Prom. No. **2826**

# An Investigation of Yarn Tension and Balloon Shape in Uptwisting

Von der

EIDGENÖSSISCHEN TECHNISCHEN HOCHSCHULE IN ZÜRICH

zur Erlangung
der Würde eines Doktors der
technischen Wissenschaften
genehmigte

PROMOTIONSARBEIT

Vorgelegt von

**Mr. GWYNFRYN JOHN MORRIS, B.Sc.**
BRITISCHER STAATSANGEHÖRIGER

Referent: Herr Prof. Dr. E. Honegger
Korreferent: Herr Prof. Dr. J. Ackeret

Cardiff 1959
Printed by S. Glossop & Sons Ltd.,
22 New Street

# *Zusammenfassung*


Es wird das Problem des Ueberkopfabwickelns von Garn von einer vertikalachsigen stehenden oder rotierenden Spule untersucht und die Bedeutung der verschiedenen Kräfte, welche auf das Garn einwirken und die Garnspannung sowie die Form des Fadenballons beeinflussen, besprochen. Wird das Garn bei niedrigen Geschwindigkeiten von einer rotierenden Spule abgezogen, so wird die Zentrifugalkraft ein wichtiger Faktor sein, der die Garnspannung bestimmt, obwohl der Luftwiderstand und die Corioliskraft auch eine gewisse Rolle spielen werden. Mit steigender Abzugsgeschwindigkeit wächst der Einfluss der Corioliskraft und möglicherweise auch der Luftreibung.

Garnspannungsmessungen werden besprochen und ein Apparat beschrieben, der entwickelt worden ist zum Messen von Garnspannungen zwischen einem Bruchteil eines Gramms und 200-300 Gramm, welche sich mit Frequenzen bis zu 100 Herz ändern. Garnspannungen und Fadenballondurchmesser sind an Garnen gemessen worden, welche mit einer Abzugsgeschwindigkeit von 50 m/Min von Kreuzspulen abgewickelt werden, die mit Umdrehungsgeschwindigkeiten von 0 bis 10.000 U/Min rotieren. Der Einfluss der Garngeschwindigkeit, der Umdrehungszahl der Spindel, der Garnnummer, des Spulendurchmessers und der Höhe der Fadenführer über der Spule, wird für Garne aus Baumwolle, aus end-losen und Stapelfaser Nylon, sowie aus Stapelfaser Viskose untersucht. Die Resultate zeigen, dass die Höchstspannung dann erreicht wird, wenn das Garn beim Verlassen des unteren Endes der Spule nur einen einzigen Fadenballon bildet. Doppelte oder mehrfache Ballone entsprechen niedrigeren Spannungen. Es wurden auch Messungen an Garnen vorgenommen, welche mit Abzugsgeschwindigkeiten von 250, 500 und 750 m/Min von stillstehenden Spulen abgewickelt wurden.

# *Summary*

The problem of unwinding yarn over-end from a vertical package is considered, and the importance of the various forces acting on the yarn and which affect yarn tension and balloon shape is discussed. When yarn is wound off a rotating package at low yarn speeds, centrifugal force is an important factor governing yarn tension although air drag and the Coriolis force have some effect. The influence of the Coriolis and air drag forces increases with increasing yarn speed.

The measurement of yarn tension is discussed and the development of an instrument capable of measuring yarn tension from less than one gram to several hundred grams and varying with a frequency up to 100 cycles per second is described. Measurements of yarn tension and balloon diameter have been made on yarns wound off at 50 m/min. from cross wound tubes rotating at speeds between 0 and 10,000 r.p.m. The influence of yarn speed, spindle speed, yarn denier, package diameter and the height of the yarn guide above the package has been examined for yarns of cotton, continuous filament and staple nylon, and staple viscose. The results show that the maximum tension is obtained when a single balloon exists as the yarn leaves the bottom of the package. Double or other multiple balloons correspond to much lower tensions. Measurements were also made on yarns taken off stationary packages at speeds of 250, 500 and 750 m/min.

# Contents

# *Symbols*

| | |
|---|---|
| $A$ | Constant in the relation $T=Ax^n$ |
| $B$ | Distance between yarn guide and bottom of package |
| $ds$ | Length of yarn element |
| $H$ | Distance between yarn guide and top of package |
| $m$ | Yarn mass per unit length |
| Min $T_A$ | Least tension at which a single balloon exists before a double balloon forms |
| Min $T_B$ | Mean tension corresponding to a double balloon |
| $n$ | Constant in the relation $T=Ax^n$ |
| $N_e$ | English cotton count |
| $N_m$ | Metric count |
| $r$ | Distance of yarn element from axis of rotation |
| $v$ | Yarn speed |
| $w$ | Angular velocity of yarn |
| $x$ | Rotational speed of package |
| $\pi d$ | Length of yarn wound off in one rotation of package |

# 1. INTRODUCTION

The production of a textile fabric involves a large number of complex operations. These can be conveniently divided into three main groups.

(*a*) The production of the required yarns from the raw material, *e.g.* cotton or woollen fibres, or synthetic polymer.

(*b*) The production of the fabric either by weaving or knitting.

(*c*) The finishing of the fabric, which may involve several different operations depending upon the final end use of the fabric.

The production of a good fabric depends upon the satisfactory completion of all the operations throughout the whole process. A consideration of the operations involved in the production of a good yarn, whether this be a staple yarn from the natural fibres or a continuous filament synthetic yarn, shows that the transfer of yarn from one package to another is of considerable importance.

The actual transfer of yarn occurs in a number of different ways. The particular type of transfer involved in both ring and cap spinning has been investigated by a number of people and several papers have appeared (references 9.03-9.15). What may be considered almost as the inverse process, that of winding a yarn off a package over-end, has not received so much attention, although this is of considerable importance, particularly for the newer synthetic fibres. With the increasing use of fine denier yarns producing fabrics which easily show up yarn irregularities, an understanding of the factors which govern yarn transfer under various operating conditions is essential.

Often the transfer of yarn from one package to another involves an essential process such as drawing, doubling, or twisting. This is not always so however, and sometimes the yarn is merely transferred to a more suitable package—either to facilitate its use in the next operation or simply to satisfy the needs of a customer.

Depending upon the process involved the yarn transfer occurs under widely differing conditions. In ring spinning the yarn is wound sideways off a flyer bobbin and passes downwards on to a rotating spinning package. In uptwisting, an operation which has acquired great importance since the introduction of rayon and the synthetic fibres, the yarn is taken off upwards from a rotating package.

In all operations it is essential to produce a good package, and yarn tension is an important factor in achieving this. If the winding tension is too low, the package is too soft and may collapse when being transported. If the tension is too high, the package former may be crushed and variations produced in the mechanical properties of the yarn. Correct yarn tension during processing is therefore essential in producing a good yarn and package, and ultimately a good fabric.

The control of yarn tension is essential, but control can be exerted only above a certain tension which exists in the yarn as a result of the operation itself. It is necessary therefore, to know how yarn tension varies under different processing conditions and what are the most important controlling factors.

In addition to the yarn tension the extent of yarn movement is important. Economically, it is desirable to have positions on a machine as close together as possible, but there must be no interference between adjacent positions.

Thus an investigation of yarn winding involves the measurement of yarn tension and the observation of yarn motion. This report examines the tension and motion of yarn taken off over-end from a package mounted vertically.

## 2. PREVIOUS RELATED WORK

The behaviour of yarn when taken off over-end from a package rotating about a vertical axis is governed by many factors. Observation of the process shows that balloon shape (*i.e.* the envelope of the yarn path) is constantly varying and with it the yarn tension. Very little work on the unwinding of yarn from packages, either stationary or rotating, has been published. Miss Padfield (reference 9.01) has considered the problem of unwinding yarn over-end from a stationary package, but restricts the problem to that of a single balloon only. A paper has also been published by K. H. V. Booth (reference 9.02) but this is confined to the case of the yarn being drawn along the package surface. Such behaviour never occurs with rotating packages and only rarely with stationary packages when the yarn speed is very low.

Although little work has been reported on unwinding, the problems of both ring and cap spinning have been considered by a number of people. One of the earliest reviews of the problem was that by Honegger and Fehr (reference 9.03) who consider some of the important factors contributing to tension variation in ring spinning. The majority of the more recent publications have been mainly theoretical and very little experimental work has been reported. The theoretical papers differ in the assumptions which the various authors adopt but all agree on the difficulty of solving the equations of any general theory. By neglecting various terms which can be justified under particular operating conditions however, the solution of the equations can be simplified.

Brief reference will be made to the more important papers and their main characteristics considered. In general, yarn is fed downwards at a constant speed passing through a guide eye vertically above the spindle and is wound up on a rotating package.

Miss Hannah (reference 9.04) has considered the problem of cap spinning. She keeps her equations fairly simple by confining the theory to narrow balloons, and considering the motion of the yarn to be influenced only by the centrifugal force due to the rotation of the yarn, and air drag. The precise effect of air drag is unknown and many of the authors differ in their assumptions concerning it.

Miss Hannah assumes that the air drag is proportional to the square of the linear velocity of the yarn and acts horizontally, opposing the direction of motion of the thread element. She states that her theoretical results agree well with actual experimental results obtained at the Wool Industries Research Association, Leeds, under the restricted conditions imposed by her assumptions. Miss Hannah's results show that spinning a finer count (*i.e.* a reduction in denier) and a decrease in twist have little effect on tension but reduce balloon diameter. An increase in balloon length increases yarn tension for free and licking balloons, and an increase in bobbin radius causes a reduction in tension.

In a later paper (reference 9.05) Miss Hannah shows how the decrease in tension which occurs as the package diameter increases can be prevented by the use of shaped caps, and she specifies the conditions for maintaining a uniform tension. Very little experimental detail is given in either paper but the tension was measured using a Brown Boveri instrument.

Mack (reference 9.06) presents a theory applicable to both cap and ring spinning but he, like Hannah, considers only the centrifugal force and air drag. He considers the air drag to be proportional to the square of the relative velocity normal to the yarn element and to act along the direction of the normal. The general equations are solved under particular conditions which provide a number of different solutions. Mack obtains (*a*) a zero air drag solution which is relatively simple but never occurs in practice, (*b*) a low air drag solution, (*c*) a high air drag solution, and (*d*) an intermediate air drag solution which provides numerical results with the aid of an electronic computer. Most of the theory is devoted to balloon shape and dimensions and very little to the calculation of yarn tension.

In references 9.07 and 9.08 experimental results obtained on a specially designed laboratory apparatus are given. This employs a fixed length of yarn, both ends of which are rotated synchronously. The agreement between experimental results and the theoretical calculations at both the zero and low air drag solutions was good.

The experimental arrangement is extremely interesting and useful for testing the theoretical conclusions. It differs considerably however from the conditions which exist in uptwisting. No package is used and a fixed length of yarn rotates without movement along its length so the results could not be applied directly to the uptwisting process. They do show the agreement of the theory with experiment under the conditions considered however and justify the assumptions made. Measurements of balloon diameter are made by a calibrated movable rod whose position is adjusted until it almost touches the balloon. Tension is measured by the extension of a spring but no details of its performance are given, although tension values are quoted to 0.1 gram.

The results show an increase in yarn tension with an increase in the angular velocity and denier of the yarn.

A more comprehensive theoretical treatment is given by Crank (reference 9.09 and 9.10). In these papers he develops a general theory of yarn spinning and then considers more particularly cap spinning in reference 9.11 and ring spinning in reference 9.12. Crank's theory is more general than that of either Hannah or Mack, and in addition to the effects of centrifugal force and air drag includes the Coriolis force due to the motion of the yarn along its length in a rotating system, and the weight of the yarn.

Crank defines the problem and sets out his basic assumptions clearly so that the development of the theory follows easily. At first he considers the air drag to be proportional to the square of the velocity of the yarn relative to the air and to act horizontally as Hannah does, but later (reference 9.10) considers that a better assumption is that in which the air drag acts normally to the yarn element.

In reference 9.09 Crank considers the effect of changing the top tension on the balloon shape, and evaluates specific cases. In practice this tension results from other factors, *e.g.* traveller weight or spindle speed and so cannot be arbitrarily chosen. In reference 9.10 he therefore considers the effect on balloon diameter and yarn tension of various parameters such as yarn denier, bobbin speed, cap and bobbin diameters, and balloon height.

Almost the whole of Crank's work is theoretical and although some experimental results are quoted to illustrate his theory no information is given on the experimental technique employed or the method used for measuring tension.

Crank used a differential analyser to obtain numerical solutions of his equations and the chief results showed that balloon diameter and bobbin tension increase with increasing denier, cap diameter and bobbin speed. Bobbin size and balloon height have little effect on balloon diameter.

In a private publication (reference 9.13, 9.14, 9.15) P. F. Grishin develops a comprehensive theory of the spinning balloon. He first derives a set of general equations and considers centrifugal force, air drag and Coriolis force acting on an element of yarn. For the particular case of spinning the Coriolis force is neglected. He develops the theory fully but owing to the complexity does not give the integration required to solve the equations but presents a set of formulae which can be used for evaluating particular cases. The presentation of the general theory is not very clear—he says for example that air drag acts in the opposite direction to the movement of the element but does not specify its plane. By examining his equations it is found that he actually considers air drag to act horizontally. Careful examination of his equations also shows that he replaces $dz/ds$ and $dy/ds$ by $dz/dx$ and $dy/dx$ ($x$ being the vertical axis, $y$ and $z$ the axes in a horizontal plane, and $s$ the distance along the yarn). He is in effect assuming $ds = dx$ and is therefore confining himself to narrow balloons although he does not say so. In reference 9.14 Grishin considers methods of balloon control by using various arrangements of control rings and compares a large number of experimental results with his theoretical predictions. In reference 9.15 he modifies his original theory as the experimental results showed some of the approximations to be incorrect and then considers the case of winding off in which the Coriolis force cannot be neglected.

## 3. THEORETICAL CONSIDERATIONS

It is not intended to develop a complete theoretical treatment of the unwinding of yarn from packages. The papers which have already appeared on the spinning of yarn have shown the complexity of any general theory and the need for simplifying assumptions to enable approximate results to be obtained under particular conditions. A consideration of the more important forces acting on the yarn during unwinding however will be instructive and will help to interpret the experimental results.

The problem can be represented diagramatically as in Fig. 1, and we shall assume that a uniform, flexible, inextensible yarn of mass $m$ per unit length is drawn off a package over-end with uniform speed $v$. The yarn passes through a guide eye vertically above the axis of the package and rotates about this axis with angular velocity $w$ in the direction indicated. Employing a right handed co-ordinate system $x$, $y$, $z$, the angular velocity vector $\vec{w}$ is directed along the positive $z$ axis.

We shall consider the forces acting on an element of yarn $ds$ at a distance $r$ from the axis. These are, its weight vertically downwards, the tensions at each end of the element, the centrifugal force due to its motion along a curve, the Coriolis force and the air drag.

The yarn tension at the element is the unknown which we seek. In practice we cannot measure the tension in any part of the yarn which rotates so we measure the tension in the vertical section of the yarn immediately above the guide eye. There will be some effect due to the friction of the yarn as it rubs on the guide so the measured tension will be higher than the actual tension of the yarn at the top of the balloon.

The weight of the yarn element acts vertically downwards. It is probably small in comparison with the other forces acting on the element and under certain conditions could possibly be neglected.

At any instant the path of the yarn depends upon the relative values of $v$, the velocity of the yarn along its length and $w$, its angular velocity. The angular velocity of the yarn when taken off a package rotating at $x$ revolutions per minute is $w = 2\pi(x + v/\pi d)$ where $\pi d$ is the length of yarn wound off in one rotation of the package. The angular velocity of yarn wound off a stationary package is $w = 2\pi v/\pi d$. When yarn is taken off a rotating package as in uptwisting, the linear velocity $v$ is small and the angular velocity $w$ large, so we can consider as an approximation that the element of yarn rotates in a horizontal circle and the centrifugal force $F = m.ds.r.w^2$ acts radially outwards perpendicularly to the axis. When yarn is taken off a stationary package, $v$ is much larger and $w$ is smaller than when taken off a rotating package. The element of yarn can no longer be assumed to move in a horizontal circle and so the centrifugal force must be considered to act along the radius of curvature of the yarn path.

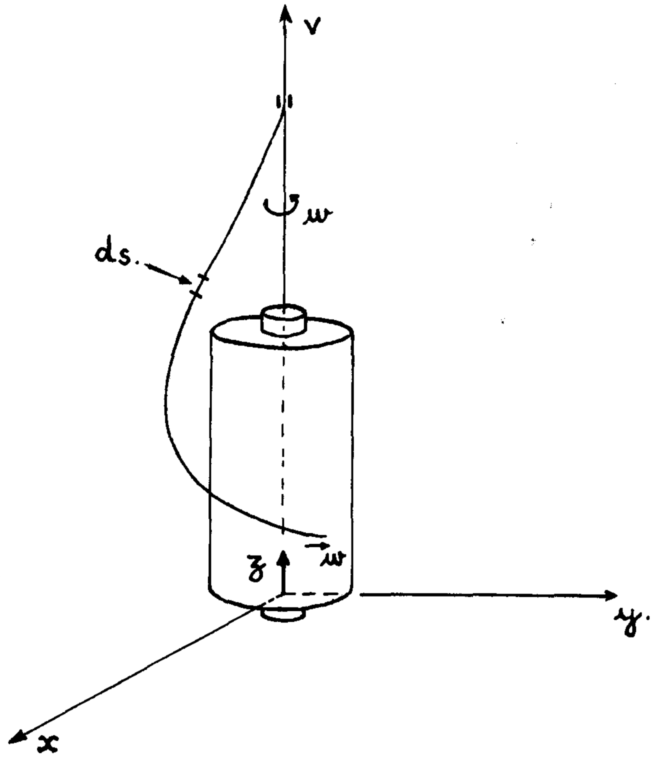



FIG. 1

The air drag acting on the element of yarn under normal conditions is not negligible. The difficulty in assessing its effect is that it cannot be expressed by a simple formula. Mack (reference 9.06) and Crank (reference 9.09) consider the air drag to depend upon the density of the air and the speed, inclination, diameter and surface characteristics of the yarn.

It is probably best to consider the air drag as having two components: that due to the motion of the yarn upwards along its own length, and that due to its rotation about the axis. The magnitude of these components will vary depending upon the values of $v$ and $w$. Crank (reference 9.10) has considered only the air drag due to the rotation of the yarn and takes this as proportional to the length of the element and to some function $f$ and acts normally to the yarn and opposed to its direction of rotation. The dependence of the air drag upon yarn velocity is not fully understood, but Crank considers that up to yarn speeds of 200 ft./sec. (approximately 60 m/sec.) it can be considered to increase as the square of the yarn velocity ($rw$) and for angles of inclination of the yarn to the vertical ($\theta$) up to about 70° it varies as $\cos^2 \theta$. Thus he takes the air drag to be $q.r^2.w^2.cos^2\theta.ds$ where $q$ is constant for a given yarn and is proportional to the yarn diameter. In his treatment Crank uses only the horizontal component of this which is $q.r^2.w^2.cos^3\theta.ds$ and neglects the other components.

This representation of the air drag in which only that due to the rotation of the yarn is considered may be valid for the case of uptwisting in which $v$ is small but then the rotational velocity ($rw$) will often exceed the value of 60 m/sec. beyond which the dependence of drag on the square of the velocity no longer holds. In the case of unwinding from a still package the component of air drag due to the motion of the yarn along its own length becomes more important. The assumption that the air drag is proportional to $r^2.w^2.cos^2\theta$, considers the yarn to be moving through still air. In practice this is not so as there is considerable air movement around the package due to its rotation. Between the top of the package and the guide eye however the air is relatively still so that as the yarn rises from the package to the guide eye it moves through air in different states of motion. In addition, the estimation of the air drag is complicated for rotating packages by the different amounts of twist inserted in the yarn at the various spindle speeds which produce differences in the surface characteristics of the yarn. It is impossible therefore to obtain an expression for the air drag which is applicable to the yarn along its whole length under all the conditions which occur.

The effect of the Coriolis force has often been omitted in theories of yarn spinning because its effect is considered small in relation to the centrifugal force. It cannot be omitted from a general consideration of the unwinding of yarn from a package however, although when unwinding at low linear yarn speeds from a rotating package its effect is probably small in comparison with the centrifugal force. The Coriolis force acting on the element $ds$ is given by the vector product $2.m.ds\left[\vec{v_r} \times \vec{w}\right]$ where $\vec{v_r}$ is the vector component of velocity in the plane perpendicular to the vector $\vec{w}$. Thus in the case of unwinding from a still package at high yarn speeds the Coriolis force is no longer small in comparison with the centrifugal force.

From the above considerations of the various forces acting on an element of the yarn it is possible to set up the differential equations of motion of the yarn. In addition however to the uncertainty of the magnitude and direction of the air drag, and the possible variation in the mass of the yarn and the nature of its surface along its length, we have to consider the movement of the end of the yarn as it leaves the package which will vary with the type of winding, and the possible changes in tension as the yarn leaves the surface of the package.

Thus the difficulty of obtaining satisfactory solutions to the general theory of unwinding is considerable. It would seem that with rotating packages the centrifugal force is the main factor influencing yarn tension, but with stationary packages the effect of air drag and the Coriolis force is very much larger. It should be possible to obtain experimentally some indication of the relative importance of the various forces by measuring the yarn tension under various conditions of yarn and spindle speeds for continuous filament and staple yarns.

# 4. EXPERIMENTAL

## 4.1 General

The motion of yarn taken off a package over-end can be seen only when the yarn speed is low. As soon as the yarn speed or rotational speed of the package exceeds a fairly low value, the eye is unable to observe the movement and sees only the envelope of the yarn path—the familiar balloon. The dimensions of the balloon, its height and diameter, specify the envelope of the yarn path and indicate the extremes of yarn movement. The yarn itself lies on a three dimensional curve which can be seen if illuminated with a stroboscope.

An investigation of yarn behaviour, therefore, involves two groups of measurements; those relating to yarn tension and those relating to balloon dimensions.

## 4.2 Measurement of yarn tension

### 4.21 General

The exact measurement of yarn tension is difficult. Mechanical devices are most often used, the yarn being made to pass around a spring-loaded pulley wheel whose deflection indicates the yarn tension. These instruments have a number of disadvantages. The simplest types significantly alter the yarn tension which it is desired to measure, so that a correct value of the tension is not obtained. The Brown Boveri instrument does not suffer from this disadvantage, but like all mechanical instruments, it is unable to follow rapid variations in yarn tension. For our purpose this was essential, so mechanical instruments could not be used.

A consideration of the limits at which we would work indicated that when taking yarn off a package at high yarn speeds it would be desirable to measure variations in tension occurring with a frequency up to about 100 cycles per second. It was considered necessary to be able to measure tensions between zero and a hundred grams weight.

Electronic devices may have high natural frequencies and one such instrument was available in the laboratory. It consisted of a pair of strain gauges fitted on opposite sides of, and in the centre of a metal strip 8 cm. long, which was clamped at each end. The strain gauges formed part of a bridge circuit and any deflection of the metal strip produced a change in the bridge output. Unfortunately, the natural frequency of this instrument was only about 15 cycles per second so it was incapable of recording rapid variations in tension. Another system of tension measurement was therefore required.

### 4.22 *Development of new instrument*

#### 4.221 Electronic

The measurement of tension was finally accomplished with the aid of a Philips inductive displacement pick-up PR 9310, used in conjunction with the Philips measuring bridge PR 9300. The chief advantages of this pick-up are its high

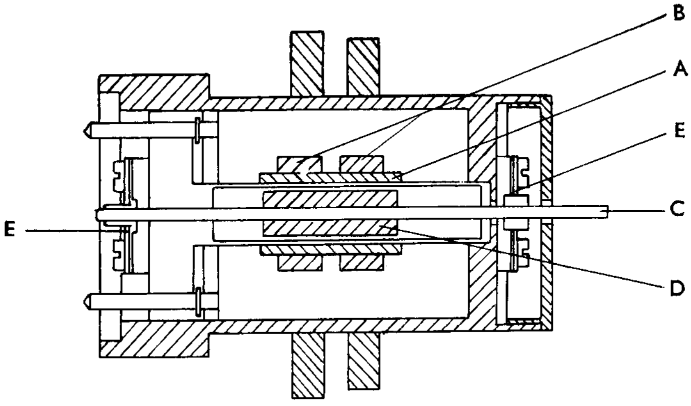

B
A
E
C
E
D

FIG. 2

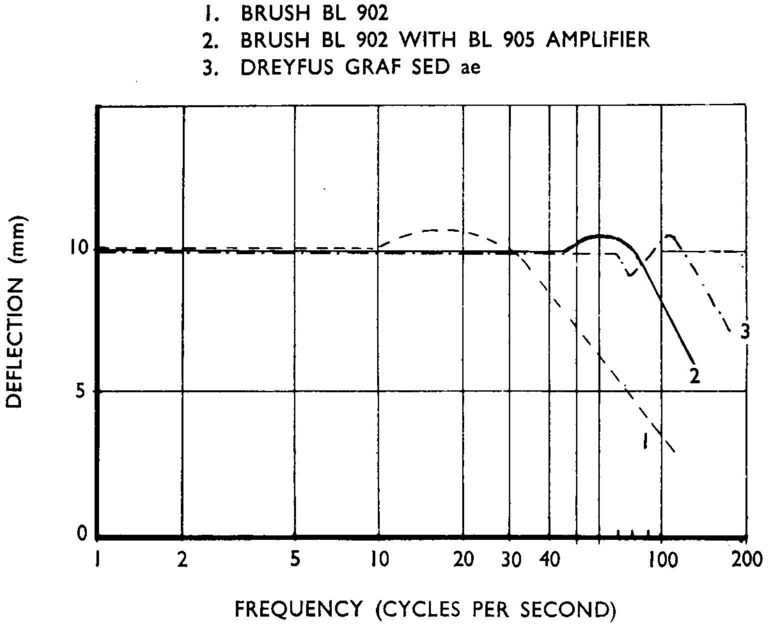

1. BRUSH BL 902
2. BRUSH BL 902 WITH BL 905 AMPLIFIER
3. DREYFUS GRAF SED ae
DEFLECTION (mm)
10
5
0
1
2
5
10
20
30
40
100
200
1
2
3
FREQUENCY (CYCLES PER SECOND)

FIG. 3

sensitivity and its small mass (approximately 1 gram). It consists essentially, (Fig. 2), of a primary coil A, which is fed with a 4000 cycles per second alternating voltage from the bridge unit PR 9300, and two secondary coils B. A thin metal pin C to which is fixed a Feroxcube core D passes through the coils and is held in position by light steel springs E. Variations in the position of the pin vary the coupling between the coils and consequently the induced voltage in the secondary coils. The secondary coils form part of a bridge network which is balanced with the pin held in its central position. Displacement from this central position unbalances the bridge and this voltage is amplified, demodulated and observed on the built-in microammeter.

The maximum displacement of the pin is $\pm$ 1 mm. from its centre position. On its most sensitive range, full scale deflection is obtained with a pin displacement of 3 microns, corresponding to 0·1 μ per division. A simple switching arrangement enables full scale deflection corresponding to displacements of 10μ, 30μ, 100μ, 0·3 mm. and 1·0 mm. to be obtained. The built-in meter can be used only when static or slowly varying deflections of the pin are to be measured; for our purpose in which variations up to 100 cycles per second were considered possible it could not be used. An external recorder was therefore required which possessed a sufficiently high response frequency.

For convenience and speed of operation a direct writing pen recorder was desired. Such a recorder must, however, have a linear response up to at least 100 cycles per second. Fig. 3 shows the response curves of two commercially available pen recorders (data published by the manufacturers). The performance of these and other recorders was discussed with various people who had had experience of these instruments and it was concluded that they would not be suitable. It was decided, therefore, to use a Siemens moving coil photographic recorder. The Siemens portable photographic recorder which was available in the laboratory is fitted with galvanometers of different sensitivities, all of which have a natural frequency of vibration in excess of 1000 cycles per second. Such a high natural frequency ensures that their response is linear up to the frequencies in which we are interested. The chart speeds are adjustable in steps between 7 cm. per second and 100 cm. per second. The maximum deflection of the galvanometer light beam is $\pm$ 35 mm.

The output of the bridge circuit is too low to drive the recorder directly, so an amplifier (Philips GM 4531) is incorporated. Fig. 4 (a) is a block schematic of the electronic apparatus, Fig. 4 (b) is a photograph of the actual equipment.

### 4.222 Mechanical

#### 4.2221 Requirements and possible solutions

The electronic apparatus is sufficiently sensitive to detect a displacement of the pin C (Fig. 2) of the order of 1 micron. The problem, therefore, was that of converting variations in yarn tension into movement of the pin.

The simple solution of fitting a roller or guide to the pin and passing the yarn at an angle over this was not possible. To balance the bridge circuit the pin must

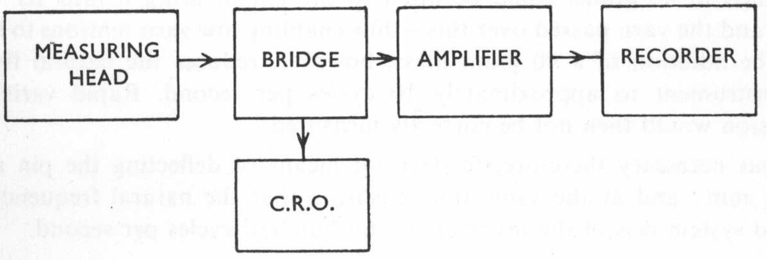



FIG. 4a

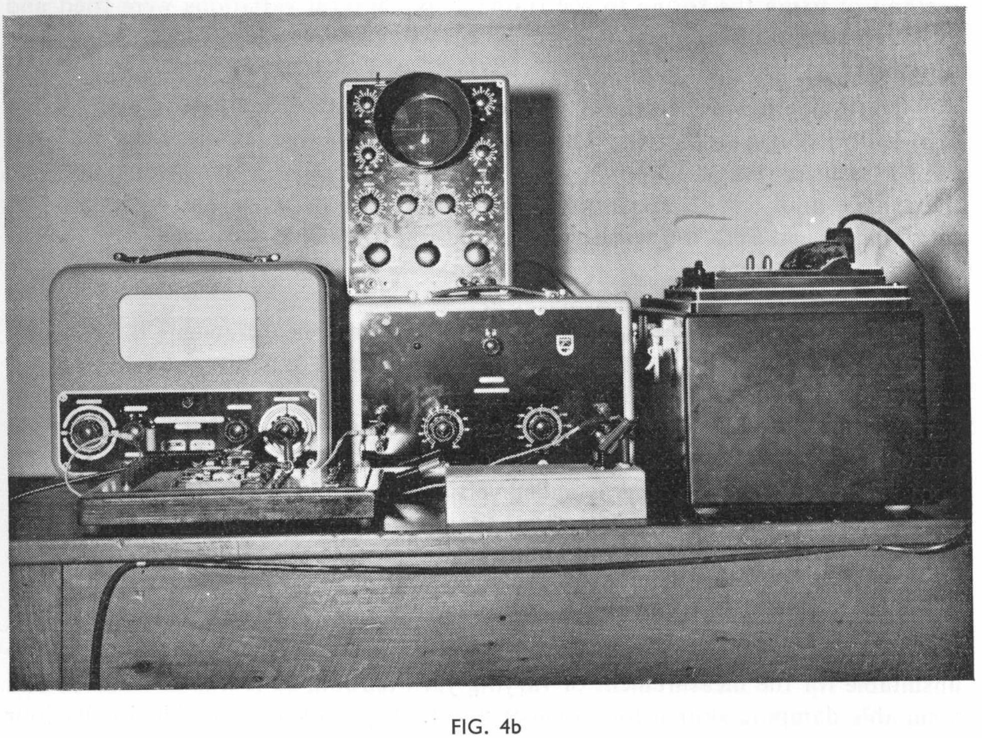


FIG. 4b

be depressed about 1 mm. from its rest position and this requires approximately 40 grams weight. Thus any yarn which did this would initially have a tension considerably in excess of 40 grams weight. It would, therefore, be impossible to measure low yarn tensions.

A mass of 40 grams could be fitted to the pin to bring it into its working position and the yarn passed over this—thus enabling low yarn tensions to be measured. The addition of a 40 gram mass, however, reduces the natural frequency of the instrument to approximately 10 cycles per second. Rapid variations in yarn tension would then not be correctly measured.

It was necessary therefore, to devise a means of deflecting the pin approximately 1 mm., and at the same time ensuring that the natural frequency of the combined system was of the order of several hundred cycles per second.

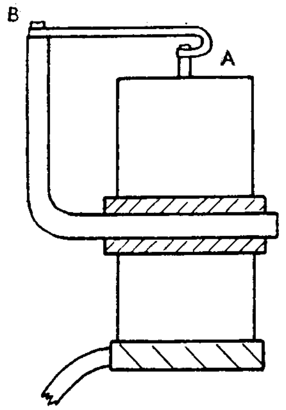
#### 4.2222 Final solution

To achieve this the arrangement in Fig. 5a was set up. The instrument was securely held in a metal bracket. A strip of spring steel (Fig. 5b) was fixed to the pin at A and clamped to the frame at B. The position of the instrument in the frame was adjusted so that the pin was depressed the required amount. In this form the instrument possessed high sensitivity and the required high natural frequency. It possessed, in addition, one disadvantage—the inability to return exactly to zero after being deflected. The extent of this non-return to zero depended upon the method of fixing the spring to the frame at B. Several variations were tried and although some improvement was produced, satisfactory return to zero could not be achieved.

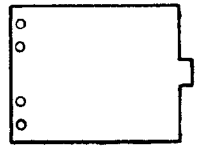
The difficulty was overcome by replacing the simple rectangular spring by one of the form shown in Fig. 6a. The shape of the frame was changed (Fig. 6b.) and the spring fixed to it at P and Q, while the pin of the pick-up was fixed securely to the tongue at A. With this arrangement the return to zero after deflection was satisfactory, and both the sensitivity and natural frequency were high.

#### 4.2223 Damping

Before the instrument could be used for dynamic measurements it had to be adequately damped. The efficiency of various damping systems which were tried, was tested by obtaining a load/extension curve of a 15 denier nylon monofilament yarn. The instrument was mounted in an inclined position so that a yarn passing over the spring hung vertically when under tension. One end of the yarn is fixed above the spring and the other is pulled vertically downwards until the yarn breaks. Fig. 7a shows the load/extension curve obtained in such a test when the instrument is undamped. The chart has been shortened for convenience of mounting so the increase in tension from zero cannot be seen, but the essential points are visible—the point at which the yarn breaks and the resultant vibration of the instrument about zero. This continued vibration about the zero makes the instrument totally unsuitable for the measurement of varying yarn tension, so it was essential to find a suitable damping system for the instrument. Fig. 7b shows the ideal behaviour

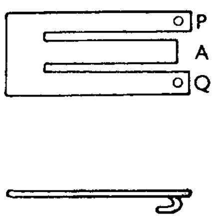



(a)

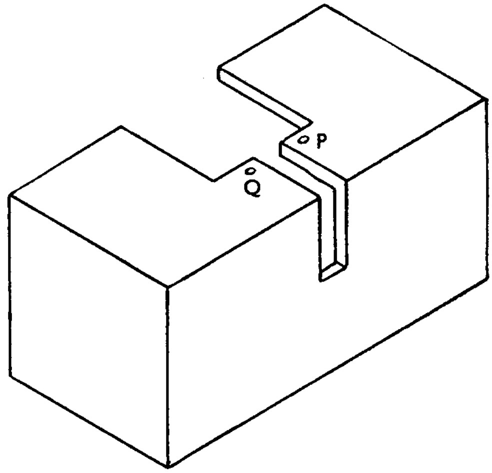


(b)

FIG. 5.




(a)




(b)

FIG. 6.

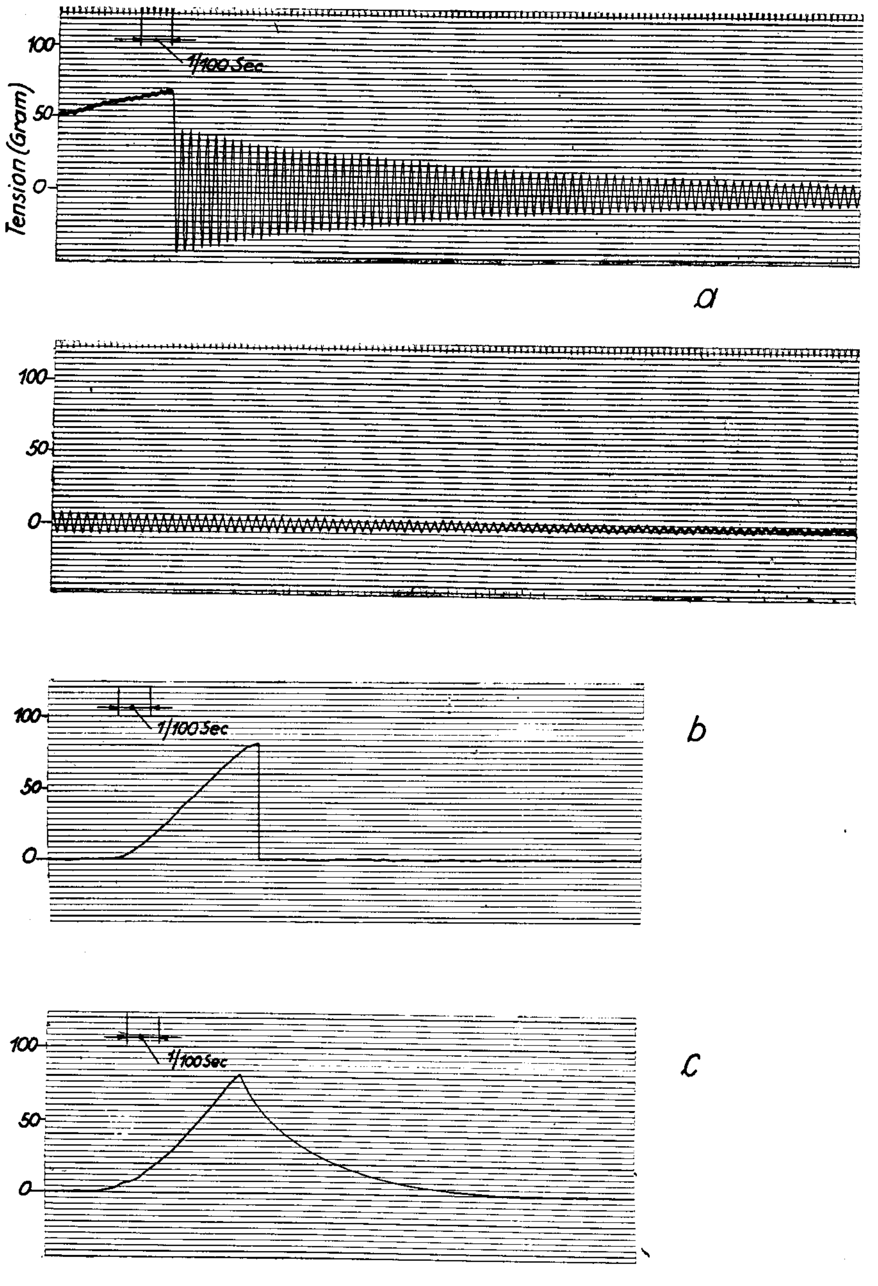

100
50
0
Tension (Gram)
1/100 Sec
a
100
50
0
100
50
0
1/100 Sec
b
100
50
0
1/100 Sec
c

FIG. 7.

which is desired—the instrument returns instantaneously to zero and does not vibrate afterwards. Fig. 7c shows the behaviour of an instrument which is too heavily damped and although all vibrations about the zero are eliminated, the time taken to return to zero limits the operating frequency of the instrument.

Initial experiments were carried out with sponge rubber to provide the necessary damping but these were not satisfactory. It was decided to employ oil damping and a small cylindrical aluminium piston was fixed to the under surface of the spring. This moved in an oil filled cylinder bored into an aluminium block, which was secured to the frame (Fig. 8).

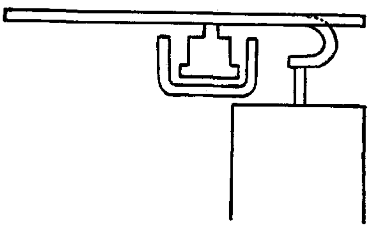


FIG. 8.

The suitability of a number of different oils which were readily available was examined, but none was satisfactory. To simplify the search for an oil of the correct viscosity, water/glycerine mixtures were used. The composition of the mixture could be quickly changed and was therefore a convenient means of providing liquids with a large range of viscosities. A mixture was found which provided the necessary damping, but a water/glycerine mixture has the disadvantage that its viscosity changes sharply with temperature so it is not suitable as a permanent damping fluid. However, knowing the viscosity of the mixture which produced the correct damping enabled a silicone oil to be chosen which was equally suitable and much less temperature sensitive.

Fig. 9a and 9b show the damping obtained when Silicone oils D.C. 200 50 Cst. and D.C. 200 10 Cst. are used. With the 50 Cst. oil the damping is slightly excessive and the instrument requires approximately 1/60th second to return to zero. With the 10 Cst. oil the instrument is slightly underdamped. Fig. 9c shows the damping produced by a 50/50 mixture by volume of these two oils. The return to zero occurs in approximately 1/250th second and there is no significant vibration about the zero.

Since the instrument is used in an inclined position there is a possibility that the damping oil may flow out, but under normal conditions surface tension forces are sufficient to prevent this. It is essential to ensure that the cylinder is completely filled with oil and that no air bubbles are allowed to form inside. Fig. 9d shows the behaviour of the instrument when incorrectly filled even though the correct oil is

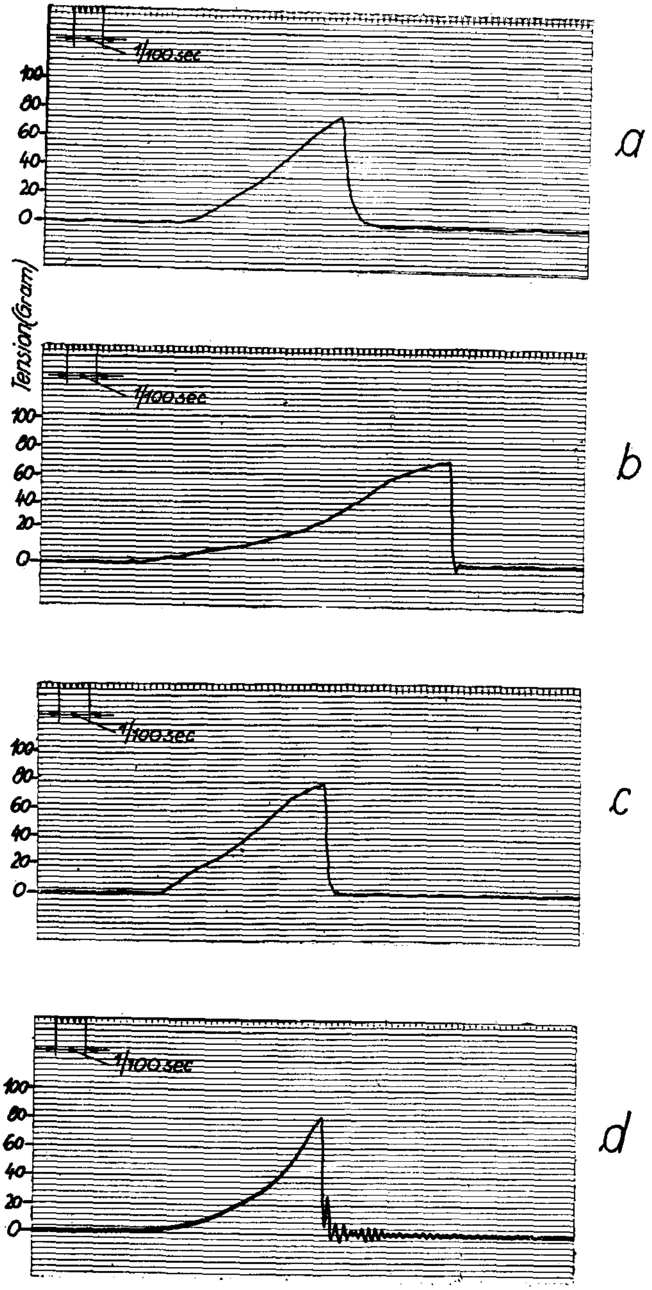



FIG. 9.

employed. With some care and a little practice however, the operation of filling the cylinder and fitting it to the frame can be quickly done. The instrument was checked to ensure that the results obtained on different occasions after refilling with oil were consistent. Yarn breaking load tests as well as repeat tension measurements on particular yarns confirmed that this was so.

### 4.23 Instrument performance

#### 4.231 Frequency response

From Fig. 7a, showing the vibration of the undamped instrument, the natural frequency of the instrument is seen to be approximately 370 cycles per second. The instrument can be used up to about one third of this value before any significant change in its linearity occurs. As a check on the response of the instrument small steel balls were allowed to fall on the spring. The rate at which they fell was not accurately controlled but the instrument always returned to zero provided the time interval between each impulse was about 1/100 second or greater.

