Coefficient of Friction between Yarns and Contact Surfaces

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The nature of the coefficient of friction between yarns and contact surfaces is discussed. The SITRA friction measuring instrument was used for the measurements. The results indicate that the hypothesis by Hansen and Tabor [Text Res J, 27 (1957) 300] that the friction between the yarn and the guide surface is equivalent to the frictional behaviour of lubricated journal bearing is true. There is a count-wise variation as well as TPI-based variation of friction. The open-end yarns have lower friction whereas acrylic and wool fibres have higher friction coefficients. A procedure to measure the lateral pressure exerted by the moving yarn on a stationary surface is suggested. Thus, the lateral pressure exerted by yarn on knitting and sewing needles could be studied.

Keywords: Coefficient of friction, Contact surfaces, Traveller, Yarn guide

1 Introduction

Differential motion between the two moving boundaries involves friction. Thus, in all technologies engaged in the movement of masses, friction is an inevitable force to be reckoned with. The process of textile manufacturing needs the movement of yarn over and through a number of guide surfaces like travellers, knitting needles, ceramic and metallic rollers and surfaces in spinning, winding, weaving and stitching operations. Production of an even product warrants uniform friction and lower friction saves energy and helps towards faster production. Thus, any new instrument designed to measure friction is a desirable addition and a useful tool in the progress of technology.

Much work has been done on the measurement of friction and all the earlier instruments are based on the measurement of tension in the yarn before and after its contact with the corresponding metallic surface made in the form of a cylinder. The friction is evaluated by using the capstan equation:

\[ \frac{T_2}{T_1} = e^{\mu \theta} \]

where \( T_1 \) and \( T_2 \) are the tensions before and after the contact; \( \theta \), the angle of lap; and \( \mu \), the coefficient of friction. Howell and Mazur\(^2\) described a sliding fibre apparatus for the measurement of fibre friction. Based on Howell and Mazur's principle\(^2\), Kalyanaraman and Prakasam\(^3\) developed a simple friction measuring device for measuring the static and dynamic friction of guide materials with respect to yarns. This paper presents the results obtained with Kalyanaraman and Prakasam's instrument\(^3,4\) and compares the same with the results obtained by earlier workers. A commercial model of the set up described by Kalyanaraman and Prakasam was used in the present study and is shown in Fig. 1.

1.1 Instrument

The principle of the instrument, described in detail earlier\(^3\), is based on the principle of inclined plane. The material the friction of which with respect to yarn is to be estimated is mounted on the yarn and the yarn on its mount is tilted by a suitable mechanism. As the tilting proceeds the material starts slipping on its own at a particular angle of tilt and the tangent of the angle of tilt of the yarn with respect to horizontal gives the coefficient of friction. The instrument in this form could be utilized to measure dynamic friction also and in such a situation the yarn is allowed to move at a constant speed. The only limitation of this method is that the material must not be very heavy so as to cause yarn to slacken under the weight of the material between the two fixed mounts. Under certain situations, it may be desirable...
to supply a certain amount of tension to the yarn so as to avoid the sag between the mounts.

2 Experimental Procedure

The instrument was first levelled with the help of levelling screws. The yarn was stretched under a constant tension of 25 g between the mounts. The traveller was mounted on the yarn and with the help of a screw mechanism the yarn was tilted till the traveller slid down the yarn. The angle of tilt corresponding to the onset of sliding was noted. The experiment was repeated several times and the average of 20 readings was taken. The tangent of the average angle of tilt directly gave the coefficient of friction. The traveller was then changed and the experiment was repeated. For measuring the kinetic friction, the yarn was advanced at a constant speed. To start with the metal, e.g. traveller, yarn guide or sewing needle, was mounted on the yarn and the yarn was moved. The mount with the yarn was then tilted. At a certain angle of tilt the metal piece just started sliding down. The moving yarn pulled it up and the gravity pulled it down. The angle at which the movement was more or less arrested was noted. For each case, 20 observations were made. The tangent of the angle gave the kinetic friction coefficient of the metal piece with respect to yarn. The experiment was repeated for all the counts and travellers. In the case of yarn guides since the weight of the yarn guide was found to be high a part of the yarn guide was cut and only the guide loop with its appropriate contact surface was used. The yarn tension was also increased from 25 to 45 g to avoid the sagging of the moving yarn. In the case of sewing needle the commercial sewing thread (3/60 s) and the needle number 16 were used in the experiment. In all the cases 20 observations were made and the average was taken.

