristic of this material/style, where the boundary values for each size are defined. This produces a signal for the garment to be sorted at the corresponding sorting station.

The function of the lift neck device is also described in section 4.6. This assembly must stay under the neck of the garment, waiting for the signal that will start its upwards movement towards the waist. It becomes evident that the lift neck device must be able to retract, away from the path of the garment when this is moved from the loading to the turning/sizing station. Once the carousel stops and the garment is in position to initiate the turning operation, the "flap" of the lift neck device is engaged to stay under the neck, waiting for the signal that will move it upwards.

The level of the neck when the garment is on the clamp, is not going to be the same for all the garments. Large size garments will have the neck at a lower level than small sizes. A further problem is to decide on the starting level of the "flap" so that the lift neck device is efficient with small and large sizes. The solution seems to be to take a decision based on a "flap" that is at the neck level for the largest size. But this solution would leave a considerable gap between the "flap" and the neck of the garment for the small sizes. Under these circumstances, it is most probable that the rollers reach the shoulders before the neck is sufficiently lifted to provide the necessary alignment of the sleeves. If this is allowed to occur, the turning operation is spoiled. The chosen solution is graphically shown in Fig. 4.42.

4.7.5 The Sorting/Stacking Operation

The size of the garment has been determined during the turning/sizing operation by the process already described. The information on the size of the garment is then passed to the clamp that is still holding the already turned garment. When the carousel is indexed one more step, the garment that has been turned and sized is moved to the sorting station No.1. This sorting station will "read" the sizing information on the clamp and will decide whether this garment must be sorted there or conveyed to the next sorting station by the next indexing step of the carousel. Eventually the size of the garment will match with one sorting station and the sorting/stacking mechanism will be activated.

As was established on the requirements of the project, the garments must be sorted and stacked in piles of the same size. When thinking about stacking, the first idea is to do it on an horizontal flat surface. However, spending some time around the idea, the conclusion is that this is likely to be the most difficult solution. Fig. 4.43 sketches three different stacking methods. The method represented in Fig.4.43 b) has been suggested by the procedure observed during the manual turning described in section 2.5. This solution poses some problems; the garments have to be placed with some accuracy, so that the centre of mass is vertically in line with the bar. As the pile increases in thickness, the situation gets worse, with the tendency for the garments to slide off. The situation could be improved to a certain extent by covering the bar with a high friction material to increase the ability to retain the garments.

Fig. 4.43 c) represents an evolution of the previous idea, where the sliding off problem is solved by increasing the projected area of the stack. Again, this angled shaped stacker should be covered with an adequate material to retain the garments by friction, especially the first of the stack.

In order to account for increasing pile heights, the stacker can be mounted on springs that will compress incrementally as the pile becomes heavier, thus keeping the top of the pile at a reasonably constant level.

The stacking of the garment can now be easily achieved and is illustrated in Fig. 4.44. At the end of the turning operation, the garment is still on the clamp, held by the waist and hanging vertically, thus being straightened by the effect of gravity. When the indexing movement of the carousel brings the garment to its sorting station, it will be there in the position shown in Fig. 4.44 a), for the same amount of time that another garment will be in the turning station. The stacker is then engaged, moving forward towards the garment and passing the vertical plane of the waist (Fig. 4.44 b). The stacker stops and the clamp releases the waist that falls on the other side of the stacker (Fig. 4.44 c). Finally the stacker returns to the waiting position to allow for the indexing rotation of the carousel. The safety of passers-by is achieved by this arrangement, due to the presence of the stackers between them and the carousel.

4.7.6 The "Flinger"

When the garment is in the final stage of the turning operation, the arms, whose rollers are still holding the cuffs, are moving away from the clamp which still holds the waist band. During this phase, but depending on the size of the garment, the reversing operation will reach the sleeves and finally the cuffs that will come off the arms. When this situation arises, the sleeves and body of the garment will fall down by the action of the gravity. As the sleeves are vertically in line with the still clamped waist, it is necessary to provide means to ensure that both sleeves and body of the garment fall to the outside of the carousel. Only in this situation will the garment be straightened as is needed to successfully carry out the sorting/stacking operation.

It is the author's opinion that this problem should be raised now, even if, at this stage, it is not essential to reach a solution that can be devised by having an external mechanical device, timed with the other mechanisms, which will be responsible for flinging the sleeves and body of the garment towards the outside of the carousel.

4.8 Kinematics and Dynamics of the Turning Movements

4.8.1 Introduction

The numbering introduced in section 4.7.2 to identify the different movements, is valid throughout this section. The movements related to the turning/sizing operation are those with numbers 1, 2, 3, 6 and 7. However, only those numbered 1, 2 and 3 are going to determine the time scale of the turning/sizing operation. They are respectively, the vertical reciprocating movements of the arms, clamp and lift neck device.

4.8.2 The Model and Kinematic Law of the Movements

Due to the similarity of these three movements, the model of Fig. 4.45 applies to all of them. It represents a vertical falling and vertical rising solid body. In this situation Newton's second law, mathematically expressed by

$$\sum F_z = m \cdot a_z \qquad (4.2)$$

where $\sum F_z$ = sum of external forces in the vertical direction
m = moving mass
a_z = acceleration in the vertical direction

can be applied.

Equation (4.2) can be rearranged according to the falling or rising situation. P is the applied thrust and W is the weight of the moving elements.

Falling body:

$$P - W = m(-a_z)$$

or, because W = mg, where g is the acceleration of gravity,

$$P = m(a_z - g) \qquad (4.3)$$

Rising body:

$$P - W = m\, a_z$$

or, because W = mg,

$$P = m(a_z + g) \qquad (4.4)$$

Equation 4.4 represents the situation where the actuator responsible for each movement is under heavier demanding conditions. In order to establish the thrust P, it is necessary to make some preliminary sums to work out the mass of the moving parts for each movement. This is carried out in Appendix 2. According to the same equation, it is also necessary to know the acceleration of the body in the direction of the thrust (a_z), being g the acceleration due to gravity. To know a_z it is necessary to have sufficient knowledge about the kinematic law of the movements. Also, the law of each movement cannot be completely separated from the actuator and mechanism that provide the respective motion.

A realistic type of motion is one named here as "modified constant velocity". It is graphically represented in Fig. 4.46 a), being a realistic development of the constant velocity motion of Fig. 4.46 b). In these figures, displacement (s), velocity (v) and acceleration (a) are plotted against time (t) in a superimposed representation. The "modified constant velocity" motion has an initial acceleration followed by a period of constant velocity and a final deceleration before stopping.

4.8.3 Investigation into Suitable Actuators for the Turning Movements

The movements under consideration require a relatively long travel, being of 1 m for the arms and clamp and nearly 0.5 m for the lift neck device. Initially, the author did not want to exclude any reasonable possibility and it must be said that the choice was quite vast: Hydraulic or pneumatic linear actuators directly driving the assemblies; Electric DC servo motors or hydraulic or pneumatic rotary actuators, using driving mechanisms like lead or ball screw and nut, rack and pinion, chains and sprockets or timing-belts and pulleys. The main factors that were taken into account when making the decision were simplicity, required power, cleanliness and occupied space.

From the simplicity standing point, pneumatic or hydraulic linear actuators represent the best choice, as they can directly drive the load without the need for any intermediate mechanism.

According to Deppert[27], in terms of power requirements and cleanliness, pneumatic actuators are a better proposition for this application. Hydraulic actuators are advisable for high thrusts which is not likely to be the situation in any of the movements. In case of leakage, the use of hydraulic fluid would certainly cause damage to the garments beyond repair. Still referring to Deppert, pneumatic actuators are applicable if high accelerations and decelerations are required, as well as high speeds. Hydraulic actuators are much slower but more speed controllable, which is not an essential feature in this case.

In terms of space, both conventional hydraulic and pneumatic linear actuators have the inconvenience of requiring a space that is twice the stroke provided. This problem has been eliminated with recent designs of the rodless type pneumatic actuators. Appendix 1 guives a summary of the main characteristics of some commercially available rodless pneumatic linear actuators.

4.8.4 Selection of the Linear Actuators

From the various available designs, the decision was taken to select the FESTO-DGO linear drive, capable of speeds up to 2 m/sec, based on the following advantageous characteristics:

1. It is an hermetically sealed system. The piston moves inside the cylinder and transmits its motion in a non-positive form to the external sleeve by means of a magnetic coupling. That means the system does not leak and is, therefore, energy saving.

2. It is equipped with end position damping which can be adjusted at both ends.

3. It can work with filtered non-lubricated compressed air which maintains a clean environment for both the operator and the garments.

Motion No.1: The turning arms assembly.

s_1 = 1 m
m_1 = 5 Kg (see Appendix 2)

According to the manufacturer, speeds of up to 3 m/sec are attainable, but 2 m/sec is recommended not to be exceeded. In this application, it is assumed an average working speed of 1 m/sec, with eventual top speed not exceeding 1.5 m/sec.

Assuming an acceleration time t_1 (see Fig.4.46 a) of 0.2 seconds to reach a top speed of 1.5 m/sec, and using equation $a = v/t$, applicable to constant accelerated rectilinear motion[28], the value for the acceleration is $a = 7.5$ m/sec^2. Using now equation 4.4, with $m_1 = 5$ Kg, $a_{z1} = 7.5$ m/sec^2 and $g = 9.8$ m/sec^2, the required thrust, using a factor of 2 is,

$$T = 5 \times (7.5 + 9.8) \times 2 = 173 \text{ N}$$

Festo DGO 25 (4.15), with a piston diameter of 25 mm will supply 213.6 N at 6 bar pressure. That means that a higher acceleration can be provided or the working pressure can be reduced if necessary.

Using equation $s=v^2/2a$, also applicable to constant accelerated rectilinear motion, it is possible to know at what distance from the start, the maximum speed is reached.

$$s = 1.5^2/(2 \times 7.5) = 0.15 \text{ m}$$

According to the manufacturer's catalogue[29], the moving mass of this actuator is 2 lbs, (approximately 0.9 Kg), which is below the mass of 1 Kg assumed in Appendix 2.

Motion No.2: The clamp assembly.

For the actuator responsible for the vertical reciprocating movement of the clamp, two main distinct designs are envisaged. One consisting of one actuator per clamp, the actuator being attached to the carousel structure. This solution implies that 8 actuators are needed on the carousel, and they will only work positively when the clamp is at the turning station. When at any of the other stations, the actuator will be stationary, just keeping the clamp at the top level. The other drawback of this design is the need for a complex control system for the actuators, as well as a very complex network of rotary valves to connect the piping from the outside to the carousel. Also, the extra mass of the actuators and valves would have to be taken into account.

These are enough reasons to consider another solution. That could be a single actuator attached to the stationary structure of the turning station. The clamp would be kept at the top level by a "latching" mechanism and when moved to the turning station, would engage with the actuator at the same time that the latch is released. The clamp would be pushed down and, when taken back to the top level, it would latch again, ready to be indexed to the first sorting station.

According to Appendix 2, the clamps mass is $m_2 = 4$ Kg. In this situation, the selection of the actuator follows the same lines of the previous one. The final decision will be made at the optimization stage.

Motion No. 3: The lift neck device assembly.

$s_3 = 0.475$ m
$m_3 = 2.5$ Kg (see Appendix 2)

As explained in section 4.7.4, the lift neck device must be capable of a fast response. Based on the garment dimensions, it is assumed that, after having detected the armholes, the rollers will travel, for the smallest sizes, 0.15 m before they establish contact with shoulders. By the reasons already explained, this situation has to be avoided, otherwise the turning operation is immediately spoiled. Assuming that during the downwards stroke, the maximum speed of the arms is 1 m/sec, that means an elapsed time of 0.15 sec. If, after this amount of time, the lift neck device is required to have moved 0.15 m to provide sufficient alignment of the sleeves, the necessary acceleration can be found using equation $a = 2\ s/t^2$.

$$a = 2 \times 0.15/0.15^2 = 13.3\ m/sec^2$$

Applying again equation 4.4 with a factor of 3 to allow for the very fast acceleration, the required thrust is,

$$P_3 = m_3(a_{z3} + g) \times 3$$

$$= 2.5 \times (13.3 + 9.8) \times 3 = 173.5\ N$$

The same FESTO DGO 25 actuator is applicable, again with enough spare power if needed, or working at a reduced inlet pressure.

4.9 Preliminary Kinematic and Dynamic Analysis of the Carousel

4.9.1 Introduction

The maximum number of sizes possibly present in one batch is 6, so is the common number of adult sizes of men's and women's garments (section 4.3). This must be the number of sorting stations unless otherwise stated by a particular customer. According to the layout of the full concept, there are also the loading and the turning/sizing stations. Hence, a total of 8 stations and consequently, 8 clamps equally spaced on the periphery of the carousel are required. Therefore, each indexed step must move the carousel through 45 degrees.

4.9.2 The Model and Kinematics of the Movement

The carousel is envisaged as a substantially prismatic frame, having 8 clamps on its periphery with the capability to slide vertically from the top to the bottom position through a linear displacement of 1 m (see Appendix 2, section A2.4). In a simplified form, the carousel can be assumed as a rigid body in rotation about a fixed axis that passes through its centre of mass. In this situation, Newton's second law can be again applied, now mathematically expressed by

$$\sum M_z = I_z . \alpha \qquad (4.5)$$

where $\sum M_z$ = sum of the external moments applied to the body around the axis z of rotation

I_z = mass moment of inertia

α = angular acceleration

The model of Fig. 4.47 is a simplification of the prismatic structure of the carousel. At this preliminary stage, and because most of its mass is going to be concentrated near the periphery, it is admissable to visualize it as a circular cylindrical shell, being in this case, $I_z = m.r^2$. As in this situation the only external moment applied to the carousel is the torque T, and considering the expression for the moment of inertia, equation 4.5 becomes,

$$T = m.r^2.\alpha \qquad (4.6)$$

In order to establish the required torque to apply to the carousel, it is necessary to make some preliminary calculations to work out its mass. According to equation 4.6, it is also necessary to know the angular acceleration as well as to have a reasonable idea of its shape and size in order to make a good estimate of a value for the radius of gyration, r.

The "modified constant velocity" motion is going to be assumed for the indexed rotation. In Fig. 4.48 the angular displacement (θ), angular velocity (ω) and angular acceleration (α) are plotted against time (t) in a superimposed representation.

4.9.3 Preliminary Selection of the Indexing Drive

Based on the design proposed in Appendix 2, section A2.4, the selection of the indexed drive can be carried out. In order to give flexibility to the system, the indexed movement of the carousel must be initiated by an external signal which is produced when: The arms have fully returned to their top level; the operator is outside a dangerous area defined by photo sensors; a new garment is on clamp; and the stacker has fully returned.

By this mode, the ergonomic position of the operator is more comfortable because the speed of the machine is flexible and adjustable to his/ her performance, which can vary during the working day.

The driving system comprises an electric motor driving a speed reducer through a clutch-brake combination.

Angle of rotation $\theta = 45^{\circ} = \pi/4$ rad

As the mass of the carousel is considerable (83 Kg, Appendix 2-A2.4), a long indexing time of 2 seconds is assumed to minimize power requirements. In this case,

$$\omega_{ave} = \pi/8 \text{ rad/sec}$$

$$= 0.393 \text{ rad/sec}$$

Assuming, on the basis of an average velocity of 0.393 rad/sec, a maximum velocity $\omega_{max} = 0.5$ rad/sec, that is,

$$N_{max} = 0.5 \times 30/\pi = 4.8 \text{ rpm}$$

and a speed at full load for the motor of 1000 rpm, the speed reducer ratio R is,

$$R = 1000/4.8 = 208.3$$

Taking $R = 1:200$

That means $N_{max} = 1000/200 = 5$ rpm and

$$\omega_{max} = 5 \times \pi/30 = 0.523 \text{ rad/sec.}$$

Assuming a relatively long acceleration time of 0.2 seconds in order to maintain the steadiness of the garments and using equation $\alpha = \omega/t$ to express the angular acceleration as a function of the angular velocity and time, it is possible to work out the required acceleration for the carousel,

$$\alpha = 0.523/0.2 = 2.6 \text{ rad/sec}^2$$

From the geometry of the carousel, a radius of gyration of 0.7 m is assumed. This corresponds to the periphery of the prismatic structure, where most of the mass is concentrated. The clamp pads and the garments are 0.3 m away from the lateral faces of the prismatic structure, giving an overall diameter of about 2 m for the carousel. Applying now equation 4.6,

$$T = 83 \times 0.7^2 \times 2.6 = 106 \text{ Nm}$$

is the required torque on the shaft of the carousel. The torque on the motor is, therefore,

$$T_{motor} = 106/200 = 0.529 \text{ Nm}$$

On the following calculations, the Warner Electric catalogue[30], is used as an example of clutch-brake selection. The catalogue is presented in the foot-pound-second (FPS) system, so, some conversions are necessary.

$$T_{motor} = 0.529 \times 0.738 = 0.39 \text{ lb.ft}$$

Using a factor of 2 to account for extra masses on the carousel and friction forces, T = 0.78 lb.ft. According to Warner Electric[30],

P = T x N/5250 where

P = power in HP
T = torque in lb.ft
N = speed in rpm

P = 0.78 x 1000/5250
= 0.15 HP

The 250 Electro Pack is recommended for this application using 1000 rpm and 1/6 (0.166) HP.

The accuracy of the indexed movement can be achieved using 8 pins equally positioned around a circumference connected to the carousel shaft. A magnetic pick-up senses one pin and sends a pulse to the control unit which switches the brake on, clutch off. Another signal will be responsible for the start of a new indexing step, sending another pulse responsible for brake off, clutch on.

4.10 The Machine Cycle

From the analysis carried out in sections 4.7 an 4.8, an average speed of 1 m/sec can be assumed for the movements of the arms, lift neck device and clamps. For the carousel indexing rotation, 2 seconds per step is initially admitted, bearing in mind that, providing no disturbance is created to the steadiness of the garments during the turning and stacking operations, this time can certainly be cut down.

That analysis leads to the displacement-time diagram of Fig. 4.49. The reversing stroke of the arms (going upwards) is carried out simultaneously with the first stroke of the clamp (going downwards). Once the reverse stroke of the clamp starts, the carousel can initiate its rotation, giving a total cycle time of just 4 seconds. However, the only way of finding the limiting speeds, particularly during the turning operation, is by experimentation with a turning and sizing rig. Only then, the behaviour of garment can be analysed under the conditions created by the turning/sizing actuation.

Fig. 4.50 represents a timing diagram for the machine cycle. Four of the movements are not represented because they do not interfere sufficiently with the timing of the machine. They are, referring to Fig. 4.40, movements No. 6, 7, 8 and 9, respectively the swinging movement of the arms, the flap rotation, the clamp pads sideways adjustment and the stacker accommodation to the weight of the stacks.

The timing diagram is useful to visualize the sequence of operations and how they overlap to cut down the overall cycle time. As it was seen in previous section 4.9, the initial part of the carousel indexing rotation overlaps with the upwards movement of the clamp. Because the carousel is only stationary for 2 seconds, movement No.5, the forward-backward movement of the stacker, is confined to be carried out in 1+1 seconds. This will not pose problems, as the corresponding displacement is only 350 mm. Another important point is the time available for the operator to load a garment on clamp. The clamping itself has to be carried out in 2 seconds, the amount of time the carousel is stationary. But in fact, as soon as the operator has finished the loading of one garment, he or she can immediately hold another one while the carousel is moving. When the carousel stops, the operator will have the next garment ready and in position to load. Hence, the operator has 4 seconds to carry out the loading operation.

4.11 Preliminary Economic Assessment

An economic assessment is based on the assumption that one machine being loaded by one operator can deliver one garment on the stackers at a rate of one every 4 seconds. The figures that follow are based on the actual situation of one of the largest European companies specialised in dyeing and finishing of garments.

Their present situation, with tagging and manual turning and sorting can be summarized as follows:

1. Average number of garments to process = 25000 dozens per week;

2. Workforce on the turning and sorting room = 22 operators. Each operator costs to the company (1982 figures), £3 per hour at 8 hours/day, 240 days/year including overheads.

3. The cost of the tagging operation is £425/week, including workforce, overheads and materials, at 48 weeks/year.

4. Cost of Kwh = 4 pence.

For simplicity, the following abbreviations will be used:

G-garment; H-hour; D-dozen; d-day; W-week; Y-year.

If the machine can deliver one garment every 4 seconds, the productivity per day is:

4 sec/G means 3600/4 = 900 G/H or 900/12 = 75 D/H.

Each operator works 8 H/d. Considering 7.5 useful hours of work, with 1/2 hour allowance for breaks, 75 D/H x 7.5 H/d = 562.5 D/d per operator and per machine. To achieve the production of 25000 D/W or 25000/5 = 5000 D/d, the number of shifts required is

5000/562.5 = 8.9

Considering 9 shifts, 3 machines are necessary, being loaded by 9 operators per day. The company works continuously in 3 shifts to minimize the down time of the installation.

After being turned and sized, the garments are sorted and stacked on the 6 sorting stations. When the limit for the number of garments in each stack is reached, the stack must be unloaded from the machine and placed on trolleys, ready to go to the "trimming" room. The unloading operation must be carried out by another operator so that the machine keeps in continuous work. This operator has to be informed when one stack is ready to be taken out of the machine. One way of doing it is by measuring the weight of the garments on the stack by its vertical displacement. Assuming that a limiting weight of 100 N is allowed per stack and that the average weight per garment is 3 N (depending on size, material, humidity), that means 33 garments per stack. The stacker would be adjusted to switch on a yellow light when the load reaches 75 N (approximately 25 garments). This would inform the operator that this particular stack needs unloading. If the stack is not taken out, the signal will change to a red flashing light if the load reaches 90 N and finally will stop the machine if the 100 N limit is reached.

In the very unlikely situation of, after the yellow light has switched on, all the next 8 garments are of this same size, that means, at 4 seconds per garment, a time gap of 32 seconds before the machine is stopped.

Bearing in mind the previous figures, it is assumed an average number of 30 garments per stack. Hence, every 30 x 4 = 120 seconds there is a stack to remove from each machine. With 3 machines to unload, there is a stack to remove every 40 seconds. This is the work to be carried out by the fourth operator. He or she will be assisting the 3 machines, unloading the stacks and placing them in the appropriate trolley. A suggestion is made to use the 4 operators in rotation; each operator would work 3/4 of the day at the loading station and 1/4 of the day unloading the garments.

According to these figures, the proposed semi-automatic operations will require 3 machines and 4 operators per shift, which is to say, 3 machines and 12 operators per 3 shift day.

Comparing now with the present situation, the savings can be worked out:

Savings in workforce:

22-12=10 operators. Each operator costs to the company, including overheads, £ 3/H at 8 H/d and 240 d/Y. That means

3 x 8 x 240 = £ 5760/Y.

For 10 operators the savings are 10 x 5760 = £ 57 600/Y

Savings by the elimination of the tagging operation:

£ 425/W x 48 W/Y = £ 20 400/Y

Running costs:

Assuming 5 KW power consumption, 24 H/d, 240 d/Y at 4 pence/KWh, and 3 machines,

5 x 24 x 240 x 0.04 x 3 = £ 3456/Y or £ 3500/Y.

For a pay back in 2 years, the savings in the same period are:

2 x (57 600 + 20 400 - 3500) = £ 149 000

The cost limit per machine is, therefore:

149 000 : 3 = £ 49 660

It is too early to make a precise estimate for the cost of the final design. Nevertheless, it is the author's opinion that £ 25000 can be assumed as a realistic figure. The feasibility of the concept is therefore demonstrated with a pay back period of around one year.

4.12 Conclusions from the Feasibility Study

A strong concept resulted from the feasibility study, capable of meeting the requirements of the project. The carousel and the sorting/stacking stations, however essential to the success of the whole concept, represent relatively conventional engineering problems. On the other hand, it is on the turning/sizing station where a real innovative process is proposed.

It has been the author's opinion that the research should first progress to the complete development of the sizing technique, in order to verify the basic ideas and methods proposed in sections 4.2.2 and 4.7.4. The sizing of the garments will be carried out while turning and, to some extent, these two functions cannot be separated. Hence, the final step will lead to the building of an experimental rig able to turn and size the garments. The experimental phase necessary to confirm the main stream of the investigations will be carried out, as much as possible, in close co-operation with the industry concerned from where samples of garments must be collected.

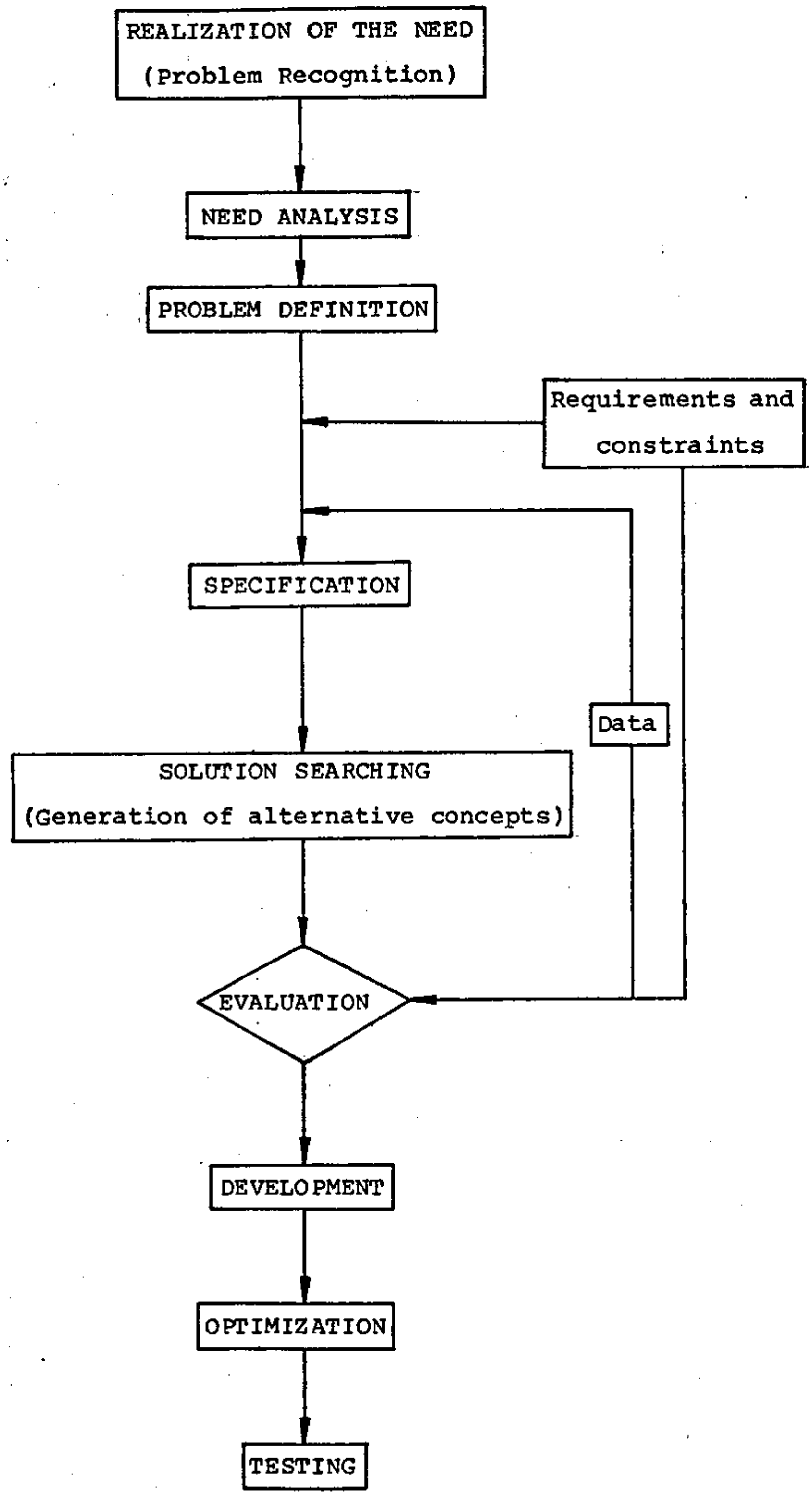


Fig. 4.1- Flowchart of the design process

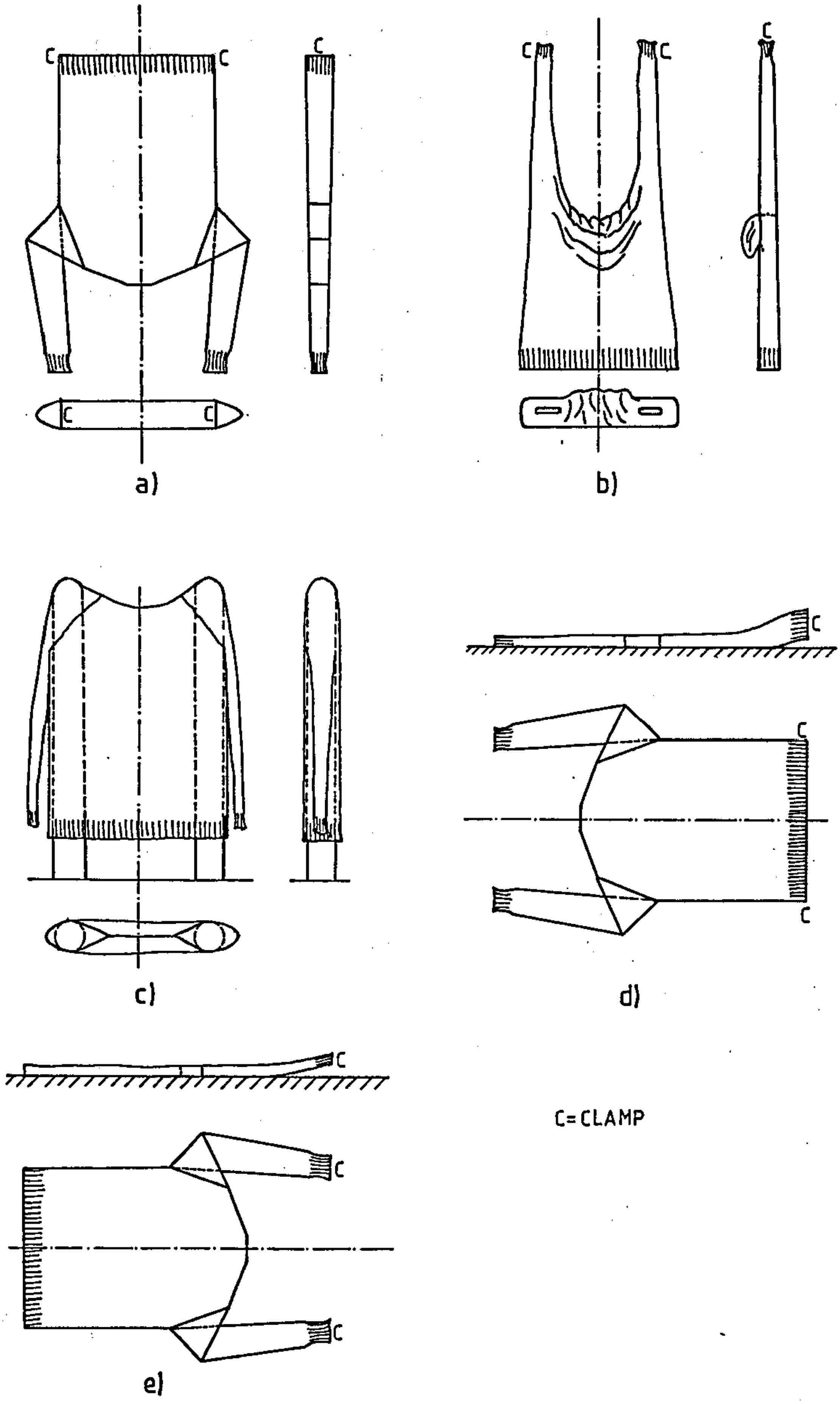
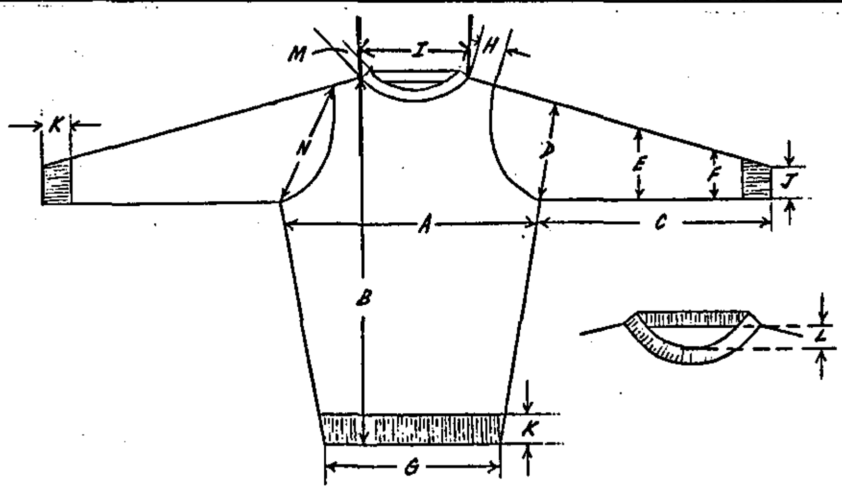


Fig. 4.2 Possible ways of positioning the garment for turning.

Date: 21.10.81	Style No. CH 2206	Specification No.
Manufacturer:	M/c Gauge: 10 g	Yarn: 2/30 Acrylic

Description: Mens L/S C/N – Ski jacquard



To Fit – Cms.								
Inch.	38		40		42		44	
A. Chest – 2·5 cms. Below Armhole	19¼	49	20	51	21¼	54	22	56
B. Length – From Shoulder Point	26	66	27	69	27	69	27	69
C. Underarm – To End of Cuff	18¾	48	18¾	48	19¾	50	19¾	50
D. Sleeve Width – At Underarm	7	18	7	18	7½	19	7½	19
E. Sleeve Width – At 25 cms. from Cuff End	5½	14	5½	14	5¾	14.5	6	15
F. Sleeve Width – At 9 cms. from Cuff End	4	10	4	10	4¼	10.5	4¼	10.5
G. Width at Welt – MID WELT	15¼	39	16¼	41	17¼	44	18¼	46
H. Shoulder Seam	5¼	13	5½	14	5½	14	6	15
I. Neck Width – SEAM TO SEAM	6¼	16	6½	16	7	18	7	18
J. Cuff Width MID CUFF	2¾	7	2¾	7	3	8	3	8
K. Cuff & Welt Depth – 2 × 2 Ribs	3	8	3	8	3	8	3	8
L. Neck Drop – Seam to Top of COLLAR	1½	4	1½	4	1½	4	1½	4
M. Width of Ribbing / Stolling	¾	2	¾	2	¾	2	¾	2
N. Armhole	8¾	22	9	23	9½	24	9¾	25
O. Depth of Polo – Flat								
P. Width of Polo – 5 cms. Above Seam								
Q. Pocket Size – Length x Width								
R.								
S.								
T.								
U.								
V.								
W. Weight Lbs./Kilos Per Doz.								

Fig. 4.3 Typical "size chart".

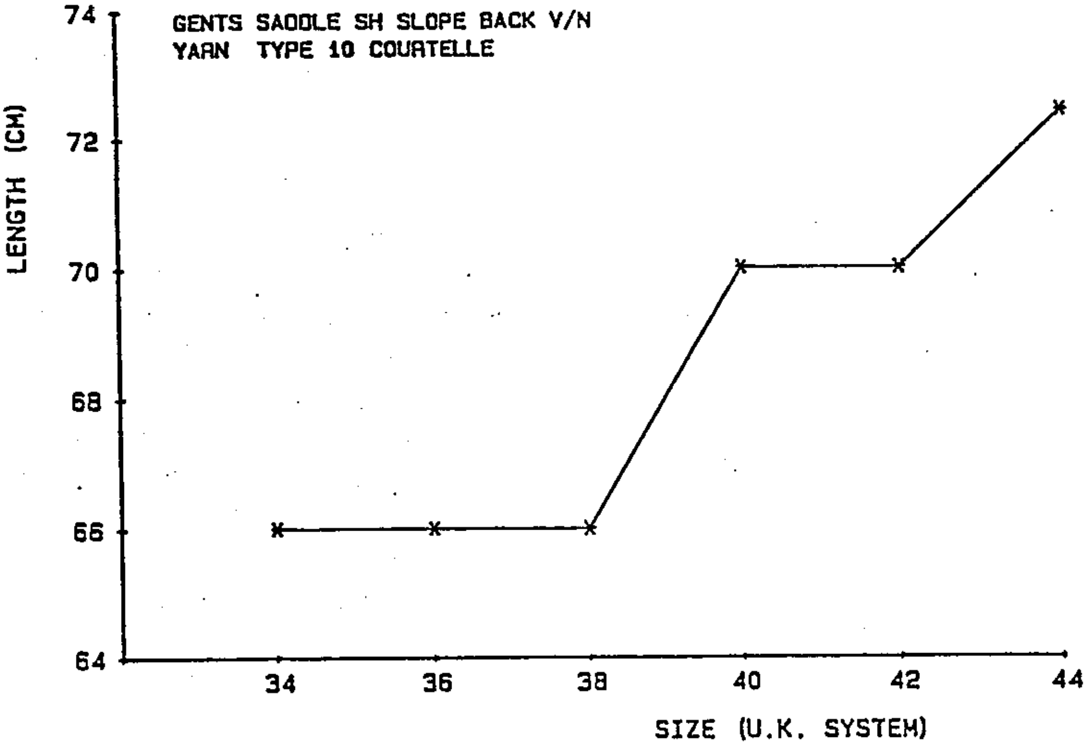


Fig. 4.4 Example of size/length relationship.

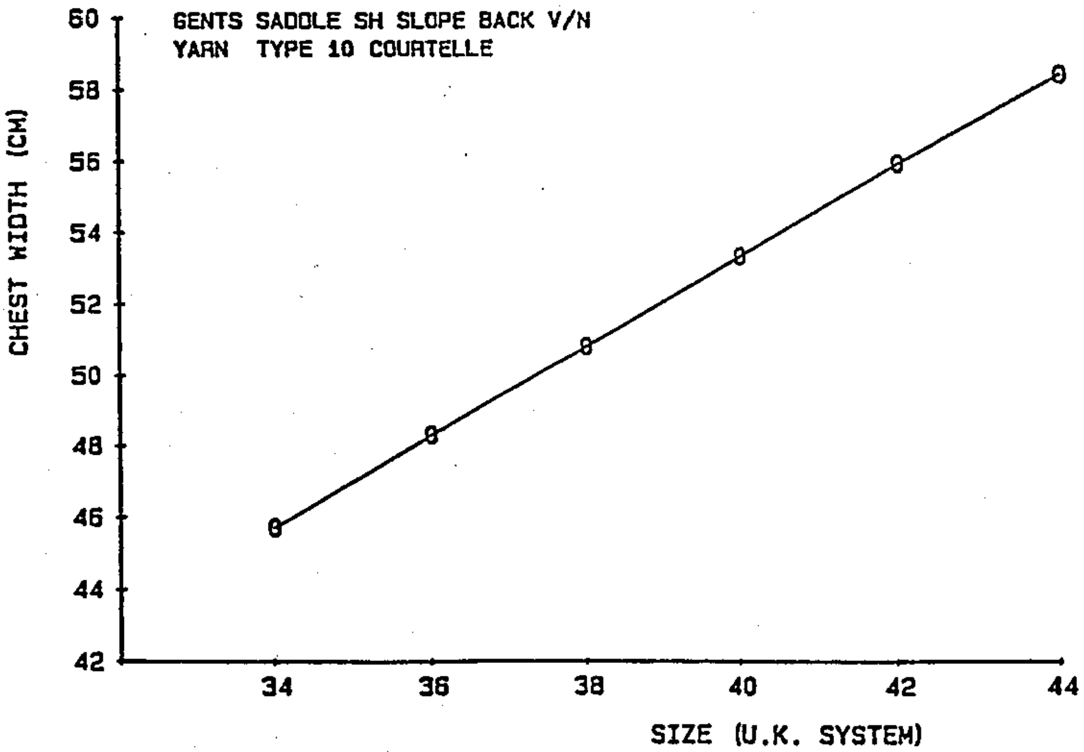


Fig. 4.5 Example of size/chest width relationship.

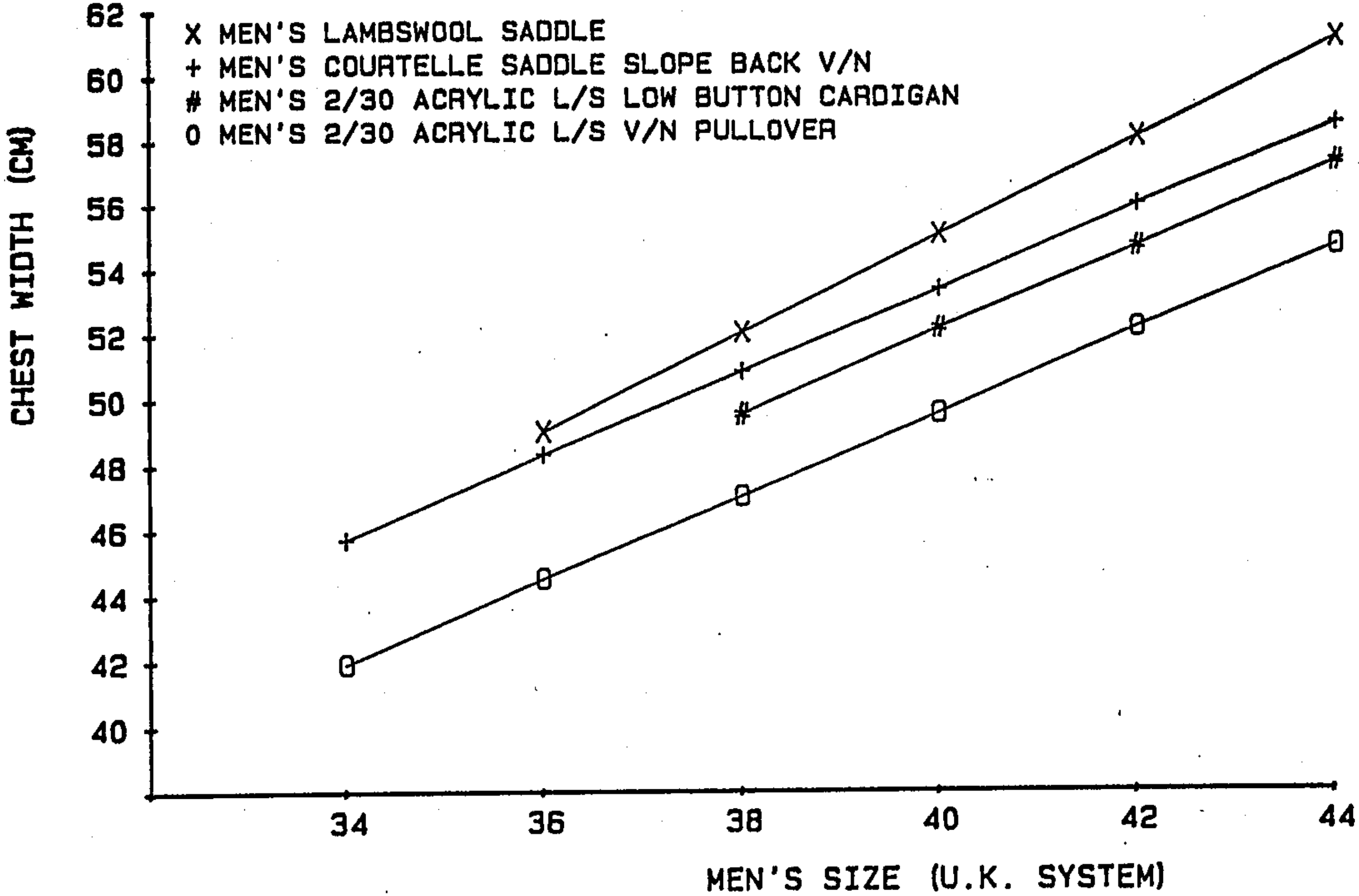


Fig. 4.6 Size/chest width relationship for different materials.

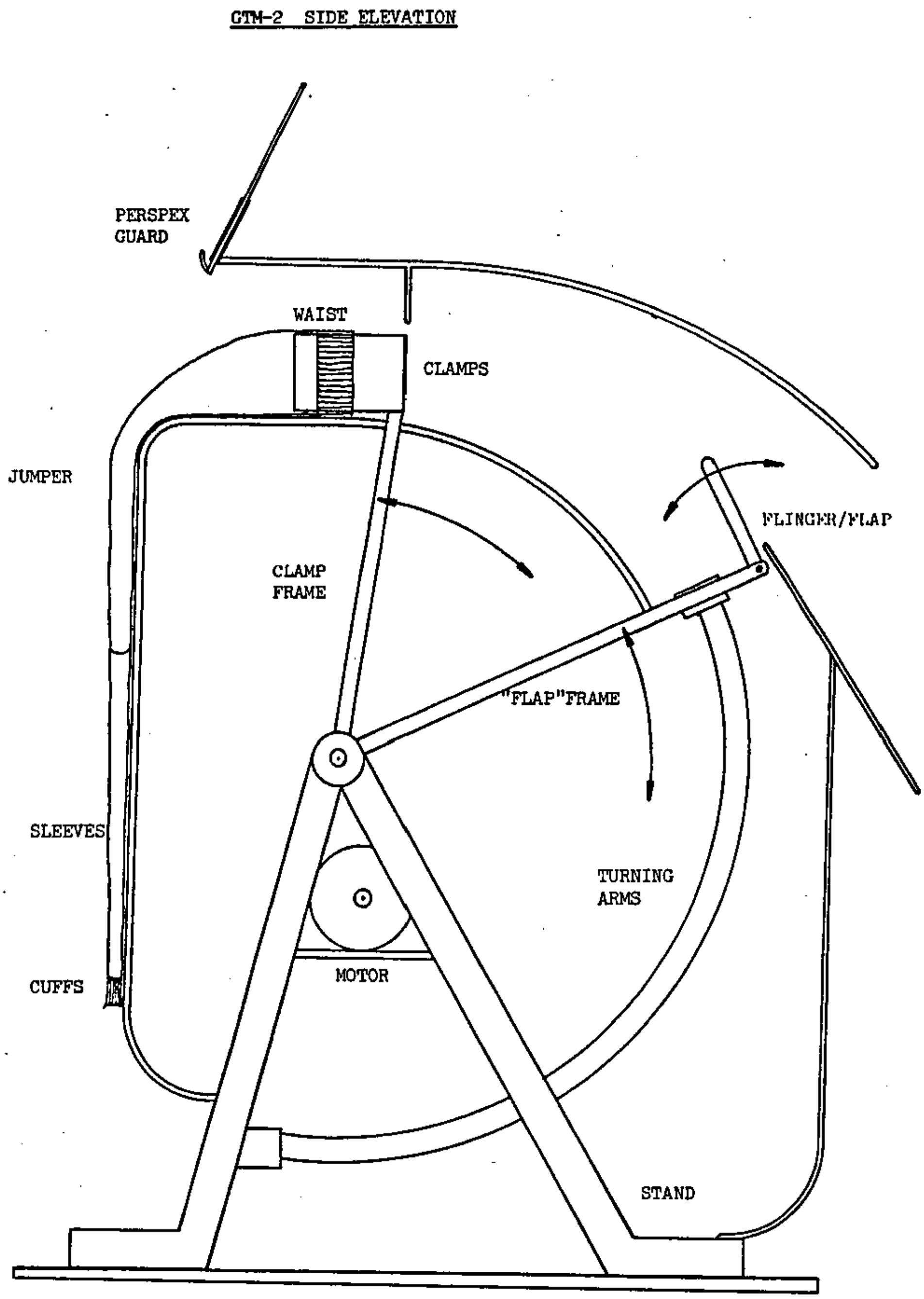


Fig. 4.7 Concept No 1.

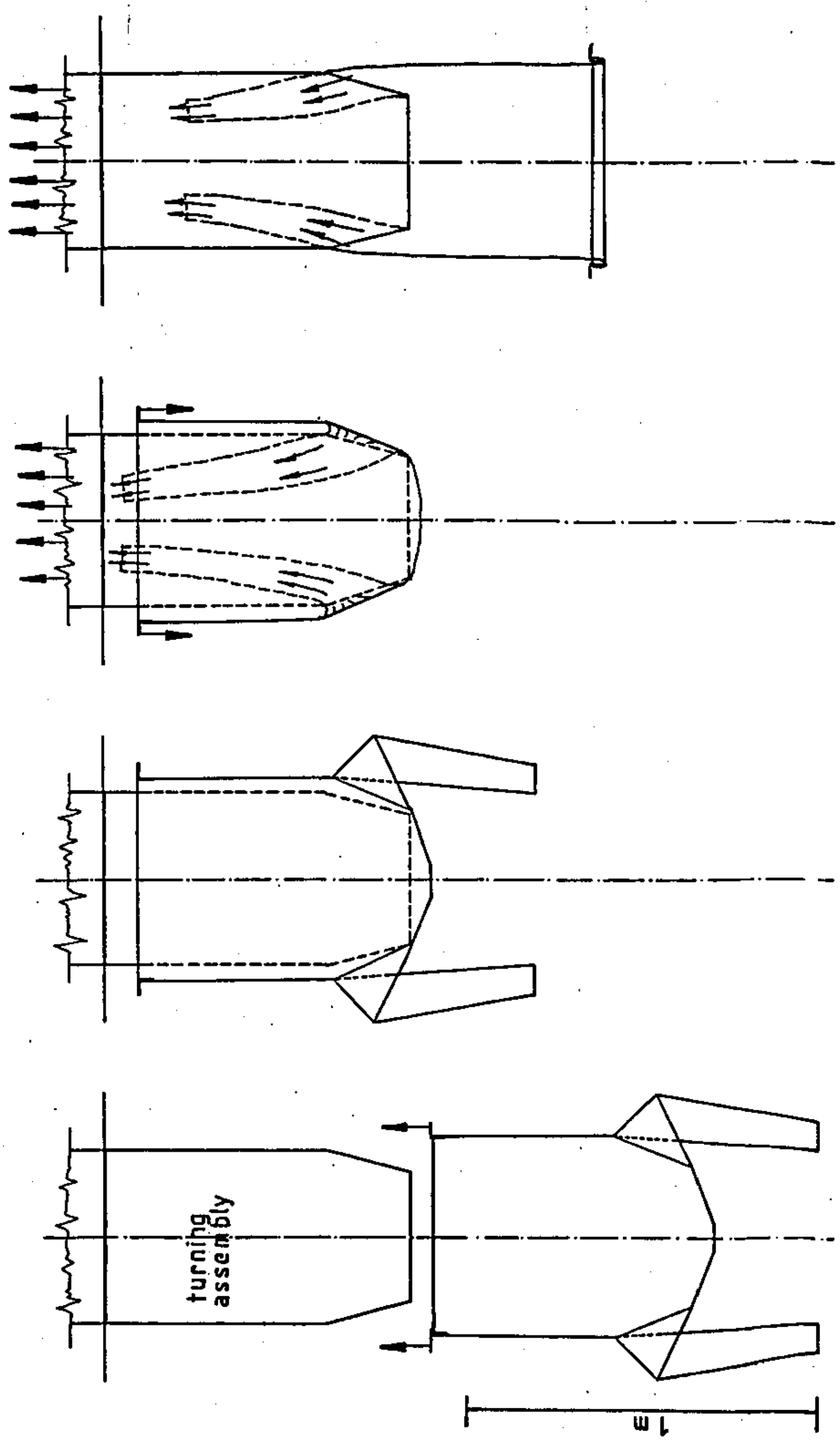


Fig. 4.8 Concept No 2.

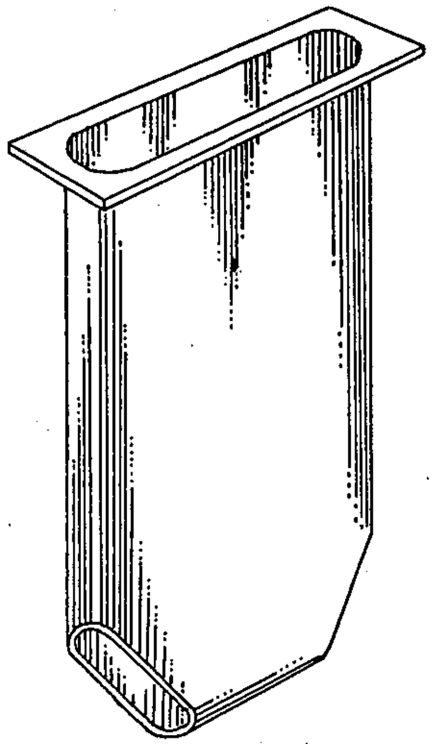


Fig. 4.9 Garment turning assembly.

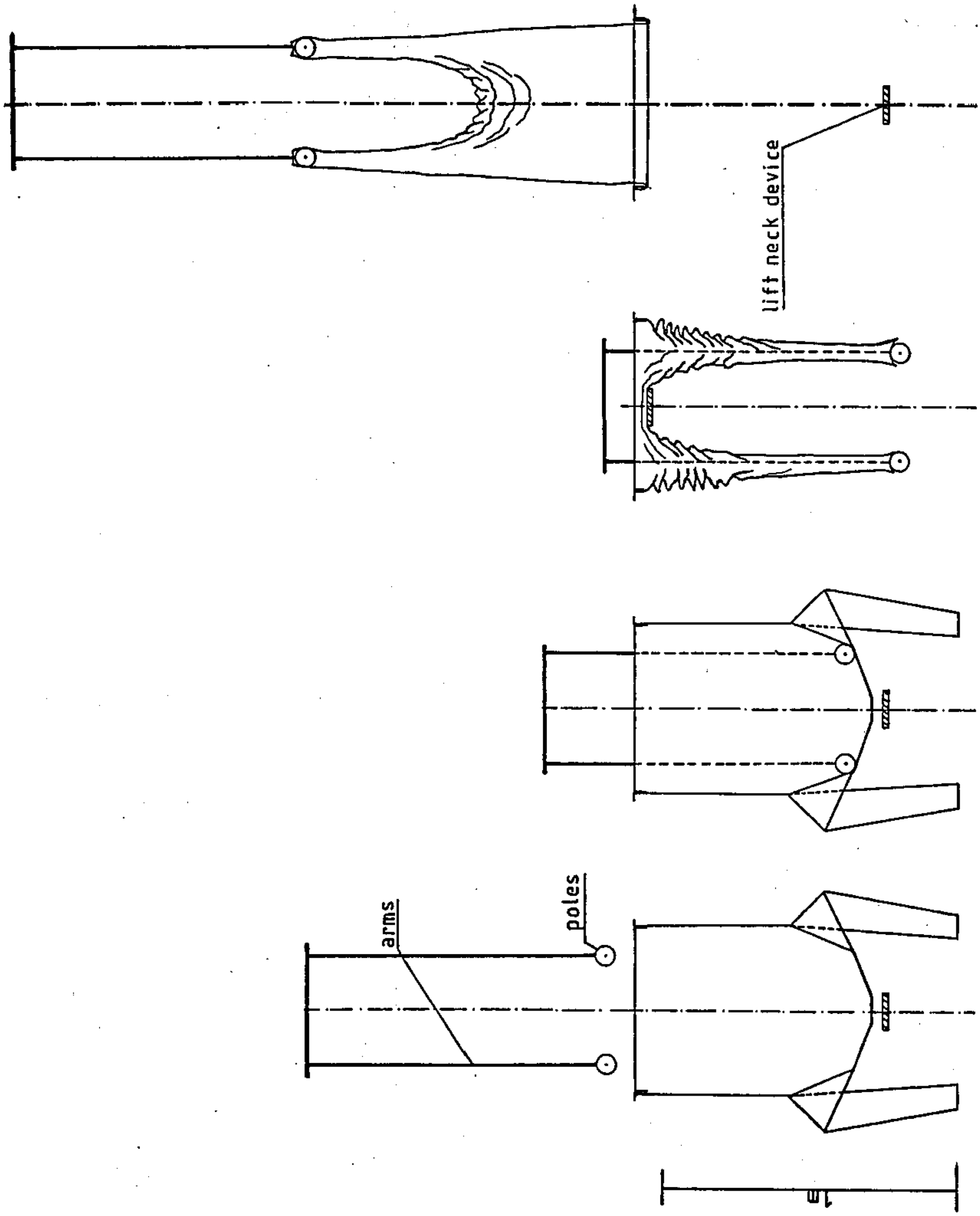


Fig. 4.10 Concept No 3.

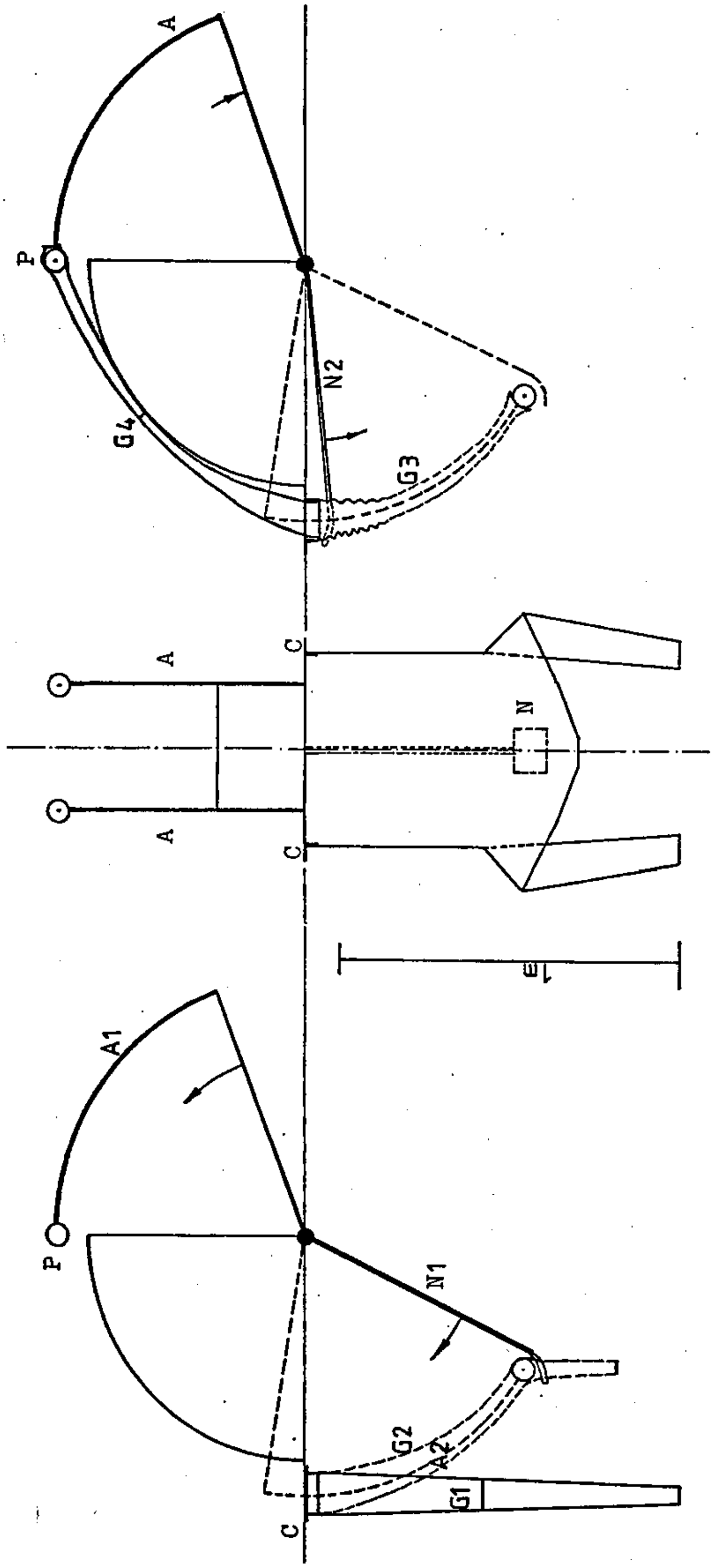


Fig. 4.11 Concept No 4.

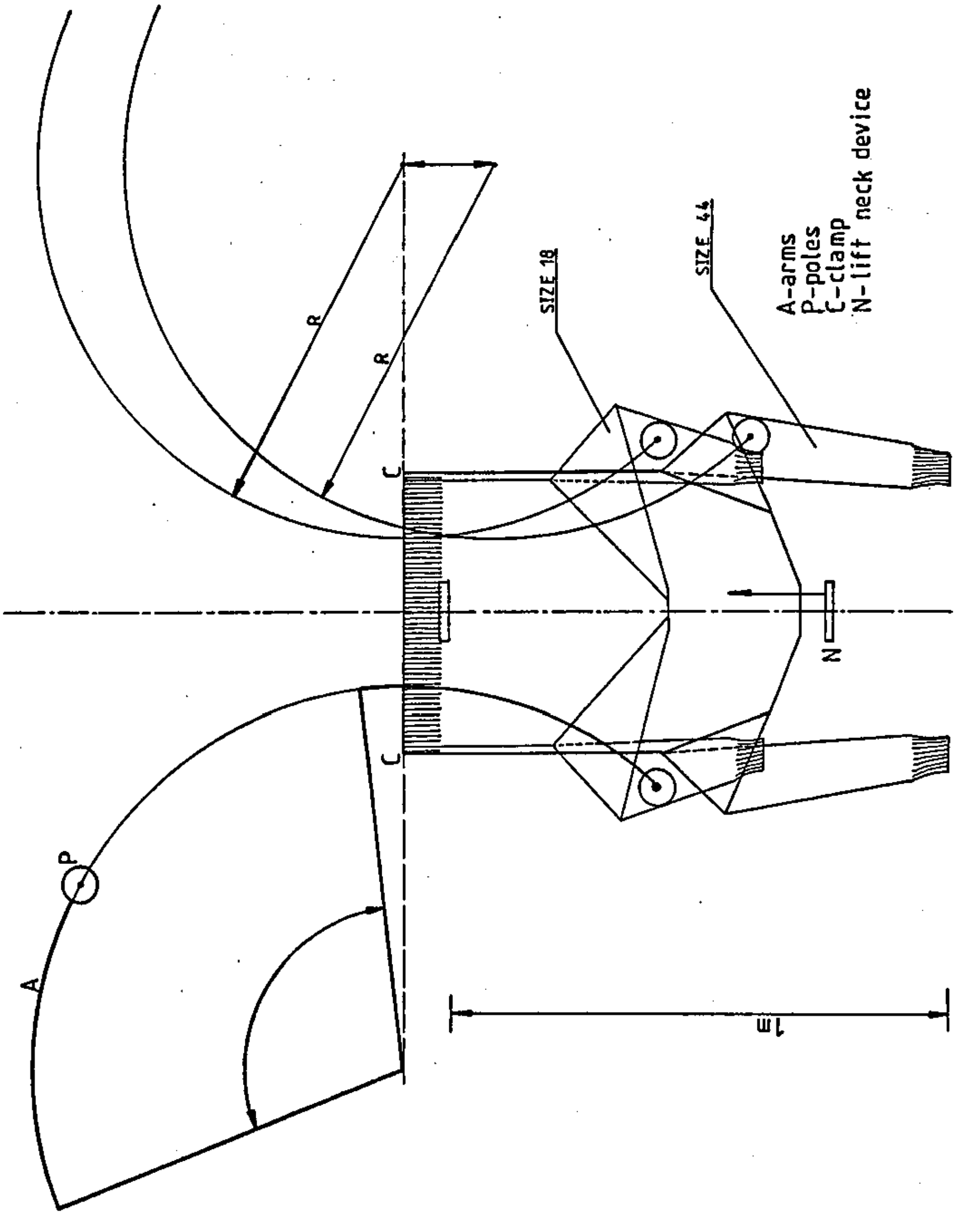


Fig. 4.12 Concept No 5.

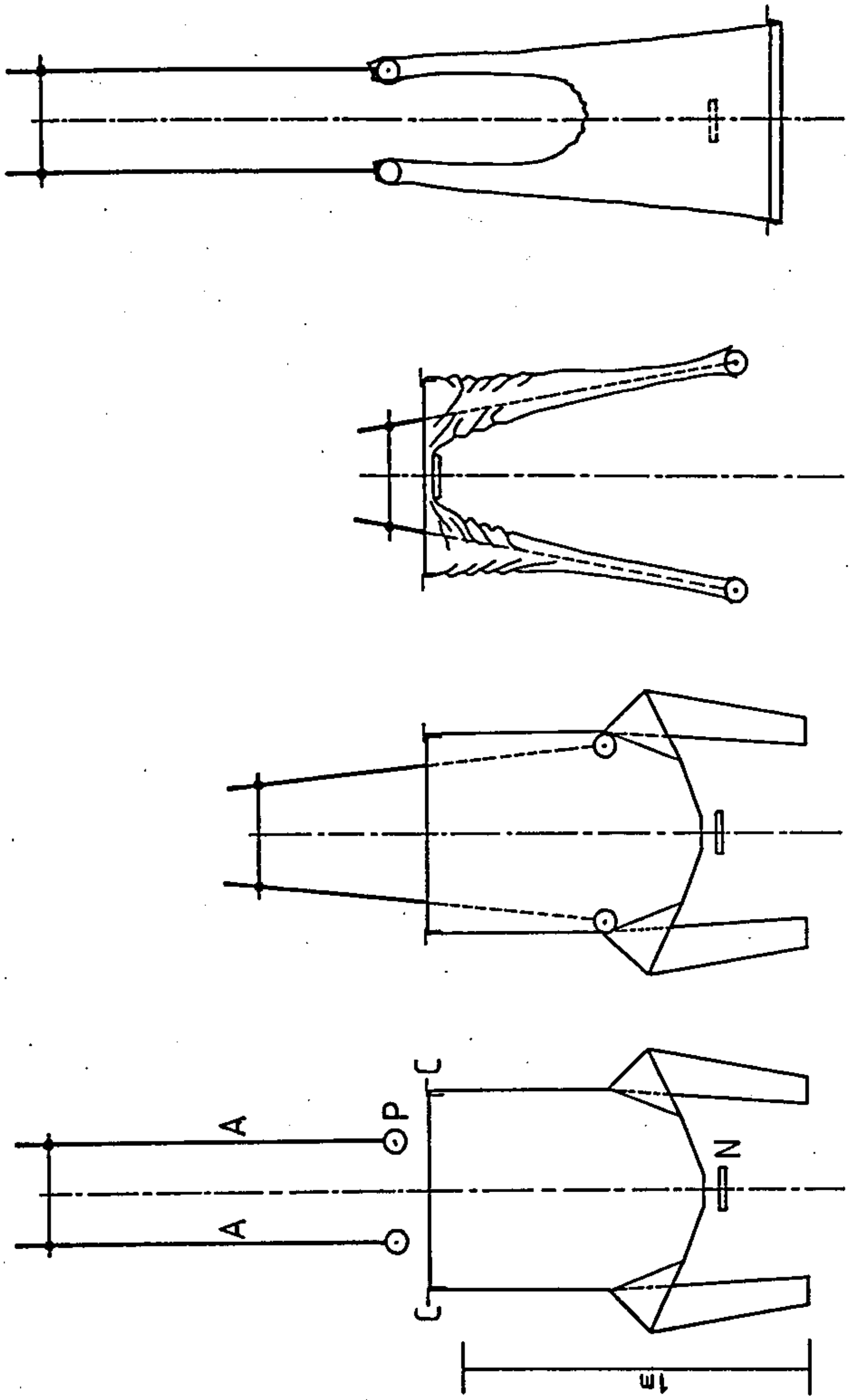


Fig. 4.13 Concept No 6.