#### 4.232 Yarn direction

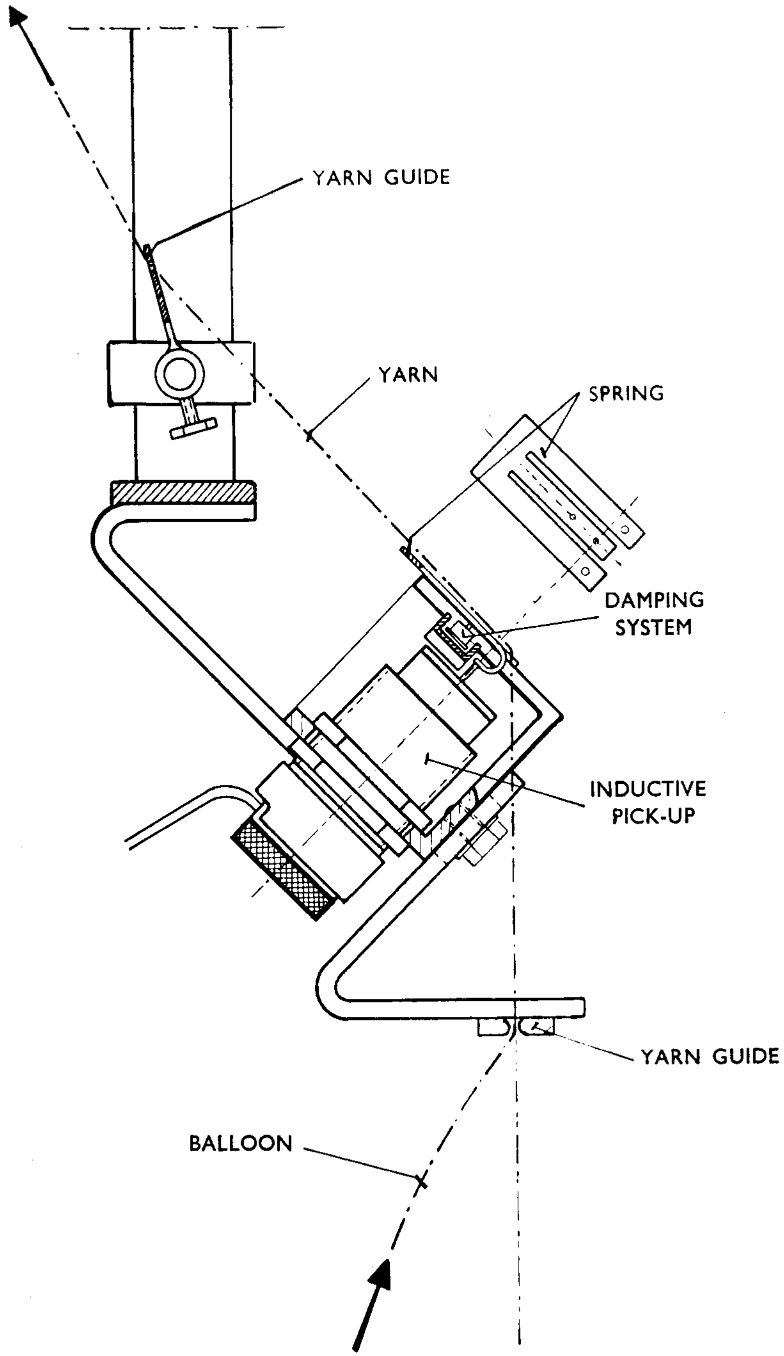
It is necessary to measure the tension in a vertical yarn so to avoid changing the direction of the yarn path and thus altering its tension, the instrument is mounted in an inclined position. With this intention the damping experiments were carried out with the instrument inclined. The instrument is fitted to a vertical steel rod at an angle of 45 degrees to the horizontal (Fig. 10 and 11). The yarn passes through 1 mm. diameter holes in small steel strips which are fixed above and below the spring. These are adjustable in position so the direction of the yarn over the spring can be carefully controlled.

The vertical yarn passes over the edge of the spring, along its surface and then to the wind up cylinder (Fig. 10). The only force causing the spring to deflect is that component of the yarn tension which is normal to the spring surface. Any change in the tension which is produced by the yarn passing over the spring has no effect on the deflection, since in this section of the yarn there is no component of tension normal to the spring. The instrument therefore actually measures the correct yarn tension and not some tension which exists only when the measuring head is in the yarn path.

#### 4.233 Calibration and sensitivity

The instrument is calibrated in its inclined position by hanging weights over the spring. The overall sensitivity can be varied in a number of ways—variation of the range setting of the bridge, adjustment of the D.C. amplifier and by selection of recording galvanometers of different sensitivities.

The galvanometers in the Siemens recorder have a maximum deflection of $\pm$ 35 mm. The output of the D.C. amplifier is set, so that the galvanometer is biassed to $-$ 30 mm. and the range from $-$ 30 to $+$ 30 mm. gives a total deflection of 60 mm. Table 1 shows the yarn tensions corresponding to a maximum deflection of 60 mm. on the various bridge settings when using a 2·5 T galvanometer (sensitivity 7·6 mm. deflection per mA) and an amplification of $\times 20$.



YARN GUIDE
YARN
SPRING
DAMPING
SYSTEM
INDUCTIVE
PICK-UP
YARN GUIDE
BALLOON


FIG. 10.

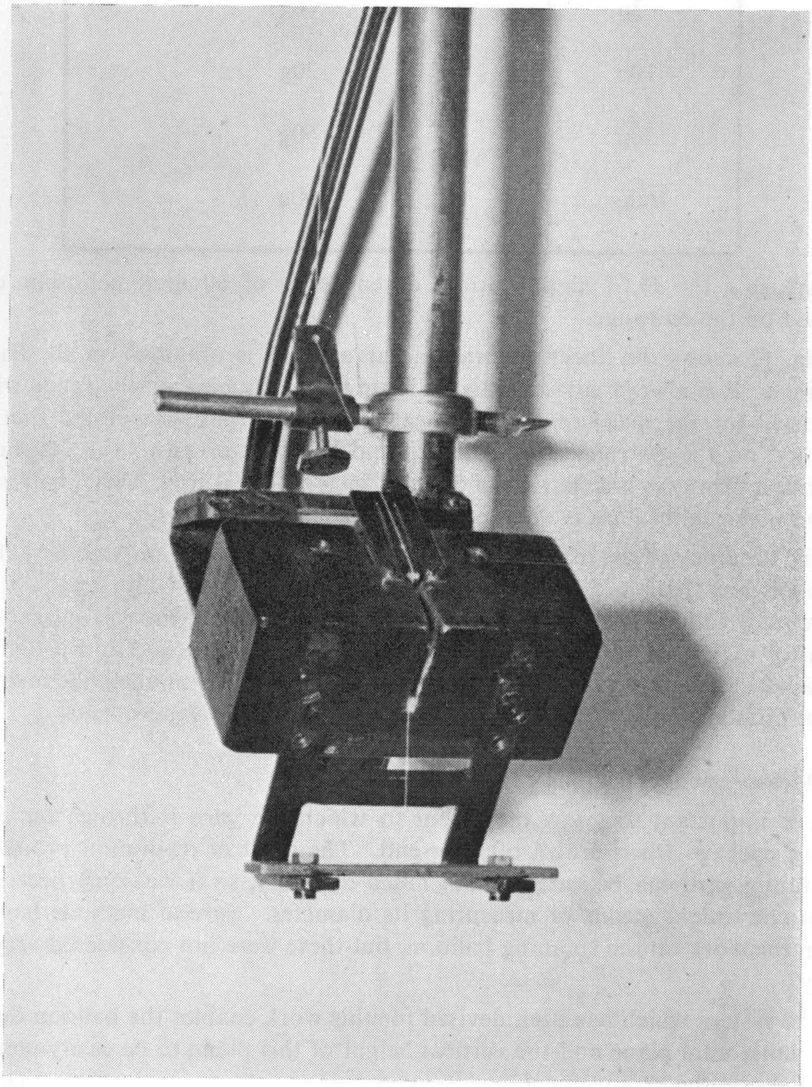


FIG. 11

TABLE 1

| Bridge Range | Maximum Tension=60 mm deflection |
|---|---|
| 3μ | 6g |
| 10μ | 20g |
| 30μ | 60g |
| 100μ | 200g |

By increasing the D.C. amplification, a sensitivity of 60 mm. per gram can be obtained on the 3μ range.

Fig. 12 shows the linear calibration curve which is obtained on all ranges of the bridge. It is always advisable to calibrate the instrument on the range which is to be used for the measurement of yarn tension. It has been noted that when calibrated on the 3μ range (6g=60mm.) and then switching to the 30μ range, a 60g tension produces a deflection of 59 mm. instead of 60 mm. This small error is avoided if the calibration is done on each range independently.

The accuracy of the instrument varies with the pin deflection, and is $\pm$ 1% for deflections less than $\pm$ 500μ. For deflections between $\pm$ 0·5 mm and $\pm$ 1·0 mm the accuracy falls to $\pm$ 5%. During our work the instrument was never used in this latter region. The stability of the calibration was checked and found to be very satisfactory. After the warming up period of about 30 minutes the instrument did not drift although this was always checked during the experiments.

### 4.3 Measurement of balloon characteristics

It is important to know the extent to which the yarn is thrown out from a rotating package when drawn off over-end. The solid of revolution produced by the rotating yarn can be seen without much difficulty, so it was only necessary to have a convenient means of measuring its diameter. Several methods have been used in the work on the spinning balloon, but these were not considered very satisfactory.

The system which has been devised for this work enables the balloon diameter at any horizontal plane and the vertical height of this plane to be easily measured. Fig. 13 shows the arrangement.

The rectangular aluminium framework ABCD slides easily along the vertical posts which are secured to a baseboard E. The framework is raised by hand and rests at any height by means of brass counter weights (not shown in Fig. 13) attached to the sides B and D. The sides B and D are solid aluminium strips, while the back and front, A and C, are both rigid aluminium frames. C carries a small aluminium frame F (similar to a slide rule cursor) to which cross wires are fitted. An endless

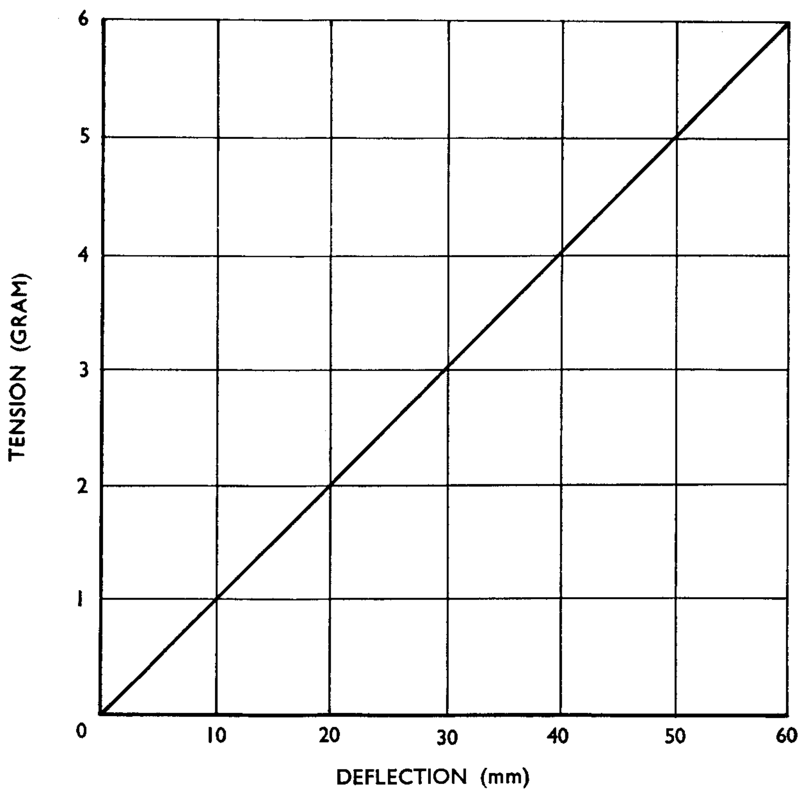



FIG. 12.

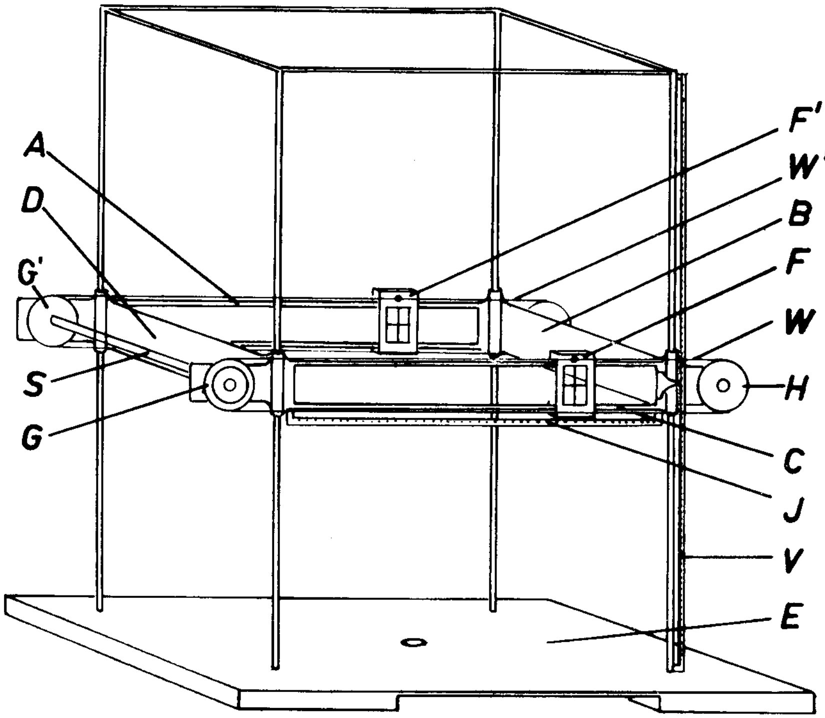



FIG. 13.

steel wire W passes around the pulley wheels G and H and is fixed to F. Rotation of the pulley wheel G causes F to move easily along C. This arrangement is repeated on the rear frame A, and the pulley wheels G, $G^1$ and H, $H^1$ are directly connected through the shafts S. The positions of F and $F^1$ on the wires W and $W^1$ are fixed so that the line joining the centres of the cross wires is horizontal and perpendicular to A and C. Rotation of G causes F and $F^1$ to move simultaneously along their guide frames A and C. A centimetre scale J is fitted to C so that the horizontal position of F can be read directly. The vertical position of the cross wires is indicated by a pointer attached to C moving along the vertical scale V. The balloon diameter is obtained by moving the frame ABCD vertically and the cross wires horizontally until they are in line with the ends of the required diameter. The whole arrangement is enclosed at both sides and the back with sheets of tinplate. These are painted matt black on the inside to facilitate the observation of the balloon.

General illumination of the apparatus although making the balloon visible is not satisfactory for measuring its diameter. A parallel beam of light illuminating only the extreme edges of the balloon so that the cross wires remain relatively dark is much more suitable. The lamp H fitted in front of the apparatus (Fig. 14) can be turned to illuminate both sides of the balloon and enables the ends of the diameter to be clearly seen and easily measured.

### 4.4 Complete apparatus

The complete arrangement assembled for measuring yarn tension and balloon characteristics is shown in Fig. 14 and 15. The package fits the spindle A which is belt driven from the tin drum B of a modified ring spinning frame C. A variable speed motor drives the tin drum and enables spindle speeds up to 10,000 r.p.m. to be obtained. The spindle is mounted on a heavy steel base D, fixed to the original spinning frame, which extends outwards so that when the yarn is drawn off the package, it does not come into contact with any part of the frame. The baseboard E carrying the apparatus for measuring balloon diameter is fixed so that the spindle projects through the hole in the centre of the board. With this arrangement the package and the moving yarn are protected from the effects of air currents set up by the rotating drum and the driving tape.

The wind-up cylinder seen in Fig. 15 is fixed to the top of the spinning frame. The support for the measuring head is secured to another table top which is quite separate from the spinning frame so that vibrations from the tin drum or the wind-up cylinder are not transmitted to the head. The measuring head is supported by bars of circular cross section which enable its position to be easily adjusted in three dimensions.

### 4.5 Yarn

#### 4.51 Types of Yarn

Although only continuous filament yarns are uptwisted and much of the experimental work reported here is similar to uptwisting, it was not intended to

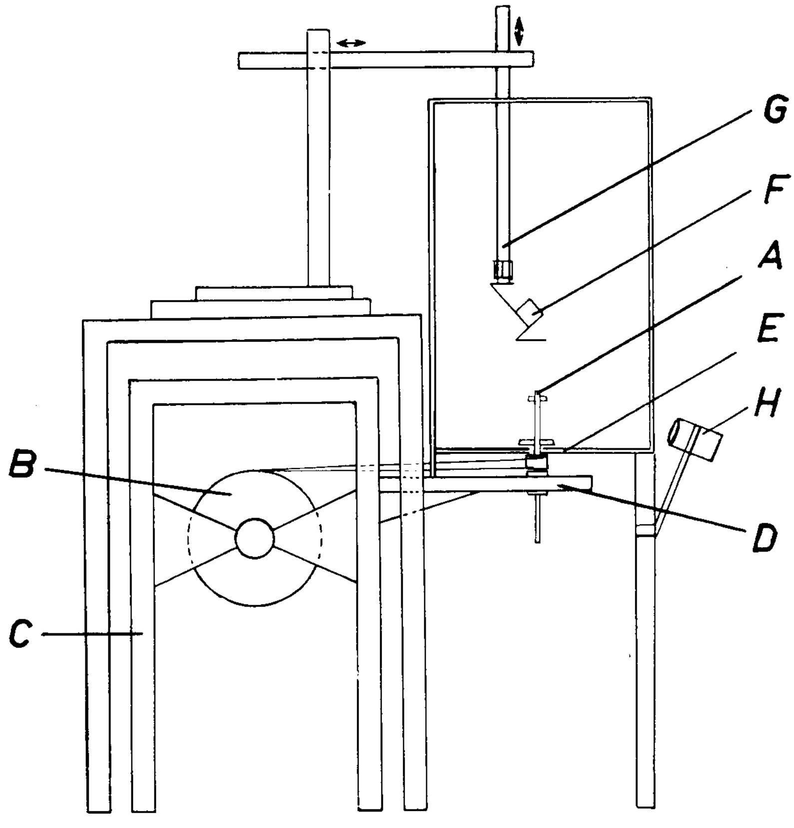



FIG. 14.

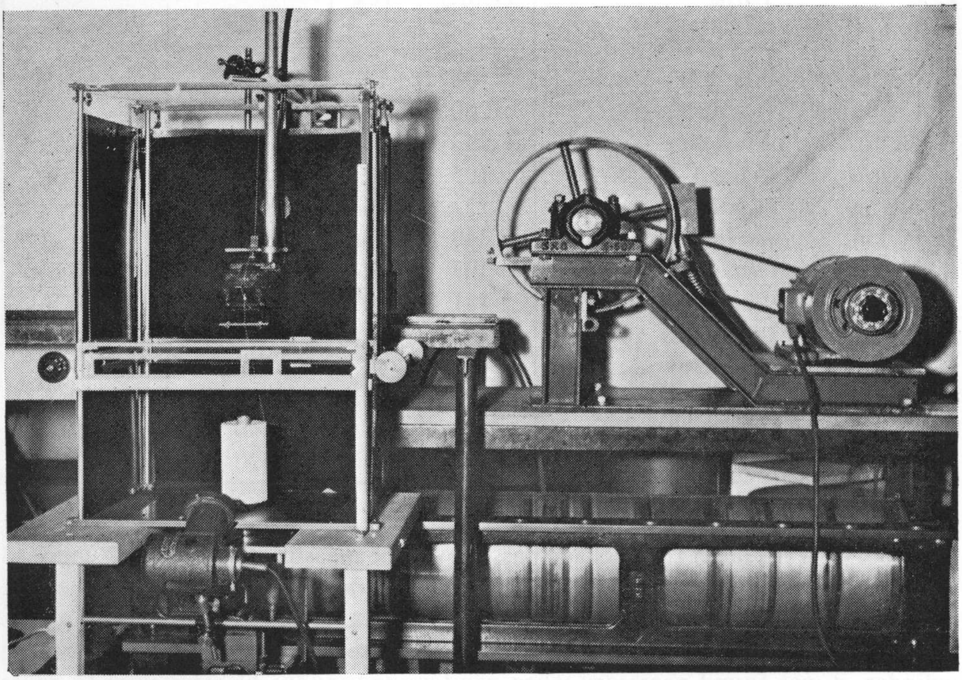


FIG. 15

confine the work to such yarns. Consequently, tests were carried out on staple as well as continuous filament yarns. We were limited by the yarns which were readily available commercially but we attempted to obtain yarns of comparable denier. Sometimes doubled yarns had to be used. Table 2 gives the measured values of denier and twist in the yarns used as measured under normal testing conditions of 65% RH and 20°C. The equivalent Tex unit (grams weight per kilometre of yarn) is also given.

**TABLE 2**

**Data on yarn used in experiments**

| Yarns | Denier | Tex | Twist (turns per metre) | |
|---|---|---|---|---|
| | | | Single | Double |
| Cotton $N_e$ 50 (staple) .. .. | 108 | 12 | 630 Z | |
| Cotton $N_e$ 20 (staple) .. .. | 260 | 29 | 570 Z | |
| Cotton $N_e$ 12 (staple) .. .. | 453 | 50 | 330 Z | |
| Nylon 100/34 (c.f.) .. .. | 105 | 12 | 180 Z | |
| Nylon 210/34 (c.f.) .. .. | 222 | 25 | 90 Z | |
| Nylon 340/100 (c.f.) .. .. | 340 | 38 | 240 S | |
| Nylon $N_m$ 170/2 (staple) .. | 107 | 12 | 850 Z | 850 S |
| Nylon $N_m$ 100/2 (staple) .. | 181 | 20 | 740 Z | 640 S |
| Nylon $N_m$ 36 (staple) .. .. | 241 | 27 | 400 Z | |
| Nylon $N_e$ 12 (staple) .. .. | 435 | 48 | 380 Z | |
| Viscose $N_m$ 160/2 (staple) .. | 114 | 13 | 900 Z | 900 S |
| Viscose $N_m$ 100/2 (staple) .. | 188 | 21 | 740 Z | 660 S |
| Viscose $N_m$ 30 (staple) .. .. | 297 | 33 | 530 Z | |

### 4.52 Yarn wind-up

The yarn taken off the package passes over the measuring head and is wrapped several times around a steel cylinder before being drawn off into a vacuum cleaner. The cylinder seen in Fig. 15 is belt driven from a variable speed motor and is mounted on top of the frame C (Fig. 14). To prevent the yarn slipping on the cylinder, it was found necessary when winding continuous filament yarn to cover the surface of the cylinder with a very fine emery paper. This was not only unnecessary with the staple yarns but also undesirable, as it tended to prevent the yarn being drawn off into the vacuum cleaner. Since the yarn does not build up on the cylinder the yarn speed is equal to the surface speed of the cylinder. Two cylinders of different circumferences (20 cm. and 100 cm.) are interchangeable and these in conjunction with an alternative pulley ratio for the driving belt enable speeds between 10 and 1,000 metres per minute to be obtained.

### 4.53 Measurement of yarn speed

The yarn speed can be obtained by measuring the rotational speed of the wind-up cylinder with a tachometer. This was often used to set the yarn speed approximately but in practice the yarn speed was always measured by passing the

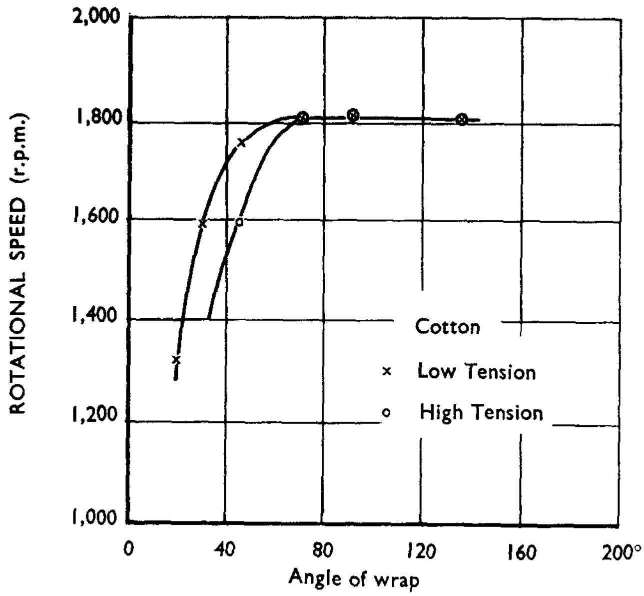



FIG. 16. (a)

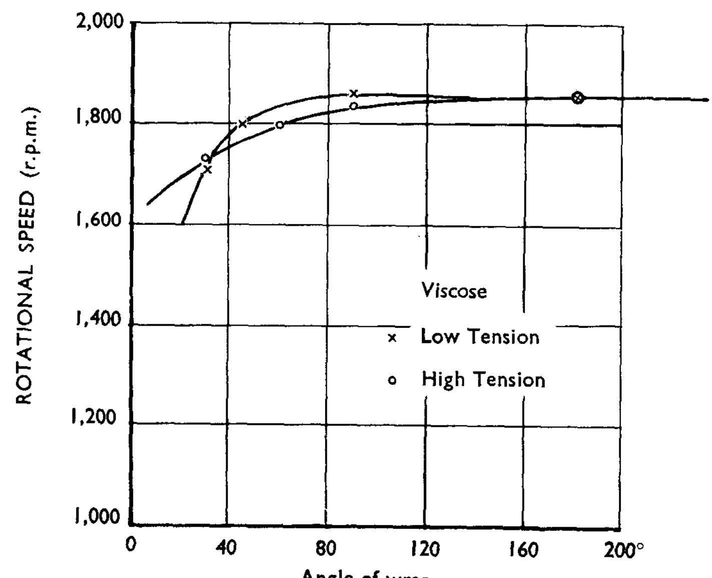



FIG. 16. (b)

yarn around a small light, freely running pulley wheel with a circumference of 10 cm. The rotational speed of this wheel is measured with a stroboscope and thus the yarn speed obtained as the product of the circumference and the rotational speed. It is important that there should be no slipping of the yarn around this wheel, so for a given yarn speed the rotational speed of the wheel as measured with the stroboscope was noted for various angles of wrap of the yarn around the wheel. Fig. 16 shows the results obtained for a staple yarn (cotton) running with low (2 grams) and high (20 grams) tensions, and a continuous filament yarn (viscose) running at tensions of 2 grams and 14 grams. As the angle of wrap of the yarn around the pulley wheel increases the rotational speed increases and quickly reaches a constant value. This is different for the two yarns as the yarn speeds employed were not equal. As can be seen from the figure, an angle of wrap of 90° for cotton and 180° for viscose ensures that the yarn does not slip around the pulley wheel. In actual use an angle of approximately 300° is used.

### 4.6 Types of package

To make any valid comparison of the effect of yarn type or denier it was essential that the yarns be wound off from the same type of package. The yarns as delivered were on a variety of different packages so it was necessary to rewind them. A small laboratory winding machine by Schärer allowed either cross wound tubes or cones to be wound and it was initially decided to use both types of package (Fig. 17). Suitable spindles were modified by fixing Tufnol discs to them so that they would carry either a cylindrical tube or a cone. During the

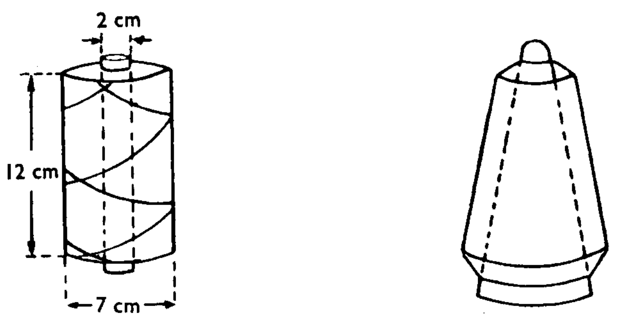



FIG. 17.

early experiments with continuous filament yarn on cones considerable trouble was experienced through loose windings (see section 5.211) and it was virtually impossible to rotate the package at high speeds without the yarn breaking down. Some trouble was also experienced with loose windings on cross wound tubes, but it was not as serious as with cones. It was decided, therefore, to confine measurements to yarn on cross wound tubes. Steel tubes of length 13·8 cm. and 2 cm. external diameter were used, the traverse length being 12 cm. and winding angle 75° to the axis of the tube.

After the intitial experiments were carried out to investigate the effect of package diameter it was decided to use packages of 7 cm. diameter. A number of good, well formed packages were wound up to a diameter of 6·5 cm. and the various yarns to be tested were wound on top of these to bring the diameter up to the required 7 cm. This system was much easier than winding the yarn directly on to the 2 cm diameter tube and saved much yarn and time. Care was taken to ensure that measurements were carried out on 'normal' packages—packages which were either very hard or very soft were not used. Such packages were rarely produced however as they were wound at a constant yarn speed and therefore yarn tension was fairly constant throughout the build of the package.

### 4.7 Markers

Observation of the yarn being wound up showed that the balloon shape varied considerably. It was desirable to relate the various shapes of the balloon with the corresponding changes in tension which were recorded. The Siemens photographic recorder is a four channel instrument, so one of the unused channels was employed as a manually operated marker circuit. One of the galvanometers was put in series with a switch and a dry battery. Whenever a particular balloon shape was observed and it was desired to know the yarn tension corresponding to this, the switch was made and a small black mark near the bottom of the recording paper obtained. Allowing for the operator's time lag it was fairly easy to find the yarn tension corresponding to any particular balloon shape. The arrangement was not suitable for high yarn speeds, however, but for any periodic variations which did not occur too rapidly this simple arrangement worked well.

### 4.8 Test procedure

It is important that the electrical apparatus is switched on and allowed to warm up at least half an hour before measurements begin. The relative humidity of the laboratory atmosphere is measured using a wet and dry bulb instrument and the package diameter and the periodic length of the yarn around the package are measured. The package is fitted to the spindle and the position of the measuring head adjusted to the required height $H$. Use of a plumb line ensures that the spring of the measuring head is correctly positioned above the package. The light source and chart speed of the Siemens recorder are set depending upon the yarn speed to be used. It is essential to check the damping of the measuring head. This is done with a breaking load test as described in section 4.2223. The instrument is carefully calibrated on the lowest range of the bridge and the tests carried out. If the tension during any one test exceeds the maximum tension of the range in use so that the next higher range has to be used, the yarn is momentarily removed from the measuring head and the zero tension on both the old and new ranges recorded. This enables a check to be made on any zero shift which may occur. At the end of a run any new range which has been used is calibrated and the zero checked.

## 5. RESULTS

### 5.1 General

Most of the results are presented graphically. The yarn used is identified by its nominal count or denier but the actual measured denier is used in drawing graphs or making calculations. Staple yarns are identified by their counts $N_e$ or $N_m$, depending on whether they are English or metric, and continuous filament yarns by the usual denier system, *e.g.* 100/34 refers to a 100 denier yarn of 34 filaments. All the results are the means of at least two and often more tests on similar packages. During all tests the instrument was calibrated at the beginning and end of a run and the zero checked whenever the range was altered.

The results apply to yarn on cross wound packages as specified in section 4.6. $H$ is the height of the guide eye above the package and was chosen to be 6, 10 or 15 cm. $B$ is the distance between the guide eye and the bottom of the package and with a constant package length of 12 cm., $B=18$, 22 or 27 cm. $H$ is the balloon height when the yarn comes off the top, and $B$ the balloon height when it comes off the bottom of the package. The "diameter=7 cm." in the legend attached to the curves refers to the mean package diameter.

The tension is measured in that part of the yarn vertically above the guide eye which fixes the value of $H$. The maximum tension may correspond to one of a number of different balloon forms depending upon the type of yarn, the rotational speed, and $H$, but was always obtained when the yarn was taken off near the bottom of the package, Generally maximum tension corresponded to a single balloon form but sometimes a single balloon did not exist.

With a rotating package and a yarn speed of 50 m/min. the rise and fall of the balloon along the package is easily seen. The balloon diameter measured was that existing when the yarn came off the bottom of the package. It was thus fairly easy to ensure that the balloon diameter was measured at the same point of yarn take-off on all occasions. The edge of the balloon usually varied by 1 or 2 mm, but several traverses of the balloon up and down the package were observed and a mean value obtained. The well formed balloon occurring with rotating packages is not observed with still packages so only approximate values of the diameter were obtained.

### 5.2 Rotating packages

#### 5.21 Observational results

Under normal conditions using a low yarn speed and a rotating package, a balloon is seen which rises and falls regularly along the package as the yarn take-off point varies. Occasionally this normal state of affairs is upset and variations in balloon shape and yarn tension are obtained. Some of the causes of this unusual behaviour will be considered.

##### 5.211 Loose windings

The initial experiments were carried out with yarn wound on cones (3° 30′ half angle) but it was found that with continuous filament yarn the rotational speed of the package was severely restricted by the formation of ' loose windings.' These are formed from the next three or four windings of yarn to be wound off the package, and rotate in a horizontal plane at approximately the centre of the package.

It was observed that if the loose windings form below the point at which the yarn is being taken off, the yarn continues to wind up for some time. Generally however, and certainly if the rotational speed of the package is increased, the number of loose windings increases. These are pulled to the top of the package by the yarn being wound up, and this excess of yarn is unable to pass through the guide eye above the package causing the yarn to break. If the rotational speed is low and only a few loose windings exist, wind up of the yarn may continue and the balloon height is then fairly constant, as the yarn comes off from approximately the centre of the package. This produces a fairly constant take-off tension, since the tension maxima and minima, occurring when yarn comes off the bottom and top of the package, are not obtained.

Loose windings occurred only with continuous filament yarn and the rotational speed at which they occurred varied considerably from one package to another. Emmenbrücke cones on which some of the nylon was received, could be run at higher speeds than cones of the same yarn which were wound in the laboratory. Variations between the laboratory wound cones showed that the formation of loose windings is very dependent upon the winding conditions of the packages.

It was found that by using cross wound parallel sided packages the effect of loose windings was considerably reduced but not eliminated. Sometimes loose windings were observed with nylon wound on these packages rotating between 5,000 and 10,000 r.p.m., but rarely did the yarn break down.

### 5.212 ' Vibrating ' balloon

Observation of the balloon formed with continuous filament nylon showed that occasionally it ' shuddered ' or ' vibrated.' This occured only when a double balloon existed and by using a stroboscope it was seen that vibration of the balloon occurred when the yarn touched the top edge of the package or the top of the cone former. The effect was of short duration and no significant change in yarn tension was detected. Balloon vibration, just as ' loose windings ', occurred less frequently with cross wound tubes than with cones.

### 5.213 ' Plucking ' balloon

This is an effect which was rarely observed and then only with a coarse cotton yarn. Instead of the gradual rise and fall of the balloon as the take-off point of the yarn moves along the package, the balloon appeared to shrink and then suddenly increase to its normal size. Careful observation with a stroboscope showed that instead of the yarn coming away smoothly and easily from the package, it tended to cling to it and then appeared to be suddenly plucked away so that variations in balloon shape and diameter were quite large. This effect produced significant variations in yarn tension—the tension increasing considerably as the yarn clung to the package. The effect depends upon the surface characteristics of the yarn, being confined almost exclusively to rough surfaced yarns with many projecting fibres. The winding of the package may also influence the ease with which the yarn leaves the package and hence the possibility of a 'plucking' balloon occurring.

### 5.22 Typical tension charts

Fig. 18 reproduces on a reduced scale typical tension charts as obtained with the Siemens photographic recorder. It shows how the tension varies along the yarn length for a cotton yarn ($N_e$ 50) drawn off a 7 cm. diameter package at 50 m/min. at spindle speeds between 0 and 10,000 r.p.m. The first chart at 0 r.p.m. shows very marked periodic variations in tension. The period corresponds to the yarn length in a complete traverse cycle of the package winding machine (approximately 100 cm.). The minima at 0·1—0·2 gram occur as the yarn comes off the top of the package. As the point at which the yarn leaves the package moves downwards so the yarn tension increases, but there is no smooth gradual increase in the tension. The large variations in tension are due to the staple yarn being drawn over the relatively rough package surface.

It is therefore difficult to specify a maximum tension, but for the comparison of different yarns under different conditions a mean value is obtained for each peak, and the mean of these taken as the maximum tension.

The second chart at 1,000 r.p.m. does not show the large variations in tension which occur at 0 r.p.m. as the yarn is not now in contact with the package. The tension is low and it is difficult to detect any periodic variation although the black markers indicate when the yarn comes off the top of the package. From 2,500-10,000 r.p.m. the long period variations again become very distinct. The amplitude of the short period tension variations is much smaller when the package rotates than when it is stationary. At both 5,000 and 7,500 r.p.m. successive maxima are of much the same value but such uniformity is not always obtained. At 10,000 r.p.m. for example we find that the maximum tension at one peak is approximately 9·5 grams and at another 12·5 grams. It has been found that variations up to $\pm$ 20% of the mean value may occur in the individual maxima on any one chart. In all our results the mean of as many peaks as are on the trace (usually at least five or six) is taken.

Up to 5,000 r.p.m. there is a fairly regular sinusoidal variation in the tension as a single balloon rises and falls along the package. On all charts up to 5,000 r.p.m. the black marks indicate that the yarn leaves the top of the package. In most cases they are clearly seen to correspond to tension minima. At 0 r.p.m. however the marks appear to correspond to tension maxima, but this is due to the observer's slow reaction and the greater difficulty of observing when the yarn actually leaves the top of a stationary package. Repeated results confirmed that the minimum tension corresponded to the yarn leaving the top of the package. At 7,500 r.p.m. the sinusoidal variation in tension is twice disturbed and at 10,000 r.p.m. four times disturbed by a sudden drop in tension. The tension remains at this lower level for a time and then increases to its maximum again. The black marks on the charts for 7,500 and 10,000 r.p.m. correspond to the appearance of a double balloon. For most of the time a normal single balloon exists but occasionally as the take-off point of the yarn approaches the top of the package a double balloon forms with a correspondingly lower tension. When only a single balloon exists and a tension diagram similar to that at 5,000 r.p.m. is obtained it is fairly easy to obtain mean values of the maximum and minimum tensions. When a double balloon exists and the tension variations as at 7,500 and 10,000 r.p.m. occur, the minimum tension does not have the same significance as at 5,000 r.p.m. We have on all such traces measured two minima. One Min $T_A$, is the least tension at which a single balloon exists before a double balloon forms (the points A at 7,500 r.p.m. Fig. 18), and the second, Min $T_B$ is the mean tension corresponding to a double balloon (the points B at 7,500 r.p.m. Fig. 18). Occasionally, as can be seen at 1,000 and 2,500 r.p.m. the tension suddenly increases and then falls back to its normal tension. In examining the various charts these maxima which seemed to occur randomly were referred to as 'instantaneous maxima' and were not used in obtaining the mean values of the maximum tension corresponding to the yarn coming off the bottom of the package.

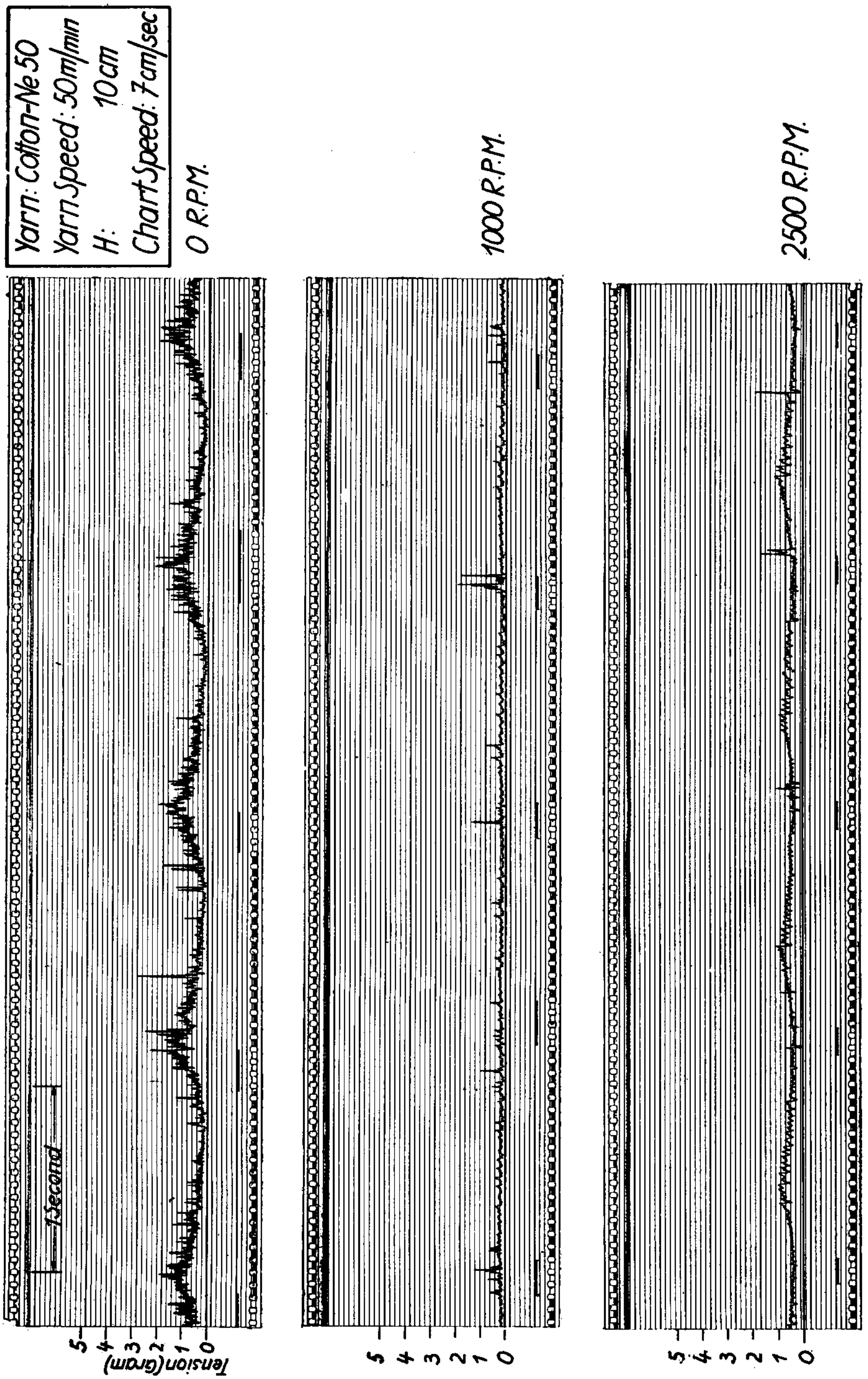
Fig. 19 is the tension chart obtained with nylon staple $N_m$ 170/2 (107 denier) using a yarn speed of 50 m/min. with $H=15$ cm. The tension variations are similar to those in Fig. 18 although a number of differences are apparent. At 0 r.p.m. the variation in tension is less in Fig. 19 than in Fig. 18 and is due to the difference in height $H$, ($H=10$ cm. in Fig. 18 and 15 cm. in Fig. 19). In Fig. 19 double balloons with their lower tension occur at a lower rotational speed (2,500 r.p.m.) than in Fig. 18. This is also due to the larger $H$ value.

Fig. 20 refers to the same yarn as Fig. 19 but $H$ is reduced to 6 cm. A comparison of Fig. 19 and 20 shows even more clearly than Fig. 18 and 19 the influence of $H$ on the tension at 0 r.p.m.—the maximum tension being very much lower at $H=15$ cm. that at $H=6$ cm.

Fig. 19 shows at all rotational speeds a very regular periodic variation in tension. Sometimes this does not occur as can be seen from Fig. 20. At 7,500 and 10,000 r.p.m. in Fig. 20 the periodicity is not as regular as in Fig. 19. This may be due to some irregularity in the winding of the package or to variation in the yarn speed. Fig. 20 shows another difference at the higher speeds of rotation from Fig. 18 and 19. Instead of the low tension corresponding to a double balloon which occurs at $H=10$ cm. and $H=15$ cm., we see only 'instantaneous' minima when $H=6$ cm.