3 Results and Discussion

The effect of filament friction on metallic surfaces have been studied in detail under different conditions by the earlier workers. Hansen and Tabor\(^1\) advanced the concept that the frictional behaviour of a thread line passing over a cylindrical guide is analogous to the frictional pattern exhibited by a journal bearing. Thus, according to them a hydrodynamic lubrication exists between a lubricated yarn and the metallic surface. They further observed that the un lubricated yarn also shows a variation in dynamic friction that qualitatively follows the variation seen in the case of a lubricated yarn. All workers observed that friction increases at higher speeds. Lyne\(^5\) reported that at high speeds the fibres soften due to the generated heat and thus give increased area of contact. Such an observation may be true for a synthetic filament but for cotton yarn perhaps such an argument may not be fully appropriate. However, the observations made here using the SITRA instrument more or less agree with the observations by other workers\(^5\) and the Hansen and Tabor’s similarity of the lubrication of journal bearing (Fig. 2) seems to be the general pattern observed in all the cases investigated.

The coefficients of friction for unwaxed and waxed yarn of 40s count and for polyester yarn are given in Table 1. The coefficient of variation and the standard deviation are also given. All the values are the average of 20 readings as recorded with the instrument. The values are reproducible and thus sug-

\[\text{Table 1—Coefficient of Friction between Yarn and Traveller} \]

| Speed cm/min | Normal yarn | | | | | Polyester yarn | |
|--------------|-------------|-------------|-------------|-------------|-------------|-------------|
|              | Coeff. of friction | CV% | Std. deviation | Coeff. of friction | CV% | Std. deviation | Coeff. of friction | CV% | Std. deviation |
| 0            | 0.423 | 5.6 | 0.024 | 0.269 | 4.2 | 0.011 | 0.244 | 3.1 | 0.007 |
| 120          | 0.171 | 4.2 | 0.007 | 0.138 | 3.8 | 0.005 | 0.064 | 4.1 | 0.003 |
| 240          | 0.166 | 4.5 | 0.007 | 0.147 | 4.6 | 0.007 | 0.079 | 2.6 | 0.002 |
| 360          | 0.153 | 2.4 | 0.004 | 0.137 | 2.8 | 0.004 | 0.122 | 3.3 | 0.004 |
| 480          | 0.150 | 3.0 | 0.005 | 0.133 | 2.4 | 0.003 | 0.211 | 2.3 | 0.005 |
| 600          | 0.144 | 2.7 | 0.004 | 0.136 | 3.0 | 0.004 | 0.225 | 2.2 | 0.005 |

Fig. 2—Frictional behaviour of journal bearing\(^1\)

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\(^1\) Hansen and Tabor
suggest the usefulness of this instrument for the measurement of friction.

Fig. 3 shows the friction for the different counts of yarn and a traveller (weight, 0.2972 g). For all the counts the general pattern of the variation of friction with speed is the same. As the count increases the coefficient of friction decreases. This may be owing to the decrease in the area of contact with the increase in count. Such an observation that the decrease in area of contact decreases the friction coefficient has also been reported by Olsen, Schick, and Kleber. The hydrodynamic nature of the friction with speed is also seen (Fig. 2). Figs 4a and 4b show the variation in yarn-to-metal friction by changing the traveller for the same yarn. It is observed that as the traveller weight increases the metal-to-yarn friction decreases. This is of interest to spinners and it suggests one possibility of reducing end breaks caused by traveller although the effect of travellers on yarn tension involves several other forces.

Figs 5a and 5b show the variation in friction for 34s and 100s count yarns with respect to plated yarn guide and porcelain yarn guide respectively. Although the porcelain guide offers a slight edge at lower speeds, at higher speeds the plated yarn guide has been found to be better. The plated yarn guide also offers less frictional resistance. The advantage of waxing disappears at higher speeds (Fig. 5c). Fig. 6a shows the frictional pattern of yarn-to-metal friction for ring-spun and open-end yarns. It is observed that the open-end yarn has lower friction. As the yarns were made of the same type of cotton and had the same TPI, the difference in the observed property may be owing to the structural difference in the yarns. Also, the stick-slip observed for ring yarns between speeds 350 cm/min and 550 cm/min is not seen for the open-end yarn. Thus, from the point of view of lower friction the open-end yarn is preferable.

Fig. 6b shows the variation in friction with speed for 16s count ring-spun yarn with two different TPIs.
Although the higher TPI yarn shows a higher friction as it should be for speeds between 200 cm/min and 500 cm/min, it follows the pattern of the lower TPI yarn. Also, the stick-slip observed for lower TPI yarns between speeds 500 cm/min and 700 cm/min is not seen for the higher TPI yarn.