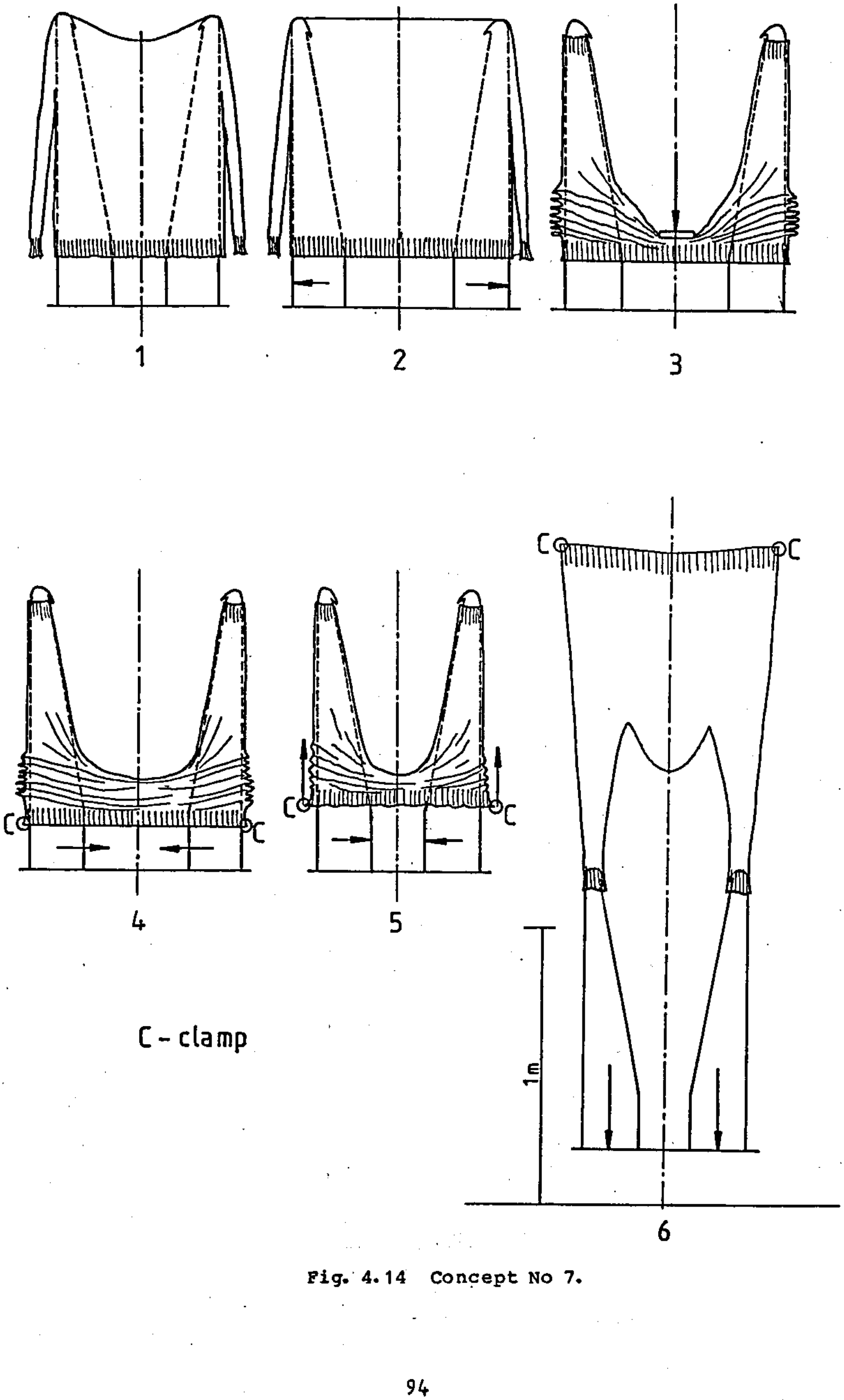
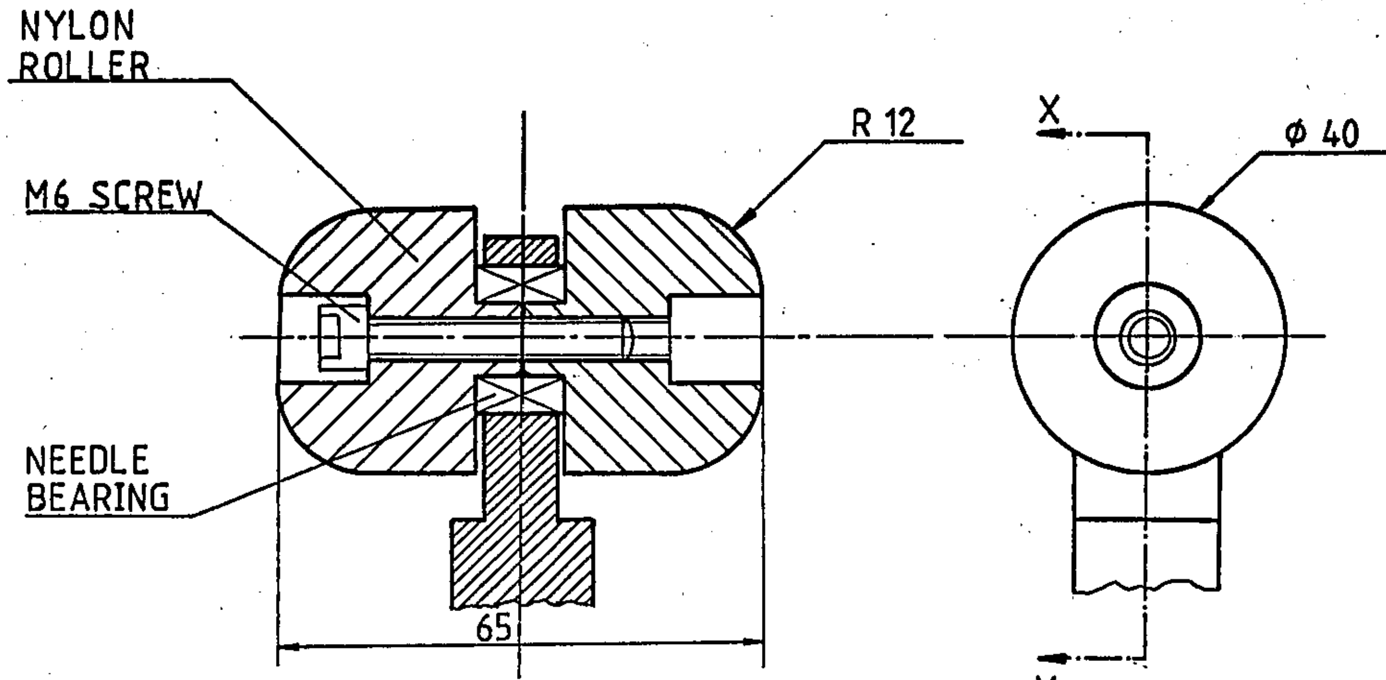


Fig. 4.14 Concept No 7.



SECTION X-X SCALE 1/1

Fig. 4.15 Arm end "Roller"

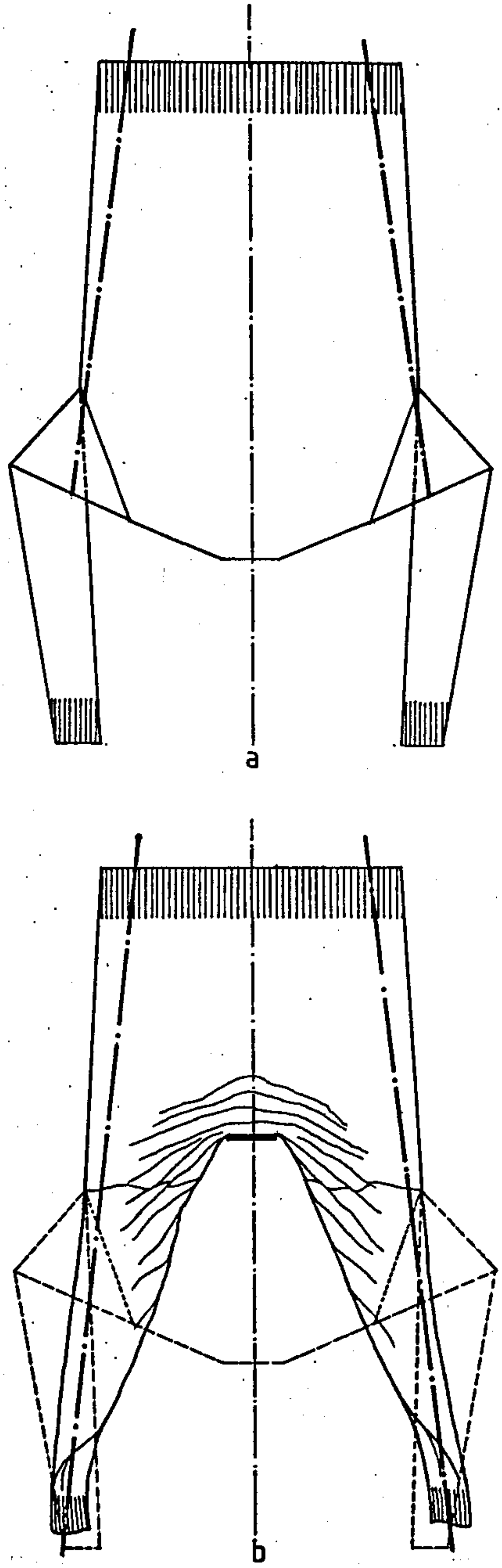


Fig.4.16 Position assumed by the sleeves; a)- before lifting the neck; b)- after lifting the neck.

Fig. 4.17 Close-up of the configuration of the sleeve near the armhole.

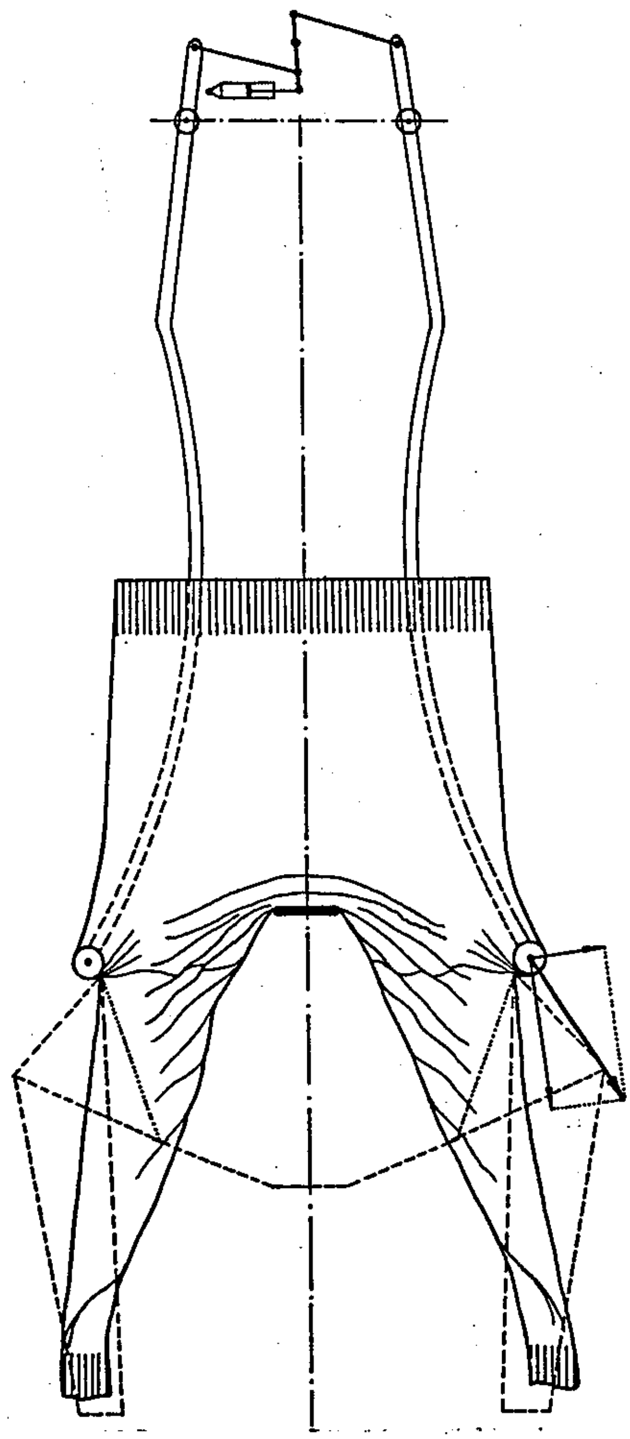


Fig. 4.18 Rollers trapped on "pockets" over the armholes.

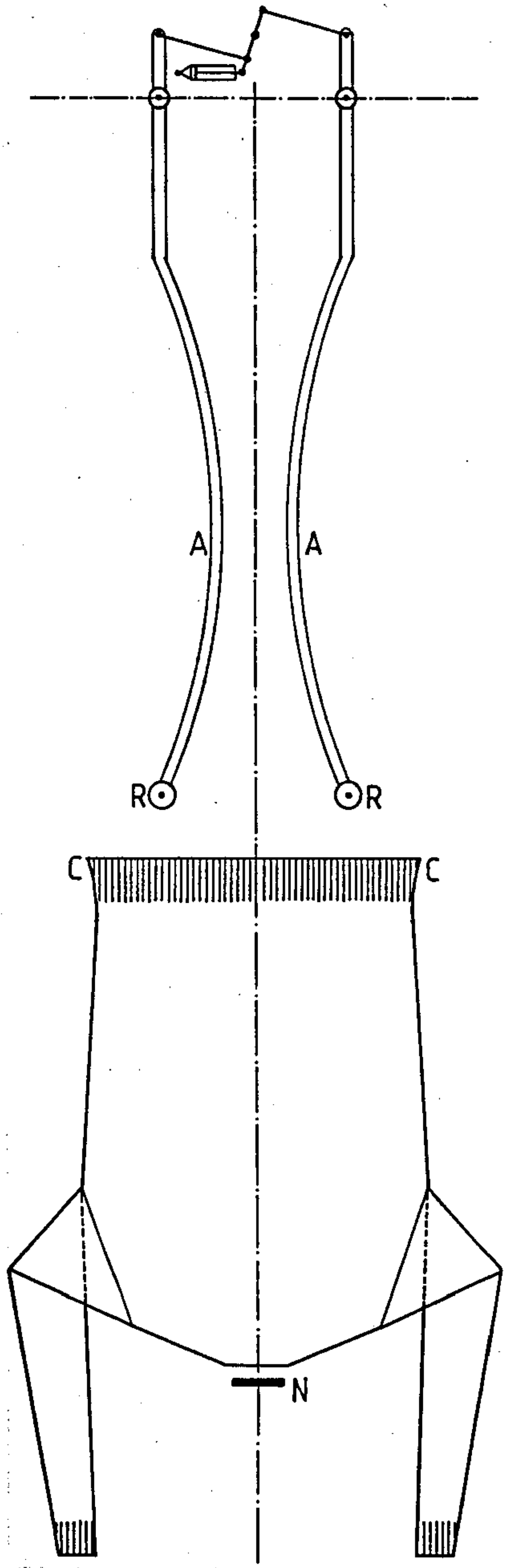


Fig. 4.19 Starting position for the turning operation.

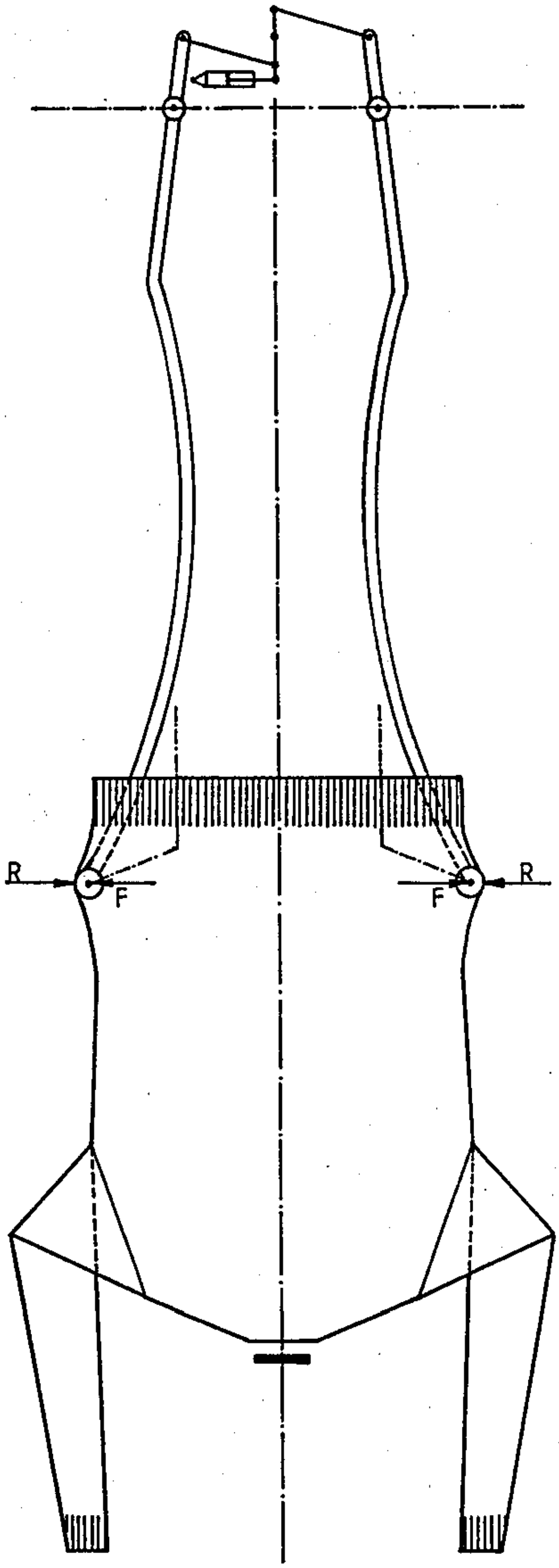


Fig. 4.20 Arms have entered the garment and swung outwards.

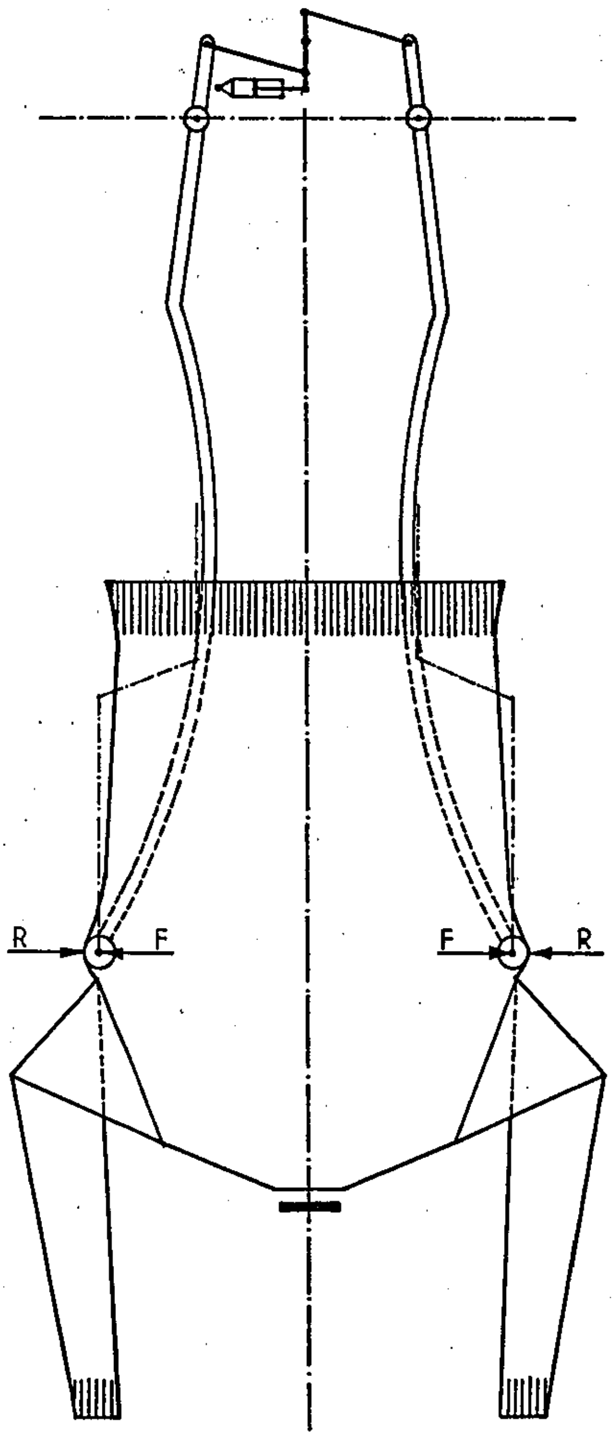


Fig. 4.21 Rollers shown at chest level.

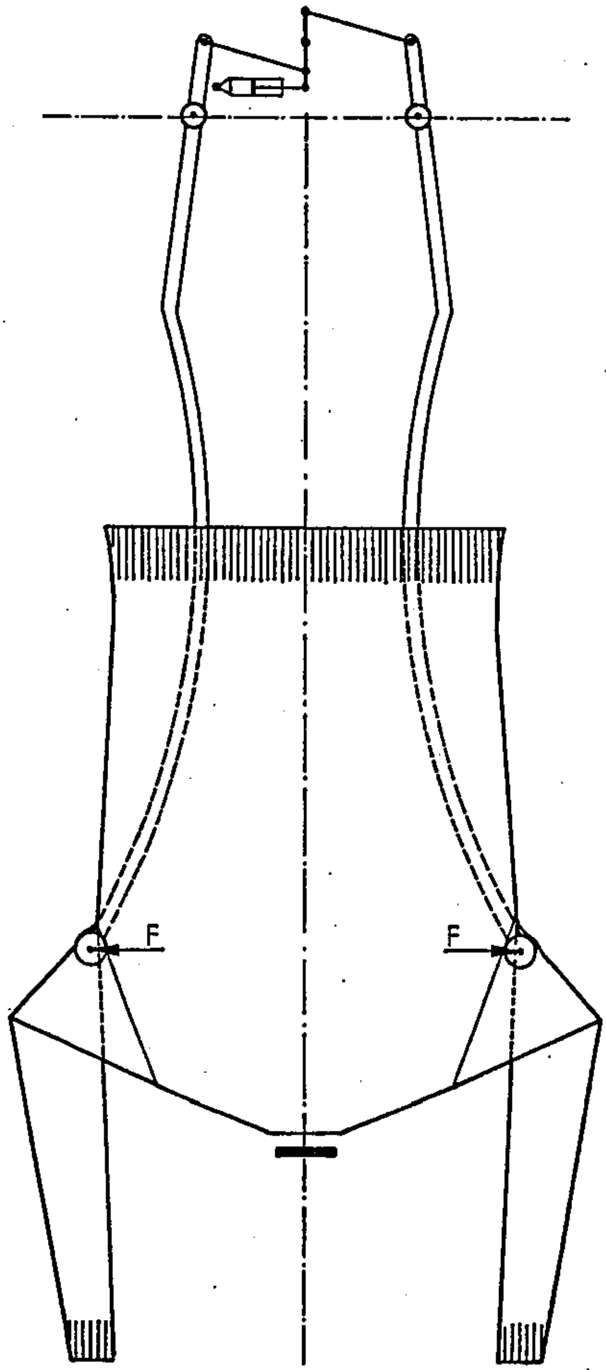


Fig. 4.22 Rollers shown entering the armholes.

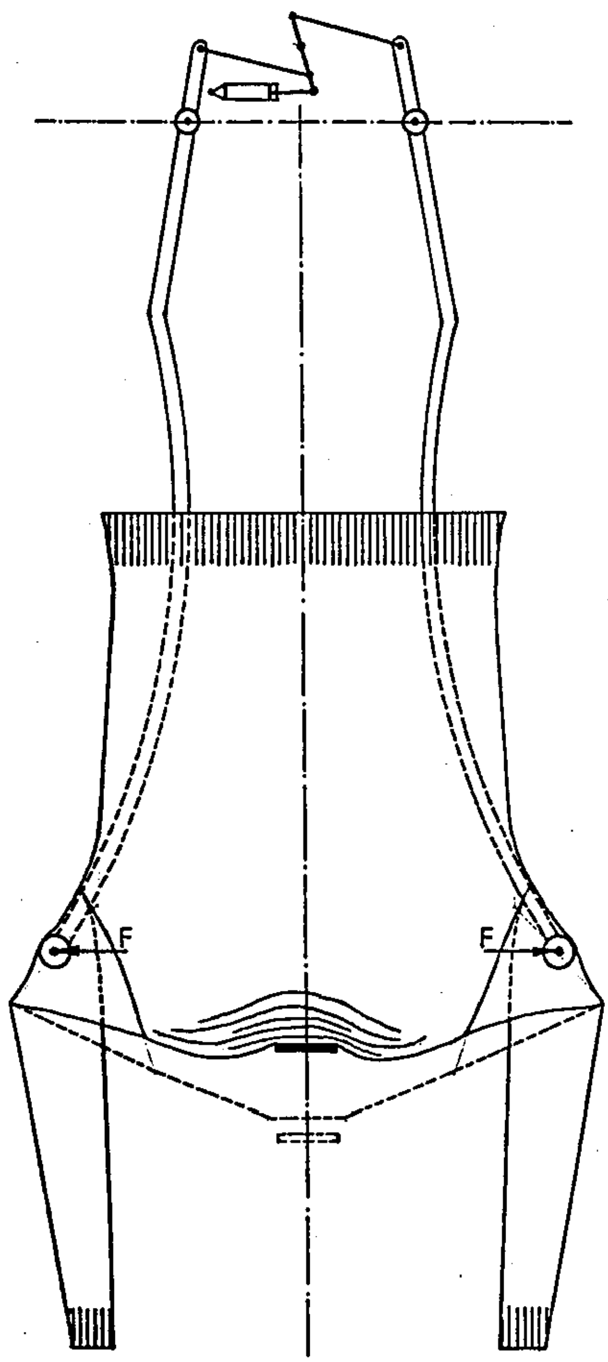


Fig. 4.23 Rollers shown entering the sleeves; lift neck device starting to move upwards.

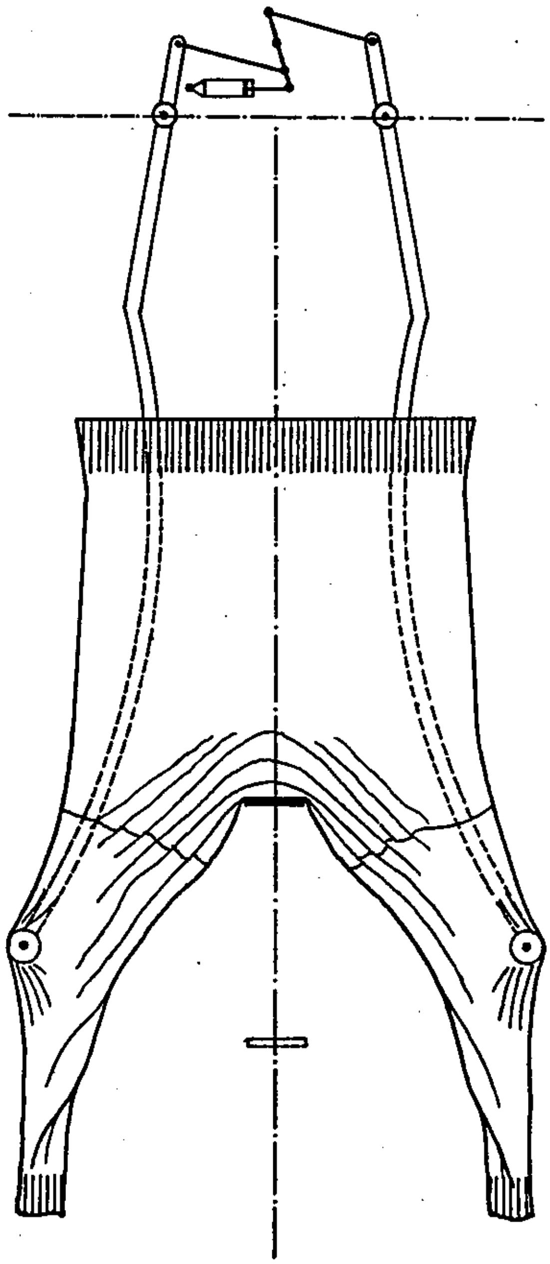


Fig.4.24 Sleeves assuming a tubular form with the arms and lift neck device still on the forward stroke.

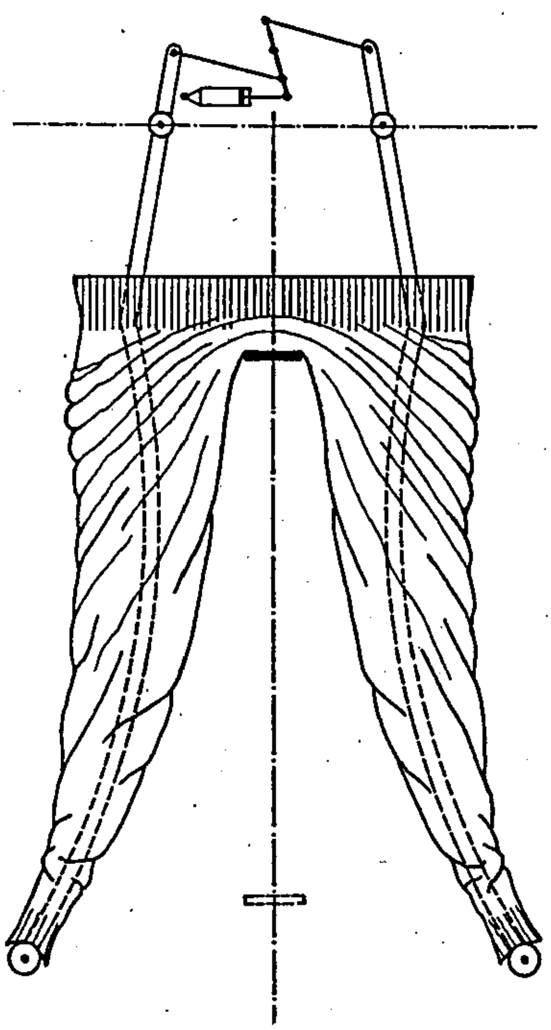


Fig. 4.25 Arms through the sleeves, the rollers already clearing the cuffs.

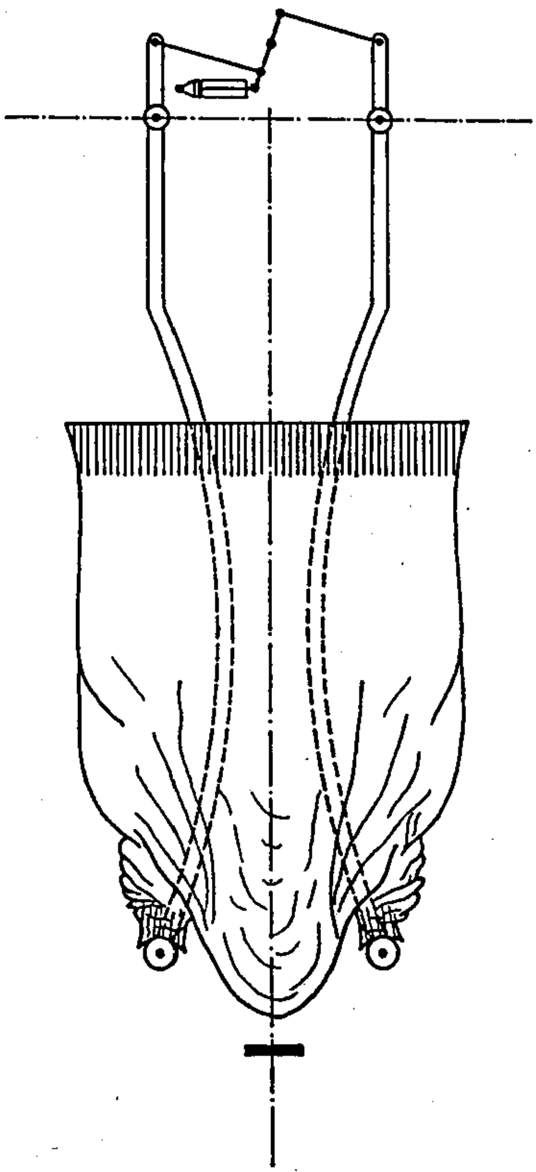


Fig.4.26 Arms on the reverse stroke, starting to turn the garment inside out.

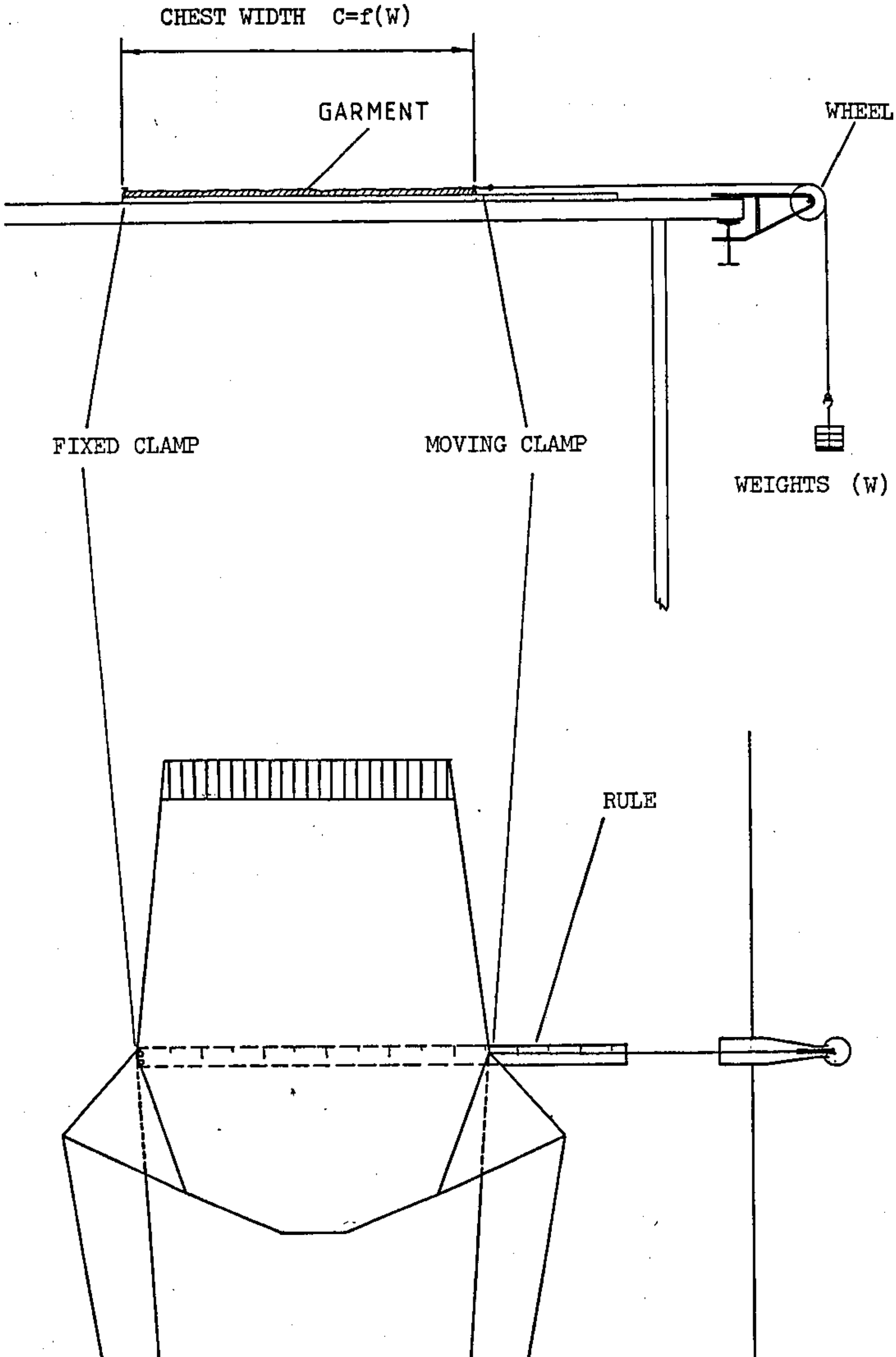
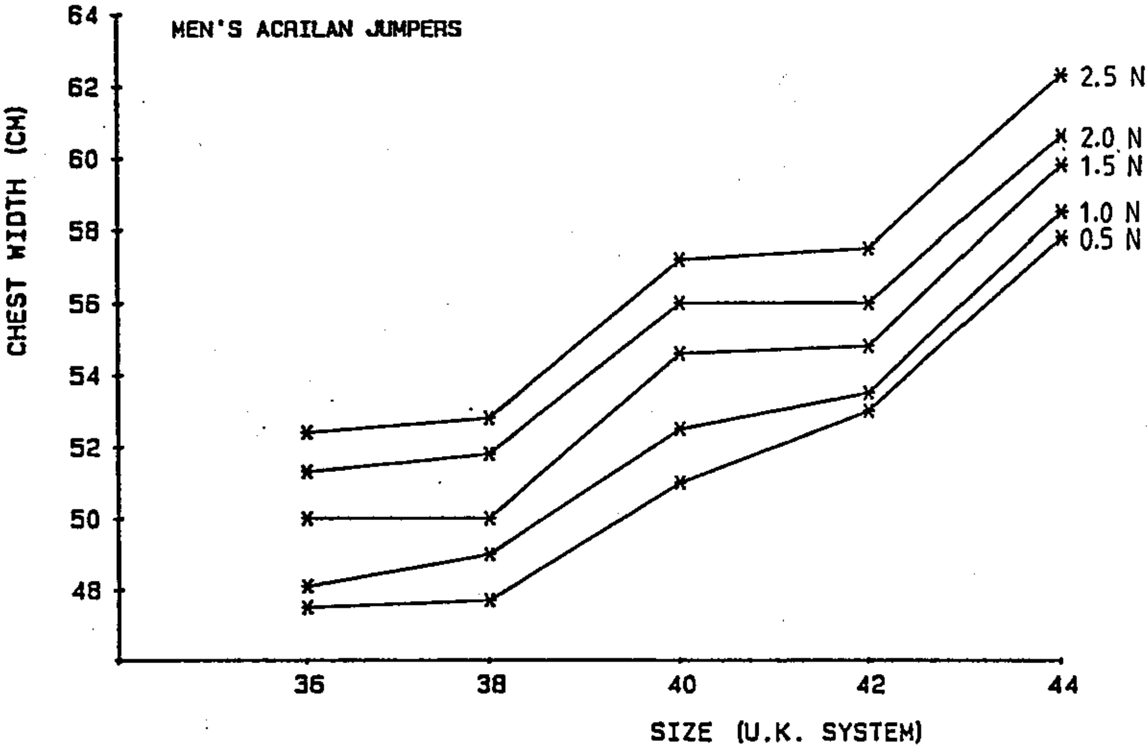
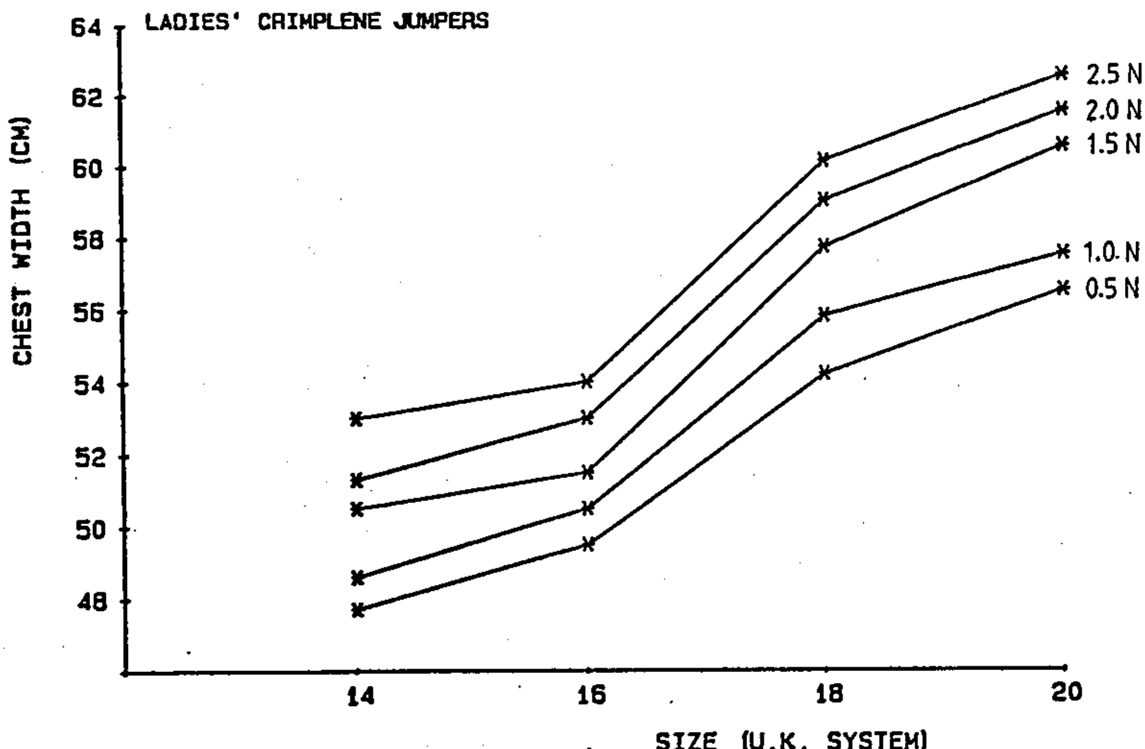


Fig. 4.27 Chest stretching experiment.

Fig. 4.28 Arrangement for chest stretching experiment.

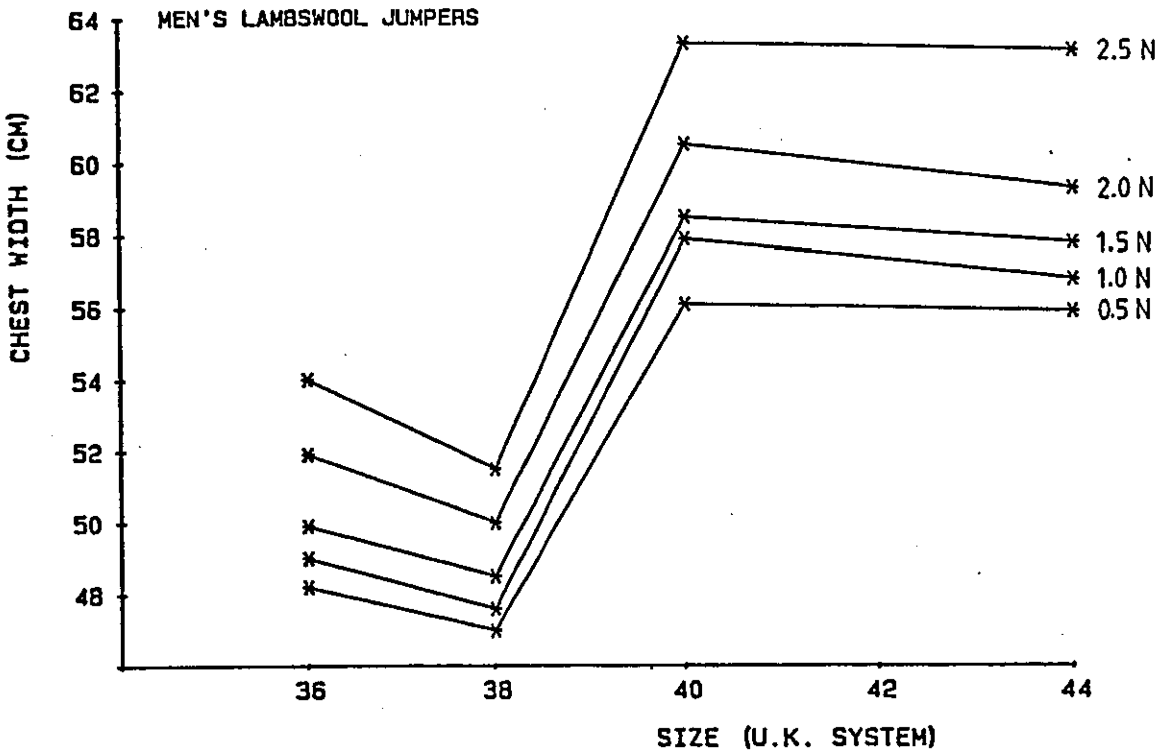


a

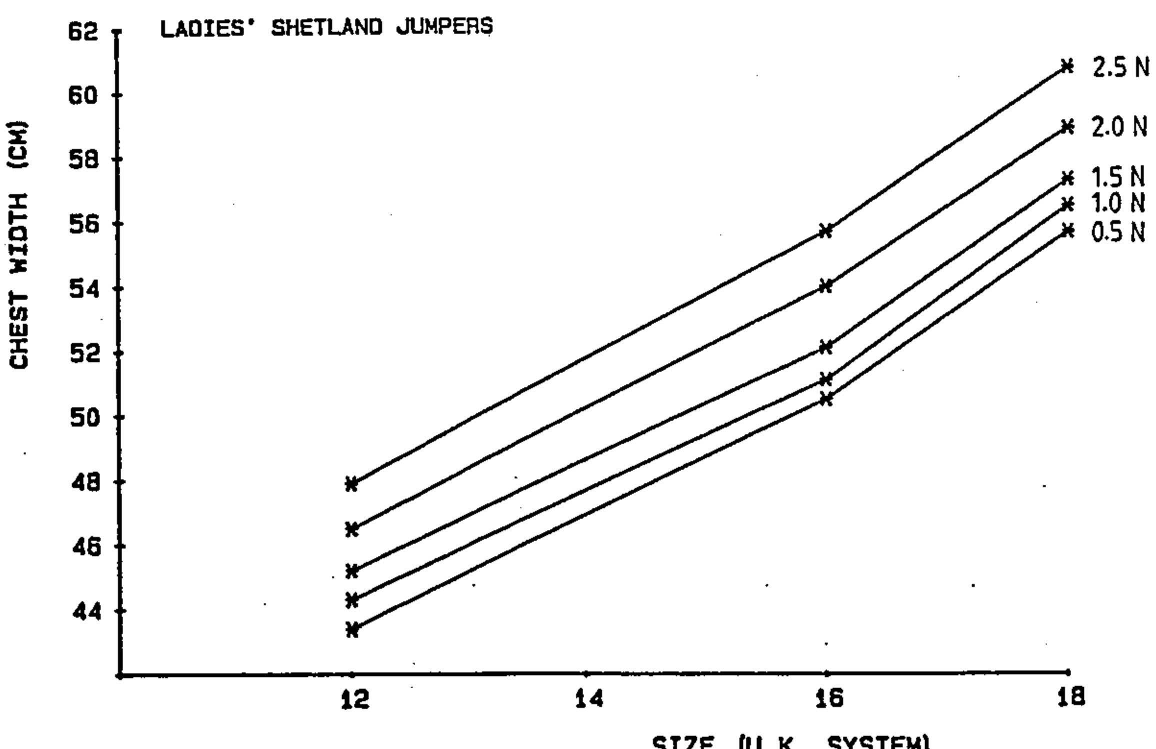


b

Fig.4.29 Plot of size versus chest width from chest stretching experiment.



c



d

Fig.4.29 Plot of size versus chest width from chest stretching experiment.

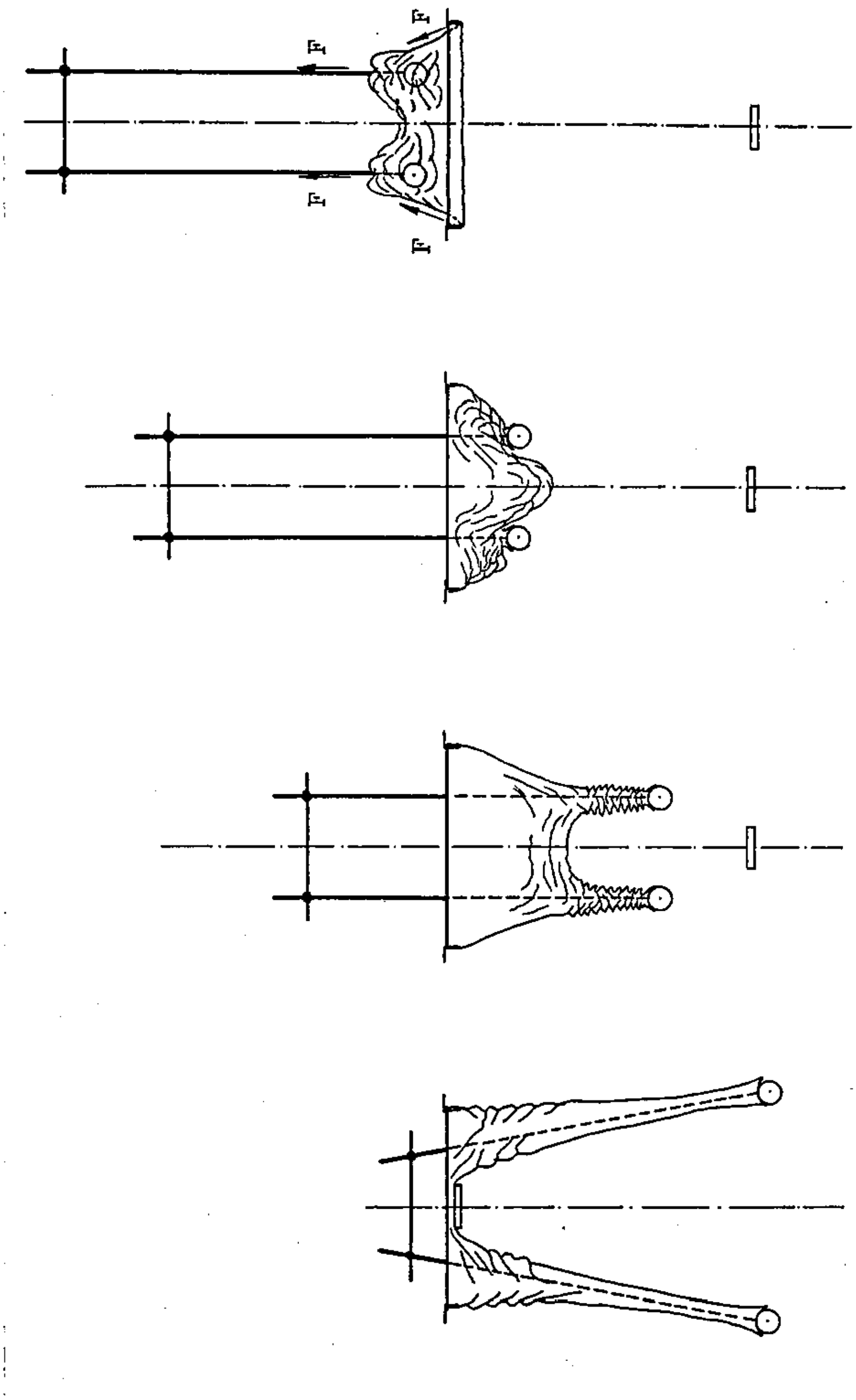


Fig. 4.30 The "concertina effect".

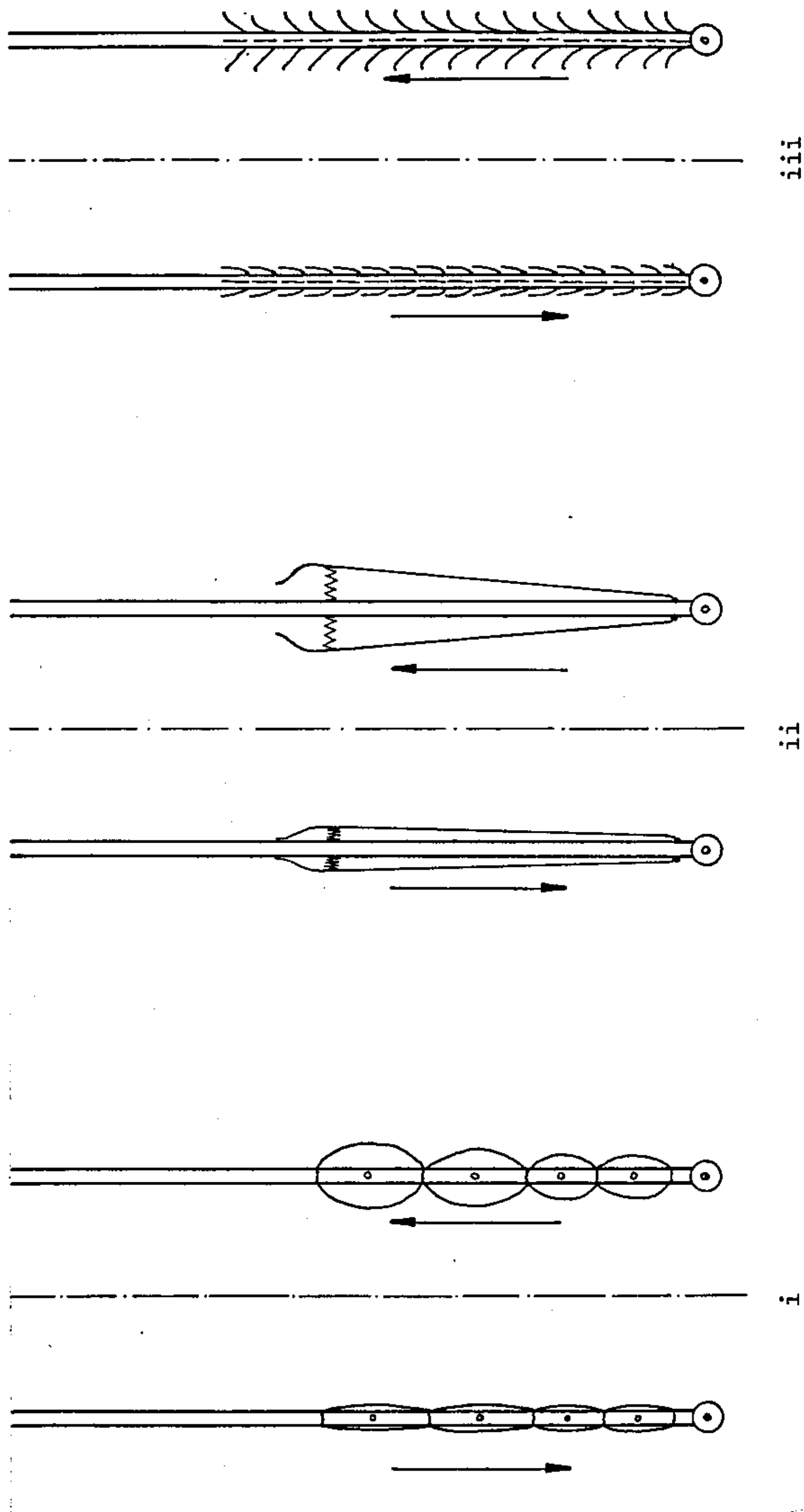


Fig. 4.31 Alternative ideas to overcome the concertina effect.

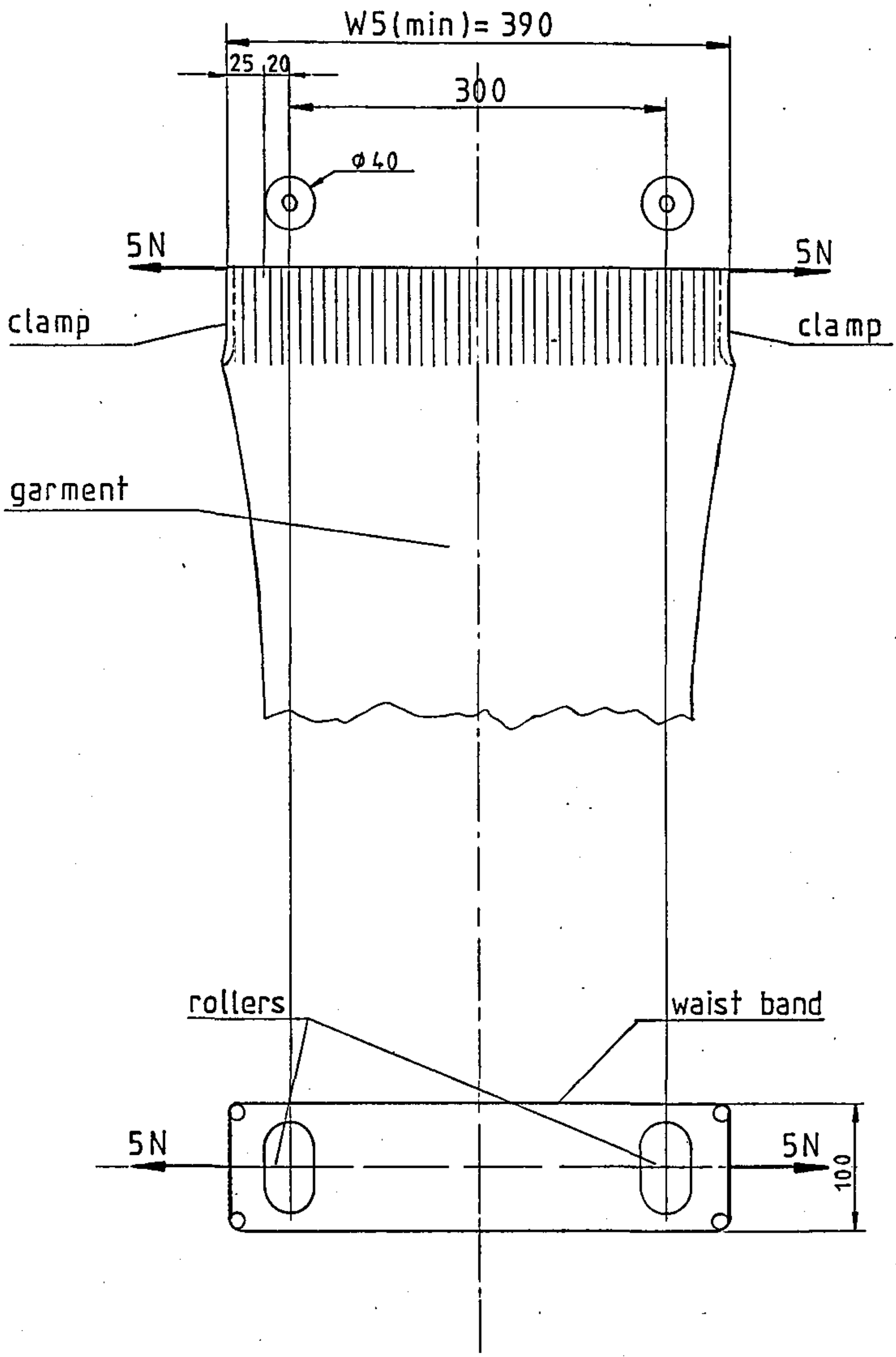


Fig.4.32 Diagram for the calculation of the minimum distance between arms.

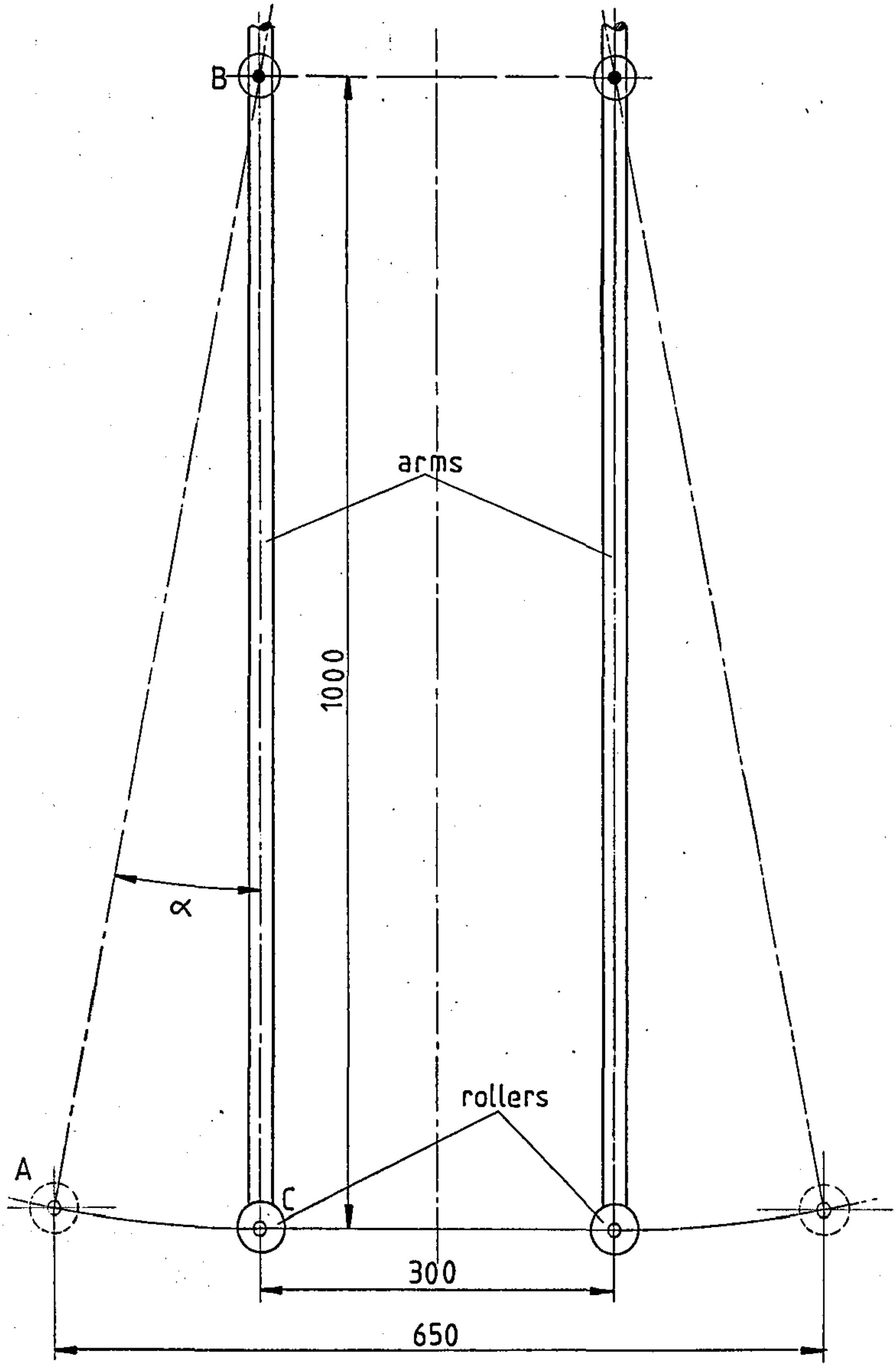


Fig. 4.33 Diagram for the calculation of the swinging angle.

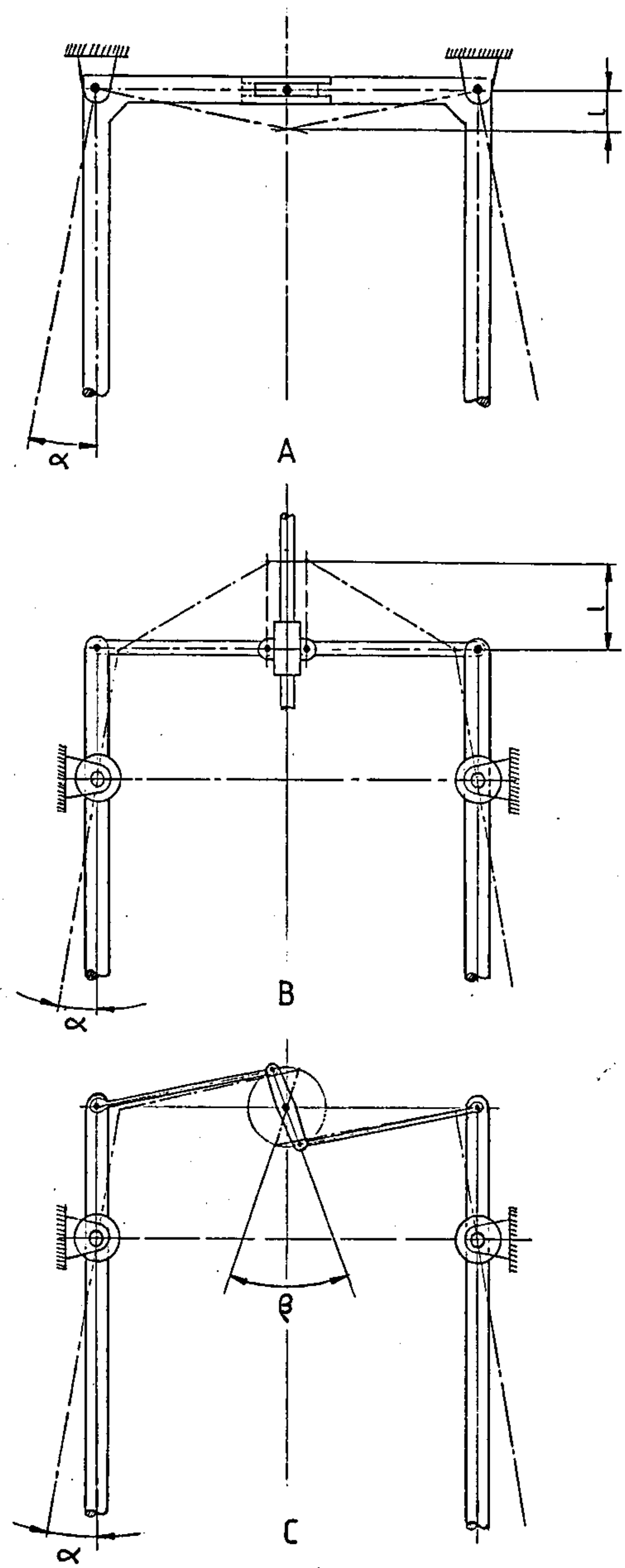


Fig. 4.34 Possible solutions for the swinging mechanism.