Fig. 21 shows the tension charts obtained with continuous filament nylon 100/34 (105 denier) with $H=6$ cm. These charts are very different from those of the staple nylon $N_m$ 170/2 (107 denier) in Fig. 20. At 0 r.p.m. the yarn comes off the package smoothly and at a very low tension showing a marked difference between continuous filament and staple yarns. Slight periodic variation is apparent at 1,000 and 2,500 r.p.m. and at the left hand side of the 5,000 r.p.m. chart. From then on and at 7,500 and 10,000 r.p.m. there is very little variation in tension and instead of the usual period we find a much shorter one. This corresponds not to a complete traverse cycle of the winding machine but to the circumference of the

[continued on page 42]


Yarn: Cotton-Ne 50
Yarn Speed: 50m/min
H: 10cm
Chart Speed: 7cm/sec
0 R.P.M.
1000 R.P.M.
2500 R.P.M.
1 Second
Tension (Gram)
5 4 3 2 1 0

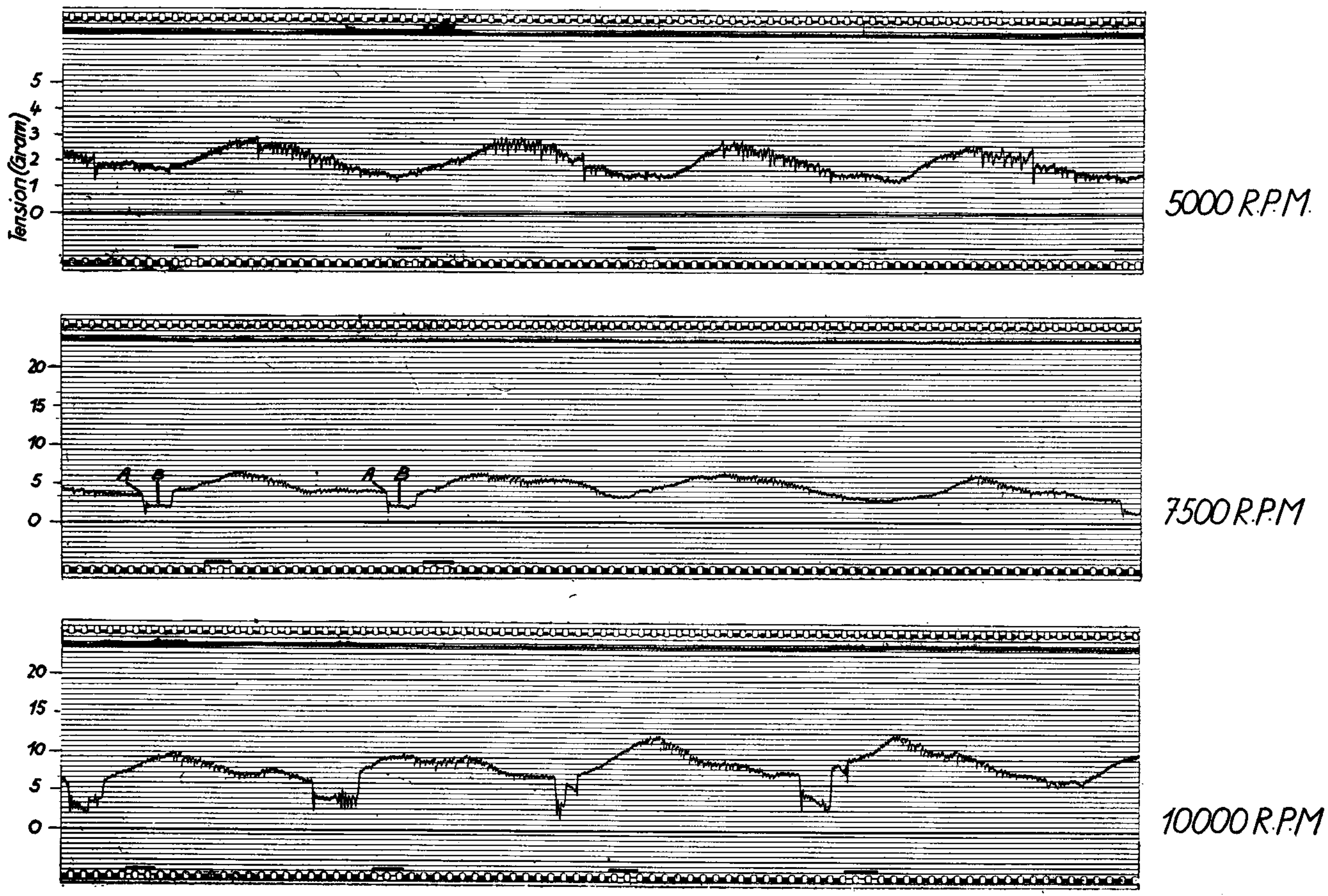
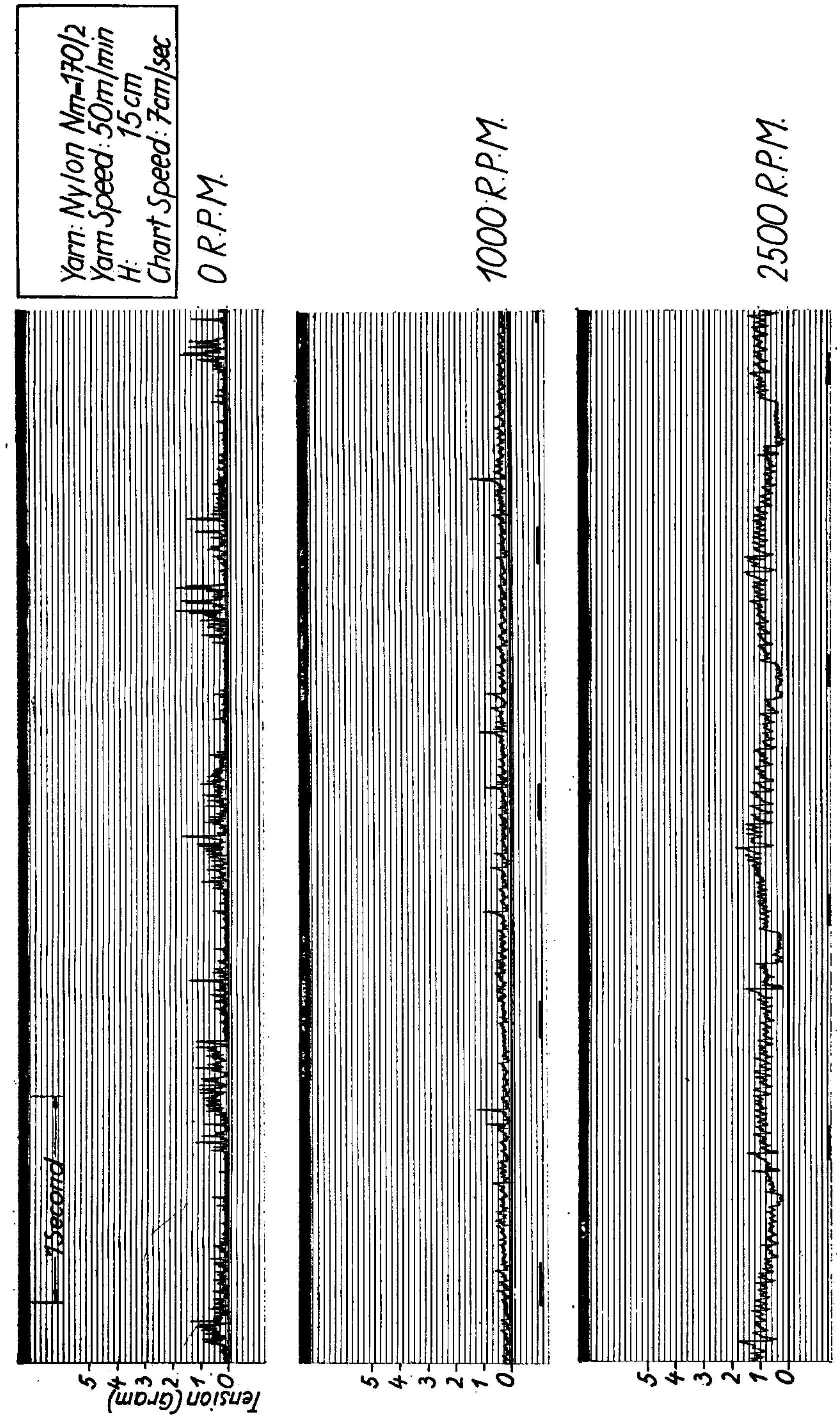

Tension (Gram)
5
4
3
2
1
0
5000 R.P.M.
20
15
10
5
0
A
B
A
B
7500 R.P.M
20
15
10
5
0
10000 R.P.M

FIG. 18.


Yarn: Nylon Nm-170/2
Yarn Speed: 50m/min
H: 15cm
Chart Speed: 7cm/sec
0 R.P.M.
1000 R.P.M.
2500 R.P.M.
1 Second
Tension (Gram)
5 4 3 2 1 0

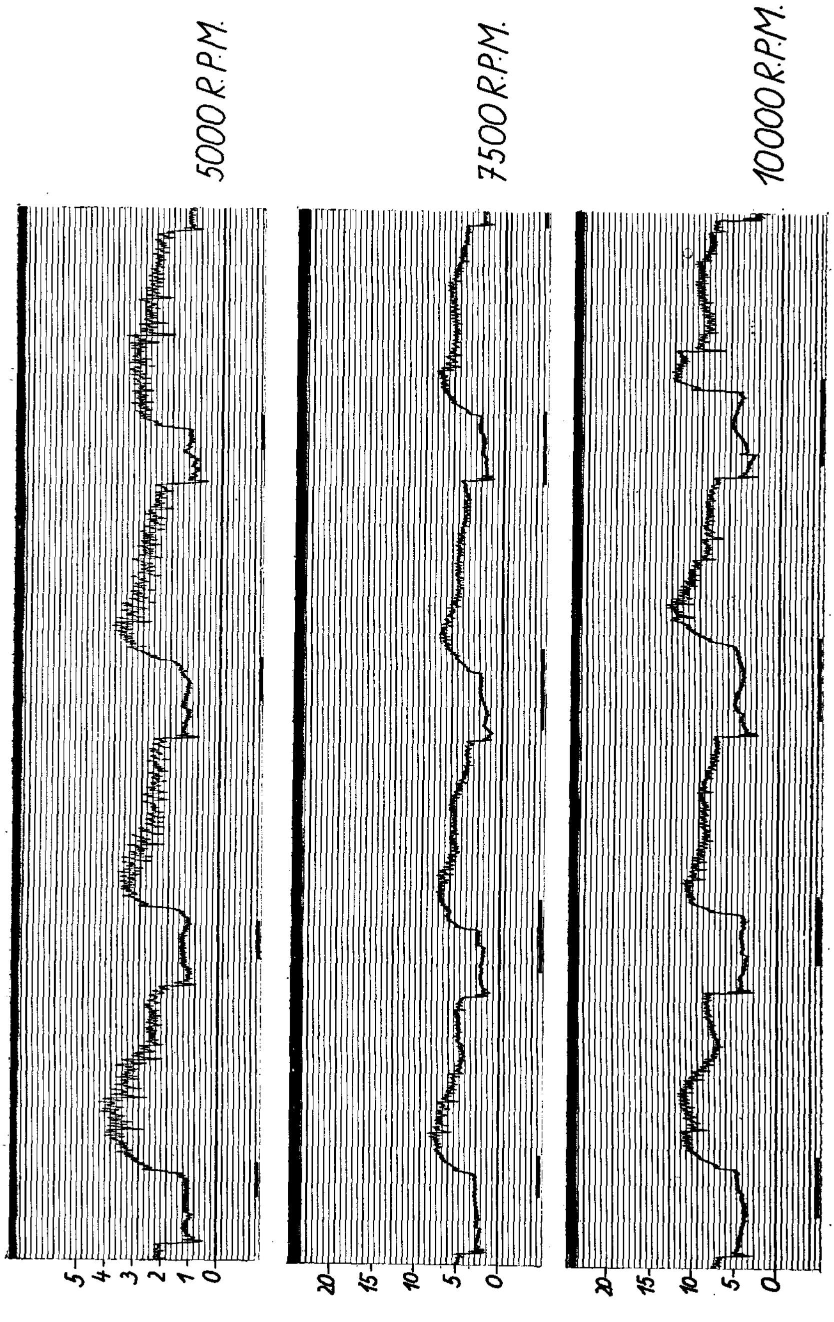
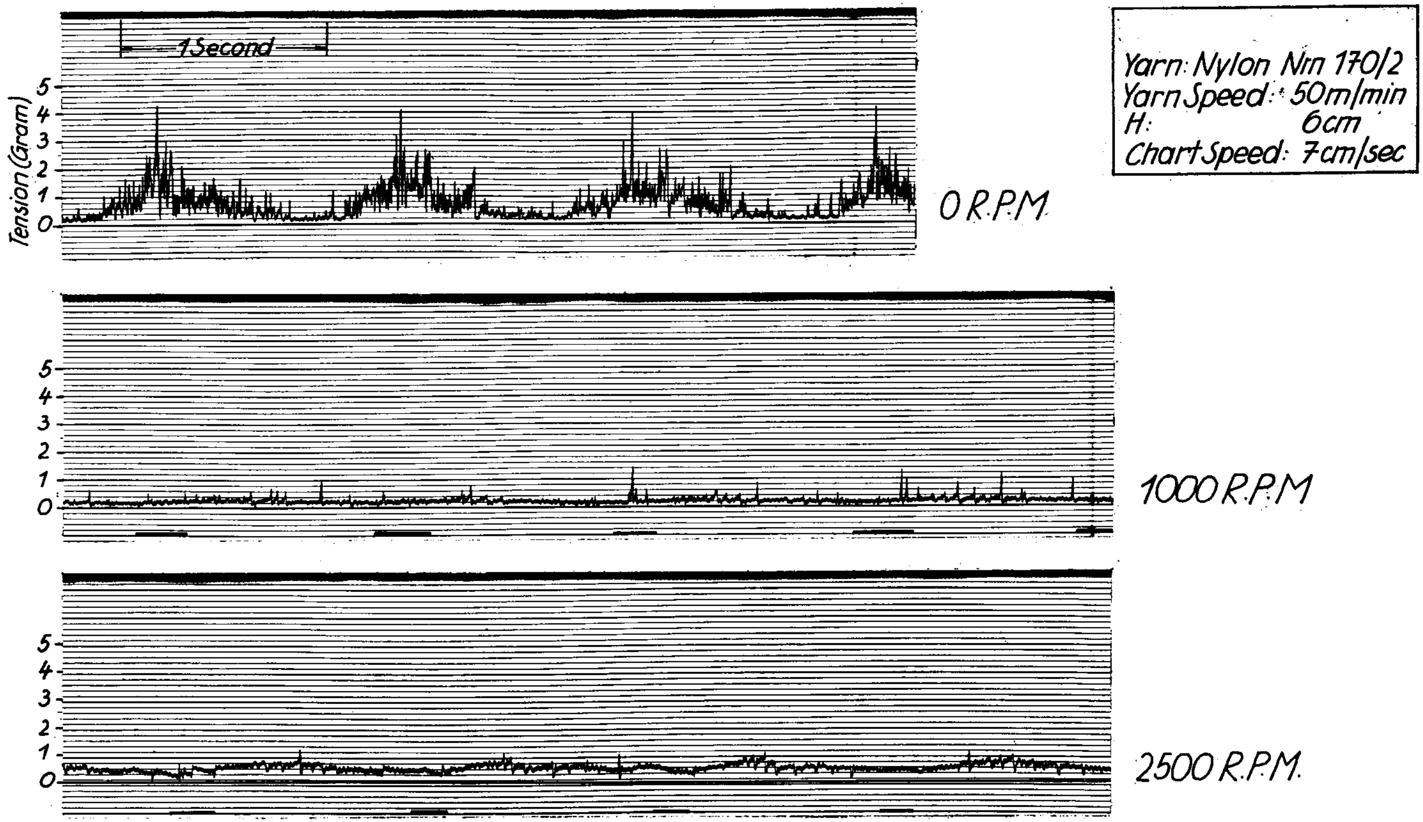



FIG. 19.


Yarn: Nylon Nm 170/2
Yarn Speed: 50m/min
H: 6cm
Chart Speed: 7cm/sec
1 Second
Tension (Gram)
5
4
3
2
1
0
0 R.P.M
1000 R.P.M
2500 R.P.M.

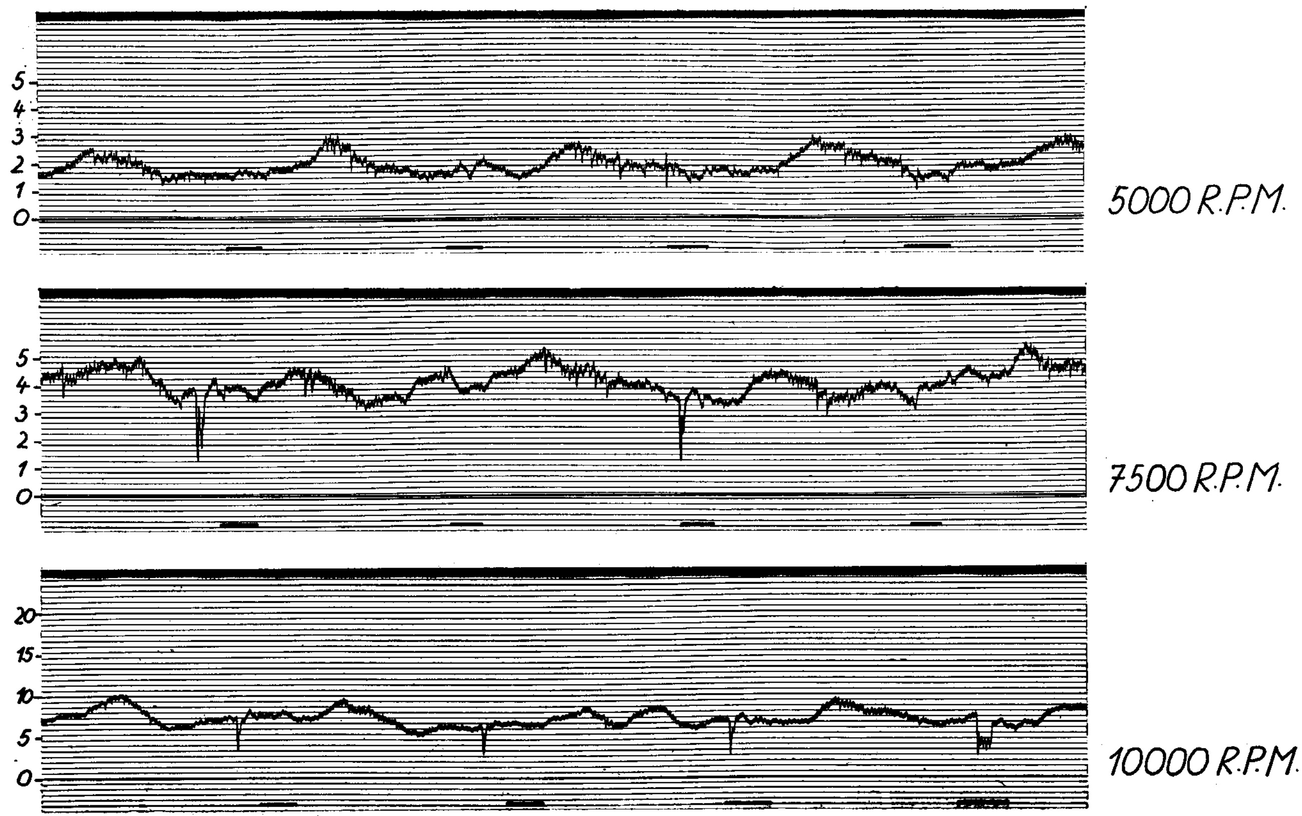
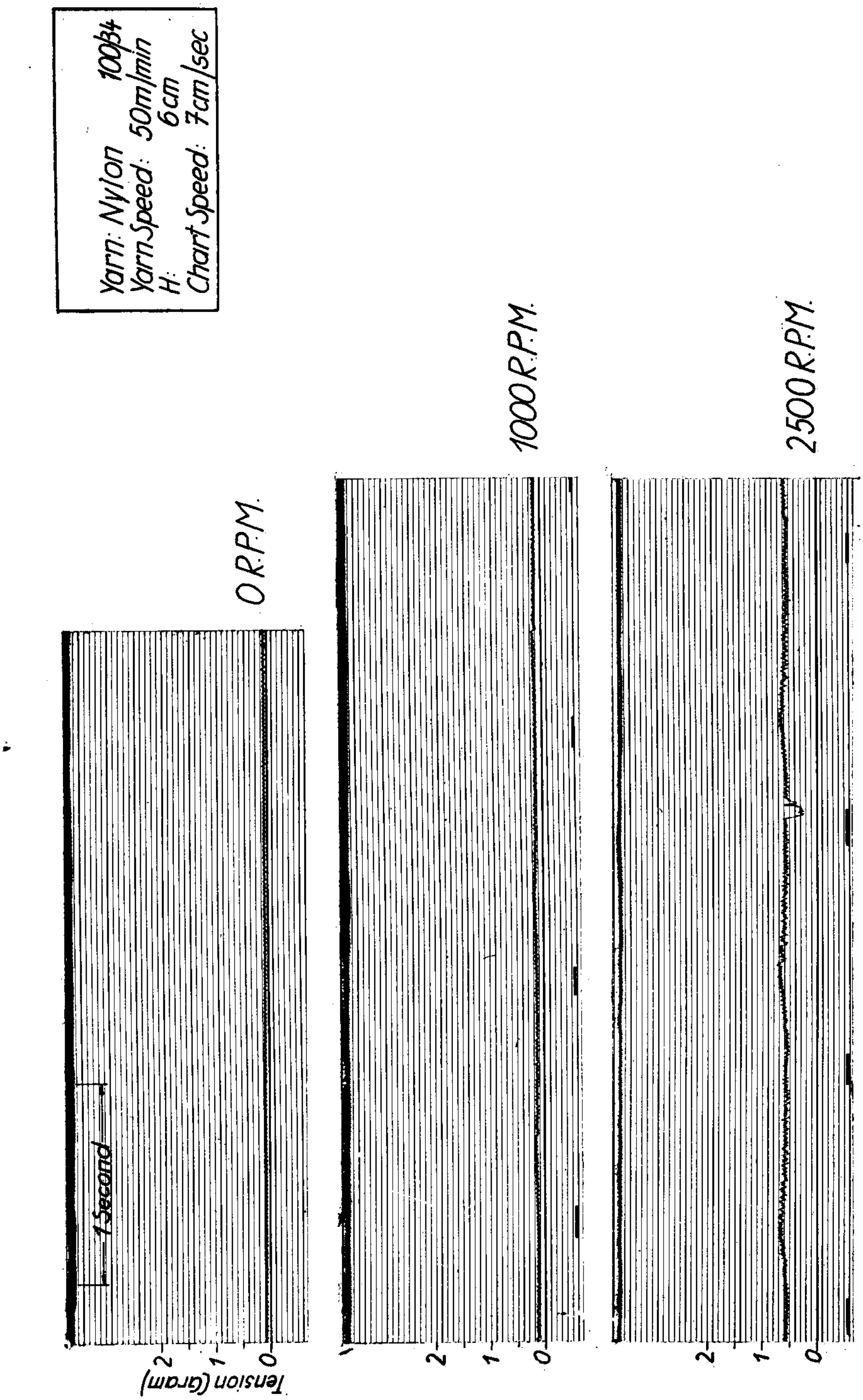



FIG. 20.


Yarn: Nylon 100/34
Yarn Speed: 50m/min
H: 6cm
Chart Speed: 7cm/sec
0 R.P.M.
1000 R.P.M.
2500 R.P.M.
1 Second
Tension (Gram)
2
1
0

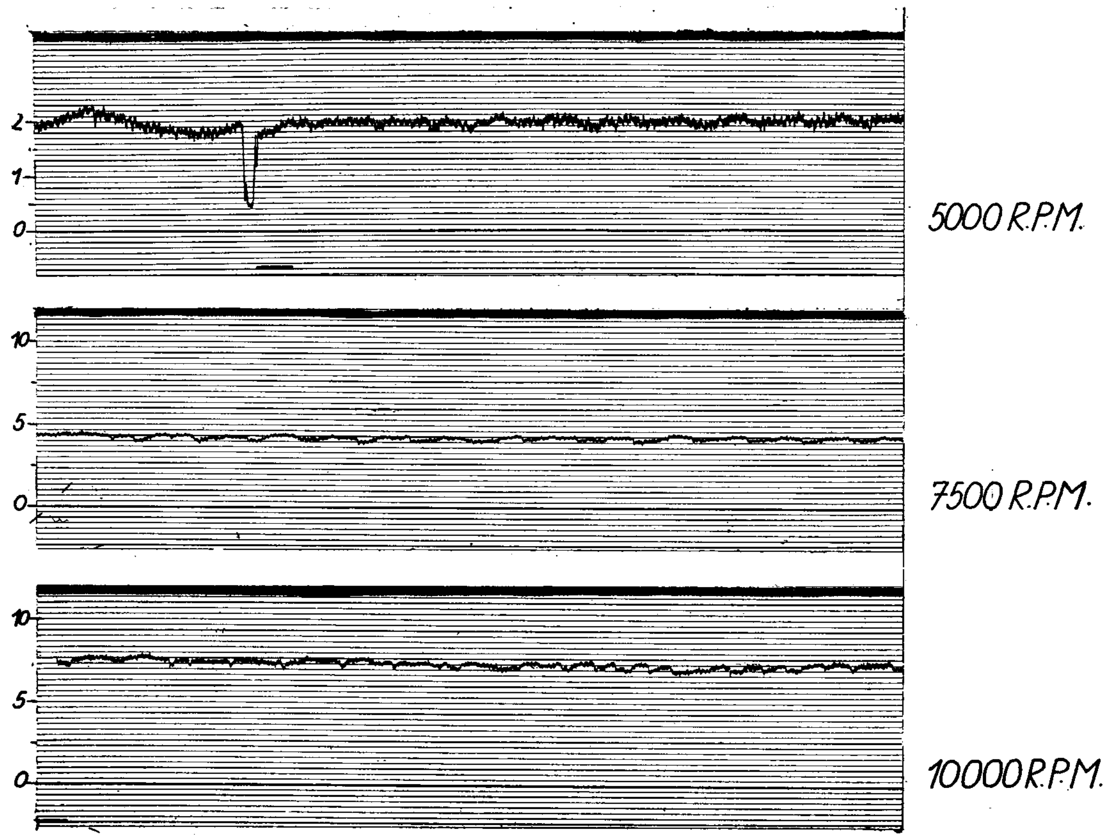



FIG. 21.

package. These charts show the effect which loose windings (see section 5.211) have on the tension. The variation in tension and the period of the variations are both reduced. Once at 5,000 r.p.m. we see the low tension corresponding to a double balloon which existed for a brief moment.

The charts (Fig. 18-21) show that variations in yarn tension are considerable—successive maxima for instance can be quite different from each other. A comparison of the effect of different variables therefore can be made only by using mean values of the tension. Provided enough values are taken the means show quite good agreement despite the variation which occurs between individual values. Table 3 shows typical results for staple nylon $N_m$ 100/2 with a yarn speed of 50 m/min., $H=10$ cm. and package diameter of 7 cm. The tensions are the mean values from each chart. Values (1) and (2) were obtained from different packages of this yarn measured on the same occasion. Values (3) and (4) were also obtained from different packages after an interval of several weeks. Considering the differences which occur on any one chart these mean values show very good agreement. The maximum tension corresponds to a single balloon. The minimum tension (A) is the lowest tension corresponding to a single balloon and minimum tension (B) is that corresponding to a double balloon (see Fig. 18 at 7,500 r.p.m.).

**TABLE 3**

**Reproducibility of results**

| | | Tension in grams | |
|---|---|---|---|
| | | 5,000 r.p.m. | 10,000 r.p.m. |
| Maximum tension | (1) | 5·1 | 19·0 |
| | (2) | 5·3 | 18·0 |
| | (3) | 5·0 | 18·6 |
| | (4) | 5·7 | 18·6 |
| Minimum tension (A) | (1) | 3·7 | 15·5 |
| | (2) | 3·4 | 14·0 |
| | (3) | 3·4 | 13·5 |
| | (4) | 3·9 | 13·6 |
| Minimum tension (B) | (1) | 2·3 | 9·5 |
| | (2) | 2·3 | 9·2 |
| | (3) | 2·4 | 9·0 |
| | (4) | 2·3 | 8·5 |

### 5.23 Photographic

Fig. 22 is a photograph of a single balloon formed as the yarn leaves the top of the package. An exposure time of 1/50 second and a spindle speed of 3,000 r.p.m. enabled a sharply defined balloon corresponding to a single rotation of the yarn to be obtained. Fig. 23 is an attempt to photograph the actual yarn path and from this it is possible to obtain some idea of the three dimensional form of the yarn path. This and all other photographs showing the actual yarn path were obtained using electronic flash equipment and an aperture of f11. The series of photographs in Fig. 24 show a single balloon formed as the yarn is taken off near the bottom of the package. Fig. 24c, taken from above the package with the measuring head removed and replaced by a small guide eye in conjunction with Fig. 24b clearly shows the three dimensional form of the yarn path.

The series of photographs in Fig. 25 illustrates a typical double balloon. In Fig. 25a the exposure time (1/25 second) and rotational speed were chosen to give approximately four rotations of the yarn. Slight differences in the balloon outline are clearly seen. The yarn path which produces this double balloon is seen in Fig. 25b and a plan view is obtained in Fig. 25c. By comparing Fig. 25b and 25c a very good three dimensional picture of the yarn path which produces the balloon in Fig. 25a can be obtained. Fig. 26a and 26b are other examples of the yarn path which is responsible for the appearance of a double balloon.

### 5.24 Factors governing balloon shape

Many factors govern balloon shape and these have been summarised in Tables 4 and 5. Table 4 shows how balloon shape varies with spindle speed and package diameter for cotton yarn $N_e$ 20. Results are given for two packages at each spindle speed. They show that for this yarn at low spindle speeds, only a single balloon exists, but at higher spindle speeds, single and double balloons alternate. For all yarns examined, if the balloon shape consisted of alternating single and double balloons, the single balloons formed as the yarn came off the lower part of the package, and double or other multiple balloons as the yarn came off the upper part of the package. Table 4 shows that a decrease in package diameter causes a double balloon to form at a lower spindle speed.

**TABLE 4**

**Dependence of balloon shape on spindle speed and package diameter**

Yarn: Cotton $N_e$ 20
$H$: 10 cm
1B: Single balloon only
1 & 2: Alternating single and double balloons

| Spindle Speed (r.p.m.) | Balloon Shape | |
|---|---|---|
| | Package Diameter =5 cm | Package Diamteer =7 cm |
| 1,000 | 1B<br>1B | 1B<br>1B |
| 2,500 | 1B<br>1B | 1B<br>1B |
| 5,000 | 1 & 2<br>1 & 2 | 1B<br>1B |
| 7,500 | 1 & 2<br>1 & 2 | 1 & 2<br>1 & 2 |
| 10,000 | 1 & 2<br>1 & 2 | 1 & 2<br>1 & 2 |

[continued on page 54]

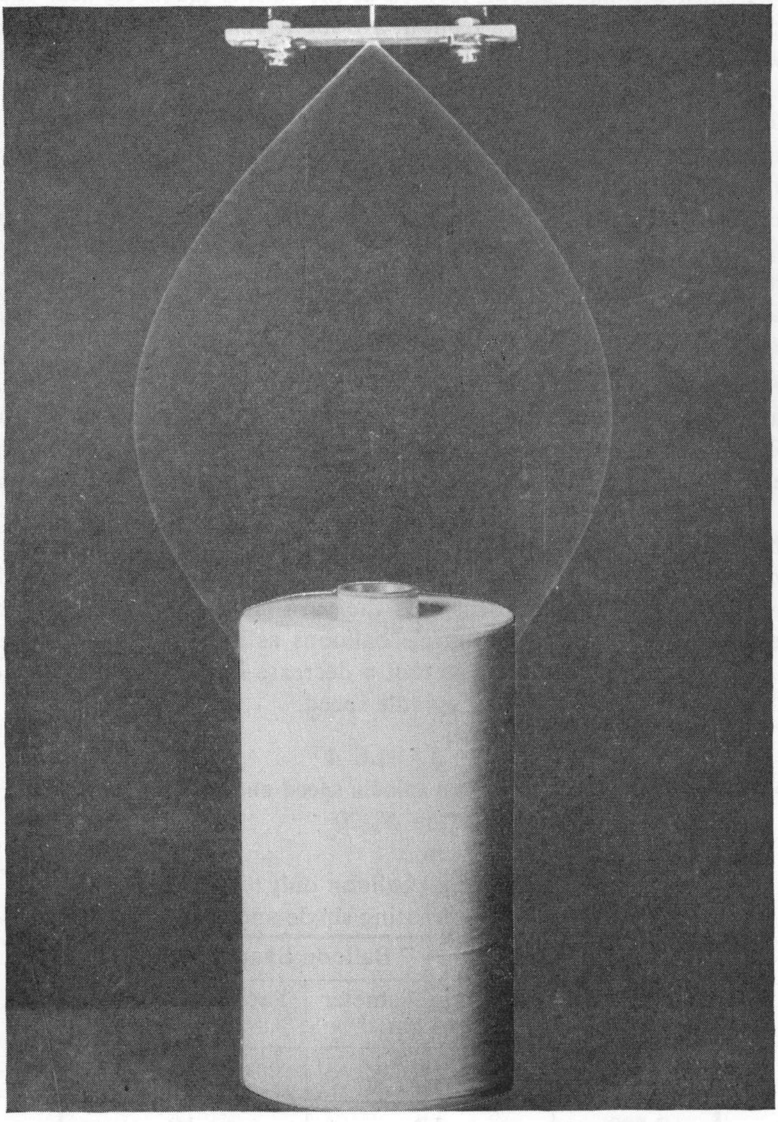


FIG. 22

Exposure: 1/50 second, f5.6

Spindle speed: 3,000 r.p.m.

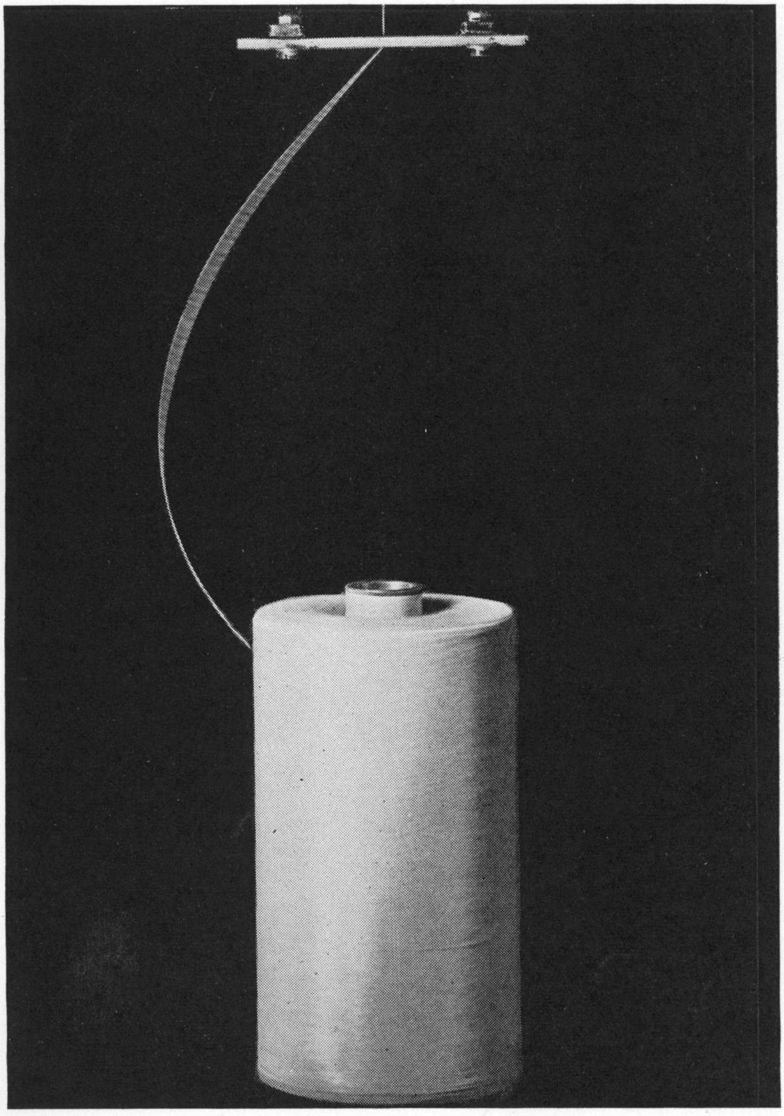


FIG. 23

Exposure: electronic flash, f11

Spindle speed: 3,000 r.p.m.

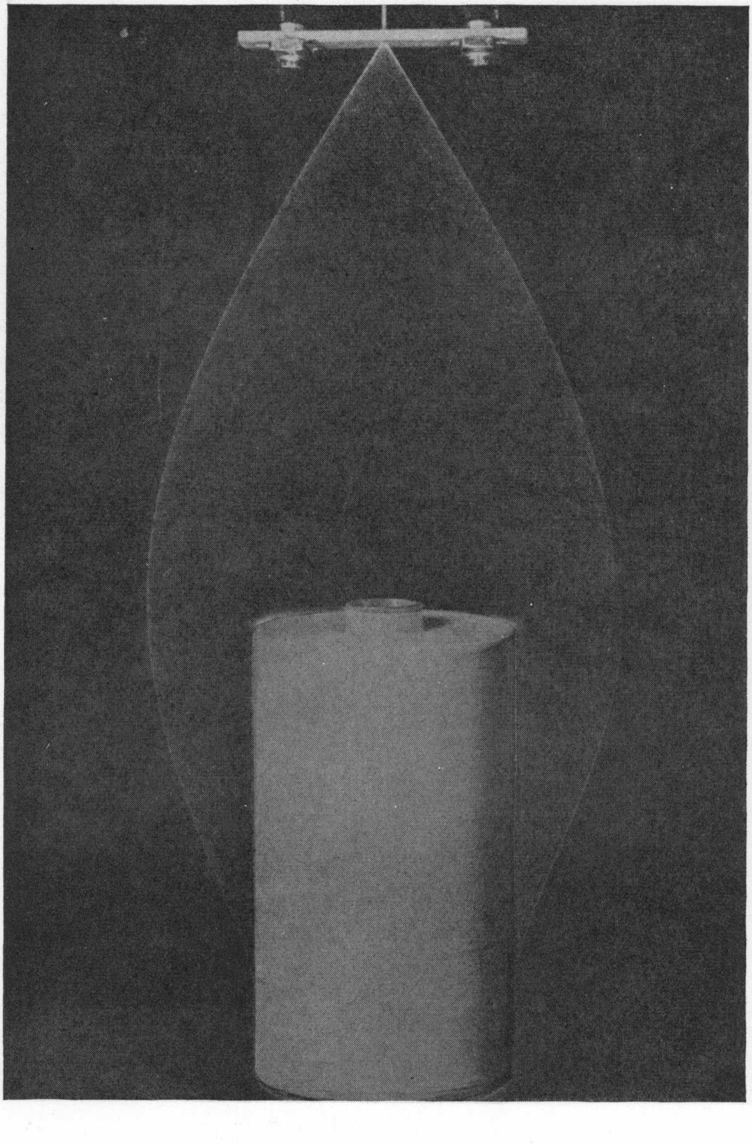


FIG. 24(a)

Exposure: 1/50 second, f5.6

Spindle speed: 3,000 r.p.m.

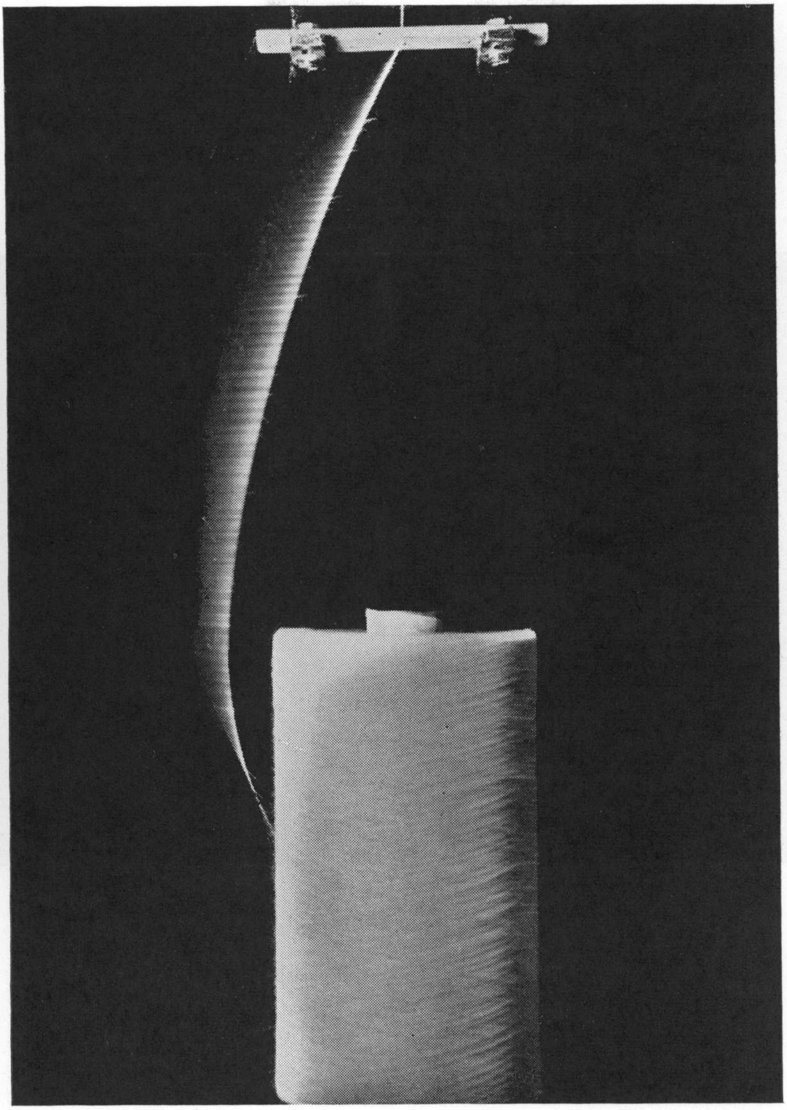


FIG. 24(b)

Exposure: electronic flash, f11

Spindle speed: 3,000 r.p.m.

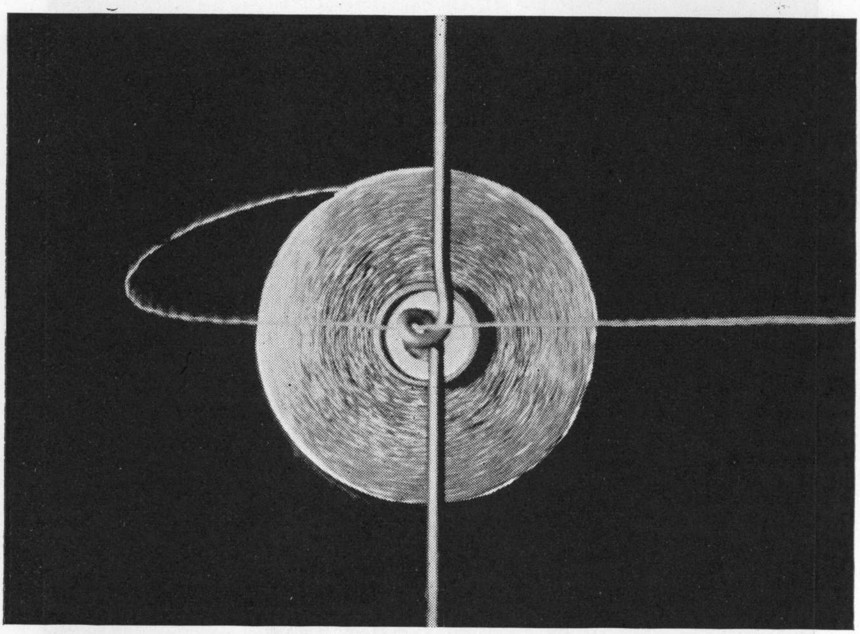


FIG. 24(c)

Exposure: electronic flash, f11

Spindle speed: 3,000 r.p.m.

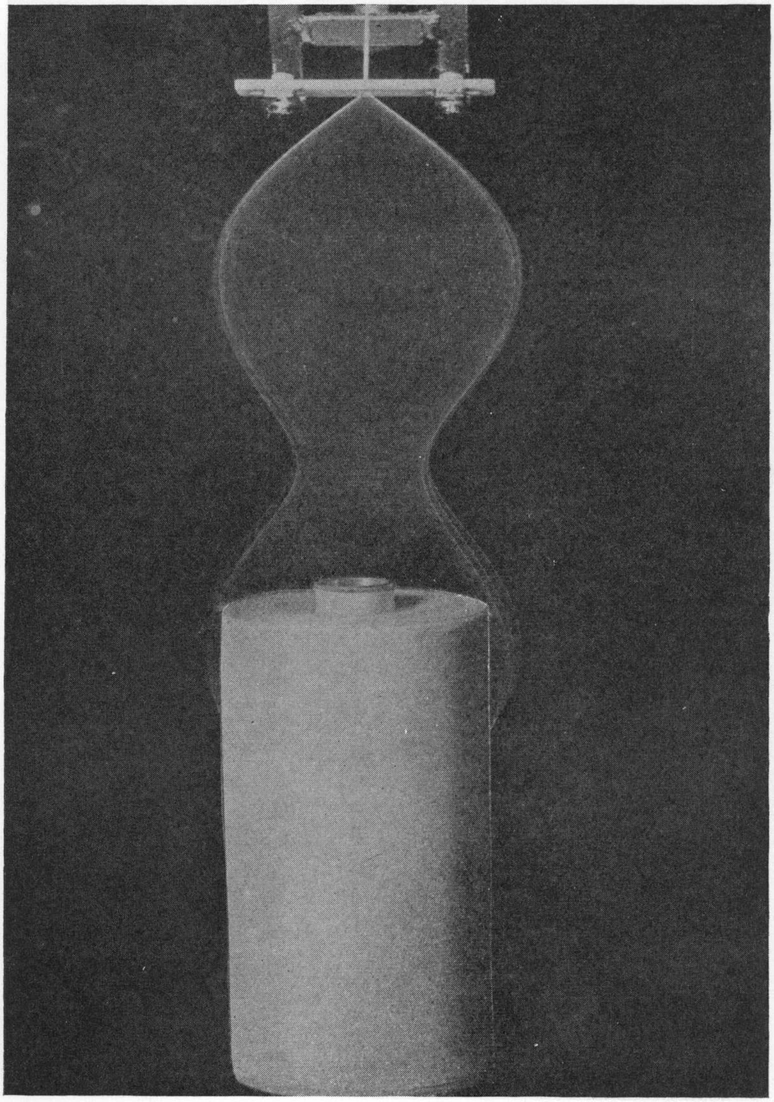


FIG. 25(a)

Exposure: 1/25 second, f5.6

Spindle speed: 6,000 r.p.m.

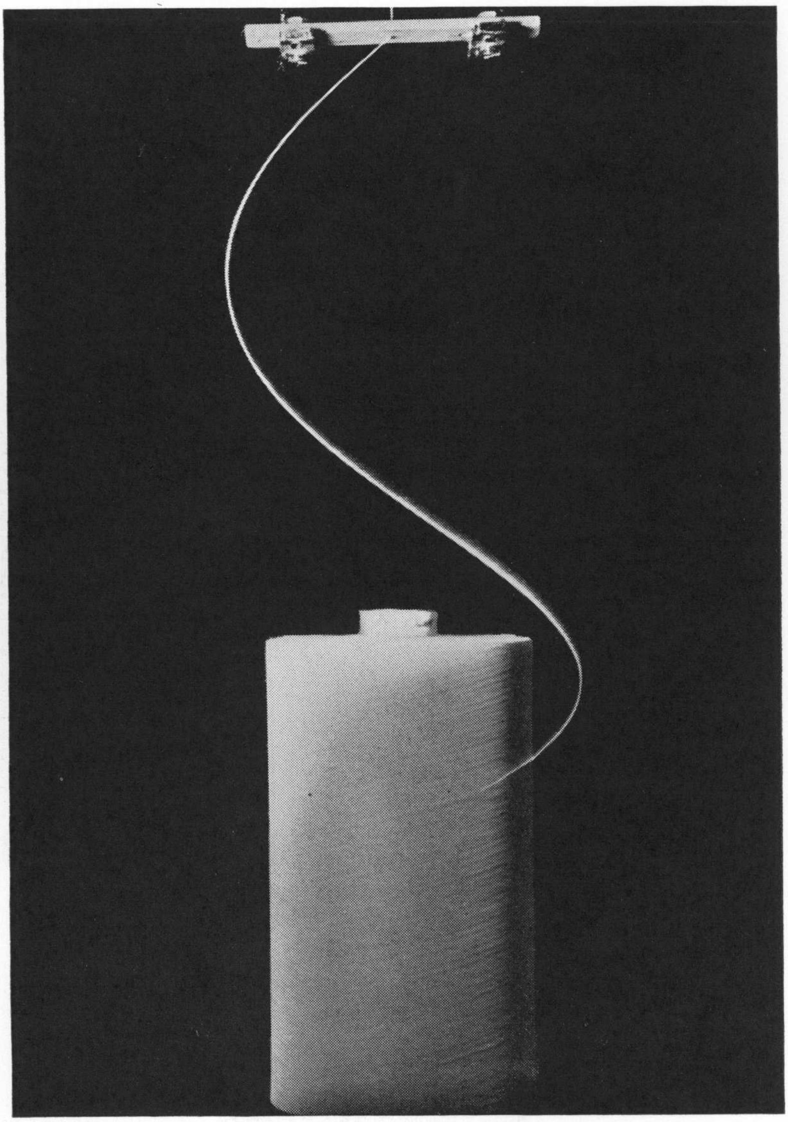


FIG. 25(b)

Exposure: electronic flash, f11

Spindle speed: 6,000 r.p.m.

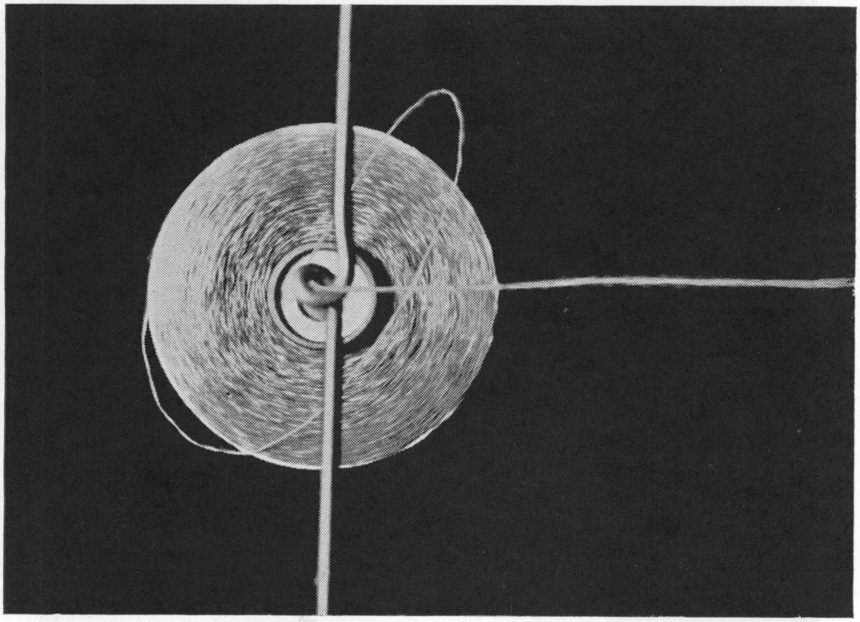


FIG. 25(c)

Exposure: electronic flash, f11
Spindle speed: 6,000 r.p.m.

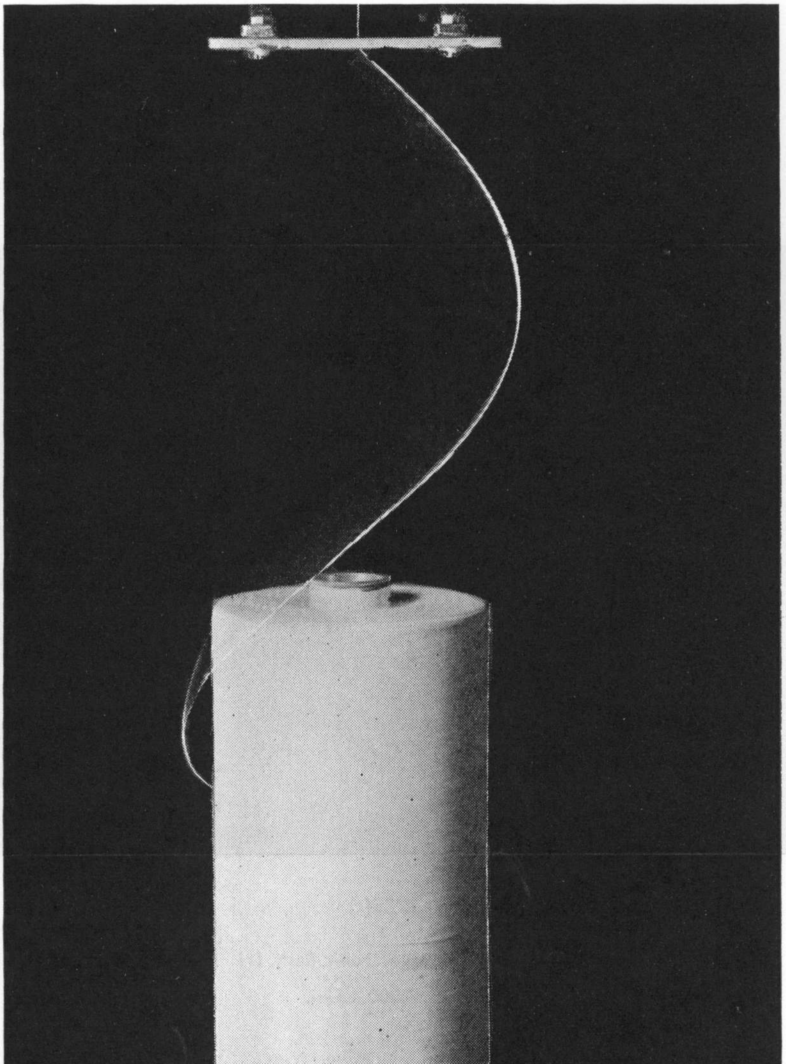


FIG. 26(a)

Exposure: electronic flash, f11

Spindle speed: 2,500 r.p.m.

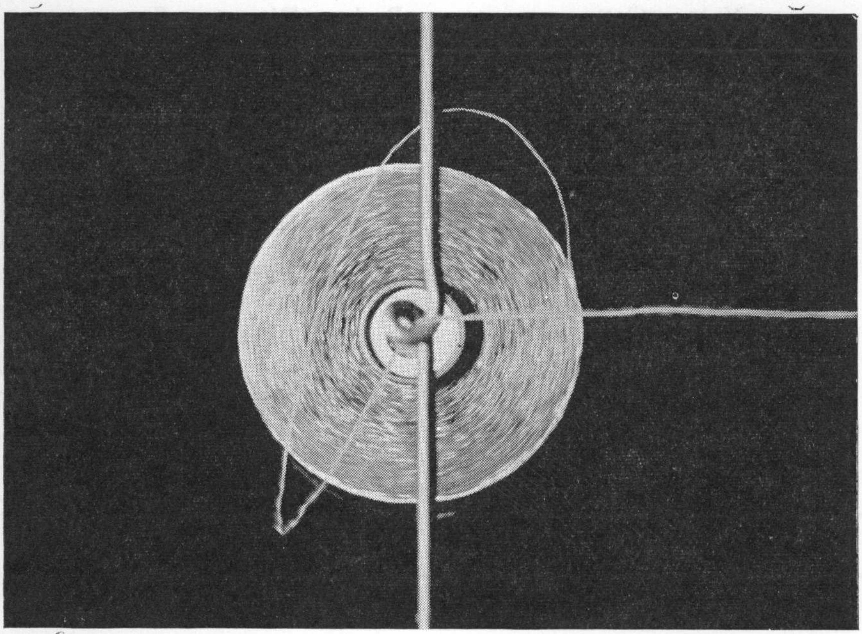


FIG. 26(b)

Exposure: electronic flash, f11

Spindle speed: 2,500 r.p.m.

## TABLE 5

**Dependence of balloon shape on spindle speed**

1B: Single balloon only

2B: Double balloon only

1 & 2: Single and double balloons alternating

2 & 3: Two and three balloons alternating

1, 2 & 3: One, two and three balloons alternating

| Yarn: Cotton | | | | Package Diameter=7 cm | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Spindle Speed (r.p.m.) | $H=6$ cm | | | $H=10$ cm | | | $H=15$ cm | | |
| | $N_e$ 50 | $N_e$ 20 | $N_e$ 12 | $N_e$ 50 | $N_e$ 20 | $N_e$ 12 | $N_e$ 50 | $N_e$ 20 | $N_e$ 12 |
| 1,000 | 1B | 1B | 1B | 1B | 1B | 1B | 1B | 1B | 1B |
| | 1B | 1B | 1B | 1B | 1B | 1B | 1B | 1B | 1B |
| 2,500 | 1B | 1B | 1B | 1B | 1B | 1B | 1B | 1B | 1 & 2 |
| | 1B | 1B | 1B | 1B | 1B | 1B | 1B | 1B | 1 & 2 |
| 5,000 | 1B | 1B | 1B | 1B | 1B | 1 & 2 | 1 & 2 | 1 & 2 | 1 & 2 |
| | 1B | 1B | 1B | 1B | 1B | 1B | 1 & 2 | 1 & 2 | 1 & 2 |
| 7,500 | 1B | 1B | 1B | 1 & 2 | 1 & 2 | 1 & 2 | 1 & 2 | 1 & 2 | 1 & 2 |
| | 1B | 1B | 1B | 1B | 1 & 2 | 1B | 1 & 2 | 1 & 2 | 1 & 2 |
| 10,000 | 1B | 1B | 1B | 1 & 2 | 1 & 2 | 1B | 1 & 2 | 1 & 2 | 1 & 2 |
| | 1B | 1B | 1B | 1 & 2 | 1 & 2 | 1 & 2 | 1 & 2 | 1 & 2 | 1 & 2 |

| Yarn: Nylon (continuous filament) | | | | Package Diameter=7 cm | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Spindle Speed (r.p.m.) | $H=6$ cm | | | $H=10$ cm | | | $H=15$ cm | | |
| | 100/34 | 210/34 | 340/100 | 100/34 | 210/34 | 340/100 | 100/34 | 210/34 | 340/100 |
| 1,000 | 1B | 1B | 1 & 2 | 1 & 2 | 1 & 2 | 1 & 2 | 1 & 2 | 1 & 2 | 1 & 2 |
| | 1B | 1B | 1B | 1 & 2 | 1 & 2 | 1 & 2 | 1 & 2 | 1 & 2 | 1 & 2 |
| 2,500 | 1B | 1B | 1 & 2 | 1 & 2 | 1 & 2 | 1 & 2 | 2B | 2 & 3 | 1 & 2 |
| | 1B | 1B | 1 & 2 | 1 & 2 | 1 & 2 | 1 & 2 | 2B | 2 & 3 | 1 & 2 |
| 5,000 | 1B | 1B | 1 & 2 | 1 & 2 | 1 & 2 | 1 & 2 | 2 & 3 | 2 & 3 | 1,2 & 3 |
| | 1B | 1B | 1 & 2 | 1 & 2 | 1 & 2 | 1 & 2 | 2 & 3 | 2 & 3 | 1 & 2 |
| 7,500 | 1B | 1B | 1 & 2 | 1 & 2 | 1 & 2 | 1 & 2 | 2 & 3 | 2 & 3 | 2 & 3 |
| | 1B | 1B | 1 & 2 | 1 & 2 | 1 & 2 | 1 & 2 | 2 & 3 | 2 & 3 | 2 & 3 |
| 10,000 | 1B | 1B | 1B | 1 & 2 | 1 & 2 | 1 & 2 | 2 & 3 | 2 & 3 | 2 & 3 |
| | 1B | 1B | 1 & 2 | 1 & 2 | 1 & 2 | 1 & 2 | 1,2 & 3 | 2 & 3 | 2 & 3 |

Most of the results of yarn tension, and balloon diameter and shape were obtained for yarns on packages of 7 cm diameter. Table 5 shows the balloon shapes which were observed at spindle speeds between 1,000 and 10,000 r.p.m. for cotton and nylon yarns at values of $H=6$, 10 and 15 cm. Occasionally results on both packages do not agree, but despite this certain trends are clearly seen. At low deniers and low values of $H$ a single balloon exists at all spindle speeds up to 10,000 r.p.m. The possibility of a double balloon forming as the yarn comes off the upper part of the package increases as spindle speed, denier and $H$ increase, and occurs more readily for a filament than a staple yarn.

### 5.25 Influence of different variables on yarn tension and balloon diameter

#### 5.251 Effect of yarn speed

The spindle speed was continuously variable between a few hundred and 10,000 r.p.m. It was necessary to select a suitable yarn speed at which to wind the yarn off the package. Two factors governed the choice of yarn speed. The first was the need to use a relatively low speed so that at the spindle speeds available a certain amount of twist is actually put into the yarn. The lowest yarn speed at which we could run was governed by the facilities provided by the photographic recorder. Its lowest chart speed was 7 cm./sec. so that a very slow yarn speed would require very long chart lengths to pick up the long period variations. The periodic yarn length on a 7 cm. diameter package is approximately 100 cm. so with a yarn speed of 10 m/min. a chart length of approximately 40 cm. would be required to record a single period. This was considered impractical. Since the chart speed could not easily be reduced it was necessary to use a yarn speed greater than 10 m/min. Before choosing a particular value it was decided to examine the influence of yarn speed on tension and balloon diameter.

Fig. 27 is a plot of the maximum tension against spindle speed for nylon staple $N_m$ 100/2 at various yarn speeds. The full lines show the tension and balloon diameter for a yarn speed of 50 m/min. while the corresponding values at 10, 100 and 200 m/min. are plotted at 5,000 and 10,000 r.p.m. Tension increases with both yarn and spindle speed but the effect of yarn speed is the smaller. Balloon diameter increases with spindle speed but is not significantly affected by yarn speed. Fig. 28 applies to nylon staple $N_e$ 12 and confirms these results. It was decided therefore to use a yarn speed of 50 m/min., as this constituted a convenient compromise between the high yarn speeds needed for ease of recording, and the low yarn speeds necessary to insert significant twist into the yarn.

#### 5.252 Effect of package diameter

The length of yarn wound off a package in recording the tension and measuring the balloon diameter at all rotational speeds up to 10,000 r.p.m. using a yarn speed of 50 m/min. is not very great. Thus, provided the package is fairly large the change in package diameter throughout a test is small. With an initial package diameter of 7 cm. it was found that the diameter was reduced by 1 or 2 mm. during a test, depending upon the type of yarn used.

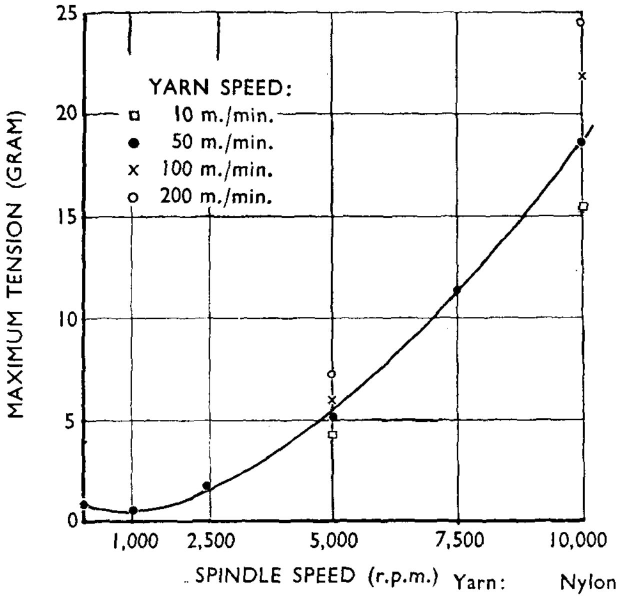



FIG. 27(a)

| | |
|---|---|
| Yarn: | Nylon $N_m$100/2 |
| Package: | Tube |
| Diameter: | 7 cm. |
| H: | 10 cm. |
| B: | 22 cm. |

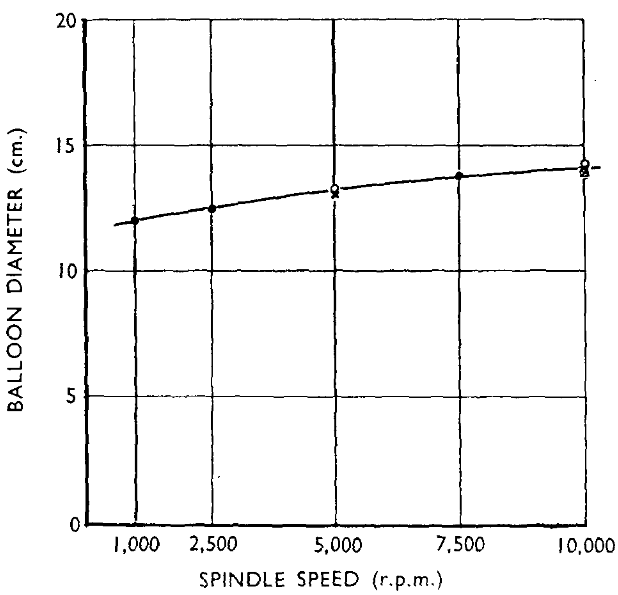



FIG. 27(b)

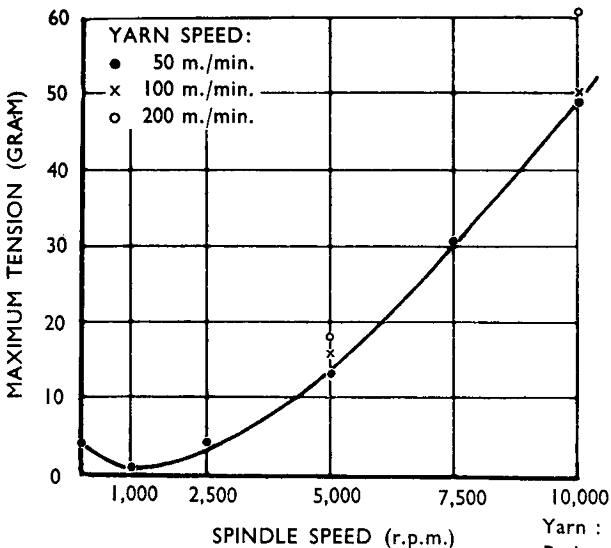



FIG. 28(a)

Yarn : Nylon $N_e$12
Package: Tube
Diameter: 7 cm.
H: 10 cm.
B: 22 cm.

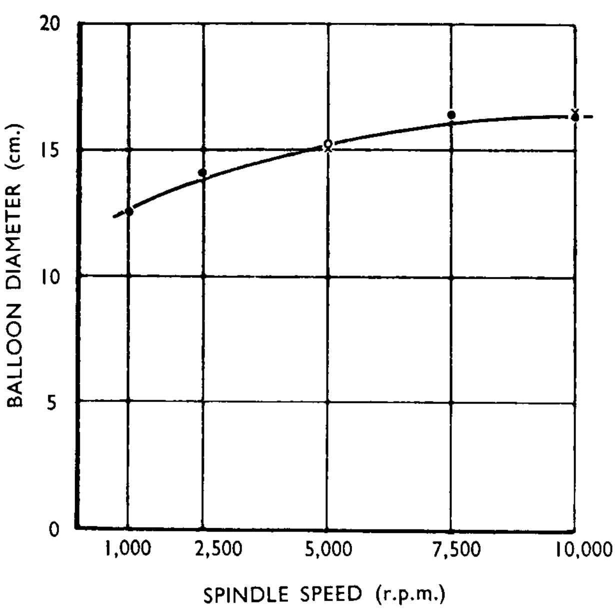



FIG. 28(b)

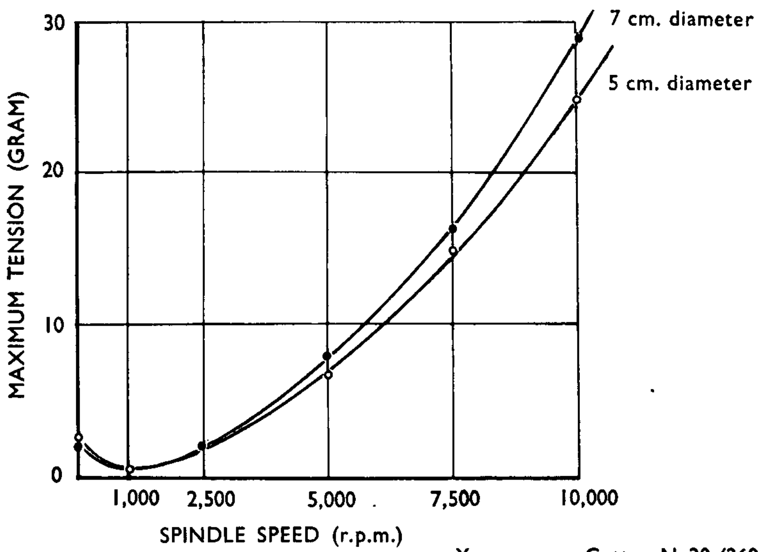



FIG. 29(a)

| | |
|---|---|
| Yarn: | Cotton $N_e$20 (260 denier) |
| Package: | Tube |
| Yarn Speed: | 50 m./min. |
| H: | 10 cm. |
| B: | 22 cm. |

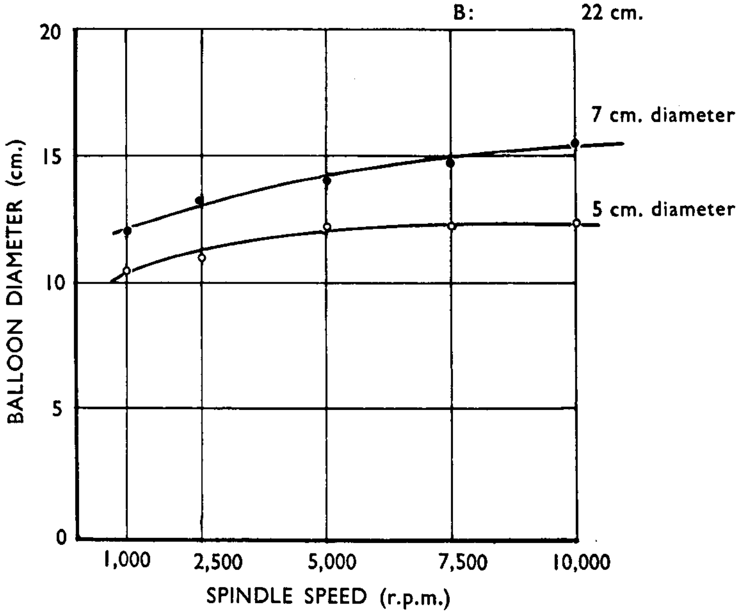



FIG. 29(b)

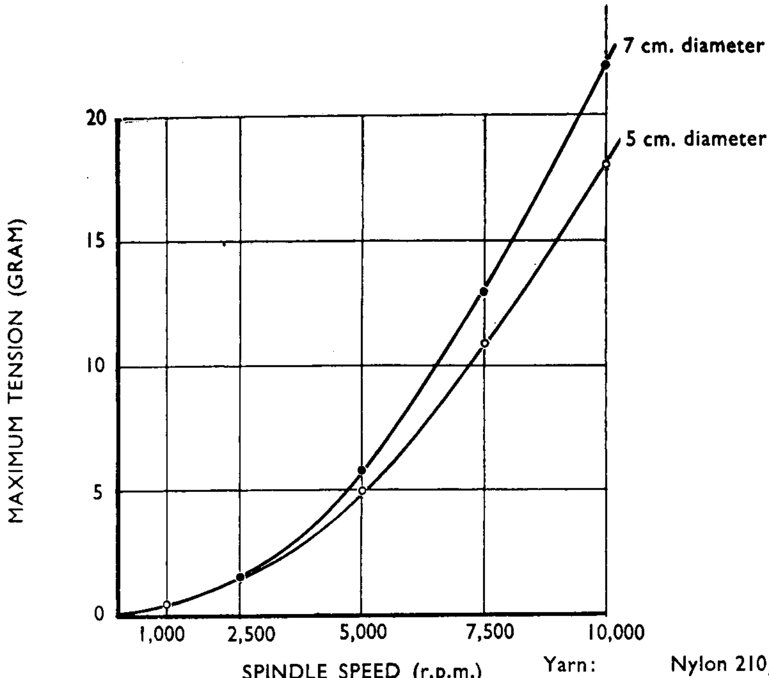



FIG. 30(a)

| | |
|---|---|
| Yarn: | Nylon 210/34 (222 denier) |
| Package: | Tube |
| Yarn Speed: | 50 m./min. |
| H: | 10 cm. |
| B: | 22 cm. |

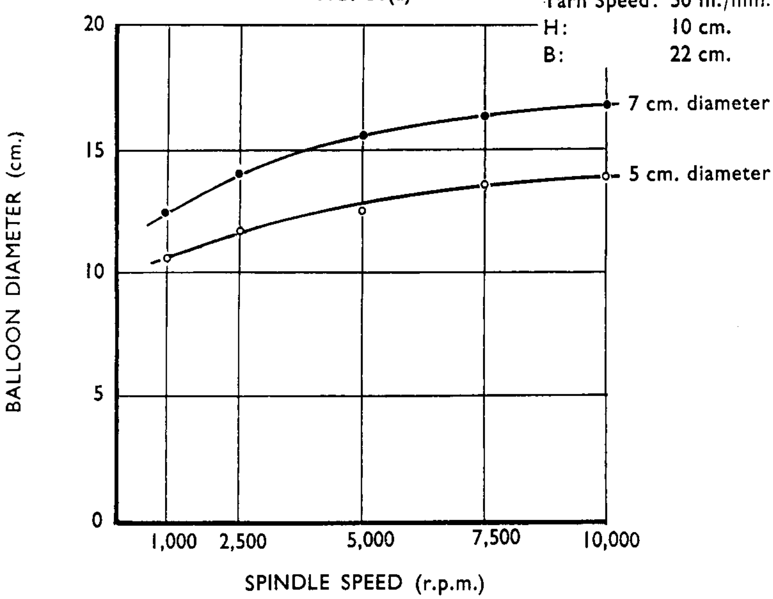



FIG. 30(b)

Fig. 29 and 30 show the effect of package diameter on yarn tension and balloon diameter for two different yarns—cotton $N_e 20$ and continuous filament nylon 210/34. The larger package produces a higher tension and a greater balloon diameter, but a change of 1 or 2 mm. in package diameter has little effect on either tension or balloon diameter. We could assume, therefore, that in any test the tensions at all spindle speeds could be considered as applying to yarn wound off a package of constant diameter.

After these initial experiments examining the effect of package diameter all measurements were made on packages which were nominally 7 cm. in diameter. Packages with heavy yarns were usually wound to about 7·1 or 7·2 cm., so that the average package diameter for all yarns did not differ much from 7 cm.

### 5.253 Effect of denier

Fig. 31-42 show the variation of maximum tension and balloon diameter with spindle speed for yarns of cotton, continuous filament and staple nylon, and staple viscose at three different values of $H$, $H=6$, 10 and 15 cm. Certain features are common to most of these curves. (1) Tension and balloon diameter increase with increasing spindle speed except between 0 and 1,000 or 2,500 r.p.m. for the staple yarns, where the tension decreases. (2) Tension and balloon diameter increase with increasing yarn denier. (3) Increasing $H$ increases tension and decreases balloon diameter except in some cases. Fig. 36 illustrates such an exception. The curves show the tension and balloon diameters of continuous filament yarns at $H=15$ cm. In Fig. 36 the solid line represents the maximum yarn tension corresponding to a single balloon. The dotted line is the maximum tension corresponding to a double balloon. Examination of the curves for the 340/100 yarn shows that up to 2,500 r.p.m. a single balloon exists with a correspondingly high tension. Above 2,500 r.p.m. no single balloon occurs, and the maximum tension which now corresponds to a double balloon is much lower than it would be if a single balloon existed. The other yarns (100/34 and 210/34) behave similarly, except that double balloons occur at lower rotational speeds.

### 5.254 Effect of $H$

Fig. 43-50 show the effect of $H$ on cotton $N_e 20$ and $N_e 12$, continuous filament nylon 100/34 and 210/34, nylon staple $N_m 170/2$ and $N_e 12$ and viscose staple $N_m 160/2$ and $N_m 30$. The staple yarns show an increase in maximum tension and a decrease in diameter with increasing $H$. The continuous filament yarns show the same trend from $H=6$ cm. to $H=10$ cm, but at $H=15$ cm. the tension is lower than at $H=6$ cm.

Fig. 51-54 show the yarn tension at spindle speeds of 2,500 and 7,500 r.p.m. plotted against balloon height. In these curves the tension plotted is not always the maximum tension but the tension corresponding to the various balloon heights. For balloon heights of 6, 10 and 15 cm., this is actually the minimum tension. A fairly good linear relation exists between tension and balloon height provided the tension corresponds to a single balloon.


[continued on page 87]

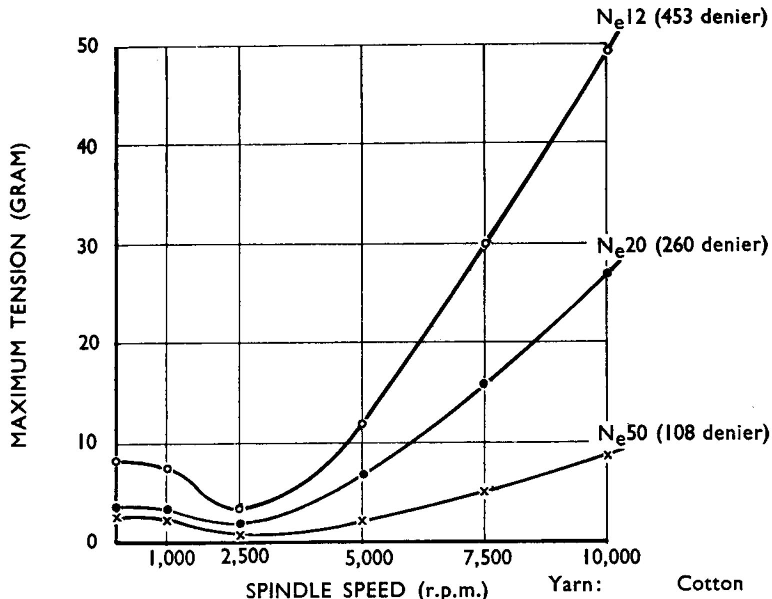



FIG. 31(a)

Yarn: Cotton
Package: Tube
Diameter: 7 cm.
Yarn Speed: 50 m./min.
H: 6 cm.
B: 18 cm.

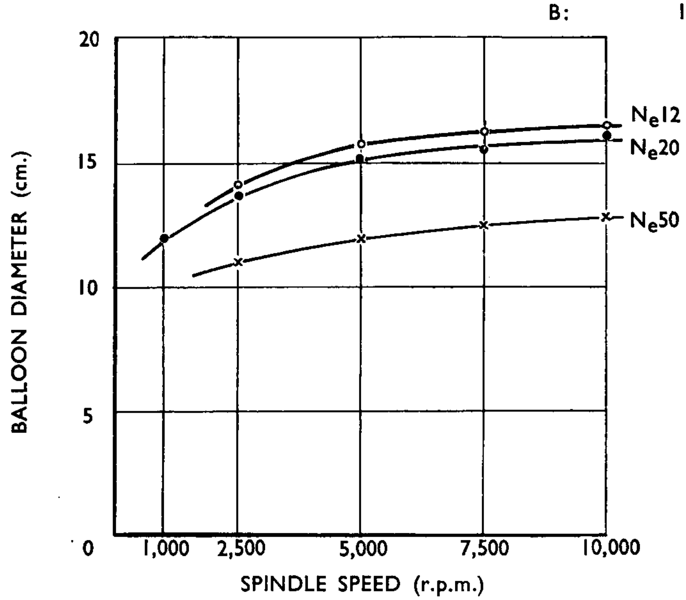



FIG. 31(b)

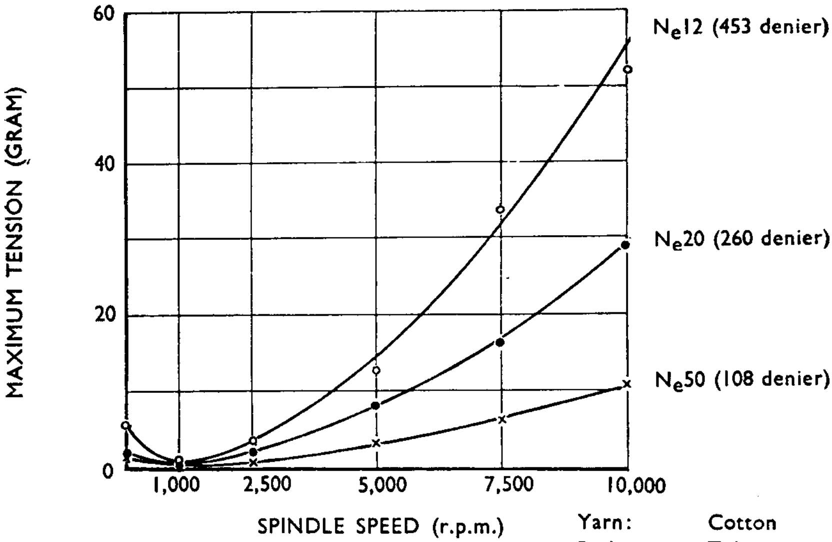



FIG. 32(a)

| | |
|---|---|
| Yarn: | Cotton |
| Package | Tube |
| Diameter: | 7 cm. |
| Yarn Speed: | 50 m./min. |
| H: | 10 cm. |
| B: | 22 cm. |

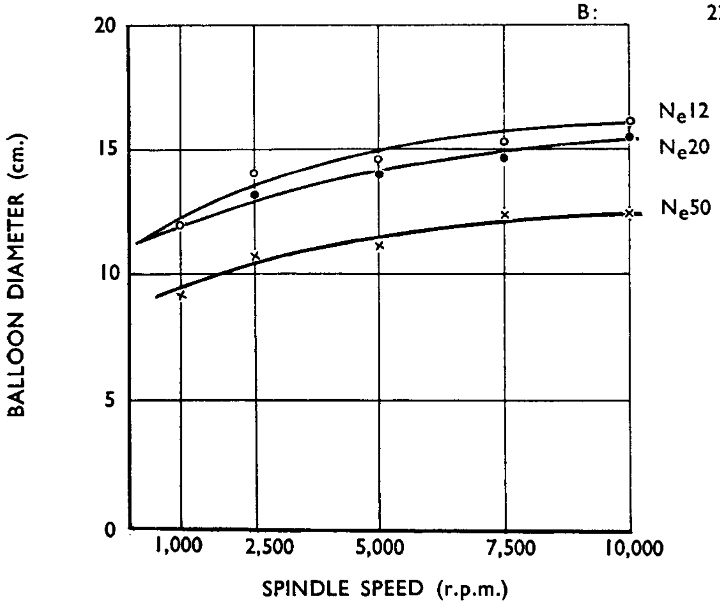



FIG. 32(b)

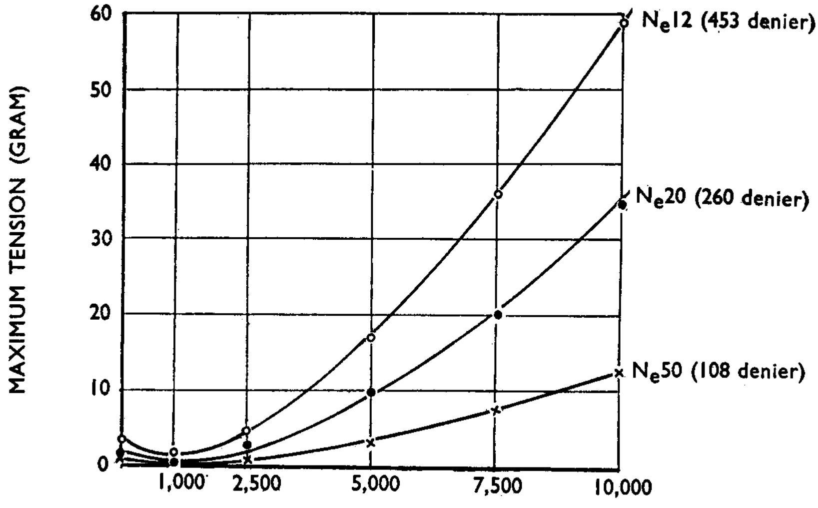



FIG. 33(a)

| | |
|---|---|
| Yarn: | Cotton |
| Package: | Tube |
| Diameter: | 7 cm. |
| Yarn Speed: | 50 m./min. |
| H: | 15 cm. |
| B: | 27 cm. |

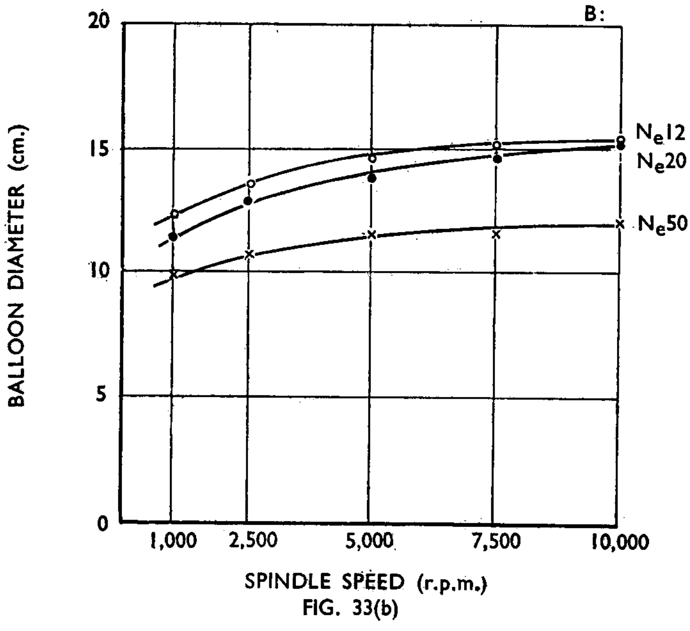



FIG. 33(b)

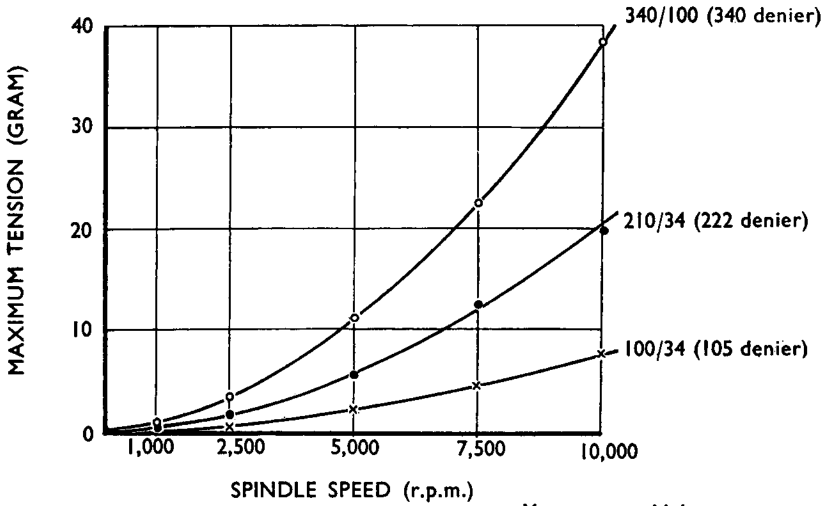



FIG. 34(a)

| | |
|---|---|
| Yarn: | Nylon |
| Package: | Tube |
| Diameter: | 7 cm. |
| Yarn Speed: | 50 m./min. |
| H: | 6 cm. |
| B:. | 18 cm. |

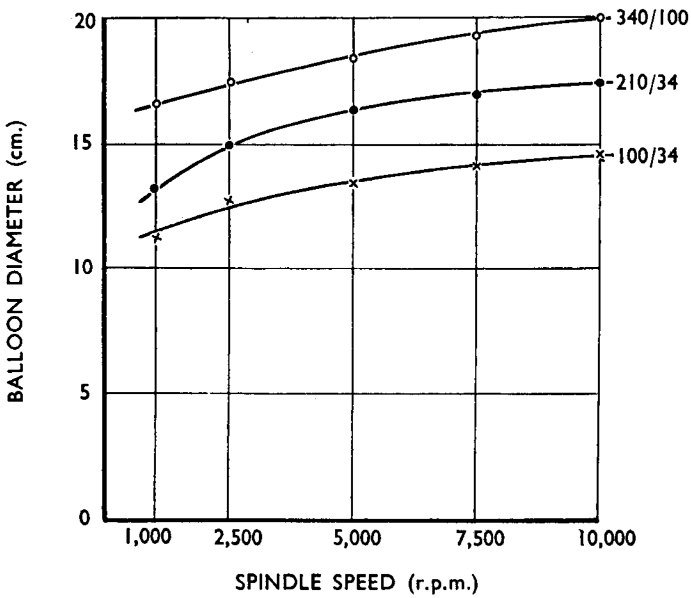



FIG. 34(b)

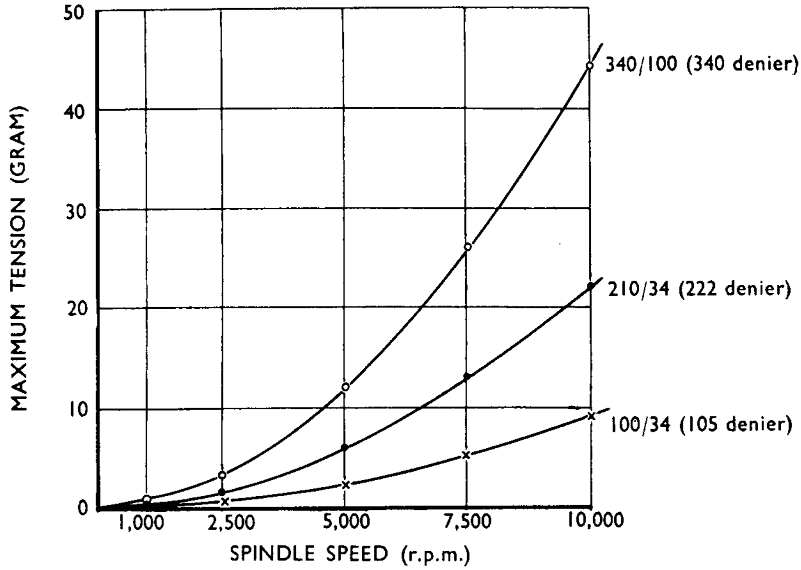



FIG. 35(a)

| | |
|---|---|
| Yarn: | Nylon |
| Package: | Tube |
| Diameter: | 7 cm. |
| Yarn Speed: | 50 m./min. |
| H: | 10 cm. |
| B: | 22 cm. |