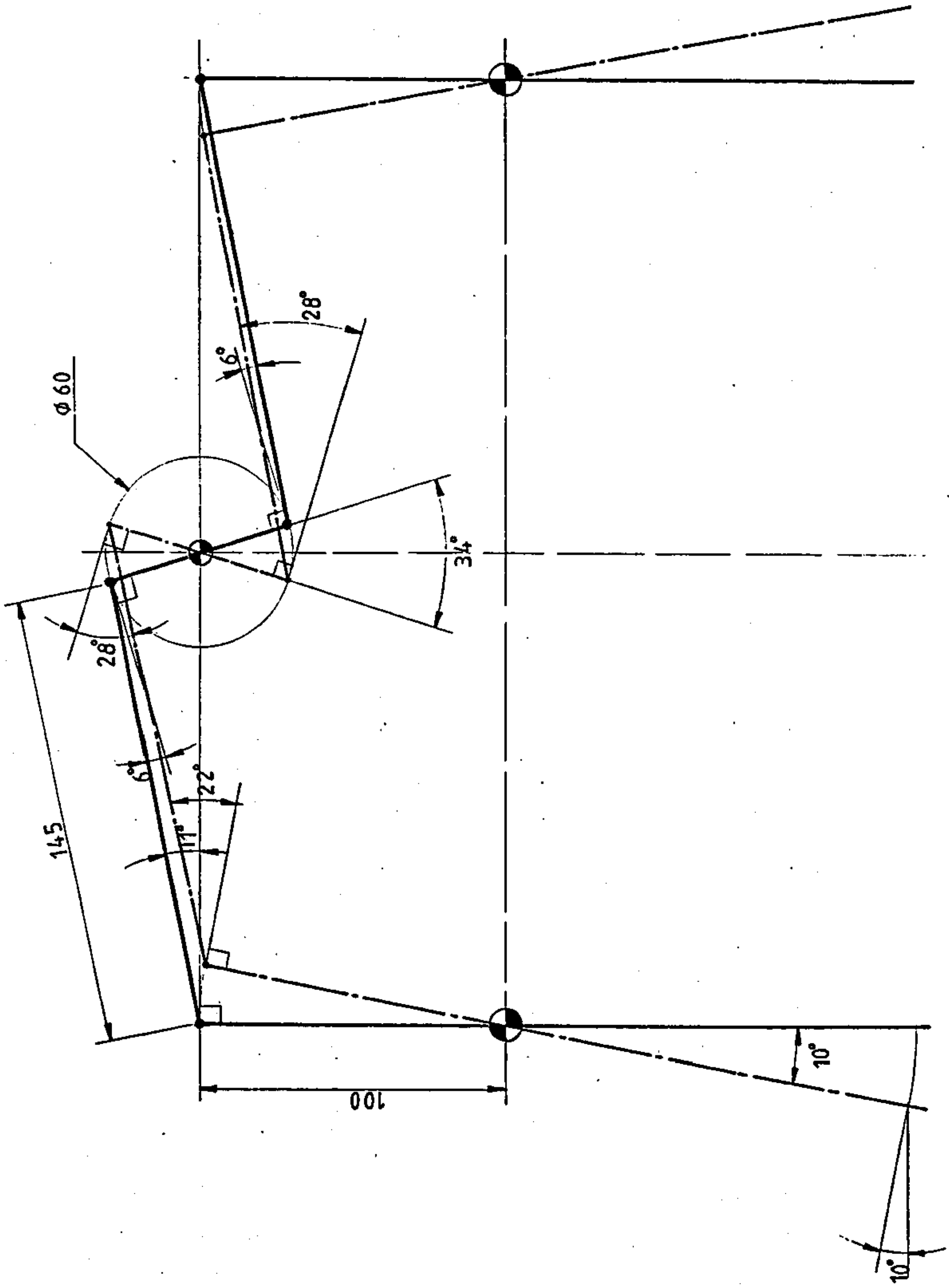


Fig. 4.35 Geometry of the selected swinging mechanism.

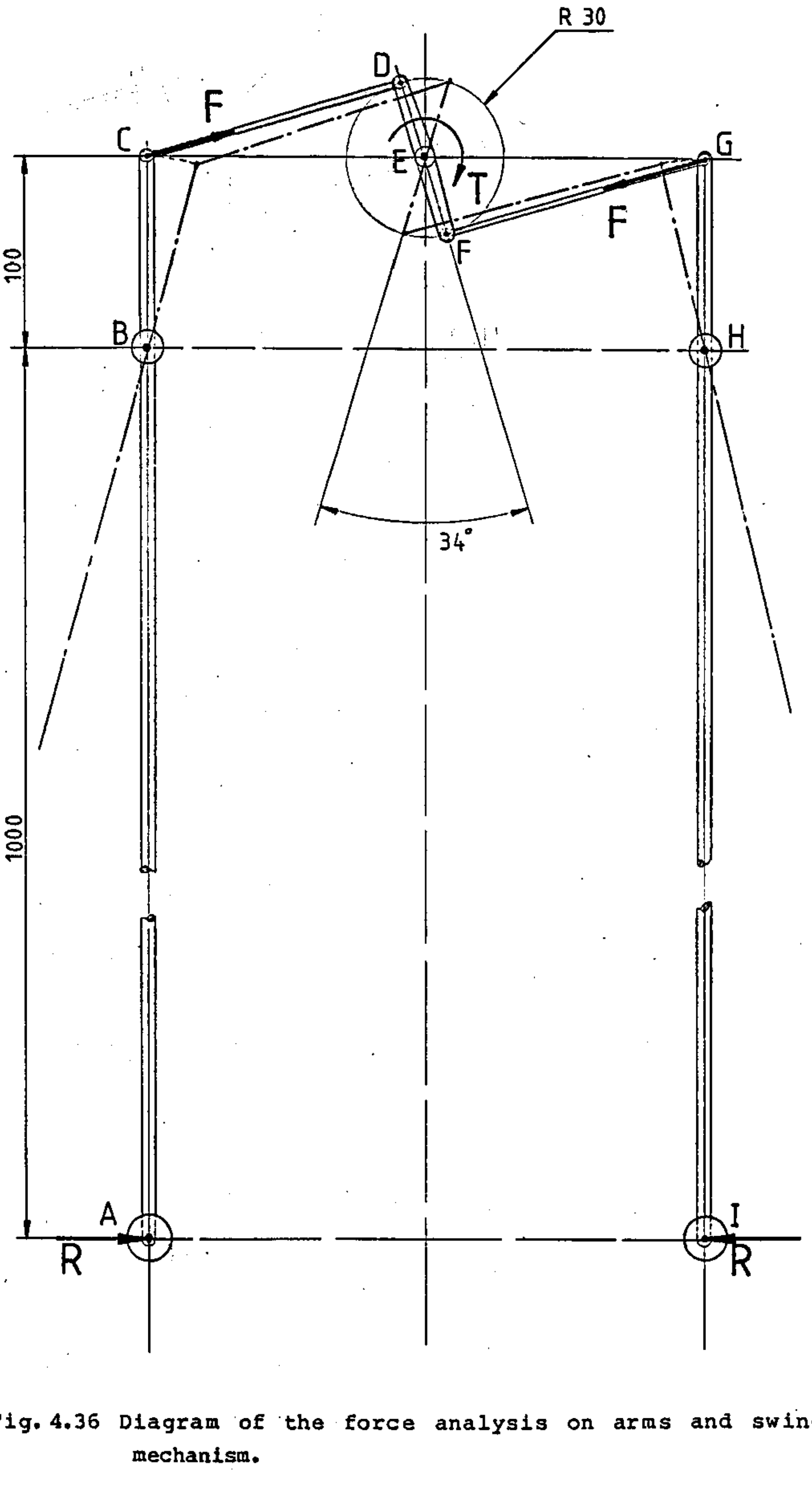


Fig. 4.36 Diagram of the force analysis on arms and swinging mechanism.

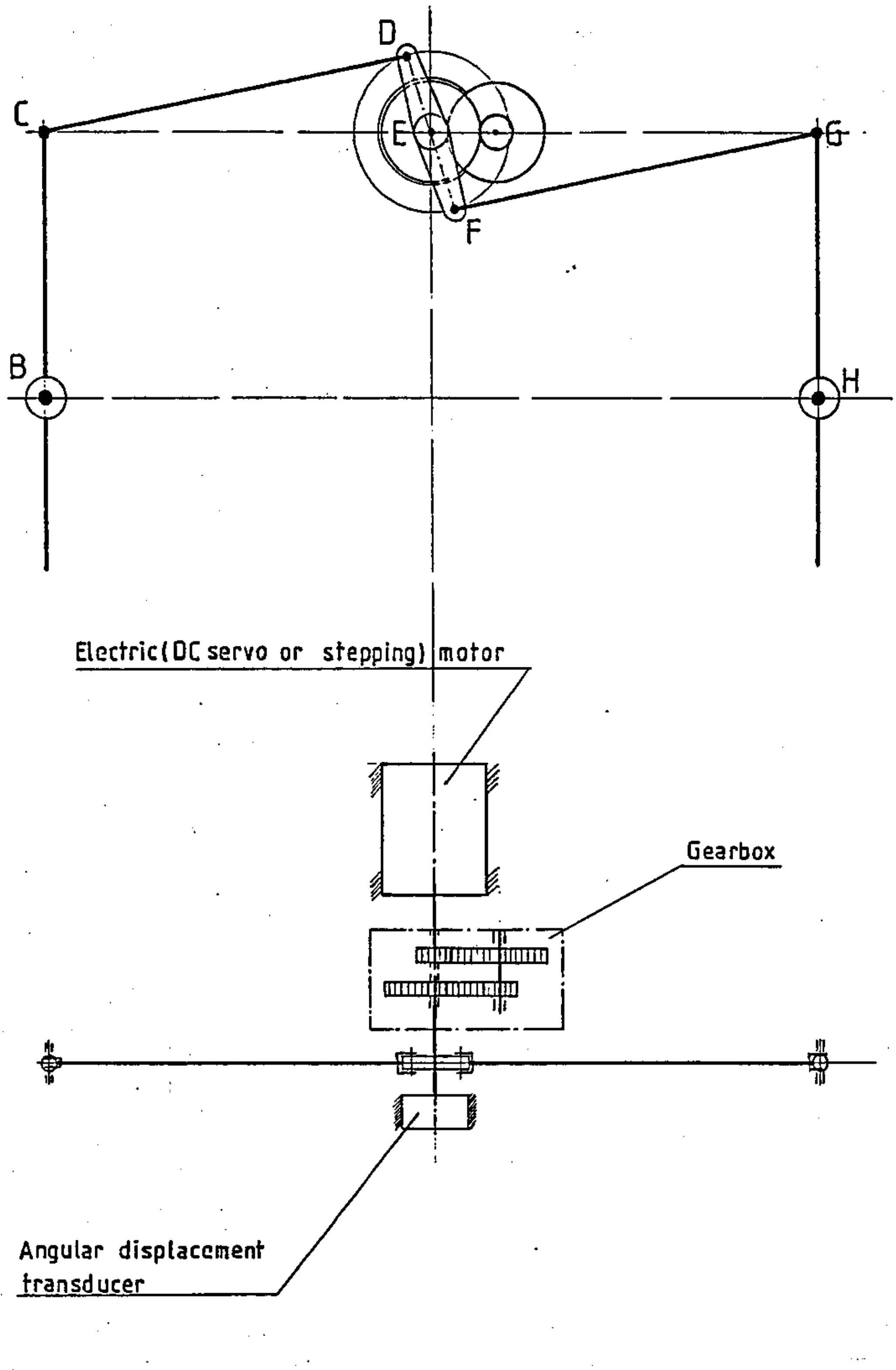


Fig. 4.37 Swinging movement using electric motor and gearbox.

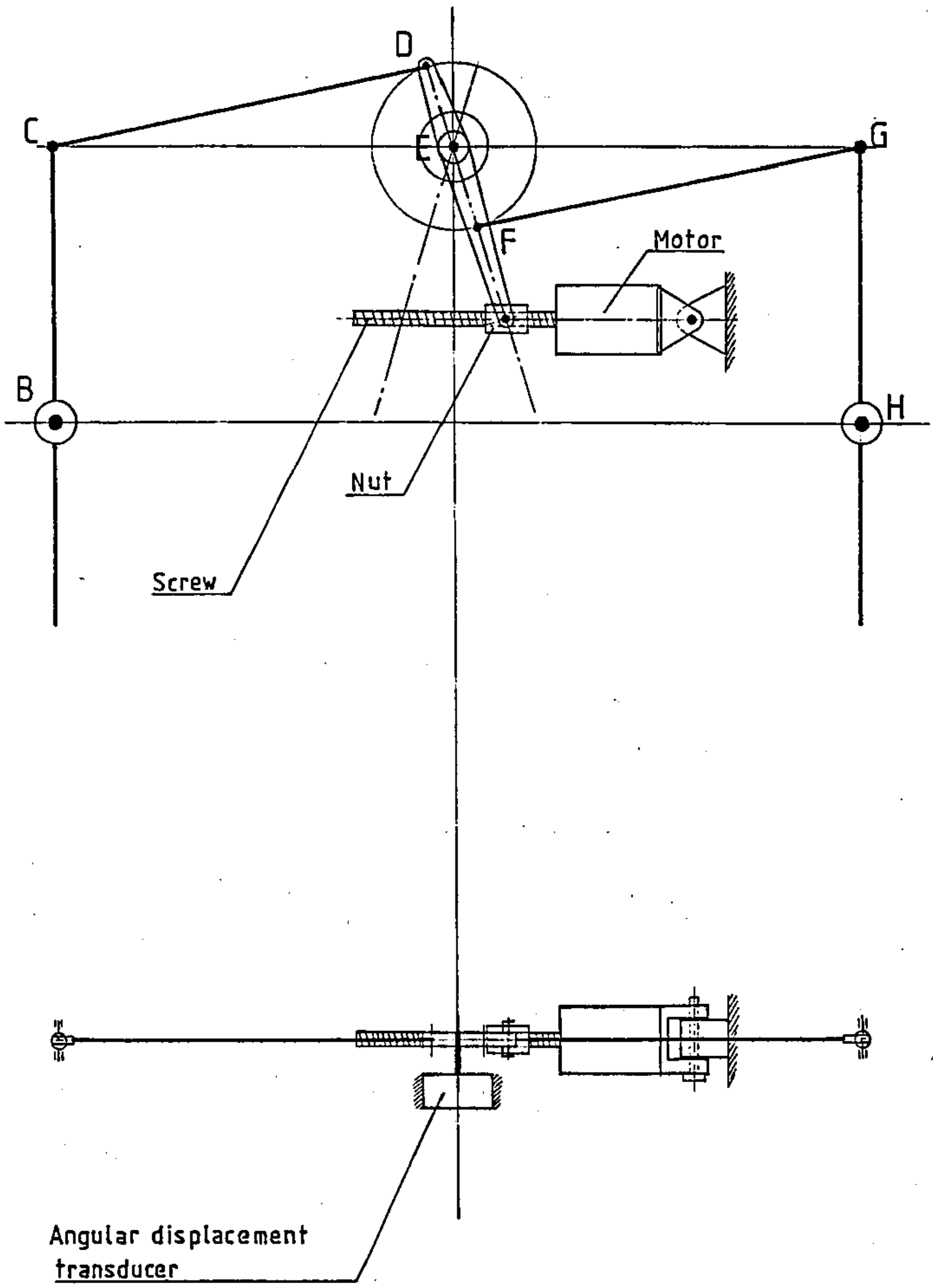


Fig. 4.38 Swinging movement using electric motor with screw and nut.

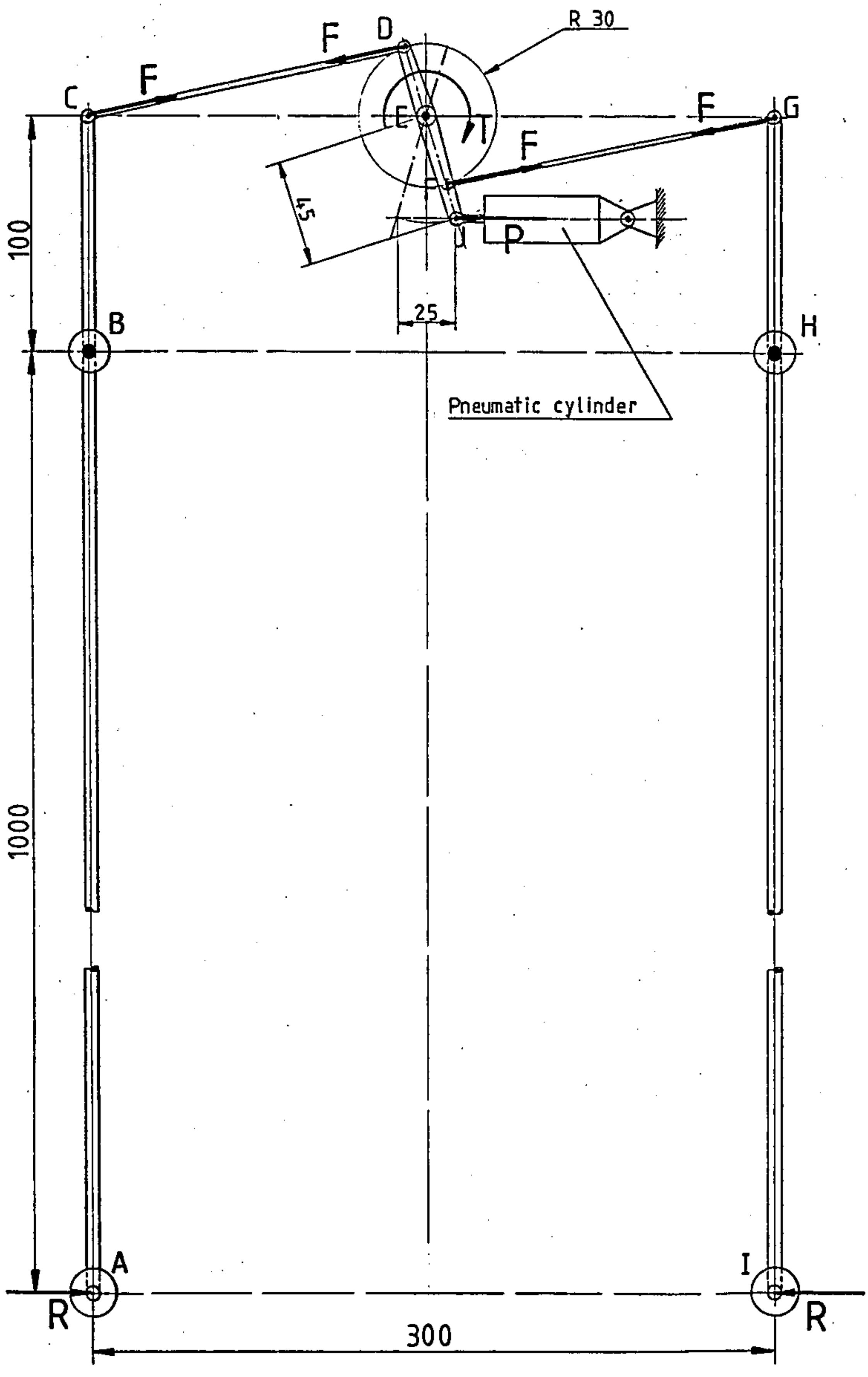


Fig. 4.39 Swinging movement using double acting pneumatic cylinder.

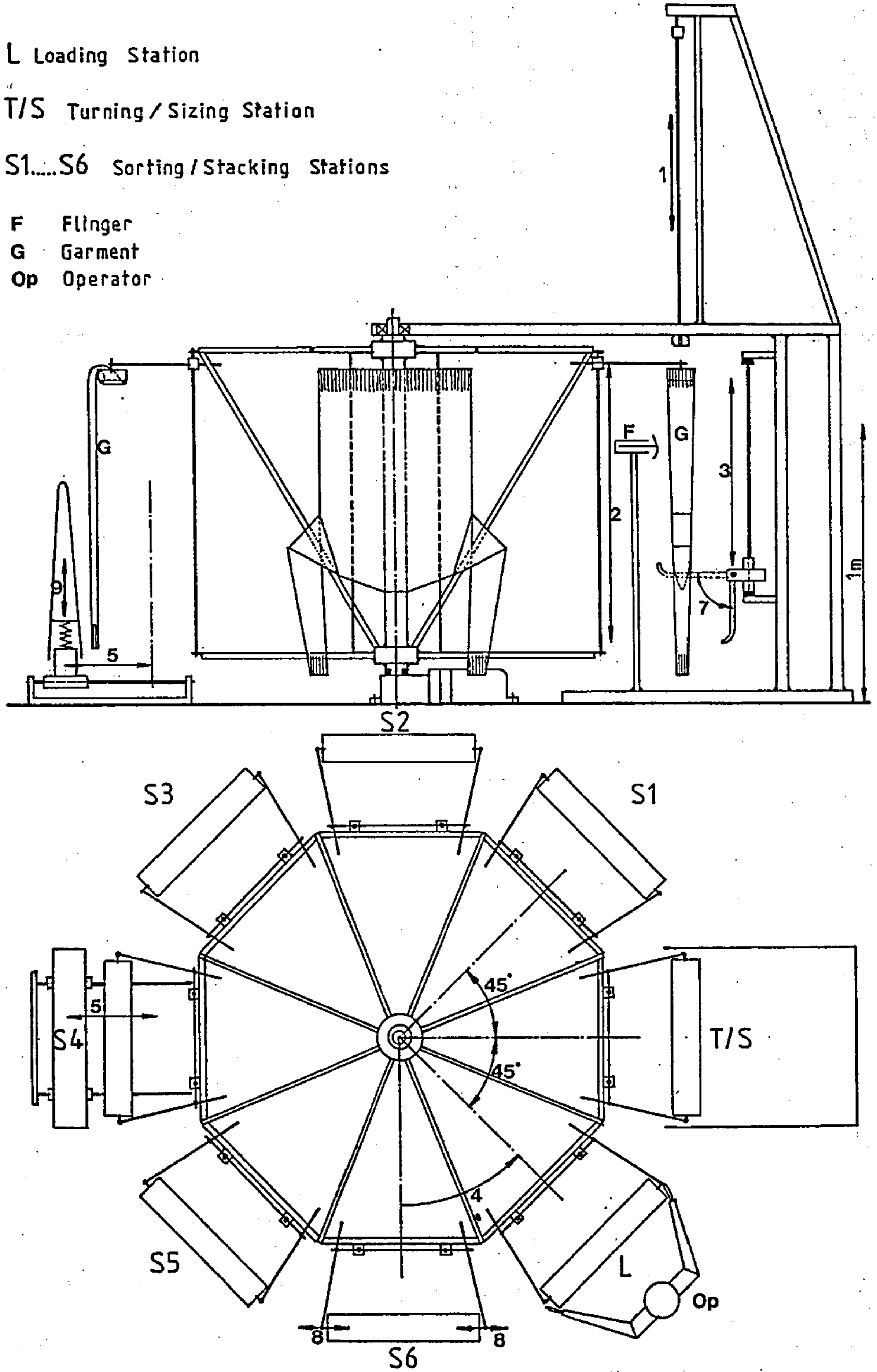


Fig. 4.40 The layout of full process "TSS" machine.

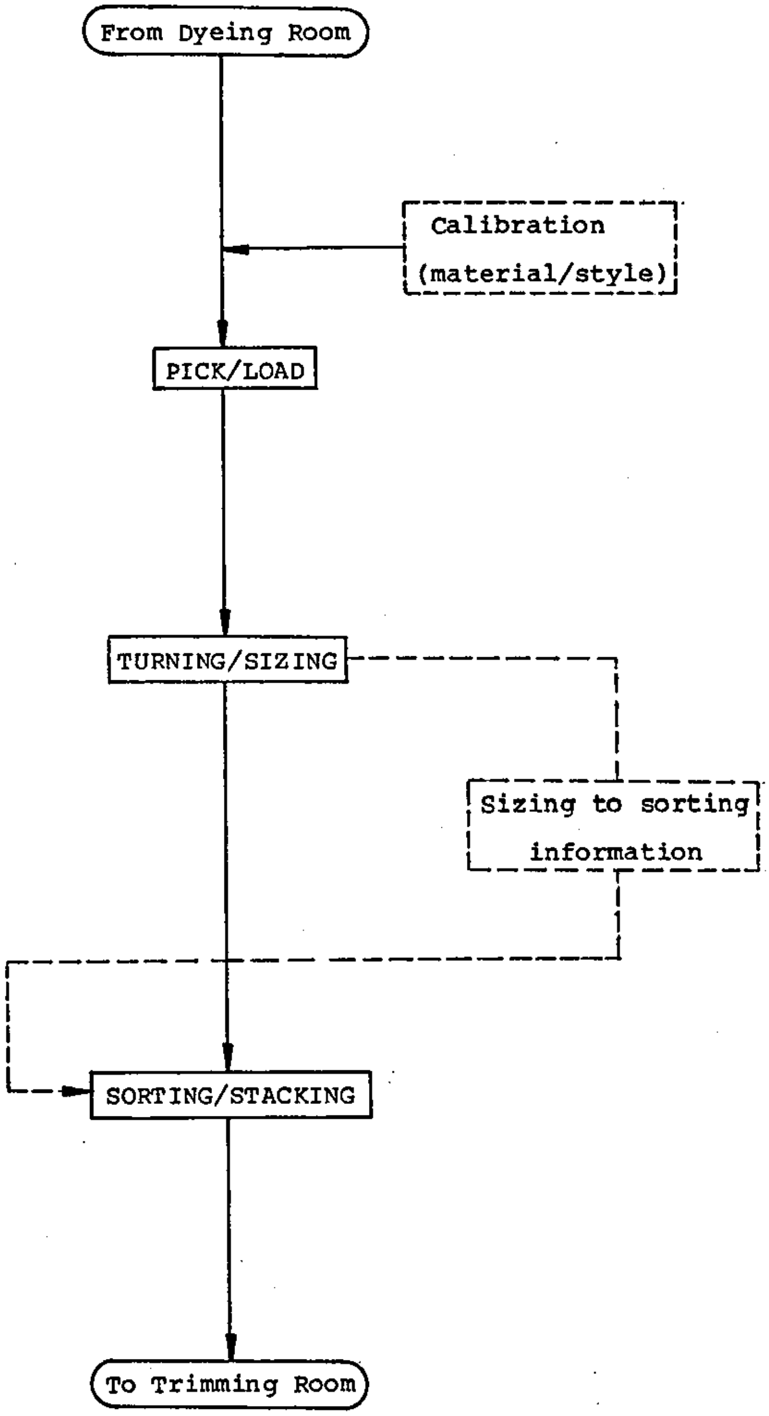


Fig. 4.41- Flowchart of "TSS" operations.

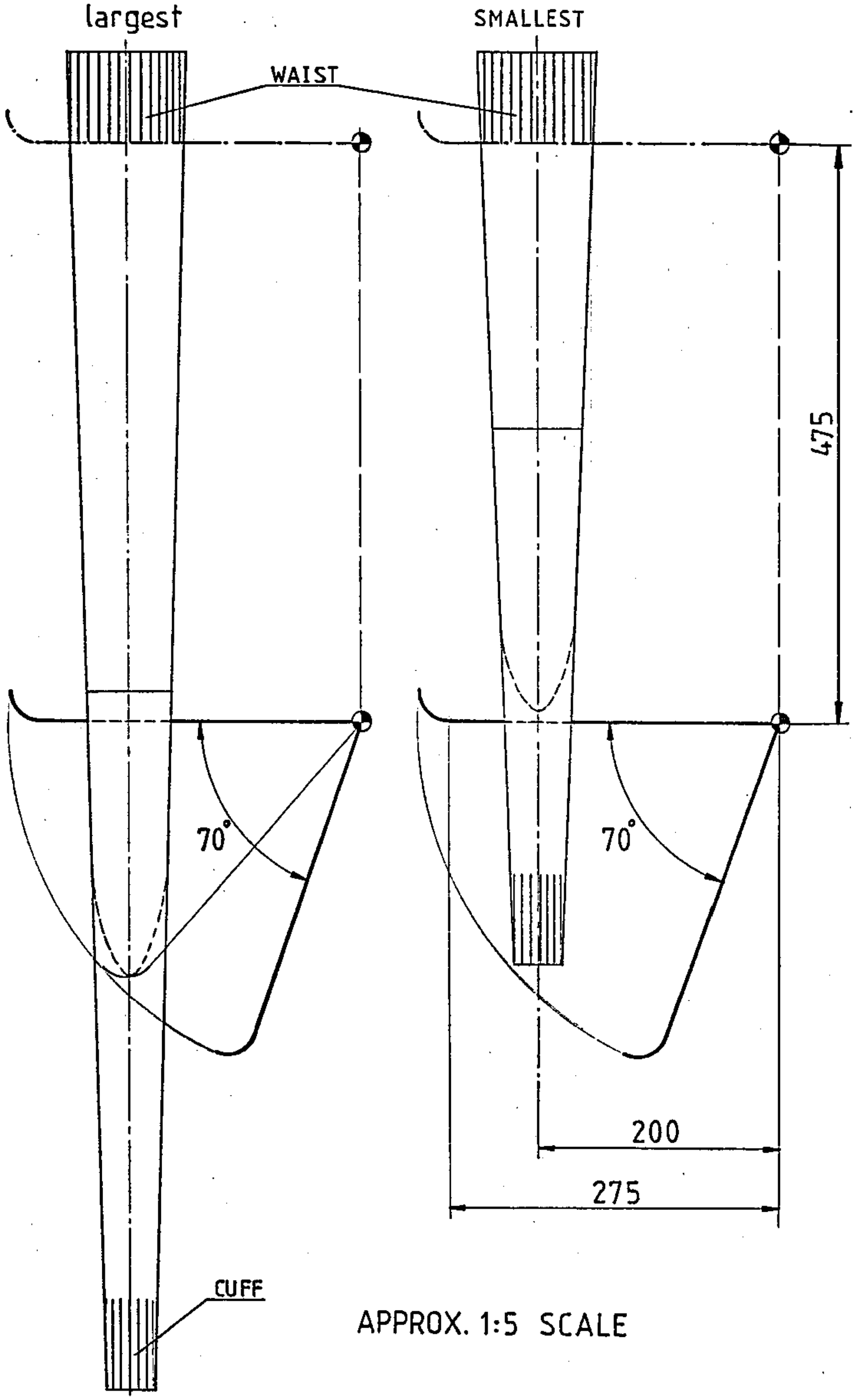


Fig. 4.42 Graphic study of the "lift neck device" actuation.

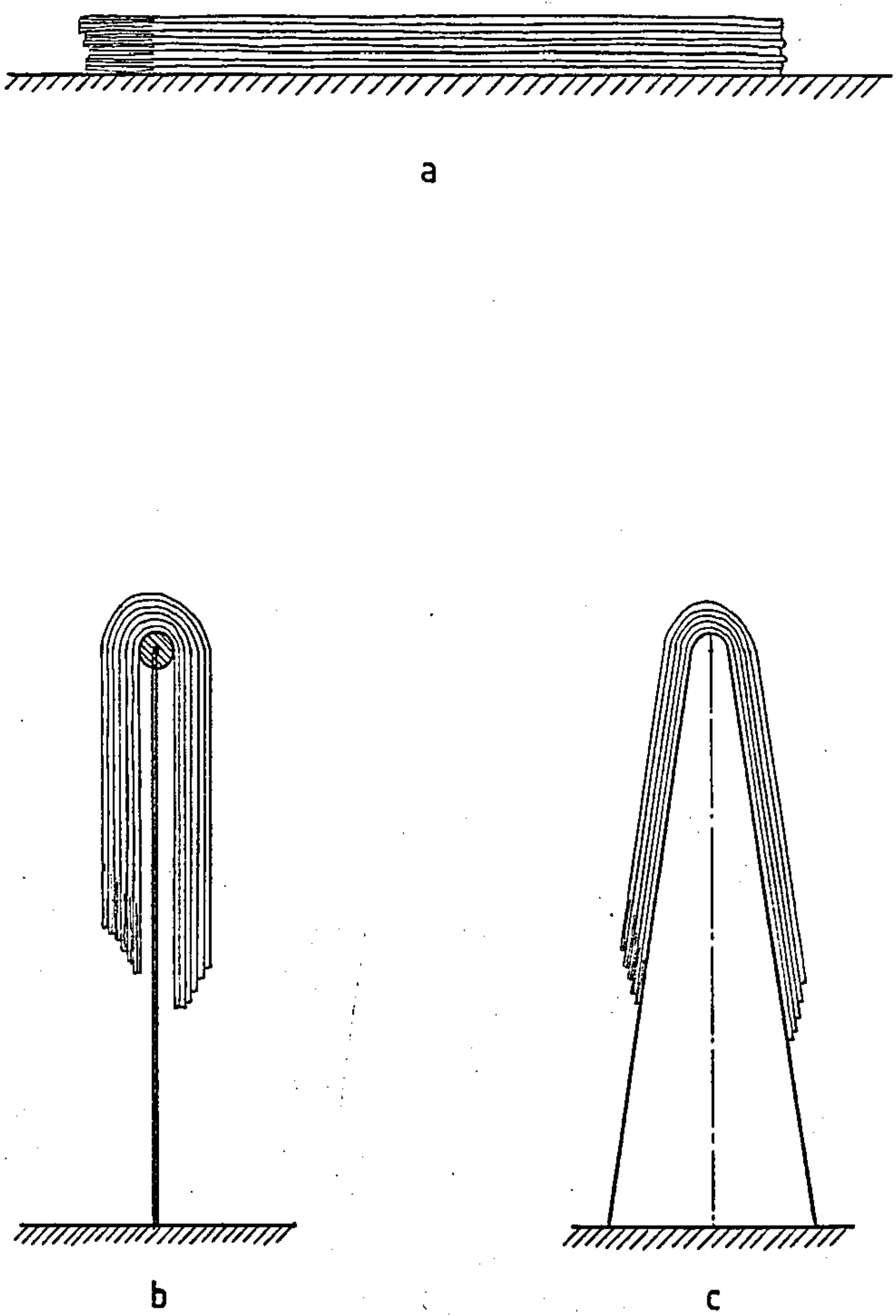


Fig. 4.43 Exploratory ideas for the stacking operation.

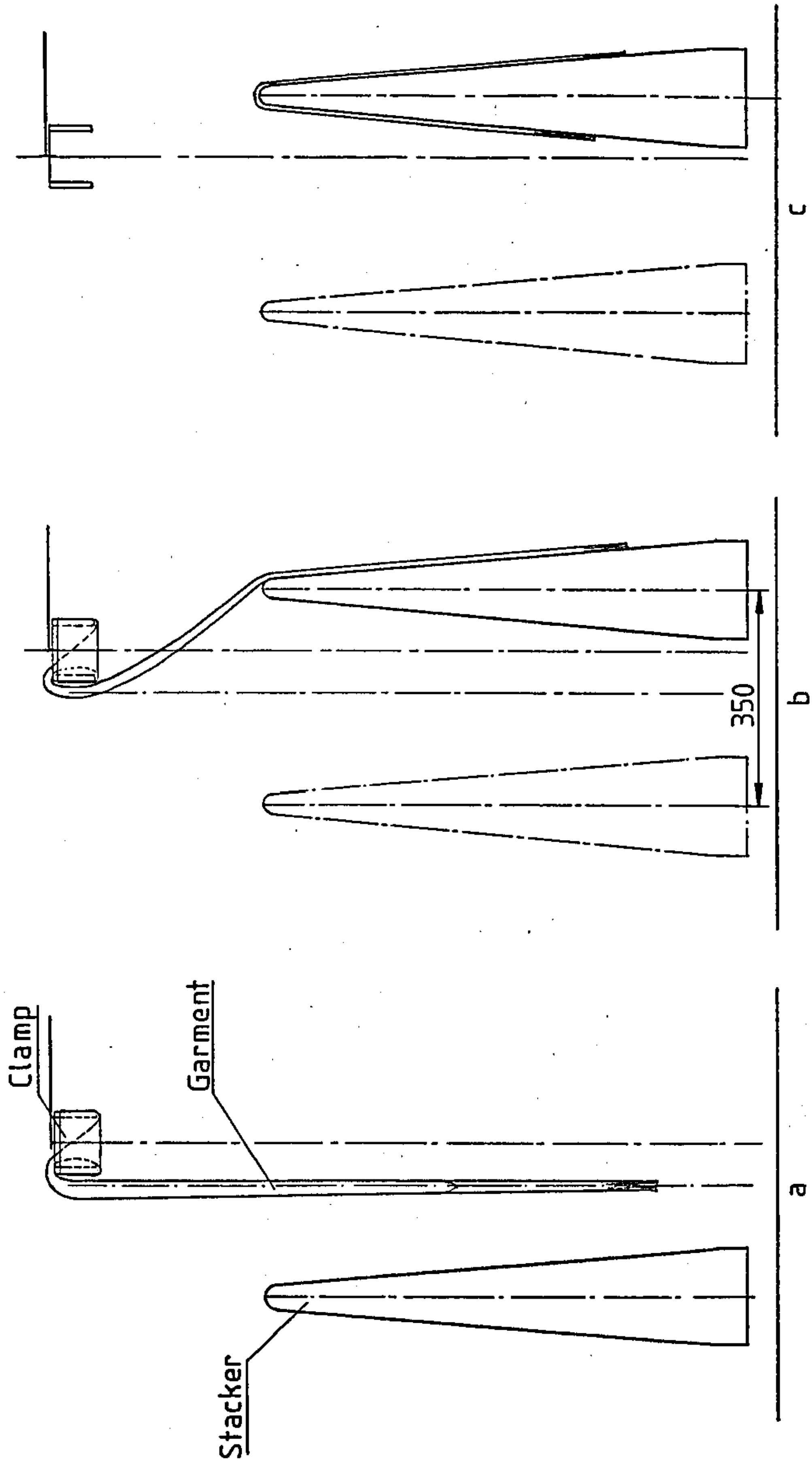


Fig. 4.44 The sorting/stacking sequence.

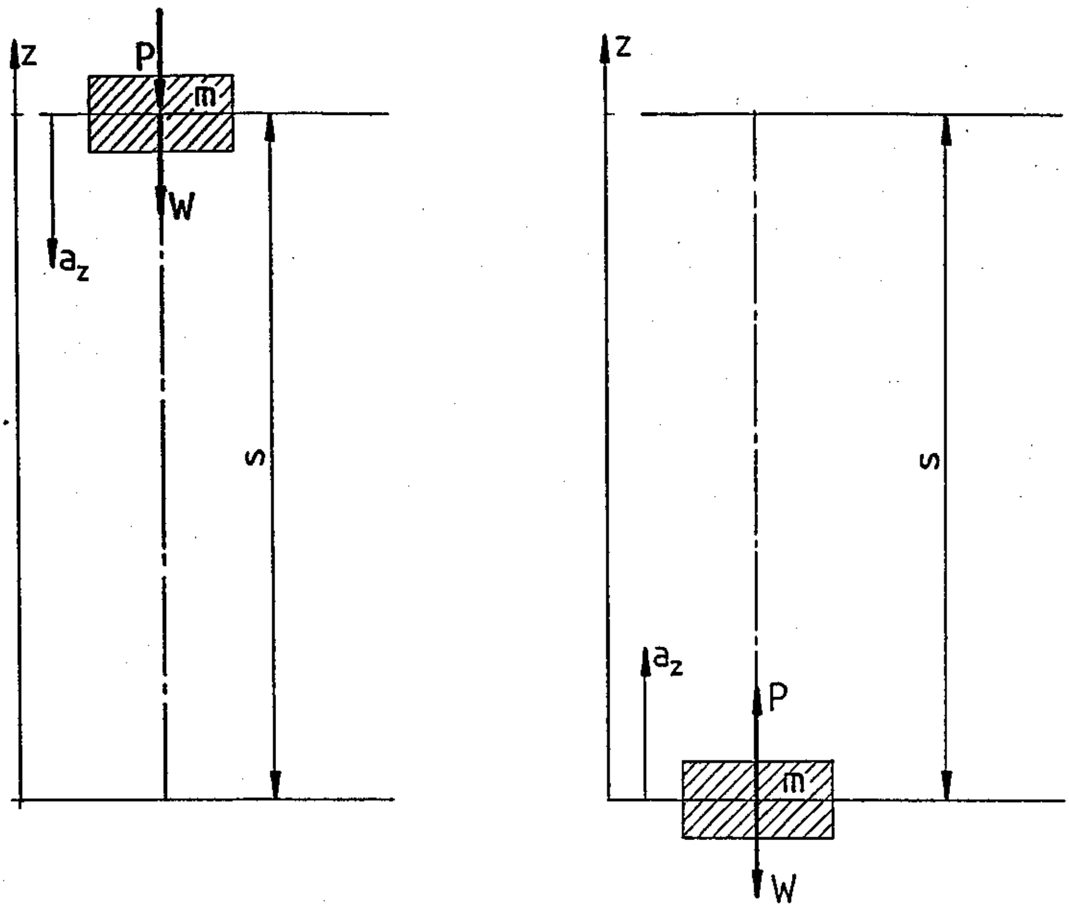


Fig. 4.45 Model for movements 1, 2 and 3.

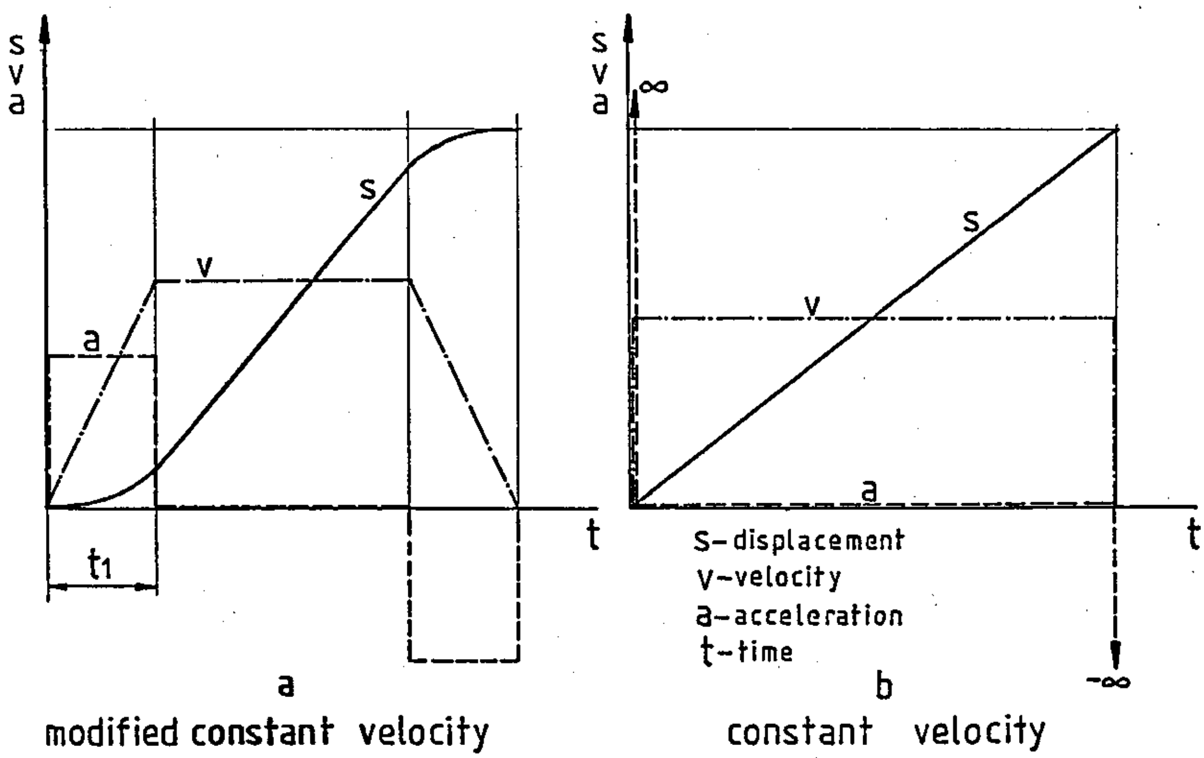


Fig. 4.46 Graphic representation of motion characteristics for the turning movements.

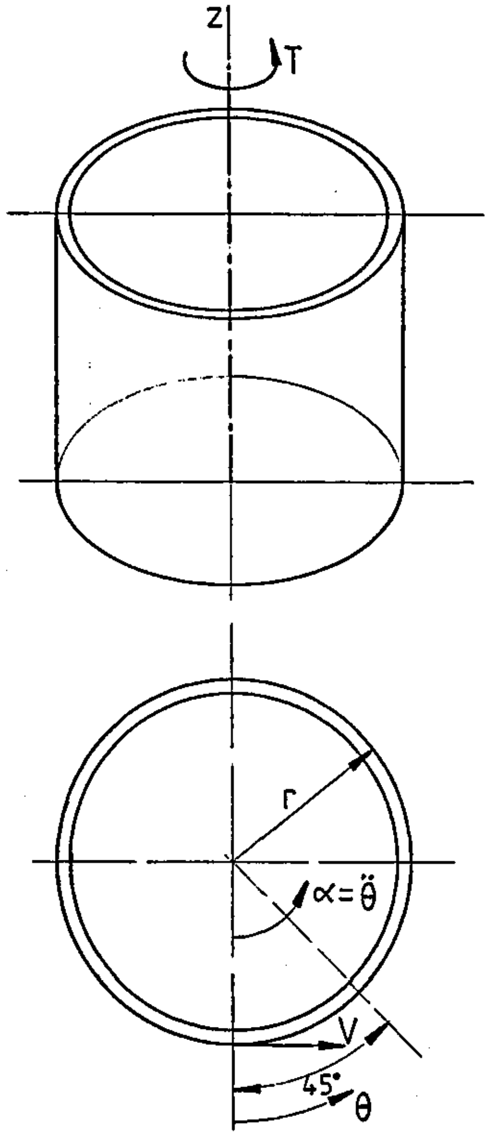


Fig. 4.47 Model for the preliminary analysis of the carousel.

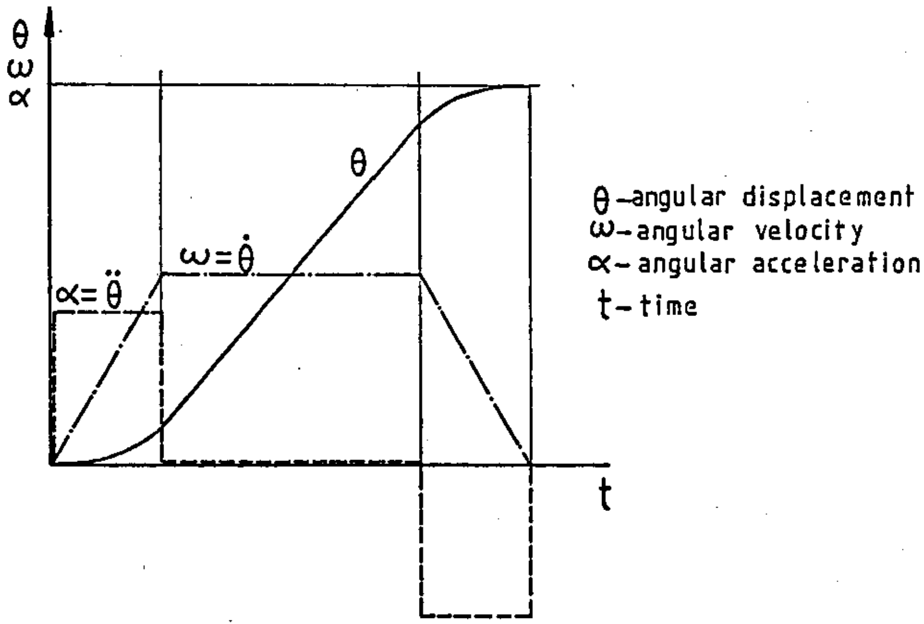


Fig. 4.48 Graphic representation of motion characteristics for the carousel indexing rotation.

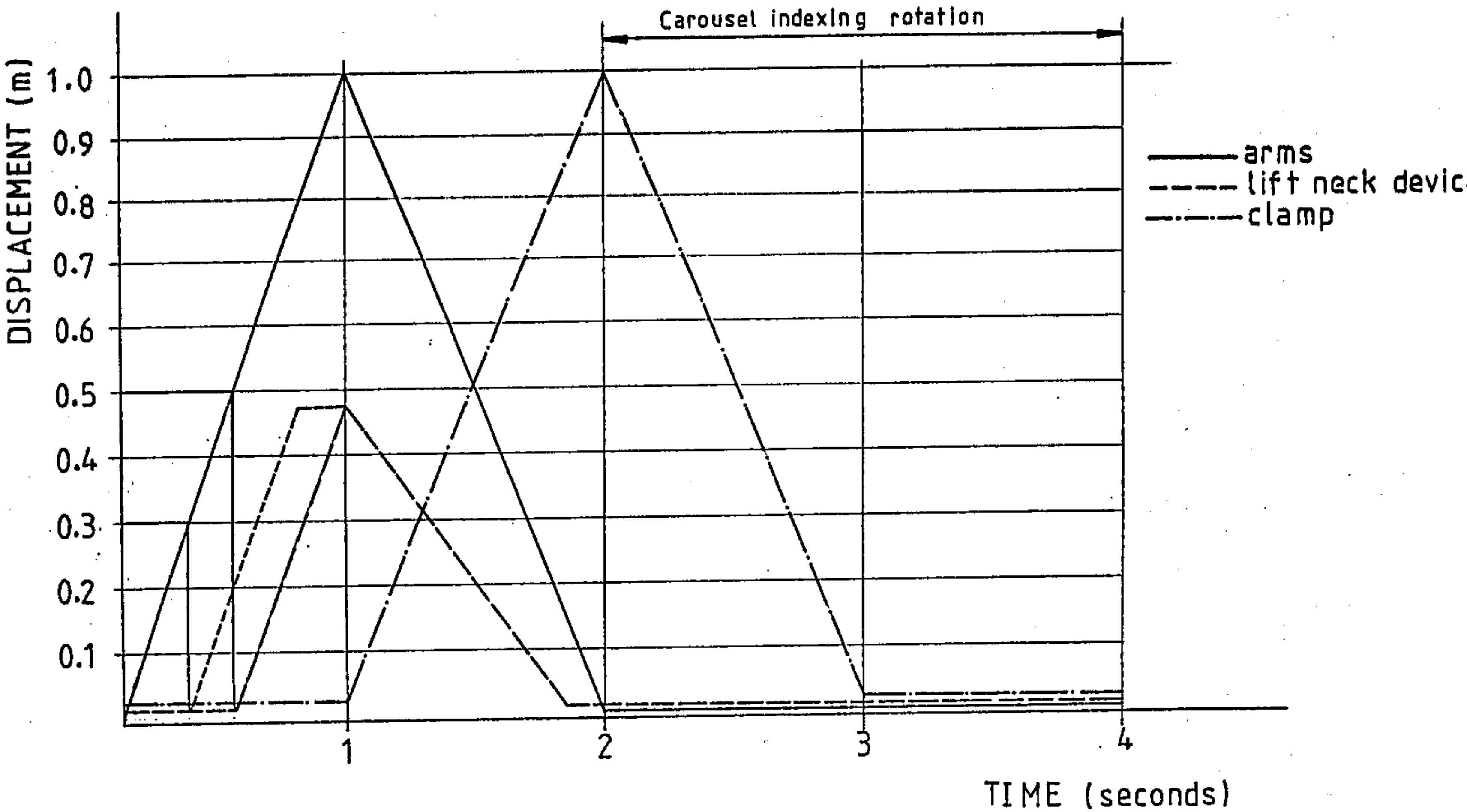


Fig. 4.49 Displacement-time diagram for the operations contributing to the machine cycle time.

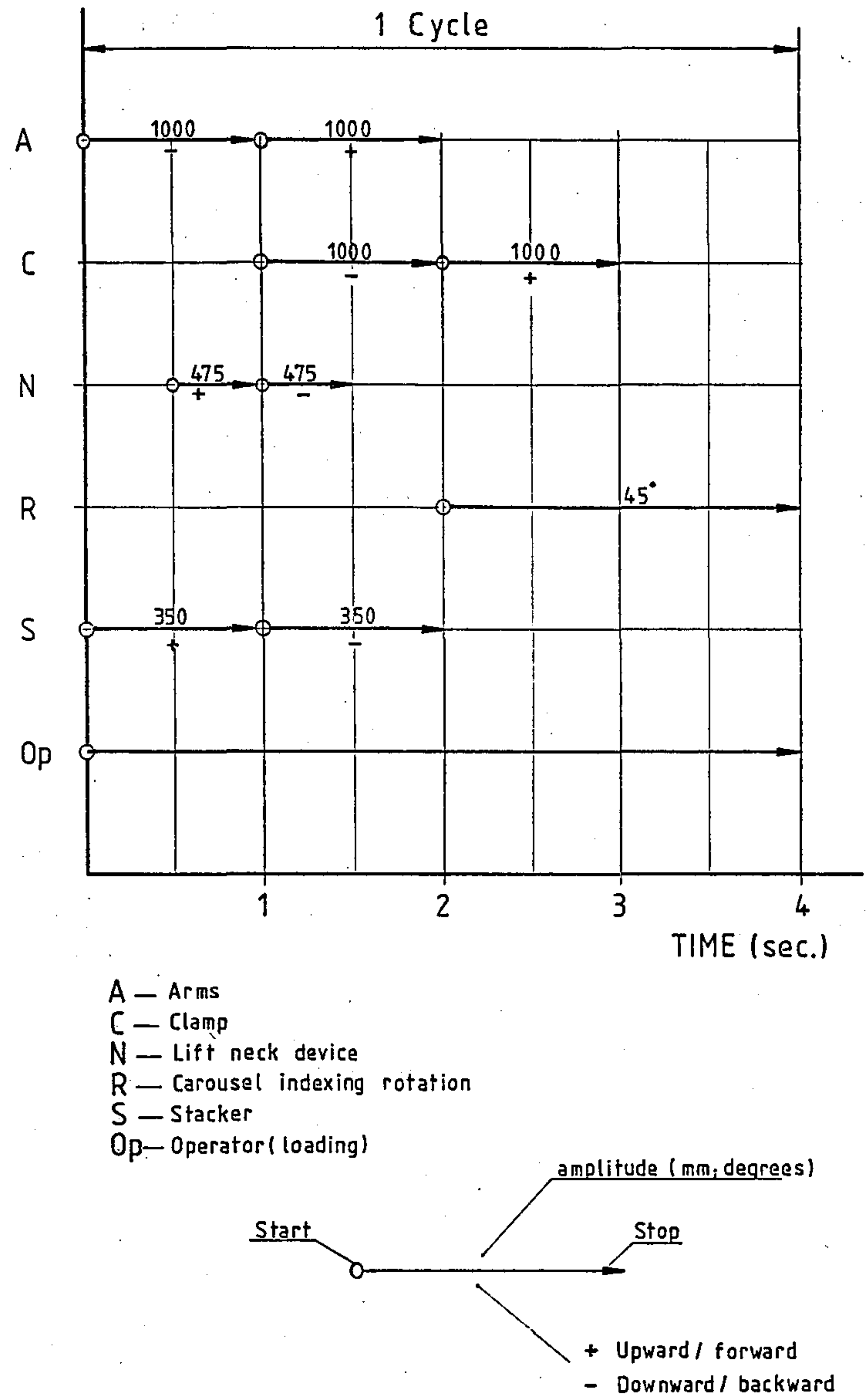


Fig. 4.50 Timing diagram of the machine cycle.

TABLE 4.1: Summary of Preliminary Requirements

	TECHNICAL	ERGONOMIC	AESTHETIC
OBJECTIVES	TURN, SORT and STACK long sleeved knitted garments	Operator must do few and short movements	Cleanliness and efficiency
SAFETY	The machine must be safe for both the operator and passers-by in accordance with safety standards. Guards must be used as well as an emergency stop switch	A safe machine is psychologically very important and improves productivity	
COST	The cost must be limited by the savings the machine will bring back		Potential customers must see considerable savings before purchasing the machine
SPEED	The machine speed must be the fastest possible in compromise with cost, power consumption and competition with manual methods	Must be flexible and easily adjustable to accommodate different operator's performance	
MATERIALS	Smooth surfaces not to damage the garments. Humidity (wet garments) is sometimes present, so materials not to oxidise (aluminium, plastic, stainless steel); garments must not be soiled by lubricants or dirt		The customers will require clean garments
NOISE	As low as possible	To accord with legislation on noise level in factories	Noise level in the turning room is low
MAINTENANCE	Down-time must be minimal. All parts that are likely to wear must be easily replaceable. Microswitches to turn off the power when guards are removed	Different parts must be easily accessible	Summary of maintenance instructions must be shown on the outside of the machine.

TABLE 4.2: Evaluation Matrix

CONCEPT No. / CRITERIA	1	2	3	4	5	6	7
1. Ability for turning	D	-	S	S	S	+	+
2. Ability for sizing	A	S	S	S	-	+	+
3. Ability to process the required range of sizes	T	-	S	S	-	+	+
4. Operator intervention	U	S	S	S	S	S	-
5. Complexity (no. of operations)	M	+	S	S	S	S	-
		+1 -2	+0 -0	+0 -0	+0 -2	+3 -0	+3 -2
1. Ability for turning	+	D	+	+	+	+	+
2. Ability for sizing	S	A	S	S	S	+	+
3. Ability to process the required range of sizes	+	T	+	+	S	+	+
4. Operator intervention	S	U	S	S	S	+	-
5. Complexity (no. of operations)	-	M	-	-	-	-	-
	+2 -1		+2 -1	+2 -1	+1 -1	+4 -1	+3 -2
1. Ability for turning	-	-	-	-	-	D	S
2. Ability for sizing	-	-	-	-	-	A	-
3. Ability to process the required range of sizes	-	-	-	-	-	T	S
4. Operator intervention	S	-	S	S	S	U	-
5. Complexity (no. of operations)	S	S	S	S	S	M	S
	+0 -3	+1 -4	+0 -3	+0 -3	+0 -3		+0 -2

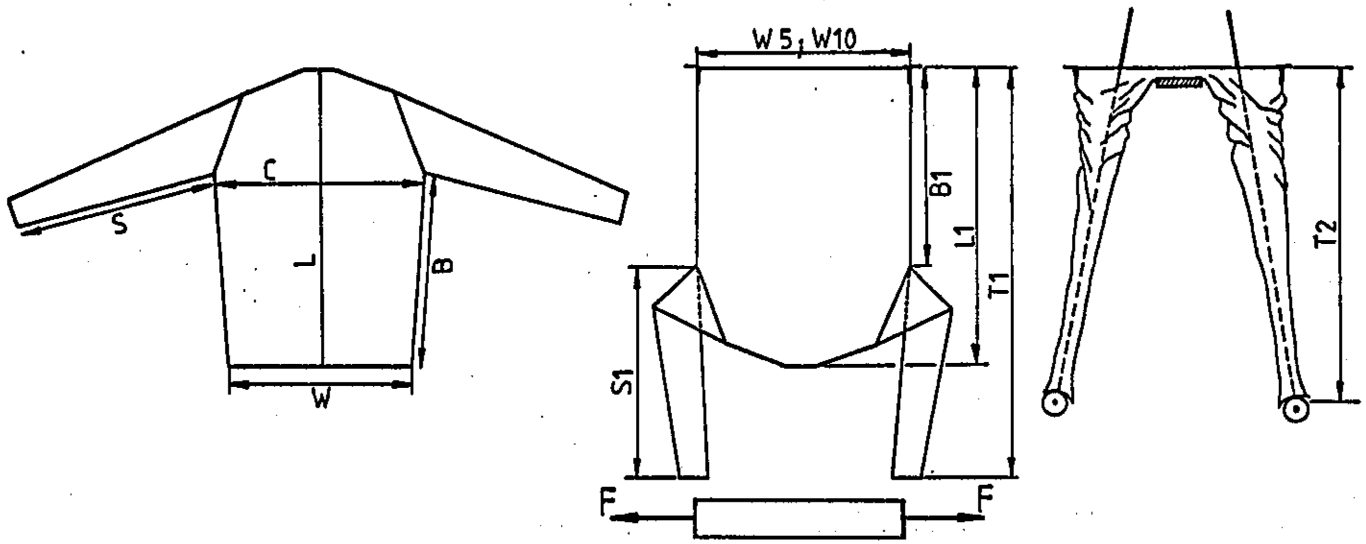


TABLE 4.3:

Data on Garment Dimensions(cm)

MODEL	SIZE	C in	C cm	W	L	B	S	T=B+S	W5	W10	L1	B1	S1	T1	T2
2320 Q. CRIMPLENE Ladies'	14	18.3	46.5	38.5	53.0	30.5	42.0	72.5	46.5	51.0	54.0	31.0	43.0	75.0	68.0
	16	19.1	48.5	40.6	56.0	32.0	43.5	75.5	49.5	55.0					
	18	21.1	53.5	49.0	55.0	30.0	45.0	75.0	55.5	62.0					
	20	21.9	55.5	47.5	59.0	31.5	44.5	76.0	56.0	63.5					
1016 Q. ACRILAN Men's	36	18.3	46.5	38.0	62.0	39.0	49.5	88.5	42.5	45.5					
	38	18.9	48.0	41.0	59.0	36.5	45.0	81.5	45.5	47.0					
	40	19.8	50.3	42.0	61.0	40.5	48.0	88.5	46.0	50.0					
	42	20.5	52.0	44.0	65.0	39.5	46.0	85.5	46.5	51.5					
	44	22.0	56.0	47.0	66.0	40.5	45.5	86.0	53.0	60.5	71.0	42.0	49.0	91.0	78.0
2536 Q. LAMBSWOOL Men's	36	18.7	47.5	39.0	63.5	39.5	54.5	94.0	42.5	45.0					
	38	18.3	46.5	40.0	64.0	40.5	43.5	84.0	44.5	46.5					
	40	21.5	54.5	40.5	68.0	44.0	53.0	97.0	49.0	52.0					
	44	21.7	55.0	47.0	74.0	46.5	54.5	101.0	52.0	57.5	77.0	52.0	57.0	109.0	87.0
3808 Q. SHETLAND Ladies'	10	17.1	43.5	35.3	56.0	35.5	44.5	80.0	39.0	42.0	58.0	38.0	45.0	83.0	70.0
	12	16.7	42.5	33.0	56.5	35.5	43.0	78.5	40.0	43.0					
	16	19.1	48.5	43.0	59.5	36.0	42.5	78.5	49.0	54.0					
	18	21.3	54.0	46.5	61.0	36.0	46.0	81.0	52.5	56.0					

TABLE 4.4: Data from the Chest Stretching Experiment (cm)

MATERIAL/STYLE	SIZE	CHEST TENSION (N) 0.5	1.0	1.5	2.0	2.5
1016 Quality Acrilan	36	47.5	48.1	50.0	51.3	52.4
	38	47.7	49.0	50.0	51.8	52.8
	40	51.0	52.5	54.6	56.0	57.2
	42	53.0	53.5	54.8	56.0	57.5
	44	57.8	58.5	59.8	60.6	62.3
2320 Quality Crimplene	14	47.7	48.6	50.5	51.3	53.0
	16	49.5	50.5	51.5	53.0	54.0
	18	54.2	55.8	57.7	59.0	60.1
	20	56.5	57.5	60.5	61.5	62.5
2536 Quality Lambswool	36	48.2	49.0	49.9	51.9	54.0
	38	47.0	47.6	48.5	50.0	51.5
	40	56.1	57.9	58.5	60.5	63.3
	44	55.9	56.8	57.8	59.3	63.1
3808 Quality Shetland	12	43.4	44.3	45.2	46.5	47.9
	16	50.5	51.1	52.1	54.0	55.7
	18	55.7	56.5	57.3	58.9	60.8

CHAPTER 5

RESEARCH INTO AUTOMATIC SIZING

5.1 Introduction and Objectives

Earlier in the feasibility study, the decision was taken to investigate the automatic sizing of knitted garments. According to the research carried out in section 4.2.2, the control dimension is the chest width which must be "measured" after applying a standard stretching force.

During the turning operation, the measurement of the width of the garments must be taken in kinematic conditions, that is, the turning arms, also used as part of the sizing system, are in a situation of movement.

The experimental phase was initiated however with a "static" apparatus. The author's intention was to start by verifying the essential of the sizing technique and then, according to the results obtained, move to successively more advanced experimental phases with the objective of simulating the conditions in which the sizing will occur in the final design.

5.2 Mark 1 Sizing Apparatus

The Mark 1 sizing apparatus is essentially the turning arms assembly, with two straight arms pivoted on a frame and connected by the swinging mechanism. The arm ends are nylon rollers according to the design of Fig. 4.15. Rigidly connected to the crank shaft of the swinging mechanism has been mounted a wheel and a protractor. Around the wheel there was a wound cable from where weights could be suspended to create the torque on the crank shaft. The maximum required torque is approximately 1.5 Nm (section 4.6.5). A radius of 30 mm has been selected for the wheel so that the torque of 1.5 Nm was reached by suspending 50 N on the cable.

When analysing the swinging mechanism (section 4.6.6), the torque on the crank shaft, using the simplified equation 4.1, was given by

$$T = 2 \times F \times a$$

with $F = 10\ R$ and $a = 0.03$ m, being R the force exerted by the rollers on the garment. Therefore, the torque, T, as a function of R, can be expressed by

$$T = 0.6\ R \tag{5.1}$$

The torque created by suspending the weight W on the cable wound on the wheel of radius r is given by

$$T = r \times W$$

With $r = 0.03$ m, T as a function of W can be expressed by

$$T = 0.03\ W \tag{5.2}$$

It is then possible to express R as a function of the weight W suspended on the cable by eliminating T between equations 5.1 and 5.2,

$$R = 0.05\ W \tag{5.3}$$

The following table gives the values of R, for different values of the weight W.

W(N)	10	20	30	40	50
R(N)	0.5	1.0	1.5	2.0	2.5

The garment was suspended on a provisional clamp so that the waist was assuming a rectangular shaped hole. The clamp level was adjustable so that the rollers could be positioned at the chest level.

5.2.1 The Experimental Procedure

The experiment consisted in applying increasing stretching forces on the chest of the garment by the rollers mounted in the arm ends, which has been achieved by suspending weights of increasing value on the cable. For each value of W, the corresponding value of the angle of rotation of the swinging mechanism crankshaft was read on the protractor and recorded.