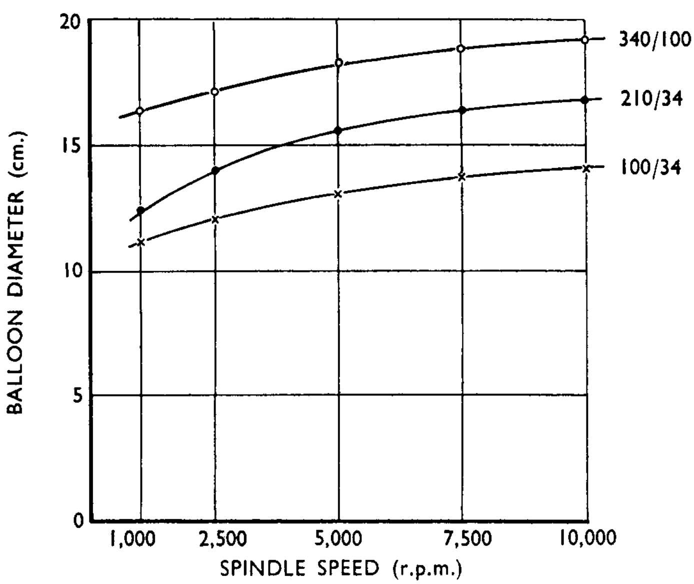



FIG. 35(b)

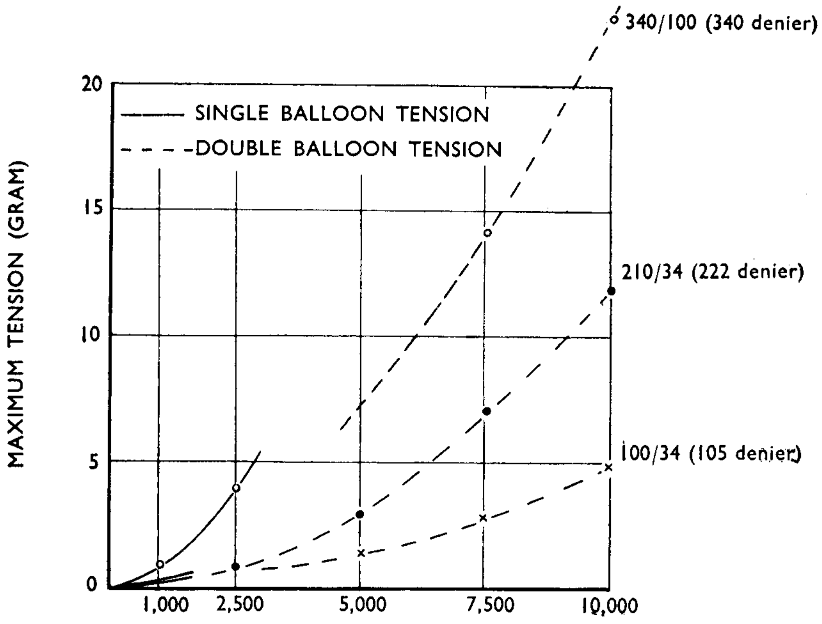



FIG. 36(a)

| | |
|---|---|
| Yarn: | Nylon |
| Package: | Tube |
| Diameter: | 7 cm. |
| Yarn Speed: | 50 m./min. |
| H: | 15 cm. |
| B: | 27 cm. |

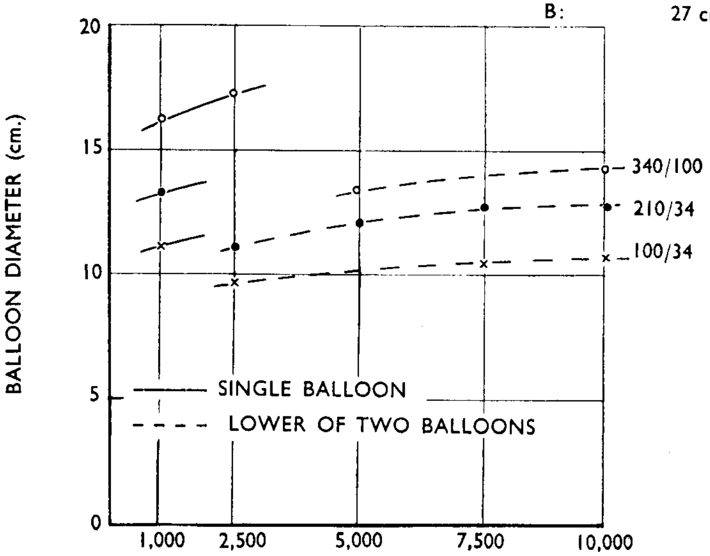



FIG. 36(b)

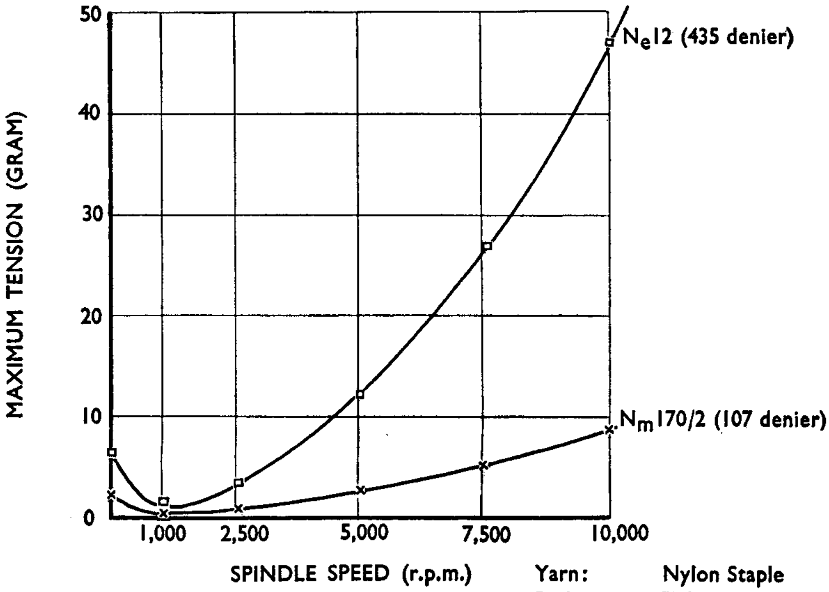



FIG. 37(a)

| | |
|---|---|
| Yarn: | Nylon Staple |
| Package: | Tube |
| Diameter: | 7 cm. |
| Yarn Speed: | 50 m./min. |
| H: | 6 cm. |
| B: | 18 cm. |

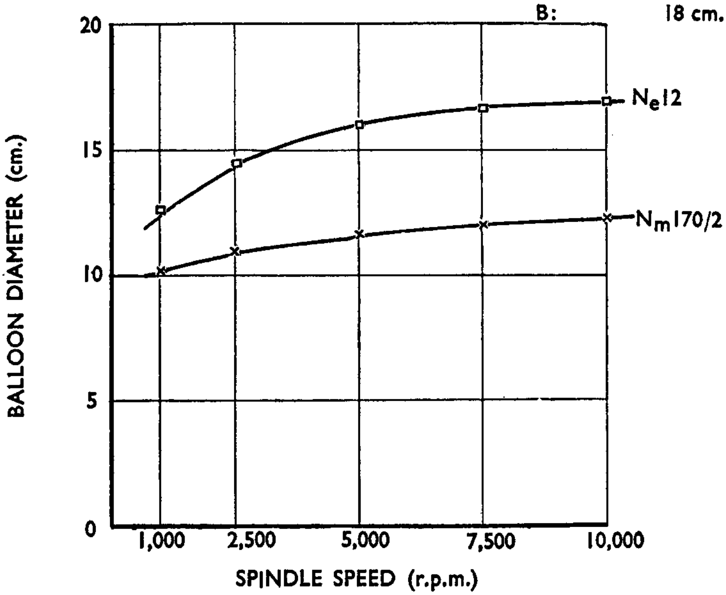



FIG. 37(b)

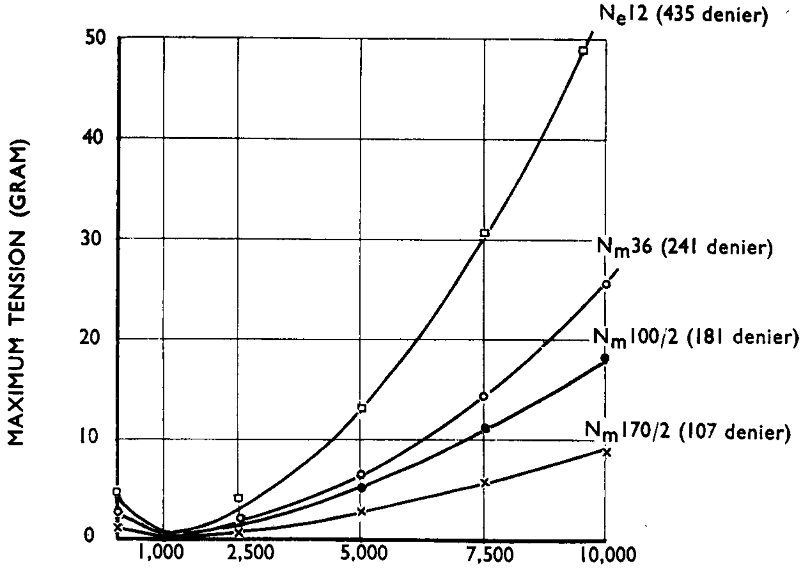



FIG. 38(a)

| | |
|---|---|
| Yarn: | Nylon staple |
| Package: | Tube |
| Diameter: | 7 cm. |
| Yarn Speed: | 50 m./min. |
| H: | 10 cm. |
| B: | 22 cm. |

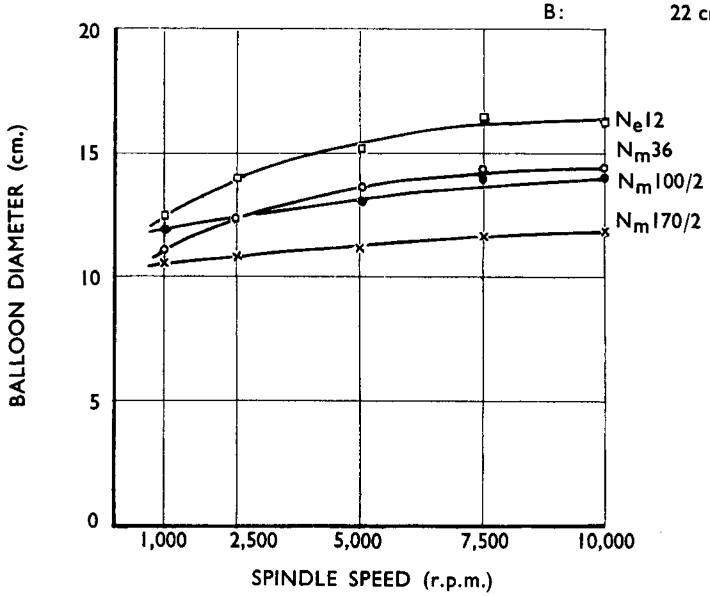



FIG. 38(b)

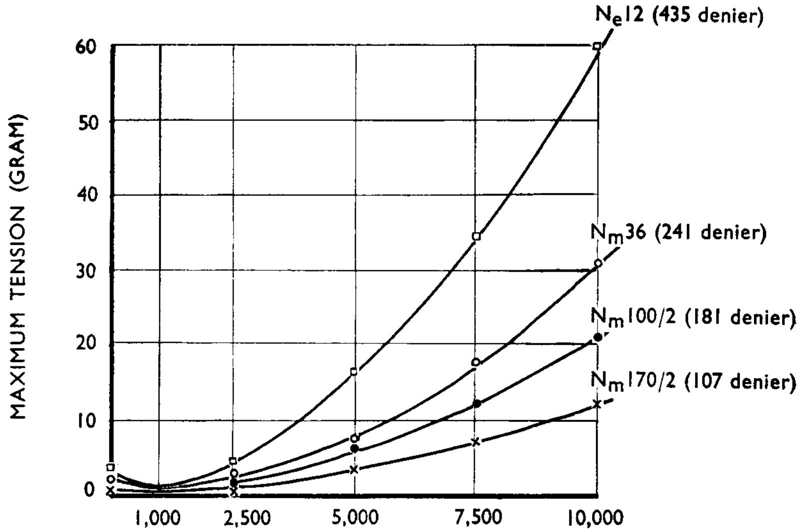



FIG. 39(a)

| | |
|---|---|
| Yarn: | Nylon Staple |
| Package: | Tube |
| Diameter: | 7 cm. |
| Yarn Speed: | 50 m./min. |
| H: | 15 cm. |
| B: | 27 cm. |

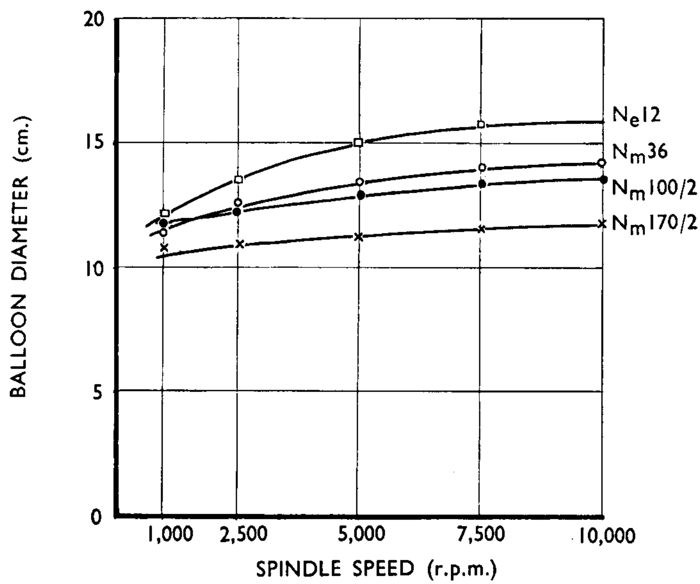



FIG. 39(b)

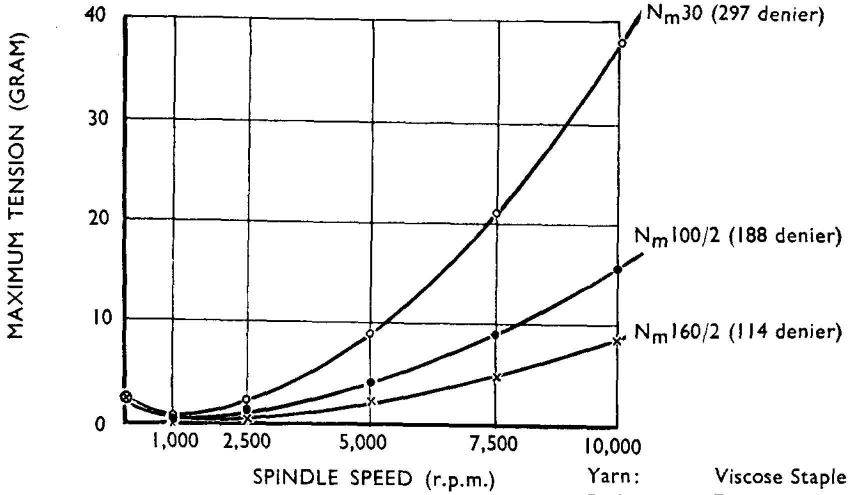



FIG. 40(a)

Yarn: Viscose Staple
Package: Tube
Diameter: 7 cm.
Yarn Speed: 50 m./min.
H: 6 cm.
B: 18 cm.

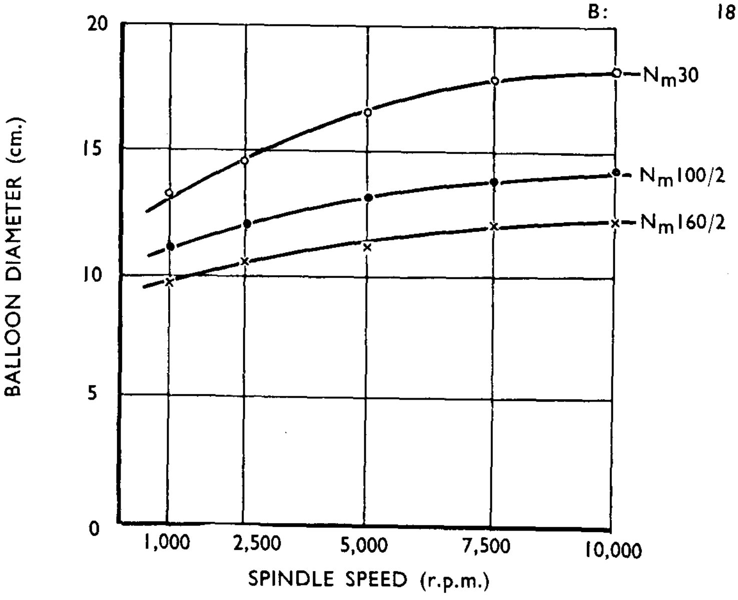



FIG. 40 (b)

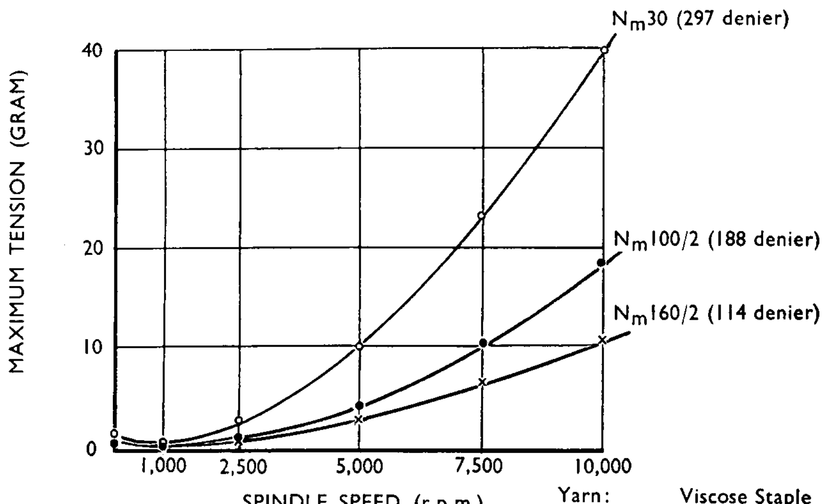



FIG. 41(a)

| | |
|---|---|
| Yarn: | Viscose Staple |
| Package: | Tube |
| Diameter: | 7 cm. |
| Yarn Speed: | 50 m./min. |
| H: | 10 cm. |
| B: | 22 cm. |

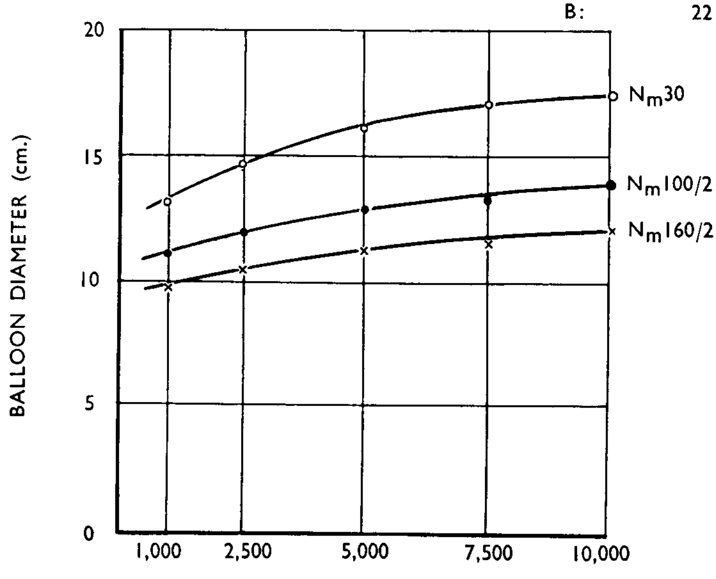



FIG. 41(b)

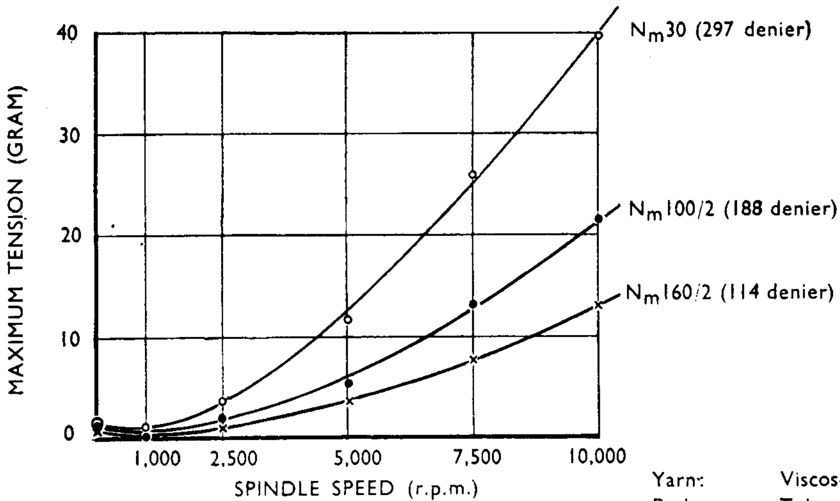



FIG. 42(a)

| | |
|---|---|
| Yarn: | Viscose Staple |
| Package: | Tube |
| Diameter: | 7 cm. |
| Yarn Speed: | 50 m./min. |
| H: | 15 cm. |
| B: | 27 cm. |

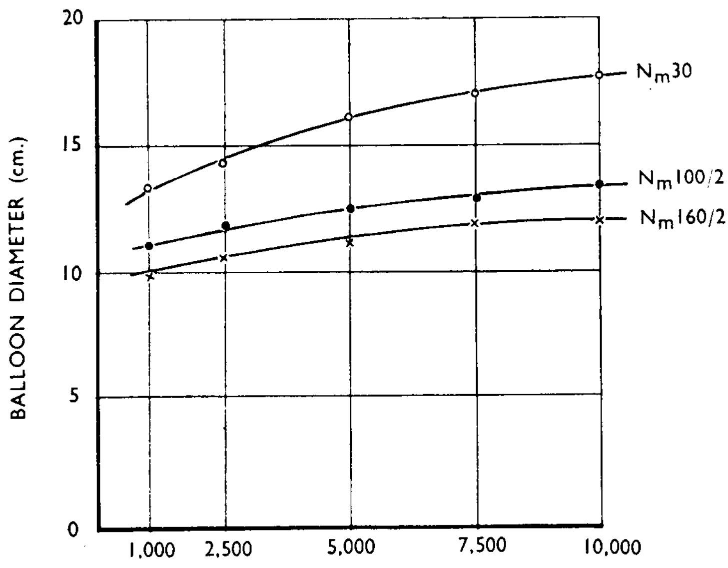



FIG. 42(b)

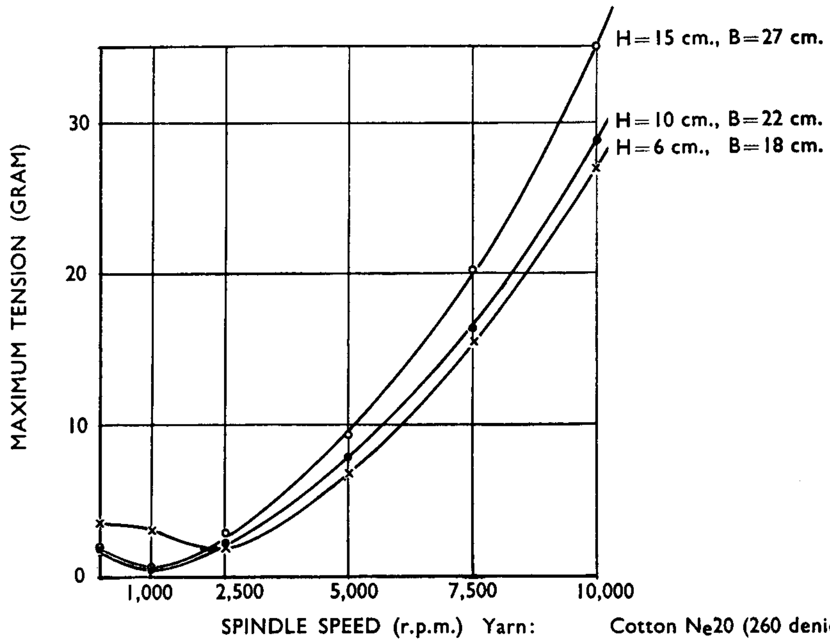



FIG. 43(a)

| | |
|---|---|
| Yarn: | Cotton Ne20 (260 denier) |
| Package: | Tube |
| Diameter: | 7 cm. |
| Yarn Speed: | 50 m./min. |

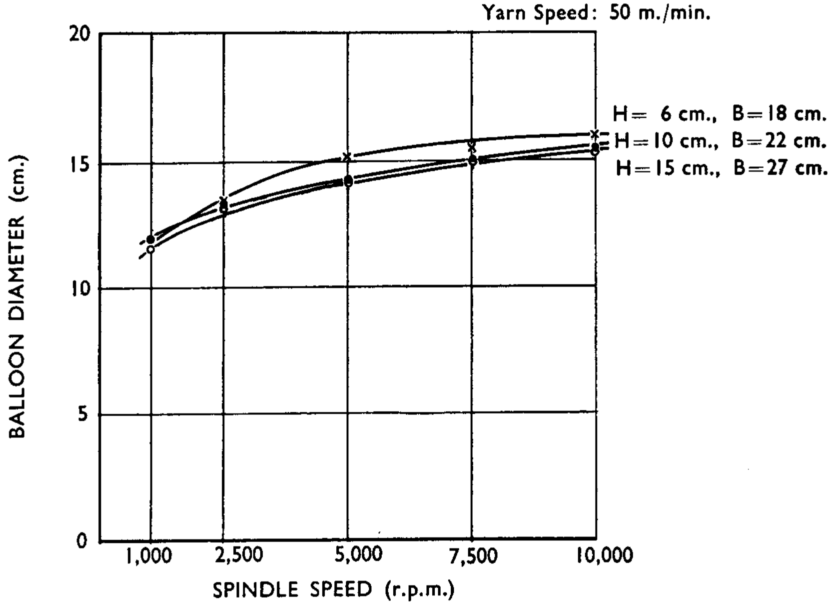



FIG. 43(b)

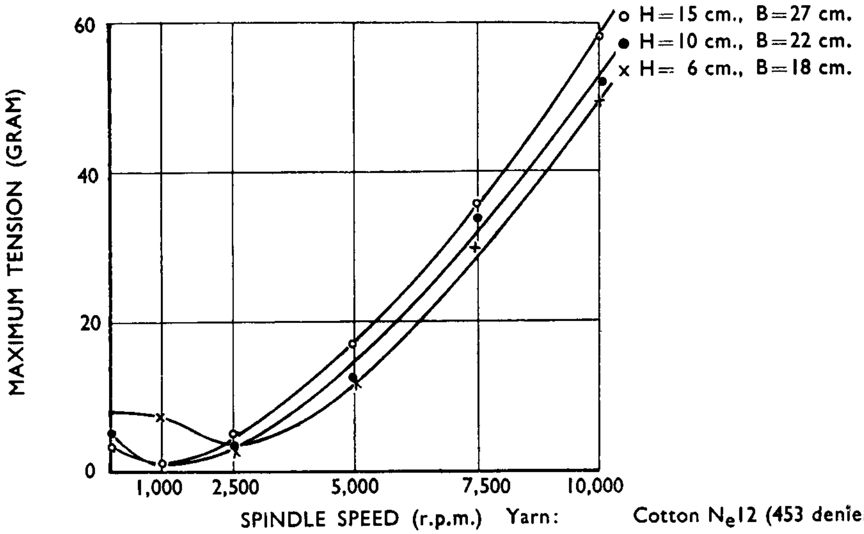



FIG. 44(a)

| | |
|---|---|
| Yarn: | Cotton $N_e$12 (453 denier) |
| Package: | Tube |
| Diameter: | 7 cm. |
| Yarn Speed: | 50 m./min. |

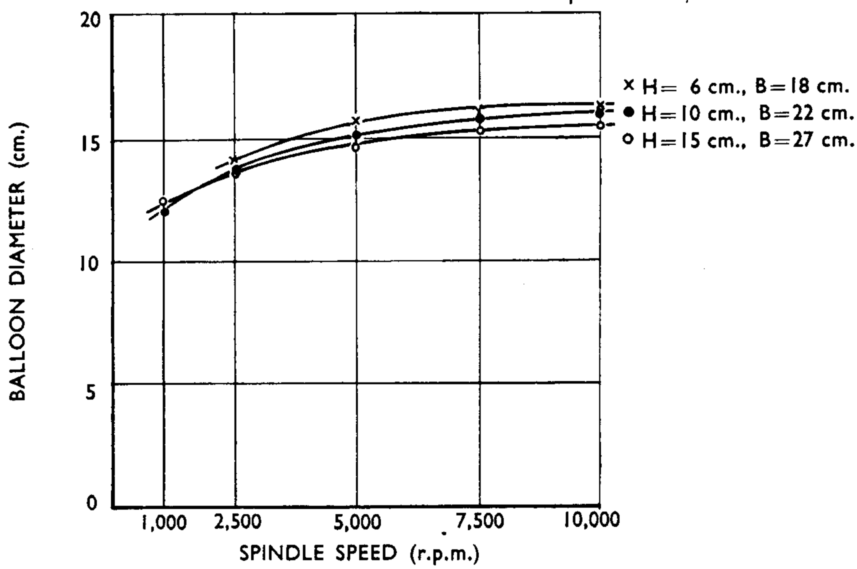



FIG. 44(b)

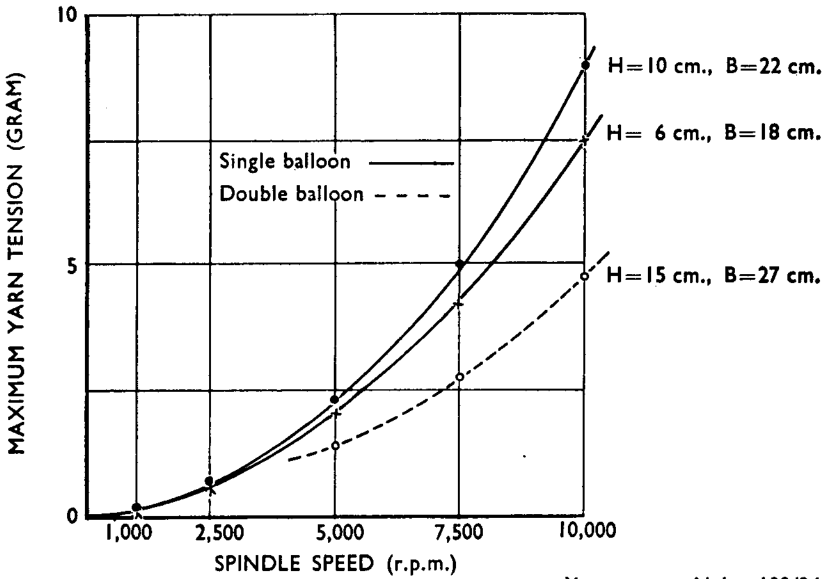



FIG. 45(a)

| | |
|---|---|
| Yarn: | Nylon 100/34 |
| Package: | Tube |
| Diameter: | 7 cm. |
| Yarn Speed: | 50 m./min. |

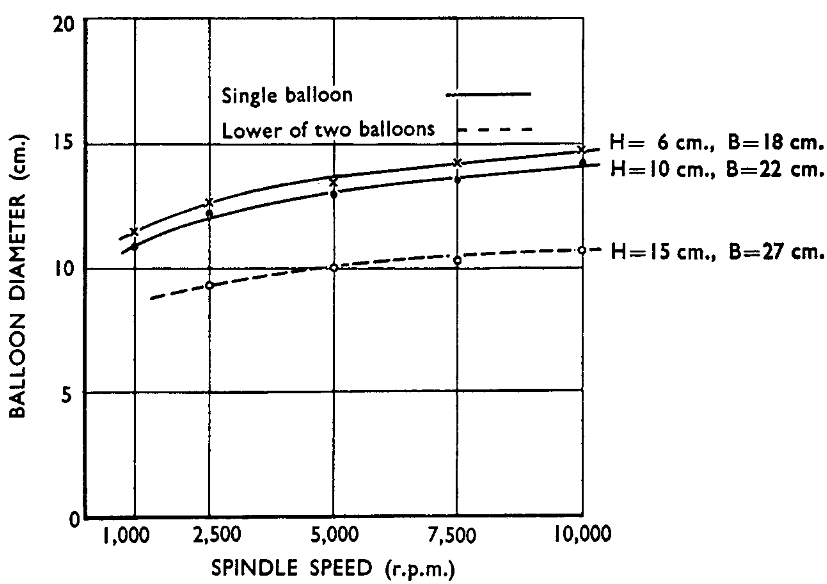



FIG. 45(b)

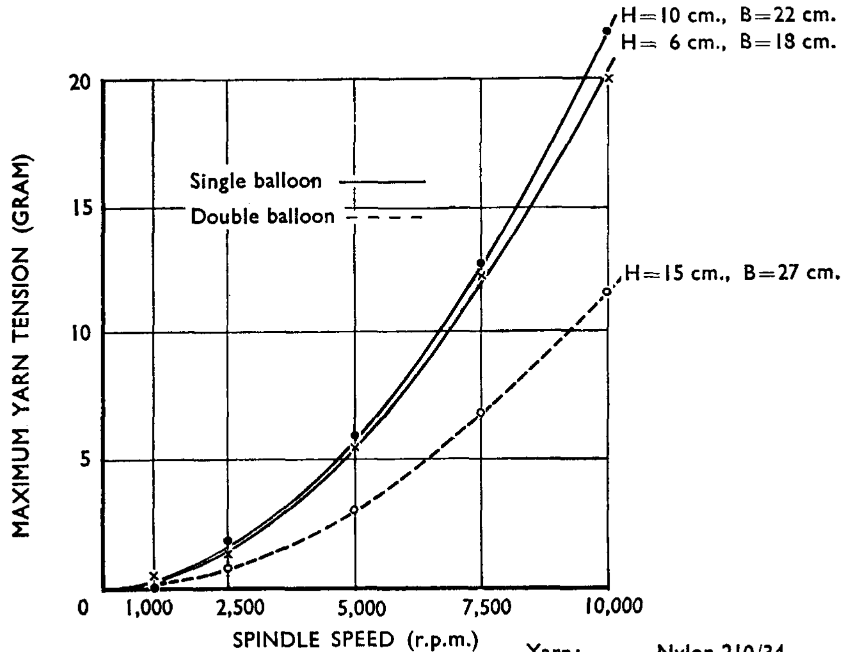



FIG. 46(a)

| | |
|---|---|
| Yarn: | Nylon 210/34 |
| Package: | Tube |
| Diameter: | 7 cm. |
| Yarn Speed: | 50 m./min. |

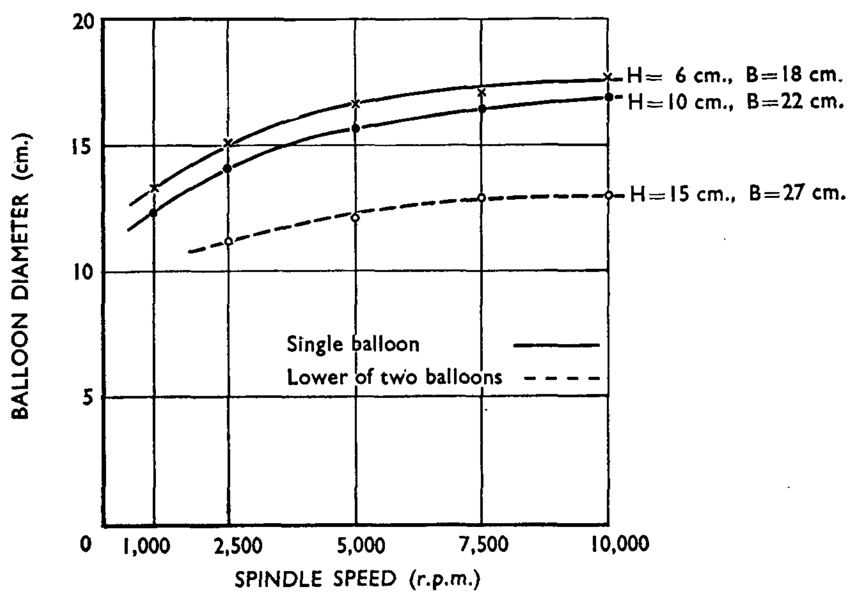



FIG. 46(b)

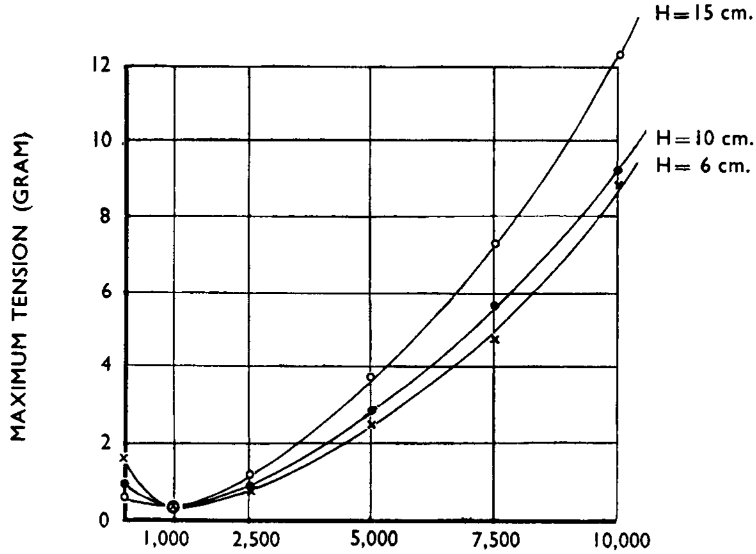



FIG. 47(a)

| | |
|---|---|
| Yarn | Nylon $N_m$170/2 (107 denier) |
| Package: | Tube |
| Diameter | 7 cm. |
| Yarn Speed | 50 m./min. |

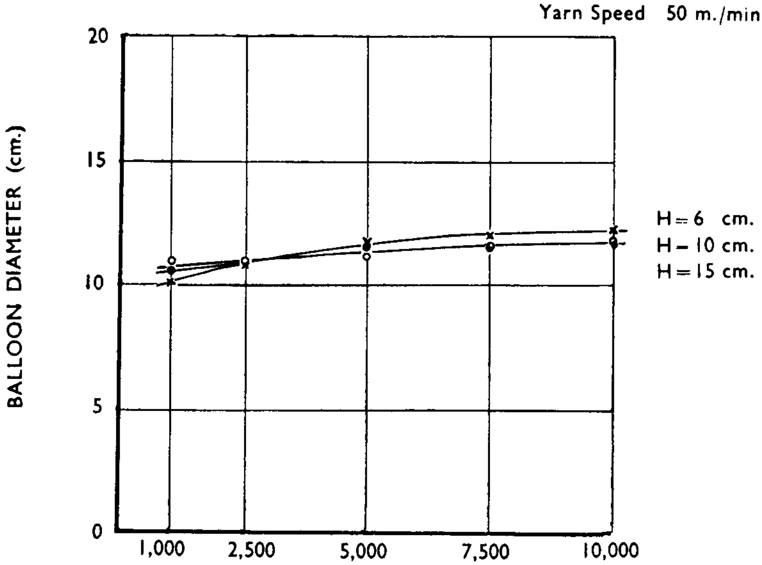



FIG. 47(b)

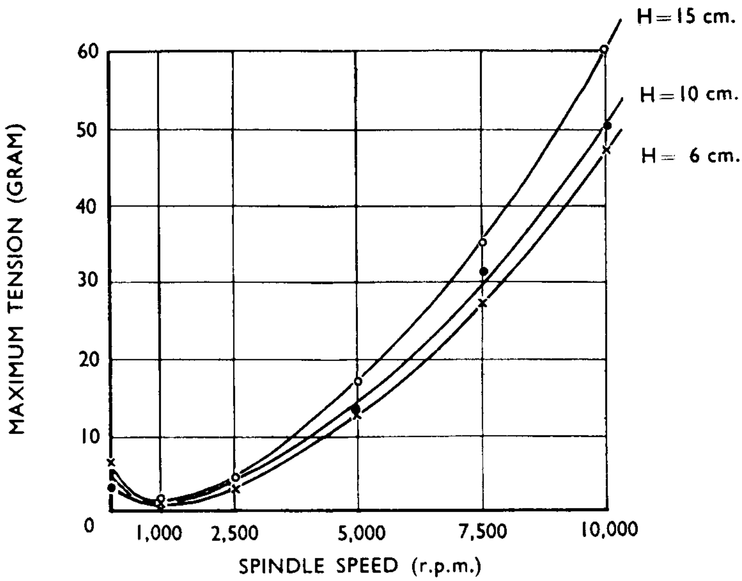



FIG. 48(a)

Yarn: Nylon $N_e$12 (435 denier)
Package: Tube
Diameter: 7 cm.
Yarn Speed: 50 m./min.

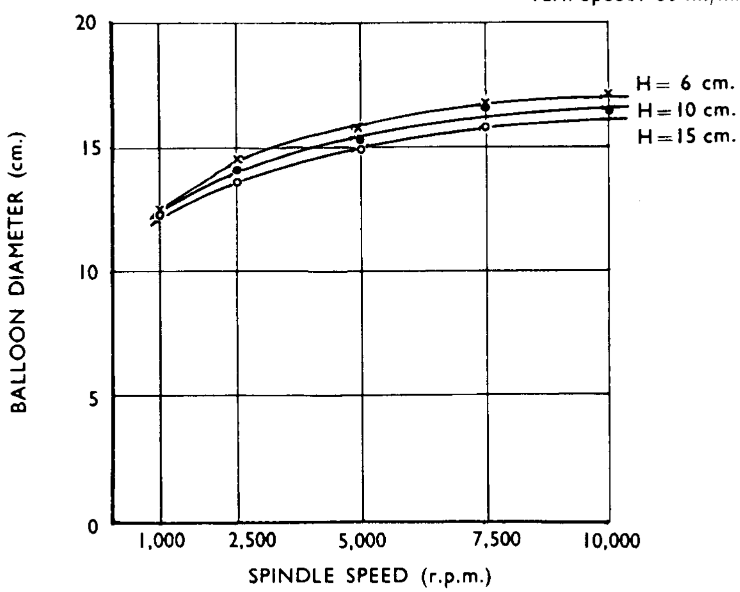



FIG. 48(b)

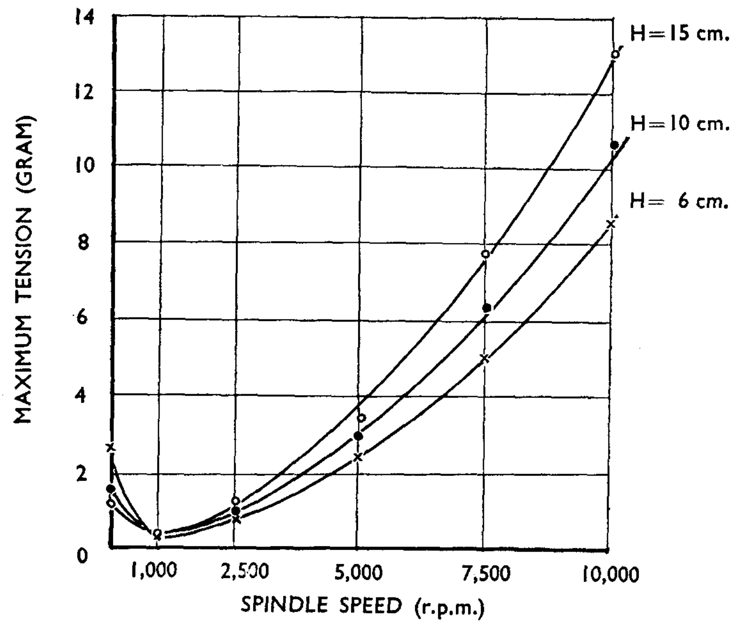



FIG. 49(a)

Yarn: Viscose $N_m$160/2 (114 denier)
Package: Tube
Diameter: 7 cm.
Yarn Speed: 50 m./min.

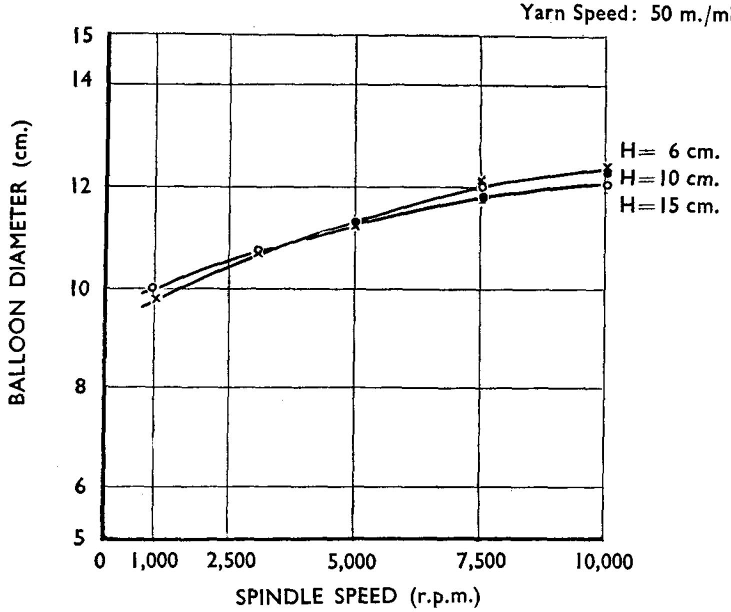



FIG. 49(b)

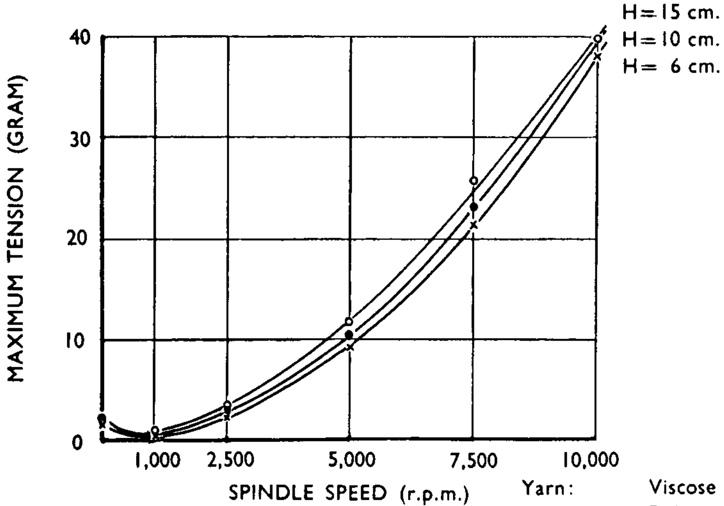



FIG. 50(a)

Yarn: Viscose $N_m30$
Package: Tube (297 denier)
Diameter: 7 cm.
Yarn Speed: 50 m./min.

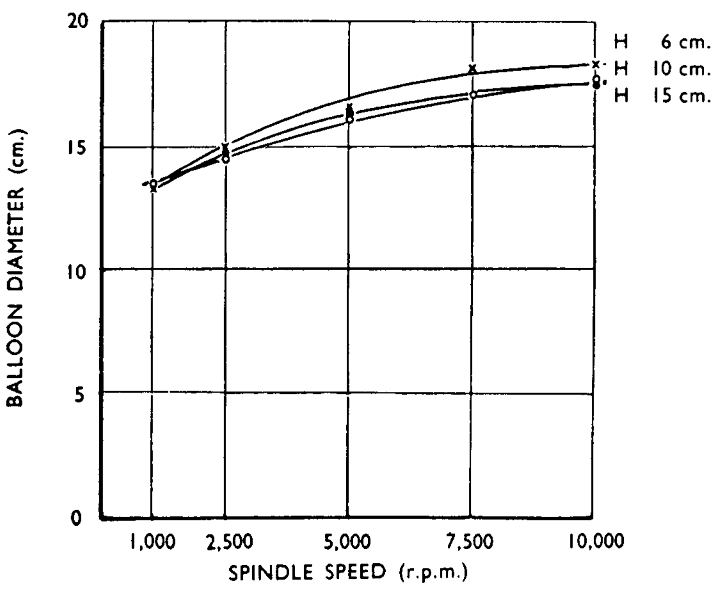



FIG. 50(b)

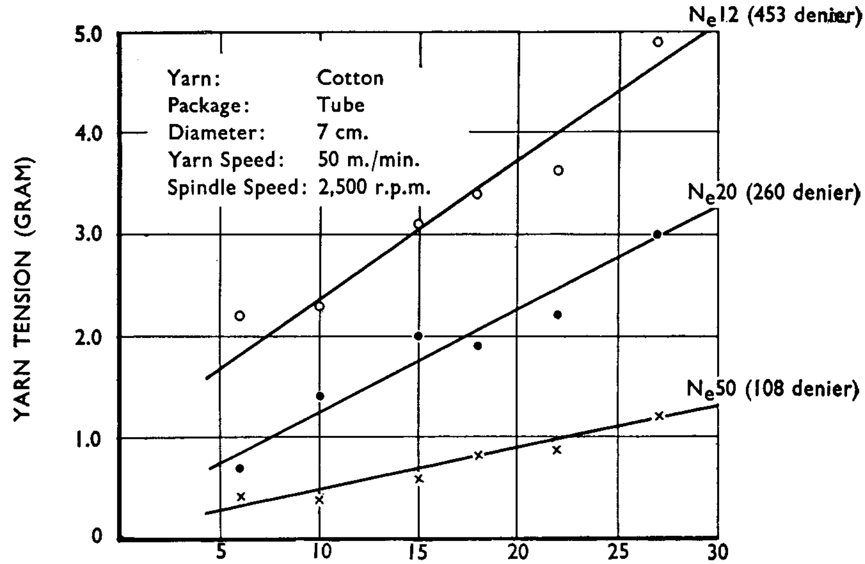



FIG. 51(a)

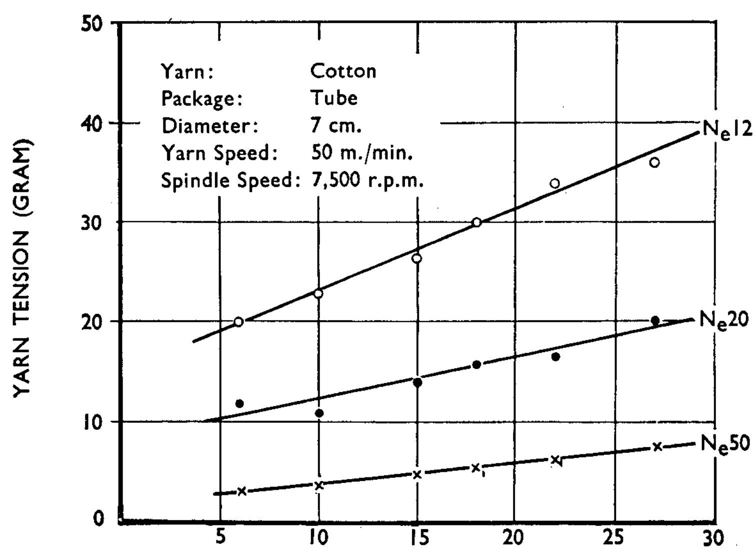



FIG. 51(b)

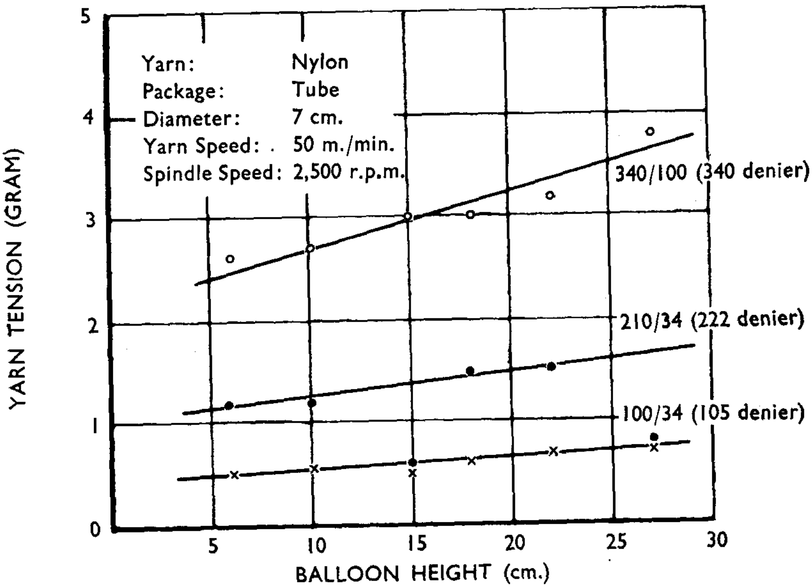



FIG. 52(a)

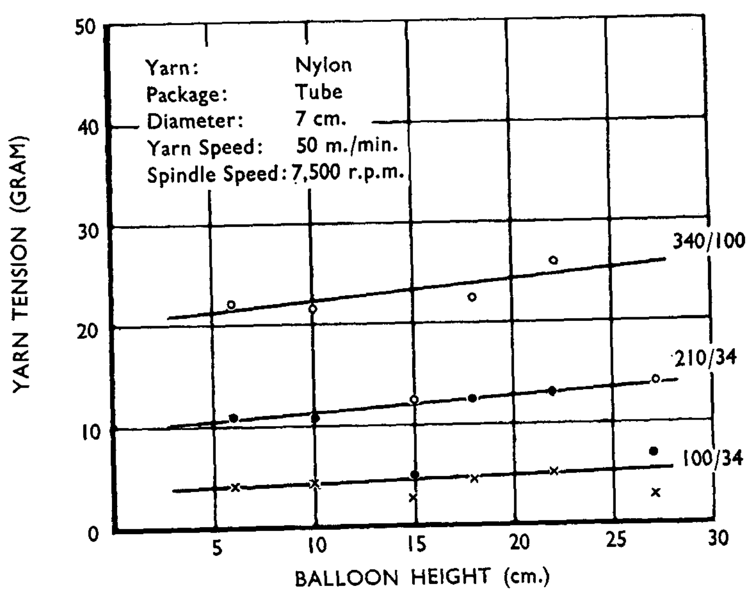



FIG. 52(b)

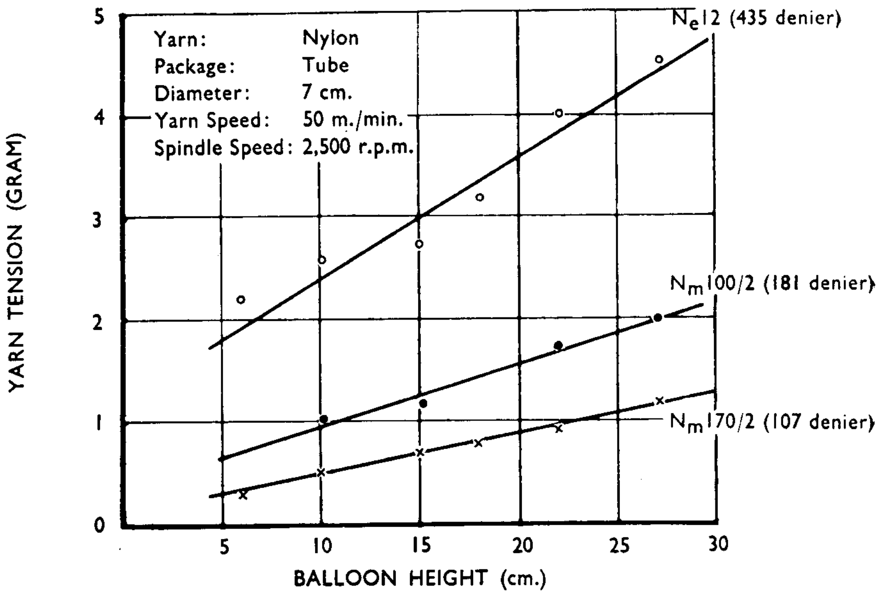



FIG. 53(a)

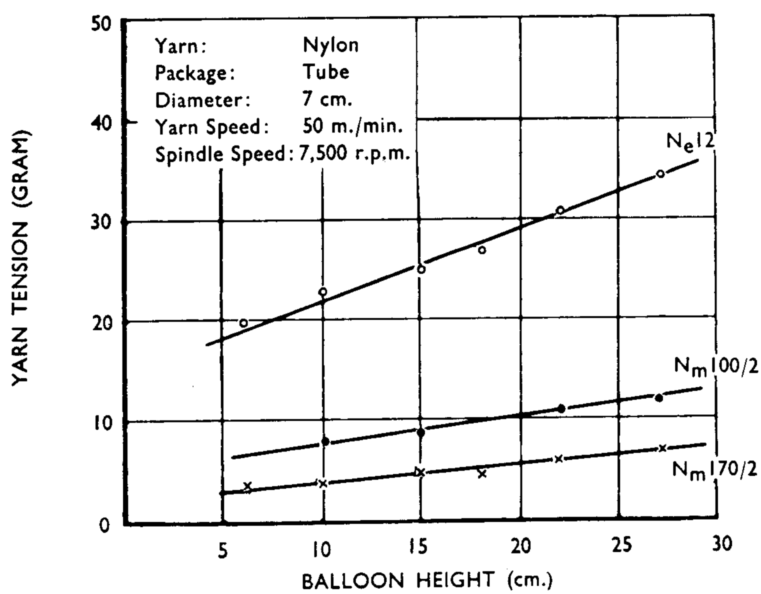



FIG. 53(b)

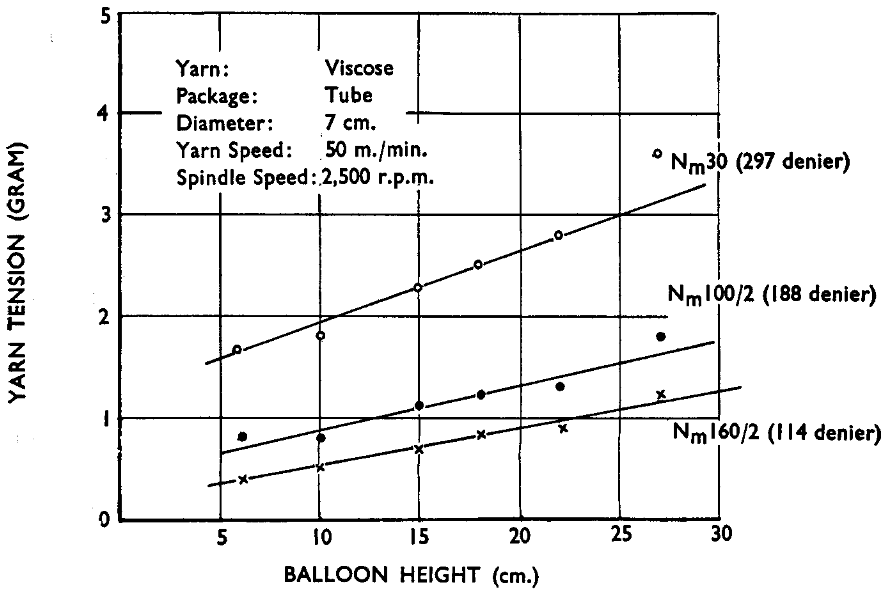



FIG. 54(a)

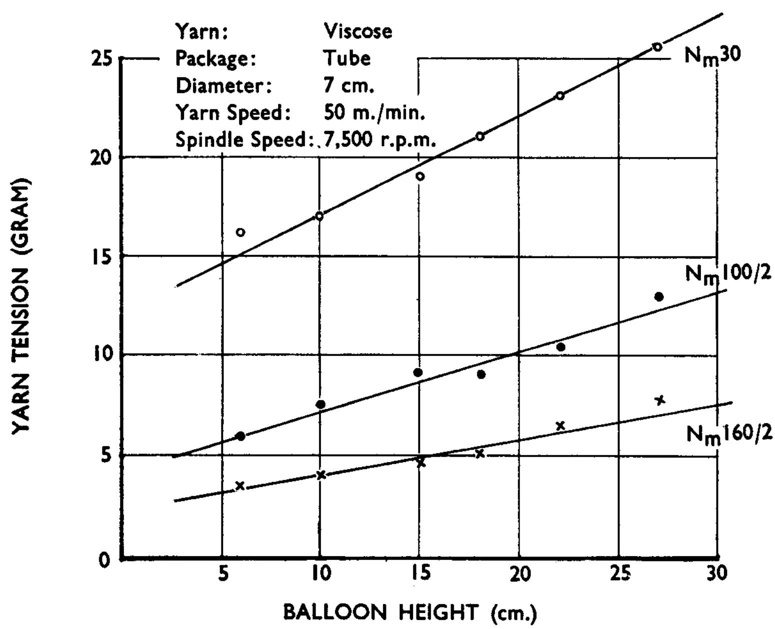



FIG. 54(b)

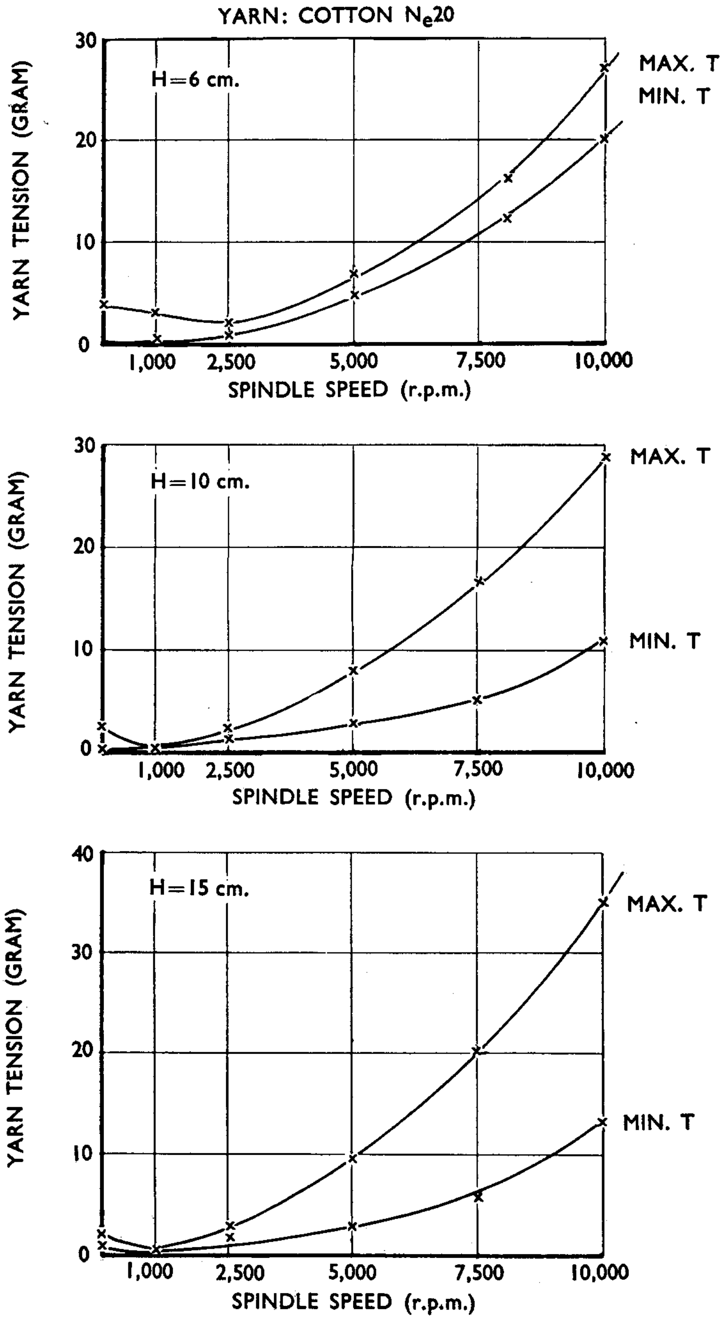

YARN: COTTON $N_e$20
H=6 cm.
MAX. T
MIN. T
YARN TENSION (GRAM)
30
20
10
0
1,000
2,500
5,000
7,500
10,000
SPINDLE SPEED (r.p.m.)
H=10 cm.
MAX. T
MIN. T
YARN TENSION (GRAM)
30
20
10
0
1,000
2,500
5,000
7,500
10,000
SPINDLE SPEED (r.p.m.)
H=15 cm.
MAX. T
MIN. T
YARN TENSION (GRAM)
40
30
20
10
0
1,000
2,500
5,000
7,500
10,000
SPINDLE SPEED (r.p.m.)

FIG. 55

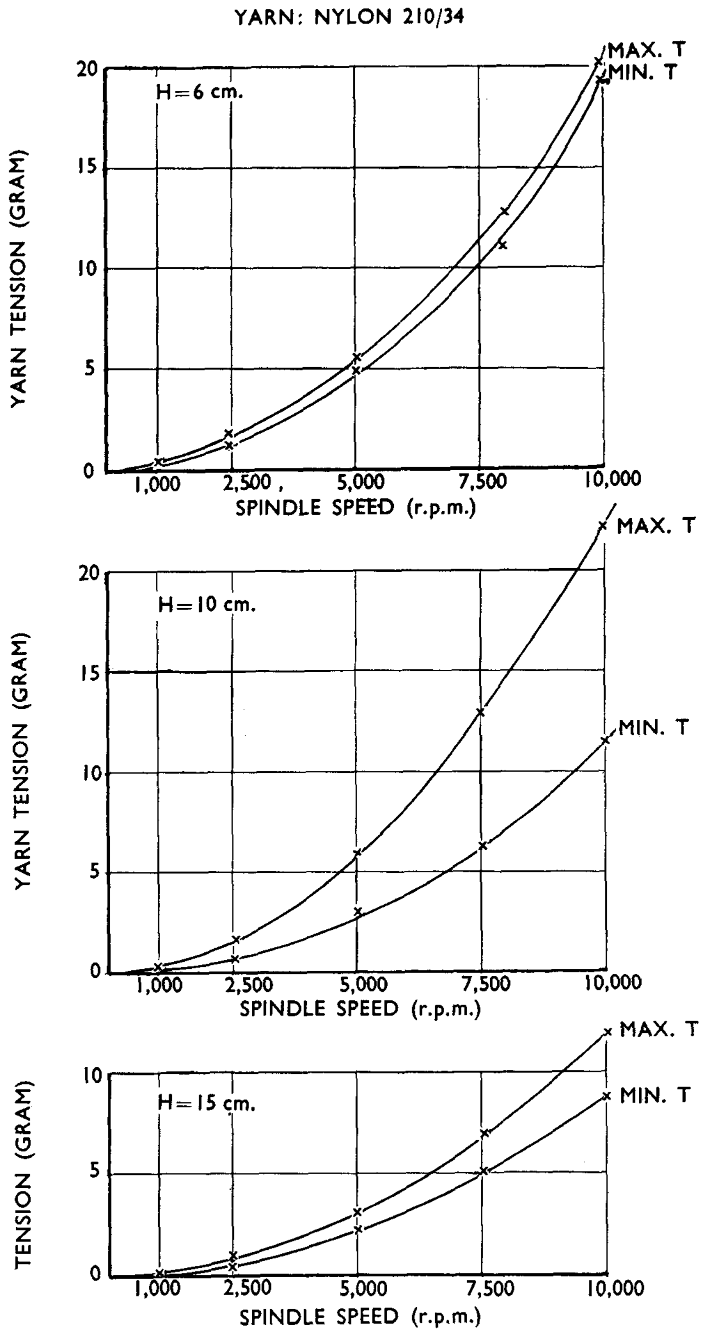

YARN: NYLON 210/34
H=6 cm.
MAX. T
MIN. T
YARN TENSION (GRAM)
20
15
10
5
0
1,000
2,500
5,000
7,500
10,000
SPINDLE SPEED (r.p.m.)
H=10 cm.
MAX. T
MIN. T
YARN TENSION (GRAM)
20
15
10
5
0
1,000
2,500
5,000
7,500
10,000
SPINDLE SPEED (r.p.m.)
H=15 cm.
MAX. T
MIN. T
TENSION (GRAM)
10
5
0
1,000
2,500
5,000
7,500
10,000
SPINDLE SPEED (r.p.m.)

FIG. 56

Maximum and minimum tensions are plotted against spindle speed for different values of $H$ and for two different yarns in Fig. 55 and 56. These curves are typical of staple and continuous filament yarns. For the staple yarn the difference between the maximum and minimum tensions is least at $H=6$ and greater at $H=10$ and $H=15$cm., but for continuous filament yarn the difference at $H=15$ is less than at $H=10$ cm. and only slightly greater than at $H=6$ cm.

### 5.255 Effect of confining ring

A ring fitted between the guide eye and the package to confine the ballooning yarn is often used in ring spinning. The effect of such a ring was investigated in our experiments. A smooth unpolished steel ring of 6 cm. diameter and slotted to allow easy insertion of the yarn, was fitted in a horizontal plane centrally about the spindle axis and at a height of 3 cm. above the top of the package (Fig. 57). It had a circular cross section of 0·5 cm. diameter.

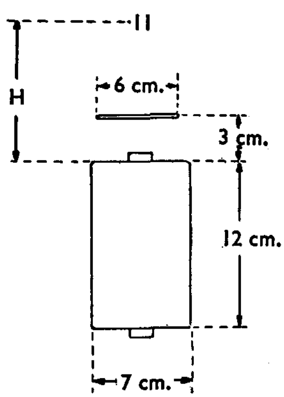



FIG. 57

Fig. 58 shows a plot of Max $T$.v r.p.m. for nylon staple $N_e 12$ and $H=15$ cm, (a) under normal operating conditions and (b) with the ring fitted in the position above. There is a marked reduction in the maximum tension in (b) as the yarn is prevented from ballooning out to the extent it would do if there were no restraining ring. With the particular conditions used in Fig. 58 the maximum tension is reduced to less than 50% of its value by the use of a confining ring.

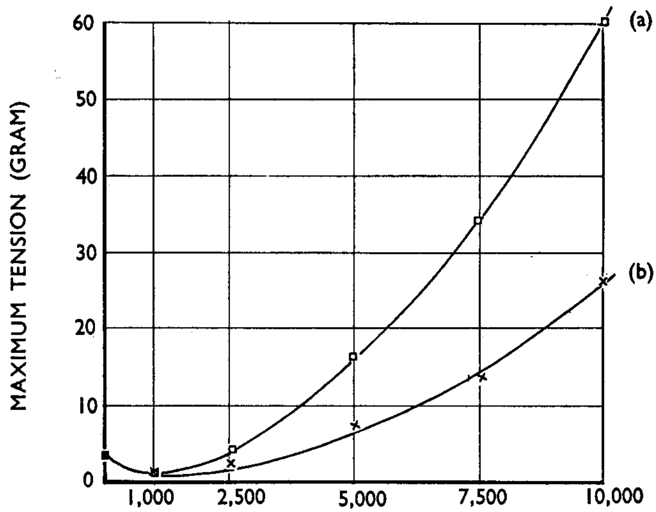



FIG. 58(a)

| | |
|---|---|
| Yarn | Nylon $N_e12$ |
| Package: | Tube |
| Diameter: | 7 cm. |
| Yarn Speed: | 50 m./min. |
| H: | 15 cm. |
| B: | 27 cm. |

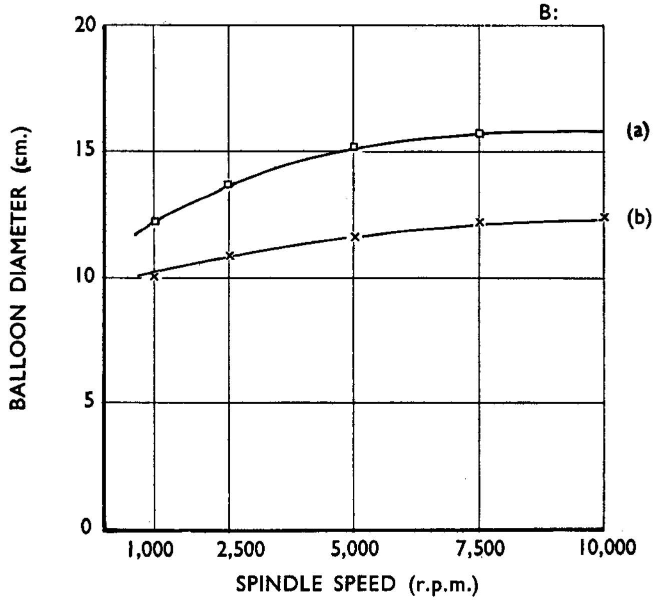



FIG. 58(b)

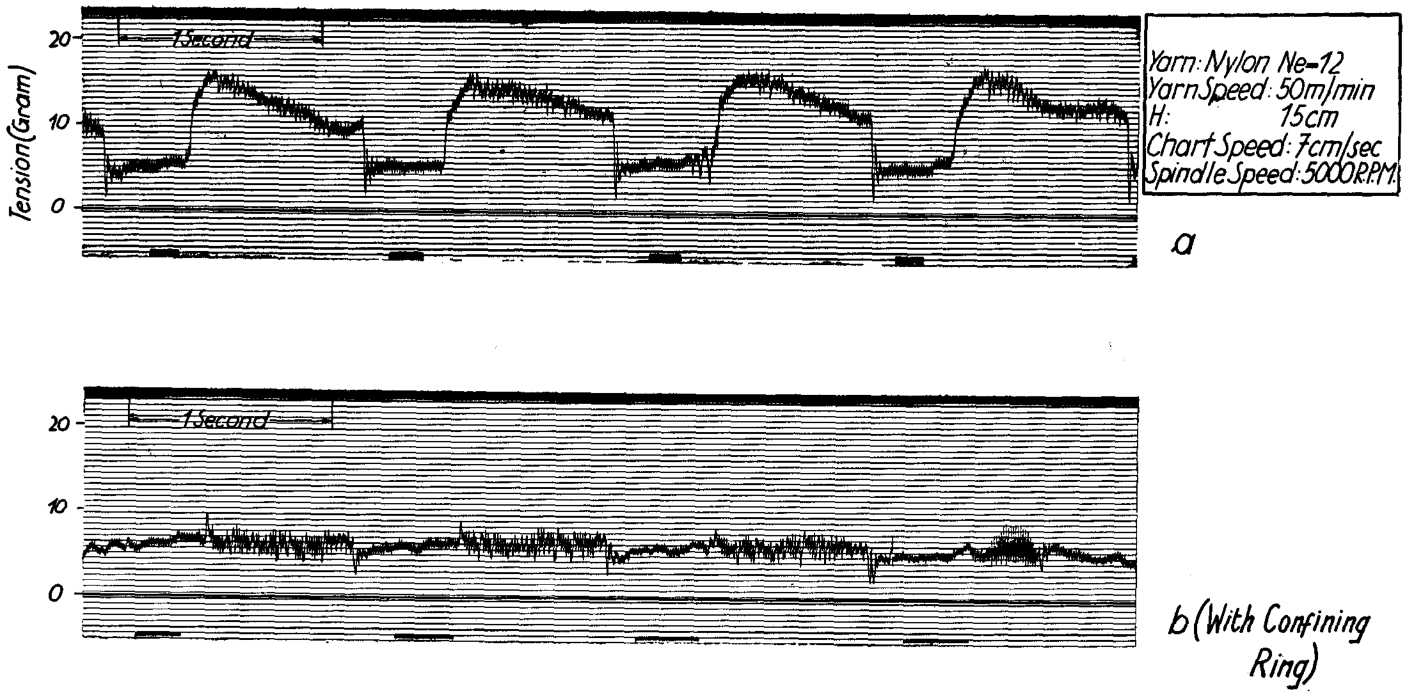

Tension (Gram)
20
10
0
1 Second
Yarn: Nylon Ne-12
Yarn Speed: 50m/min
H: 15cm
Chart Speed: 7cm/sec
Spindle Speed: 5000 R.P.M.
a
1 Second
b (With Confining Ring)

FIG. 59.

Fig. 59 shows the tension charts obtained at a rotational speed of 5,000 r.p.m. Fig. 59(a) shows the normal trace with the usual large periodic variations in tension, and Fig. 59(b) the trace obtained when the confining ring is used. The sections of minimum tension can be identified in both traces (almost directly above the black markers) but whereas in (a) the tension rises to a maximum and then falls periodically, in (b) there is very little increase in the mean level of the tension, although there is a greater variation about the mean as the yarn rubs on the ring. If a double balloon tends to form as the yarn comes off the top of the package, the ring does not prevent this, but it does limit the diameter of a single balloon and thus prevents a large increase in tension.

**5.26 Miscellaneous results on yarn loops**

A comparison of the results for yarns of similar denier in Fig. 31-42 showed that continuous filament yarns had larger balloon diameters than staple yarns of comparable denier. This appeared to be due to differences in air drag so a number of simple experiments were carried out in which the behaviour of different yarns under the same conditions was compared. Two loops of yarn, one of 100/34 (105 denier) continuous filament nylon and the other of staple nylon $N_m$ 170/2 (107 denier) were fixed at opposite sides of a 7 cm. diameter package as in Fig. 60.

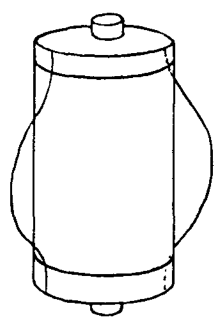


FIG. 60

The ends of the yarn are securely held by two strips of sellotape at the top and bottom of the package leaving a 14 cm. length of free yarn. The loops of yarn are fixed on opposite sides of the package which is rotated at 1,000 and 5,000 r.p.m. The loops are observed using a stroboscope set at 2,000 and 10,000 r.p.m. respectively. This superimposes the images of the two yarns, and observing from above, it is possible to compare the extent to which the two loops are deflected. If there were no air drag we would expect both loops to lie in a radial plane due to centrifugal force. Because of air drag the loops of yarn are deflected from the radial direction and the staple yarn is deflected more than the continuous filament yarn.

This results in the staple yarn having a smaller balloon diameter than the continuous filament yarn, and shows how the air drag varies with the nature of the yarn surface.

During these experiments the influence of twist on the continuous filament yarn was observed. Provided there was sufficient twist in the yarn to keep the filaments together, the staple yarn was always deflected out of the radial plane more than the continuous filament yarn. When all the twist was removed from the filament yarn however it was deflected from the radial plane more than the staple yarn. This shows that the air drag on a yarn whose filaments are separated is much greater than on a yarn whose filaments are twisted together.

In addition to the above experiment on loops of yarns of comparable denier but of different surfaces, a similar experiment on loops of yarn of different deniers was carried out. A loop of 100/34 continuous filament yarn and a loop of 1,200 denier cotton yarn were fixed to the package as above and examined with a stroboscope. The continuous filament yarn was very much more depressed out of the radial direction than was the heavy staple yarn. This result does not contradict the earlier one in which the staple yarn was depressed more than the continuous filament yarn but illustrates the relative effects of centrifugal force and air drag on yarns of different denier.

## 5.3 Stationary packages

### 5.31 General

The experiments on rotating packages showed that the package diameter influenced both yarn tension and balloon diameter. The change in package diameter during a test, however, was small enough for the results to be considered as applying to a package of constant diameter.

With yarn speeds of 250, 500 and 750 m/min., the package diameter decreases so rapidly that the change which would occur during a test could not be neglected. It was necessary, therefore, after measuring the tension at each yarn speed to rewind the package to 7·1 or 7·2 cm. This ensured that the tension measurements were not significantly influenced by changes in package diameter. Tension was measured on continuous filament and staple yarns and the results are the means of at least two measurements.

With a stationary package and high yarn speeds, the clearly defined balloon obtained with a rotating package is not observed, although the yarn does rotate about the package as it is drawn off. Consequently no precise measurements of balloon diameter as were made with rotating packages were possible. In general, however, balloon diameter increased with package diameter and yarn denier, but only slightly increased with yarn speed. Increasing $H$ decreased balloon diameter.

### 5.32 Tension charts

Fig. 61 shows the tension charts obtained for nylon $N_m$ 170/2 wound off a still package at speeds of 250, 500 and 750 m/min. The yarn tension is low but increases with yarn speed. A slight periodicity can be seen at 250 m/min., which becomes more marked at 500 and 750 m/min. (AA in Fig. 61). This corresponds

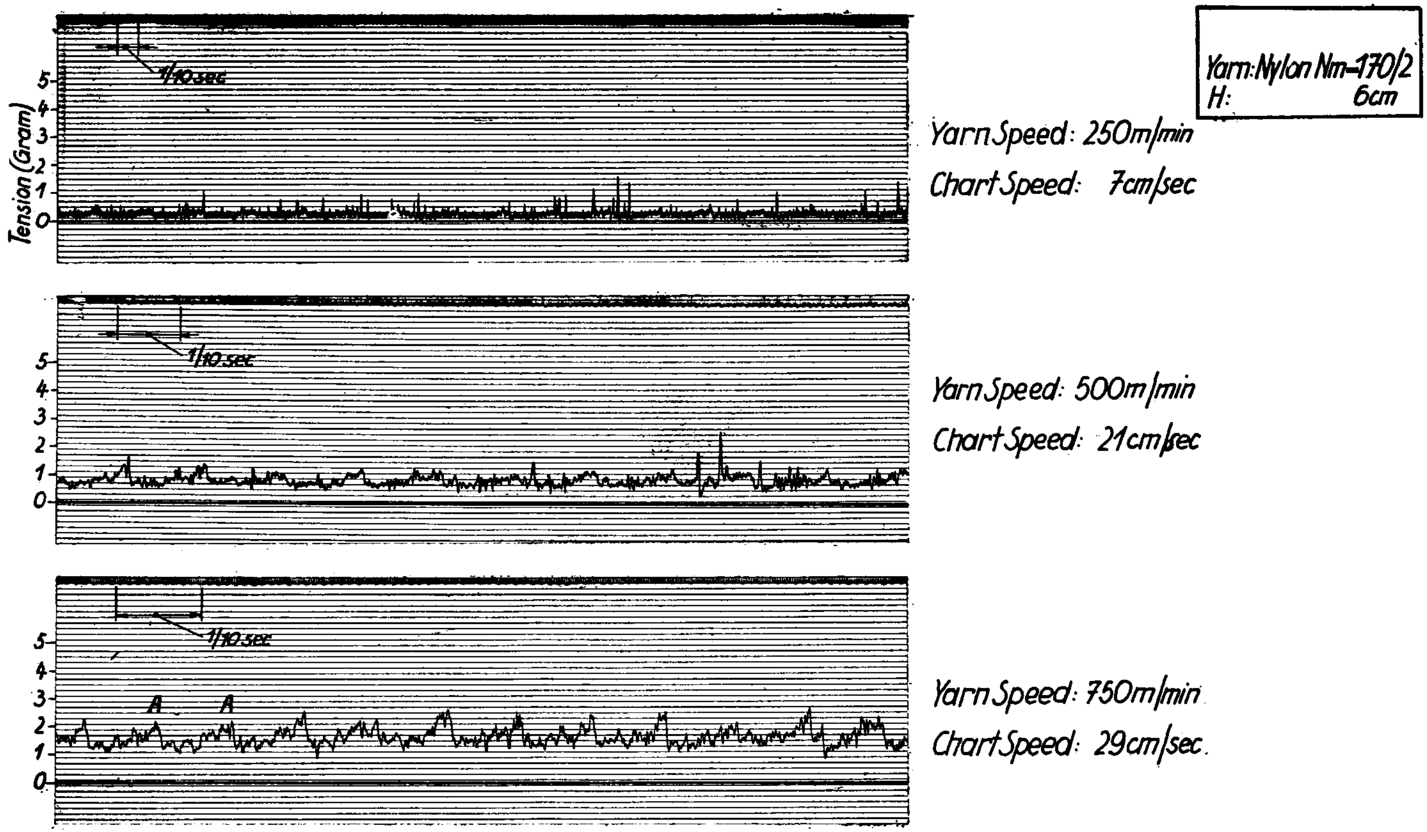

Yarn: Nylon Nm-170/2
H: 6cm
Tension (Gram)
5
4
3
2
1
0
1/10 sec
Yarn Speed: 250m/min
Chart Speed: 7cm/sec
Yarn Speed: 500m/min
Chart Speed: 21cm/sec
A
A
Yarn Speed: 750m/min
Chart Speed: 29cm/sec.

FIG. 61.

to a yarn length of approximately 100 cm., which is the length of yarn laid on a 7 cm. diameter package during a complete traverse cycle of the winding machine. Occasionally, 'instantaneous' maxima occur in the tension charts, but these are not included in the calculation of the periodic maxima. They occur quite randomly and are probably due to variations in the winding of the package.

### 5.33 Effect of package diameter

Fig. 62-65 show the variation of maximum tension with yarn speed for different yarns and package diameters. Each tension measurement was made on the correct package diameter, the package being rewound after each measurement, so that even at 750 m/min., the reduction in package diameter during a test was not more than 3 or 4 mm. For all the yarns, at both $H=6$ cm. and $H=15$ cm., the tension increases as package diameter decreases, and as yarn speed increases.

### 5.34 Effect of yarn type and denier

Fig. 66 and 67 show the variation of maximum tension with yarn speed for various yarns at package diameters of 3.5 cm and 7 cm and at $H=6$ cm and 15 cm. They show very clearly the increase in tension with increasing yarn speed and with increasing yarn denier. These relations hold at both package diameters and both values of $H$. In all cases the staple nylon $N_m$ 170/2 (107 denier) has a higher tension than the continuous filament nylon 100/34 (105 denier).

### 5.35 Effect of *H*

Table 6 compares the tensions at $H=6$ cm. and $H=15$ cm. for the staple and continuous filament yarns at package diameters of 3.5 cm. and 7 cm.

**TABLE 6**

**Comparison of maximum tension at $H=6$ cm and $H=15$ cm.**

| Yarn | 3.5 cm. Diameter | 7 cm. Diameter |
|---|---|---|
| Nylon .. | Tension at $H=6$ cm. is $<,=$ or $>$ Tension at $H=15$ cm. | Tension at $H=6$ cm. is $<,=$ or $>$ Tension at $H=15$ cm. |
| $N_m$ 170/2 .. | $\leq$ | $<$ |
| $N_m$ 36 .. | $<$ | $<$ |
| 100/34 .. | $>$ | $\leq$ |
| 340/100 .. | $>$ | $>$ |

Examination of this table shows:

1. Except for the 100/34 yarn the results show the same trends for both package diameters.
2. For both staple yarns the tension at $H=6$ cm. is less than the tension at $H=15$ cm.
3. For the continuous filament yarn 340/100 the tension at $H=6$ cm. is greater than the tension at $H=15$ cm. but for 100/34 it depends upon the package diameter.