Soon after starting the experiment, it was realized that the straight shape of the arms should be modified. Fig. 5.1 a) shows a photographic view of the first version of the Mark 1 apparatus. In Fig. 5.1 b) the garment is in position with the clamp adjusted so that the rollers are at the chest level. In Fig. 5.1 c) the torque is applied and it is clearly visible why the arms have to be reshaped. Two problems arose: One consisted of the interference between the arms and the two clamps, especially serious as the garment is wider and as the force increases; the other being the tendency for the portion of the arm that is inside the garment to establish contact with it. The second problem originated the situation where the force, designed to be applied on the chest of the garment, was spread over a large region and applied not only by the rollers, but also by all the portion of the arm inside the garment.

The problem was immediately solved by reshaping the arms as it is shown in Fig. 5.2. The relative position of the rollers remains the same, but the arms have been bent so that the area that would stay near the waist level was closer to the centre line. Apart from this modification, the experimental procedure has been the one already described.

The experiment was relatively crude at this stage, but the author's intention was to assess the system capabilities by inexpensive methods, rather than going directly to more complex rigs without enough guarantees that the basic principles w ere tested.

5.2.2 Results and Conclusions

The sample of garments used with the Mark 1 apparatus was the same as that used with the "chest stretching experiment" seen in section 4.6.3. As it will be seen later, it was a "bad" sample but the only one available at the time. On the other hand, it was possible to compare the results with those of the chest stretching experiment.

The results of the experiment are recorded in Table 5.1 for four different sets of garments. The chest width of each garment for the different applied stretching forces is recorded as a function of the angle β, the angle of rotation of the crank shaft of the swinging mechanism. The resolution on the readings of the angle β was 1/4 of a degree.

As for the chest stretching experiment, the results are plotted in terms of size versus chest width, here expressed by β and are represented for the four sets in Figs. 5.3 a) ,b), c) and d). Each line on each graph corresponds to one of the forces W being used. Visually comparing these four graphs with those of Fig. 4.29, the similarity is evident as it would be expected. However, as it was found during the chest stretching experiment, the expected linearity of the lines relative to one particular value of W is not clearly evident.

The values of Table 5.1 were then plotted in terms of force (W) versus β. The resultant graphs represented in Fig. 5.4 a), b), c) and d) are rather curious. In the set made of Acrilan, the garments labelled size 40 and 42 almost merge in the same line and the 36 and 38 are not very different from each other. A visual comparison of the garments has shown that those labelled 36 and 38 are very similar in overall dimensions as well as those labelled 40 and 42. The sample would be better labelled using the grades S (for small), M (for medium) and L (for large) as is becoming the practice with some retailers and chain stores. This is suggested in Fig. 5.4 a) by the hypothetical sizing.

In Fig. 5.4 b), the results for the Crimplene set are plotted. Garments labelled as sizes 14 and 16 show a very similar chest width. Again, an hypothetical sizing is suggested where these two garments are treated as being size 14; in this situation, size 16 is represented by the dotted line in a visionary manner.

The observation of the Lambswool set in Fig. 5.3 c), shows size 36 being larger than the 38 which is rather strange. By a careful examination, it was found that, for some reason, the paper labels used to identify the sizes had been exchanged between the two garments. On the other hand, garments labelled 40 and 44 are very similar which is confirmed by a visual comparison. Therefore, admitting that the one labelled 40 is in fact a size 44, it is possible to visualize the hypothetical lines relatives to the missing sizes 40 and 42 as shown in Fig. 5.4 c) by the dotted and chain dotted lines respectively. In Fig. 5.4 d), the missing size 14 of the Shetland set is also represented by the dotted line in a visionary manner.

These results, however not completely clear, helped to formulate the hypothesis that, for a sample with a considerable number of garments per size, the result of a similar experiment would be as represented in Fig. 5.5. Each size would be expected to spread over a band due to small variations in dimensions within garments of the same size.

5.3 Mark 2 Sizing Apparatus

Following the first set of experiments, some improvements have been made to the apparatus as shown in Fig. 5.6, in order to take it closer to what would be the sizing system in the final design. The torque is applied, as designed in section 4.6.6, by a 12 mm bore, 25 mm stroke pneumatic actuator. Based on its compactness, the Mecman 1300 DV 12-25 double acting pneumatic cylinder[31] has been selected. It is pivoted at rear by a trunnion mounting and at the front by a clevis type mounting.

The distance between rollers is monitored by a potentiometric transducer rigidly connected to the swinging mechanism crank shaft. The mounting procedure is shown in the detail drawing of Fig. 5.7. A close-up view of the swinging mechanism is shown in Fig. 5.8 where the wheel and protractor used with Mark 1 version are still in place. The selected angular displacement transducer is a RS conductive plastic servo potentiometer. It is very compact and light which is convenient, as in the final design the arms are one of the moving assemblies. Its shaft is mounted in two bearings for low torque and long life. The electrical rotation is 340° and it shows a very good linearity of $\mp$ 0.5% [32].

The garment is clamped by two "bulldog" type clips at the two opposite seams on the waist band. The clips are held by cables which, after passing over two idlers, hold weights at the other end.

The pneumatic cylinder is switched on-off by means of a solenoid operated two position five port valve. The stretching force applied by the rollers is controlled by adjusting the air pressure on a pressure regulator. The signal from the position transducer is then amplified and fed into a voltmeter or a chart recorder. Fig. 5.9 shows the pneumatic and electric layout of the apparatus.

5.3.1 The Experimental Procedure

The experiment was similar to the one carried out with Mark 1 sizing apparatus. There were, however, some differences apart from those introduced by the use of the pneumatic cylinder and transducer. The garment was held by the clips and balanced by weights suspended on the cables. In this position the rollers were inside the garment whith the waist just over the rollers. The valve was operated to swing the arms outwards, stretching the garment. This situation is shown in Fig. 5.10 a). By moving the counterbalancing weights down, the garment was moved upwards. This operation was carried out carefully so that the garment could be stopped when the rollers were at the chest level. This situation is shown in Fig. 5.10 b). For that position, the voltage on the voltmeter was recorded against the air pressure for each size within the same material-style.

5.3.2 Results with Mark 2 Sizing Apparatus

In order to assess the capabilities of the system, the first sample to be tested had already been subjected to the "trimming" operation as described in section 2.5.

The sample was made up of 3 sets of garments, each one having 4 sizes and 6 garments per size. The materials of the 3 sets were 2606 Courtelle, 1708 Lambswool and 2135 "bubble" stitch Shetland Wool. The size charts for the sample are given in Appendix 3.

The results of the experiment are shown in Table 5.2. For each material-style, the garments of one size were numbered 1 to 6. According to section 4.6.6, the pneumatic cylinder was designed for a air pressure of 4 bar. In the experiment, pressures of 3, 4 and 5 bar were used to assess the behaviour of the system and to decide the pressure to use in the final design.

The results of Table 5.2 are graphically displayed in Fig. 5.11, 5.12 and 5.13 for the 3 sets of garments. The chain dotted lines represent the average values for each size. The values of the chest width of each garment, translated into voltage, group according to size for each value of pressure as was expected. For the 2606 Courtelle set, the 4 sizes fall into bands very distinct and separated. The result is equally good with the 1708 Lambswool set, the only difference being that sizes 40 and 42 are a little closer together than 38 and 40 or 42 and 44. However, no overlapping is present at any time. The observation of Fig. 5.14, where the results with the 2135 Shetand wool are represented, shows a considerable overlapping between sizes 40 and 42. A justification was found for this size overlap on a careful examination of its size chart (see Appendix 3). The finished measurements for the chest width (taken 1 cm below armhole) progress in steps of 3 cm. However, there is an admissible tolerance of -1 +2 cm, certainly to allow for the high elasticity of the "bubble" stitch. Hence, if one garment size 42 is in the lower limit of the tolerance, it will have 56 - 1 = 55 cm chest width. By the same reasons, a garment size 40 on the higher limit of the tolerance will have 53 + 2 = 55 cm. This justification has however its weakness. In fact the overlapping does not take place between sizes 38 and 40 or 42 and 44 as it would be expected following the same logic. The answer may have to be found by the analysis of some knitting details, particularly the number of loops at the chest level for the different sizes. For this material-style the facts would suggest that a sizing based in 3 sizes, small (S), medium (M) and large (L) would be a better proposition.

A second sample has then been collected and tested, this one being of garments in a non-trimmed condition, that is, the garments were in the state as they reach the turning department. The sample was made up of 12 garments of the same material/style, divided in four sets of 3 garments per size. The data of the test is collected in Table 5.3 and graphically displayed in Fig. 5.14. The analysis of this diagram shows a separation between the sizes with only two garments in the "wrong" place: One garment labelled size 40 appears as 42 while one labelled 42 appears as 40. It is difficult to find an acceptable explanation for this fact. The most reasonable is, however, given by differences in the yarn properties or knitting machine adjustments that caused a more "tight" fabric in one situation or a more "loose" fabric in the other. Other possible justification comes from the the assembling of the different knitted panels. The operator can join the front and back panels making the seam closer or further away from the edges of the fabric, resulting in a slightly wider or narrower garment. The result is the production of a garment that is size 40 according to chest width when intended to be a size 42, or on the contrary, the production of garment size 42 when the intention was to produce a size 40. This situation is not completely unusual and according to the technical staff of the company that supplied the sample, can cause very serious problems in terms of the quality of the garments. The most evident of these problems is given by a garment that was knitted "tight" and was later "corrected" by the framed steaming of the trimming operation to a size not suitable to its natural dimensions. The result is an abnormal shrinkage in the first domestic wash!

5.3.3 Assessment of the Friction Forces between the Rollers and Garment

The Mark 2 Sizing Apparatus has been used to assess the friction forces resulting from the interaction between the rollers and the garment. The knowledge of the magnitude of these forces would give valuable indications for the design of the clamping system, as they are pulling the garment off the clamp during the turning operation.

The garment was in position on the "bulldog" clips, balanced by the weights on the other side of the cable. The pressure was supplied to the pneumatic cylinder which caused the garment to be stretched by the rollers at a level near the waist. Weights were then added to both cables until the movement of the garment was imminent. The weights on each cable represent the force that is pulling the waist off the clamp during turning.

The results are collected in Table 5.3. The pulling force on each clamp is always less than the weight of the garment, in the region of 70 to 75% for a stretching force achieved with 5 bar pressure.

5.3.4 The Size-Mass Relationship

The mass of the garments of the two samples has been measured with a digital scale; the data (Tables 5.5 and 5.6), is graphically displayed in Fig. 5.15 and 5.16, respectively for the trimmed and non-trimmed samples.

The trimmed sample shows a good separation between the sizes by their mass for the Lambswool set and with one odd overlap for the Courtelle set. The situation is rather different with the Shetland wool set. Sizes 42 and 44 completely overlap and there is an odd overlap between sizes 40 and 42. Only size 38 is completely defined. This could be explained by the fact that both sizes 42 and 44 have the same length (see Appendix 3). If the length, in terms of the total amount of yarn on the garment, is more significant than the difference in chest width, the result could be explained.

The non-trimmed sample shows a distribution by mass coincident with the manufacturer's labelling. This fact gives some support to the justification given in section 5.3.2 for the difference in the chest dimension of two garments of this sample. Their mass is in accordance with the intended size which means that the correct amount of yarn has been used. Their chest dimension is smaller or larger than the intended size which means different conditions during knitting or assembling.

5.3.5 Conclusions from Mark 2

The experimental phase carried out with Mark 2 sizing apparatus has been a big step forward in the investigation of an automatic sizing system. The main conclusions can be summarized as follows:

1. The hardware of the sizing system, comprising the swinging mechanism, the actuator and the position transducer gave sufficiently accurate results.

2. The hypothesis formulated in section 5.2.2 is validated. The system can be used for quality control purposes as it bases the sizing on the most characteristic physical dimension of the garment: The chest width.

3. The investigation of the size-mass relationship has been carried out for comparison purposes only. Though it gave results in accordance with the manufacturer labelling in most of the cases, the situation that arose with the Shetland wool sample, displayed in Fig. 5.15, is enough to rule it out.

4. The behaviour of the garments at 3, 4 or 5 bar pressure on the pneumatic actuator is very similar. In future experiments 4 bar will be used, unless new factors arise.

5.4 Mark 3 Microprocessor Controlled Sizing Rig

In Mark 1 and Mark 2 sizing apparatus, the chest width of the garment has been "measured" in static conditions, that is, the rollers were stationary at the chest level of the garment when the reading was taken from the voltmeter. The objective now was to simulate the kinematic conditions of the final design, where "measurements" have to be taken with the arms in a situation of movement through the garment. In relative terms, the situation was the same as if the arms were stationary and the garment was moved upwards. This was relatively easier to achieve without having to introduce a further hardware, than moving the arms assembly and keeping the garment stationary. In a sense, this had already been achieved with Mark 2, but some development was necessary.

Fig. 5.17 shows the first version of Mark 3 sizing rig. The cables from each "bulldog" clip have been joined together and the single cable has been wound onto a wheel to which a slotted disc was attached. On the end of the cable, weights were suspended to counterbalance the weight of the garment. By moving the weights down, the garment was moved upwards. With the arms stretching outwards, the rollers were following the opposite seams of the garment body until finally entering the armholes.

The signal from the position transducer was then fed into a microcomputer after passing through an analog-to-digital converter. The slotted disc, that was rotated by the cable that moved the garment, was used to generate pulses to monitor the relative position between garment and rollers.

As is known, for the success of the turning and sizing operations, it is of crucial importance to sense the moment the rollers reach the armholes. This dictates the moment when a signal must be generated to start the movement of the "lift neck device". In terms of sizing, it also means the start of a sequence of instructions with which the machine fetches the "measurement" taken 2 cm before (the width at the standard chest level), and finds the corresponding size. This can be accomplished by comparison with the boundary values of the different sizes for the material/style being processed. To achieve that objective, several ideas have been considered.

A "sensor" on the rollers, basically made with a microswitch, has been one of the approaches. When the rollers are stretching the garment, the resisting force against them would switch off the microswitch. When the rollers enter the armholes, the fabric resistance disappears and the microswitch goes "on". The use of the force transducer mentioned in section 4.6.6 to sense the bending moment on the arms would be an alternative. If the transducer is measuring the resisting force applied by the garment against the rollers, this force would collapse when the rollers enter the armholes and could be used to generate the required signal.

With the introduction of the microprocessor to control the rig, the solution to the problem could be found without the need of any extra hardware. The idea is based on the fact that, if "measurements" are taken in steps of 1 cm as suggested in section 4.7.4, their value will be increasing progressively as the garment is widening from waist to armholes. When the rollers reach the armholes, they will move rapidly outwards and the distance between them will increase very sharply. The microprocessor could then be instructed to find this sudden increase in the distance between the rollers and initiate the sizing procedure.

In the final stages of the experimentation with Mark 2 apparatus, the shape of the arms was optimized in order to get the sharpest increase in the above mentioned distance between the rollers when entering the armholes. The output signal from the position transducer was fed into a chart recorder and by moving the garment upwards, the evolution of the signal was registered and analysed. In Fig. 5.18 are represented two characteristic outputs. In Fig 5.18 a) the arms used were those of Mark 1 apparatus. The sudden increase in the voltage output is noticed around 5 to 5.5 mark but is not very sharp. On the other hand, using the smoothly curved arms represented in Fig. 5.17, the sudden increase in the voltage output at the armholes is very well defined by mark 4.4 on the chart recorder output as seen in Fig. 5.18 b). The garments used in the two examples are of different sizes. In both figures, the considerable tortuosity of the portion of the line corresponding to the garment width before the armholes, is due to the fact that, during these tests, the garment was moved by manually pushing down the counterbalancing weights. Under these circumstances the speed of the garment could not be kept at a constant level.

In the final version of the Mark 3 sizing rig shown in Fig.5.19, a pneumatic actuator of the rodless type, with adjustable speed by an exhaust flow regulator, has been used to move the garment at constant speed.

5.4.1 The Digital Transducer to Monitor the Relative Position Garment/Rollers

In both the experimental rig and the final design, only the relative position between the rollers and the garment is required. This is dictated by the fact that, after having detected the armholes, the system must be able to step back 2 cm and fetch the value of the chest width of the garment.

The solution to this problem is represented in the photographic close-up of Fig. 5.20. The cable that moves the garment is wound on a wheel, so that the linear speed of the cable is the same as the linear speed of the periphery of the wheel. Rigidly attached to the wheel is a slotted disc moving through a slotted opto switch. Every time a slot of the disc passes through the opto switch, a pulse is generated to instruct the computer to "read" and store the value of the garment width transmitted from the position transducer and already converted into digital form. The geometry of the wheel and disc are designed so that a pulse is generated every centimetre of the cable/garment displacement. This is simply achieved by having 10 equally spaced slots on the disc and a wheel diameter of 31.8 mm, that is, a circumference of 10 centimetres.

5.4.2 The Amplification of the Angular Displacement Transducer Movement

The maximum angle of rotation of the swinging mechanism crank shaft is 34° and the electrical rotation of the RS servo potentiometer is 340°. The microcomputer used on the rig is a Rockwell AIM 65 with a 6502 micoprocessor which is an 8-bit machine. Hence, the analogue signal from the potentiometer can be digitised in up to 2^8=256 discrete values. To achieve this result, the potentiometer should be geared up with a 1:10 ratio.

In order to reduce backlash problems, a "Flex-E-Grip" miniature timing belt and "No Walk Pulleys", manufactured by Winfred M. Berg Inc. have been used. The highest available ratio is obtained using pulleys with 120 and 14 teeth. The ratio is then r = 120:14 = 8.57 and the electrical rotation of the position transducer will be

$$34^\circ \times 8.57 = 291^\circ$$

Under the circumstances, the resolution on the microcomputer will be 291°: 256 = 1.14° of the potentiometer rotation.

A close-up photographic view of the new arrangement is shown in Fig. 5.21. It provides adjustable centres by pivoting the mounting support. The selection of the belt is made in Appendix 5.

5.4.3 The Rockwell AIM65 Microcomputer and the 6502 Microprocessor

On grounds of availability a Rockwell AIM65 microcomputer has been used. Its central processing unit (CPU) is the widely used R6502 8-bit microprocessor[33]. It has an 8-bit bidirectional data bus, 8-bit accumulator and registers and operates at 1 MHz, which means that the instruction execution time is the number of cycles in microseconds. It is combined with memory and input/output integrated circuits to form the microcomputer. These include the R6522 Versatile Interface Adapter (VIA) which is entirely user dedicated and has two 8-bit I/O ports, the R6532 RAM-Input/Output Timer (RIOT), the R6520 Peripheral Interface Adapter (PIA), the R2332 Read Only Memory (ROM) for the operating system, and the R2114 Read/Write Random Access Memory (RAM). It incorporates a 20 column thermal printer for permanent record of commands, data and programs, as well as a 20 characters visual display in parallel with the printer. Other I/O devices are the 54-key full size keyboard and a remote controlled audio cassete recorder for permanent storage of programs and data.

5.4.4 The Analog-to-Digital Converter

In section 5.4.2, the need to digitise the signal that translates the garment width was mentioned. This is due to the fact that computers cannot handle analogue signals. A common method of dealing with this problem is to employ an analog-to-digital converter (ADC), as schematically shown in Fig. 5.22[34].

According to Zaks[35], there are three methods of A/D conversion: successive approximation, integration, and direct comparison. It is not under the scope of this thesis to explain in detail the different A/D conversion techniques but it is generally accepted that the successive approximation is the most frequently used with microprocessors as it is characterized by high speed, high resolution and low cost[35,36]. Analog-to-digital converters of this type are commercially available as complete units at relative low cost.

For the present application, the National Semiconducter ADC 0808 8-bit microprocessor compatible A/D converter has been selected[37]. It is a monolithic CMOS device containing a high impedance comparator, a 256 R voltage divider with an analogue switch tree and a successive approximation register. Conversion is performed using a successive approximation technique where the unknown analogue voltage is compared to the resistor tie points using analogue switches. When the appropriate tie point voltage matches the unknown voltage, conversion is complete and the digital output contains an 8-bit binary word corresponding to the unknown voltage. The conversion is performed in 100 μs in a ratiometric system, that is, the voltage being measured is expressed as a percentage of full-scale. This is convenient as the potentiometer used as a position sensor is in fact a ratiometric transducer. The position of the wiper is directly proportional to the output voltage which is a ratio of the full-scale voltage across it.

When interfacing an A/D converter of the successive approximation type to a microprocessor, at least three control signals are required: the "start conversion" signal from the microprocessor to instruct the ADC to start the conversion; the "end of conversion" signal, which tells the microprocessor that the conversion has been completed; finally an "output enable" signal has to be generated by the microprocessor to release the data from the ADC output register onto the data bus. A problem now arises in that the ADC is much slower to complete the conversion than the microprocessor to execute the corresponding instructions. As a consequence, the microcroprocessor will try to read the data long before it is available. According to Cluley[38], one way of avoiding this problem is to interpose a delay loop between the two referred instructions to give the ADC time to complete its conversion. This could be achieved by a fixed delay loop, with a duration somewhat greater than the conversion time. However, in order to optimize the program, the loop is directly terminated as soon as the data becomes available. This is accomplished (see section 5.4.8) by reading the interrupt flag register and checking when CB1 interrupt flag is set. This will mean that the conversion is finished and the data can now be stored in the appropriate memory space.

5.4.5 The Experimental Procedure

This experimental phase has been initiated with the first version of the Mark 3 sizing rig shown in Fig 5.17. After holding the garment on the "bulldog" type clips, the arms were actuated to establish contact with the garment and the rollers positioned near the waist band. The garment was then moved upwards which was achieved by pushing down the counterbalancing weights at the end of the cable. Figs. 5.23 a) and b) are photographic views of the initial and final positions respectively. By this procedure, the distance between the rollers, taken at 1cm intervals of the garment displacement, was stored in the form of a row of hexadecimal values in the computer memory. From the starting position, up to the moment the rollers go into the armholes, these values translate the garment width. Details of the software are given in section 5.4.8.

Before making any attempt towards the sensing of the moment the rollers move into the armholes, it was necessary to just "measure" the garments under these kinematic conditions and analyse the results in order to realize how the distance between the rollers progresses. A program has been prepared to fulfil this requirement which is named "TSS12" in section 5.4.8. After instructing the computer to start running the program, the arms were then tensioned out and the identification of the garment input through the keyboard. For example SHT12 for a Shetland garment labelled size 12. The computer was then instructed to start storing "measurements" as soon as the garment was moved.

Having moved the garment as explained above, until the rollers touch the shoulders, the computer was instructed to print out all the numbers corresponding to the distance between rollers at 1 cm intervals. The graphic display of these numbers would give the garment "profile", as well as the path of the rollers after entering the armholes.

This procedure has been carried out with a comprehensive selection of garments. The print out was then graphically displayed for each garment and its shape analysed. As an example, the results with a Shetland wool garment size 12 and an Acrilan garment size 40 are shown in Figs. 5.24 and 5.25 respectively. The shape of the lines resulting by joining together consecutive points, does show two very distinct areas: One corresponding to the garment body, widening from the waist (W to A); the other corresponding to the area from the armholes to the beginning of the sleeves (A to S). The analysis of similar results with a comprehensive number of other garments has shown that the horizontal difference between points A (last "measurement" before armholes) and B (see Fig. 5.24), is always bigger than 10 decimal counts or hexadecimal 0A. This conclusion has been important in preparing the software capable of detecting the transition of the rollers to the armholes.

Once point A is detected, the computer can be instructed to step back 2 centimetres (2 counts) and fetch the "measurement" at point C, the defined standard chest level. In the example of Fig. 5.24 the chest width of the garment is translated by the hexadecimal value 4F while in the one of Fig. 5.25 is 86 (hex.). A small difference can be noticed between the two figures. In Fig. 5.24, point A still belongs to the garment body, being exactly on the transition to the armholes. On the other hand, in Fig 5.25, point A corresponds to a situation where the rollers are already accelerating outwards through the armholes. However, the horizontal distance between A and the previous point is not large enough to give a clear indication of that situation. The computer may have to wait until point B appears, to get the clear indication that the armholes have been reached. As it can be seen, in practical terms that makes no difference to the number picked up to translate the chest width of the garment. In fact, in the region just before the armholes, the points fall on a small portion of straight line. Hence, the number that is picked up is the same stepping back 2, 3 or even 4 centimetres. This finding is reflected in the next stage, where the computer is instructed to step back 3 centimetres to fetch the chest "measurement".

With the results and conclusions of this experiment, the software has been modified so that the computer could find the transition to the armholes and stop taking more "measurements". The hexadecimal number corresponding to the chest width was then selected and displayed. The software was also rearranged so that the number of "measurements" was displayed as well. If the position to start taking measurements is standardized, this number can be related to the garment length along the seam from the waist to the armhole. However, it has been already seen that "garment length" is not a good sizing parameter. Furthermore, with this rig, it was impossible to make sure that the garments were accurately positioned at the start, with the rollers at the same waist level. During the experiment, this number has been recorded with the sole intention of demonstrating this other feature of the system. The program is named "TSS13" in section 5.4.8.

As far as the rig is concerned, the final version of the Mark 3 shown in Fig. 5.19 has been used. The procedure is similar to that of the first version, the only difference being in the fact that the garment is moved at a reasonably constant speed by means of a long stroke pneumatic actuator to which the cable is attached. Fig. 5.26 shows a photographic sequence of the experiment. In a) is represented the starting position, the rollers already tensioning out the garment near the waist band. In b) the garment is moving upwards, the rollers being midway between waist and armholes. In c) the rollers are at the chest level, about to move into the armholes. In d) is represented the final position; the rollers are well into the armholes in their outmost position. The curvature of the arms, provided for the reasons explained in sections 5.2.1 and 5.4, gives a helpful "lead-in" into the sleeves which will improve the turning of the garment.

5.4.6 Results with Mark 3

The final experiment has been carried out with a sample of garments reference 0606 Shetland wool. The sample was in the conditions as it goes to the turning room, that is, not "trimmed". It was made up of 5 sizes with 12 garments per size. The garments have been identified by numbering them from 1 to 12 within each size. For example, SH/38.11 means shetland, size 38, number 11. The computer print out with the results of the experiment for the set labelled size 36 is reproduced in table 5.7. For each garment, the identification is printed followed by two hexadecimal numbers in the first row. The first on the left is the number of "measurements" which gives the distance from the start near the waist to the armholes, in centimetres. It is relatively irrelevant because of the previously explained difficulties in establishing the waist level position at the start. The second on the right is the number that translates the chest width of the garment, this time taken 3 cm before reaching the armholes. Next, all the numbers corresponding to the garment width from waist to armholes are printed, five per row.

Concentrating for example on the first print out for the garment identified by SH/36.1, the "length" is 2B (hex) or 44(dec). That is 44 cm from the start near the waist to the detection of the armholes. The chest width is given by 52 (hex). Looking now at the last numbers in the sequence, it is possible to realize that the computer was "alerted" to the presence of the armholes by the sudden jump in the garment width from 61 to 6E which is 13 (dec). Therefore 61 is the last "measurement" before the rollers have entered the armholes. Moving back 3 steps, the corresponding number is 52.

Fig. 5.27 is a graphic display of the chest width for all the 5 sizes of the sample, obtained by this method. The respective data is shown in table 5.8. From the graph, it is clearly visible how the various sizes separate with only 2 overlapping cases out of 59, which represents just over 3% (garment 38.12 was found faulty, hence was not tested). They are garments 44.4 which would be better sorted as a

42, and garment 42.4 which appears on the top limit of size 40 band. From the results of the experiment, an hypothetical configuration of size boundaries is proposed for this material-style. For example, size 40 would be limited by hexadecimal 77 and 88 admitting that the boundary values belong to the smaller size.

After intensive tests, the boundary values could be established for each material-style. They would be automatically fed into the appropriate computer memory locations once the identification code is input to the machine every time a new material-style is processed.

5.4.7 The Size-Mass Relationship

The procedure described in section 5.3.4 entirely applies to the present one. The data on the mass of the garments is shown in table 5.8 and is graphically displayed in Fig. 5.28.

The distribution by mass is consistent with the labels for sizes 36, 38 and 40 with the odd exception of garment 38.10 being rather light for its intended size. On the other hand, sizes 42 and 44 completely overlap by mass while the chest width gave a distinct separation. The size chart could not be obtained, but the possible reasons for the fact are the same given in section 5.3.4 for the overlapping by mass of sizes 42 and 44 on another sample of Shetland wool garments.

5.4.8 The Software Design

In this section the software, designed to cope with the different phases of the experimentation with Mark 3 sizing rig, is described and analysed in some of the more important details.

In engineering applications, such as this, the computer is working in "real time" or "on line", directly controlling the mechanical and electrical hardware. During the research, the microprocessor is part of the microcomputer for easy programming and the need for constant changes and readjustements. In the final application, a "dedicated computer" must be used. This is a microprocessor based system, built for the very purpose of the machine, having the software permanently stored in EPROMs.

Writing and optimizing the software can take as much time as the design of the hardware. This phase of the work involves a thorough understanding of the architecture of the 6502 microprocessor as well as the Versatile Interface Adapter (VIA) and the general input/output procedure[33,36,39].

Fig. 5.29 shows the flowchart of the program identified as "TSS12", designed to "measure" the garment width under kinematic conditions (as described in section 5.4.5). The flowchart is in a very general and simplified form to give a quick insight into what is happening during the experimental procedure. The analog-to-digital conversion is included in the flowchart, as it is the microprocessor that sends a "start conversion" signal to the A/D converter, staying then in a waiting loop until the conversion process ends. It then "reads" the converted value into the accumulator from where it is transferred to the memory table.

The program itself is listed in the respective coding sheet-Program TSS12 in Appendix 4, where the sequence of instructions appears in machine code (the hexadecimal numbers corresponding to the 8-bit binary words that are recognized by the computer), and assembly language.

The analysis of the interrupt routine gives a total of 92 cycles which corresponds to an elapsed time of 92 μs, as the AIM65 is fitted with a 1 MHz clock. As stated in section 5.4.4, the conversion time of the A/D converter is 100 μs [37], which gives a total conversion/interrupt time of 192 μs. Rounding off this value to 200 μs, it is then possible to make a simple calculation to see how this time compares with the speed at which the garment is moved within the rig during the experiments.

The interrupt routine is called every time a pulse is generated by the slotted disc of the digital transducer. Hence, a minimum interval of 200 μs must be kept between pulses. As there are 10 slots on the disc, there are 10 pulses per revolution, and then a limiting speed corresponding to 2000 μs per revolution. The velocity of the garment is the velocity of the cable and also the linear velocity of the periphery of the wheel where the cable is wound. The following expression gives this linear velocity, v, as a function of the angular velocity, ω, and the diameter D.

$$v = \omega \times D/2$$

$$D = 31.8 \text{ mm (section 5.4.1)}$$
$$\omega_{max} = 2\pi/(2000 \times 10^{-6}) = 3142 \text{ rad/sec}$$

then $$v_{max} = 3142 \times 31.8 \times 10^{-3}/2$$

$$= 50 \text{ m/sec}$$

is the maximum velocity at which the garment can be moved without loosing any "measurement". This value must be compared with an actual velocity of around 1 m/sec to realize how much time the computer has to spare!

Fig. 5.30 shows the flowchart of the program identified as "TSS13". The procedure is similar to the one with "TSS12" in that the measurements of the garment width are taken at 1 cm intervals under kinematic conditions. After storing each measurement in the appropriate memory space, the computer is then instructed to search for whether or not the armholes have been reached by the rollers. Fig. 5.31 helps to illustrate the technique that has been used; the garment width is measured at regular intervals $\Delta h = 1$ cm. These measurements are D1, D2, D3, ..., Di,...,Dn. For each new value of D except for the first, the computer works out ΔD. While the rollers are running along the seams, the value of ΔD is relatively small as the garment is progressively widening towards the chest (see Figs. 5.24 and 5.25). Di represents the last measurement before the rollers enter the armholes. The rollers then move rapidly outwards so that the next measurement Di+1 represents a large jump from Di. The difference is now ΔDi. Every time the computer works out ΔD, it checks its value against a standard number that has been found during the first experimental phase with Mark 3 (section 5.4.5). The computer recognizes that the magnitude of ΔDi means that the rollers have just entered the armholes. It then stops the measurement procedure, goes back 3 places in the memory table where the numbers are stored and fetches the measurement corresponding to the standard chest level. The program is listed in the coding sheet-Program TSS13 in Appendix 4.

The interrupt routine is now longer with a total of 121 cycles or 121 μs. Adding 100 μs conversion time, the interrupt routine consumes 221 μs. Making a similar calculation to the one with TSS12 program with a rounded off value of 230 μs, the maximum velocity at which the garment can be moved is 43.4 m/sec.

5.4.9 Conclusions from Mark 3

The Mark 3 sizing rig has been designed to simulate the conditions in which the sizing of the garments takes place in the final design. Under these circumstances, the results obtained are in complete agreement with the conclusions taken from Mark 2.

The use of the microprocessor has been the key for the success of the idea of sizing while turning and represents a major advance towards the automatic sizing completely independent of any human intervention, as well as the possibility of introducing an element of quality control in the manufacturing process.

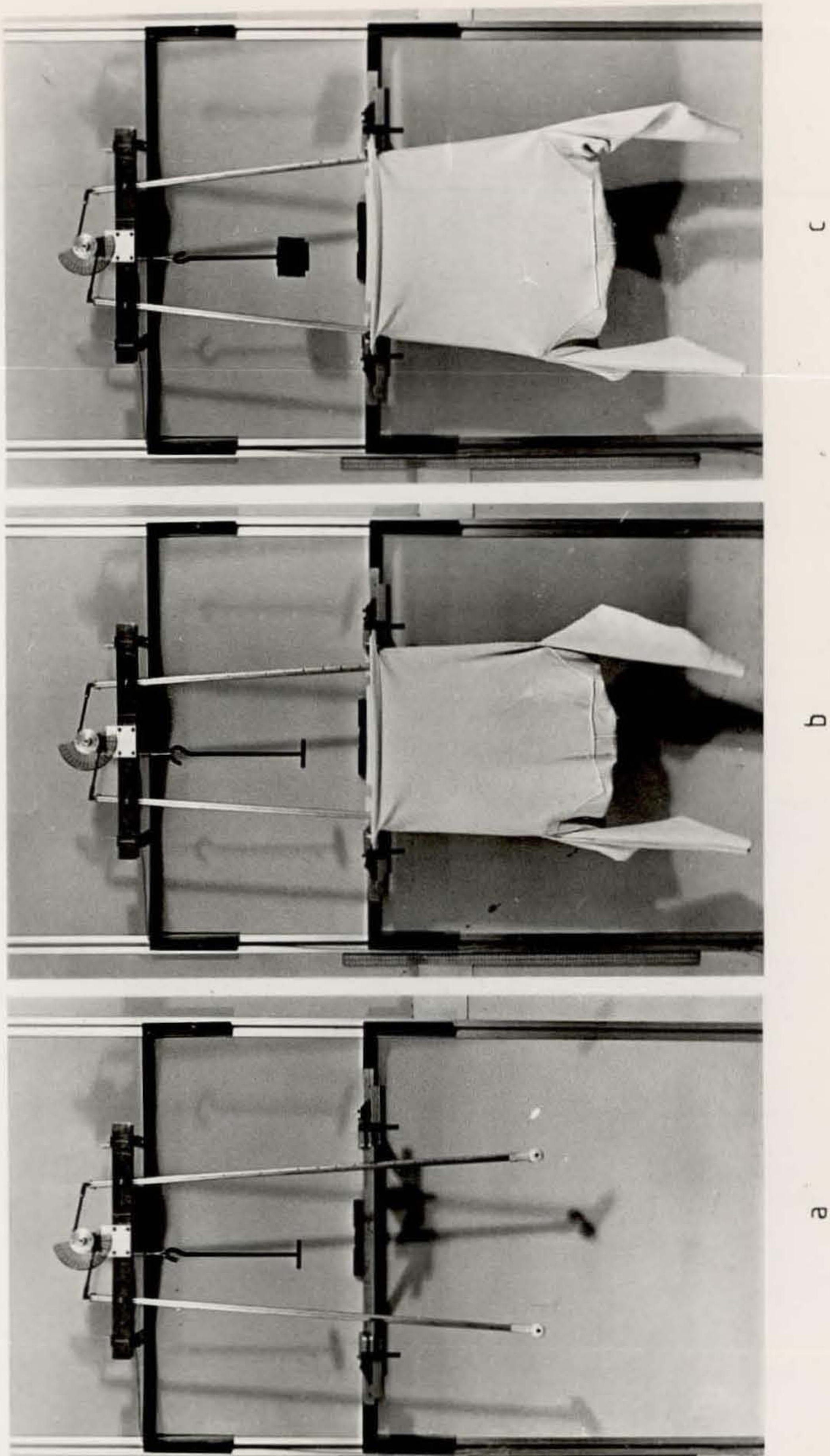
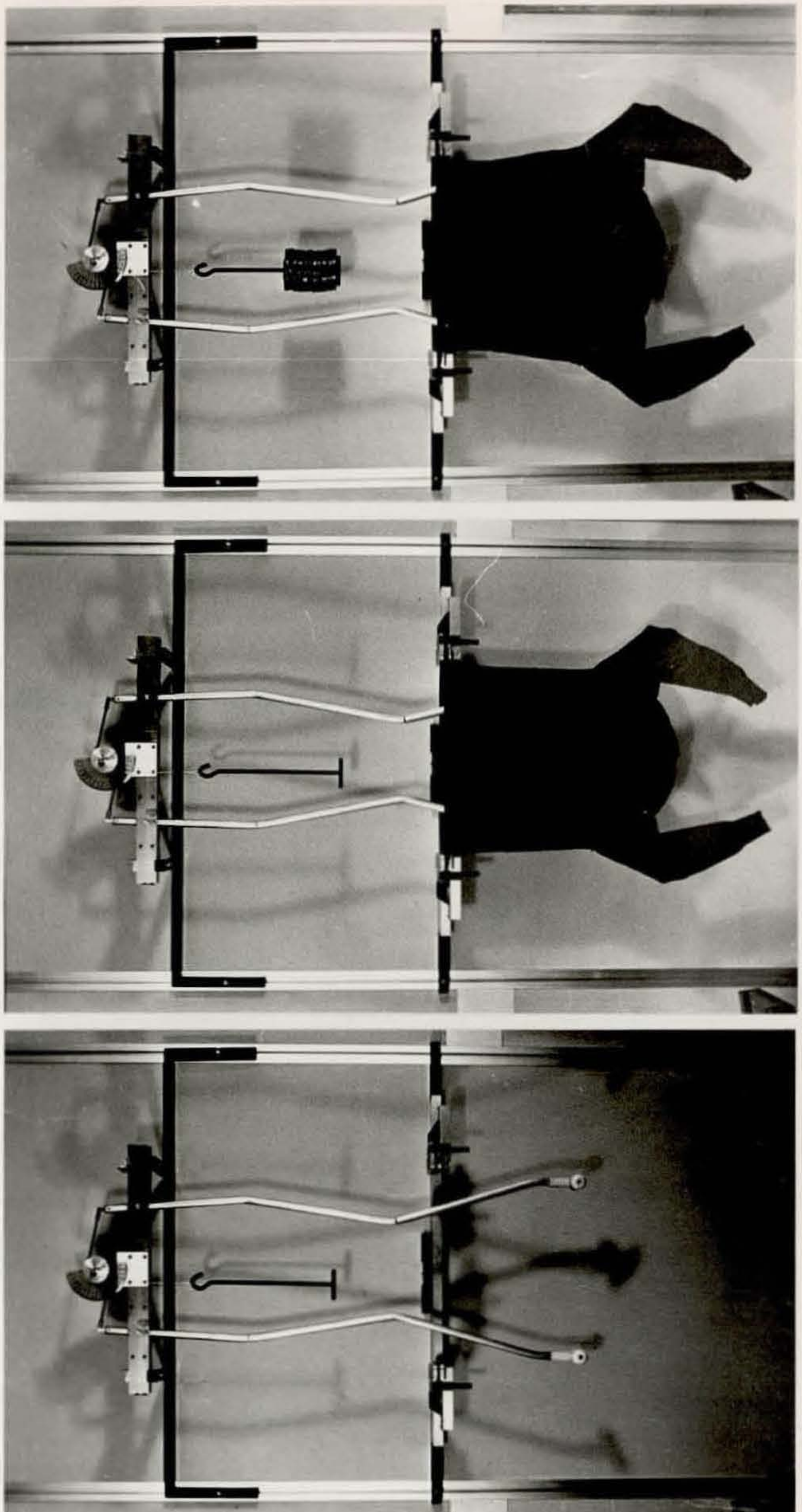


Fig. 5.1 Straight arms in Mark 1 sizing apparatus.

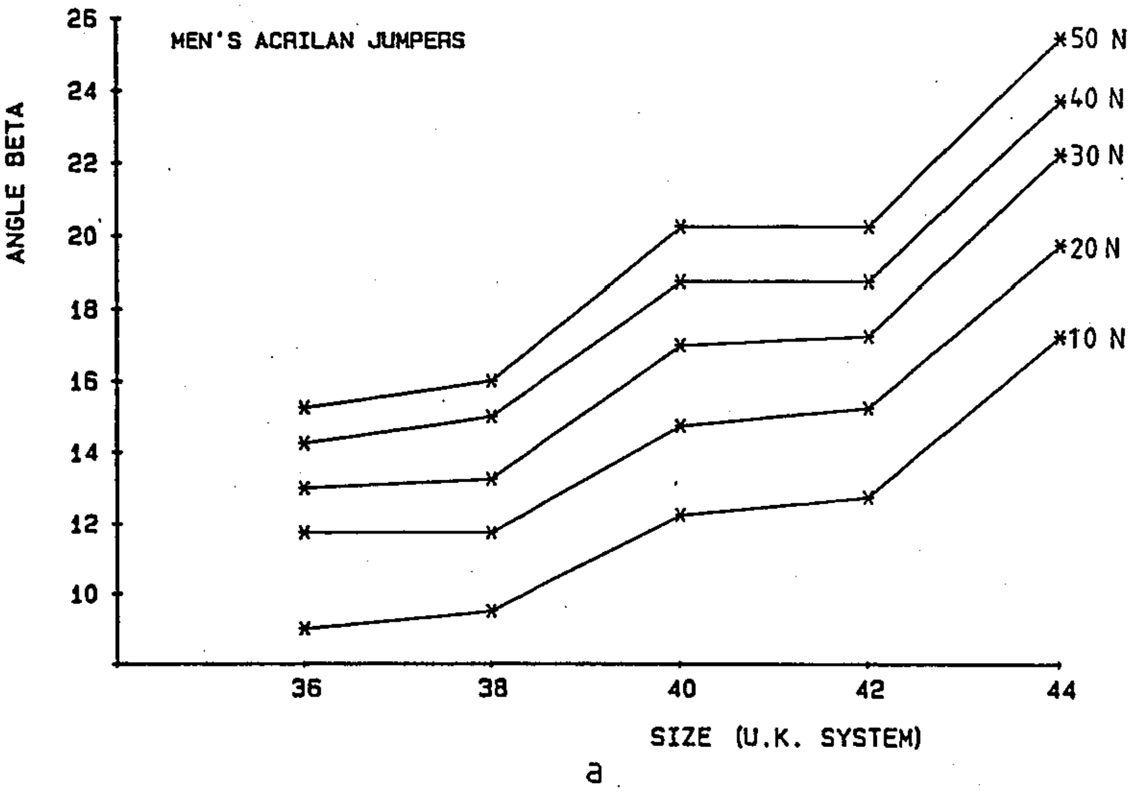


c

b

a

Fig. 5.2 Reshaped arms in Mark 1 sizing apparatus.



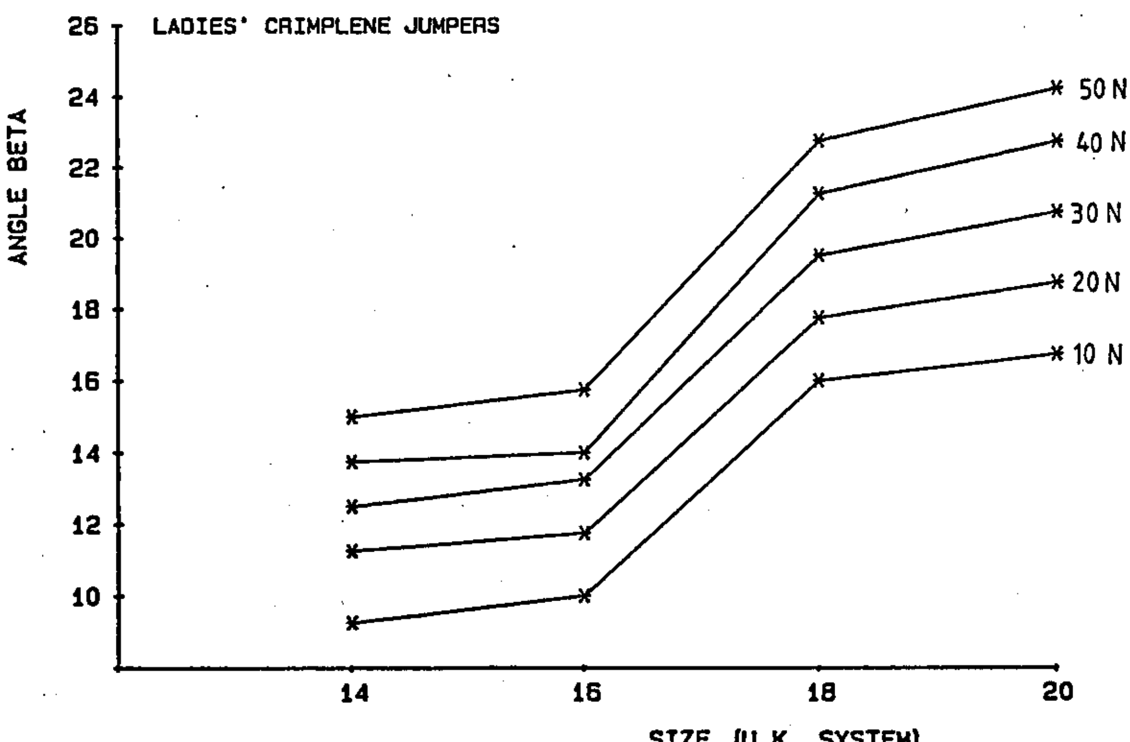
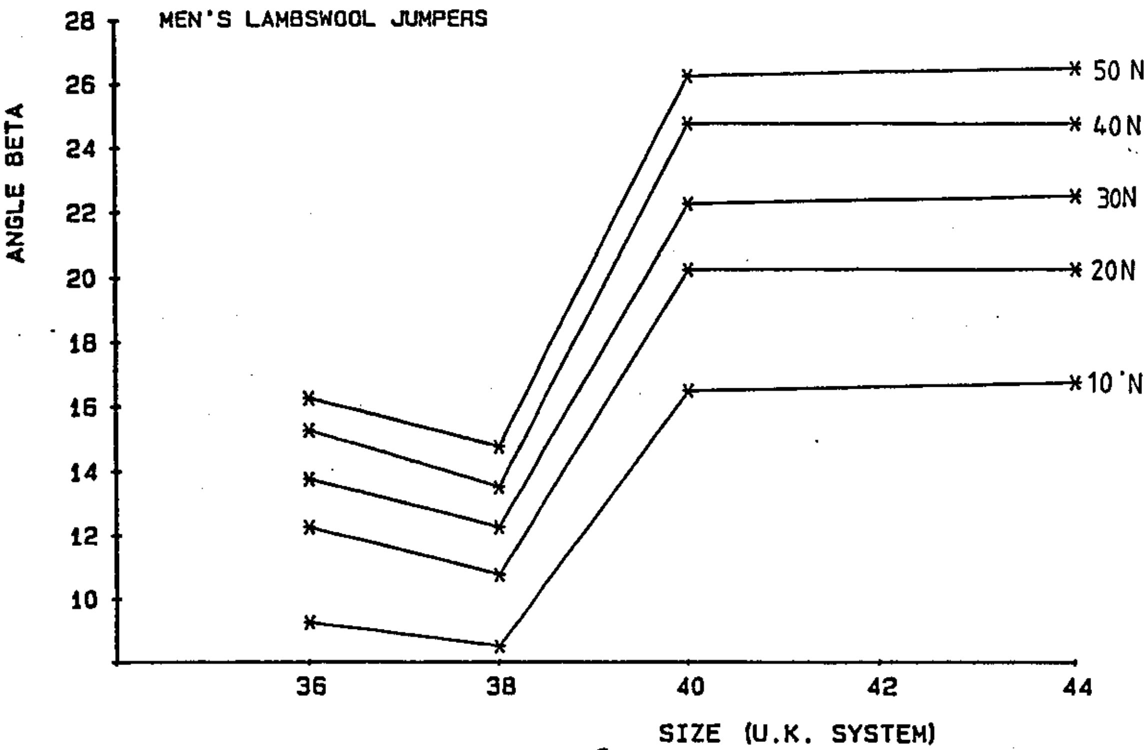
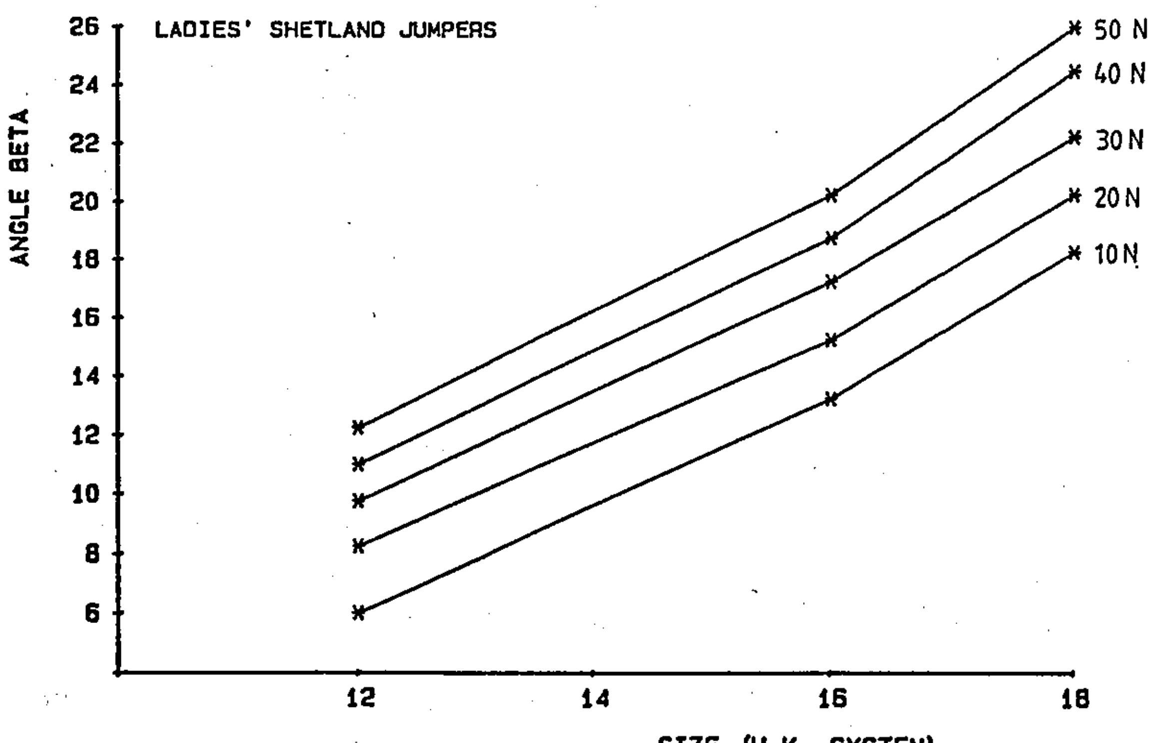


Fig. 5.3 Plot of size versus β for Mark 1 apparatus.

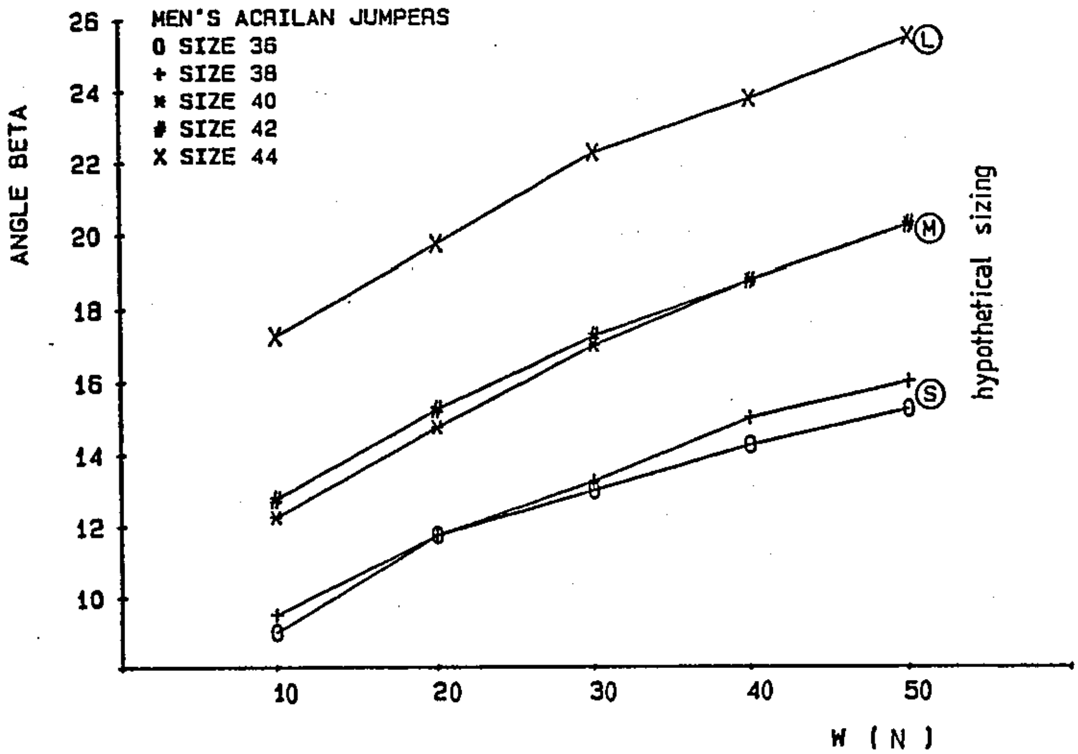


c

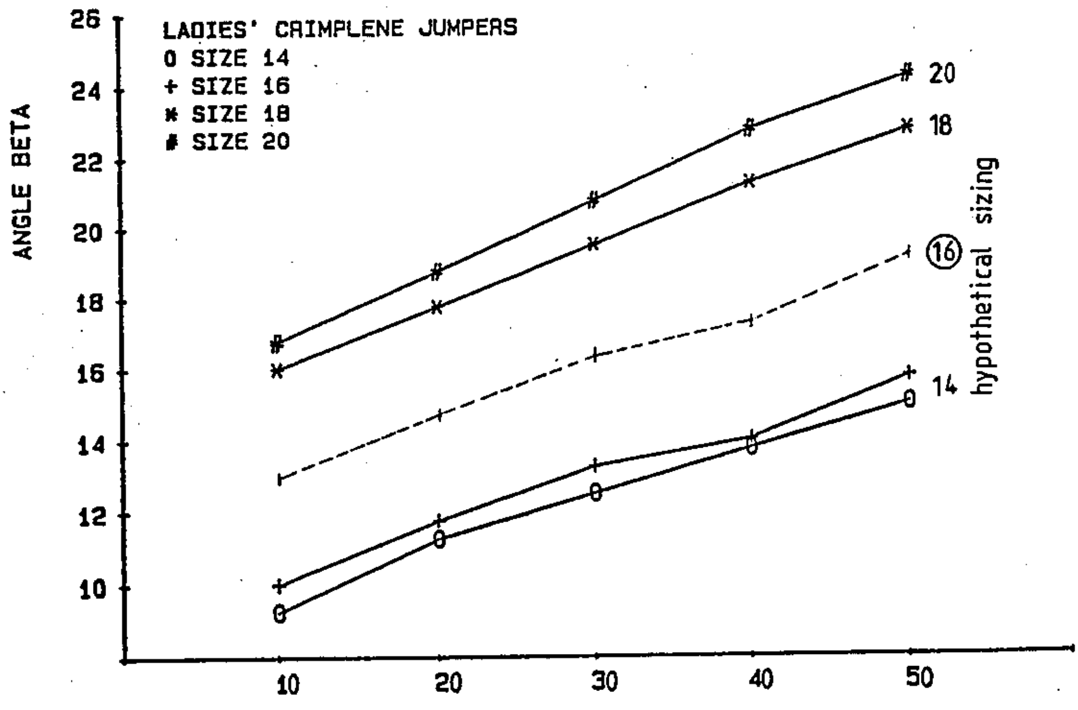


d

Fig. 5.3 Plot of size versus β for Mark 1 apparatus.

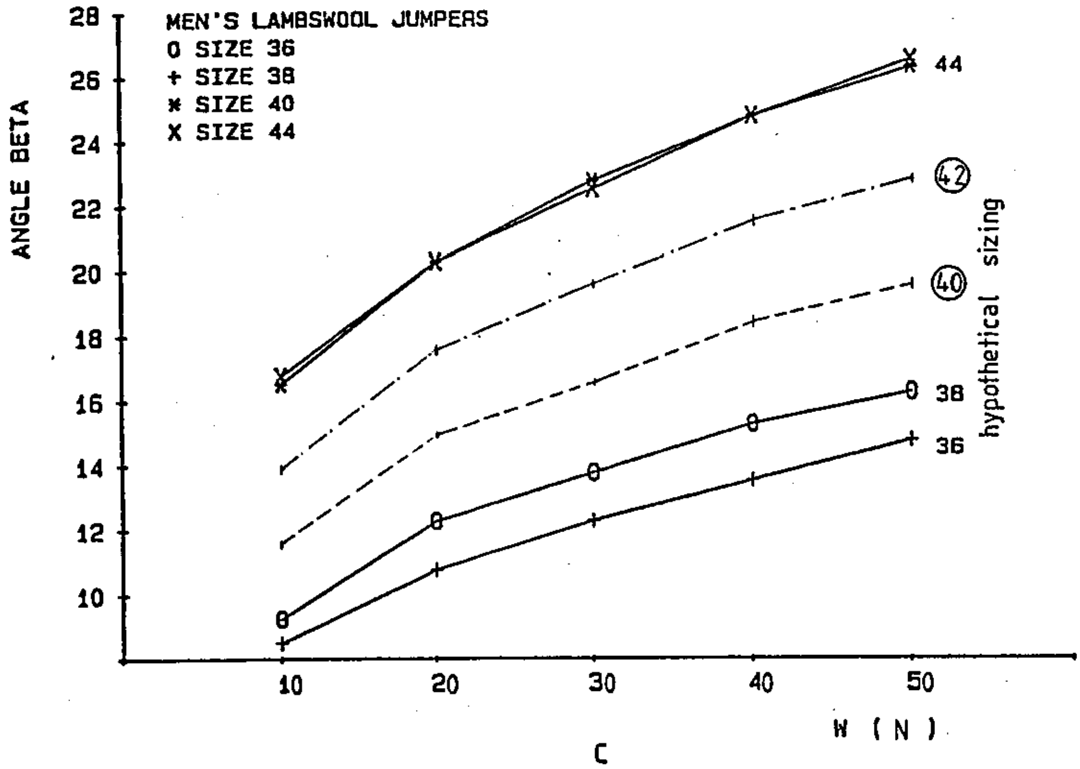


a



b

Fig. 5.4 Plot of force (W) versus β for Mark 1 apparatus.



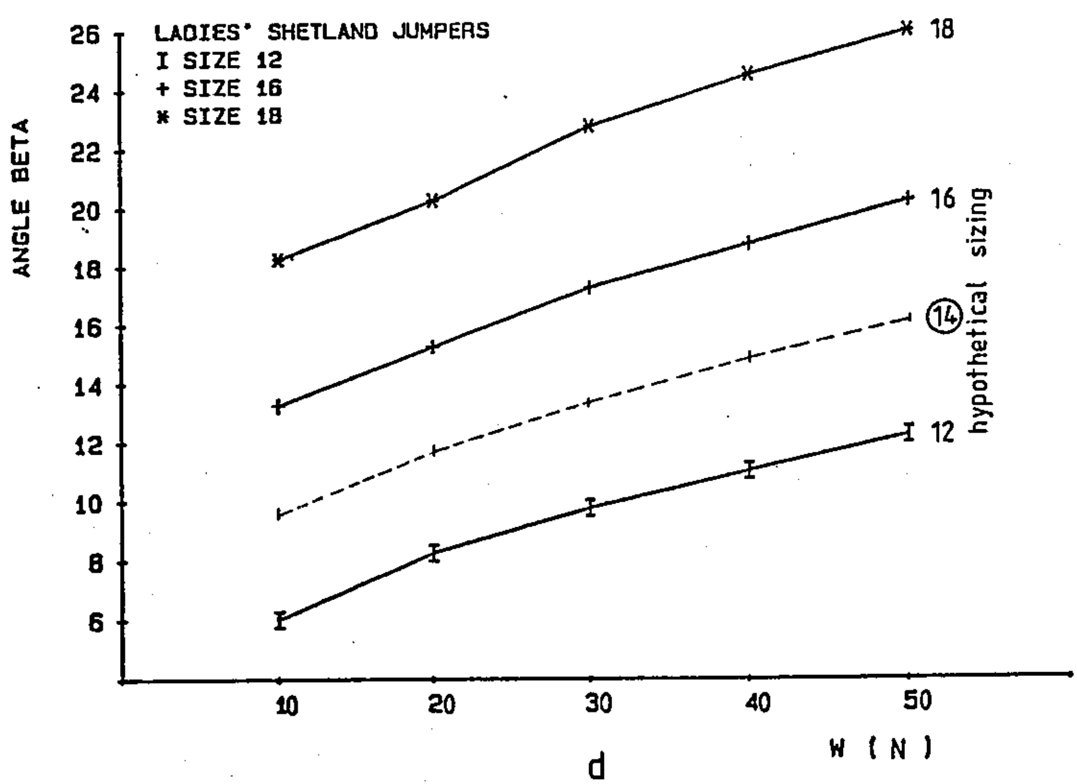


Fig. 5.4 Plot of force (W) versus β for Mark 1 apparatus

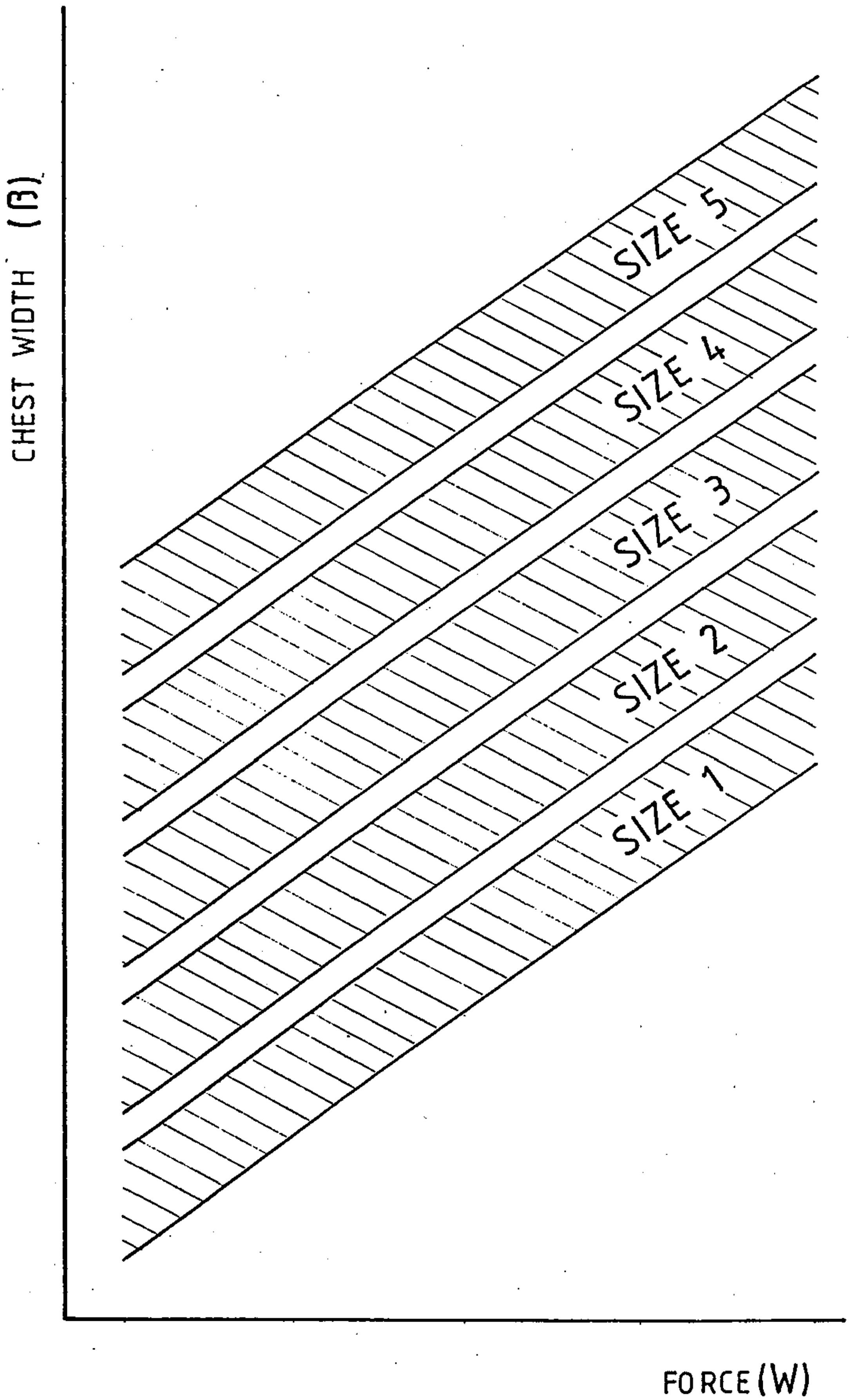


Fig. 5.5 Hypothetical size distribution on a W-β plot for a sample with various garments per size.

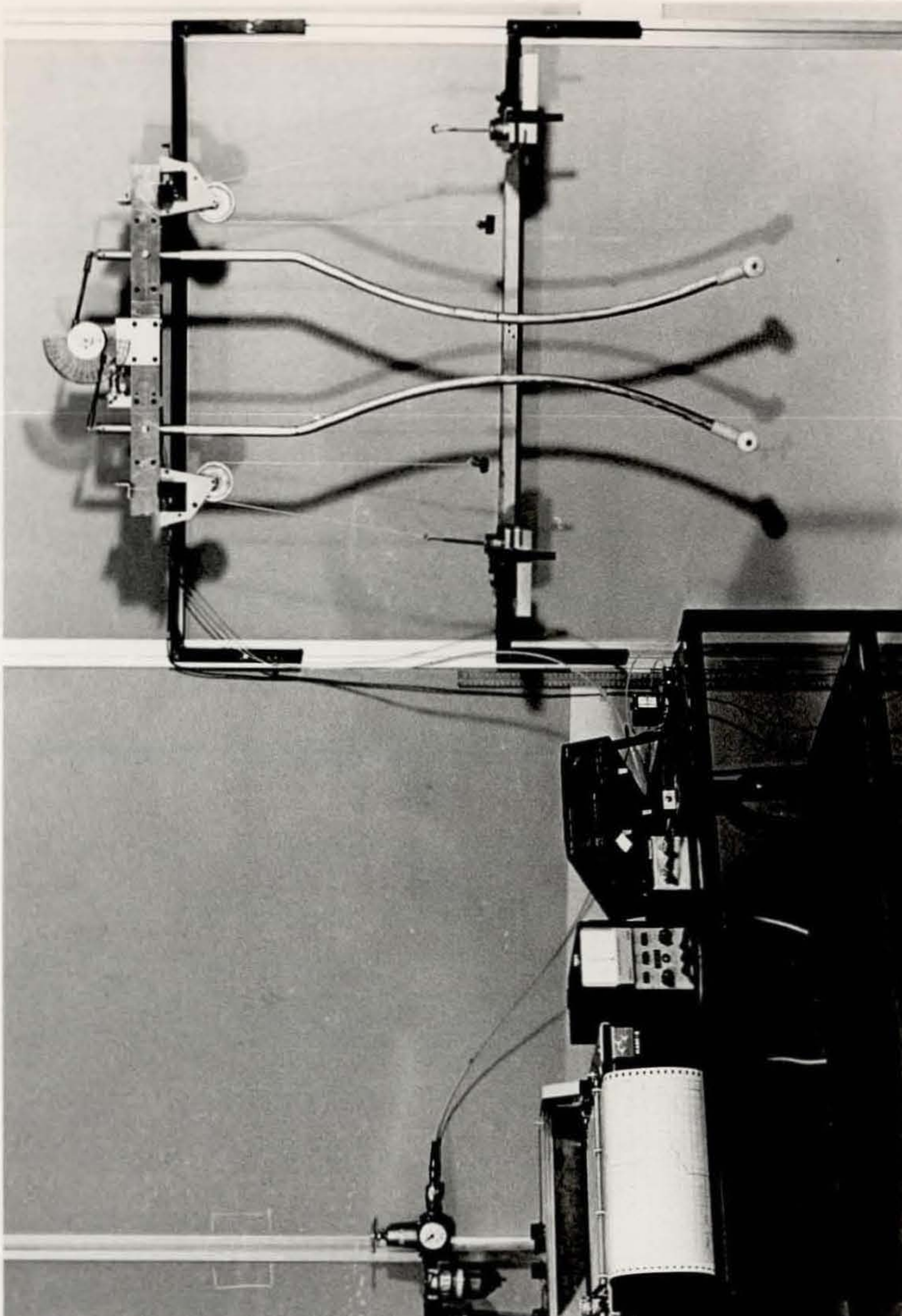


Fig. 5.6 Mark 2 sizing apparatus.

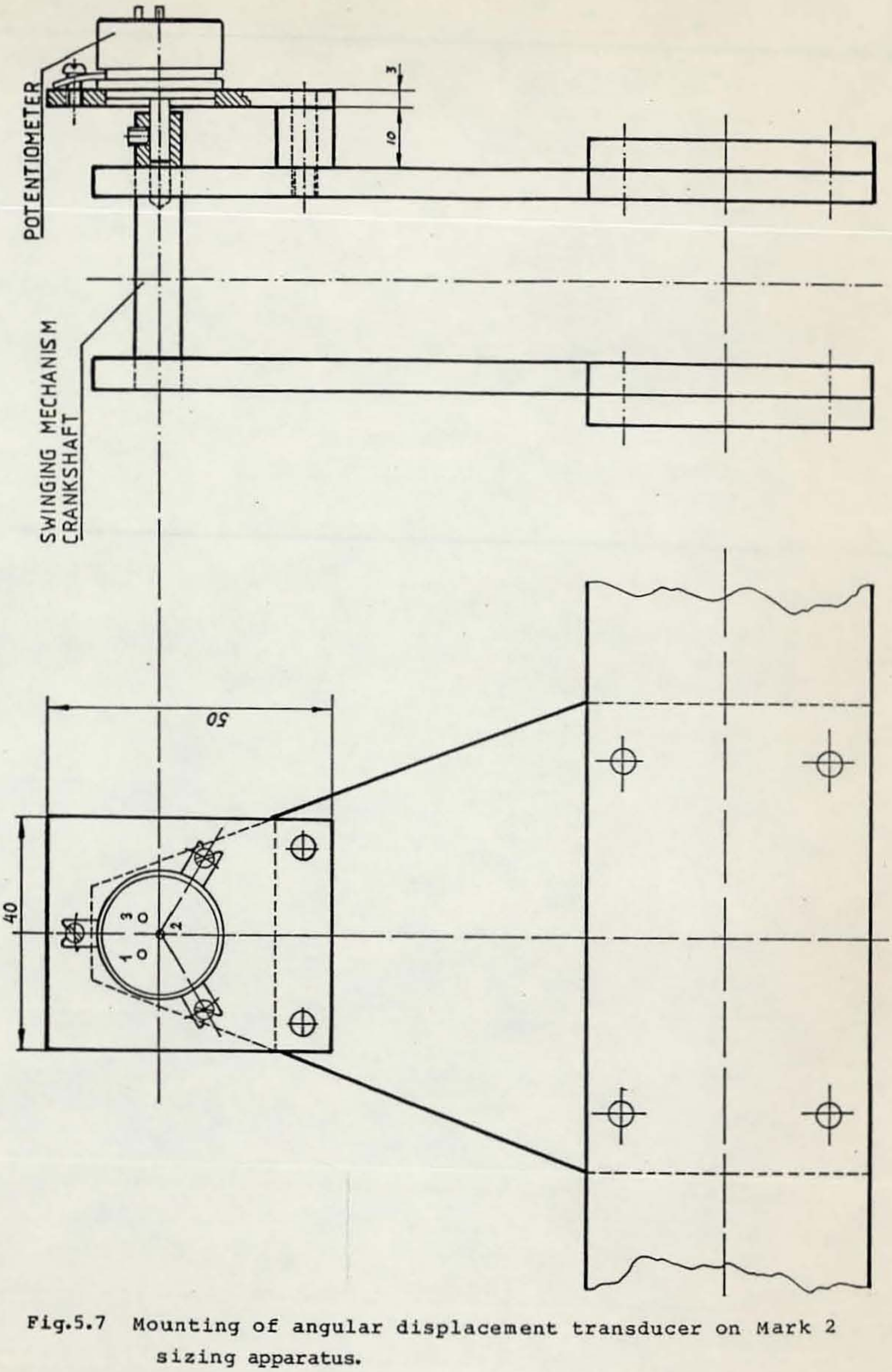


Fig.5.7 Mounting of angular displacement transducer on Mark 2 sizing apparatus.

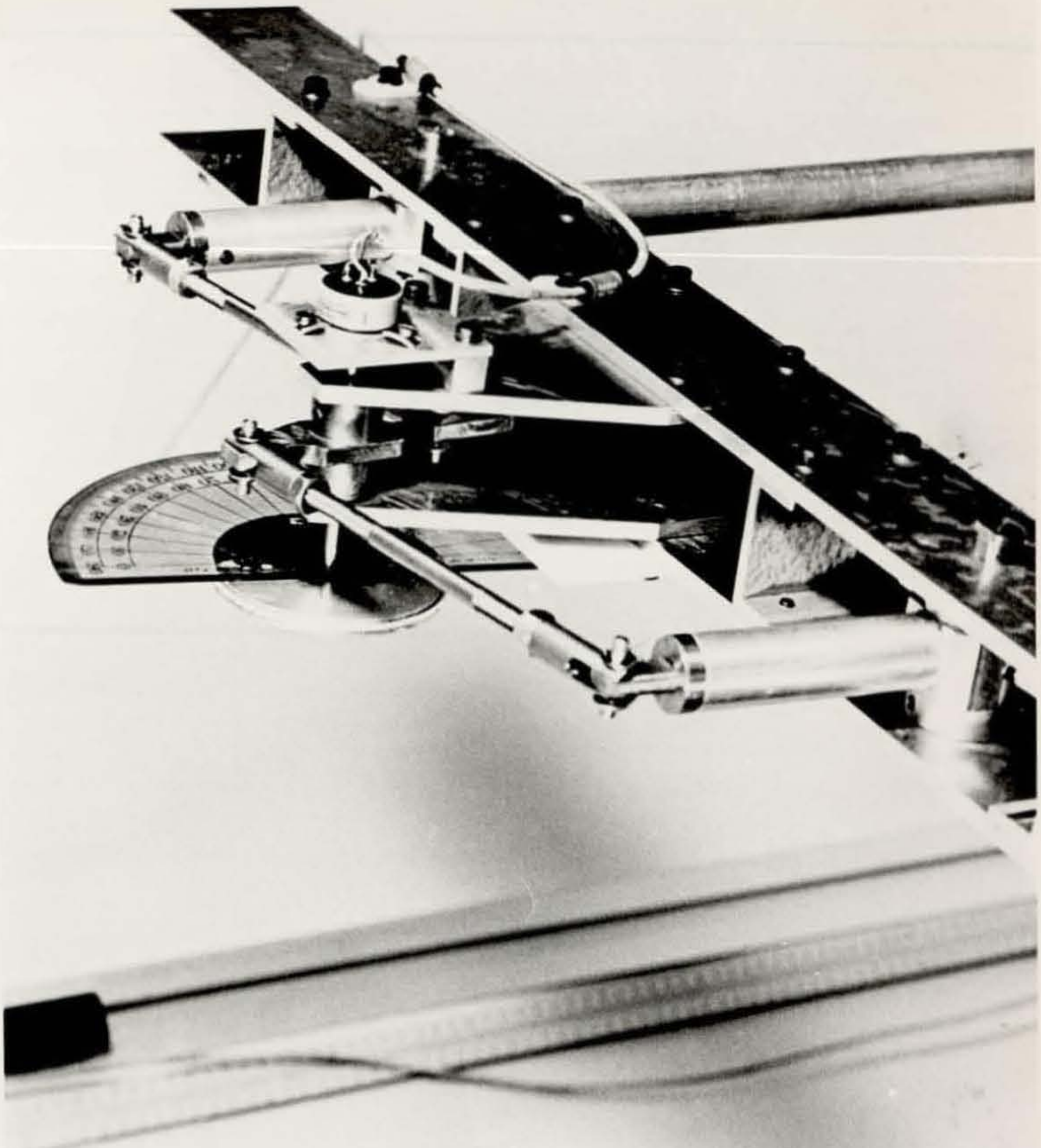


Fig. 5.8 Close-up of swinging mechanism.

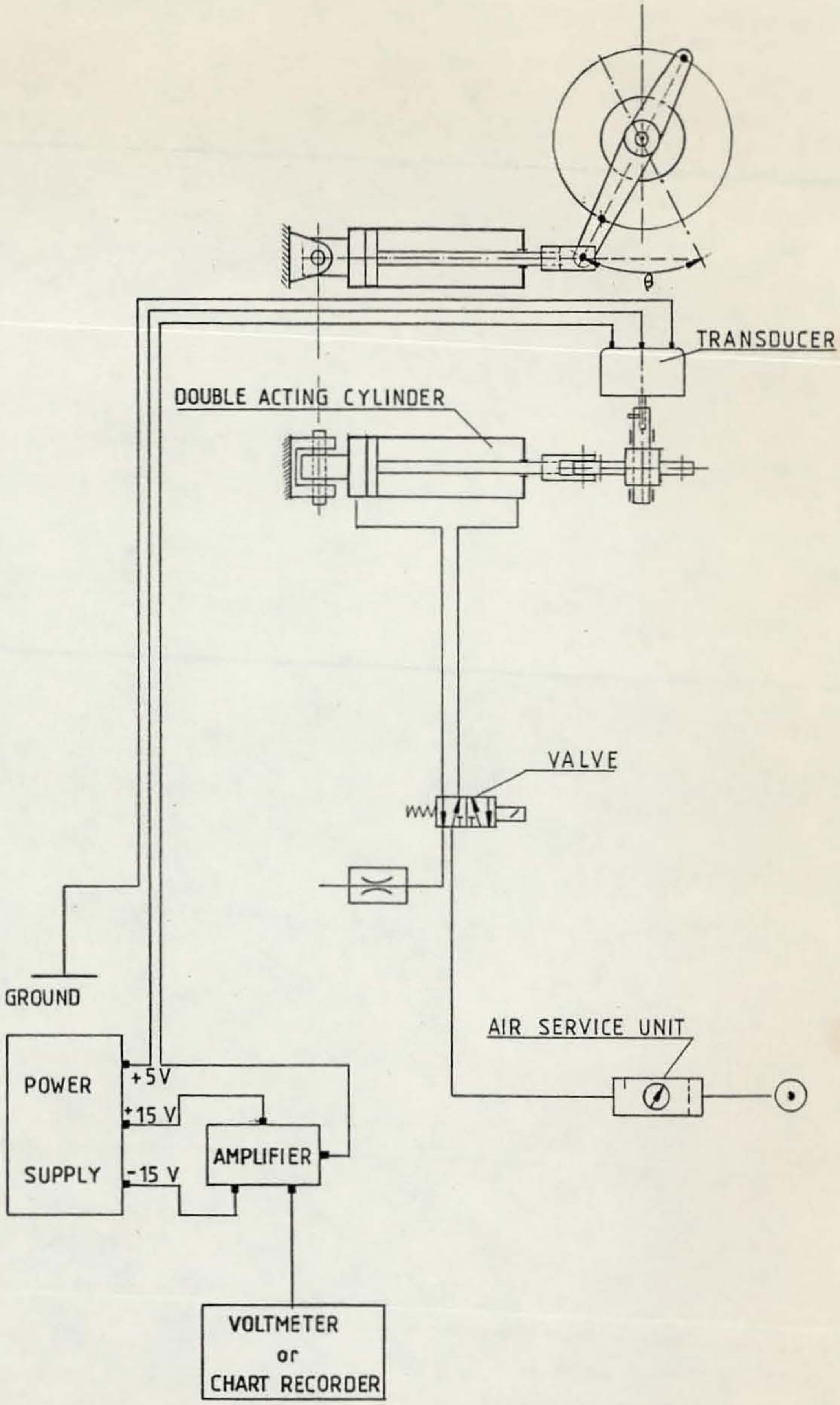


Fig. 5.9 Pneumatic and electric layout of Mark 2 sizing apparatus.

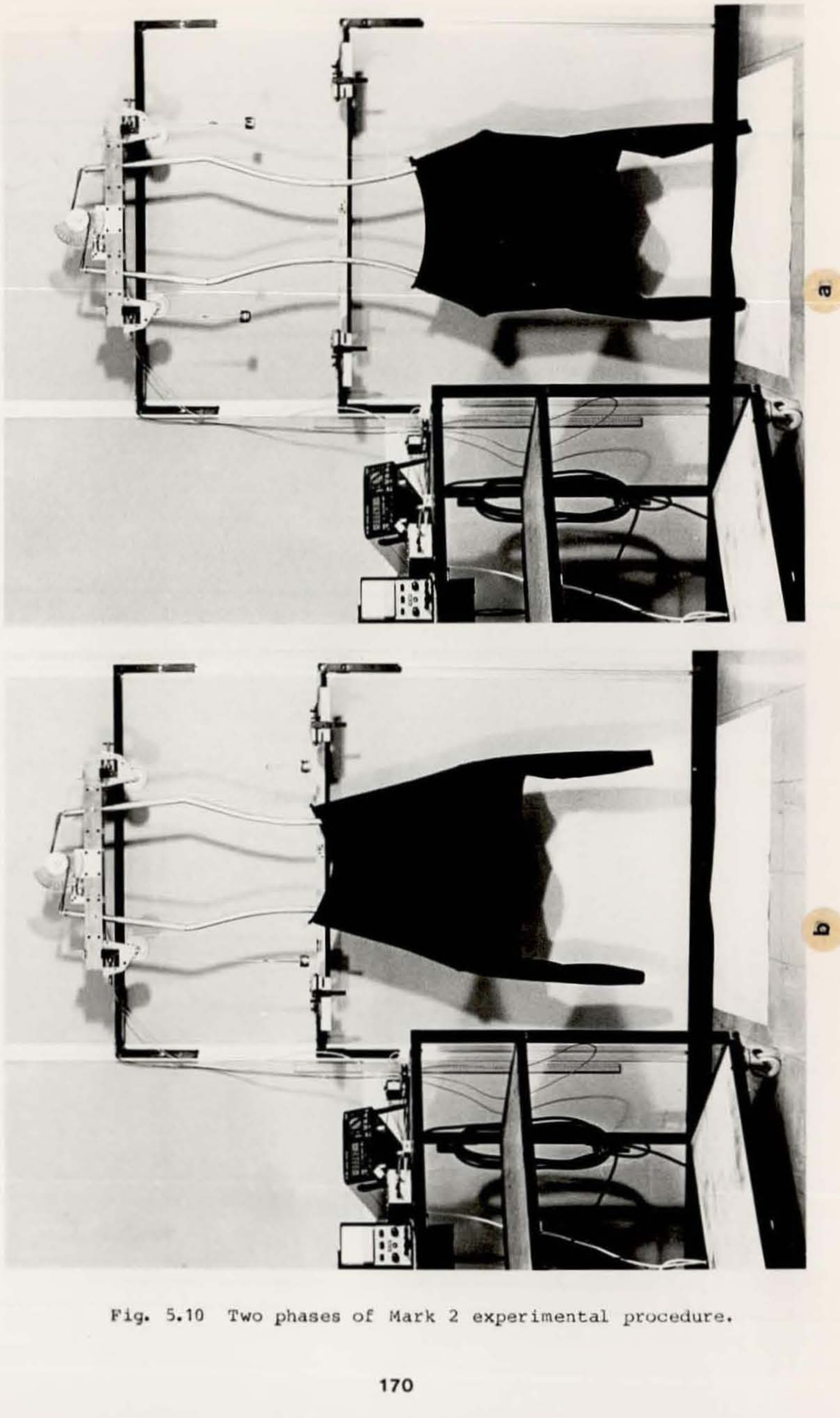


Fig. 5.10 Two phases of Mark 2 experimental procedure.

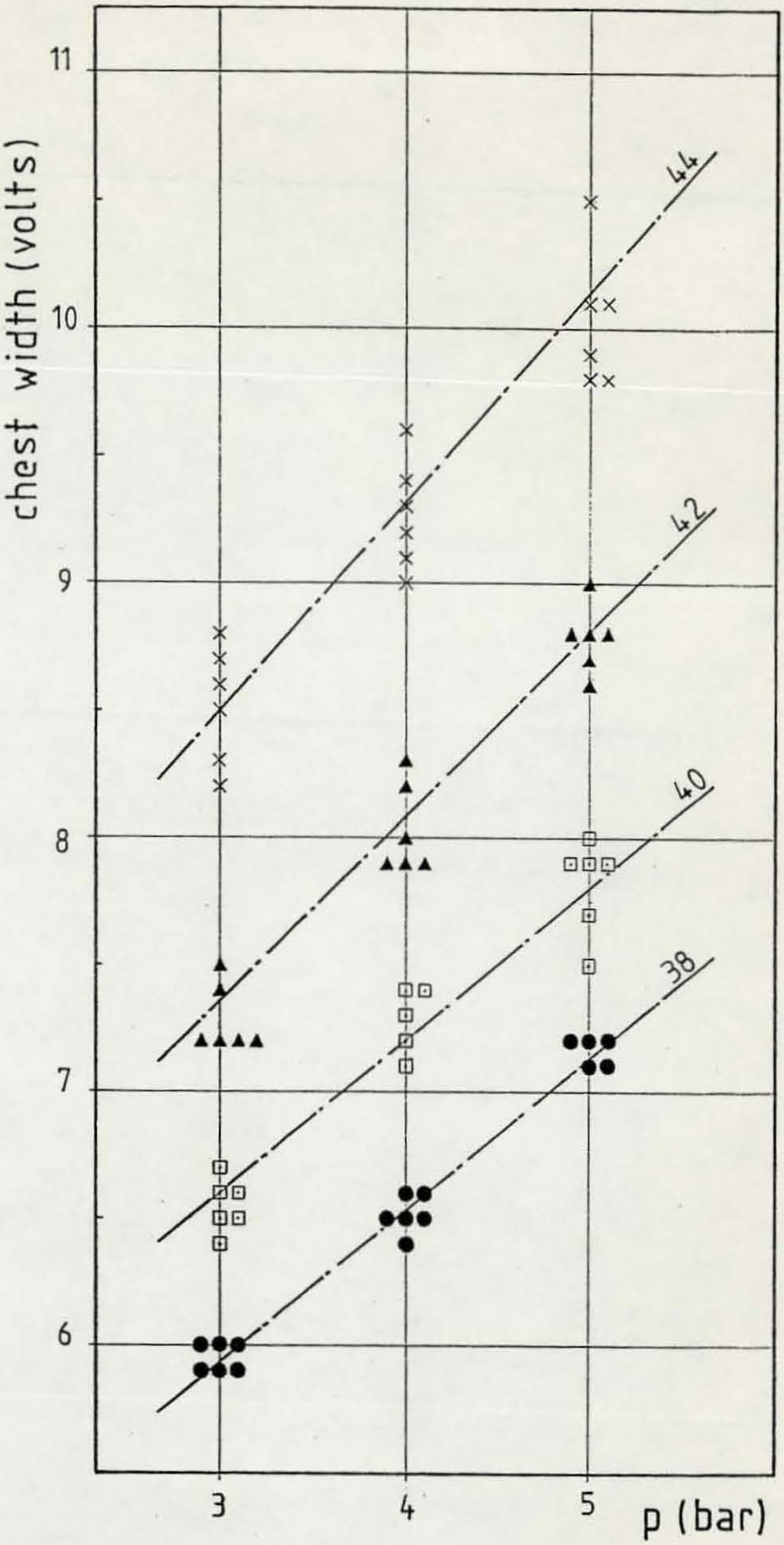


Fig. 5.11 Pressure versus voltage for 2606 Courtelle sample.

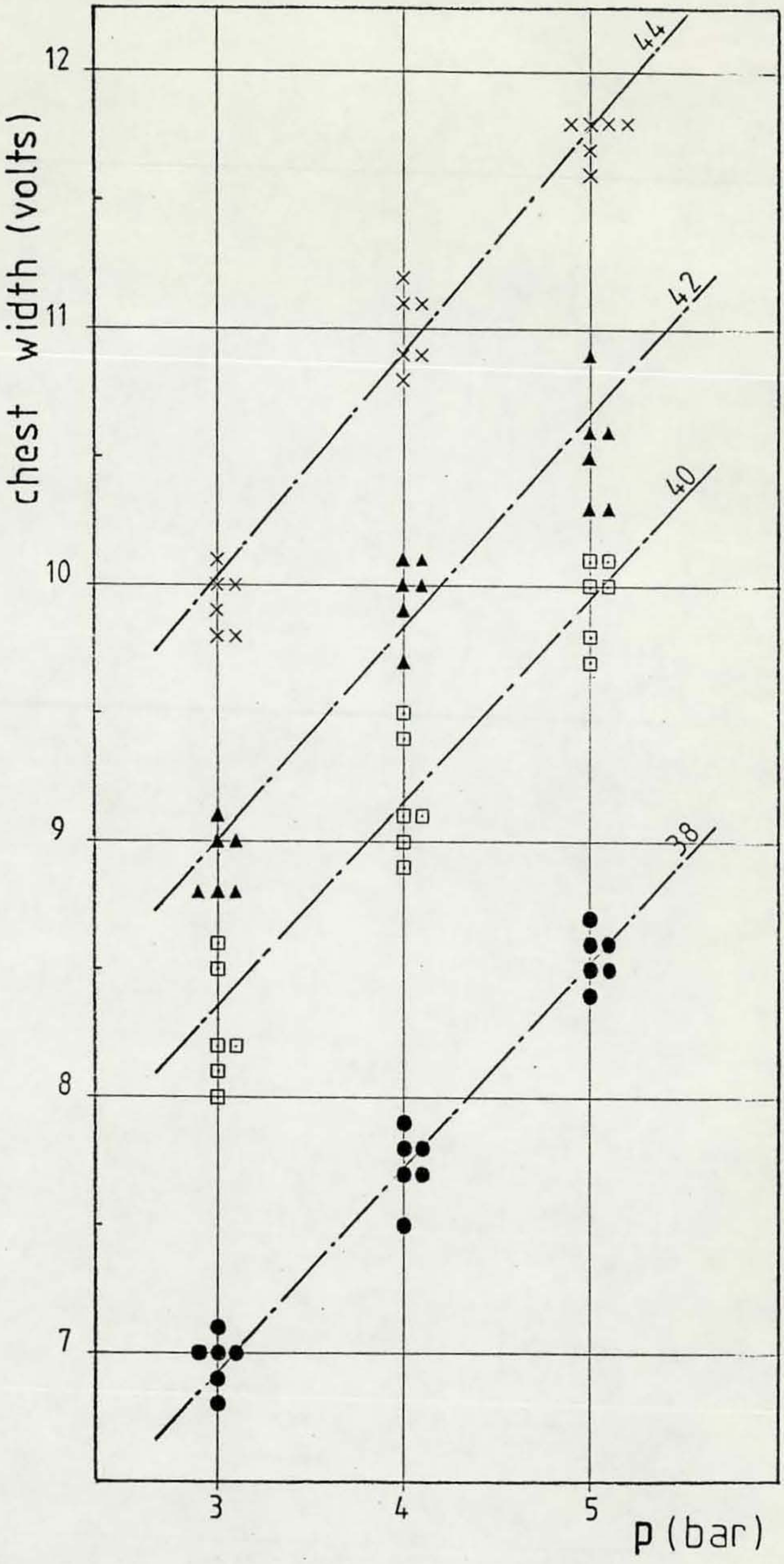


Fig. 5.12 Pressure versus voltage for 1708 Lambswool sample.

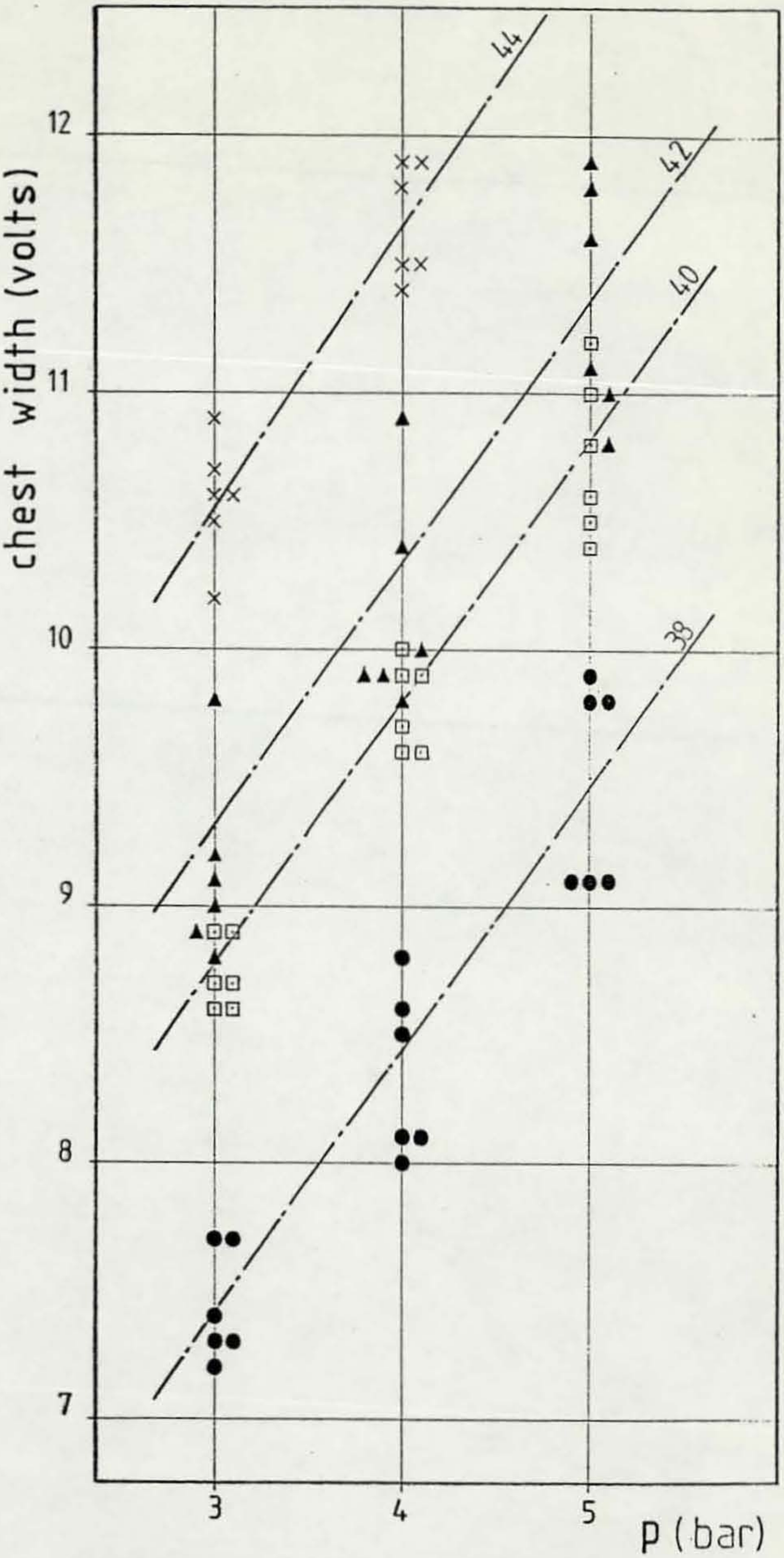


Fig. 5.13 Pressure versus voltage for 2135 Shetland wool sample.

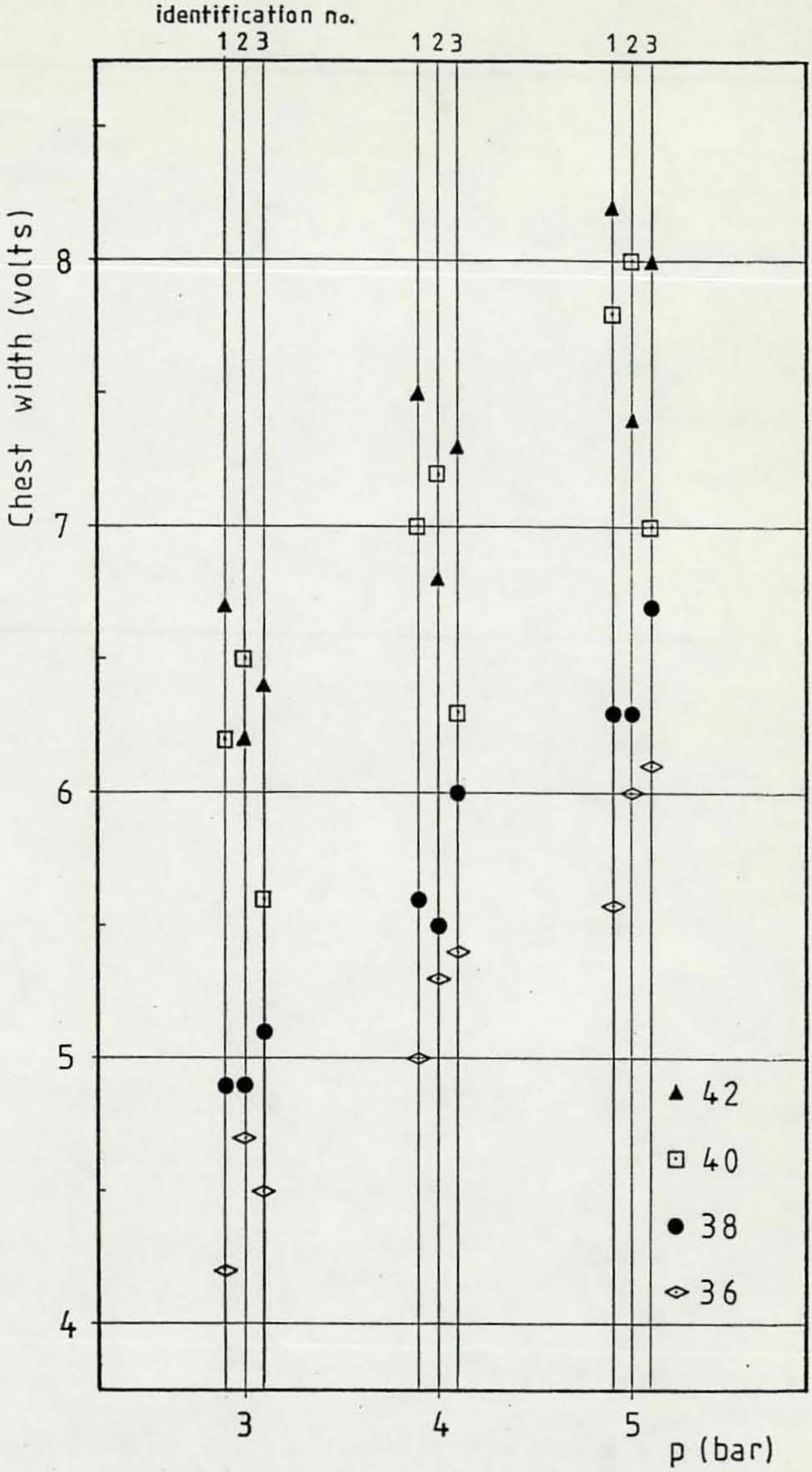


Fig. 5.14 Pressure versus voltage for the non-trimmed Courtelle sample.

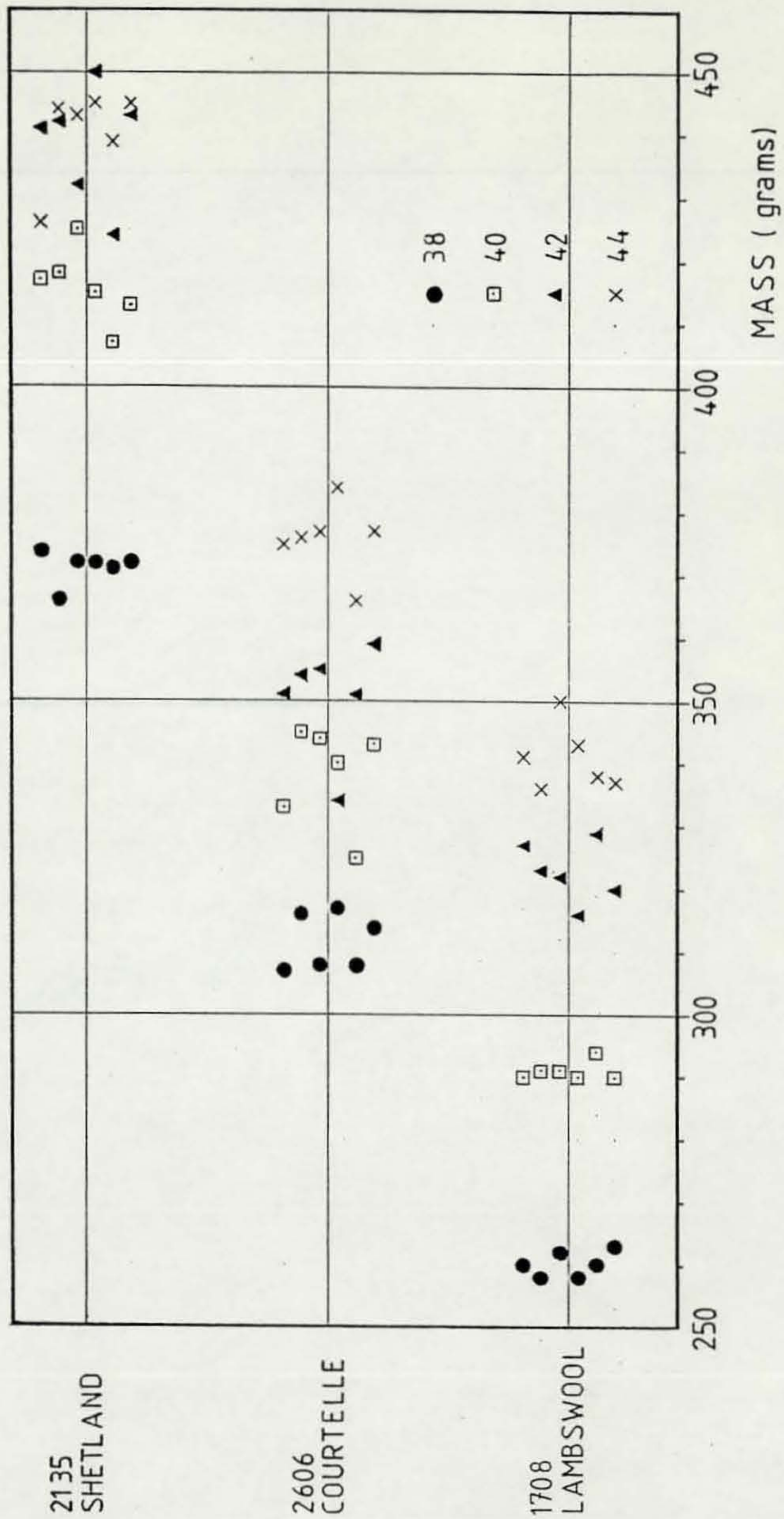


Fig. 5.15 Mass-size distribution for the trimmed sample.

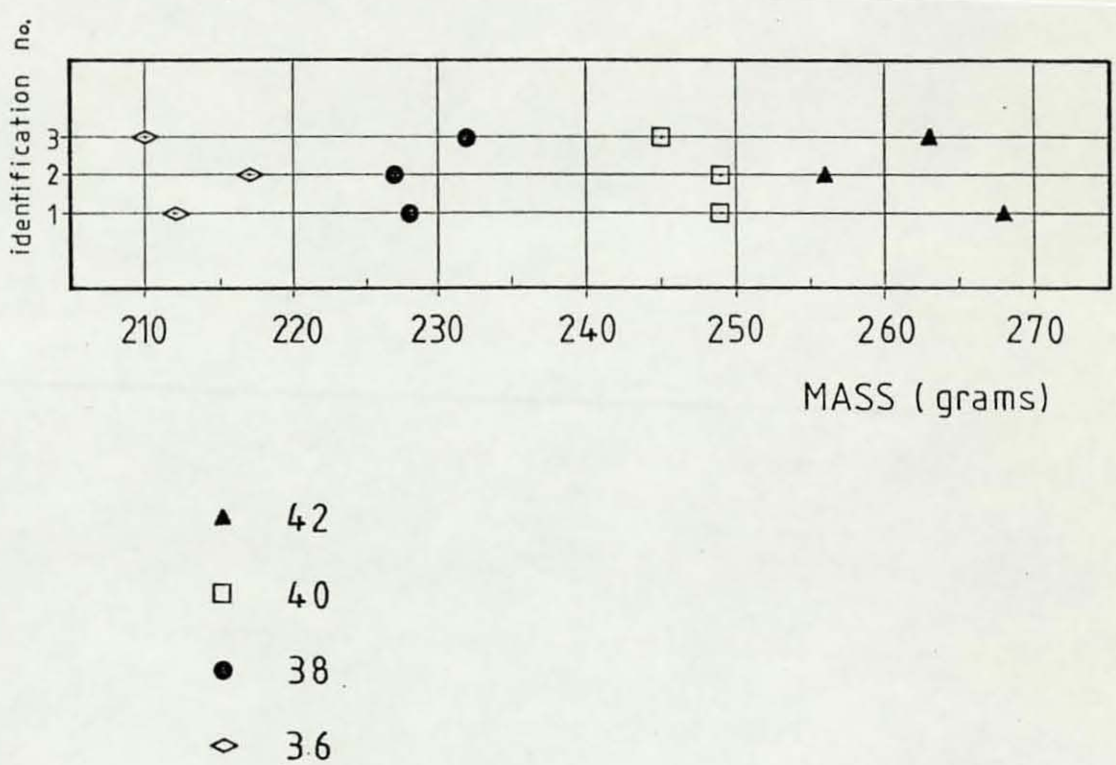


Fig. 5.16 Mass-size distribution for the non-trimmed sample.

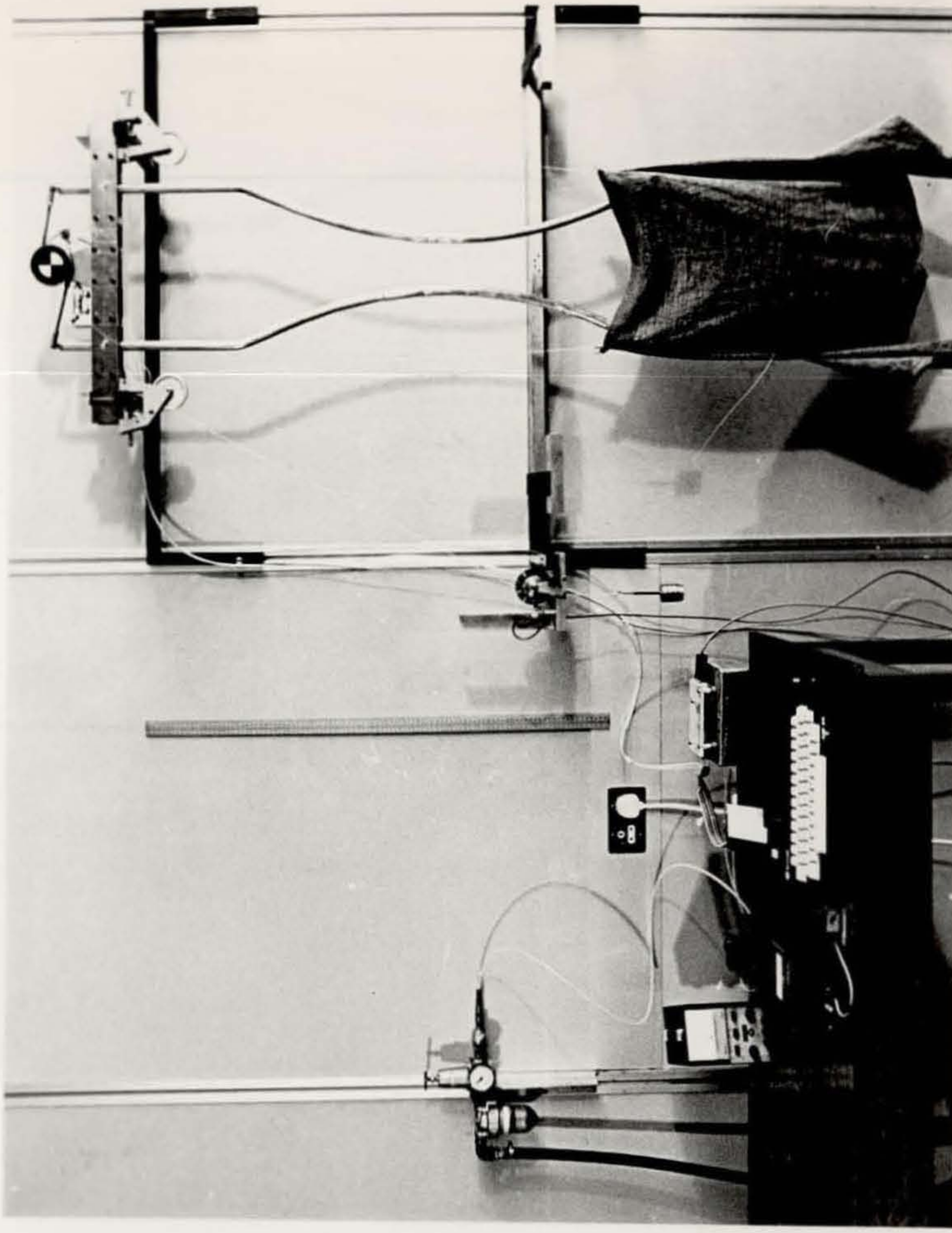


Fig. 5.17 First version of Mark 3 sizing rig.

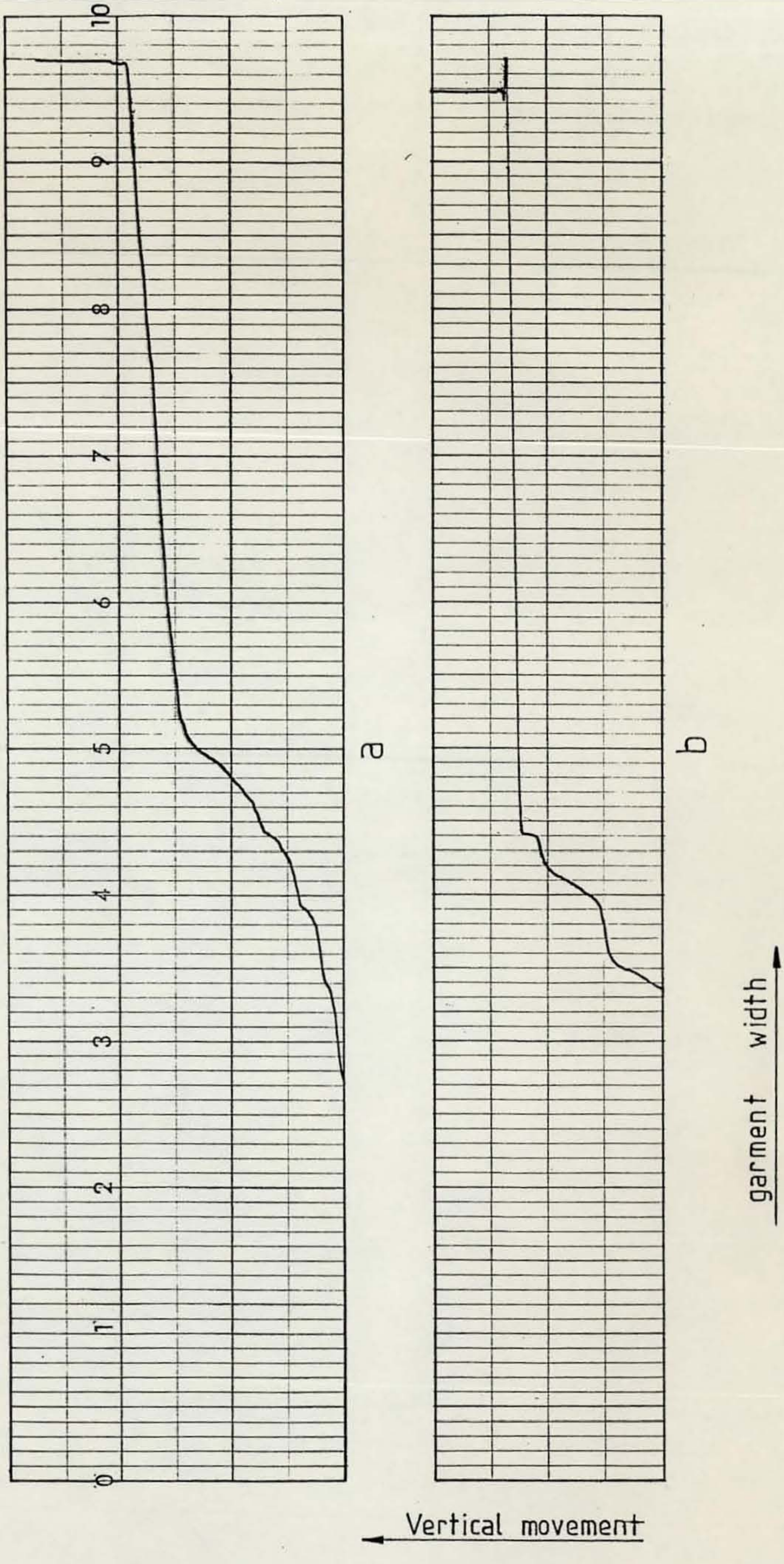


Fig.5.18 Chart recorder output of the variation in garment width for the optimization of the shape of the arms.

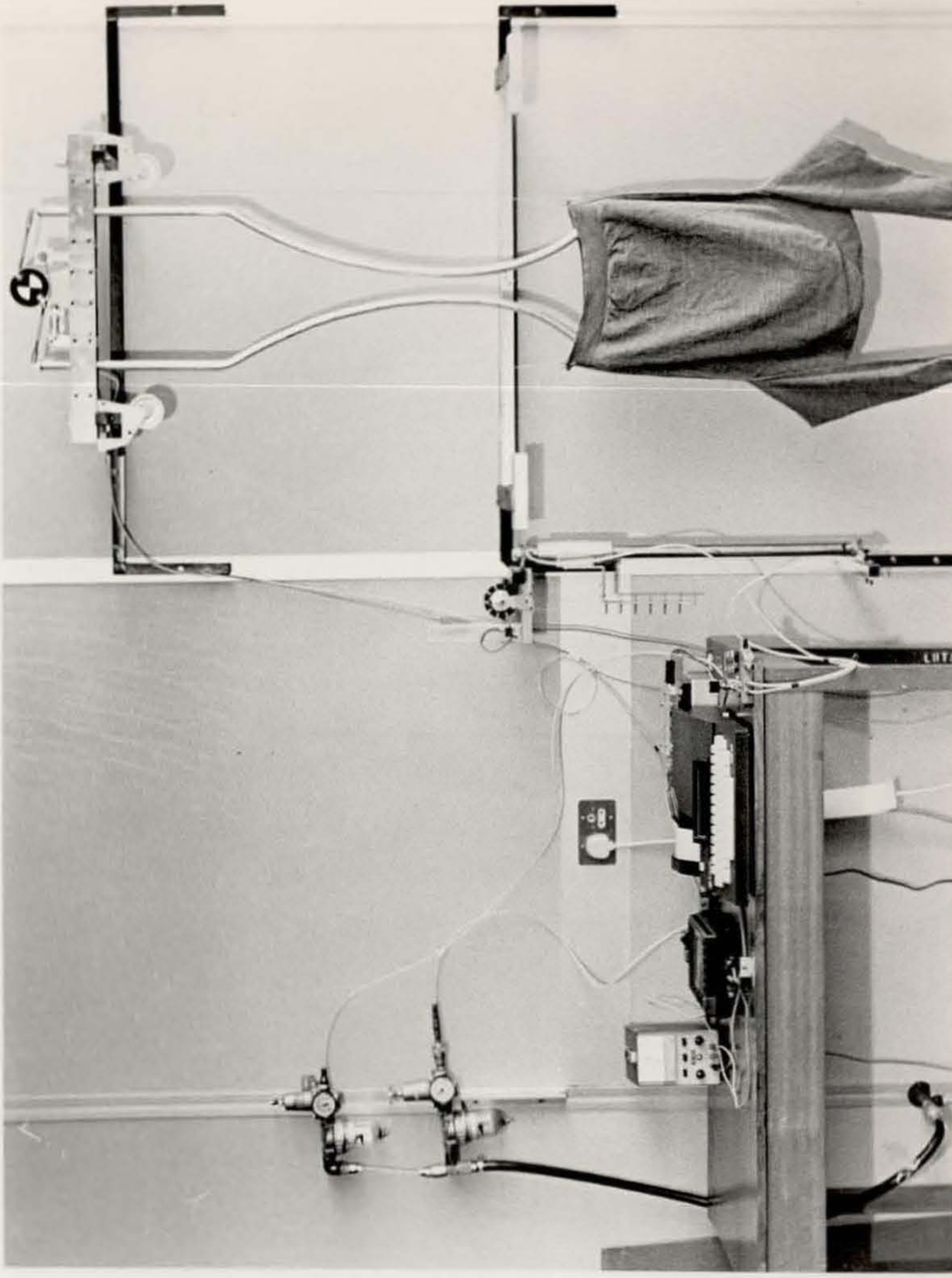


Fig. 5.19 Final version of Mark 3 sizing rig.

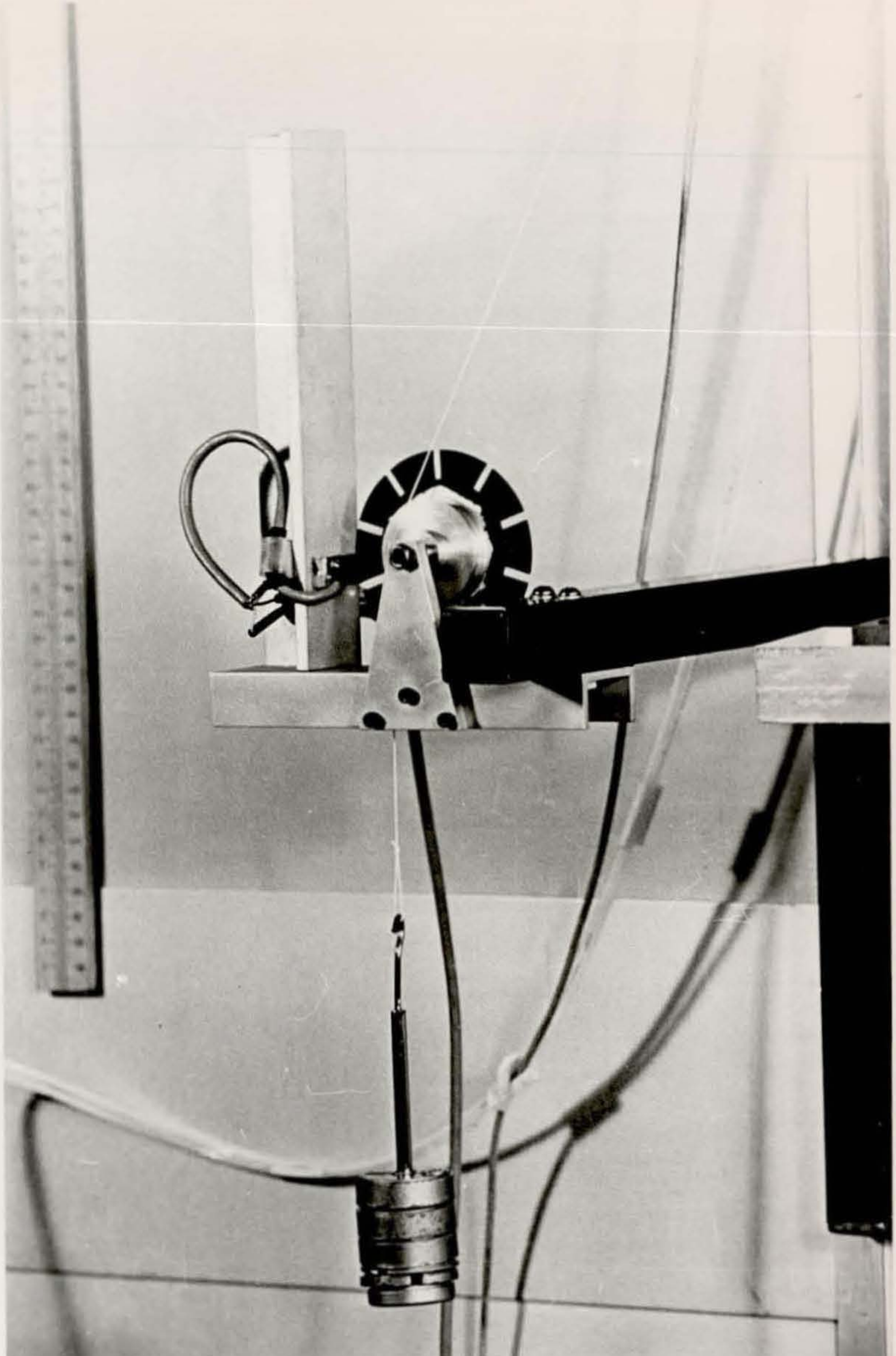


Fig.5.20 The digital transducer to monitor the relative position garment/rollers.

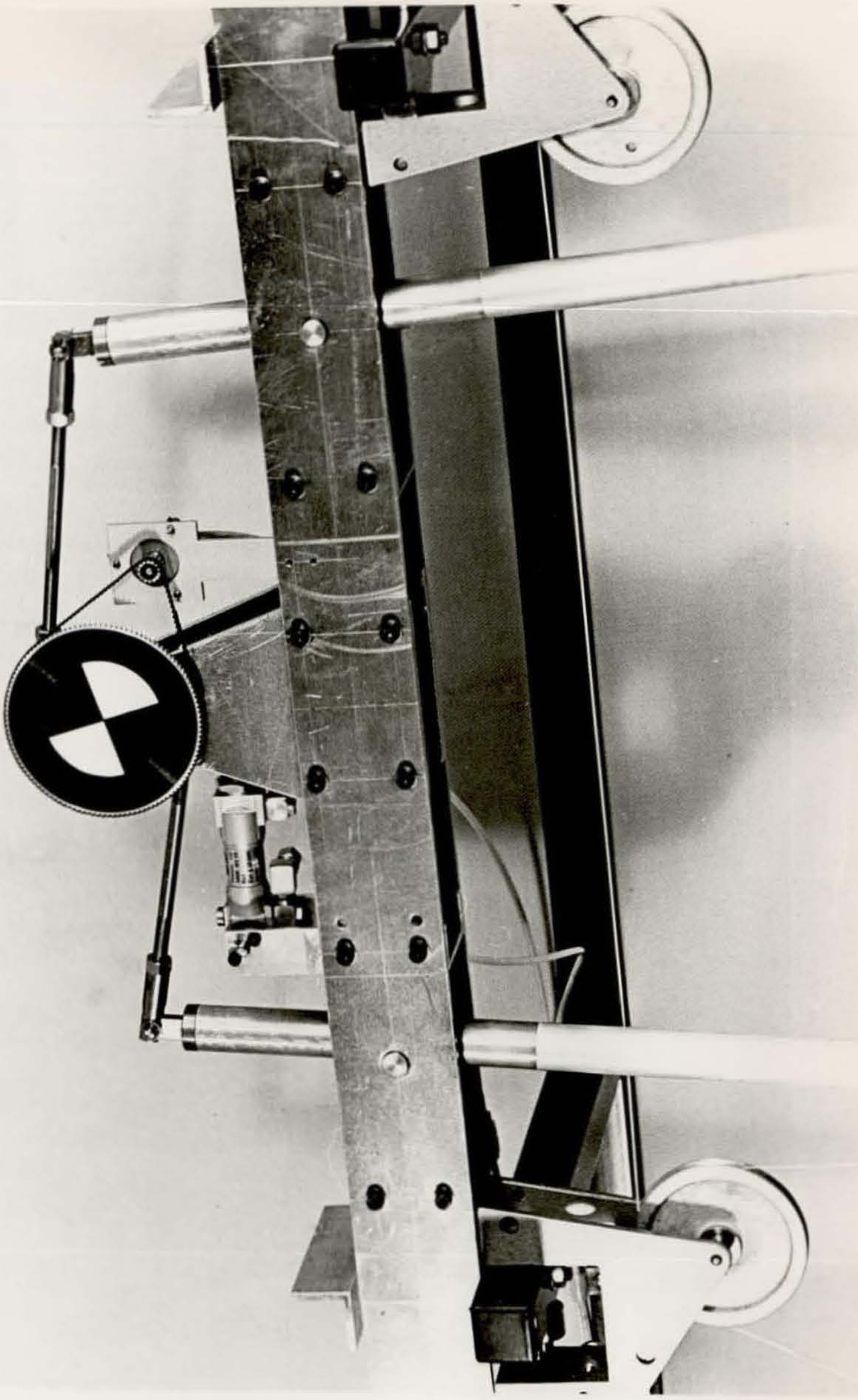


Fig.5.21 Close-up photographic view of the angular displacement transducer drive.

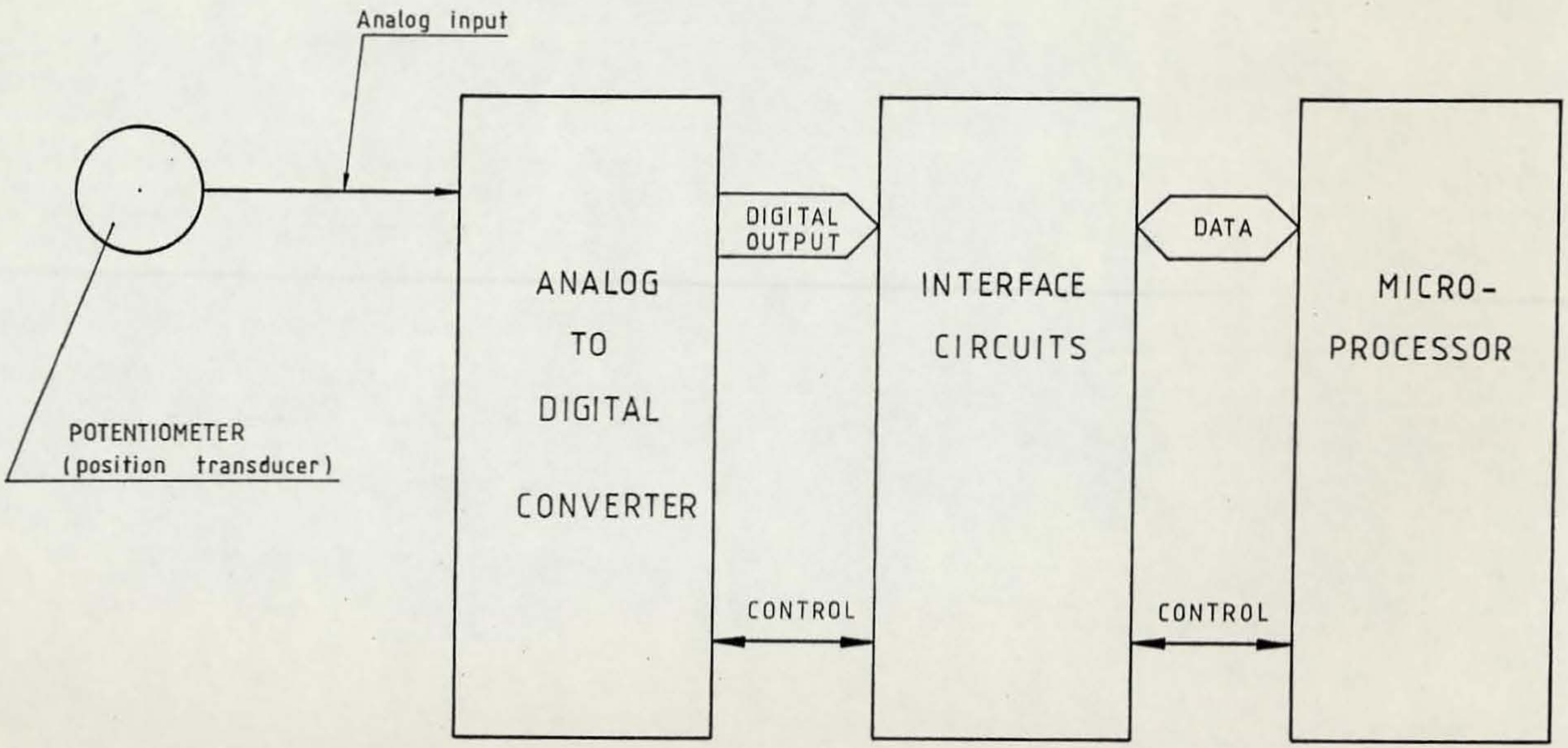
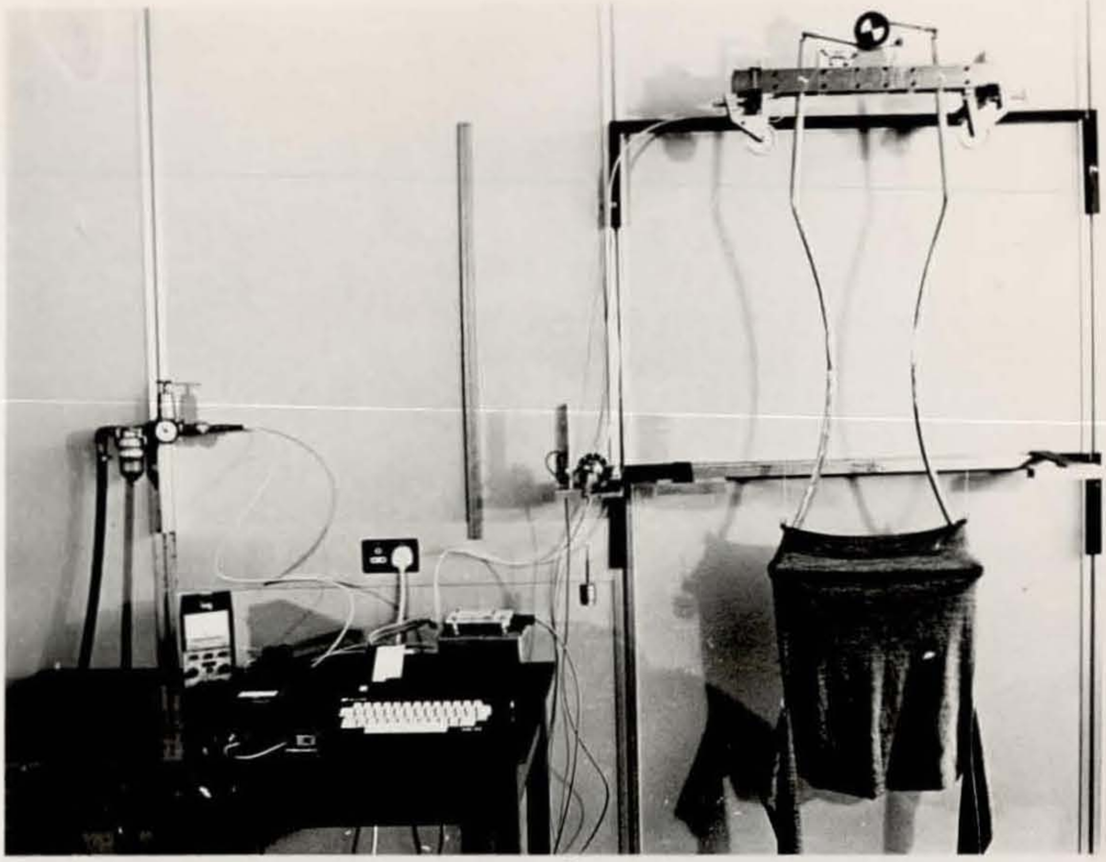
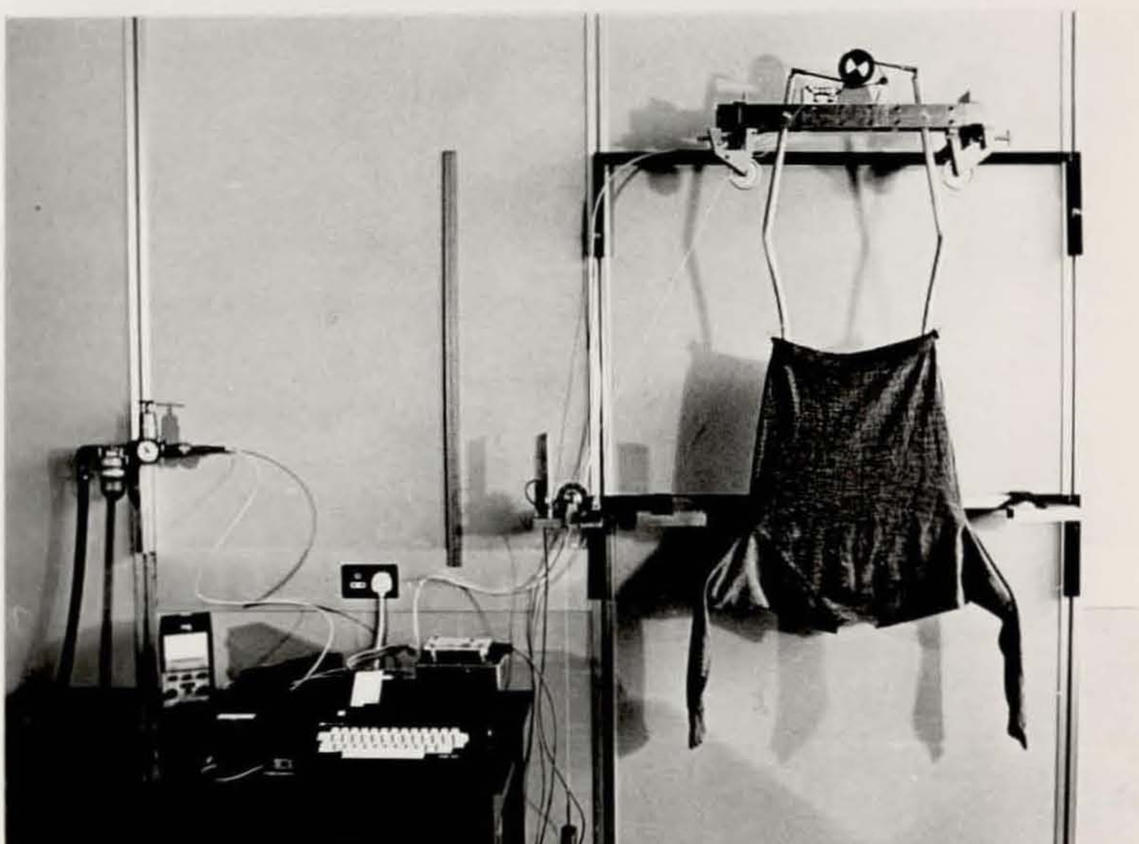


Fig. 5.22 Digital conversion of the transducer analog signal.



a



b

Fig. 5.23 Mark 3 sizing rig; The initial and final positions of the garment during the tests.