[*continued on page 100*]

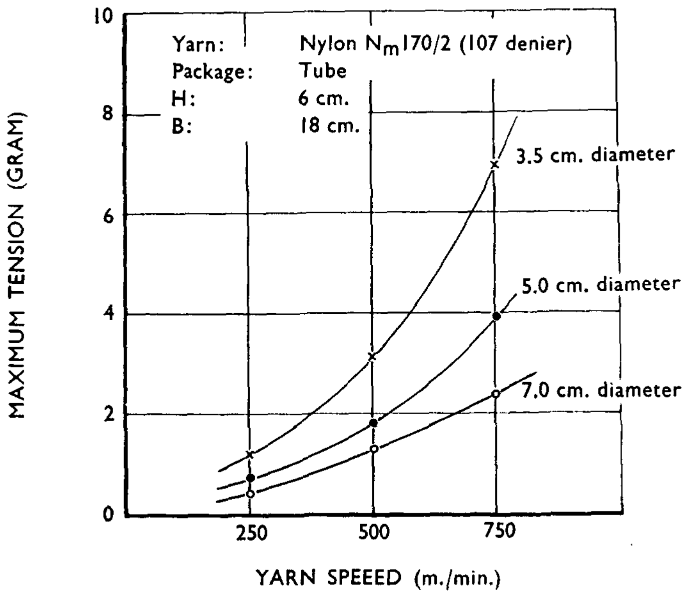



FIG. 62(a)

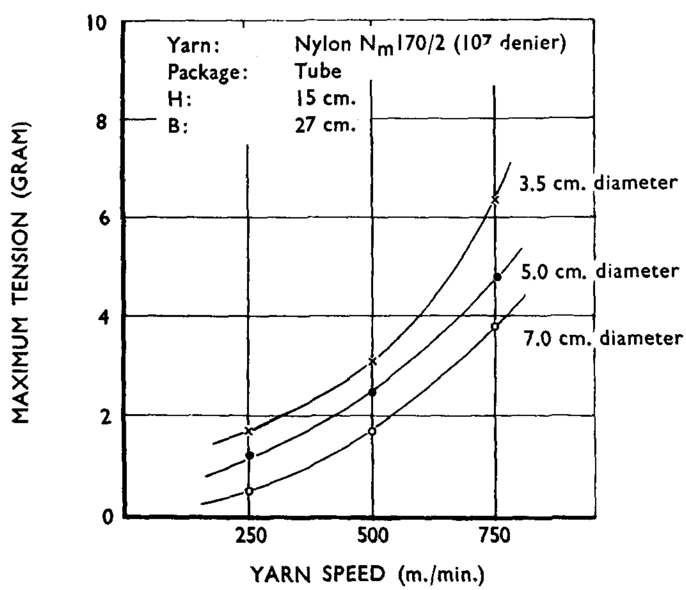



FIG. 62(b)

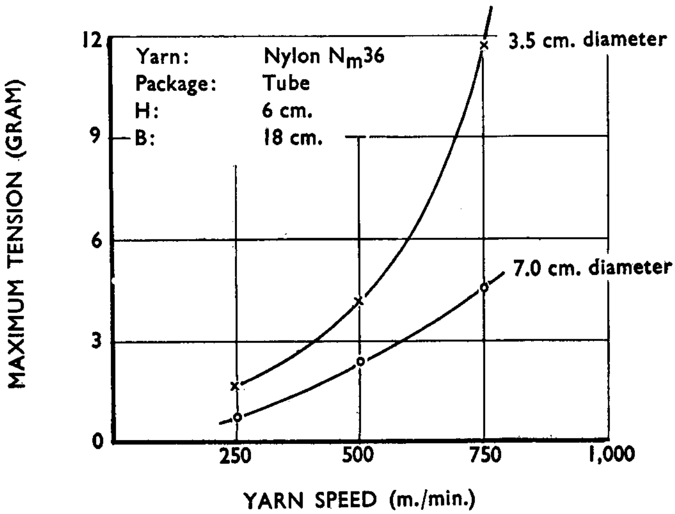



FIG. 63(a)

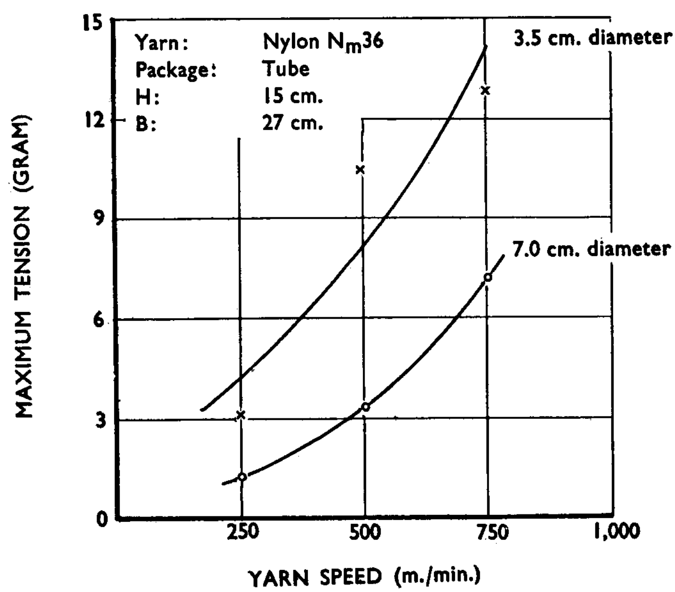



FIG. 63(b)

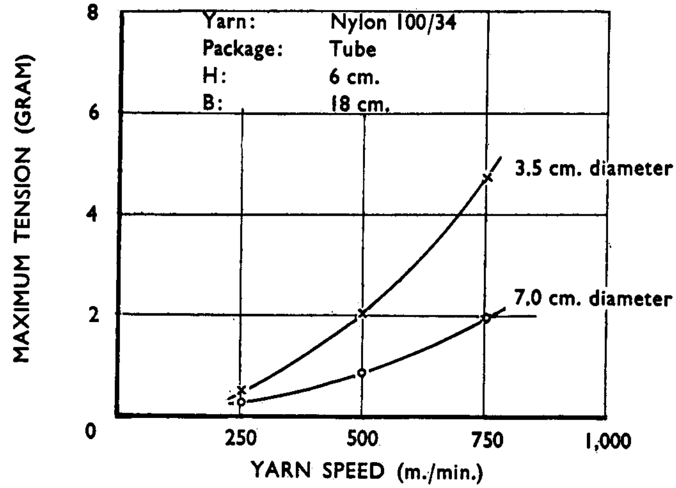



FIG. 64(a)

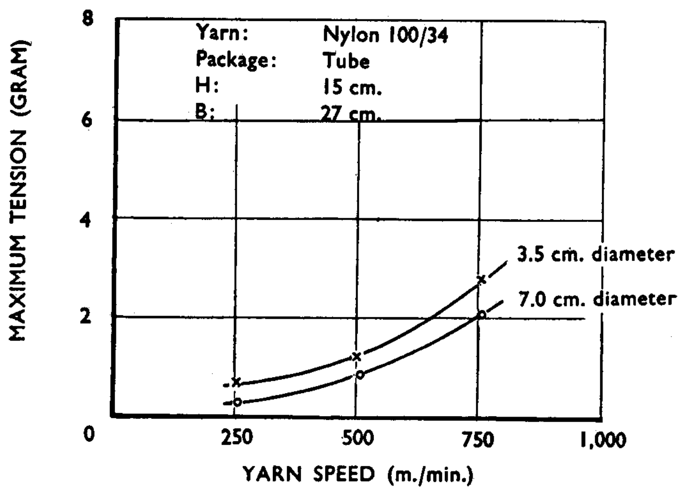



FIG. 64(b)

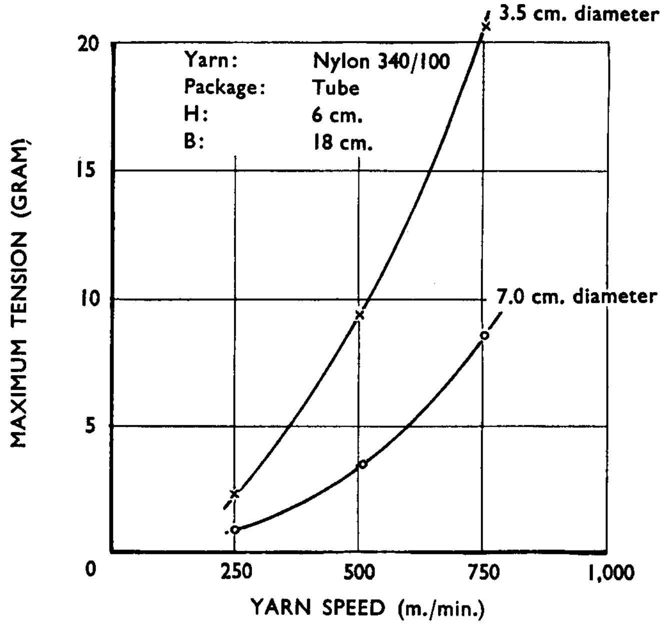



FIG. 65(a)

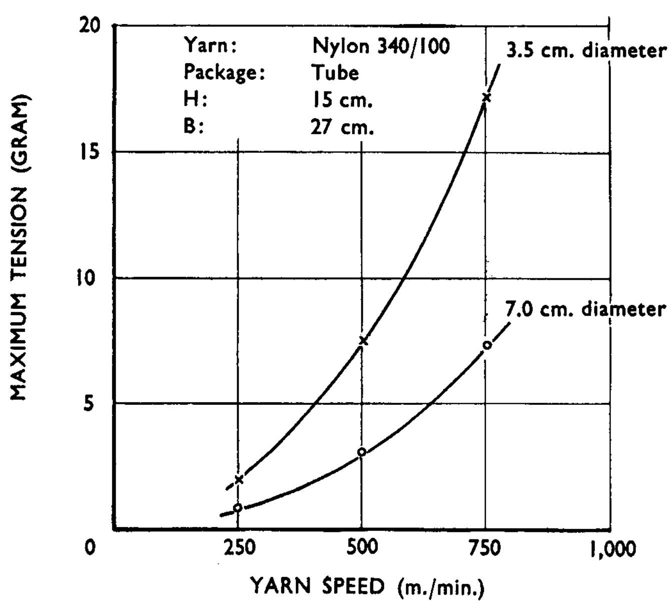



FIG. 65(b)

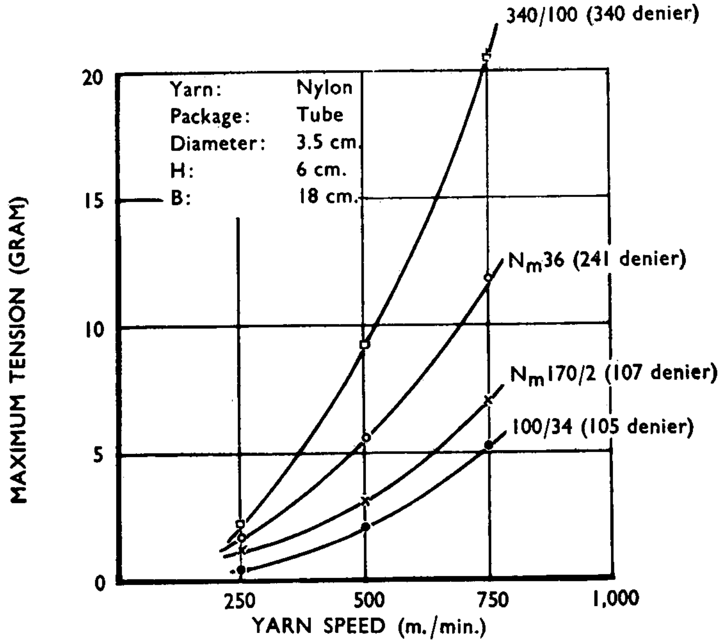



FIG. 66(a)

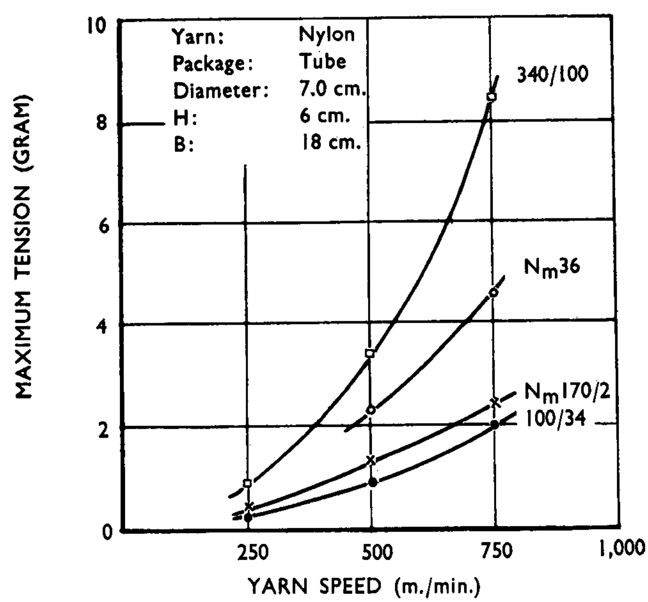



FIG. 66(b)

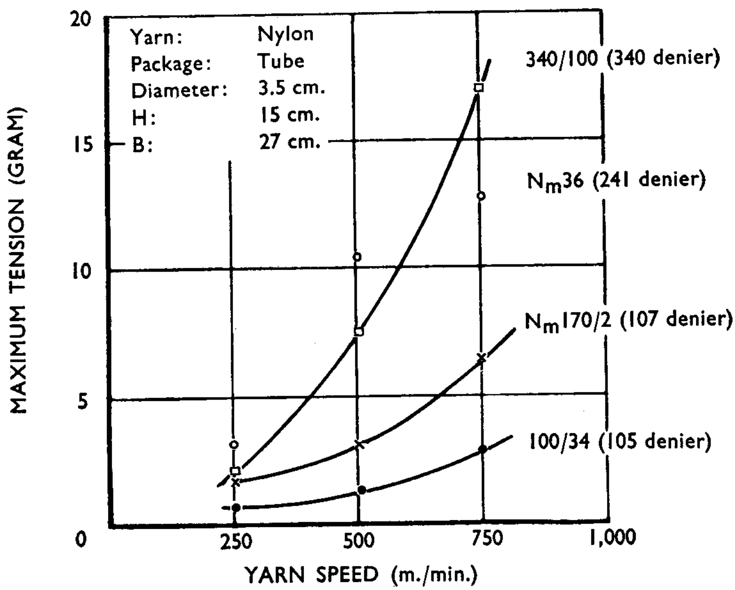



FIG. 67(a)

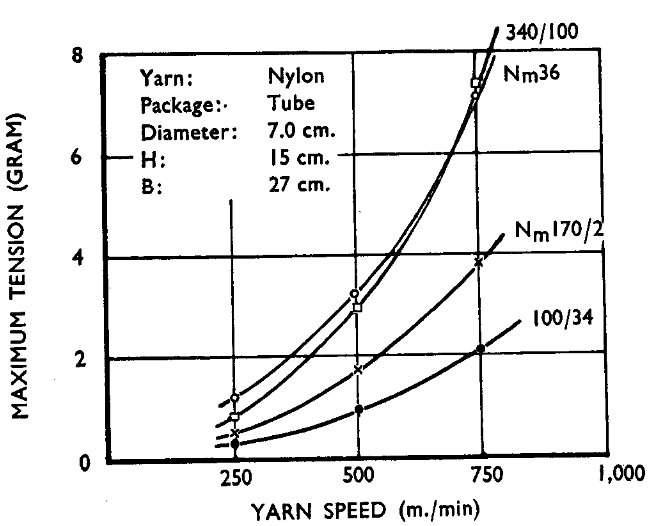



FIG. 67(b)

## 6. DISCUSSION

### General

In discussing the experimental results and drawing conclusions from them, it is important to realise that values of yarn tension and balloon diameter represent mean values. The tension charts (Fig. 18-21) show that large differences can occur between successive maxima. There are several reasons for this. One is the inherent variability of a textile yarn itself—its mass or twist per unit length may vary. This is supported by the fact that variations in successive maxima are greater for staple than for continuous filament yarns. Another is the variation in the winding of the package itself. Although care was taken to ensure that winding conditions remained constant, it is most unlikely that any coil of yarn wound off the package will be identical or will be wound off under identical conditions to any other coil. Despite the variations which occur between successive values, the reproducibility of mean tensions is very satisfactory and has enabled several reliable conclusions to be drawn from the results.

All measurements were made under laboratory conditions and not under actual operating conditions. The measurements were made on yarn taken off a single package, and the apparatus was designed to protect the yarn from the influence of air movement due to external disturbances. Such ideal conditions do not exist in practice and it is possible that excessive air movement due to the large number of positions on a machine may have a considerable effect on yarn behaviour.

### Rotating packages

The observational results in section 5.21 showed a number of interesting features. The 'plucking' balloon was not a common occurrence but had a very large effect on yarn tension. It was observed only with a coarse cotton yarn because the projecting fibres caused the yarn to cling to the package. The effect never occurred with continuous filament yarns and would not cause any difficulty in a normal uptwisting process. The 'vibrating' balloon was observed only when a double balloon existed, and although it had no effect on yarn tension it could possibly damage the yarn if the projecting package former which the yarn touches, were not perfectly smooth. 'Loose-windings' however were a much more serious cause of trouble. The type of package and the winding of the yarn on the package had a very large effect on the occurrence of loose windings. When loose windings are present both the balloon diameter and the yarn tension have fairly constant values. The yarn take-off point does not rise and fall along the package so the usual maxima and minima in yarn tension do not occur. This constancy of yarn tension is very desirable but as it represents an unstable state there is always the danger that the number of loose windings will increase and the yarn break down.

### Balloon shape and corresponding yarn tension

Observation of the balloon showed that a large variety of shapes occurred under the various conditions employed. The most frequent form was that in which a single and double balloon alternated regularly, but often only a single balloon existed whose height varied with the position at which the yarn left the package. Occasionally double balloons alternating with other multiple balloons occurred. Sometimes it was noted that a regular pattern of balloon shapes would be interrupted for no obvious reason. The yarn may regularly change from a single to a double balloon and then suddenly instead of forming a double balloon, a single balloon would persist for the period when one would expect a double balloon, after which the regular pattern of alternating single and double balloons would continue. The tension chart at 10,000 r.p.m. in Fig. 18 shows this effect. There are four sections of low tension corresponding to a double balloon but where one would expect a fifth, the low tension and double balloon do not occur.

Although this irregularity in the normal behaviour is sometimes observed there are several interesting features which consistently occur. (1) If single and double balloons alternate, the double balloon always occurs when the yarn is taken off near the top of the package, and the single balloon when the yarn is taken off the lower part of the package. (2) Double balloons may occur when the yarn comes off the bottom of the package, but then it is usual for three or even four balloons to form when the yarn is taken off the top of the package. (3) A double balloon always corresponds to a significantly lower tension than a single balloon, but the difference in tension corresponding to a double balloon and three balloons is not large. (4) Whereas the tension corresponding to a single balloon varies considerably depending upon the height of the balloon (*i.e.* the point at which the yarn leaves the package) the variation in tension with a double balloon as the yarn moves up and down the package is very small. There are, therefore, a number of advantages in operating under conditions which produce a double balloon; the tension is lower and the variations in tension are smaller, but there is the possibility of damage to the yarn if it makes contact with a rough surfaced former.

Examination of the tension charts, *e.g.* at 7,500 and 10,000 r.p.m. in Fig. 18 shows that as the balloon shape changes from single to double, the tension often falls instantaneously to a very low value. Because of their brief duration, only a tension recorder with a high speed of response could record such momentary changes in tension. Such sudden changes in tension however may have very important consequences during yarn processing and may affect yarn quality. Instantaneous maxima also occur which are much larger than the maximum tensions normally obtained and could easily cause the yarn to break.

**Factors governing yarn tension and balloon shape**

The experimental results which have been obtained confirm the theoretical considerations of section 3. With rotating packages the centrifugal force is an important factor governing yarn tension. Both the Coriolis force and the air drag have an effect but it is small in comparison with that of the centrifugal force. The influence of yarn speed on the tension (Fig. 27 and 28), and the comparison of continuous filament and staple 100 denier nylon yarns show that these forces do have an effect.

Mack and Smart (references 9.07, 9.08) in their experiments on rotating yarns of fixed length have shown the effect of air drag on the yarn path. At normal atmospheric pressures three dimensional yarn paths similar to those in Fig. 22-26 were observed, but at low air pressures (3 mm mercury) the air drag effect was negligible and the yarn path occupied a vertical radial plane. In their experiments Mack and Smart rotated the ends of their yarn synchronously so that with no air drag the yarn path lies in a vertical radial plane.

Many factors influence the balloon shape and corresponding yarn tension of which the most important are—rotational speed, the height $H$ of the guide eye above the package, yarn denier and type (whether continuous filament or staple). Yarn speed and package diameter have an effect which is relatively small so nearly all the results were obtained at one yarn speed (50 m/min.) and one package diameter (7 cm.). Other variables such as the shape of the package and the nature of the winding on the package have not been investigated. The influence of the more important variables governing tension and balloon shape will be considered separately.

**Effect of spindle speed**

The rotational speed of the yarn depends upon the spindle speed, yarn speed and package diameter, although the angle at which the yarn is laid on the package also has some slight effect. In our experiments in which yarn speed and package diameter were effectively constant, the rotational speed of the yarn depended only on the spindle speed. All the experimental results showed that tension increases with spindle speed except for staple yarns at low spindle speeds. Staple yarns wound off a stationary package have a higher tension than when wound off a package rotating at 1,000 r.p.m. Not only is the tension at zero r.p.m. greater but the variations in tension are very much larger than at 1,000 r.p.m. The tension charts in Fig. 18 at zero and 1,000 r.p.m. clearly show the differences which occur. This does not happen with continuous filament yarn (Fig. 21). The surface of a package wound with staple yarn is very much rougher than one wound with a filament yarn. Thus pulling a staple yarn over such a surface of a stationary package requires a greater force than pulling a continuous filament yarn over a smooth surfaced package. When the spindle rotates at 1,000 r.p.m. the yarn is no longer drawn along the surface of the package and the tension becomes much lower.

The simplest relation which can be assumed to exist between the maximum tension and the spindle speed is of the form $T=Ax^n$ where $T$ is the maximum tension, $x$ the spindle speed and $A$ and $n$ are constants. $\text{Log}_{10}T$ and $\log_{10}x$ ($x$ being the spindle speed in thousands) have been plotted in Fig. 68-71 for all yarns at $H=10$ cm., and a linear relation found between them. In drawing the straight lines the points at 1,000 r.p.m. were neglected as several factors make these values less reliable than those at higher spindle speeds; the possible error in setting the spindle speed is greater, and the percentage error in measuring the tension, which is quite low at 1,000 r.p.m. is very much greater than at the higher spindle speeds.

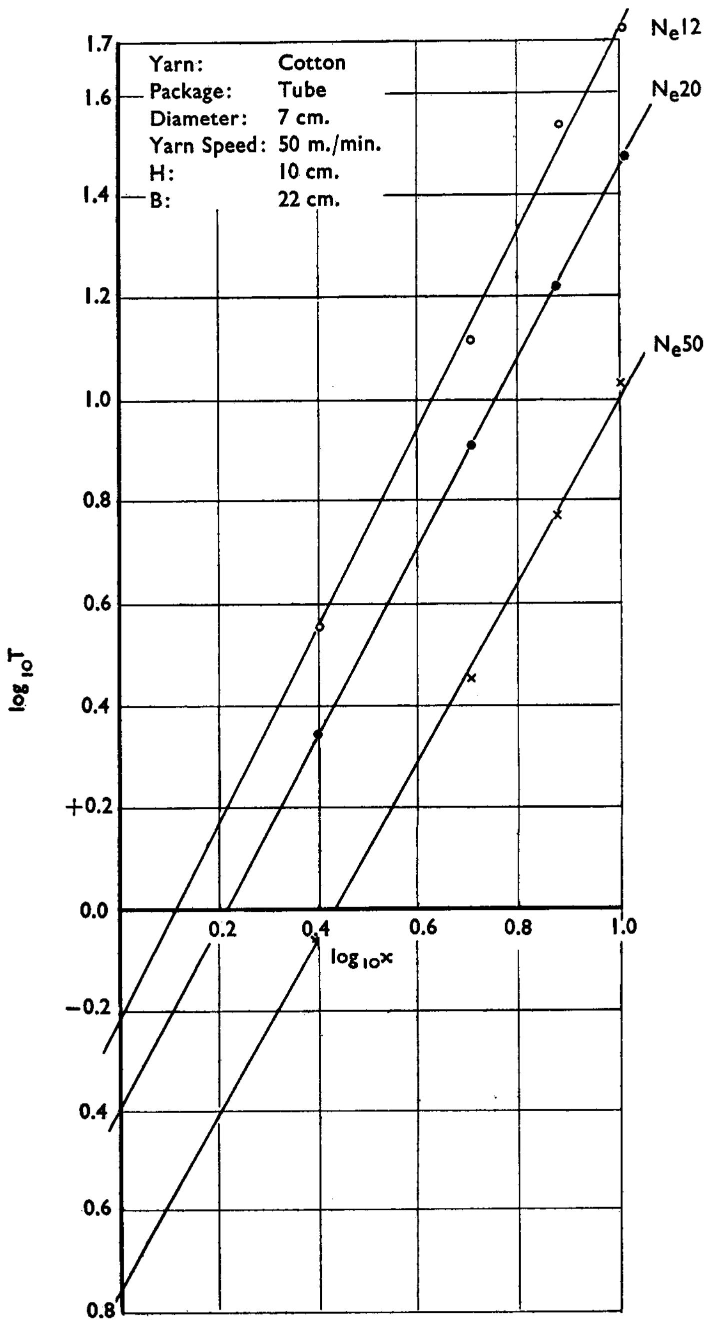

Yarn: Cotton
Package: Tube
Diameter: 7 cm.
Yarn Speed: 50 m./min.
H: 10 cm.
B: 22 cm.
N_e12
N_e20
N_e50
1.7
1.6
1.4
1.2
1.0
0.8
0.6
0.4
+0.2
0.0
−0.2
0.4
0.6
0.8
0.2
0.4
0.6
0.8
1.0
log₁₀x
log₁₀T

FIG. 68

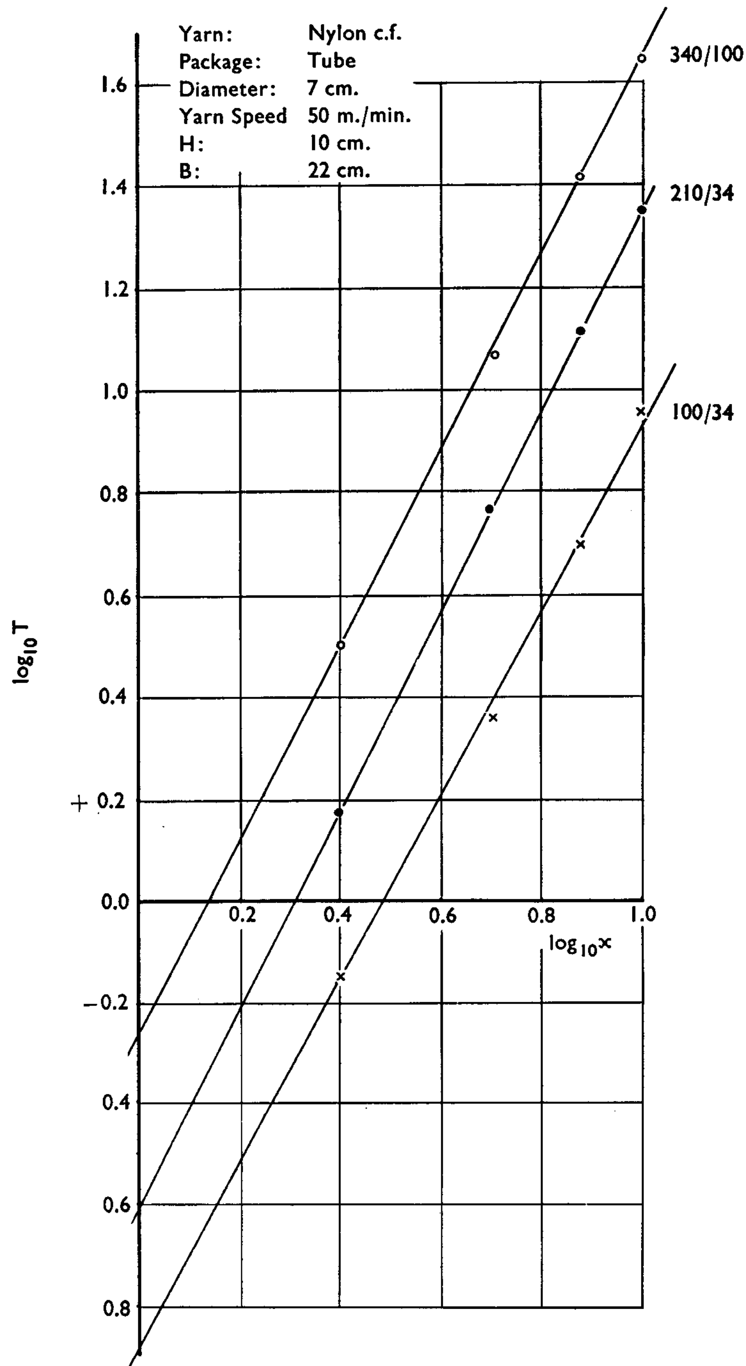
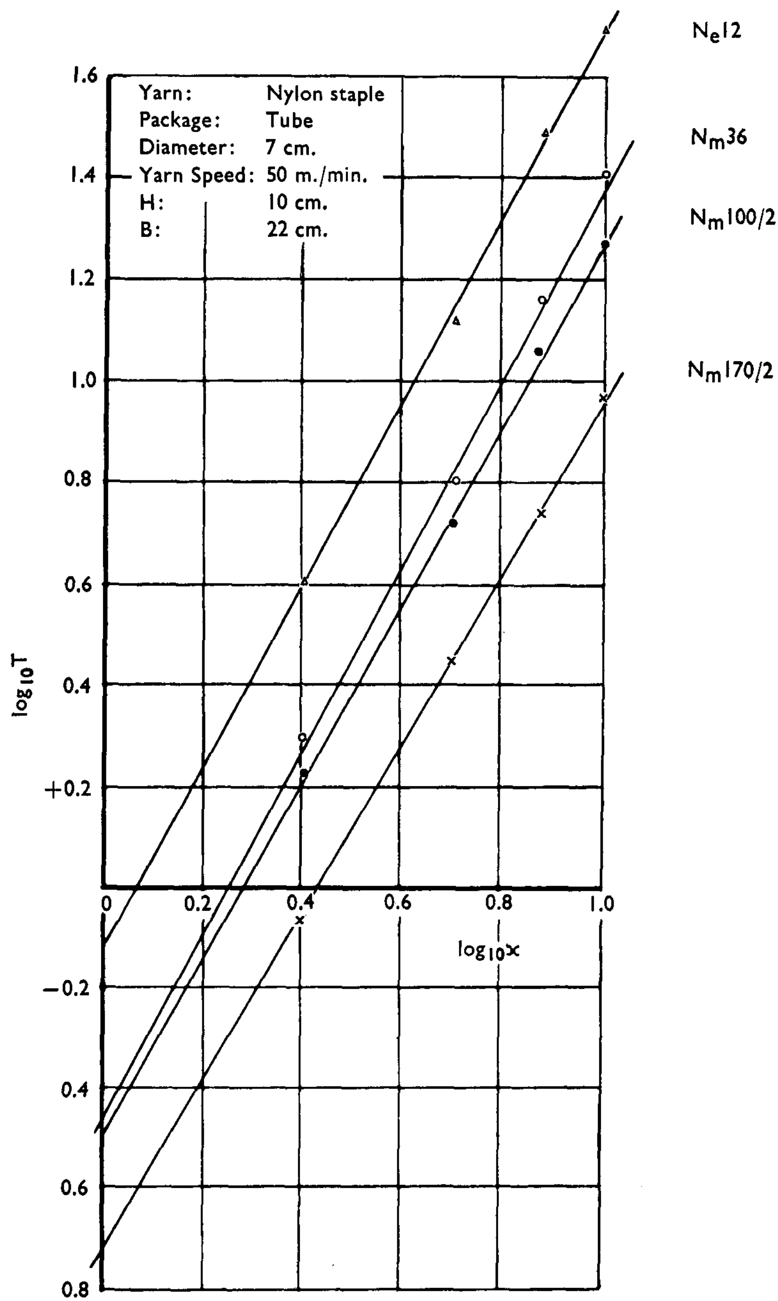

Yarn: Nylon c.f.
Package: Tube
Diameter: 7 cm.
Yarn Speed 50 m./min.
H: 10 cm.
B: 22 cm.
340/100
210/34
100/34
1.6
1.4
1.2
1.0
0.8
0.6
0.4
+ 0.2
0.0
−0.2
0.4
0.6
0.8
$\log_{10}T$
0.2
0.4
0.6
0.8
1.0
$\log_{10}x$

FIG. 69



Yarn: Nylon staple
Package: Tube
Diameter: 7 cm.
Yarn Speed: 50 m./min.
H: 10 cm.
B: 22 cm.
$N_e12$
$N_m36$
$N_m100/2$
$N_m170/2$
$\log_{10}T$
$\log_{10}x$
1.6
1.4
1.2
1.0
0.8
0.6
0.4
+0.2
0
0.2
0.4
0.6
0.8
1.0
−0.2
0.4
0.6
0.8


FIG. 70

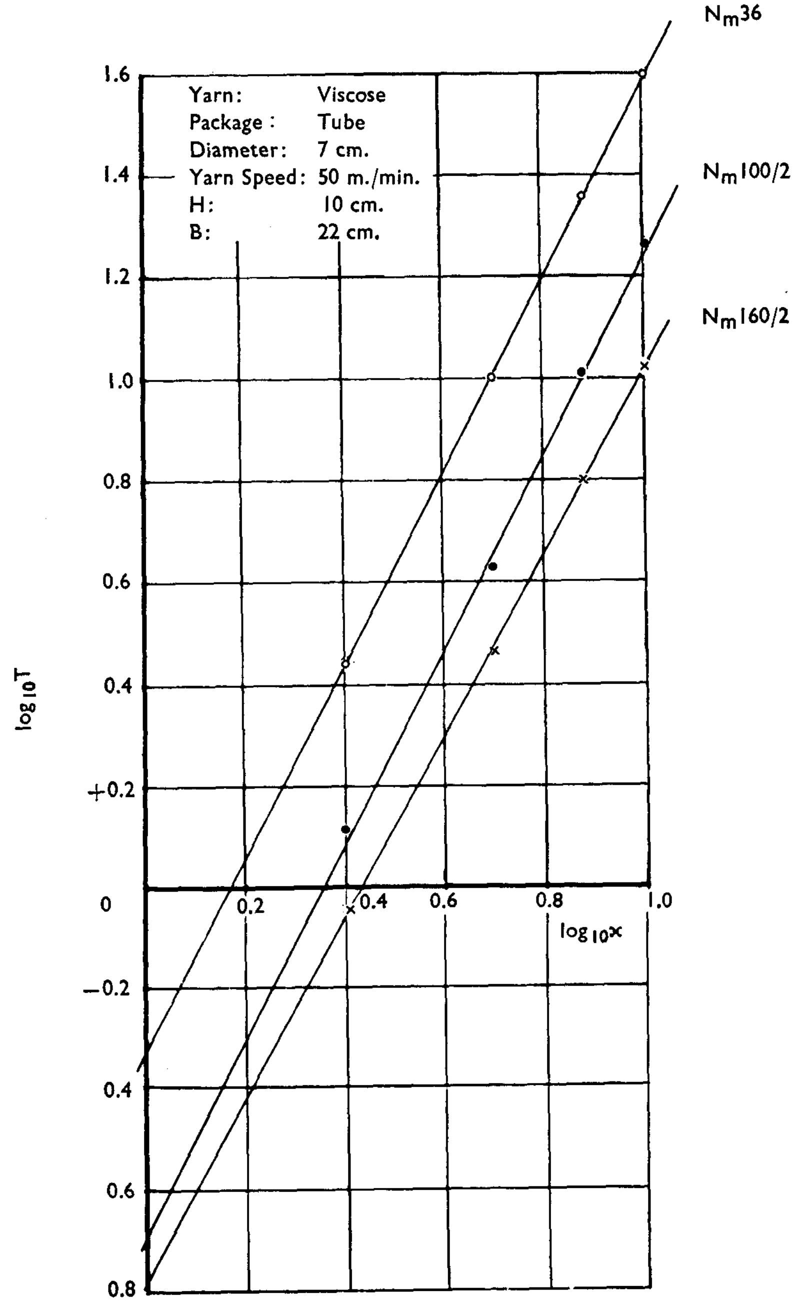

Yarn: Viscose
Package : Tube
Diameter: 7 cm.
Yarn Speed: 50 m./min.
H: 10 cm.
B: 22 cm.
$N_m36$
$N_m100/2$
$N_m160/2$
1.6
1.4
1.2
1.0
0.8
0.6
0.4
+0.2
0
−0.2
0.4
0.6
0.8
0.2
0.4
0.6
0.8
1.0
$\log_{10}T$
$\log_{10}x$

FIG 71

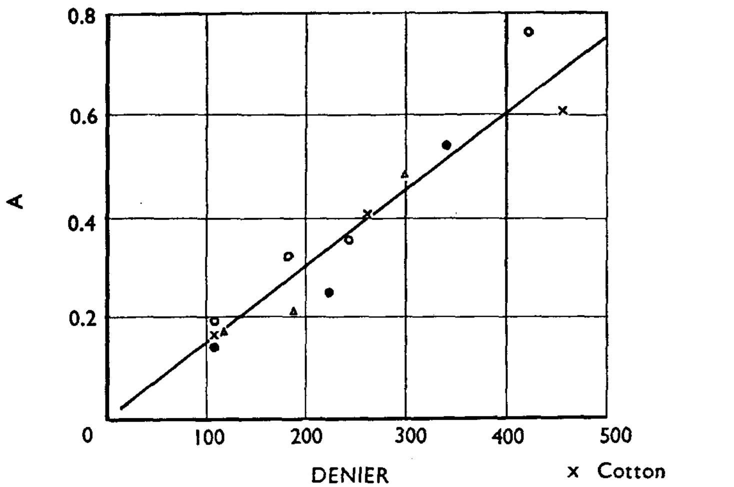



FIG 72(a)



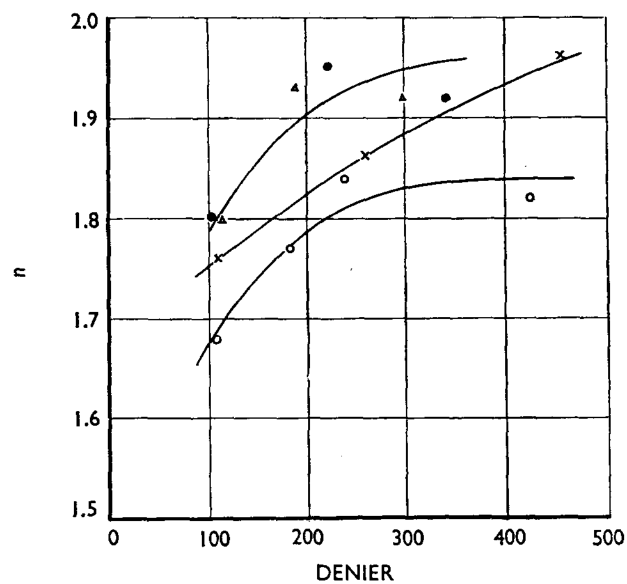



FIG. 72(b)

Table 7 gives the values of $A$ and $n$ for the different yarns obtained from Fig. 68-71. Both $A$ and $n$ increase with denier and a fairly good linear relation exists between $A$ and denier which is independent of the type of yarn (Fig. 72a). The value of $n$ never exceeds 2 but the relation between $n$ and denier is dependent on the type of yarn (Fig. 72b). Several factors such as the nature of the yarn surface and the amount of twist in the yarn influence the value of $n$. Because of the large variation in $n$ it is not possible to obtain very precise values of the tension which would exist in any unknown yarn at a given spindle speed, but since $n$ does not exceed 2 a maximum value of the tension could be obtained using a value of $A$ corresponding to the yarn denier (obtained from Fig. 72a).

**TABLE 7**

**Values of $A$ and $n$ in the relation $T=Ax^n$ for various yarns**

| Yarn | | Denier | $H=10$ cm. | |
|---|---|---|---|---|
| | | | $A$ | $n$ |
| Cotton | $N_e$ 50 | 108 | 0·16 | 1·76 |
| Cotton | $N_e$ 20 | 260 | 0·40 | 1·86 |
| Cotton | $N_e$ 12 | 453 | 0·60 | 1·96 |
| Nylon c.f. | 100/34 | 105 | 0·13 | 1·81 |
| Nylon c.f. | 210/34 | 222 | 0·25 | 1·95 |
| Nylon c.f. | 340/100 | 340 | 0·54 | 1·92 |
| Nylon staple | $N_m$ 170/2 | 107 | 0·19 | 1·68 |
| Nylon staple | $N_m$ 100/2 | 181 | 0·32 | 1·77 |
| Nylon staple | $N_m$ 36 | 241 | 0·35 | 1·84 |
| Nylon staple | $N_e$ 12 | 435 | 0·76 | 1·82 |
| Viscose staple | $N_m$ 160/2 | 114 | 0·17 | 1·80 |
| Viscose staple | $N_m$ 100/2 | 188 | 0·21 | 1·93 |
| Viscose staple | $N_m$ 30 | 297 | 0·48 | 1·92 |

**Effect of yarn speed**

Most of the results were obtained using a constant yarn speed of 50 m./min., but the effect of yarn speeds up to 200 m./min. was examined on two different yarns. These showed that increasing yarn speed increased yarn tension but had very little effect on balloon diameter. Increasing yarn speed increases the rotational speed of the yarn and hence the centrifugal force, but since $w=2\pi\ (x+v/\pi d)$ this increase is small at large $x$, and is also dependent on the package diameter. This is confirmed by the constancy of the balloon diameter. The increase of tension with yarn speed which is actually found shows the influence of other factors additional to the centrifugal force. These are the Coriolis force due to the yarn moving along its length in a rotating system and an air drag component along the yarn.

The effect of yarn speed on the tension is small in comparison with the effect of rotational speed. This is fairly obvious from the curves in Fig. 27 and 28 but

Table 8 shows the effect even more clearly. Table 8 (a) summarises the values of the maximum tension at yarn speeds of 10, 50, 100 and 200 m./min. and spindle speeds of 2,500, 5,000, and 10,000 r.p.m. for nylon staple yarn $N_m$ 100/2. Tables 8 (b) and (c) show the percentage changes in yarn tension produced by comparable percentage changes in spindle speed and yarn speed at different values of these variables throughout the range considered. Very clearly, rotational speed has a very much greater effect than yarn speed.

**TABLE 8**

**Variation of maximum tension with spindle speed and yarn speed**
**Nylon $N_m$ 100/2**
**$H$=10 cm.**

(a)

| | Maximum Yarn Tension (gram) | | | |
|---|---|---|---|---|
| Spindle Speed (r.p.m.) \ Yarn Speed (m./min.) | 10 | 50 | 100 | 200 |
| 2,500 | 1·2 | 1·5 | 1·7 | 2·0 |
| 5,000 | 4·2 | 5·2 | 5·8 | 7·2 |
| 10,000 | 15·3 | 18·5 | 21·8 | 24·5 |

(b)

| Increasing spindle speed (r.p.m.) from: | % increase in maximum tension at yarn speeds of: 10 m./min. | 50 m./min. | 100 m./min. | 200 m./min. |
|---|---|---|---|---|
| 2,500 to 5,000, *i.e.* 100% | 250% | 245% | 240% | 260% |
| 5,000 to 10,000, *i.e.* 100% | 265% | 255% | 275% | 240% |

(c)

| Increasing yarn speed (m./min.) from: | % increase in maximum tension at spindle speeds of: 2,500 r.p.m. | 5,000 r.p.m. | 10,000 r.p.m. |
|---|---|---|---|
| 10 to 50, *i.e.* 400% | 25% | 24% | 21% |
| 50 to 100, *i.e.* 100% | 13% | 12% | 18% |
| 100 to 200, *i.e.* 100% | 18% | 24% | 12% |

**Effect of package diameter**

Both staple and continuous filament yarns show that tension and balloon diameter decrease as package diameter decreases. Thus, in taking yarn off a rotating package the tension decreases as the operation proceeds unless other means are taken to maintain the original tension level. The centrifugal force ($F$) acting on an element of yarn of mass $m$ rotating with angular velocity $w$ at a distance $r$ from the axis is given by $F=m.r.w^2$. As the package diameter decreases $r$ decreases because of the reduction in package diameter, and $w$ increases since $w=2\pi\ (x+v/\pi d)$. The relative decrease in $r$ is larger than the increase in $w^2$ so that an overall decrease in the centrifugal force occurs. The effect of change in package diameter on the centrifugal force varies with the spindle speed. A given change in package diameter affects $r$ independently of the spindle speed but the effect on $w$ is very much larger at low spindle speeds than at high.

**Effect of yarn denier**

The curves in Fig. 31-42 all show increasing tension and balloon diameter with increasing yarn denier. To illustrate the effect of denier more clearly the yarn tensions at two spindle speeds (5,000 and 10,000 r.p.m.) have been plotted against denier for all the yarns used (Fig. 73, 74, 75). The tension increases linearly with denier. Not all points lie on the straight lines but the linear relation is clearly established and confirms the opinion that the centrifugal force and not air drag is mainly responsible for the yarn tension. This requires the tension to vary directly with the mass and therefore the denier of the yarn. The air drag does have some effect on the tension and varies with the type of yarn and the denier.

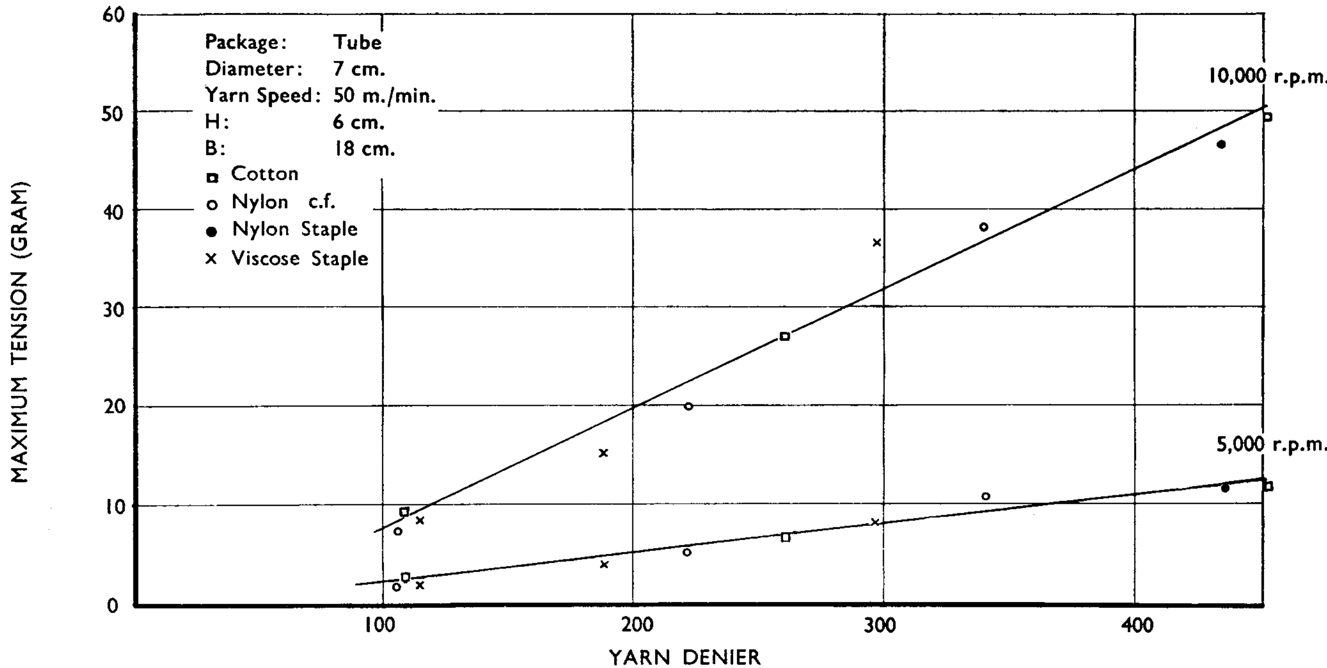
The results on loops of yarn in section 5.26 showed that low denier yarns were deflected from the radial plane much more than high denier yarns. This illustrates the relative effects of air drag and centrifugal force. The air drag, depending upon the surface area of the yarn, varies directly with the yarn radius whereas the centrifugal force, depending upon the mass or volume of the yarn, varies as the square of the yarn radius. Thus as yarn denier increases, the centrifugal force increases more rapidly than the air drag so that heavy denier yarns are less deflected from the radial plane than low denier yarns.