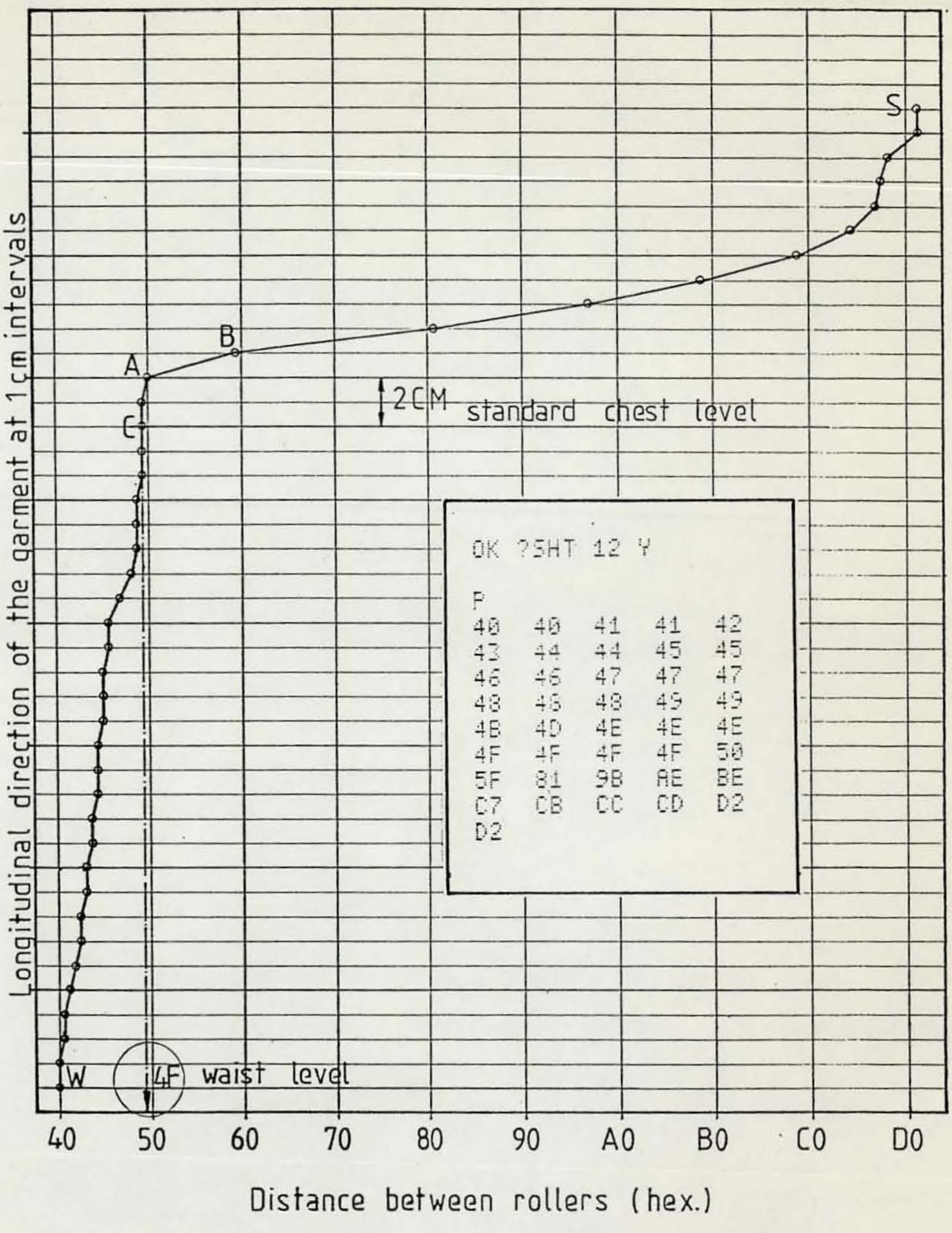


Fig.5.24 Path of the rollers for a garment Shetland wool size 12, plotted from the computer print out.

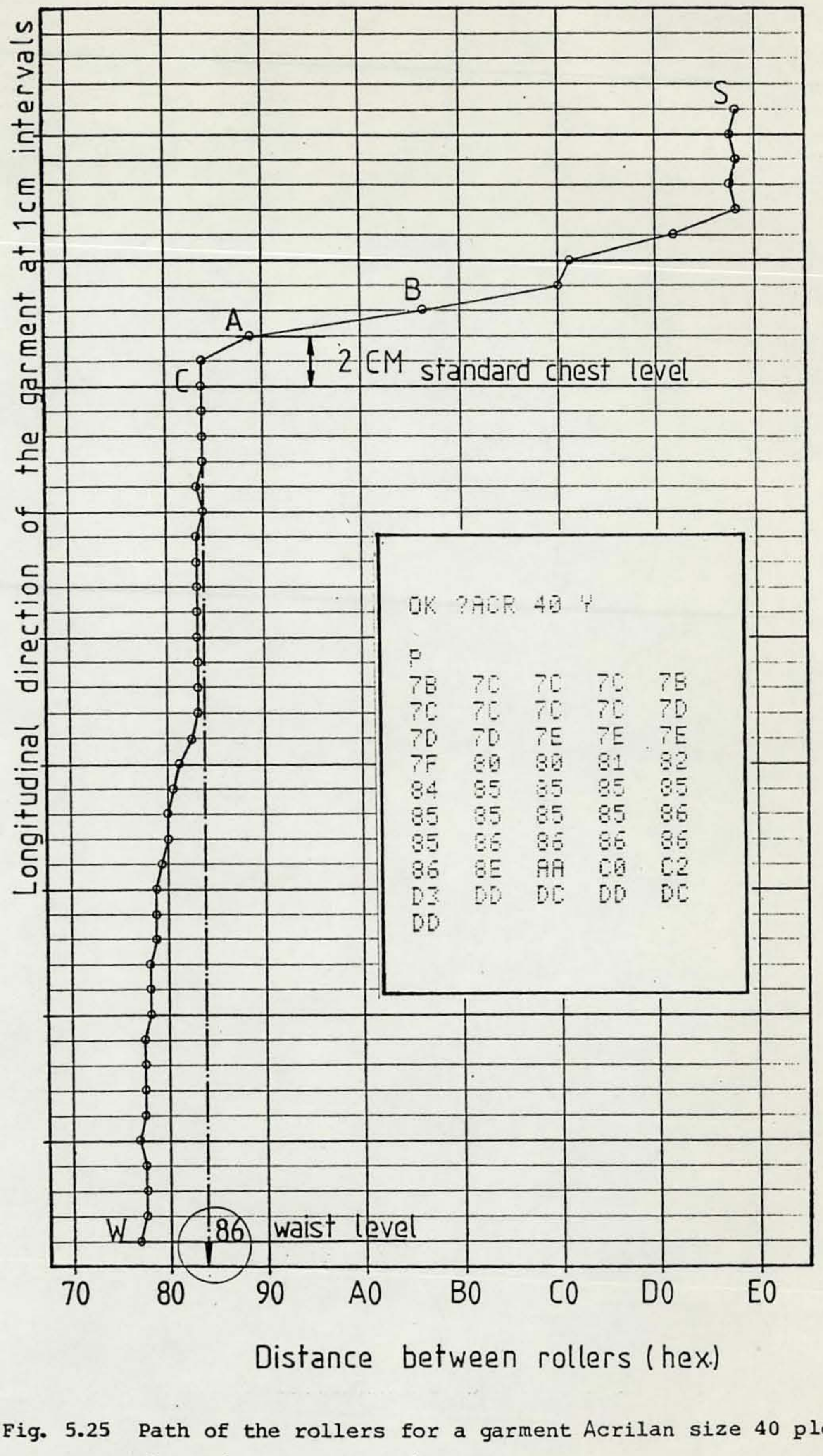


Fig. 5.25 Path of the rollers for a garment Acrilan size 40 plotted from the computer print out.

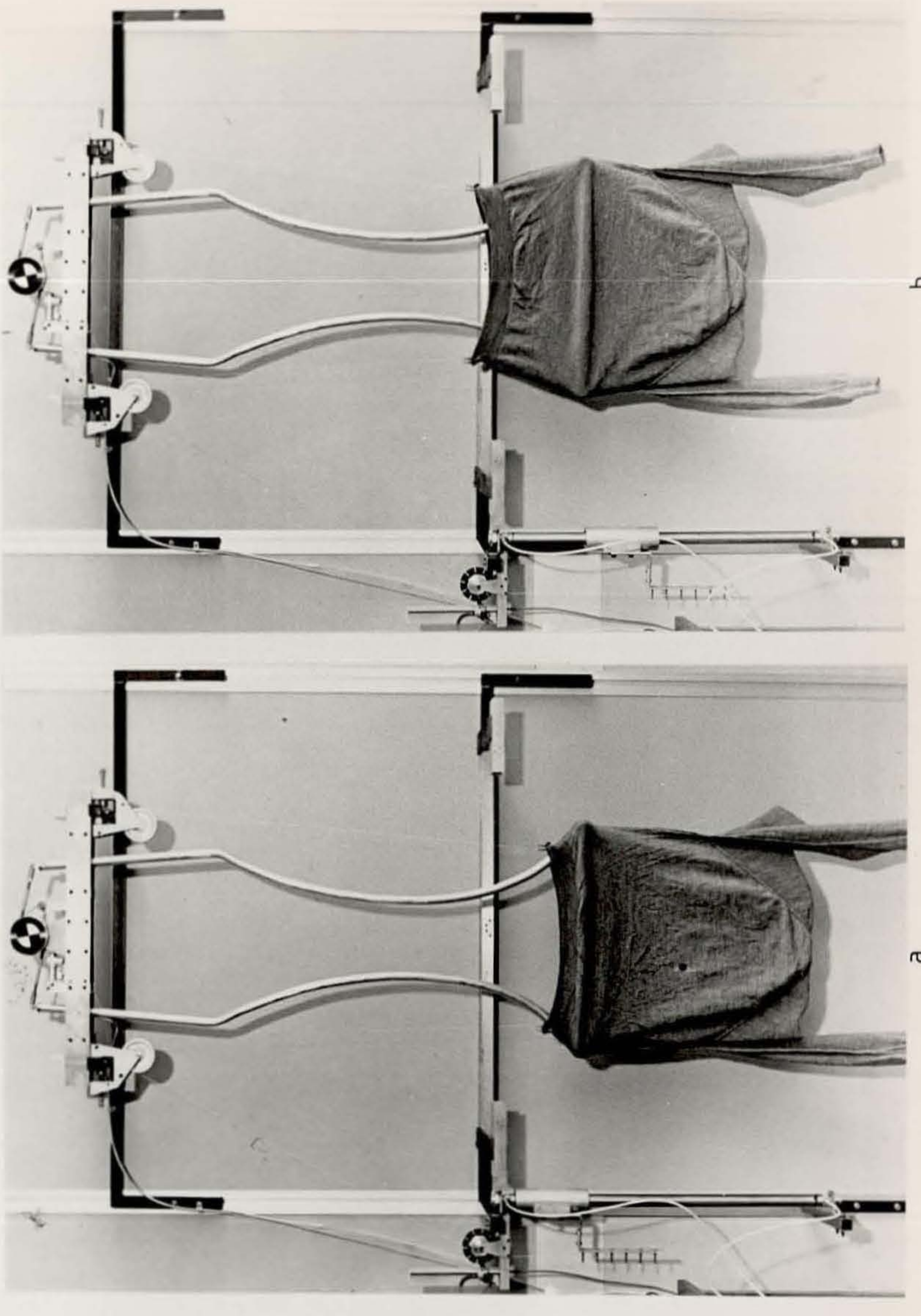


Fig.5.26 Sequence of the experiment with the final version of Mark 3 sizing rig.

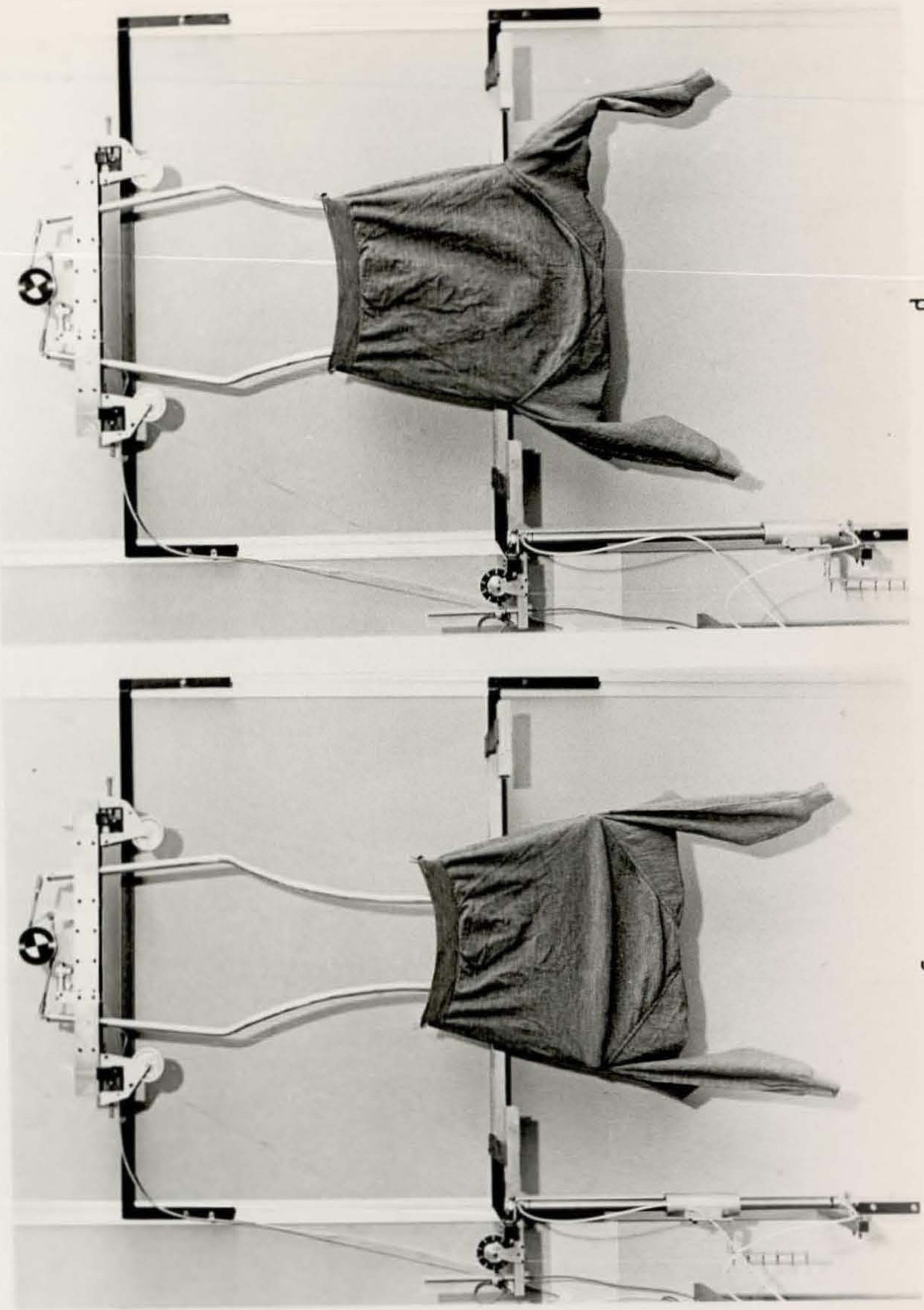


Fig. 5.26 Sequence of the experiment with the final version of Mark 3 sizing rig.

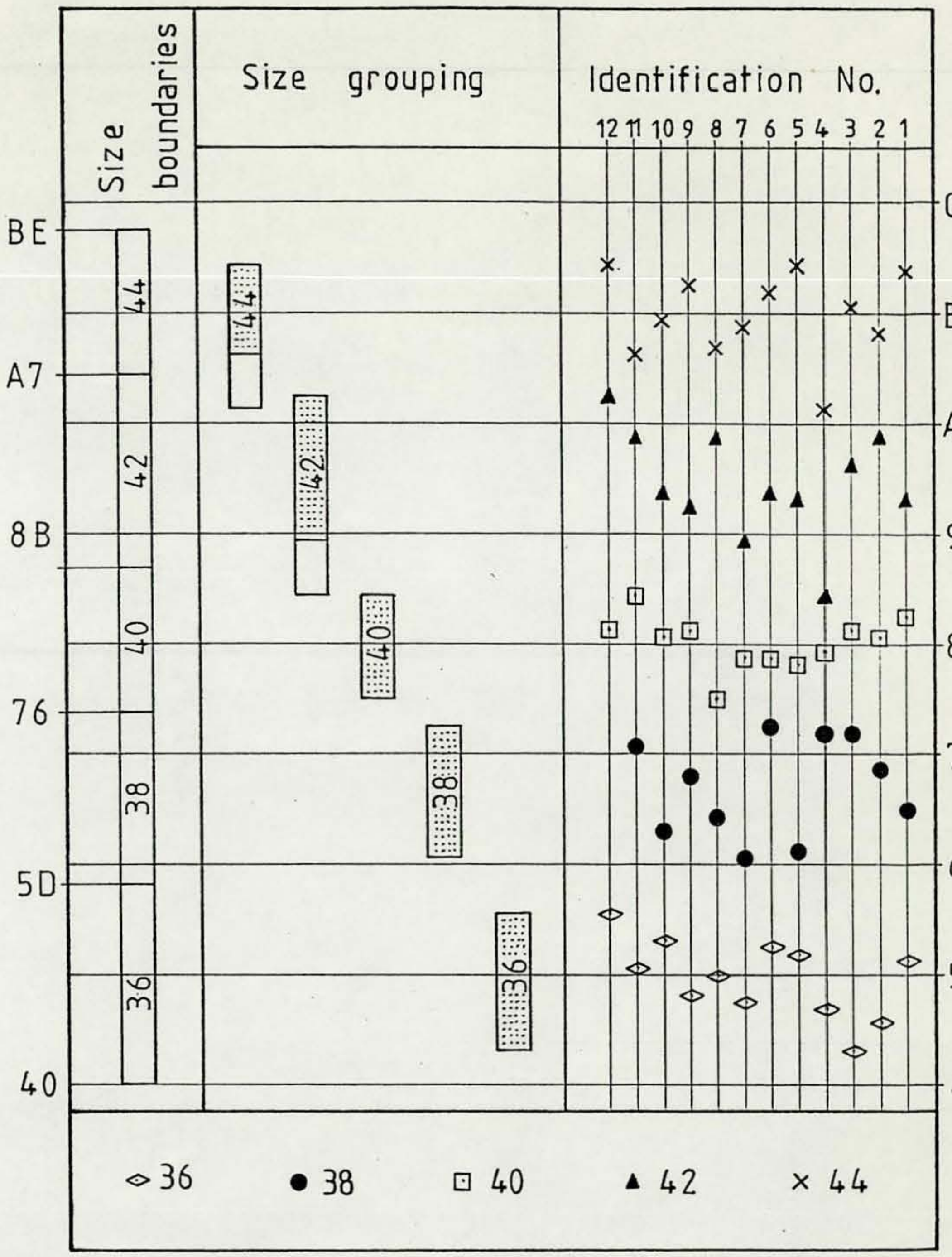


Fig. 5.27 Graphic display of results with Mark 3 sizing rig.

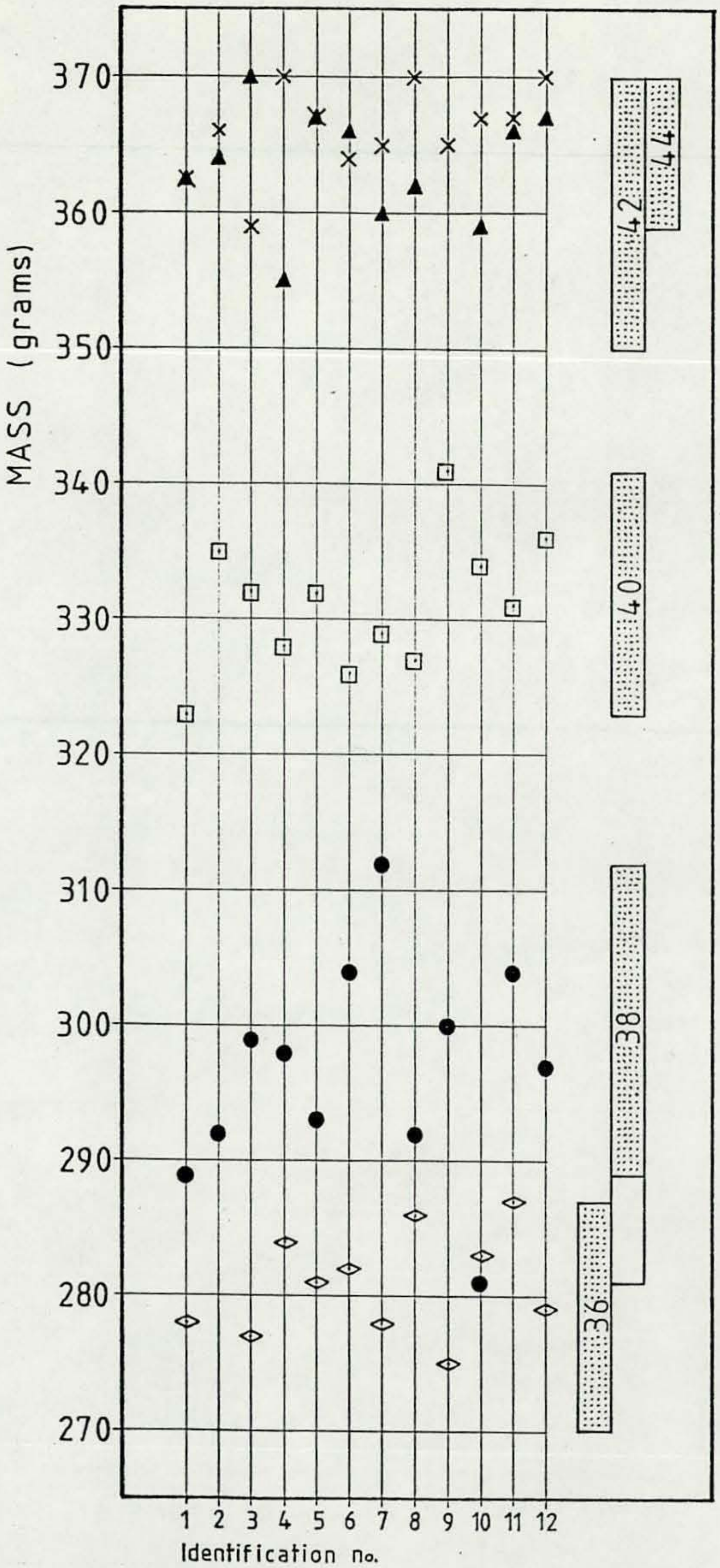


Fig.5.28 Mass-size distribution for the Shetland wool sample tested with Mark 3 sizing rig.

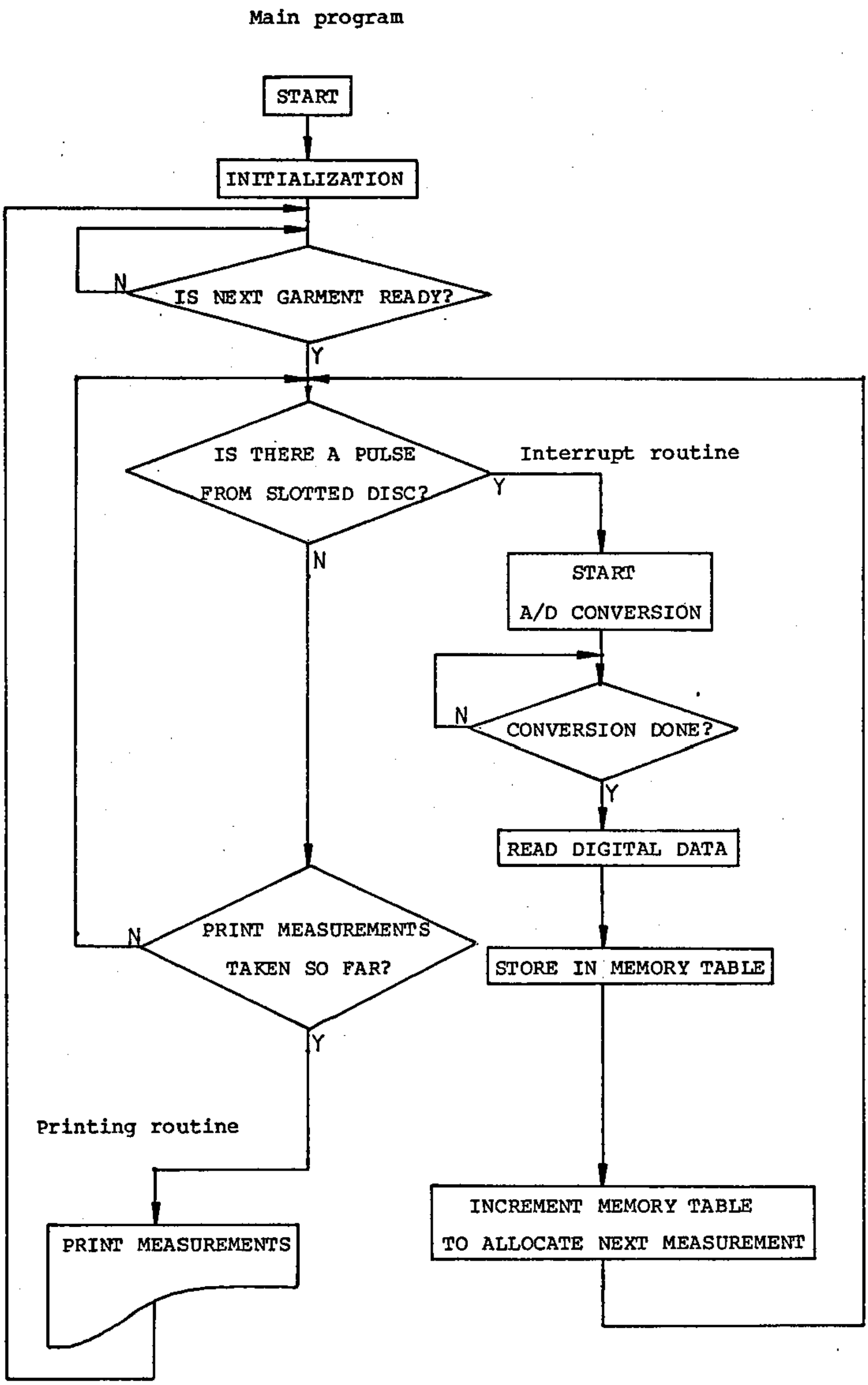


Fig. 5.29 TSS12 General Flowchart

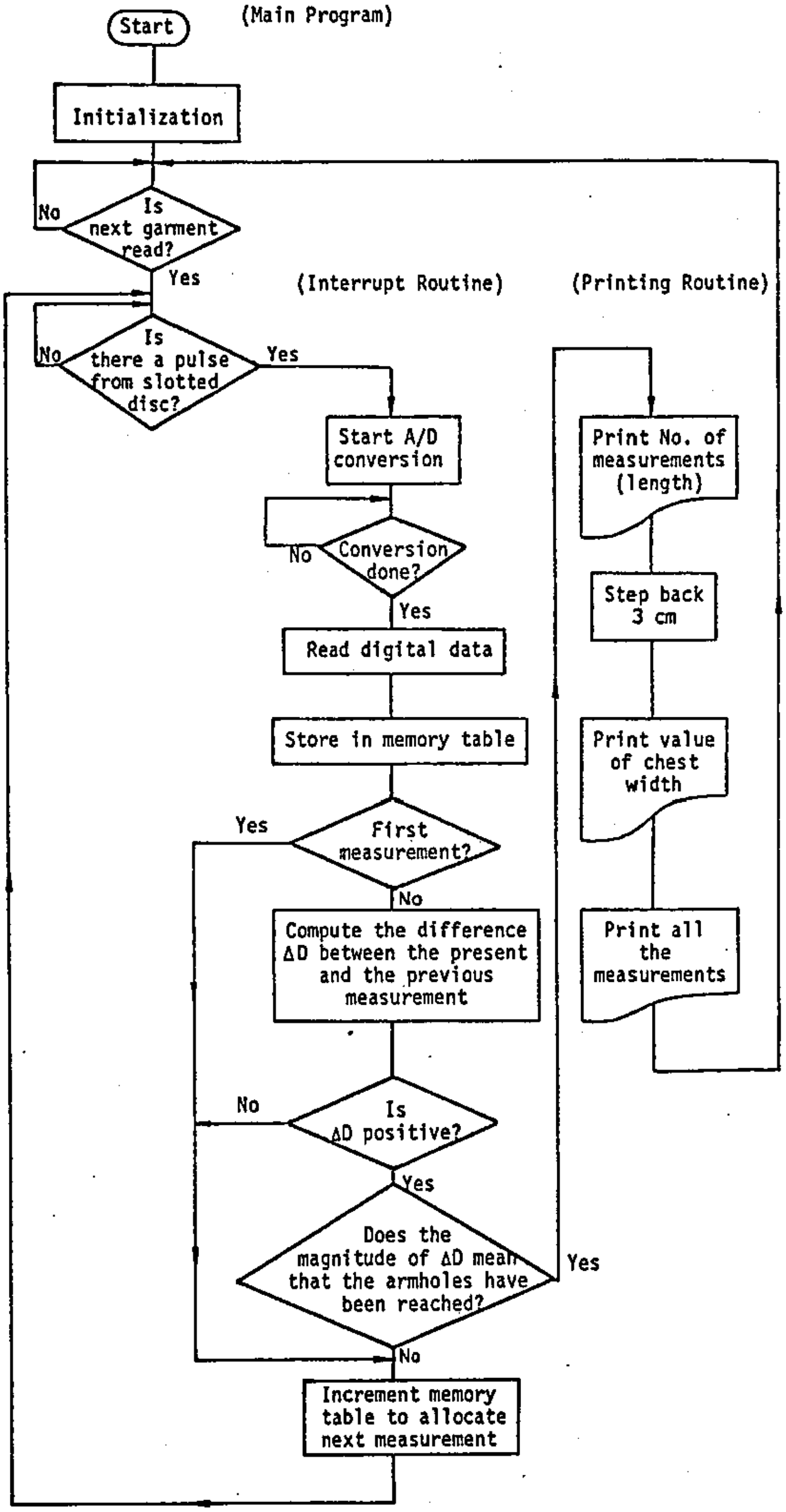


Fig. 5.30 "TSS13" general flowchart

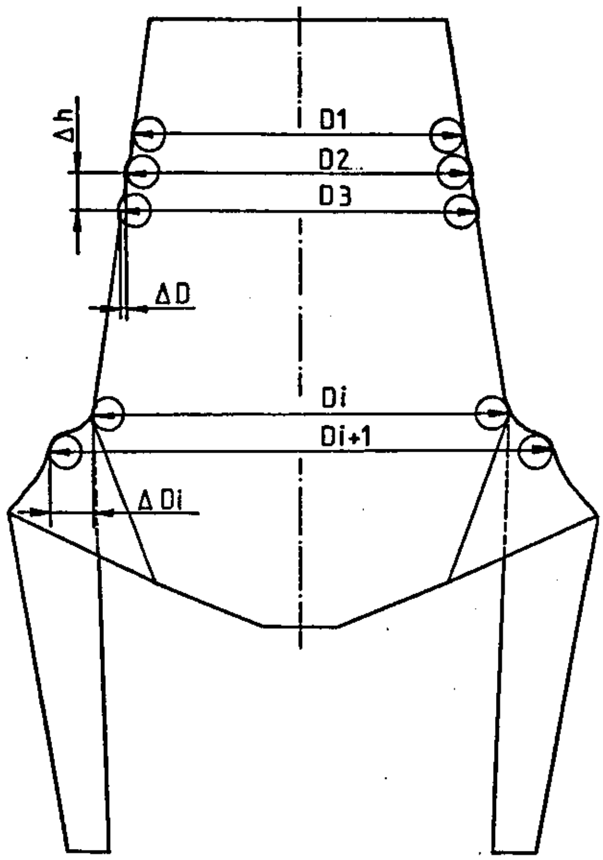


Fig. 5.31 Illustration of the measurement technique

TABLE 5.1

Values of the chest width in terms of the angle β (degrees) for Mark 1 sizing apparatus.

Material = Acrilan (Men's)

W(N) \ Size	36	38	40	42	44
10	9.00	9.50	12.25	12.75	17.25
20	11.75	11.75	14.75	15.25	19.75
30	13.00	13.25	17.00	17.25	22.25
40	14.25	15.00	18.75	18.75	23.75
50	15.25	16.00	20.25	20.25	25.50

Material = Crimplene (Ladies')

W(N) \ Size	12	14	16	18	20
10		9.25	10.00	16.00	16.75
20		11.25	11.75	17.75	18.75
30		12.50	13.25	19.50	20.75
40		13.75	14.00	21.25	22.75
50		15.00	15.75	22.75	24.25

TABLE 5.1 (cont.)

Values of the chest width in terms of the angle β (degrees) for Mark 1 sizing apparatus.

Material = Lambswool (Men's)

W(N) \ Size	36	38	40	42	44
10	9.25	8.50	16.50		16.75
20	12.25	10.75	20.25		20.25
30	13.75	12.25	22.75		22.50
40	15.25	13.50	24.75		24.75
50	16.25	14.75	26.25		26.50

Material = Shetland (Ladies')

W(N) \ Size	12	14	16	18	20
10	6.00		13.25	18.25	
20	8.25		15.25	20.25	
30	9.75		17.25	22.75	
40	11.00		18.75	24.50	
50	12.25		20.25	26.00	

TABLE 5.2: Values of the Chest Width in terms of Voltage for the Trimmed Sample with Mark 2 Sizing Apparatus

MATERIAL		1708 LAMBSWOOL						2606 COURTELLE						2135 SHETLAND					
P(bar)	Size / Ident.No.	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
3	38	7.0	6.8	7.0	7.1	6.9	7.0	6.0	5.9	5.9	5.9	6.0	6.0	7.4	7.3	7.7	7.3	7.2	7.7
4	38	7.7	7.5	7.7	7.8	7.8	7.9	6.5	6.4	6.5	6.5	6.6	6.6	8.8	8.1	8.6	8.0	8.1	8.5
5	38	8.7	8.6	8.5	8.6	8.4	8.5	7.2	7.0	7.2	7.2	7.1	7.1	9.9	9.1	9.8	9.1	9.1	9.8
3	40	8.2	8.6	8.2	8.5	8.0	8.1	6.6	6.4	6.5	6.5	6.7	6.6	8.9	8.6	8.6	8.7	8.9	8.7
4	40	9.1	9.5	9.1	9.4	8.9	9.0	7.4	7.0	7.1	7.2	7.4	7.3	9.6	9.9	9.7	9.6	10.0	9.9
5	40	10.0	10.1	10.0	10.1	9.7	7.8	7.9	7.5	7.7	7.9	8.0	7.9	10.6	10.8	10.5	10.4	11.0	11.2
3	42	8.9	9.0	8.8	9.0	8.8	9.1	7.5	7.2	7.2	7.2	7.4	7.2	9.8	9.0	9.1	9.2	8.9	8.8
4	42	9.9	10.1	10.0	10.0	9.7	10.1	8.2	8.0	7.9	7.9	8.3	7.9	10.9	9.8	10.4	10.0	9.9	9.9
5	42	10.5	10.9	10.3	10.6	10.6	8.8	8.8	8.8	8.6	8.7	9.0	8.8	11.9	11.1	11.8	11.6	10.8	11.0
3	44	10.1	10.0	9.8	9.8	10.0	9.9	8.3	8.3	8.8	8.6	8.5	8.7	10.6	10.6	10.5	10.9	10.2	10.7
4	44	11.2	10.9	11.1	10.8	10.9	11.1	9.1	9.0	9.6	9.4	9.2	9.3	11.8	11.5	11.5	11.9	11.4	11.9
5	44	11.8	11.8	11.7	11.6	11.8	11.8	9.8	10.1	10.5	9.9	9.8	10.1	*	*	*	*	*	*

* System overloaded

TABLE 5.3: Values of the chest width in terms of voltage for the non-trimmed sample with Mark 2 sizing apparatus

		Pressure (bar)		
Size	Identification No.	3	4	5
36	1	4.2	5.0	5.6
	2	4.7	5.3	6.0
	3	4.5	5.4	6.1
38	1	4.9	5.6	6.3
	2	4.9	5.5	6.3
	3	5.1	6.0	6.7
40	1	6.2	7.0	7.8
	2	6.5	7.2	8.0
	3	5.6	6.3	7.0
42	1	6.7	7.5	8.2
	2	6.2	6.8	7.4
	3	6.4	7.3	8.0

TABLE 5.4: Friction Forces Between Rollers and Garment (N)

		SIZE			
Material	p(bar)	38	40	42	44
2606 COURTELLE	3	0.21	0.22	0.23	0.24
	4	0.22	0.23	0.24	0.25
	5	0.23	0.24	0.25	0.26
1708 LAMBSWOOL		38	40	42	44
	3	0.18	0.19	0.21	0.22
	4	0.19	0.20	0.22	0.28
	5	0.20	0.21	0.23	0.24
2135 SHETLAND WOOL		38	40	42	44
	3	0.25	0.27	0.29	0.29
	4	0.26	0.28	0.30	0.30
	5	0.28	0.29	0.31	0.31

TABLE 5.5: Mass of Trimmed Sample (grams)

Size \ Identification No.	1	2	3	4	5	6
	COURTELLE					
38	314	308	317	308	316	307
40	343	325	340	344	345	335
42	359	351	334	357	353	351
44	377	366	389	377	376	375
	LAMBSWOOL					
	1	2	3	4	5	6
38	263	260	258	262	258	260
40	290	294	290	291	291	290
42	320	329	316	322	323	327
44	337	338	343	350	336	341
	SHETLAND					
	1	2	3	4	5	6
38	372	371	372	372	366	374
40	413	397	405	415	408	407
42	443	424	450	432	442	441
44	445	439	445	443	444	426

TABLE 5.6: Mass of Non-Trimmed Sample (grams)

Size \ Identification No.	1	2	3
36	212	217	310
38	228	227	232
40	249	249	245
42	268	256	263

Table 5.7 Example of print out with TSS13

```
OK ?SH/36.1/Y

2B   52

33   33   33   34   35
36   37   38   39   3A
3A   3B   3B   3B   3B
3B   3B   3B   3B   3B
3B   3C   3C   3C   3C
3D   3E   3F   41   42
44   46   48   4B   4F
51   52   52   52   52
54   59   61   6E

OK ?SH/36.2/Y

28   49

2E   2E   2E   2F   30
31   31   32   33   33
34   34   34   35   35
35   36   36   36   36
36   36   36   36   36
36   36   37   37   37
37   38   39   3C   41
46   49   49   4B   51
5B

OK ?SH/36.3/Y

29   45

2F   2F   2F   2F   31
33   33   34   34   35
35   36   36   36   37
37   37   37   37   37
37   37   37   38   38
38   38   38   38   38
38   38   38   38   3A
3D   42   45   45   48
4F   5B

OK ?/36.4/Y

27   4B

30   30   30   31   32
33   34   35   35   36
37   37   38   38   39
39   3A   3B   3C   3C
3D   3D   3E   3E   3F
40   42   43   45   47
49   4A   4B   4B   4B
4B   4B   4B   4F   5A
```

```
OK ?SH/36.5/Y

2A   53

2D   2E   2E   2E   2E
2F   30   32   34   36
37   38   38   38   38
39   39   39   39   39
39   39   39   39   39
39   39   3A   3A   3B
3D   40   44   49   4E
52   53   53   53   55
5A   63   70

OK ?SH/36.6/Y

2A   54

31   31   31   31   32
33   34   35   35   36
36   37   37   38   38
38   38   38   39   39
3A   3A   3B   3C   3D
3E   3E   3E   3E   3F
3F   40   41   43   47
4B   51   54   54   56
5B   62   6E

OK ?SH/36.7/Y

2A   4C

34   34   34   34   35
35   36   37   38   38
39   39   3A   3A   3A
3A   3B   3B   3B   3B
3B   3B   3B   3C   3C
3C   3C   3D   3E   40
42   44   46   49   4B
4C   4C   4C   4C   4D
51   5A   63

OK ?SH/36 8/Y

2A   50

30   30   30   31   32
33   34   34   35   35
36   36   36   36   37
37   37   37   38   38
38   38   38   38   38
38   39   39   39   39
3A   3C   3F   44   48
4C   4F   50   50   50
50   57   63
```

```
OK ?SH/36.9/Y

28   4D

2F   2F   2F   30   32
35   36   37   37   38
38   38   39   39   39
39   3A   3A   3A   3A
3B   3B   3B   3B   3C
3C   3C   3D   3E   42
46   4B   4D   4D   4D
4D   4D   4D   50   59
6A

OK ?SH/36.10/Y

27   55

2E   2E   2F   30   33
34   35   36   36   37
37   38   38   38   39
39   39   39   39   3A
3A   3A   3B   3B   3C
3E   41   44   46   47
48   49   4A   4D   51
55   55   57   5F   6D

OK ?SH/36.11/Y

28   51

36   36   36   36   37
38   39   39   3A   3A
3B   3B   3B   3B   3C
3C   3C   3C   3C   3D
3D   3D   3D   3D   3E
3E   3E   3F   40   43
47   4B   4E   50   51
51   51   51   51   57
64

OK ?SH/36.12/Y

28   59

34   34   34   35   36
38   3A   3B   3B   3B
3C   3D   3D   3E   3E
3E   3E   3F   3F   3F
3F   3F   40   40   40
41   42   44   48   4B
4E   50   52   53   54
56   59   5A   5B   62
74
```

TABLE 5.8: Data Collected with a Shetland Wool Sample of Garments During Tests with Mark 3 Sizing Rig

cw - chest width (hexadecimal number)
m - mass (grams)

Size / Identification No.	36		38		40		42		44	
	cw	m	cw	m	cw	m	cw	m	cw	m
1	52	278	68	289	84	323	95	363	B6	363
2	49	270	6E	292	81	335	9E	364	4D	366
3	45	377	72	299	82	332	9A	370	B1	359
4	4B	284	72	298	7F	328	87	355	A2	370
5	53	281	62	293	7D	332	95	367	B7	367
6	59	282	73	309	7E	326	96	366	B3	364
7	4C	278	61	312	7E	329	91	360	AE	365
8	50	286	67	292	78	327	9E	362	AB	370
9	4D	375	6D	300	82	341	94	350	B4	365
10	44	382	65	281	81	334	96	359	AF	367
11	51	287	71	304	87	331	9E	366	AA	367
12	59	379		297	82	336	A4	367	B7	370

CHAPTER 6

OPTIMIZATION OF THE MACHINE CONCEPT

6.1 Introduction

Chapter 4 has explained the basic approach to the problem, the selection of the concept for turning and sizing, and the introduction of the preliminary concept for the whole process. In Chapter 5 the sizing technique has been comprehensively investigated with quite encouraging results. The microprocessor controlled system is not only able to measure the garment under kinematic conditions, but also detects the precise moment the rollers move into the armholes. It can then be programmed to generate a signal to start the upward movement of the lift neck device which is an essential feature of the turning technique.

Having demonstrated the feasibility of the sizing technique and its contribution to the turning operation, the way ahead was to work towards a turning/sizing rig. Before doing so, the preliminary concept needed to be analysed in more detail to see whether improvements and simplifications were possible. It is well known that for almost any favourable feature in a design, there is an unfavourable one. Optimization is, therefore, the process to arrive at a balance between the factors that pull in opposite directions, that is, the process to reach the best compromising solution.

In the concept that arose from the feasibility study, there were conflicting factors. One of them was the complexity of the carousel with 8 vertically moving clamps, in order to reduce the stroke of the arms and the overall height of the machine. The conveying carousel itself cuts the overall cycle time by allowing the simultaneous loading, turning and sorting, but the price is paid in terms of increased floor space. In the following sections, different approaches intended to simplify and optimize the preliminary concept are summarized.

6.2 One Single Actuator Driving the Vertical Movement of the Clamps

The first simplification to the initial concept has already been introduced in Chapter 4. The carousel with 8 vertically moving clamps, each one with its own actuator, gave place to the more efficient design with one single actuator to drive all the clamps when they reach the turning/sizing station. The simplification resides in the fact that 7 out of 8 actuators are eliminated and that all the pneumatic network is reduced and taken to the stationary part of the machine.

The unfavourable aspect resulting from the new design, is essentially the need for a mechanism responsible for the engagement between the actuator and the clamp when it reaches the turning/sizing station. This mechanism must release the clamp once the turning operation is completed, so that it can be rotated within the carousel to the first sorting station. Once the clamp is out of the turning station, it must stay at the top position within the carousel, to make possible the sorting/stacking operation as described in section 4./.5. When one clamp is indexed to the turning/sizing station, it must simultaneously engage with the actuator and be released from some sort of "latching" mechanism that holds it at the top position.

Fig. 6.1 schematically represents the engagement/disengagement and latching mechanism for the function described above. When the clamp is about to engage with the actuator, the engaging element 1 attached to the clamp, rolls into the slot of the component 2, fixed to the linear actuator. At the same time, the latch releases the clamp by means of a stationary cam. The clamp is now free to be moved downwards and brought up again during the turning operation.

When the carousel is indexed again, the clamp is rotated, which forces the latch to hold it again before the engaging element 1 is released by component 2.

6.3 The Concept of Dual Clamps with Transference of the Garment

The primary objective of this approach is to explore the possible replacement of the carousel and by doing so, to avoid the complexity of the vertical movement of the clamps within a system that is itself rotating with an indexing movement. The clamp could then be part of the turning station and have its vertical reciprocating movement within a stationary frame. The main problems arising in a situation of direct loading can be stated as:

1. Sorting has to be carried out directly from the turning station, certainly by means of some external mechanical arm.

2. Loading of a new garment will have to wait the complete turning and removing of the one being processed.

The second problem could be overcome using indirect loading, by means of an intermediate clamp that will act as a buffer, so that the next garment can be loaded on it while another one is still being turned. The procedure, supported by Figs. 6.2 and 6.3 can be described as follows:

1. Operator loads a garment onto "transfer" clamp which will adjust itself widthwise to accommodate the waist width of the garment.

2. When the "turning clamp" is cleared from the garment that has been previously turned, the "transfer clamp" is engaged to move from the loading position and deposit the garment on the "turning" clamp which will then grasp it. As soon as the tranference of the garment is done, the "transfer" clamp can start the movement that

will bring it back to the loading position. The turning/sizing operation can then start. When the "transfer" clamp returns to the loading station, it will automatically adjust itself to the innermost position in order to be prepared to accommodate the next garment.

3. After being turned, the garment has to be taken away from the turning station and sorted/stacked on the respective sorting station by means of an external unloading/sorting mechanical arm.

Certainly this concept has its weaknesses. The garments have to be removed directly from the turning/sizing station, and part of the consumed time has to be added to the cycle time of the machine. There are two sets of clamps working independently from each other during the major part of the cycle, but they have to match their widths when the transference occurs. In fact, the "turning" clamp will have to adjust its width to the one of the "transfer" clamp so that the garment can be transferred from one to the other. Some sort of feedback between them is required, which, with the need for a very precise width matching, will make the dual clamp system very complex.

After transferring the garment to the "turning" clamp, the "transfer" clamp cannot return to the loading position through the same path by simply reversing its movement. In fact, the garment will now be in its way as can be seen in Fig. 6.2. The path of the "transfer" clamp has to assume the shape of a loop, returning to the original loading position using a different path, out of the way of the garment. According to Tao[40], this shape of looping path can be achieved with the use of a dedicated designed four bar linkage. Methods for the synthesis of the mechanism are given by Hrones and Nelson[41].

6.4 Carousel with 3 Clamps and Sorting Robotic Arm

Behind this approach is the intention of reducing the size of the carousel and consequently its mass and the time of the indexing rotation. The carousel is similar to the one proposed in the preliminary concept, but having 3 instead of 8 clamps. One will be at the loading station, another at the turning/sizing station and the third will be at the unloading station, where the already turned garment will be removed and sorted/stacked to an appropriate position by an external robotic arm.

The carousel can then be made lighter, but having only 3 clamps, each indexing rotation will have to perform 120°. The sorting/stacking of the garments is carried out by a similar procedure to the one proposed in the preliminary concept. There is, however, a major difference that requires careful consideration. The mechanical arm grasps the garment as close to the waist as possible. Once this is achieved, the clamp will release the garment that will be transferred to the robotic arm. According to the size of the garment, this sorting arm has to rotate from the unloading station to the correspondent sorting station. Unlike the 8 clamps carousel concept, where the same 45° rotation occurs for each indexed movement, the angular movement required to sort one garment is now dependent on the size of the garment and the position of the corresponding sorting station. In the worst case this can be nearly 180° and to return the arm to the unloading station, the same amount of movement is required.

6.5 Carousel with Stationary Clamps in the Vertical Direction

The vertical reciprocating movement of the clamps has been dictated by the aim of reducing the overall dimensions of the machine, in particular its height. All the attempts to simplify the system keeping the clamp in reciprocating movement, have led to unsatisfactory embryonic solutions that are summarized in previous sections 6.2, 6.3, 6.4.

Already mentioned when the selected concept was first introduced in section 4.4 (concept no.6), is the alternative possibility of keeping the clamps stationary in the vertical direction within the carousel. The unfavourable result of this solution is that the turning of the garment has to be accomplished entirely by the stroke of the arms. As a consequence, the overall height of the turning and sizing station will be stretched by about 1 m. On the other hand, there are several advantages:

1. The actuator previously responsible for the vertical movement of the clamps at the turning station is eliminated. Only two long stroke actuators remain: the one that drives the arms, whose stroke will be extended to approximately 2 m, and the actuator driving the lift neck device. The pneumatic network will have reduced piping and reduced number of valves, as well as a simplified control circuit.

2. A major simplification is introduced to the carousel. As there is no need for the clamps to move vertically within the carousel, the prismatic structure can be replaced by an "umbrella" structure with the clamps circularly arranged in the same plane. The carousel can, therefore, be made much lighter and a reduction in the indexing time is definitely possible without increasing the power of the driving system.

3. The cost of the design will definitely be reduced. The actuator that was previously responsible for the vertical movement of the clamps is eliminated and with it a considerable part of the pneumatic network. The cost of the carousel will also be reduced; the structure will be greatly simplified and all the linear bearings and shafts are eliminated.

4. In the final stages of the turning operation, when the sleeves are about to come off the arms, the garment has to be flung by the reasons pointed out in section 4.7.6. In all the previous solutions, the flinging actuation had to be carried out when the clamp is approching its lowest level, near the floor. The presence of the prismatic structure of the carousel left very little room for

positioning the flinger. This problem can be better understood by the observation of Fig. 4.40. As a result of the new arrangement, the flinger can be positioned in an extension of the frame of the turning/sizing station, where there are no space problems, as can be realized by the observation of Fig. 6.5.

6.6 Conclusions

The overall simplification achieved with this design is certainly enough to justify the price paid in terms of the extended height of the turning/sizing station to around 3.4 m.

The actuator that drives the arms will have its stroke extended to about 2 m, which is well within the scope of the selected design (see Appendix 1).

This optimization phase has been primarily directed towards the turning/sizing operation in order to establish all the necessary parameters for the design of the turning/sizing rig. The new configuration of the carousel is, therefore, a useful consequence of the new turning/sizing station layout.

The sorting/stacking operation, still at its embryonic stage in the feasibility study, is considered to be a satisfactory concept. Therefore, no attempt has been made to improve the original concept since it does not play any important part in the planning of the turning/sizing rig.

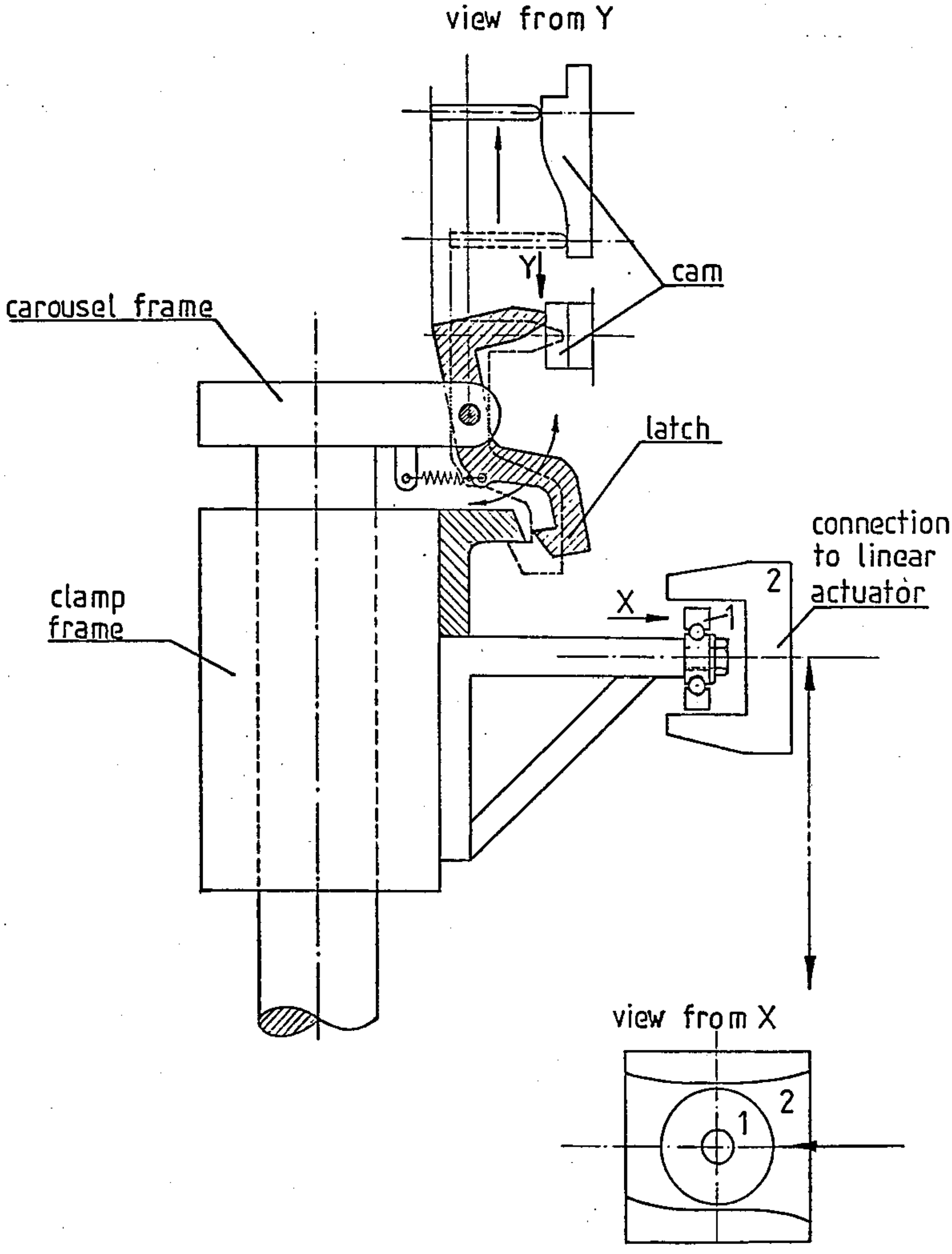


Fig.6.1 Schematic representation of the engaging/disengaging and latching mechanism.

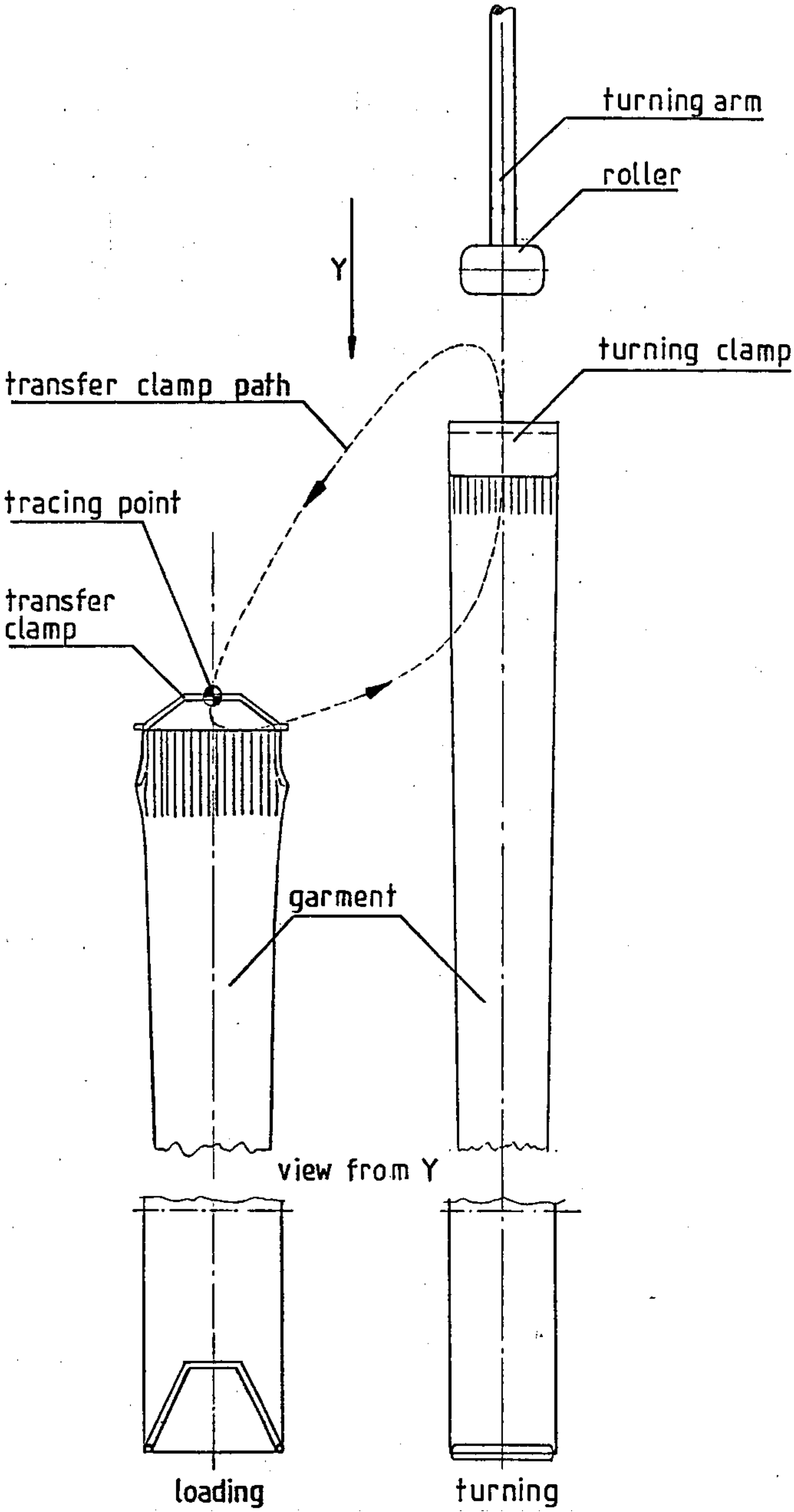


Fig. 6.2 Schematic representation of an hypothetical path for the "transfer clamp".

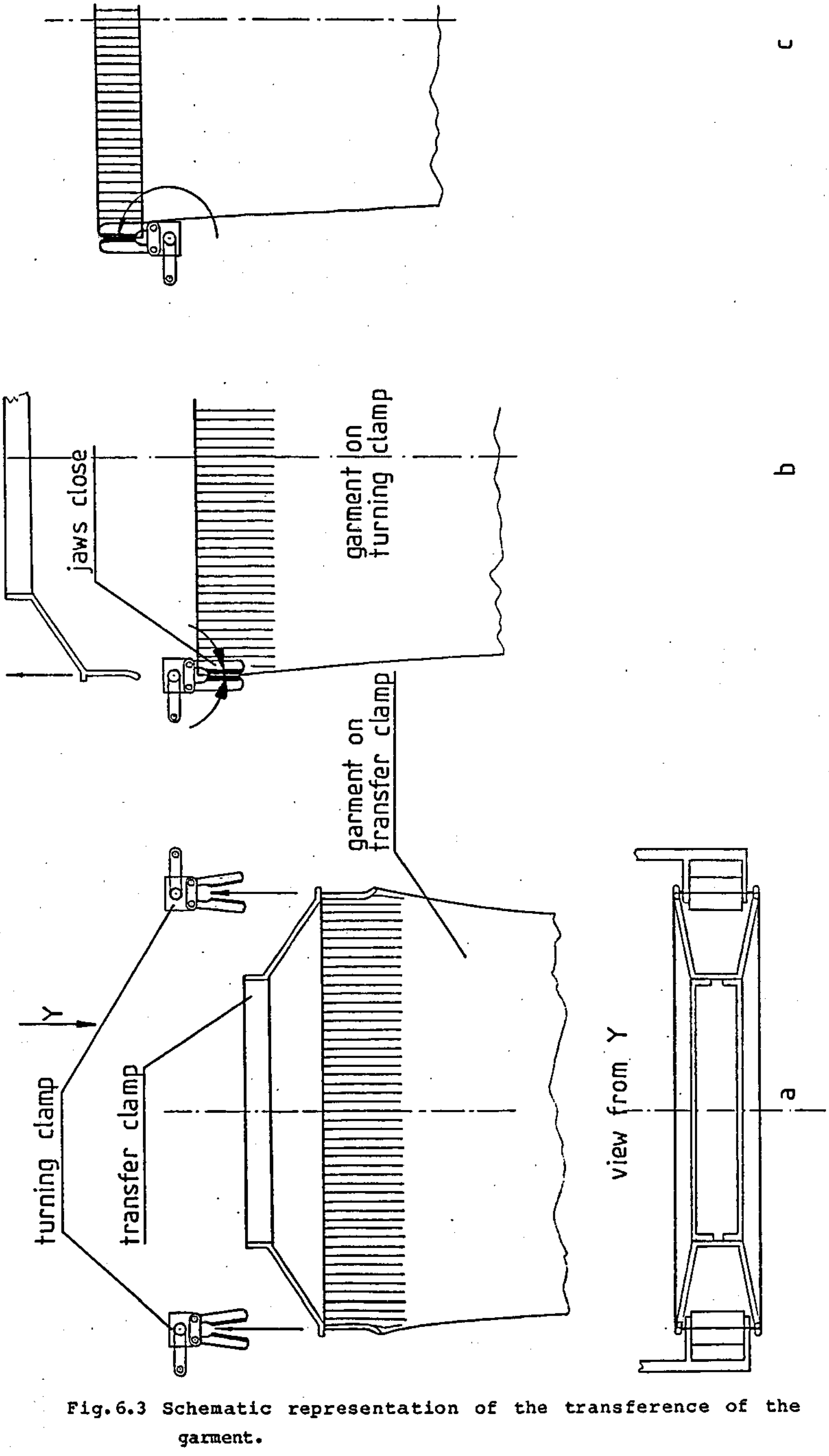


Fig.6.3 Schematic representation of the transference of the garment.

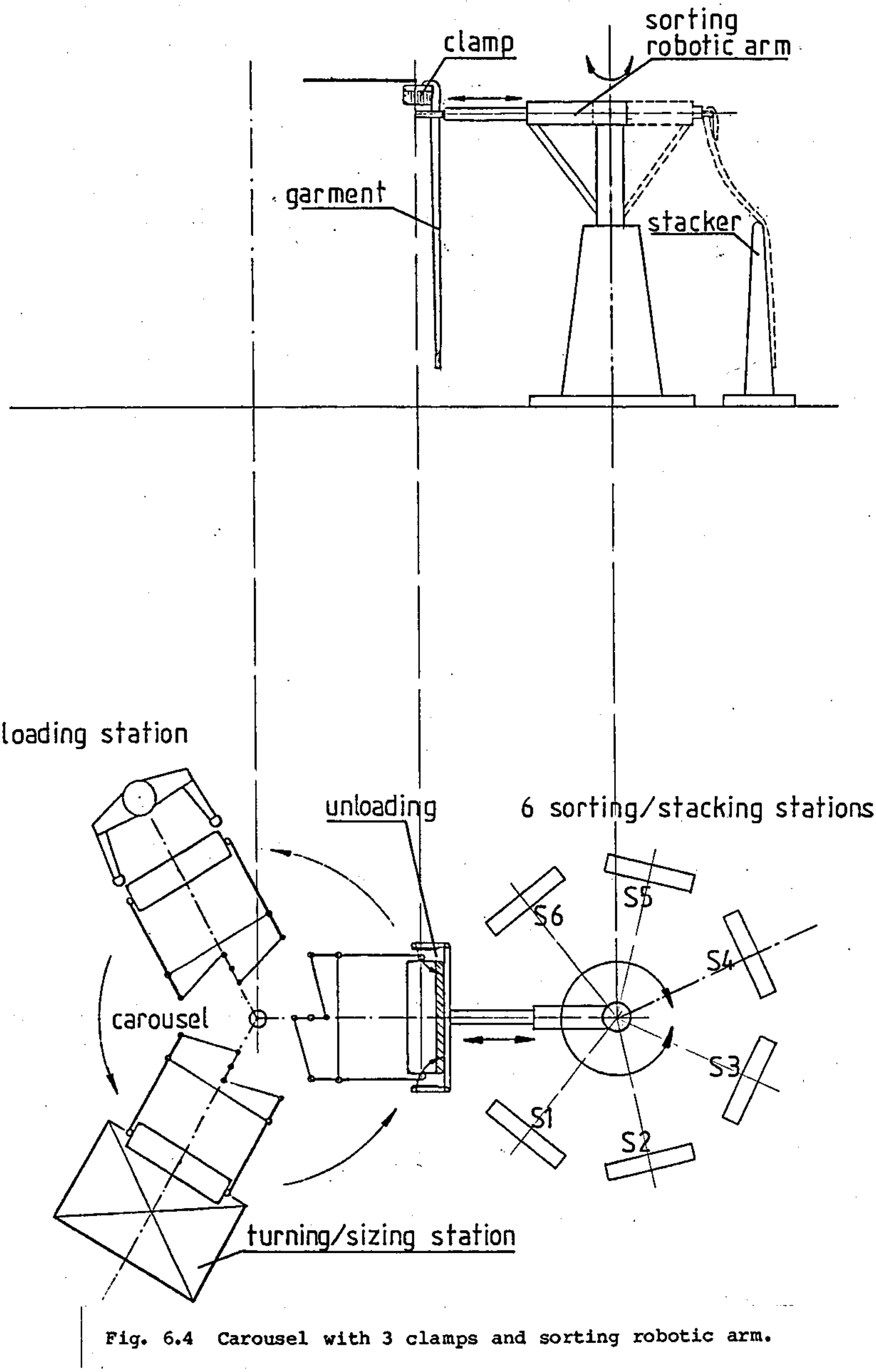
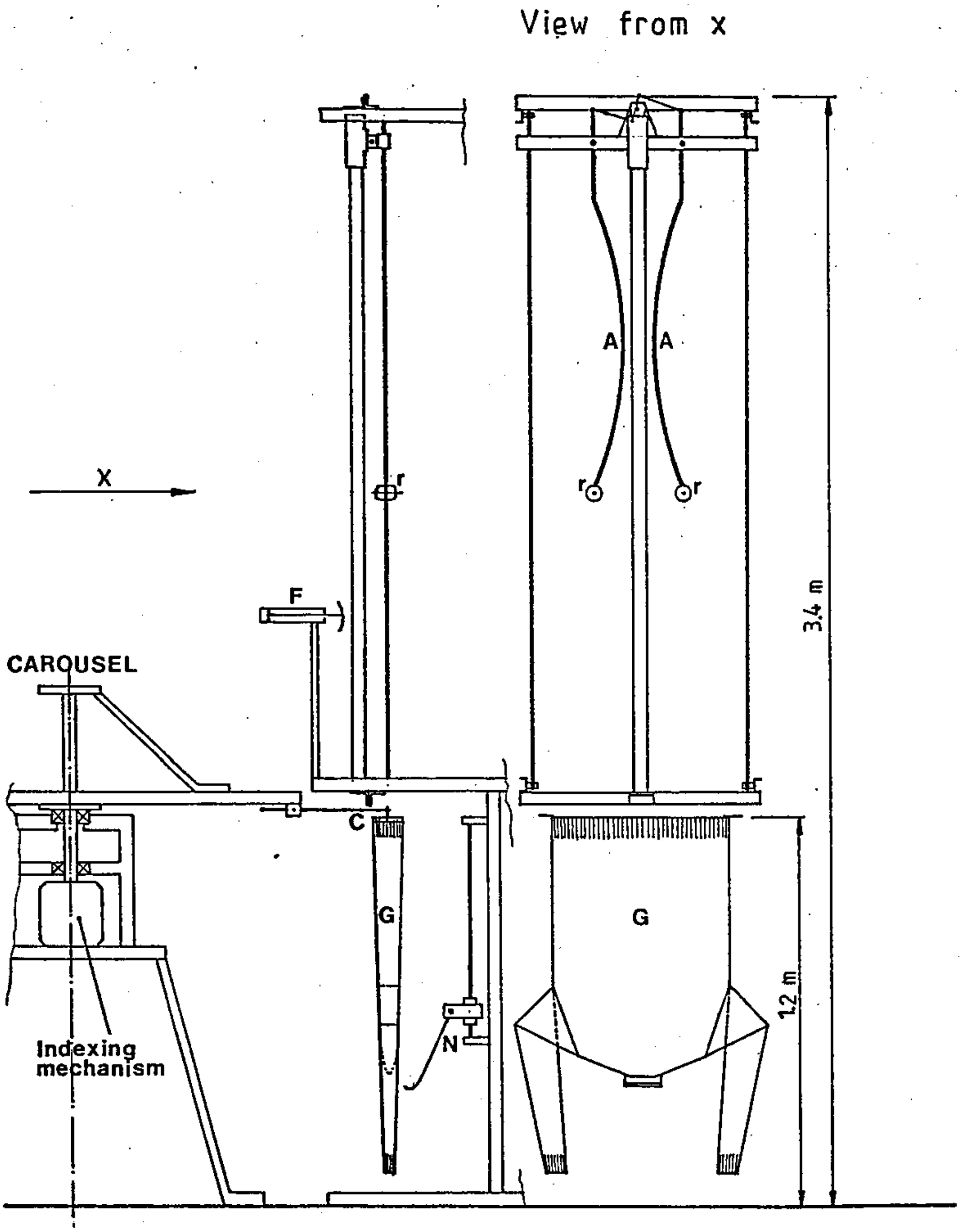


Fig. 6.4 Carousel with 3 clamps and sorting robotic arm.



A Turning arms
C Clamp
N Lift neck device
F Flinger
r roller
G Garment

Fig. 6.5 Carousel with stationary clamps in the vertical direction.

CHAPTER 7

RESEARCH INTO MICROPROCESSOR CONTROLLED TURNING AND SIZING

7.1 Introduction and Objectives

The optimization work summarized in Chapter 6 led to the definition of the main aspects of the design, especially in respect to the turning/sizing station and its interaction with the carousel.

The present chapter describes the rig built to carry out the turning/sizing operation using the information and the knowledge gained during previous stages of the research. The rig, though still a development phase of the concept, was designed to be a simplified prototype of the turning/sizing station.

7.2 Turning and Sizing Rig

The turning and sizing rig is basically the turning/sizing station of the whole concept. The carousel and the sorting/stacking stations are not under the scope of the present rig as they have only been suggested in an embryonic form during this work. Their inclusion in the rig is not necessary to demonstrate the capabilities of the proposed innovative techniques for turning and sizing. On the other hand, their design and manufacture was beyond the author's time scale for the project and would have demanded a large amount of technician time as well as materials and components for which no funds were available. However, the need to hold the garment in position during the process dictated the design of a clamp that was attached to the rig.

The rig is shown in the photographic view of Fig.7.1 where the three main assemblies, arms, clamp and lift neck device can be seen incorporated in a simplified structure. The geometry and design of these assembies, as well as the layout of the complete rig are given in more detail in Chapter 8.

It was decided to mount the clamp in a pivot fixed to one member of the structure. By this method, the garment can be loaded onto the clamp in an accessible position where it is away from the arms and the lift neck device. This is safer for the person conducting the tests and allows a more confortable loading position, similar to the one envisaged for the final design. There are two other advantages of the chosen arrangement:

a) There is no interference with the mounting of the other assemblies, especially the lift neck device;

b) After being loaded with a garment, the clamp is rotated about 180° on the above mentioned pivot and positioned by a cam and latching mechanism, which ensures that the garment is centralized with the arms and lift neck device and that the clamp is locked in place during the process. The pivoted movement of the clamp from the loading to the turning position, can in a sense, be compared with the indexing movement of the carousel.

7.3 The Experimental Procedure

One of the main objectives of the rig was to assess the capabilities of the proposed concept for turning outerwear knitted garments inside out. As far as this objective is concerned, the rig was entirely successful. Different garments of various sizes, styles and materials were easily and smoothly turned inside out.

The rig did not incorporate the "barbed arms" referred to in section 4.6.4. During the tests, the foreseen phenomenon of the bunching of the sleeves, though occurring, was not as serious as the author previously imagined. However, with the more bulky and high friction materials, the phenomenon was more evident. In some cases, the restriction on the reverse stroke of the arms was clearly visible with a temporary slowing down at the beginning of the reversal of the sleeves. The flinger, mentioned in section 4.7.6, was not incorporated in the rig. However, its need was completely verified as predicted.

The experimental procedure can then be described as follows:

1. The garment was grasped by the waist which was put in position onto the clamp. With both hands occupied, the operator would press a foot switch to actuate the mechanism that expands the waist to create grip. Fig. 7.2 a) shows the garment in this position on the clamp.

2. The clamp was then rotated around its pivot to place the garment in the turning position as seen in Fig 7.2 b). This movement was carried out manually but would be an automatic indexed movement of the carousel in the final design.

3. For safety reasons, the operation was commenced by pressing a start button after the operator has moved away from the rig. The actuators then started the sequential movement that resulted in the turning of the garment inside out. Finally the computer produced a print out for each garment, in the same terms as with the sizing rig described in section 5.4, stating the measurements taken at 1cm intervals and the measurement corresponding to the chest of the garment.

7.4 Software for Microprocessor Control

The software designed to cope with the needs of the turning and sizing rig followed similar lines to the one already described in section 5.4.8. However, a major modification was introduced to simplify the programme, by connecting all the control signals to computer port B, which, for that reason, was configured for both input and output. By this method, the use of interrupts was abandoned. The new configuration of port B is shown in Fig. 7.3. There are two new signals:

a) "Start measuring" on PB5 to instruct the computer to commence accepting measurements from the garment. The switch that generates this signal is positioned so that the arms have already entered the garment and swung outwards, being the rollers in contact with the garment and following the opposite body seams. The justification for the "start measuring" signal is that, if the computer was allowed to accept measurements from the start, where the arms are at the innermost position, the outwards movement of the arms when entering the garment would be taken as if the armholes were reached.

b) As soon as the computer detects the armholes, a pulse is sent to PB2 which energises the valves that start the movement of the lift neck device (section 8.4.1). The data on the garment width is fed into the computer through port A as before.

Fig. 7.4 shows the flowchart of the program identified as "TSS18". The program itself is listed in the respective coding sheet-Program TSS18 in Appendix 4.

7.5 Results and Conclusions

The final tests with the turning/sizing rig were carried out with a sample of Men's Lambswool jumpers. The sample, in a non-trimmed condition, was made up of 3 sizes, small (S), medium (M) and large (L). Initially intended to be of 6 garments per size, it was soon realized that a garment classified as Large was actually a Medium. Therefore, the sample had 6 garments size S, 7 size M and 5 size L. The garments were identified by numbers, 1 to 6 for size S, 1 to 7 for size M and 1 to 5 for size L.

The data on the chest width, as it was printed by the computer in terms of an hexadecimal number, is shown in Table /.1 and graphically displayed in Fig. /.5. From the observation of the mentioned graph, it is clearly visible how the various sizes separate. It is also evident that garment M/ could not be a size L garment as it was initially classified by mistake.

From the results of the experiment, an hypothetical configuration of size boundaries is proposed for this material-style. They would be, as shown in Fig. 7.5:

Size S: 7F to 8E;
Size M: 8F to A2;
Size L: A3 to B0;

The results on sizing, however limited to one small sample of garments, confirmed the sizing capabilities already verified with the sizing rig and described in Chapter 5.

It is the author's opinion that with this final research rig, the innovative techniques for both turning and sizing of knitted outerwear garments were demonstrated.

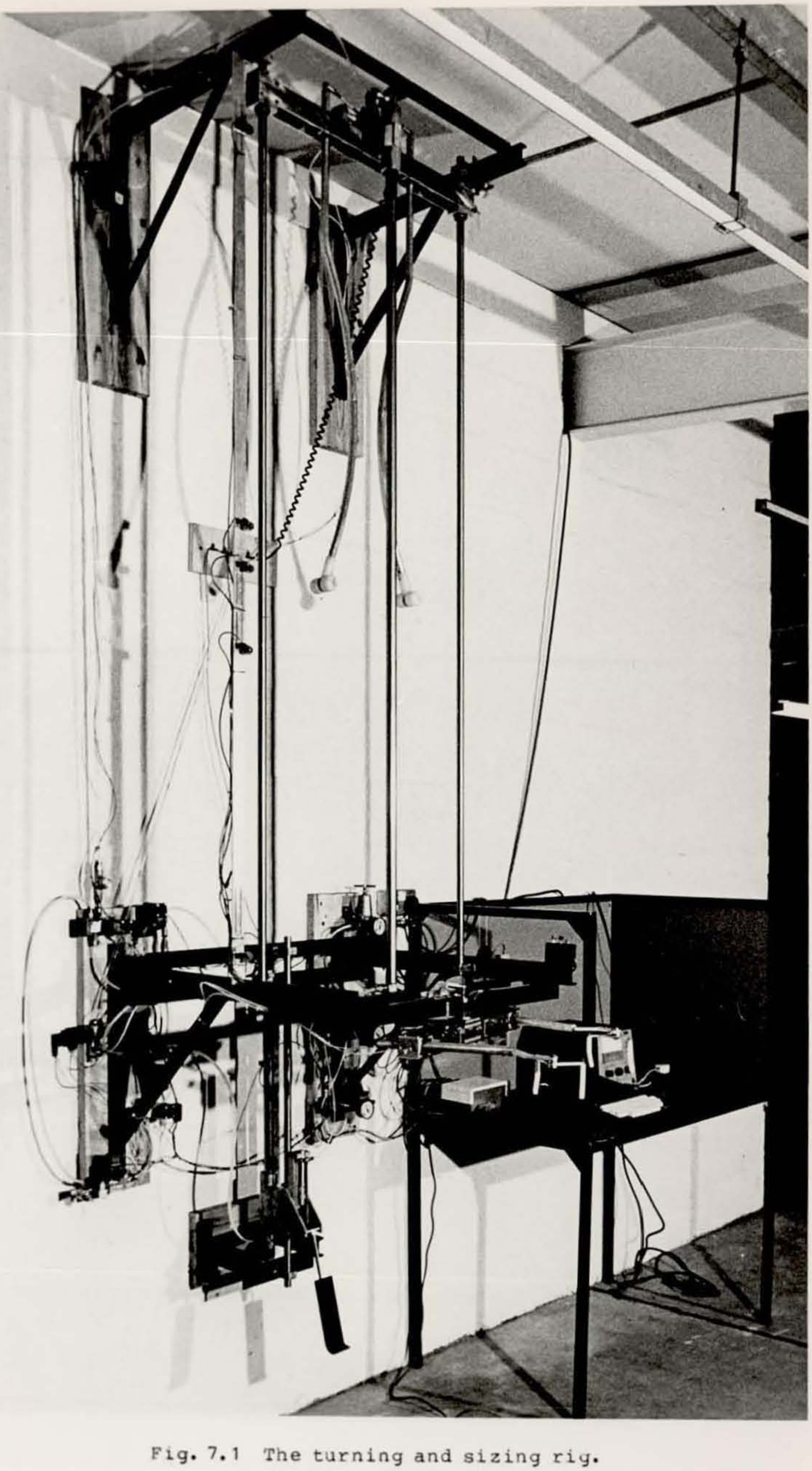


Fig. 7.1 The turning and sizing rig.

Fig. 7.2 Clamping of a garment on turning/sizing rig.

Pin No.	7	6	5	4	3	2	1	0
Function	X	DISC	START MEASURING	EOC	OE	VALVES	SC	ALE
0-Input 1-Output	1	0	0	0	1	1	1	1

0 - ALE (Address Latch Enable)

1 - SC (Start Conversion)

2 - VALVES 5 and 8 (Lift neck device)

3 - OE (Output Enable)

4 - EOC (End of Conversion)

5 - START MEASURING (Switch S4)

6 - DISC (Digital transducer)

7 - Not used

FIGURE 7.3: Configuration of Computer Port B for Turning and Sizing Rig

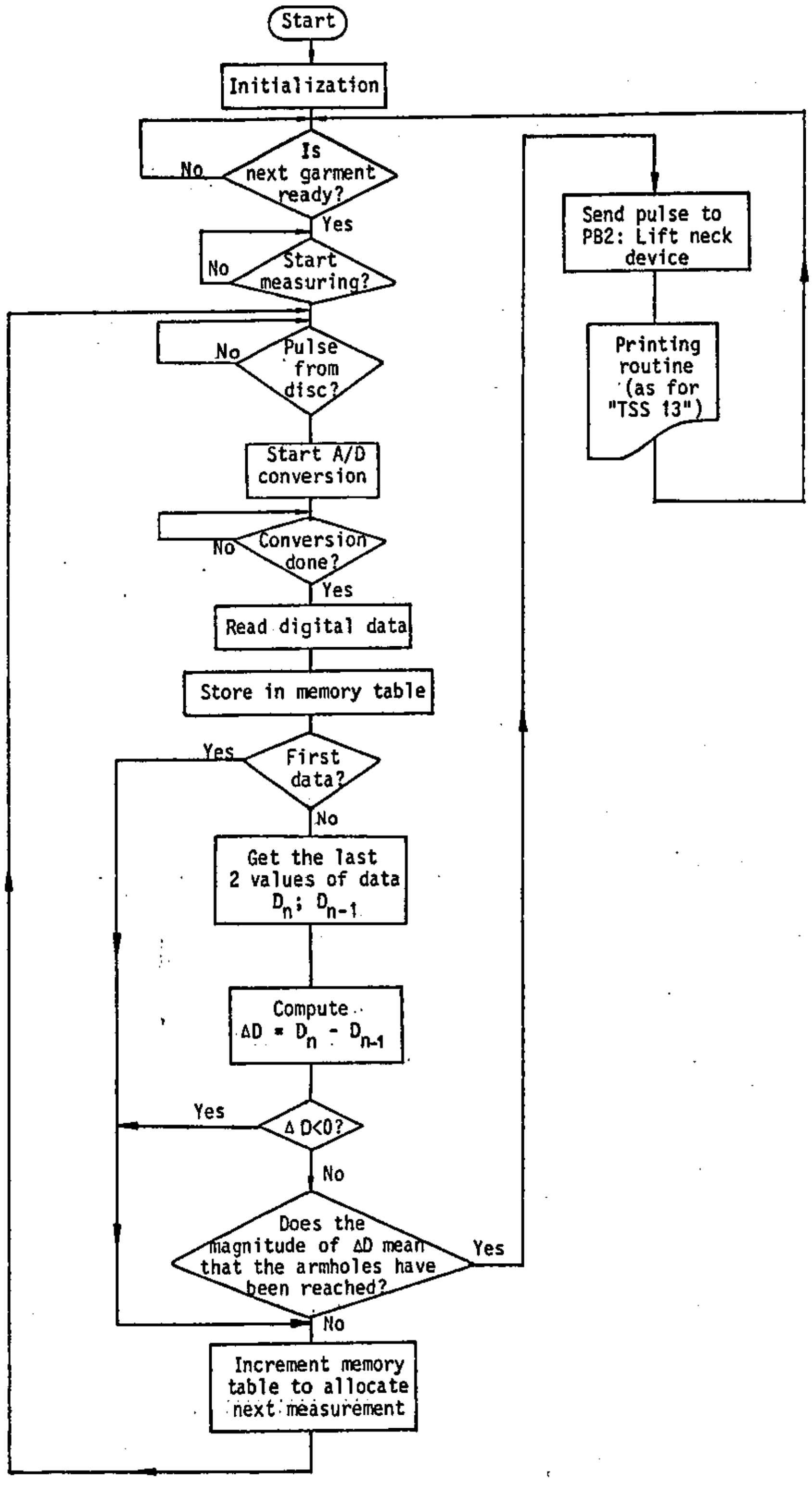


Fig. 7.4 "TSS 18" general flowchart.

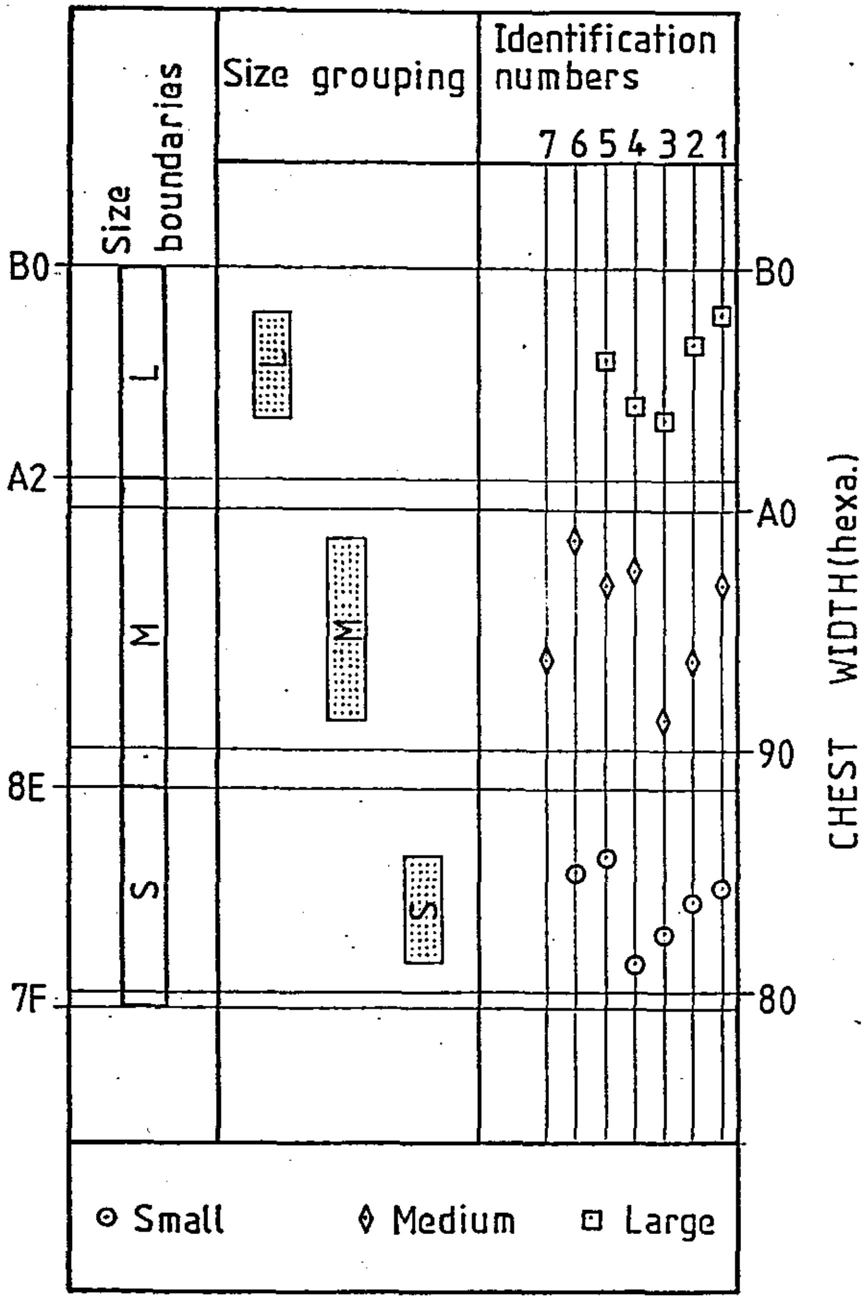


Fig. 7.5 Graphic display of results with the turning/sizing rig.

TABLE 7.1: Data Collected with a Lambswool Sample of Garments During Tests with the Turning/Sizing Rig (Hexadecimal Numbers)

Identification No. \ Size	S	M	L
1	87	9B	AD
2	86	96	AB
3	84	92	A6
4	82	9C	A7
5	89	9B	AA
6	88	9E	
7		96	

CHAPTER 8

MACHINE DESIGN

8.1 The Turning Arms Assembly

The turning arms assembly is represented in the assembly drawing ME/TSS 01 (Fig. 8.1). Being a vertically moving part, mass reduction has been one of the primarily concerns. For that reason aluminium has been widely used. Other advantages of using aluminium is its resistence to corrosion and consequent cleanliness.

The arms are made of 19 mm OD x 1.6 mm thickness extruded aluminium tube. At one end of the arms, nylon rods are attached to mount the rollers, also made of nylon and mounted on needle bearings for reduced friction. The arms are pivoted on the frame by means of cylindrical brass pivots and connected together at the top by the swinging mechanism. The links and crank are made of mild steel while the crank shaft and the pins of the articulations are of silver steel. As the pivoted movement of the arms is of small amplitude and relatively slow, the brass pivots work directly on the aluminium plates of the frame.

The arms frame is made of two long aluminium plates separated by small lengths of 38 x 19 mm aluminium channel. One of these separators was especially designed to be the rear trunnion support of the pneumatic cylinder responsible for the swinging movement of the arms. Bolted to the plates of the frame are two other small aluminium plates that support the swinging mechanism crank shaft. Fixed to one of the plates of the frame is the mounting of the potentiometer used as a position transducer for the swinging mechanism. Mounting details and selection of the timing belt are shown in Appendix 5.

At both ends of the frame are bolted aluminium blocks, each one housing a pair of linear recirculating ball bearings that run on two vertical parallel shafts to guide the movement of the arms assembly. The decision to use a pair of linear bearings at each side of the frame was taken due to the considerable distance of 700 mm between the guiding shafts.

The total mass of the moving parts is 5.08 Kg including the moving element of the actuator which is just over the 5 Kg of the preliminary calculations.

8.1.1 The Flexible Transmission

The vertical reciprocating movement of the arms assembly is provided by a 1900 mm stroke rodless pneumatic actuator. The long displacement of the arms assembly and the consequent need for a careful alignment of the two guiding shafts, dictated the use of a flexible transmission between the assembly and the moving element of the pneumatic actuator. Thus, the otherwise difficult alignment of three long parallel elements, the two guiding shafts and the linear actuator, is reduced to two shafts only, and hence, the alignment between the axis of the actuator and the two shafts is no longer critical.

The flexible transmission is made of a silver steel pin housed in an aluminium component bolted to the moving element of the actuator. The pin has flat faces at each end which fit into two slotted steel angles bolted to the arms frame.

8.2 The Lift Neck Device Assembly

The lift neck device assembly is represented in the assembly drawing ME/TSS 02(Fig. 8.2). Similarly to the arms, it is a vertically moving assembly that, for the reasons pointed out in sections 4.7.4 and 4.8.4, must be capable of a fast acceleration on the upward stroke. This calls for reduced mass of the moving parts and a conveniently overdesigned actuator. For that reason, aluminium has again been used extensively.

The lift neck device is a linear moving assembly made of an aluminium block which houses two linear recirculating ball bearings. The bearings run in a vertical shaft which guides the movement. The pneumatic rodless linear actuator is mounted with its axis parallel to the guiding shaft, so that it drives the assembly through 475 mm by means of a flexible transmission of the same design as described in section 8.1.1 for the arms assembly. Mounted on the main block are two aluminium plates that support the "flap" and its actuator.

The flap is a pivoted assembly that can move from rest to the horizontal position through an angle of 70°. The element responsible for directly acting on the garment is a 5 mm thick perspex plate covered with sheet rubber to prevent the garment from sliding to one side. This could happen if for some reason one of the arms finds a more restricted path through the sleeves, resulting in an incomplete turning. In the worst case, the arms could snag when entering the sleeves and pull the garment off the clamp.

The actuator is mounted on a 50 x 25 mm aluminium channel especially designed to act as a rear trunnion support.

The mass of the lift neck device is 1.4 Kg which, taking into account the mass of the moving element of the actuator gives a total of about 2.4 Kg, just under the 2.5 Kg of the preliminary calculations.

8.2.1 Selection of the Flap Actuator

As soon as the cycle is initiated, the flap that was retracted to allow for the passage of the garment, is engaged to stay in the horizontal position under the neck of the garment between the sleeves. The lift neck device is then waiting for the signal from the computer to start its vertical upwards movement.

The decision was taken to use a single acting pneumatic cylinder to engage and disengage the flap. In principle, the force exerted on the flap is less than the weight of the garment. However, to account for the fact that the lift neck device is acting against the friction forces originated by the arms that are simultaneously moving downwards through the sleeves, 15 N was considered the force on the flap. Fig. 8.3 schematically represents the geometry of the flap when engaged, where the thrust supplied by the pneumatic cylinder is

$$P = 15 \times 200/36$$
$$= 83 \text{ N}$$

which led to the selection of the single acting normally retracted cylinder FESTO ESN-16x50-P (16mm bore x 50mm stroke) with a maximum thrust of 90 N at 6 bar.

8.3 The Clamp Assembly

The clamp assembly is represented on the assembly drawing ME/TSS 03 (Fig. 8.4), which includes the pivot by which the clamp is attached to the structure of the turning/sizing rig. Once again, for reasons of mass reduction, aluminium has been extensively used. This is not of primary importance as far as the experimental rig is concerned, but will be in the final design in order to reduce the overall mass of the carousel and consequently its moment of inertia.

The design of the clamp assembly is similar to the one of the arms assembly, incorporating two pivoted aluminium tubular bars, connected by a swinging mechanism with the appropriate geometry. In the end of each bar there is a pivoted self aligning component to which two rubber covered pins are connected, 100 mm from each other. There are then four pins, two at each side of the clamp, which can move sideways expanding the waist of the garment and gripping it by friction. The amount of sideways movement of the two sets of pins is dependent on the size and elasticity of the garment waist band.

By a rotation of 52° of the swinging mechanism, the clamp bars rotate 25°, allowing the distance between the two pairs of pins to vary from 325 mm to 590 mm in order to accommodate the full range of adult size garments.

As for the arms, the clamp frame is made of two aluminium plates separated by pieces of aluminium channel.

8.3.1 Selection of the Clamp Swinging Movement Actuator

Fig. 8.5 schematically illustrates the geometry of the clamp and the forces involved. The actuator was selected based on a force of 5N to expand the waist of the garment. Using the simplification where it is assumed that the clamp bars and links are at right angles, as well as the links and the crank, the torque, T, at the crank shaft is given by

$$T = 2 \times (5 \times 3 \times 0.05)$$
$$= 1.5 \text{ Nm.}$$

Selecting a 40 mm stroke actuator, the resulting geometry gives a distance s = 46 mm. The force required to the actuator is then,

$$P = 1.5/0.046$$
$$= 33 \text{ N}$$

which led to the selection of the double acting pneumatic cylinder FESTO DSN 12-40-P (12 mm bore, 40 mm stroke) using an air pressure of 3.5 bar. The reason for an apparent oversized cylinder, is that the required force of 5 N is achieved with an air pressure of 3.5 bar, which makes it easy to increase or decrease the force by simply adjusting the air pressure if during the tests it proves to be necessary. For that reason, a pressure regulator is mounted on the clamp actuator supply line.

8.4 The Turning/Sizing Station Layout

The layout of the turning/sizing station is shown in the assembly drawing ME/TSS 04 (Fig. 8.6), as it was designed for the turning/sizing rig. A general view of the complete rig was shown in Fig. 7.1. The three assemblies, turning arms, clamp and lift neck device are put together within a structure that, for reasons of limited finance and manufacturing availability, was simplified as much as possible.

A wall was used to support the main brackets of the structure to which the three assemblies are connected. The brackets, made of hot-rolled steel channel of 50 x 25 mm section, were deliberately overdesigned in order to absorb disturbing forces during the turning operation. The solid 20 mm diameter shafts that guide the movement of the arms assembly are used as part of the structure. Joining the two sides of the structure are steel angles of 38 x 38 mm section which are also used to support the main actuators, the guiding shaft of the lift neck device and the pivot of the clamp.

The position of the arms relatively to the garment is monitored by the same digital transducer, described in section 5.4.1, now driven by a cable connected to an extension of the arms frame.

8.4.1 The Pneumatic Circuit

The pneumatic circuit is shown in Fig. 8.7. There are five cylinders identified by A, B, C, D and E.

A- Double acting (12 mm bore-40 mm stroke), is responsible for actuating the clamp, expanding the waist band to grip the garment.

B- Rodless double acting (25-1900), is the actuator that drives the arms frame.

C- Single acting (16-50), normally retracted, is the flap actuator.

D- Double acting (12-25), is responsible for the swinging movement of the arms.

E- Rodless double acting (25-475), is the actuator that drives the lift neck device.

The cylinders are operated by valves 1 to 5. Valves 6 and 7 control the velocity of cylinder B and valve 8 the velocity of cylinder E. Valve 9 is on the main air supply. Its function is to make sure that, when air is supplied by opening valve 15, nothing happens until the power is switched on and the other valves are set to operate the rig to the start condition. Valves 10 to 14, as well as 16 and 17, are flow regulators by which the velocity of the different actuators can be adjusted. Components 18, 19 and 20 are pressure regulators; 18 controls the pressure to the clamp actuator and therefore the stretching force exerted on the waist of the garment; 19 controls the pressure to the actuator responsible for the swinging movement of the arms, that is, the stretching force exerted by the rollers on the garment. As this force has critical influence on the measurements taken for sizing purposes, component 19 is a precision pressure regulator. Component 20 is the main line pressure regulator. Component 21 is a manifold to ensure an even distribution of pressure between the 5 cylinders.

All valves are solenoid operated with spring return. The piping network and size of the valves was selected bearing in mind the maximum required flow rates. The information is given on the diagram of Fig. 8.7, which shows the circuit in its starting position after air and power on. A brief description of the cycle is given as follows:

The garment is put in position around the clamp pins. With both hands grasping the garment, a foot switch provides the signal s1 to operate valve 1 which forces the outstroke of cylinder A (clamp). The clamp is then rotated around its pivot into position where it locks operating a microswitch (ms). A start button (st) is then pressed to start the cycle. Only with these three signals (s1, ms, st) a signal s2 is generated to initiate the cycle which simultaneously operates valves 2 and 3. Valve 2 starts the downwards movement of the arms (cylinder B), while valve 3 operates cylinder C, the flap actuator. The arms are now moving down at a velocity, adjusted by flow regulator 10. The triggering element on the arms frame passes contactless switch c which is ignored on the downwards stroke. At switch d valve 7 is operated; the exhaust air is then diverted through a second flow regulator 11 to slow down the velocity of the arms when they move through the garment. Next is switch s3 which operates valve 4, swinging the arms outwards. This switch is positioned so that the arms remain at the innermost position until the rollers have passed the waist level. Next is switch s4 which does not interfere directly with the pneumatic network, but instructs the computer to start "reading" the measurements taken from the garment at 1 cm intervals.

The rollers in the arm ends are following the garment body seams. When they enter the armholes the computer generates the signal s5 which operates valves 5 and 8 simultaneously. Valve 5 operates cylinder E to start the upwards movement of the lift neck device and, as a fast response is required, valve 8 provides a quick exhaust. When the triggering element of cylinder E passes switch f, valve 8 is closed again, diverting the exhaust air through flow regulator 16 to cut down the velocity of the lift neck device before reaching the top position where switch e1 is triggered. At the same time the arms have gone to the lower position triggering switch b1 at the end of the stroke. At this stage, the arms have gone through the sleeves and cleared the cuffs, helped by the action of the lift neck device.

When both switches b1 and e1 have been triggered, signal s6 is generated to deactivate valves 2, 3, 4 and 5, reversing cylinders B, C, D and E; that is, the arms move upwards at the same time that the flap retracts. Simultaneously, the arms swing inwards and the lift neck device moves down to rest. The same signal s6 also operates valve 6 to provide quick exhaust and consequently fast velocity for the reverse stroke of the arms actuator. Cylinders C, D and E return smoothly due to flow regulators 13, 14 and 17 respectively. On the reverse stroke, all switches are ignored exept c, which shuts valve 6, diverting the exhaust air of cylinder B through flow regulator 12 to slow it down before stopping.

The turning operation is finished with the garment still on clamp. To release the garment, a button is pressed (s7) to deactivate valve 1 and retract cylinder A.

8.4.2 The Sequence Controller

A dedicated sequence controller was built to control the rig. The logic diagram of the controller is shown in Fig.8.8 which was designed to perform the sequence described in the previous section 8.4.1.

As far as safety is concerned, some provisions were taken. When the rig is switched on, the air supply valve 9 is only operated after a small time delay to give time for the controller to reset itself.

As a result, the rig is automatically set to the start of the sequence, which in practical terms means that the arms are driven to the top position to conform with the diagram of Fig. 8.7. To start the cycle three signals are required:

- s1- the garment is on clamp.
- ms- the clamp has been rotated and locked in position which is detected by a microswitch.
- st- the start button has been pressed.

By this method, the rig cannot unintentionally be started if the garment has not been loaded on the clamp and the latter has not been rotated and locked in position for turning. An emergency stop button is provided, which, when pressed, immediately interrupts the sequence, bringing the rig to the start position.

8.5 Final Machine Cycle

As a result of the optimization work, modifications were introduced to the concept that arose from the feasibility study. The turning of the garments is now entirely achieved by the movement of the arms, as the clamp remains stationary during the turning cycle.

It became clear during the tests that the area more sensitive to high velocity was, as expected, the one corresponding to the path of the rollers from just over the armholes to the middle of the sleeves.

The restricted time available did not allow the complete development of the rig to its full capabilities. Particular reference is made to problems encountered on the actuation of valves 6 and 7, which control the velocity of the vertical movement of the arms. When these valves are working properly, the arms will move at fast velocity until the rollers enter the garment to slow down to a velocity acceptable by the garment. On the reverse stroke full velocity can be used. Instead, due to malfunction of the mentioned valves, a moderate velocity was used during the whole cycle.

Under the circumstances, the turning operation was performed in about 6 seconds, but the author is confident that, once the mentioned problems are solved, the cycle time can be reduced to a figure very close to the initially predicted 4 seconds. It must be emphasized that the time of the carousel indexing rotation will not be added to the cycle. As soon as the operator completes the loading of a garment and presses the foot switch, the carousel will be ready to rotate 45°at the same time that the arms move through the first half of the downwards stroke. The clamp will then be in position with another garment before the rollers reach the waist level and the arms enter the garment.

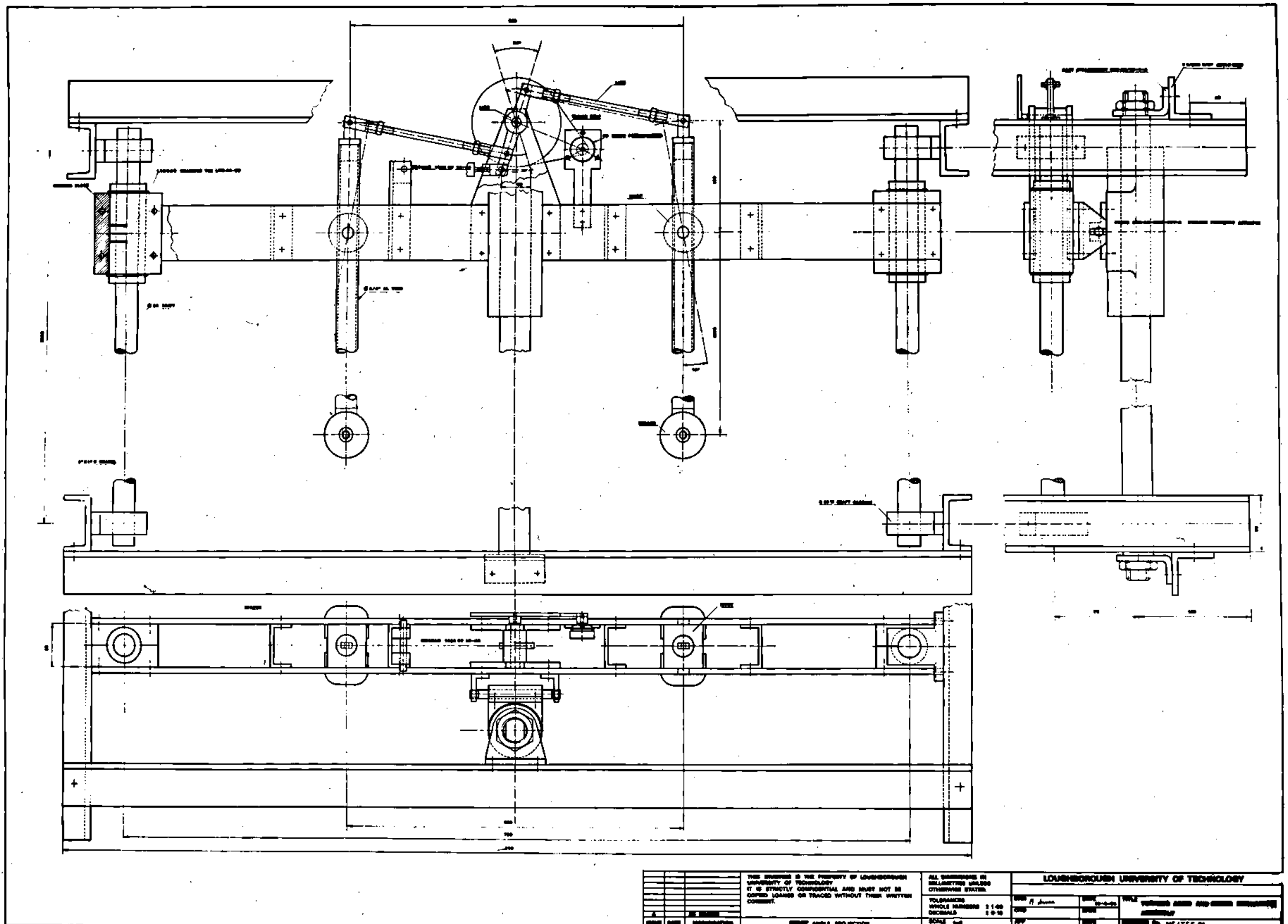


Fig.8.1 Assembly drawing ME/TSS 01.

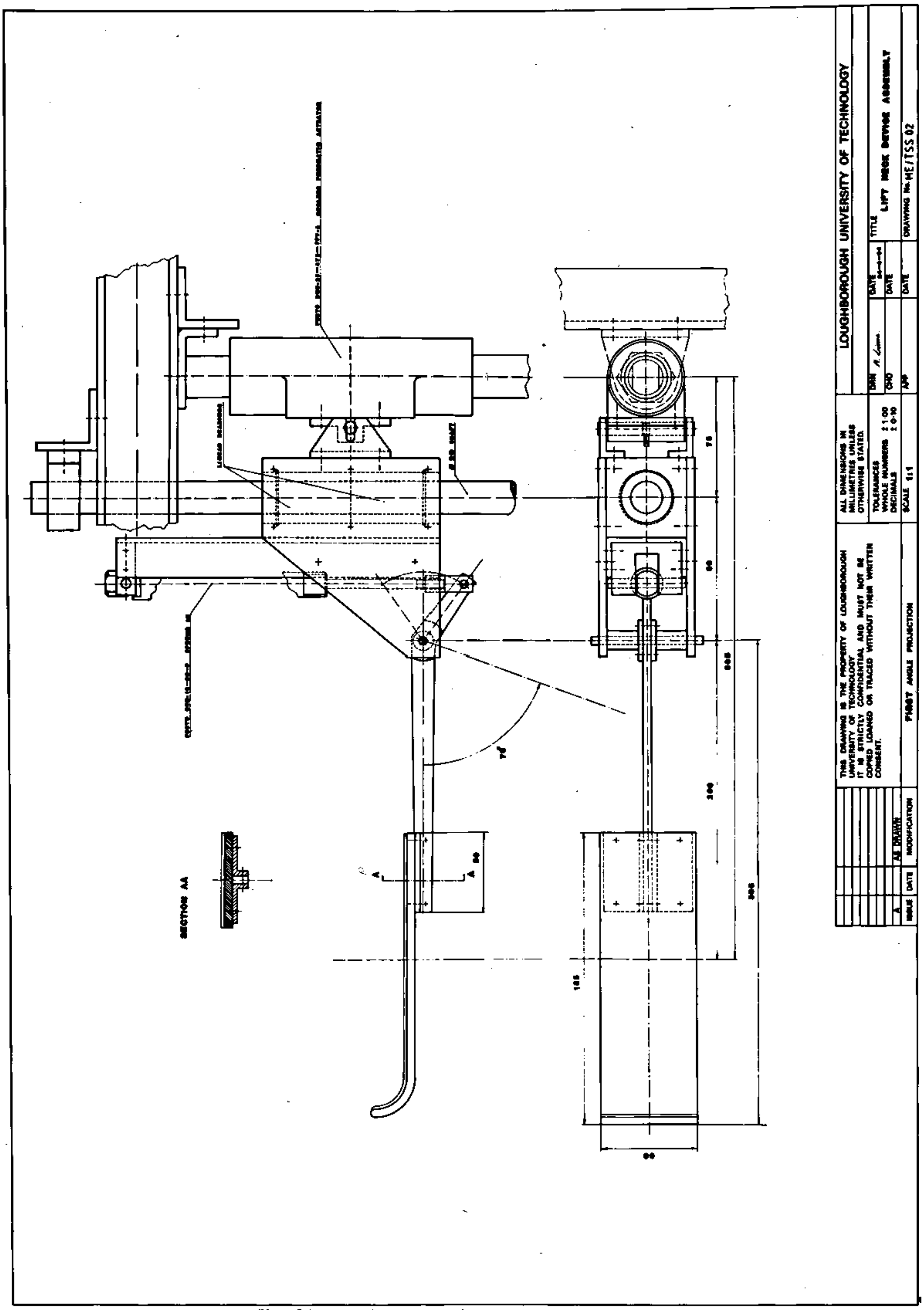


Fig. 8.2 Assembly drawing ME/TSS 02.

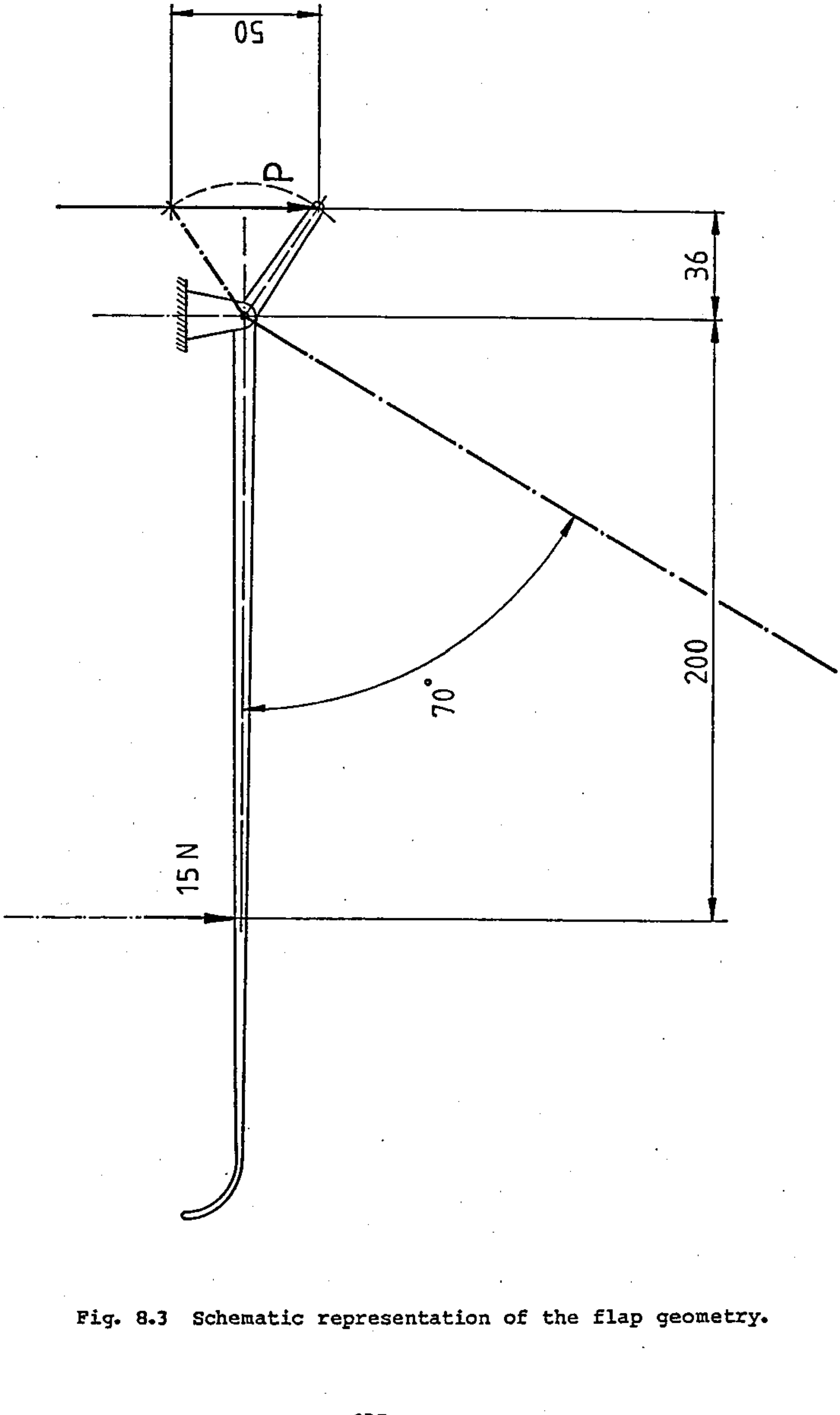


Fig. 8.3 Schematic representation of the flap geometry.

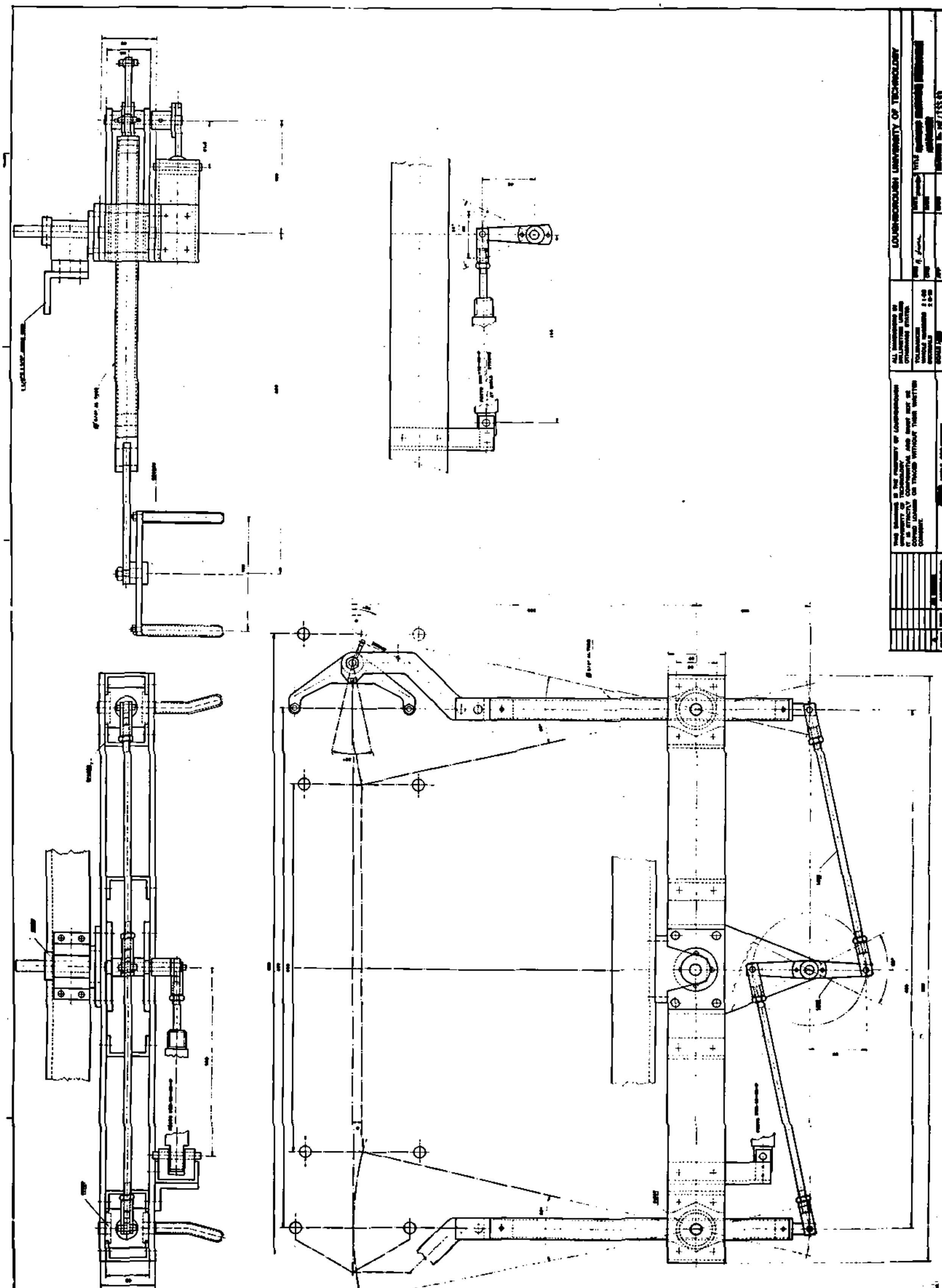


Fig. 8.4 Assembly drawing ME/TSS 03.

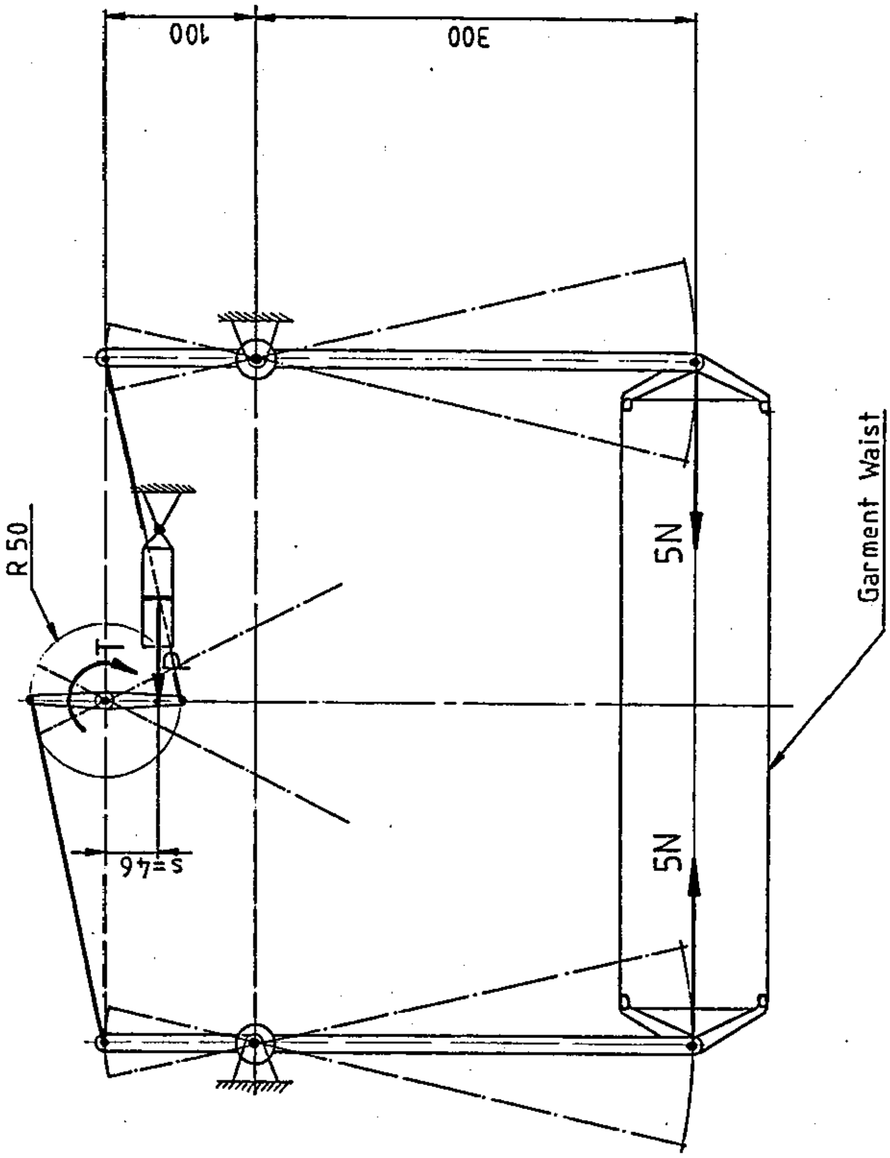


Fig. 8.5 Schematic representation of the clamp geometry.

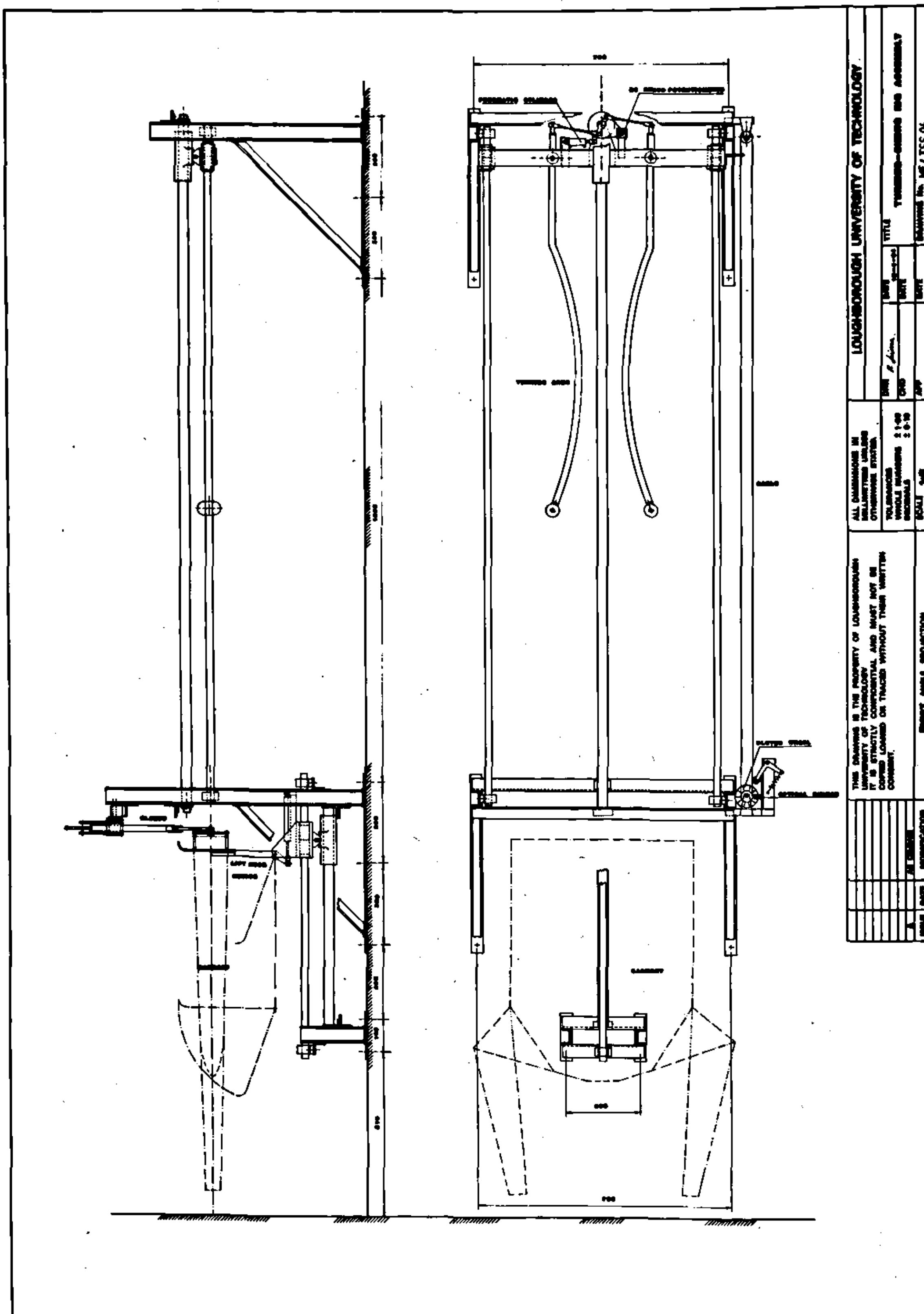
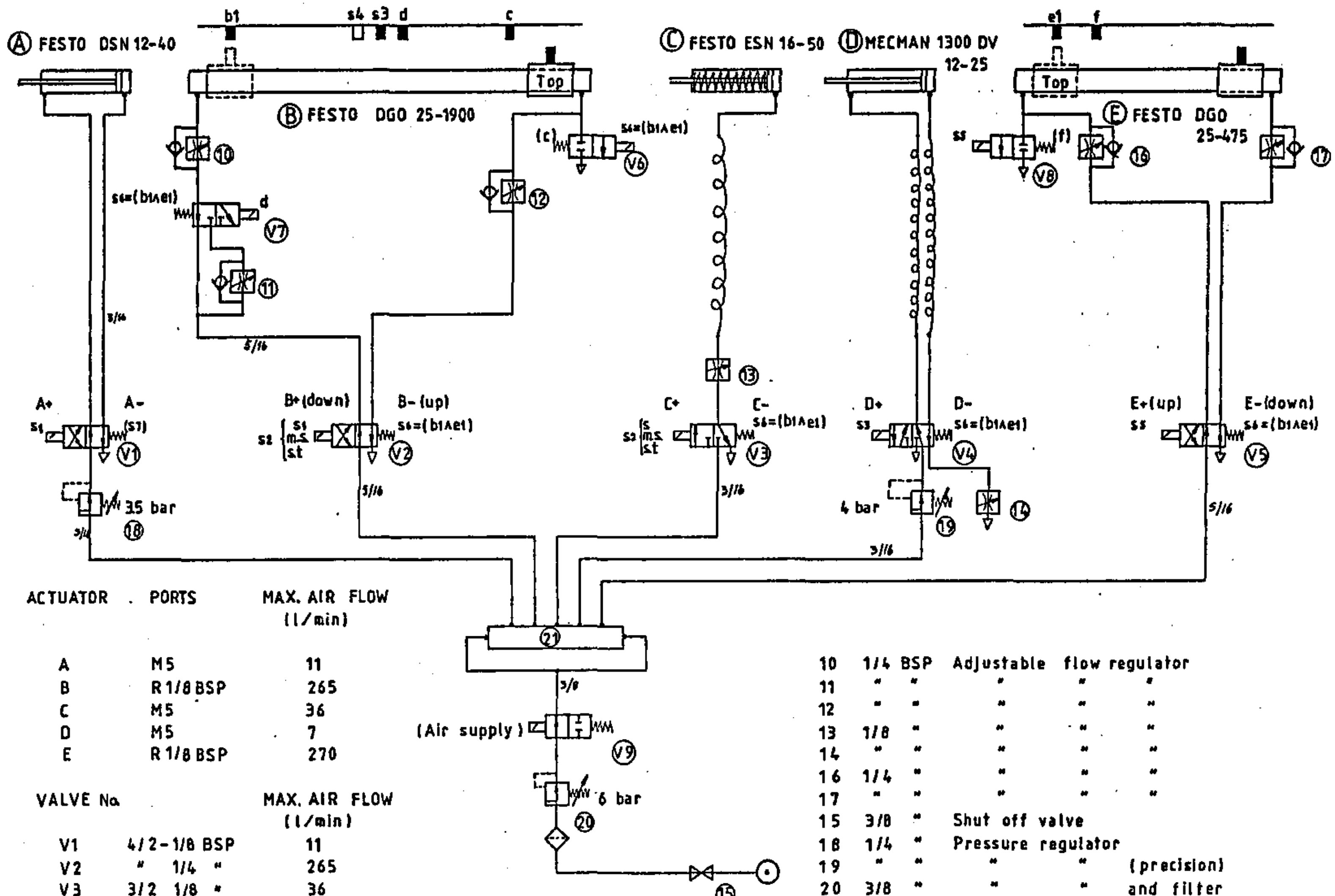


Fig. 8.6 Assembly drawing ME/TSS 04.



ACTUATOR	PORTS	MAX. AIR FLOW (l/min)
A	M5	11
B	R 1/8 BSP	265
C	M5	36
D	M5	7
E	R 1/8 BSP	270

VALVE No.		MAX. AIR FLOW (l/min)
V1	4/2-1/8 BSP	11
V2	" 1/4 "	265
V3	3/2 1/8 "	36
V4	5/2 1/8 "	7
V5	4/2 1/4 "	270
V6	2/2 1/4 "	265
V7	3/2 1/4 "	265
V8	2/2 1/4 "	500

10	1/4	BSP	Adjustable flow regulator
11	"	"	" " "
12	"	"	" " "
13	1/8	"	" " "
14	"	"	" " "
16	1/4	"	" " "
17	"	"	" " "
15	3/8	"	Shut off valve
18	1/4	"	Pressure regulator
19	"	"	" " (precision)
20	3/8	"	" " and filter
21	3/8 IN, 1/4 OUT		Manifold

Fig. 8.7 Diagram of pneumatic circuit.