At each spindle speed at $H=6$ cm. and $H=10$ cm. (Fig. 73 and 74) continuous filament and staple yarns fall on the same straight line, the maximum tensions corresponding to single balloons. At $H=15$ cm. (Fig. 75) the continuous filament and staple yarns fall on different straight lines, because the maximum tension of the staple yarns corresponds to a single balloon but the maximum tension of the filament yarns corresponds to a double balloon and is accordingly much lower. The 340/100 yarn does however form a single balloon at 5,000 r.p.m. and falls on the staple yarn line, but at 10,000 r.p.m. forms a double balloon like the other filament yarns.

**Effect of *H***

The balloon height depends upon the position at which the yarn leaves the package and $H$, the distance of the yarn guide above the package. In the curves


[continued on page 114]



Package: Tube
Diameter: 7 cm.
Yarn Speed: 50 m./min.
H: 6 cm.
B: 18 cm.
Cotton
Nylon c.f.
Nylon Staple
Viscose Staple
10,000 r.p.m.
5,000 r.p.m.
MAXIMUM TENSION (GRAM)
YARN DENIER
0
10
20
30
40
50
60
100
200
300
400


FIG. 73

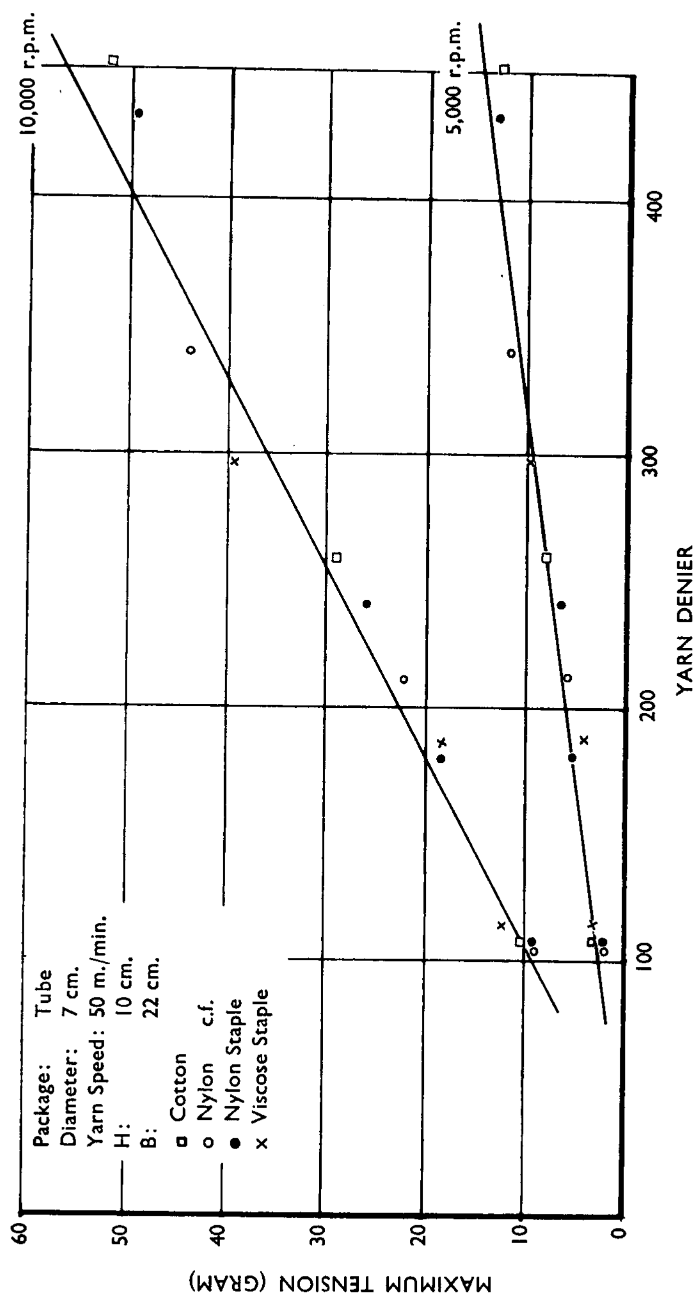
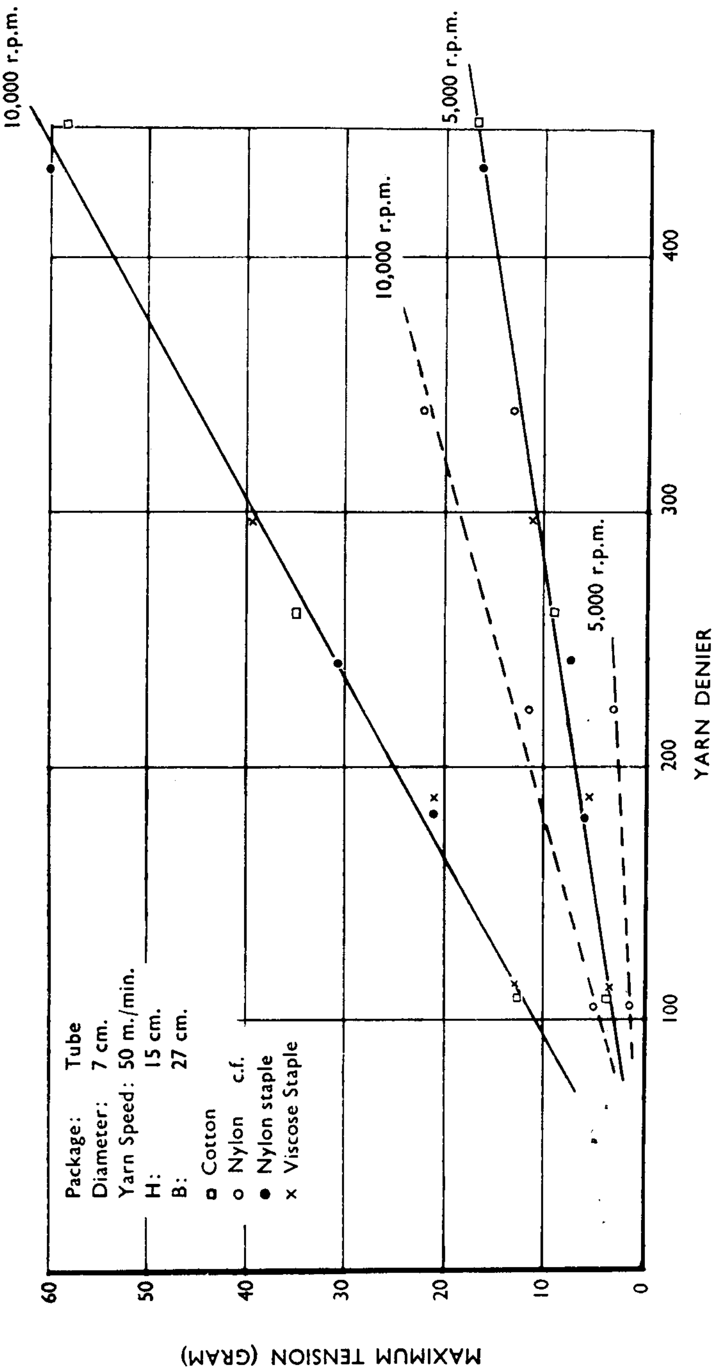

Package: Tube
Diameter: 7 cm.
Yarn Speed: 50 m./min.
H: 10 cm.
B: 22 cm.
Cotton
Nylon c.f.
Nylon Staple
Viscose Staple
10,000 r.p.m.
5,000 r.p.m.
MAXIMUM TENSION (GRAM)
0
10
20
30
40
50
60
YARN DENIER
100
200
300
400

FIG. 74



10,000 r.p.m.
5,000 r.p.m.
10,000 r.p.m.
5,000 r.p.m.
Package: Tube
Diameter: 7 cm.
Yarn Speed: 50 m./min.
H: 15 cm.
B: 27 cm.
Cotton
Nylon c.f.
Nylon staple
Viscose Staple
0
10
20
30
40
50
60
MAXIMUM TENSION (GRAM)
100
200
300
400
YARN DENIER


FIG. 75

for the staple yarns (Fig. 43, 44, 47-50) we found that the maximum tension increased but balloon diameter decreased with increasing $H$. Generally we have found that at constant $H$, yarn tension and balloon diameter change together. In this case of increasing $H$ however although the balloon diameter decreases, the length of yarn which rotates actually increases, and so does the tension. This increase in maximum tension with increasing $H$ does not always hold for continuous filament yarn (Fig. 45, 46). When $H$ is increased from 10 cm. to 15 cm. for the filament yarns, the maximum tension falls because no single balloon exists at $H=15$ cm. and this maximum tension corresponds to a double balloon.

The tension at any spindle speed has been found to increase linearly with the balloon height provided the tensions correspond to the same balloon shape (tensions at 2,500 r.p.m. and 7,500 r.p.m. have been plotted in Fig. 51-54). If the tension is considered to be due primarily to the centrifugal force the slopes of the Tension v. Balloon Height lines (Fig. 51-54) for the different yarns should vary with the mass, *i.e.* the denier of the yarn. If the tension is considered to be due to air drag the slopes should vary with the surface area, *i.e.* the yarn radius and therefore the square root of the yarn denier. In table 9 the slopes of the lines in Fig. 51(b) and 52(b) chosen as typical of the yarns tested are compared with the deniers and the square roots of the deniers of the various yarns.

**TABLE 9**

| Yarn | Denier | Ratio of deniers | Ratio of $\sqrt{\text{deniers}}$ | Ratio of slopes |
|---|---|---|---|---|
| **Data from Fig. 51(b). Cotton yarns at 7,500 r.p.m.** | | | | |
| $N_e$ 12 | 453 | 4·2 | 2·0 | 4·1 |
| $N_e$ 20 | 260 | 2·4 | 1·6 | 2·1 |
| $N_e$ 50 | 108 | 1·0 | 1·0 | 1·0 |
| **Data from Fig. 52(b). Nylon yarns at 7,500 r.p.m.** | | | | |
| 340/100 | 340 | 3·2 | 1·8 | 3·3 |
| 210/34 | 222 | 2·1 | 1·5 | 2·5 |
| 100/34 | 105 | 1·0 | 1·0 | 1·0 |

For convenience the ratios of the slopes of the different yarns are compared with the ratios of the denier and $\sqrt{\text{denier}}$. Agreement between the slopes and the denier is good, but with $\sqrt{\text{denier}}$ is poor, thus confirming the dependence of the tension on centrifugal force.

At low values of $H$ a single balloon forms as the yarn comes off all parts of the package. As $H$ is increased a single balloon exists as the yarn comes off the bottom and a double balloon as the yarn comes off the top of the package. Further increases in $H$ cause double and triple balloons to be formed as the yarn leaves all parts of the package. This effect of $H$ on yarn tension and balloon shape can be clearly seen from Fig. 55 and 56 and Table 5. At $H=6$ cm. Max. $T$ and Min. $T$ are fairly close to each other for both types of yarn, continuous filament and staple. Max. $T$ corresponds to the yarn coming off the bottom of the package and Min. $T$ to yarn coming off the top, a single balloon forming in each case. At $H=10$ cm. for both the staple and filament yarns there is a much greater difference between Max. $T$ and Min. $T$. The Max. $T$ still corresponds to a single balloon as the yarn leaves the bottom of the package, but Min. $T$ now corresponds to a double balloon as the yarn leaves the top of the package. At $H=15$ cm. the staple and filament yarns behave differently. The staple yarn still shows a large difference between Max. $T$ and Min. $T$ and both tensions are higher that at $H=10$ cm.—Max. $T$ still corresponds to a single balloon and Min. $T$ to a double balloon. The filament yarn however has values of Max. $T$ and Min. $T$ which are lower at $H=15$ cm. than at $H=10$ cm. and the difference between them is smaller, the reason being that a single balloon no longer exists, and Max. $T$ corresponds to a double balloon and Min. $T$ to a triple balloon.

**Effect of yarn type**

The results of Fig. 31-42 in which yarns of the same type (continuous filament or staple) are compared, show that the larger tension always corresponds to the larger balloon diameter. Fig. 76, 77 and 78 in which Max. $T$.v r.p.m. is plotted for yarns of comparable denier but of different type, show that the largest tension does not correspond to the largest balloon diameter. At $H=6$ cm. and $H=10$ cm. (Fig. 76 and 77) there is not much difference between the tensions of the different yarns but the continuous filament yarn does have a slightly lower value than the staple yarns. Although the tension is lower, the balloon diameter of the filament yarn is greater than either of the staple yarns. This illustrates the effect of different yarn surfaces. Air drag which affects the staple yarn more than the filament yarn deflects the staple yarn further than the filament yarn from the radial plane, thereby reducing the balloon diameter and increasing the yarn tension. At $H=15$ cm. (Fig. 78) the difference between staple and filament yarns is more marked. Although the yarn deniers are similar, the maximum tension for the staple yarns corresponds to a single balloon but for the filament yarn corresponds to a double balloon and is therefore very much lower.

Fig. 79 also illustrates the effect of air drag on different yarn types. In this case the yarn deniers are not equivalent and as we would expect, the heavier yarns have the higher tensions. We would therefore expect from the results of Fig. 31-42 that the balloon diameters would also be greater for the heavier yarns. This does hold for the two staple yarns, $N_e$ 20 (260 denier) having a larger diameter than $N_m$ 36 (241 denier) but we find that the 210/34 yarn (222 denier) has a balloon diameter larger than either of the staple yarns, despite its lower denier.

Continuous filament yarns form double balloons more easily than staple yarns. Increasing the spindle speed or $H$ causes a double balloon to form, and filament yarns form double balloons at lower spindle speeds and $H$ values than staple yarns. Since a staple yarn is deflected from the radial plane more than a filament yarn due to air drag, then it might be assumed that as the take-off point

[continued on page 120]

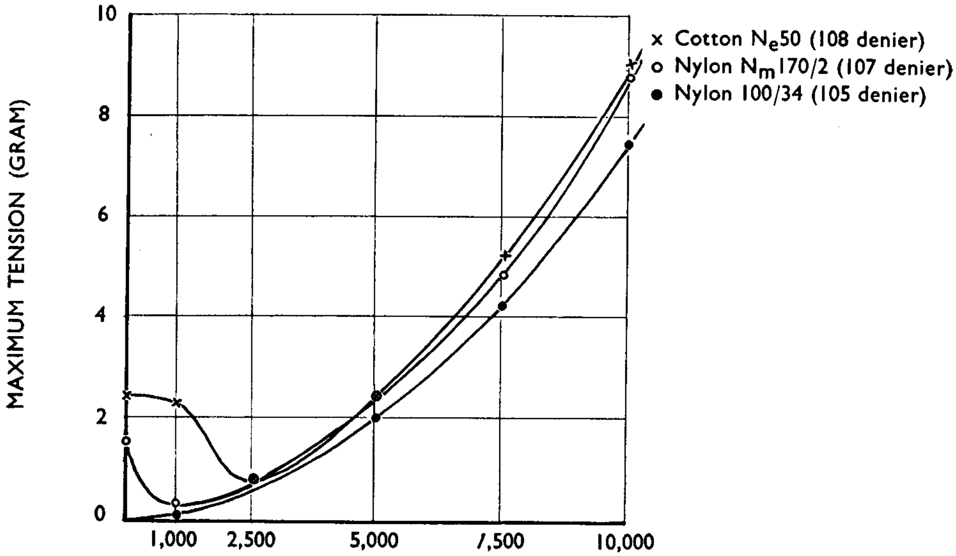



FIG. 76(a)

| | |
|---|---|
| Yarn: | Cotton and Nylon |
| Package: | Tube |
| Diameter: | 7 cm. |
| Yarn Speed: | 50 m./min. |
| H: | 6 cm. |
| B: | 18 cm. |

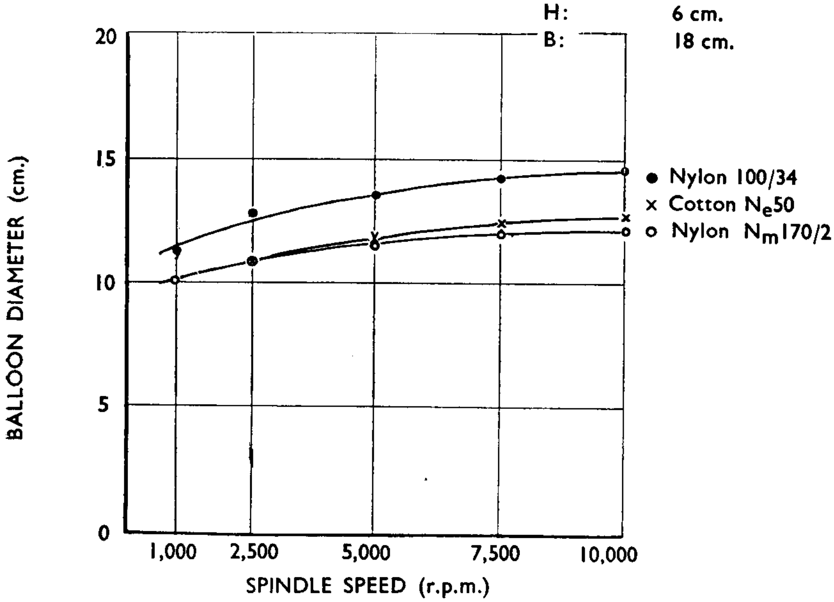



FIG. 76 (b)

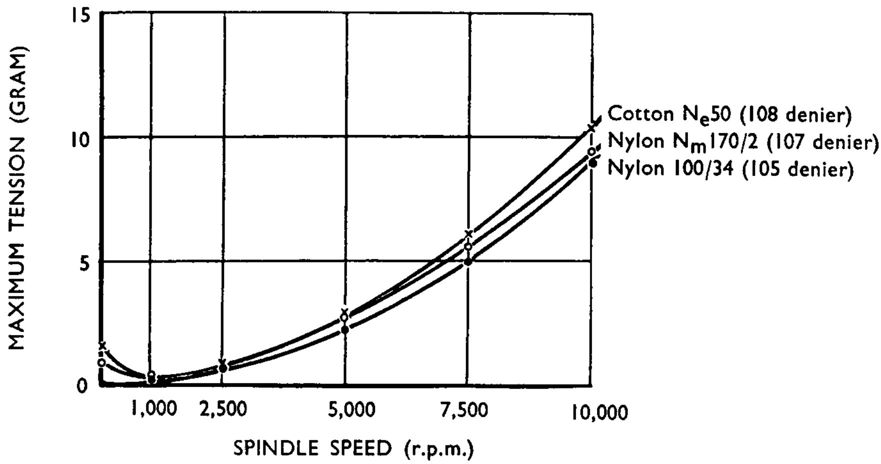



FIG. 77(a)

| | |
|---|---|
| Yarn: | Cotton and Nylon |
| Package: | Tube |
| Diameter: | 7 cm. |
| Yarn Speed: | 50 m./min. |
| H: | 10 cm. |
| B: | 22 cm. |

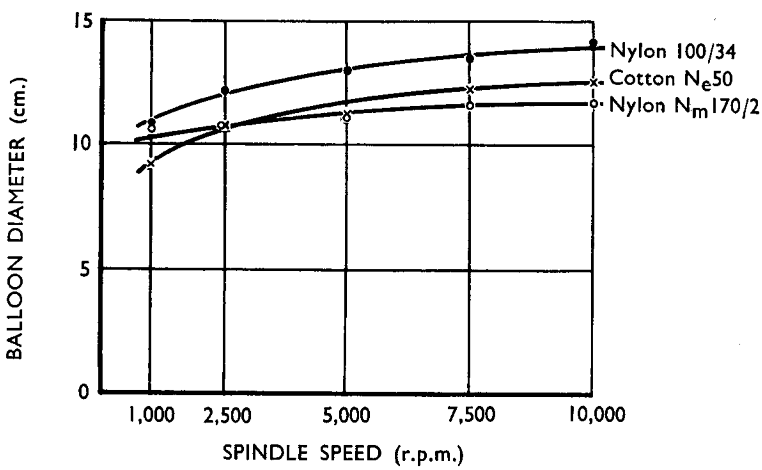



FIG. 77(b)

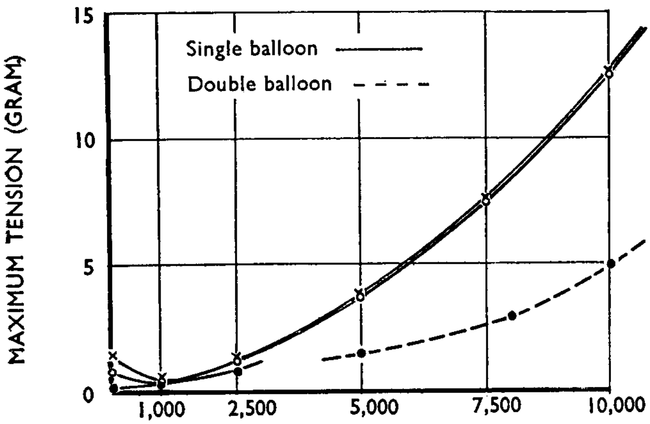



FIG. 78(a)

Yarn: Cotton and Nylon
Package: Tube
Diameter: 7 cm.
Yarn Speed: 50 m./min.
H: 15 cm.
B: 27 cm.

× Cotton $N_e50$ (108 denier)
● Nylon 100/34 (105 denier)
o Nylon $N_m170/2$ (107 denier)

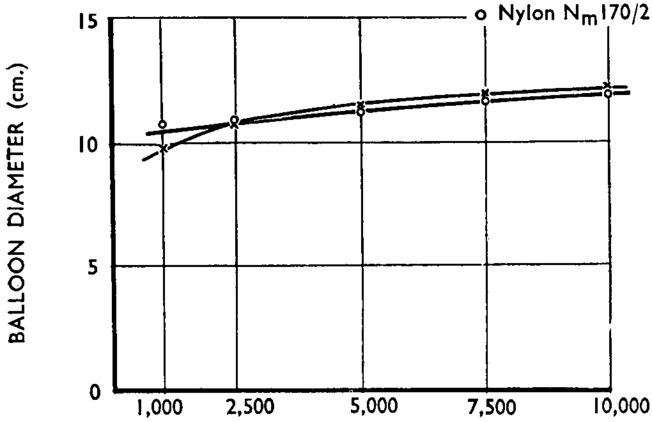



FIG. 78(b)

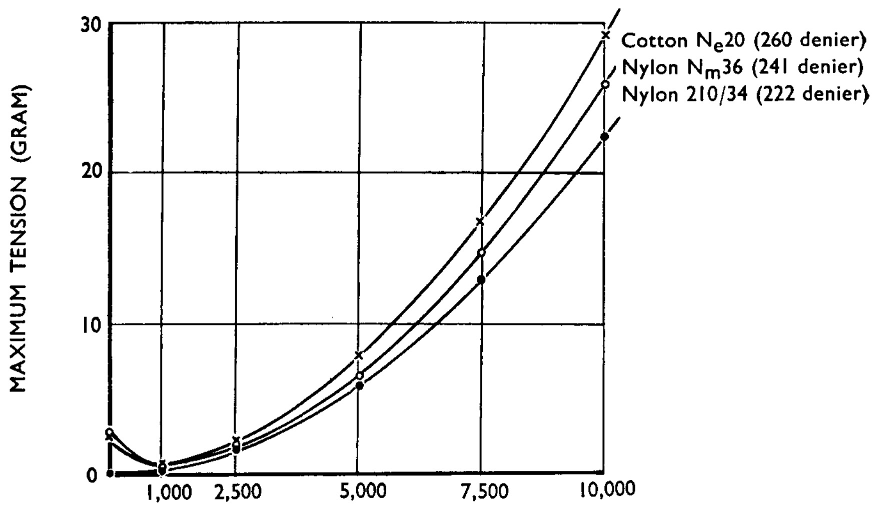



FIG. 79(a)

Yarn: Cotton and Nylon
Package: Tube
Diameter: 7 cm.
Yarn Speed: 50 m./min.
H: 10 cm.
B: 22 cm.

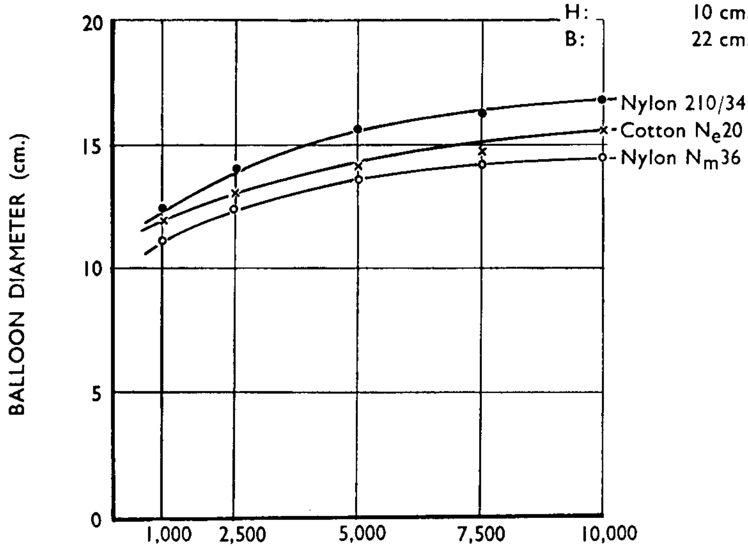



FIG. 79(b)

of the yarn rises to the top of the package a staple yarn would form a double balloon more easily than a filament yarn. This does not happen probably because the frictional forces between yarn and package are much higher for staple than for filament yarns. As the yarn take-off point rises to the top of the package the filament yarn slips over the edge to form a double balloon but this does not happen so easily with a staple yarn and package.

In all the experiments a change from a single to a double balloon corresponded to a reduction in tension. The tensions (Min $T_A$ Fig. 18) at which a double balloon formed, were calculated as a percentage of the maximum tension at each spindle speed. The values of Min $T_A$ and Min $T_B$ (the mean tension corresponding to a double balloon) are given in Table 10. They show that the tension, as a percentage of the maximum tension, at which a double balloon forms, does not vary much with spindle speed, but this value is higher for filament yarns (approximately 85%) than it is for staple yarns (approximately 70%).

**TABLE 10**

**Values of Min $T_A$ and Min $T_B$ as percentages of the maximum tension $H$=10 cm.**

| Continuous filament nylon 100/34 | | | | | | Staple nylon $N_m$ 170/2 (107 denier) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| r.p.m. | Max $T$ | Min $T_A$ | Min $T_A$ as % of Max. $T$ | Min $T_B$ | Min $T_B$ as % of Max. $T$ | r.p.m. | Max $T$ | Min $T_A$ | Min $T_A$ as % of Max. $T$ | Min $T_B$ | Min $T_B$ as % of Max. $T$ |
| 2,500 | 0·7 | 0·6 | 86 | 0·4 | 57 | | | | | | |
| 5,000 | 2·3 | 2·1 | 91 | 1·2 | 52 | 5,000 | 2·8 | 1·7 | 61 | 1·1 | 39 |
| 7,500 | 5·0 | 4·3 | 86 | 2·7 | 63 | 7,500 | 5·6 | 3·7 | 66 | 2·4 | 43 |
| 10,000 | 9·0 | 8·0 | 89 | 5·0 | 56 | 10,000 | 9·2 | 6·7 | 73 | 4·3 | 47 |
| MEAN | | | 88% | | 57% | MEAN | | | 67% | | 43% |

| Continuous filament nylon 210/34 | | | | | | Staple nylon $N_m$ 100/2 (181 denier) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| r.p.m. | Max $T$ | Min $T_A$ | Min $T_A$ as % of Max. T | Min $T_B$ | Min $T_B$ as % of Max. $T$ | r.p.m. | Max $T$ | Min $T_A$ | Min $T_A$ as % of Max. $T$ | Min $T_B$ | Min $T_B$ as % of Max. $T$ |
| 2,500 | 1·5 | 1·2 | 80 | 0·7 | 47 | | | | | | |
| 5,000 | 5·8 | 4·8 | 83 | 2·8 | 58 | 5,000 | 5·2 | 3·6 | 69 | 2·3 | 44 |
| 7,500 | 12·9 | 10·6 | 82 | 6·2 | 48 | 7,500 | 11·3 | 8·1 | 72 | 5·1 | 45 |
| 10,000 | 22·0 | 19·3 | 88 | 11·4 | 52 | 10,000 | 18·5 | 14·7 | 79 | 9·4 | 51 |
| MEAN | | | 83% | | 51% | MEAN | | | 73% | | 47% |

TABLE 10—*continued*

| Continuous filament nylon 340/100 | | | | | | Staple nylon $N_m$ 36 (241 denier) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| r.p.m. | Max $T$ | Min $T_A$ | Min $T_A$ as % of Max. $T$ | Min $T_B$ | Min $T_B$ as % of Max. $T$ | r.p.m. | Max $T$ | Min $T_A$ | Min $T_A$ as % of Max. $T$ | Min $T_B$ | Min $T_B$ as % of Max. $T$ |
| 2,500 | 3·2 | 2·7 | 84 | 1·7 | 53 | | | | | | |
| 5,000 | 11·7 | 9·5 | 81 | 5·7 | 49 | 5,000 | 6·4 | 4·3 | 67 | 2·5 | 39 |
| 7.500 | 26·0 | 21·5 | 83 | 13·0 | 50 | 7,500 | 14·5 | 9·4 | 65 | 5·0 | 34 |
| 10,000 | 44·0 | 38·0 | 86 | 23·0 | 52 | 10,000 | 25·8 | 16·2 | 63 | 8·9 | 35 |
| MEAN | | | 84% | | 51% | MEAN | | | 65% | | 36% |

**Relation of yarn tension to balloon diameter**

All the results have shown that increasing spindle speed increases both balloon diameter and yarn tension, but the tension increases more rapidly than diameter. Fig. 80 shows the relation between the maximum tension and balloon diameter for continuous filament and staple nylon yarns. It is clearly seen that the tension corresponding to any particular balloon diameter depends very much on the type of yarn, so that balloon diameter alone which is much easier to measure than the yarn tension, cannot be used as an indication of yarn tension.

**Confined balloon**

Ideally, in any winding operation a low constant tension is desired. In taking yarn off a rotating package the tension may be very high and may vary considerably as shown by the tension charts in Fig. 18-21. The greatest difference in tension occurs when the maximum tension corresponds to a single balloon and the minimum tension to a double balloon, but even when a single balloon always exists the difference in tension between a balloon at the top of the package and one at the bottom is quite large. The least variation in tension occurs when either two, three or even four balloons exist. Because of the possible damage to the yarn however this is not a satisfactory state in which to operate.

Since the yarn tension is due primarily to the centrifugal force of the rotating yarn, any system which prevents the formation of a large single balloon will be advantageous in reducing tension. The confining ring described in section 5.255 does this and produces a marked reduction in the maximum tension as seen in Fig. 58 and 59. The mean value of the tension is approximately equal to that corresponding to a double balloon, and although some variation occurs as the yarn rubs on the ring the high maxima corresponding to the single balloon have been completely eliminated. The particular results quoted, in which the tension was reduced to less than 50% of its value, serve only to illustrate the advantages of such a ring. It may be possible by careful choice of ring material, size and position to produce an even more uniform tension.

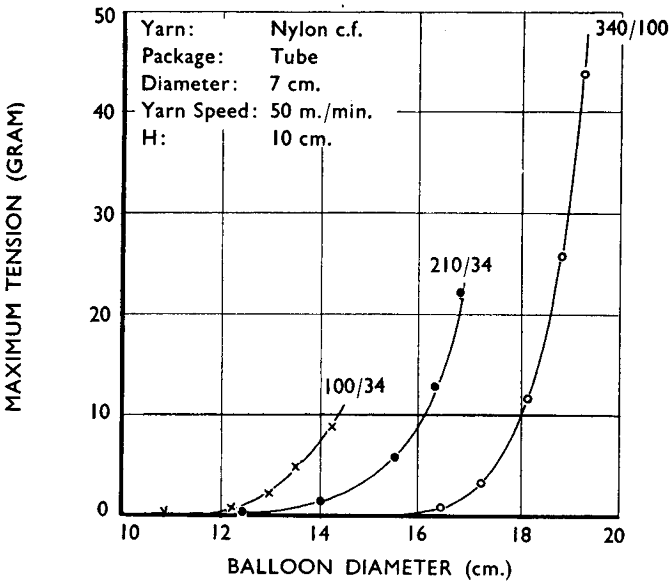



FIG. 80(a)

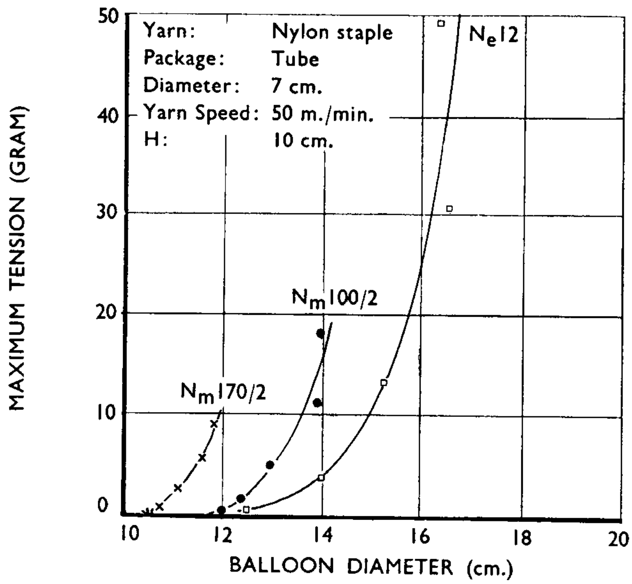



FIG. 80(b)

### Stationary packages

#### General

Only a limited number of measurements have been made on yarn taken off stationary packages but some of the results are quite different from those obtained on rotating packages. The tension increases with increasing denier and yarn speed as for rotating packages, but it also increases with decreasing package diameter.

It was not possible to observe specific balloon shapes and diameters as in the case of rotating packages. With these packages in which the yarn linear velocity is low and the rotational velocity high, the yarn rotates many times while moving only a short distance along the package so that a sharply defined balloon is seen. With stationary packages however, the yarn moves a considerable distance along the package for each rotation of the yarn so that no distinct balloon can be seen.

The forces which contribute to yarn tension are the same for stationary as for rotating packages, centrifugal, air drag and Coriolis, but their relative contributions are different. When unwinding from a stationary package the yarn speed is very much greater relatively than when unwinding from a rotating package so the Coriolis force is greater while the centrifugal force is smaller. Since the package does not rotate, the centrifugal force is due only to the unwinding of the yarn from the package. An indication of the relative contributions of the centrifugal and Coriolis forces can be obtained by considering an element of yarn under two different conditions, (a) a spindle speed of 5,000 r.p.m. and a yarn speed of 50 m/min. and (b) zero spindle speed and a yarn speed of 500 m/min. If we assume a value of 20 cm. as the circumferential length of yarn around the package, the rotational speed of the yarn is in (a) $5{,}000+50.100/20=5{,}250$ r.p.m. and in (b) $500.100/20=2{,}500$ r.p.m. The radius at the element in the second case $r_b$, will be less than $r_a$ because of the lower rotational speed. Thus the centrifugal forces in (a) and (b) are in the ratios $r_a\,(2\pi.5250)^2 : r_b\,(2\pi.2500)^2$ with $r_b < r_a$, so that the centrifugal force in (b) is much less than that in (a). Similarly a comparison of the Coriolis forces ($2m\,[v_r \times w]$), $v_r$ being proportional to $v$, shows that the ratio in (a) to (b) is $[50 \times (2\pi.5250)] : [500 \times (2\pi.2500)]$, so that the Coriolis force in (b) is greater than in (a).

In addition to affecting the centrifugal and Coriolis forces the differences between the rotational and linear speeds of the yarn in the cases (a) and (b) will also influence the air drag acting on the yarn.

#### Effect of package diameter

With rotating packages a decrease in package diameter produced a decrease in yarn tension, but with stationary packages the reverse is true as shown in Fig. 81. In considering the effect of package diameter, the linear yarn speed is constant but the rotational speed of the yarn varies. A reduction in package diameter from 7 cm. to 3·5 cm. at constant yarn speed requires twice as many turns of yarn to be wound off the package, so the rotational speed of the yarn increases by a factor of 2. This increases the Coriolis force ($2\,m.\,[v_r \times w]$) because of the change in

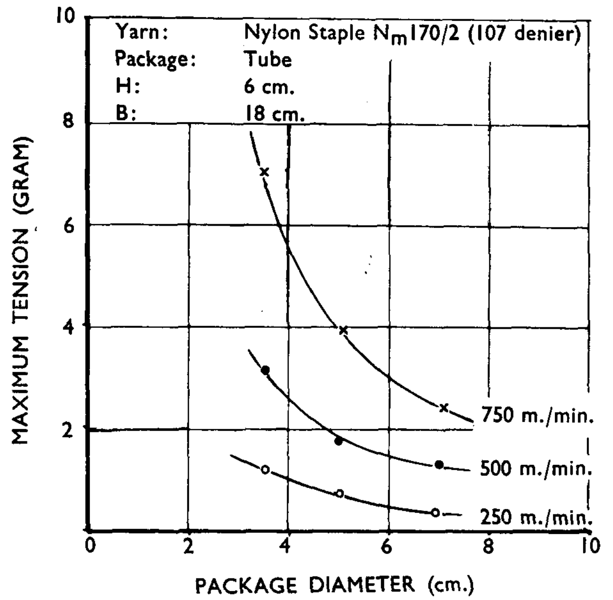



FIG. 81(a)

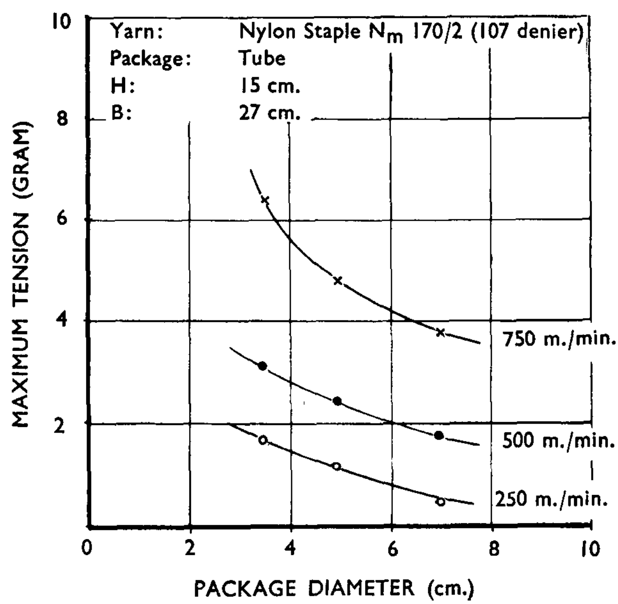



FIG. 81(b)

$w$, and the centrifugal force ($m\ r\ w^2$) because although $r$ decreases due to the reduction in package diameter the increase in $w^2$ more than compensates for this. The combined effect of these changes and any changes due to air drag produces an increase in tension of approximately $\times 2$ to $\times 3$ when the diameter changes from 7 cm. to 3·5 cm.

**Effect of yarn speed**

Increasing the yarn speed increases the yarn tension considerably, because of the changes in the Coriolis and centrifugal forces as well as in the components of air drag. An increase in the yarn speed ($v$) increases the number of turns of yarn which must be wound off the package and therefore the rotational speed ($w$) of the yarn. Thus both the Coriolis and centrifugal forces are increased because of the changes in $v$ and $w$. The results have shown that increasing $v$ from 250 to 750 m./min. often increases the tension by approximately $\times 7$ and such a large change would be expected from the considerations above.

**Effect of *H***

The results showing the influence of $H$ on the yarn tension appear to show a confused picture which is probably due to the influence of air drag and the friction of the yarn on the package. Since the length of yarn between the package and guide eye increases on increasing $H$, one would expect the tension at $H=15$ cm. to be greater than the tension at $H=6$ cm. This occurs for the two staple yarns but not for the filament yarns. We have seen how with rotating packages continuous filament yarns form double balloons much more easily than staple yarns. If a similar behaviour occurs here then a lower tension at $H=15$ cm. than at $H=6$ cm. would be possible, and would be in accord with the observed tension values.

## 7. CONCLUSIONS

The following conclusions are based on the results obtained for cotton, continuous filament and staple nylon, and staple viscose yarns.

**Rotating packages**

1. Centrifugal force is an important cause of yarn tension although air drag and the Coriolis force do have some effect.

2. Yarn tension increases with increases in the following variables:
   (*a*) spindle speed
   (*b*) yarn speed
   (*c*) yarn denier
   (*d*) guide height $H$ (except when a double balloon forms)
   (*e*) package diameter

3. Balloon diameter increases with increases in:
   (*a*) Spindle speed

(*b*) yarn denier
(*c*) package diameter

4. Balloon diameter decreases with an increase in:
   (*a*) guide height $H$
   and is little influenced by:
   (*b*) yarn speed.

5. At low values of $H$ only single balloons occur and the tension varies periodically with the position at which the yarn leaves the package,—maximum tension as it leaves the bottom and minimum tension as it leaves the top of the package.

6. Successive maxima corresponding to a single balloon from the bottom of the package may vary by as much as $\pm$ 20% from the mean value while testing conditions remain unchanged.

7. As $H$ or spindle speed increases, a double balloon with a correspondingly lower tension will form as the yarn leaves the top of the package. For filament yarns this happens at lower values of $H$ and lower spindle speeds than for staple yarns.

8. Tensions corresponding to double balloons are very much less than those corresponding to single balloons, and the variation in tension as the yarn rises and falls along the package is much less.

9. The high tensions which occur with large diameter balloons can be prevented by using a ring fitted between the top of the package and the yarn guide and concentric with the axis to confine the yarn.

**Stationary packages**

1. Yarn tension increases with increases in:
   (*a*) yarn denier
   (*b*) yarn speed
   (*c*) guide height $H$

2. Yarn tension decreases with an increase in:
   (*a*) package diameter.

## 8. ACKNOWLEDGEMENTS

It is a pleasure to acknowledge the help and interest of Professor Dr. E. Honegger during this work. The co-operation of Herr Schweizer during the development of the measuring head and of Herr Berthold is appreciated. Finally the author wishes to thank British Nylon Spinners Ltd. who arranged for him to study under Professor Honegger.

## 9. REFERENCES


9.01 Miss D. G. Padfield, Journal of the Textile Institute **47,** 6, (1956), T301-T308. "A note on the fluctuations of tension during unwinding".

9.02 K. H. V. Booth, British Journal of Applied Physics **8,** 4, (1957), 142-144. "Variations of tension of an unwinding thread".

9.03 E. Honegger & A. Fehr, Journal of the Textile Institute **38,** 8, (1947), P353. "Effects of accessory influences on ring spinning of cotton and spun rayon".

9.04 Miss M. Hannah, Journal of the Textile Institute **43,** 10, (1952), T519-T535. "Applications of a theory of the spinning balloon I".

9.05 Miss M. Hannah, Journal of the Textile Institute **46,** 1, (1955), T1-T16. "Applications of a theory of the spinning balloon II".

9.06 C. Mack, Journal of the Textile Institute **44,** 11, (1953), T483-T498. "Theoretical study of ring and cap spinning balloon curves (with and without air drag)".

9.07 J. Gregory, C. Mack, E. J. L. Smart, Journal of the Textile Institute **46,** 9, (1955), T606-T613. "The ballooning thread apparatus".

9.08 J. Gregory, C. Mack, E. J. L. Smart, Journal of the Textile Institute **46,** 9, (1955), T614-T626. "Measurements of balloon characteristics".

9.09 J. Crank, Textile Research Journal **23,** 4, (1953), 266-276. "A theoretical investigation of cap and ring spinning systems".

9.10 J. Crank and Miss D. D. Whitmore, Textile Research Journal **23,** 9, (1953), 657-663. "Balloon diameters and thread tensions calculated for different cap spinning conditions".

9.11 J. Crank and Miss D. D. Whitmore, Textile Research Journal **24,** 5, (1954), 434-437. "The effect of cap-edge friction on spinning".

9.12 J. Crank and Miss D. D. Whitmore, Textile Research Journal **24,** 11, (1954), 1006-1010. "The influence of friction and traveller weight in ring spinning".

9.13 P. F. Grishin, Platts Bulletin **8,** No. 6, 161-191. "Balloon control" Parts I and II.

9.14 P. F. Grishin, Platts Bulletin **8,** No. 8, 240-260. "Balloon control" Part III.

9.15 P. F. Grishin, Platts Bulletin **8,** No. 11, 333-352. "Balloon control" Parts IV and V.

## Curriculum Vitæ

*I was born at Briton Ferry in the county of Glamorgan, Great Britain on 13th November,* 1924. *After primary school I spent six years* (1937-1943) *at the Grammar School for Boys, Neath, Glamorgan, obtaining the School and Higher Certificates of the Central Welsh Board. On completion of military service in the Royal Signals* (1943-1947) *I entered the University College of Swansea, University of Wales. A course in mathematics and physics was completed in* 1950 *with the award of the degree of Bachelor of Science (Honours) Class II Division I in physics.*

*From* 1950 *until* 1954 *I was employed in the Research Department of British Nylon Spinners Limited who seconded me to the Swiss Federal Institute of Technology to study under Professor Dr. E. Honegger. During this period* (1954-1956) *the work on yarn tension and balloon shape was carried out. In* 1954 *I was elected an Associate of the Institute of Physics, London.*