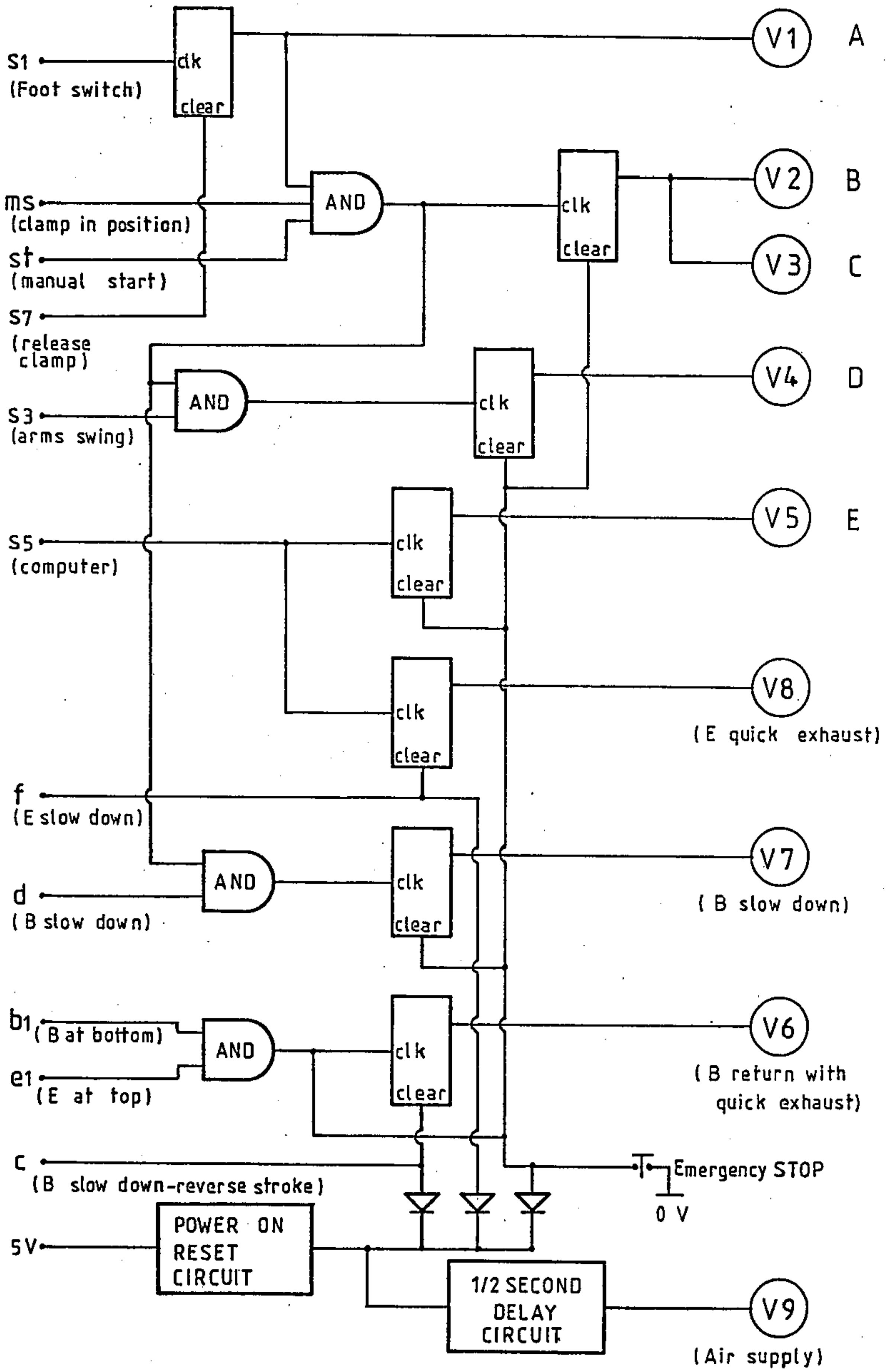


Fig. 8.8 Logic diagram of the sequence controller.

CHAPTER 9

CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER WORK

9.1 Conclusions

The main objectives of the project have been achieved. The final research rig demonstrated the validity of the concept for turning and sizing knitted outerwear garments.

As far as automatic sizing is concerned, the innovative technique is based on the measurement of the garment chest width, which was found to be the most characteristic sizing parameter. Unlike the present methods of tagging and visual recognition, the machine will not be "complacent" if garments intended to be of one particular size, have a chest width unacceptably out of its size range. Garments in these circumstances would be properly sorted according to their physical dimensions. In this aspect, the machine can be used for quality control purposes.

The preliminary economic assessment remains applicable as it is envisaged that the final cycle time, after development and optimization work is carried out, will be of the predicted magnitude. The power consumption, calculated on the basis of the available information, will be around 3 KW, well below the assumed 5 KW of the preliminary calculations. This figure for the power consumption, although reducing the running costs, does not affect significantly the economic analysis.

In a system of batch production, the manufacturer is responsible for supplying the correct amount of garments per size to his customer. At the present, it is up to the manufacturer (knitting and assembling departments) to control the parameters of the production.

The finisher relies on the manufacturer's sizing and conducts the final trimming operation accordingly. If the garments have been improperly manufactured, the finisher may have to face embarrassing situations where the trimming of the garments results in an abnormal alteration of their relaxed dimensions. However, with improved quality control of the manufacturing stage, it would certainly not be difficult to persuade a manufacturer and his customers to accept a small amount of size variations in each batch due to acceptable dimensional differences. Statistically, the amount of interchanges between sizes would certainly tend to balance itself, correcting the final size distribution.

9.2 Recomendations for Further Work

The author would like to suggest the following actions to be taken:

1. The present rig must be developed in order to optimize its working cycle. A major step forward would be to use a computer with a fully developed system. The AIM 65 with its I/O handling and editing limitations makes programming laborious. If a computer with an I/O expansion is used, the dedicated sequence controller can be eliminated and its functions carried out by the computer which can be used as a versatile sequence controller until the cycle is optimized.

2. The contactless reflective opto switches used on the control of the rig as position sensors, have shown some degree of sensitivity to ambient illumination. It is suggested that magnetic proximity switches should be used instead.

3. In order to reduce the deceleration time of the arms on the reverse stroke, the use of shock absorbers is recommended. Adopting this procedure, the pneumatic network would be considerably simplified.

4. A comprehensive number of tests should be carried out in close collaboration with the industry concerned. The rig should be tested with garments from a wide spectrum of materials and styles in order to assess its limitations and to get the maximum possible information for any alterations to be introduced into the final design. Particular attention must be given to the handling of the very large sizes where difficulties were experienced due to insufficient amplitude of the swinging movement of the arms. The results on sizing of non-trimmed garments must be compared with the manufacturer's intended sizing to assess the actual state of production before the final trimming operation.

5. In the light of the results on sizing, the author is envisaging, as a spin-off from this research, an apparatus to be used by the manufacturers on random samples after knitting and assembling. The apparatus, an improved version of the sizing rig mentioned in Chapter 5, would provide some quality control of the manufacturing process.

6. Further design work is still necessary on the clamp assembly to make it more efficient, especially on the releasing of the garment after turning. The clamp must be provided with a means of detecting the situation where the waist of the garment has been pulled off the clamp during the turning operation, in which case the machine should be immediately stopped. The garment would then be removed by hand before resetting the machine to the starting position.

7. Finally, a prototype of the complete machine must be designed and built. In the redesign of the turning station, the potentiometer that translates the garment width in terms of the position of the swinging mechanism could be replaced by a digital transducer such as an absolute optical encoder. The A/D converter would then be eliminated simplifying the hardware and the software.

9.3 Possible Future Automation

It is the author's opinion that close co-operation between garment designers, manufacturers and finishers is necessary to achieve a higher degree of automation in garment manufacture, certainly in the area where this research has been directed. It might well be necessary that concessions have to be made in order to adapt old established methods to the constraints of new machines. If manufacturers could be persuaded to alter the present process, which is to join the collar and other trims after the "finishing" process, the author could futuristically envisage the situation where the garments would be loaded onto the clamp of the turning and sorting machine to start a fully automatic cycle that would turn and sort the garments into the appropriate "trimming" frames for steaming and pressing. The process would finish by automatic folding, bagging and packing.

APPENDIX 1

Main Characteristics of Commercially Available Rodless Pneumatic Linear Actuators

1. FESTO DGO pneumatic linear drive[29].

It has an hermetically sealed system using a magnetic coupling between the piston and the external collar.

Main features:

- Possible contactless scanning of the piston positions;
- Operates with filtered lubricated or filtered non-lubricated compressed air;
- Maximum operating pressure - 8 bar;
- Speeds up to 2 m/sec. ;
- Available in three sizes:

Piston dia. (mm)	Max. standard stroke (mm)	Effective thrust at 6 bar (N)
16	2500	90.0
25	3500	213.6
40	4500	645.0

2. ORIGA rodless cylinders[43].

According to the manufacturer, "the cylinder barrel is provided with a slit along its entire length. Force is transmitted by means of a lug screwed to the piston and projecting through the slit. A thin steel band covers the full length of the slit from the inside and provides a good sealing".

Main features:

- Adjustable end position dampers in both ends;
- Possible contactless scanning of the piston positions;
- Operates with filtered lubricated compressed air;
- Maximum operating pressure - 8 bar;
- Maximum recommended speed 1m/sec.
- Available sizes:

Piston dia. (mm)	Max. stroke (mm)	Thrust at 6 bar (N)
25	5000	250
40	7000	600
63	7000	1550
80	7000	2600

3. KAY ROL-AIR-MOTA[44].

The actuator consists of a length of special air hose sealed at both ends with plugs incorporating air inlets. A rolling element, incorporating two spring loaded rollers, squeezes the hose and travels along it under the influence of the internal air pressure. Main features:

- Operates with non-lubricated compressed air;
- Maximum operating pressure-10 bar;
- Maximum recommended speed 2.5 m/sec.;
- Stroke only limited by the maximum hose length of 30 m;
- Available in two sizes:

	Hosedia.(mm)	Thrust (N) at 2 bar	4 bar	7 bar	10 bar
KRM25	25	105	210	350	525
KRM45	45	320	640	1070	1605

4. TOL-O-MATIC cable cylinder[45].

The air pressure applied to one side of the piston moves it within the cylinder. A cable is attached to both ends of the piston that pulls it around two pulleys to impart the desired motion to the driven mechanism through an attaching bracket. Main features:

- Available strokes up to 60 feet;
- Cylinder bore sizes from 3/4" to 8";
- Cushioning at each end of the cylinder;
- Thrust at 80 psi from 34.8 lbs force for the 3/4" bore,to 3990 lbs force for the 8" bore.

5. LINTRA rodless cylinders[46].

This design works on the same principle as the Origa cylinders, but with detail differences in the cylinder barrel and sealing strips. It also features external guides.

Main features:

- Cushioning at both ends;
- Available in 5 sizes:

Cylinder dia. (mm)	25	32	40	50	63
Thrust at 6 bar (N)	294	482	754	1178	1870

6. MARDRIVE linear transporter[47].

This design works on the same principle of the Festo DGO, being a sealed system using a magnetic coupling between the piston and the external carriage. The main detail difference is that the external carriage rolls along flat faces on the tube instead of sliding.

Main features:

- Available strokes up to 10 m;
- Speeds up to 10 m/sec are possible;
- Available in one size with a piston area of 1 square inch. The maximum thrust is 400 N.

APPENDIX 2

Preliminary Calculations of the Mass of the Moving Assemblies

The preliminary calculations carried out in this appendix reflect some lack of knowledge about the details of the different components at the initial stages of the work. They are based on preliminary sketches and not on proper engineering drawings as it would be at the design stage.

A2.1 ARMS

For simplicity, the term "arms" identify here, not only the turning arms themselves, but also the rollers, swinging mechanism and its pneumatic actuator, pivots, and the frame which supports the assembly holding linear bearing guides. Also to be taken into account as a moving mass, is the moving element of the pneumatic actuator, as well as the angular displacement transducer that measures the rotation of the swinging mechanism. For the different named components refer to Fig. A2.1.

1. 2 aluminium tubes, 3/4" OD x 1/16" wall (19 mm x 1.6 mm), 1100 mm long. (Al specific gravity = 2.6).

$$\pi.(19^2-15.8^2)/4 \times 1100 \times 2.6 \times 10^{-6} \times 2 = 0.50 \text{ Kg}$$

2. 2 aluminium plates, 800 x 50 x 5 mm.

$$800 \times 50 \times 5 \times 2.6 \times 10^{-6} \times 2 = 1.04 \text{ Kg}$$

3. 2 aluminium bearing blocks, 75 x 60 x 38 mm less 32 mm dia cylindrical hole.

$$[75\times60\times38-(32^2\times \pi/4)\times75]\times2.6\times10^{-6}\times2 = 0.58 \text{ Kg}$$

4. 4 linear bearings THK LME-20.

0.10 Kg each $\times 4 = 0.4$ Kg

5. 2 nylon rollers, 40mm dia x 70 mm.
(nylon specific gravity = 1.15)

$\pi \times 40^2 \times 70/4 \times 1.15 \times 10^{-6} \times 2 = 0.20$ Kg

6. 2 brass pivots, 35 mm dia. x 38 mm less 19 mm dia. hole.
(brass specific gravity = 8.5)

$(35^2 \times \pi \times 38/4 - 19^2 \times \pi \times 35/4) \times 8.5 \times 10^{-6} \times 2 = 0.45$Kg

7. 2 aluminium crank support plates, 5 mm thick.

$(80 \times 50 + 80 \times 100/2) \times 5 \times 2.6 \times 10^{-6} \times 2 = 0.21$ Kg

8. 4 aluminium separators.
(U channel 1 1/2" x 3/4" (38 x 19 mm) x 50 mm)

$(38 \times 19 - 31.6 \times 15.8) \times 50 \times 2.6 \times 10^{-6} \times 4 = 0.12$ Kg

9. 2 steel links, 6mm dia x 150 mm.
(steel specific gravity = 7.8)

$(6^2 \times \pi \times 150/4) \times 7.8 \times 10^{-6} \times 2 = 0.07$ Kg

10. 1 steel crank.

$[(85 \times 10 \times 5) + (20^2 \times \pi \times 38/4)] \times 7.8 \times 10^{-6} = 0.13$ kg

11. 1 12mm dia. x 25 mm stroke pneumatic actuator = 0.1 kg.

The sum of these masses is 3.80 kg. Assuming 1 kg for the moving masses of the actuator and allowing 0.2 Kg for fasteners and transducer, the total value for m_1 is 5 Kg.

A2.2 CLAMP

In sections 4.6.2 and 4./.3, some reference is made to the clamping system. Succinctly, it holds the waist by stretching it with two 100 mm wide pads and a force of 5 N. The clamp must be self adjustable to the width of the garment waist, this being achieved by a sideways movement of the pads (movement No.8 on Fig. 4.40). According to Table 4.3 (data on garment dimensions), allowing for the smallest unstretched garment and for the largest stretched one, the decision was taken to make the clamp pads adjustable from a minimum 330 mm width to a maximum of around 600 mm. The clamp also has to slide vertically within the carousel to provide enough extension of the garment when turning. Fig. A2.2 represents, in a simplified sketch, this approach to the clamp system.

1. 2 Al tubes, 3/4" OD x 1/16" wall (19mm x 1.6mm), 400 mm long.

$$\pi \times (19^2 - 15.8^2)/4 \times 400 \times 2.6 \times 10^{-6} \times 2 = 0.18 \text{ Kg}$$

2. 2 Al plates, 400 x 50 x 5 mm.

$$400 \times 50 \times 5 \times 2.6 \times 10^{-6} \times 2 = 0.52 \text{ Kg}$$

3. 2 bearing blocks, /5 x 60 x 38 mm, less 32 mm dia. hole.

$$L/5 \times 60 \times 38 - (32^2 \times \pi/4 \times /5) \times 2.6^{-6} \times 2 = 0.58 \text{ Kg}$$

4. 2 separators, U channel 1 1/2"x3/4" (38 x 19 mm) x 50 mm.

$$(38 \times 19 - 31.6 \times 15.8) \times 50 \times 2.6 \times 10^{-6} \times 2 = 0.06 \text{ Kg}$$

5. 4 linear bearings THK LME-20.

0.10 Kg each x 4 = 0.40 Kg

6. 2 steel links, 6 mm dia. x 240 mm.

$6^2 \times \pi/4 \times 240 \times 7.8 \times 10^{-6} \times 2 = 0.11$ Kg

7. 1 Al crank.

$(110 \times 10 \times 5 + 20^2 \times \pi/4 \times 38) \times 2.6 \times 10^{-6} = 0.05$ Kg

8. 2 Al crank supports, 5 mm thick.

$80 \times 100/2 \times 5 \times 2.6 \times 10^{-6} \times 2 = 0.10$ Kg

9. 2 brass pivots, 35 mm dia. x 30 mm, less 19 mm dia. hole.

$(35^2 \times \pi \times 30/4 - 19^2 \times \pi \times 35/4) \times 8.5 \times 10^{-6} \times 2 = 0.32$ Kg

10. 4 brass pivot supports.

$(40 \times 5 + 20 \times 5) \times 35 \times 8.5 \times 10^{-6} \times 4 = 0.36$ Kg

11. 2 Al clamp pads.

$100 \times 70 \times 3 \times 2.6 \times 10^{-6} \times 2 = 0.11$ Kg

The sum of these masses is 2.79 Kg. Allowing 0.2 Kg for fasteners and other small parts, the clamp mass is assumed to be 3 Kg. As for the arms assembly, if 1 Kg is assumed for the moving parts of the actuator, a total mass of 4 Kg must be considered on the vertical movement.

A2.3 LIFT NECK DEVICE

For the different components refer to sketch of Fig. A2.3

1. 1 aluminium bearing block, 50 x 50 x 100 mm less 32 mm dia. cylindrical hole.

   $(50^2 \times 100 - 32^2 \times \pi \times 100/4) \times 2.6 \times 10^{-6} = 0.44$ Kg

2. 2 linear bearings THK LME-20.

   0.10 Kg each x 2 = 0.20 Kg

3. 1 actuator.

   assumed 0.15 Kg

4. 1 aluminium crank flap.

   $400 \times 10 \times 5 \times 2.6 \times 10^{-6} = 0.05$ Kg

5. 2 aluminium side plates, 5 mm thick.

   $[(120 + 80)/2] \times 100 \times 5 \times 2.6 \times 10^{-6} \times 2 = 0.26$ Kg

Assuming 1 Kg for the moving parts of the actuator, the total mass rises to 2.1 Kg. It will be rounded off to 2.5 Kg.

A2.4 CAROUSEL

The carousel is essentially a prismatic structure as shown in the simplified sketch of Fig. A2.4. The basic prism has 8 faces for the 8 clamps and 2 bases. The structure has a centre tube of 50 mm OD connected to the drive shaft at the bottom end and supported by a thrust bearing. Another radial bearing fixed to the structure of the turning station provides radial support at the top end.

There are two bases made of 8 square tubular steel struts (19 mm x19 mm x 1.6 mm thick) welded to make an octagonal shape. These two bases are also welded to the centre tubular shaft. Connecting the two bases are two sets of four oblique bars of the same square tubular steel. One set joins the bottom centre and the outside top; the other joins the top centre and the outside bottom. This arrangement will give a light but rigid structure. On each side of the prism there are a pair of tubular shafts where a pair of linear bearings are mounted to guide the clamp motion.

There are three different lengths of square steel tube on the structure as seen in Fig. A2.4. The structure is made up with:

16 lengths a = 16 x 0.76 = 12.16 m	
16 lengths b = 16 x 0.58 = 9.28 m	Total = 32.16 m
8 lengths c = 8 x 1.34 = 10.72 m	

1. 32.16 m of square tubular steel.

$(19^2 - 15.8^2) \times 1000 \times 7.8 \times 10^{-6} = 0.87$ Kg/m

$32.16 \times 0.87 = 28$ Kg

2. 1 Centre shaft, 1,1 m of 50 mm OD tubular steel at 3.12 kg/m according to the manufacturer.

$1.1 \times 3.12 = 3.4$ Kg

3. 16 (2 per face) tubular shafts, 20 mm OD, 3 mm wall, 1.1 m length.

$(20^2 - 14^2) \times \pi/4 \times 1000 \times 7.8 \times 10^{-6} = 1.25$ Kg/m

$16 \times 1.1 \times 1.25 = 22.0$ Kg

4. 8 clamps at 3 Kg each. It must be pointed out that in this situation, the mass of the moving parts of the clamp actuator is not considered.

$8 \times 3 = 24$ Kg

5. 7 garments. This is the maximum number possibly present at once around the carousel (350 grams each).

$7 \times 0.35 = 2.5$ Kg

6. 32 Al shaft supports (2 per shaft, 0.072 Kg each).

$32 \times 0.072 = 2.3$ Kg.

The total mass of the carousel is $m_4 = 83$ Kg

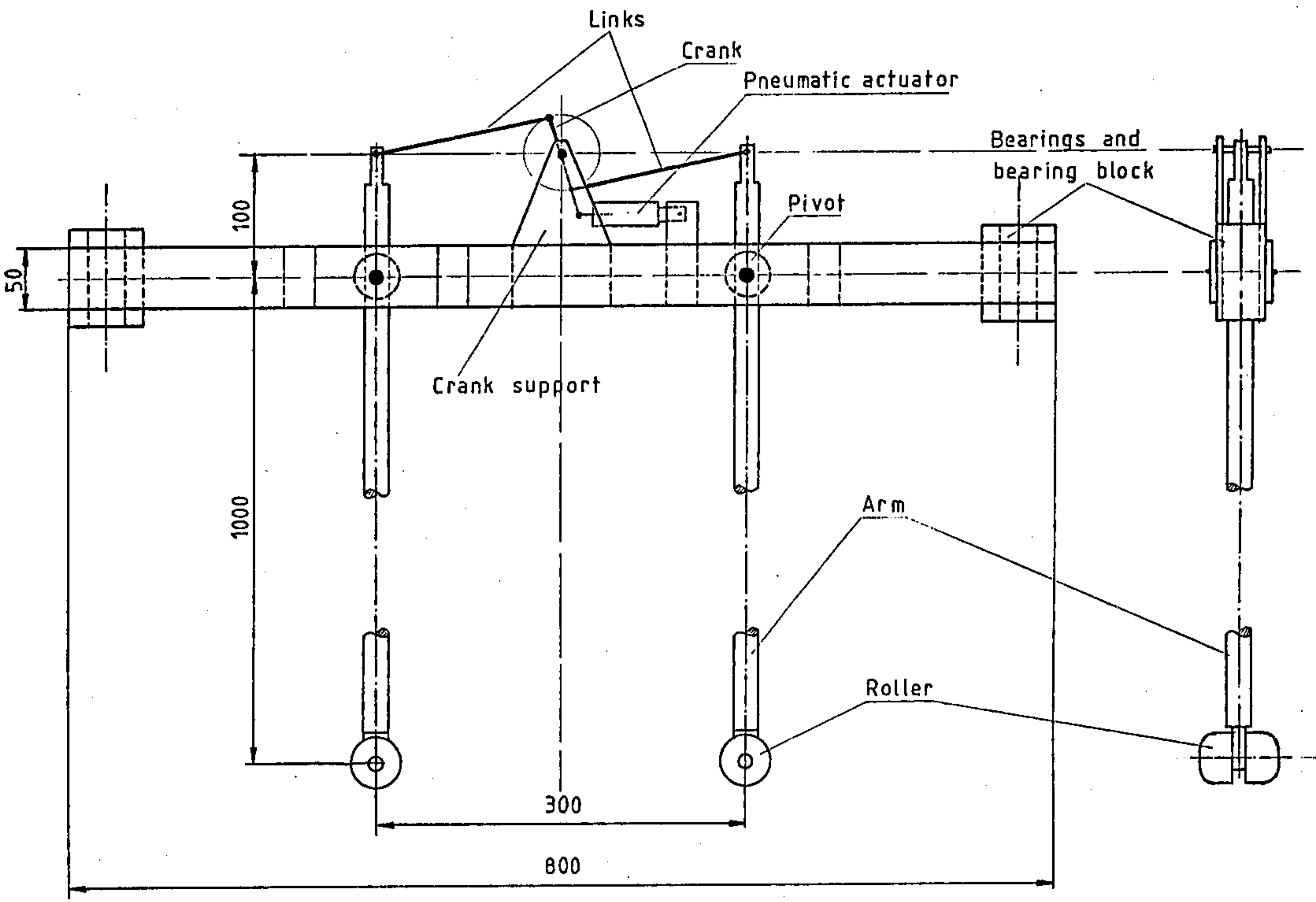


Fig. A2.1 Preliminary sketch of the turning assembly.

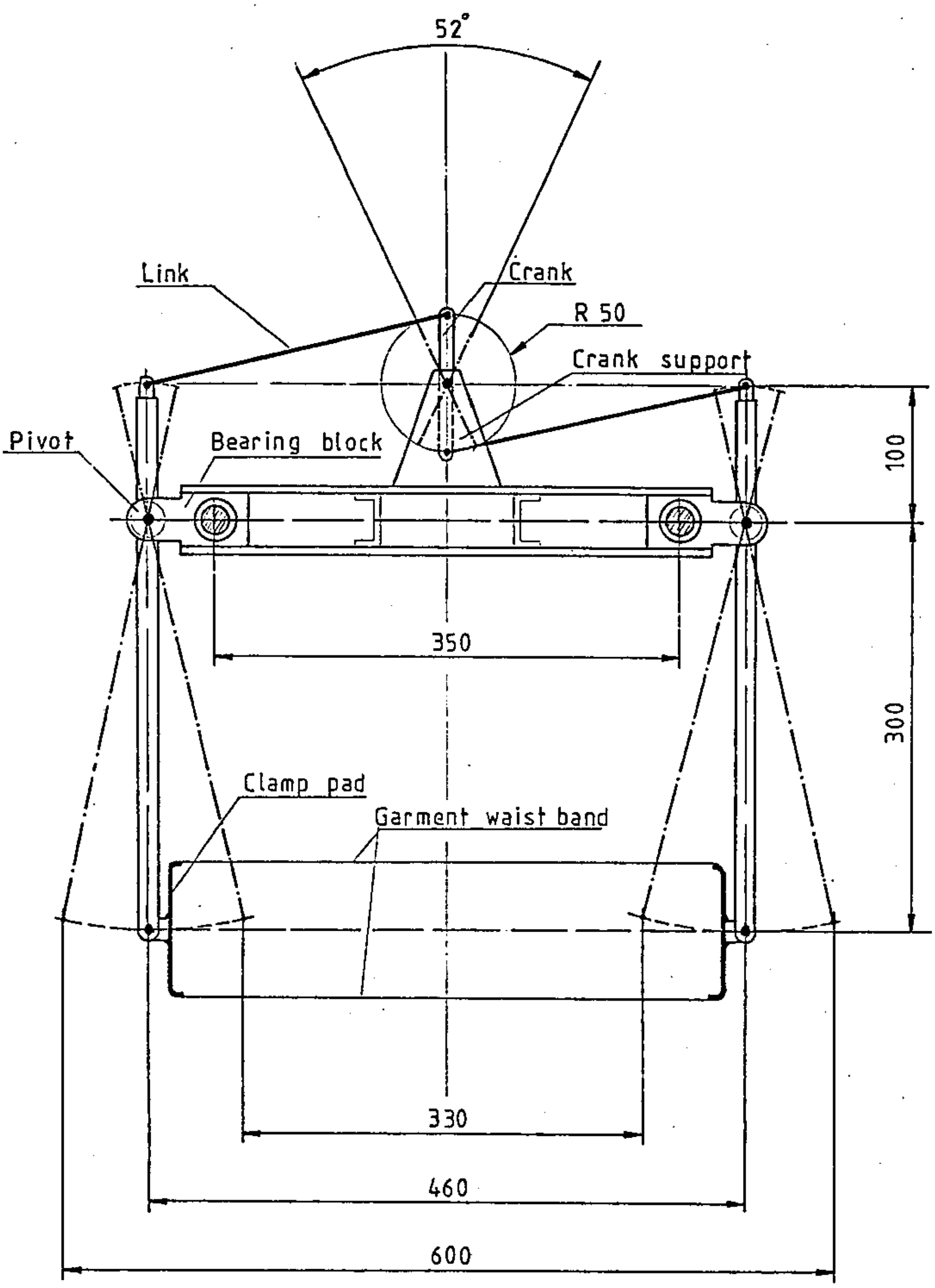


Fig. A2.2 Preliminary sketch of the clamp assembly.

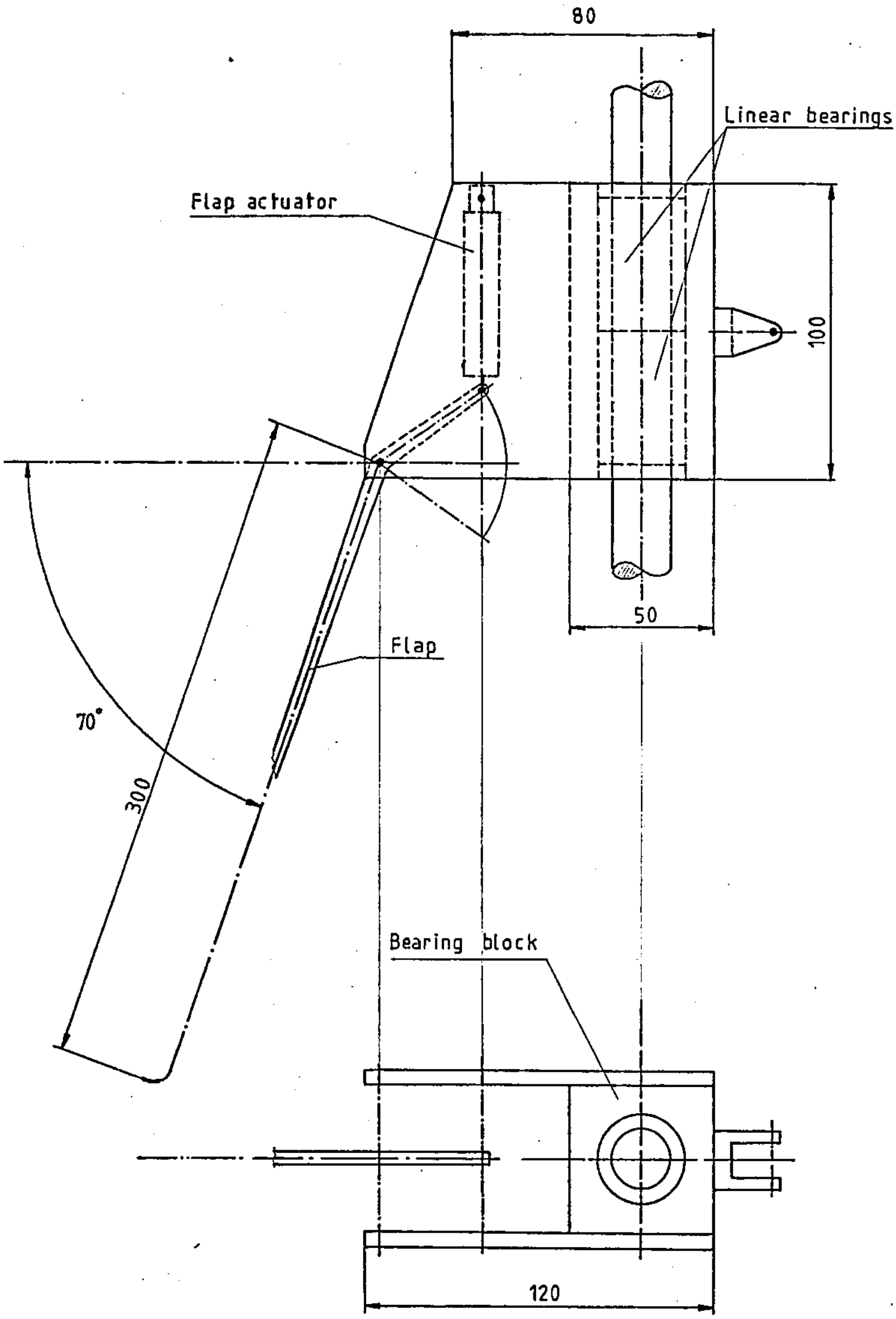


Fig. A2.3 Preliminary sketch of the lift neck device assembly.

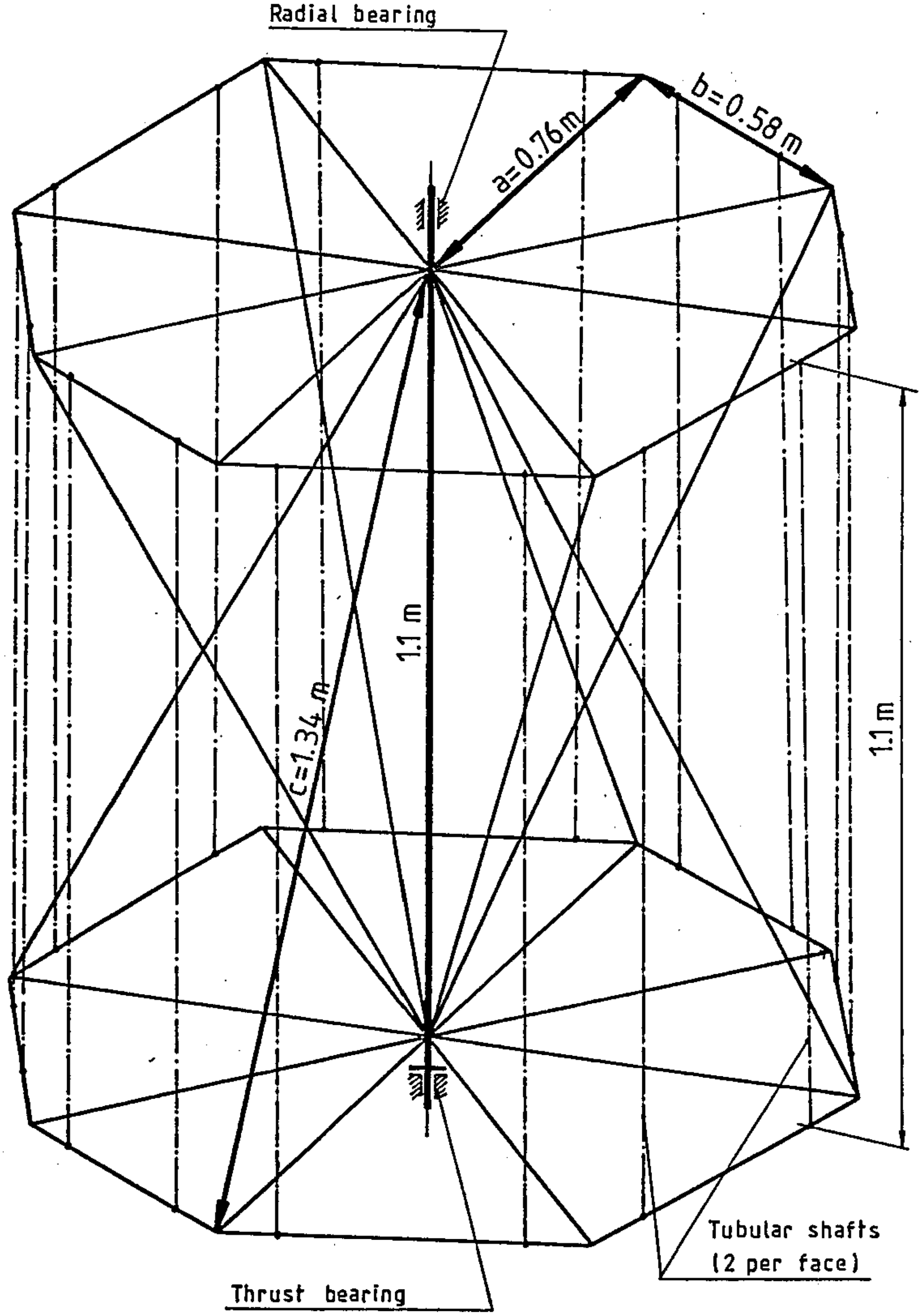


Fig. A2.4 Simplified sketch of the carousel structure.

APPENDIX 3

Size charts of garments tested with Mark 2 sizing apparatus

[illegible] FULLY FASHIONED KNITWEAR

Slazenger
492100.

GARMENT DESCRIPTION: Gents Saddle SH Slope Back V/N P/O

STYLE NO: ~~1302/1326~~

YARN: Type 10 Courteus

COUNT: 2/30s

GAUGE: ~~18/21~~ 2606

DATE: 1/2/80

SIGNATURE:

SIZE CHART 1542

FINISHED MEASUREMENTS Inches

	SIZE 32	34	36	38	40	42	44	46	48
To Fit	INCHES								
Length (side of neck)	26	26	26	26	27½	27½	28½	28½	28½
Chest width (at armhole)	17	18	19	20	21	22	23	24	25
Welt width (base of welt)	13	14	15	16	17	18	19	20	21
Armhole Overall	10½	11	11½	12	12¼	12½	12½	13	13½
Armhole fash.	9	9¼	9¼	9½	9½	9½	10	10½	10½
Sleeve ~~xxxxxxxxxxxxxxxxxxxxxxxx~~ Underarm with cuff turned back 2"	18	18	18	18	19	19	19	19	19
Sleeve at widest (right angles to	7½	8	8½	8½	9	9	9½	9½	9½
Shoulder length (neck rib to armhole)	3	3¼	3¼	3½	4¼	4¼	4¼	4½	4½
Width across shoulder fash to fash on ~~Front~~	11½	12	12¼	12½	13	13¼	13½	14	14½
Cuff rib depth (Turn Back Cuff)	4	4	4	4	4	4	4	4	4
Body rib depth	3½	3½	3½	3½	3½	3½	3½	3½	3[illegible]
Cuff rib width (at top)	3½	3½	3½	3½	3½	3½	3½	4	4
Stole width	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Number of pockets	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Pocket width	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Pocket depth	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Neck stretch									
Neck drop to first button	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Vee neck drop	7½	7½	7½	7½	7½	7½	8	8	8
Back neck (crease to crease)	6	6	6	6	6	6	6	6½	6½
Neck rib depth	5/8	5/8	5/8	5/8	5/8	5/8	5/8	5/8	5/8
Number of buttons	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Button style	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

HO.291 - 1/79

MARKS & SPENCER LTD. KNITWEAR GROUP DEPARTMENT: T.30

GARMENT DESCRIPTION: SUPERFINE LAMBSWOOL SADDLE STYLE NO. T720? / 1708 FOR BOTH OF THESE

YARN: 100% LAMBSWOOL COUNT: 2/24's GAUGE:

BASIC CHART: F.F.2. DATE: 20.10.81 SIGNATURE: M.R. SOLAMITO

FINISHED MEASUREMENTS	SIZE / TO FIT	36"		38"		40"		42"	44"
A FRONT LENGTH (shoulder at neck join)		63		63		66		69	69
B CHEST WIDTH (at 1 cm below armhole)		49		52		55		58	61
C WELT WIDTH (at bottom of welt)		35		38		41		44	47
C RIB COUNT									
D HORIZONTAL SADDLE SEAM		9		9.5		10		10	10.
E VERTICAL SADDLE SEAM		20		21		22		23	24
F SADDLE DEPTH (front over to back, corner to corner)		8		8		8		8	8
G SLEEVE UNDERARM (to end of sleeve)		51		51		51		51	51
H SLEEVE AT WIDEST (at right angles to overarm)		18		18		19		20	20
I ELBOW WIDTH (fold end of sleeve to armhole)		15		15		16		17	17
J CUFF WIDTH (at end of sleeve)		7.5		7.5		8		9	9
J RIB COUNT									
K WELT DEPTH		5		5		5		5	5
L CUFF DEPTH		10		10		10		10	10
ACROSS CHEST (AT CENTRE OF VERTICAL SADDLE)									
SIZE CHART 2014									
M NECK DETAIL									
BACK NECK (BETWEEN SEAMS)		15		15		15		15	15
DEPTH OF 'V' LINKING TO LINKING		22		22		22		24	24
WIDTH OF NECK RIB		2		2		2		2	2
N XXXXXX BASE OF MOTIF TO BE LEVEL WITH BASE OF GARMENT 'V' NECK									
(a) XXXXX ACROSS FRONT		11		11		11		11	11
(b) DEPTH									
(c) STRAP SEAM TO POCKET LEADING EDGE									

GARMENT DESCRIPTION MENS V NECK BUBBLE STITCH P/O　　STROKE NO. -/2155

YARN 2/8's SHETLAND　　GAUGE 9G

LABEL REFERENCE　　PROVISIONAL/CONFIRMED

SIGNATURE [signature]

	FULLY FASHIONED SIZE CHART / FINISHED MEASUREMENTS	SIZE / TO FIT	36"	38"	40"	42"	44"				Tolerance	
A.	FRONT LENGTH (FROM SHOULDER AT NECK JOIN)		63	63	66	69	69				+2	-1
B.	ACROSS FRONT (AT FASHIONING POINT)		38	39	40	41	42					
C.	CHEST WIDTH (1.CM BELOW ARMHOLE)		47	50	53	56	59				-1	+2
D.	WELT WIDTH (AT BOTTOM)		33	36	39	42	45					
E.	SADDLE LENGTH											
F.	SADDLE DEPTH											
G	ARMHOLE (STRAIGHT LINE)		22	22	23	24	24					
H.	ARMHOLE (FASHIONING SEAM AREA)		17	17	18	19	19					
I.	ARMHOLE (LINKED SEAM AREA)											
J.	RAGLAN FRONT											
K.	RAGLAN BACK											
L.	SLEEVE OVERARM (TO END OF SLEEVE)											
M.	SLEEVE UNDERARM (TO END OF SLEEVE)		47	47	47	47	47				+1	-1
N.	SLEEVE AT WIDEST (RIGHT ANGLE TO OVERARM)		17	17	18	19	19				+1	-1
O.	ELBOW WIDTH (FOLD OF SLEEVE TO ARMHOLE)		15	15	16	17	17					
P	CUFF WIDTH (AT BOTTOM)		7	7	8	9	9					
Q	NECK AREA - NECK DROP		22	22	22	24	24					
R.	- BACK NECK - SEAM TO SEAM											
S.	- BACK NECK - OVERALL		16	16	16	16	16					
T.	SHOULDER SEAM		14	15	15	15	16					
U.	NECK STRETCH MINIMUM											
V.	RIB DEPTHS - WELT		6	6	6	6	6					
W.	- CUFF		6	6	6	6	6					
X.	- NECK		3	3	3	3	3					
Y.	RIB COUNTS - WELT		37	39	41	43	45					
Z.	- CUFF		17	17	19	21	21					
ZA.	- NECK		56	56	56	60	60					
	OTHER DETAILS											

MARKS & SPENCER P.L.C. RETAINS THE RIGHT TO ACCEPT/REJECT MERCHANDISE WHICH FALLS OUTSIDE THE AGREED LIMITS.

APPENDIX 4

Microcomputer Coding Sheets

MICROCOMPUTER CODING SHEET-Program TSS12-Main program

		Machine Code		Assembly Language			
LINE	ADDRESS	OP. CODE	OPERAND (HEX)	MNEMONIC	OPERAND (ASSEMBLER)	NO.OF CYCLES	COMMENTS
1	0000	D8		CLD			Clear decimal mode
2	0001	A9	FF	LDA	#FF		
3	0003	8D	02A0	STA	A002		Make port B outputs
4	0006	A9	00	LDA	#00		
5	0008	8D	03A0	STA	A003		Make port A inputs
6	000B	A9	15	LDA	#15		Set PCR (Peripheral control
7	000D	8D	0CA0	STA	A00C		register) to establish interrupt modes.
8	0010	A9	65	LDA	#65		Set IER (interrupt enable
9	0012	8D	0EA0	STA	A00E		register). Disable CA2 and
10	0015	A9	9A	LDA	#9A		enable CA1, CB1 and CB2.
11	0017	8D	0EA0	STA	A00E		
12	001A	A9	00	LDA	#00		Load interrupt start
13	001C	8D	01A4	STA	A401		address 0040 into
14	001F	A9	40	LDA	#40		interrupt start vector.
15	0021	8D	00A4	STA	A400		
16	0024	A9	00	LDA	#00		Reset counter to zero.
17	0026	85	3F	STA	3F		
18	0028	20	0002	JSR	0200		Subroutine to display "OK?" and wait for "Y".
19	002B	58		CLI			Enable interrupts.
20	002C	20	96FE	JSR	FE96		Has "P" been pressed?
21	002F	C9	50	CMP	#50		
22	0031	D0	F9	BNE	002C		No, check again.
23	0033	20	2002	JSR	0220		Yes, print results.
24	0036	4C	0B00	JMP	000B		Prepare for next garment.

TSS12-Interrupt routine

25	0040	48		PHA		3	Save the accumulator and X
26	0041	8A		TXA		2	register on the stack.
27	0042	48		PHA		3	(special memory locations)
28	0043	A6	3F	LDX	3F	3	Load X reg. with counter.
29	0045	A9	01	LDA	#01	2	Generate pulses to start
30	0047	8D	00A0	STA	A000	4	the A/D conversion.
31	004A	A9	02	LDA	#02	2	
32	004C	8D	00A0	STA	A000	4	
33	004F	A9	00	LDA	#00	2	
34	0051	8D	00A0	STA	A000	4	
35	0054	AD	0DA0	LDA	A00D	4	Fetch contents of IFR (interrupt flag register).
36	0057	29	01	AND	#01	2	CB1 interrupt flag set? (conversion done?)
37	0059	F0	F9	BEQ	0054	3	No, wait until it is.
38	005B	78		SEI		2	Disable interrupts.
39	005C	A9	F1	LDA	#F1	2	Read data from position
40	005E	8D	0CA0	STA	A00C	4	transducer and save it in
41	0061	AD	01A0	LDA	A001	4	memory table.
42	0064	95	80	STA	80,X	4	
43	0066	A9	D1	LDA	#D1	2	
44	0068	8D	0CA0	STA	A00C	4	
45	006B	AD	00A0	LDA	A000	4	Clear the IFR.
46	006E	E8		INX		2	Increment the table counter
47	006F	E0	5E	CPX	#5E	2	Is the memory space for the table exhausted?
48	0071	F0	B1	BEQ	0024	3	Yes, then start again.
49	0073	86	3F	STX	3F	3	No, save counter.
50	0075	68		PLA		4	Restore X register and
51	0076	AA		TAX		2	accumulator contents.
52	0077	68		PLA		4	
53	0078	58		CLI		2	Enable interrupts.
54	0079	40		RTI		6	Return and wait next pulse.

Total = 92 cycles

TSS12-"Start" routine

55	0200	A9	4F	LDA	#4F		Print "OK?"
56	0202	20	7AE9	JSR	E97A		
57	0205	A9	4B	LDA	#4B		(Input the identification
58	0207	20	7AE9	JSR	E97A		of the garment)
59	020A	20	3EE8	JSR	E83E		
60	020D	20	D4E7	JSR	E7D4		
61	0210	20	96FE	JSR	FE96		
62	0213	C9	59	CMP	#59		Has "Y" been pressed?
63	0215	D0	F9	BNE	0210		No, check again.
64	0217	20	13EA	JSR	EA13		
65	021A	20	13EA	JSR	EA13		
66	021D	60		RTS			Yes, return.

TSS12-Printing routine

67	0220	20	13EA	JSR	EA13		
68	0223	A2	00	LDX	#00		Counter X=0
69	0225	B5	80	LDA	80,X		Print value stored in
70	0227	20	46EA	JSR	EA46		memory location 80+X.
71	022A	20	3BE8	JSR	E83B		
72	022D	E4	3F	CPX	3F		Have all been printed?
73	022F	F0	04	BEQ	0235		Yes, return ready for next garment.
74	0231	E8		INX			No, get next value of the
75	0232	4C	2502	JMP	0225		memory table.
76	0235	20	13EA	JSR	EA13		
77	0238	20	13EA	JSR	EA13		
78	023B	78		SEI			
79	023C	60		RTS			

MICROCOMPUTER CODING SHEET-Program TSS13-Main program

LINE	ADDRESS	Machine Code: OP. CODE	Machine Code: OPERAND (HEX)	Assembly Language: MNEMONIC	Assembly Language: OPERAND (ASSEMBLER)	NO.OF CYCLES	COMMENTS
1	0000	D8		CLD			Clear decimal mode.
2	0001	A9	FF	LDA	#FF		Make port B outputs.
3	0003	8D	02A0	STA	A002		
4	0006	A9	00	LDA	#00		Make port A inputs.
5	0008	8D	03A0	STA	A003		
6	000B	A9	15	LDA	#15		Set PCR to establish
7	000D	8D	0CA0	STA	A00C		interrupt modes.
8	0010	A9	65	LDA	#65		Set IER
9	0012	8D	0EA0	STA	A00E		Disable CA2 and enable
10	0015	A9	9A	LDA	#9A		CA1, CB1 and CB2.
11	0017	8D	0EA0	STA	A00E		
12	001A	A9	00	LDA	#00		Load interrupt start
13	001C	8D	01A4	STA	A401		address into interrupt
14	001F	A9	40	LDA	#40		start vector.
15	0021	8D	00A4	STA	A400		
16	0024	A9	00	LDA	#00		Reset counter to zero.
17	0026	85	3F	STA	3F		
18	0028	20	0002	JSR	0200		Display "OK?" and await "Y"
19	002B	58		CLI			Enable interrupts.
20	002C	A0	FF	LDY	#FF		Waiting loop.
21	002E	88		DEY			
22	002F	D0	FD	BNE	002E		
23	0031	4C	2C00	JMP	002C		
24	0034	4C	4002	JMP	0240		Printing routine.

TSS13-Interrupt routine

25	0040	48		PHA		3	Save the accumulator and X
26	0041	8A		TAX		2	reg. on the stack.
26	0042	48		PHA		3	
27	0043	A6	3F	LDX	3F	3	Load X register with counter.
28	0045	A9	01	LDA	#01	2	Generate pulses to start
29	0047	8D	00A0	STA	A000	4	the A/D conversion.
30	004A	A9	02	LDA	#02	2	
31	004C	8D	00A0	STA	A000	4	
32	004F	A9	00	LDA	#00	2	
33	0051	8D	00A0	STA	A000	4	
34	0054	AD	0DA0	LDA	A00D	4	Fetch contents of IFR
35	0057	29	10	AND	#10	2	CB1 interrupt flag set? (conversion finished?)
36	0059	F0	F9	BEQ	0054	3	No, wait until it is.
37	005B	78		SEI		2	Yes, disable interrupts,
38	005C	A9	F1	LDA	#F1	2	read data from position
39	005E	8D	0CA0	STA	A00C	4	transducer and save it in
40	0061	AD	01A0	LDA	A001	4	memory table.
41	0064	95	90	STA	90,X	4	
42	0066	A9	D1	LDA	#D1	2	
43	0068	8D	0CA0	STA	A00C	4	
44	006B	AD	00A0	LDA	A000	4	Clear the IFR.
45	006E	E0	00	CPX	#00	2	First measurement?
46	0070	F0	0D	BEQ	007F	3	Yes, ignore next 8 instructions.
47	0072	B5	90	LDA	90,X	4	No, get the last two
48	0074	CA		DEX		2	measurements, D_n; D_{n-1}
49	0075	38		SEC		2	
50	0076	F5	90	SBC	90,X	4	Compute $\Delta D=D_n-D_{n-1}$.
51	0078	30	04	BMI	007E	3	If $\Delta D<0$, read next data.
52	007A	C5	3E	CMP	3E	4	Does ΔD mean armholes?
53	007C	B0	B6	BCS	0034	3	Yes, find chest width and print results.

Interrupt routine (cont.)

54	007E	E8		INX		2	No, increment counter to
55	007F	E8		INX		2	allocate next measurement.
56	0080	E0	4F	CPX	#4F	2	Is the memory space for the table exhausted?
57	0082	F0	A0	BEQ	0024	3	Yes, then start again.
58	0084	86	3F	STX	3F	3	No, save counter.
59	0086	68		PLA		4	Restore X register and
60	0087	AA		TAX		2	accumulator contents.
61	0088	68		PLA		4	
62	0089	58		CLI		2	Enable interrupts.
63	008A	40		RTI		6	Return and wait for next pulse.

Total=121 cycles

TSS13-"Start" routine

64	0200	A9	4F	LDA	#4F		Print "OK?"
65	0202	20	7AE9	JSR	E97A		
66	0205	A9	4B	LDA	#4B		(Input garment
67	0207	20	7AE9	JSR	E97A		identification)
68	020A	20	3EE8	JSR	E83E		
69	020D	20	D4E7	JSR	E7D4		
70	0210	20	96FE	JSR	FE96		
71	0213	C9	59	CMP	#59		Has "Y" been pressed?
72	0215	D0	F9	BNE	0210		No, check again.
73	0217	20	13EA	JSR	EA13		
74	021A	20	13EA	JSR	EA13		
75	021D	60		RTS			Yes, return.

TSS13-Routine to find the chest width and print results

76	0240	A5	3F	LDA	3F		Print No. of measurements
77	0242	20	46EA	JSR	EA46		(garment length).
78	0245	20	3BE8	JSR	E83B		
79	0248	A6	3F	LDX	3F		Step back 3 cm and get the
80	024A	CA		DEX			width of the garment at
81	024B	CA		DEX			the standard chest level.
82	024C	CA		DEX			
83	024D	CA		DEX			
84	024E	EA		NOP			
85	024F	EA		NOP			
86	0250	B5	90	LDA	90,X		Print value of chest width.
87	0252	20	46EA	JSR	EA46		
88	0255	20	13EA	JSR	EA13		
89	0258	20	13EA	JSR	EA13		
90	025B	A2	00	LDX	#00		Print all measurements;
91	025D	B5	90	LDA	90,X		when printing is completed
92	025F	20	46EA	JSR	EA46		get ready for next garment.
93	0262	20	3BE8	JSR	E83B		
94	0265	E4	3F	CPX	3F		
95	0267	F0	04	BEQ	026D		
96	0269	E8		INX			
97	026A	4C	5D02	JMP	025D		
98	026D	20	13EA	JSR	EA13		
99	0270	20	13EA	JSR	EA13		
100	0273	78		SEI			
101	0274	4C	2400	JMP	0024		

MICROCOMPUTER CODING SHEET-Program TSS18-Main program

		Machine Code		Assembly Language		
LINE	ADDRESS	OP. CODE	OPERAND (HEX)	MNEMONIC	OPERAND (ASSEMBLER)	COMMENTS
1	0200	A9	00	LDA	#00	Clear PCR (Peripheral Control
2	0202	8D	0C0A	STA	A00C	Register).
3	0205	85	C0	STA	C0	Reset counter to zero.
4	0207	8D	030A	STA	A003	Make port A inputs.
5	020A	A9	8F	LDA	#8F	Port B inputs on pins 4, 5, 6;
6	020C	8D	020A	STA	A002	outputs on others.
7	020F	20	0030	JSR	0300	Display "OK?" and wait "CR"
8	0212	AD	00A0	LDA	A000	Start measuring?
9	0215	29	20	AND	#20	
10	0217	D0	F9	BNE	0212	No, check again.
11	0219	AD	00A0	LDA	A000	Yes. Pulse from disc?
12	021C	29	40	AND	#40	
13	021E	F0	F9	BEQ	0219	No, check again.
14	0220	A6	C0	LDX	C0	Yes, fetch counter.
15	0222	A9	01	LDA	#01	Address latch enable (ALE).
16	0224	8D	00A0	STA	A000	
17	0227	A9	02	LDA	#02	Start conversion.
18	0229	8D	00A0	STA	A000	
19	022C	A9	00	LDA	#00	
20	022E	8D	00A0	STA	A000	
21	0231	AD	00A0	LDA	A000	Conversion done?
22	0234	29	10	AND	#10	
23	0236	F0	F9	BEQ	0231	No, check again.

TSS18-Main program (cont.)

24	0238	A9	08	LDA	#08	Yes, output enable (OE)
25	023A	8D	00A0	STA	A000	
26	023D	AD	01A0	LDA	A001	Read data on port A.
27	0240	9D	0004	STA	0400,X	Store in memory table.
28	0243	A9	00	LDA	#00	
29	0245	8D	00A0	STA	A000	
30	0248	E0	00	CPX	#00	First measurement?
31	024A	F0	10	BEQ	025C	Yes, take other measurement.
32	024C	BD	0040	LDA	0400,X	No, get the last two
33	024F	CA		DEX		measurements, D_n; D_{n-1}.
34	0250	38		SEC		
35	0251	FD	0040	SBC	0400,X	Compute $\Delta D = D_n - D_{n-1}$.
36	0254	30	05	BMI	025B	If $\Delta D<0$ read next data.
37	0256	CD	7002	CMP	0270	Does ΔD mean armholes?
38	0259	B0	11	BCS	026C	Yes, start lift neck device,
						find chest and print results.
39	025B	E8		INX		No, increment counter to
40	025C	E8		INX		allocate next measurement.
41	025D	86	C0	STX	C0	Save counter.
42	025F	A2	01	LDX	#01	Delay to wait for next slot
43	0261	A0	0A	LDY	#0A	of the disc.
44	0263	CA		DEX		
45	0264	D0	FD	BNE	0263	
46	0266	88		DEY		
47	0267	D0	FA	BNE	0263	
48	0269	4C	1902	JMP	0219	Wait next pulse from disc.
49	026C	4C	4003	JMP	0340	

TSS18-"Start" routine

50	0300	A9	4F	LDA	#4F	Print "OK?"
51	0302	20	7AE9	JSR	E97A	
52	0305	A9	4B	LDA	#4B	(Input the identification
53	0307	20	7AE9	JSR	E97A	of the garment).
54	030A	20	3EE8	JSR	E83E	
55	030D	20	D4E7	JSR	E7D4	
56	0310	20	96FE	JSR	FE96	
57	0313	C9	0D	CMP	#0D	Has "CR" been pressed?
58	0315	D0	F9	BNE	0310	No, check again.
59	0317	20	13EA	JSR	EA13	
60	031A	20	13EA	JSR	EA13	
61	031D	60		RTS		Yes, return to main program.

TSS18-Routine to start lift neck device and print results

62	0340	A9	04	LDA	#04	Send pulse to PB2 to start
63	0342	8D	00A0	STA	A000	lift neck device.
64	0345	A0	02	LDY	#02	
65	0347	88		DEY		
66	0348	D0	FD	BNE	0347	
67	034A	A9	00	LDA	#00	
68	030C	8D	00A0	STA	A000	
69	034F	EA		NOP		
70	0350	A9	4C	LDA	#4C	Print No. of measurements;
71	0352	20	7AE9	JSR	E97A	
72	0355	20	3BE8	JSR	E83B	
72	0358	A9	3D	LDA	#3D	
73	035A	20	7AE9	JSR	E97A	
74	035D	20	3BE8	JSR	E83B	
75	0360	A5	C0	LDA	C0	
76	0362	20	46EA	JSR	EA46	
77	0365	20	13EA	JSR	EA13	
78	0368	20	13EA	JSR	EA13	
79	036B	A9	43	LDA	#43	

TSS18-(cont.)

80	036D	20	7AE9	JSR	E97A	
81	0370	A9	48	LDA	#48	
82	0372	20	7AE9	JSR	E97A	
83	0375	A9	45	LDA	#45	
84	0377	20	7AE9	JSR	E97A	
85	037A	A9	53	LDA	#53	
86	037C	20	7AE9	JSR	E97A	
87	037F	A9	54	LDA	#54	
88	0381	20	7AE9	JSR	E97A	
89	0384	20	3EE8	JSR	E83E	
90	0387	A9	3D	LDA	#3D	
91	0389	20	7AE9	JSR	E97A	
92	038C	20	3EE8	JSR	E83E	
93	038F	A6	C0	LDX	C0	Step back "3 cm" and get the
94	0391	CA		DEX		width of the garment at the
95	0392	CA		DEX		defined chest level.
96	0393	CA		DEX		
97	0394	CA		DEX		
98	0395	EA		NOP		
99	0396	EA		NOP		
100	0397	BD	0004	LDA	0400,X	Print value of chest width.
101	039A	20	46EA	JSR	EA46	
102	039D	20	13EA	JSR	EA13	
103	03A0	20	13EA	JSR	EA13	
104	03A3	A2	00	LDX	#00	Print all measurements.
105	03A5	BD	0004	LDA	0400,X	
106	03A8	20	46EA	JSR	EA46	
107	03AB	20	3BE8	JSR	E83B	
108	03AE	E4	C0	CPX	C0	
109	03B0	F0	04	BEQ	03B6	
110	03B2	E8		INX		
111	03B3	4C	A503	JMP	03A5	
112	03B6	20	13EA	JSR	EA13	
113	03B9	20	13EA	JSR	EA13	
114	03BC	4C	0002	JMP	0200	Get ready for next garment.

APPENDIX 5

Selection of the Timing Belt to Drive the Angular Displacement Transducer

The selection of the timing belt is carried out following the manufacturer instructions[42]. The tensile force on the belt can be determined from the technical specification of the potentiometer. The maximum torque at the start is 28×10^{-4} Nm[32]. The pulley on the potentiometer shaft has a pitch diameter of 0.364". The tensile force is given by:

$$F = T/r$$

$$r = 0.364 \times 25.4/2 = 4.62 \text{ mm}$$
$$T = 28 \times 10^{-4} \times 1000 = 2.8 \text{ Nmm}$$

$$F = 2.8/4.62$$
$$= 0.61 \text{ N}$$
$$= 0.61 \times 0.225$$
$$= 0.14 \text{ lbf}$$

There are 4 available pitches. As the forces involved are minimal, the belt in the lower end of the range has been selected. It is the 40 pitch (XXL) miniature, 1/8" wide, designed for an operating tensile force of 7 lbf.

Fig. A5.1 shows the geometry of the mounting procedure. The belt length is given by the following expression:

$$L = 2\,C\cos\phi + \pi\,[(D+d)/2 + (D-d)\phi/180]$$ where

L = Pitch length of belt (inches)

D = Pitch diameter of large pulley. $D = 3.120''$

d = Pitch diameter of small pulley. $d = 0.364''$

C = Centre distance = 65 mm = 2.559"

$\phi = \sin^{-1}(D-d)/2C$ (degrees)

$= \sin^{-1}(3.120-0.364)/(2 \times 2.559)$

$= 32.58^{\circ}$

$$L = 2 \times 2.559 \times \cos 32.58^{\circ} + \pi\,[(3.12+0.364)/2+(3.12-0.364) \times 32.58/180]$$

$= 11.352''$

According to the manufacturer, the nearest belt is the stock number 8TB-139 with 139 pitches and a pitch length of 11.3424". The manufacturer gives the following expression for the corrected value of the center distance C:

$$C = [K + (K^2 - 32(D-d)^2)]^{-2}/16$$

Where $K = 4 \times L - 6.28(D+d)$

$= 4 \times 11.3424 - 6.28(3.12+0.364)$

$= 23.49$

The corrected value of C is then

$$C = [23.49 + (23.49^2 - 32(3.12-0.364)^2)]^{-2}/16$$

$= 2.566''$

$= 65.2$ mm

The difference from the initially assumed value of 65 mm is minimal and the adjustable centres will absorb it.

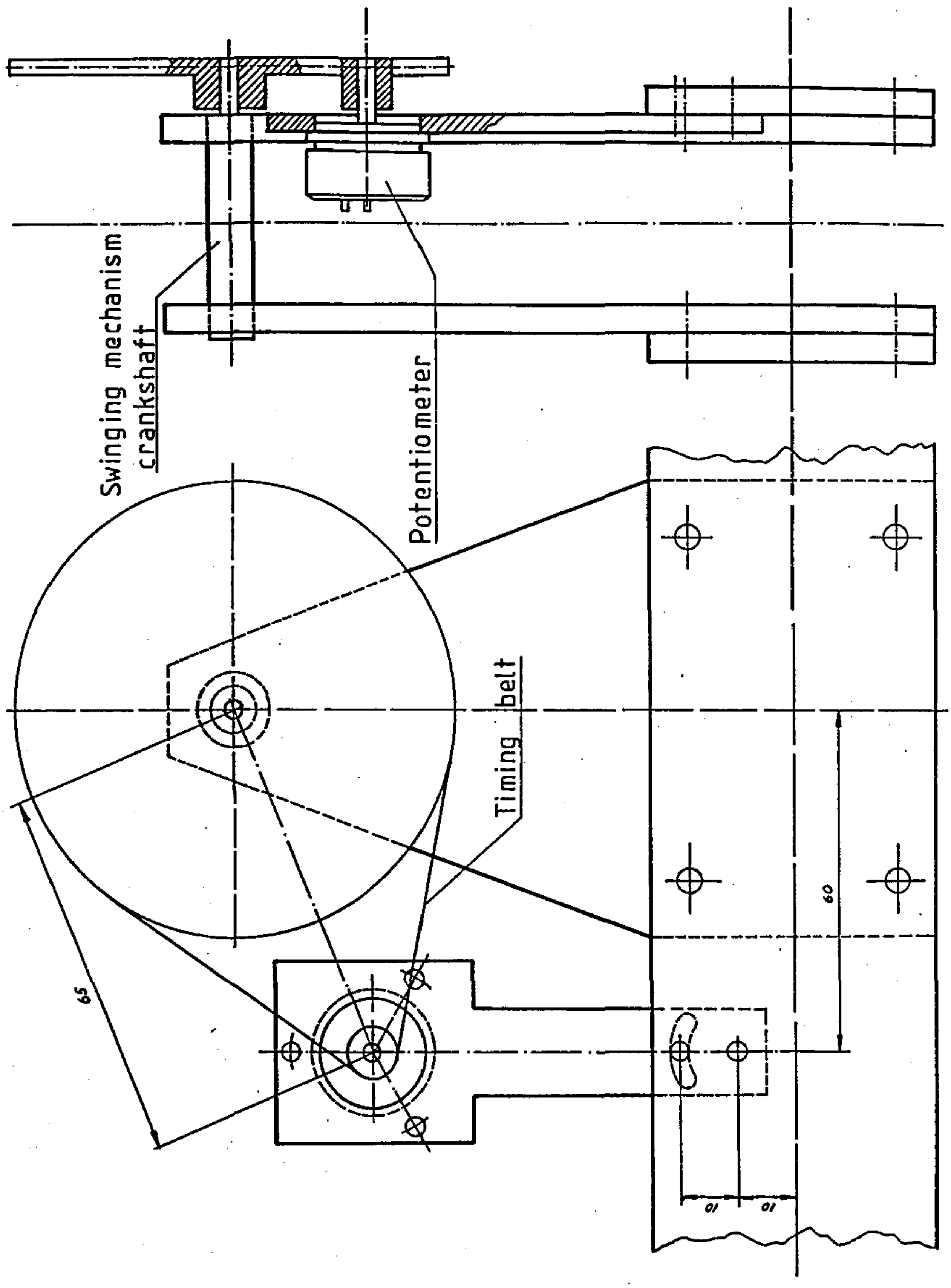


Fig. A5.1 Potentiometer mounting geometry.

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