Fig. 7 shows yarn-to-metal friction for the sewing needle. The experiment was done with the commercial sewing thread (3/60s cotton yarn). The stick-slip is seen very well. Also, it is clear that at certain speeds the yarn flow is smooth through the needle. The lowest observed friction for this yarn needle combination was at 200 cm/min. Thus, if the speed is maintained around 200 cm/min the end breakages of the sewing thread will be minimum. However, since the minimum is sharp, if there is a small change in speed the pull on the yarn would be more and the stitch uniformity will be lost. If stitch uniformity is the primary criterion it is desirable to use yarn speeds between 250 cm/min and 400 cm/min. Thus, this instrument could be effectively used to select advantageous speeds for improving the performance of sewing and thus there appears to be a sufficient reason why the estimation of friction between sewing thread and the needle would be useful technologically.
Figs 8 and 9 show the friction for the acrylic yarn, wool yarn and cotton yarn of the same diameter. It is observed that the acrylic yarn has a comparatively high coefficient of friction. This is an important finding since the acrylic yarn when spun in cotton system would lead to greater wear and tear in the drafting arrangement. The wool yarn also shows a similar trend; however, it does not have the coefficient of friction as high as in the case of acrylic yarn. Wool yarn also exhibits a stick-slip between speeds 300 cm/min and above 700 cm/min.

From the above study it appears that the acrylic processing and wool processing need rollers which should have more smooth finishes and hardened surfaces so that the wear out is minimum. Perhaps the higher friction exhibited by these fibres may set a limit to the speed of processing these fibres.

Thus, the necessity to check the frictional behaviour of fibres before the onset of processing is brought out clearly. This would help in bringing about changes in the process and the process machinery used for these fibres.

It is concluded here that the yarn-to-metal friction generally follows the metal lubrication with boundary, semi-boundary and hydrodynamic conditions. This division is based on the sharp transitions observed in the friction vs yarn speed plots. As the speed increases initially the friction decreases. This may perhaps be due to the fact that the protruding hairs of yarn reduce the area of contact of the metal to the yarn. At initial speeds, the object perhaps leap-frogs from hair to hair and thus the area of contact being small the friction decreases. As the speed increases the hairs might bent down and the surface

![Fig. 7—Coefficient of friction vs linear yarn speed](image1)

![Fig. 8—Coefficient of friction vs linear yarn speed](image2)

![Fig. 9—Coefficient of friction vs linear yarn speed](image3)
area of the contacts increases, contributing to increase in friction. The flat regions of the graph where the friction remains constant over a small range may be owing to the constant hair resilience. As the speed increases further the secondary set of hairs, having lower protruding length, may assume importance and thus it could show a second flat region.

Thus, it appears that as the speed increases, in addition to the forward component of friction opposing the movement, there is a lateral component of friction working at right angles to the direction of motion and thus the friction increases as the resultant of these two forces.

According to Olsen, an increase in the roughness of guide surface can be considered analogous to an increase in the pressure between the yarn and the guide. Olsen's observation was on filaments and in the present case the change in hairiness or the TPI variation of the yarn causes the change in roughness.

Thus, if one could estimate from plots the lateral pressure exerted by the yarn (in principle it is possible), the contribution of lateral pressure by the yarn on the performance of knitting needle or the sewing needle could be understood. Such an analysis would help in understanding the knitting and stitching processes better.

All observations were made only up to 800 cm/min speed under laboratory conditions (RH 65% and 22.2°C) except for data presented in Table 1 which were obtained at 35°C and 60% RH. The results are on cotton yarn. The sample yarn used in 34s, 40s and 100s and the sewing yarn were commercial samples. The waxed yarn used was the sample yarn of 40s and the open-end yarns were spun from the same cotton samples. The yarn tension used was 25 g. In the case of plated, painted and porcelain yarn guides a tension of 45 g was used.

4 Conclusions

4.1 The kinetic friction of unlubricated cotton yarn follows the hydrodynamic profile qualitatively as has been reported earlier for lubricated filaments. The stick-slip phenomenon is observed and as the yarn count increases the coefficient of friction decreases for the same reference surface. Open-end yarns have lower frictional coefficient. Plated surfaces are superior to ceramic surfaces and the advantage of waxing disappears at higher speeds.

4.2 The method could be effectively used for measuring the coefficient of friction of new synthetic yarns so as to bring out specification changes for optimal performance in the spinning machinery. Also, this method could be used as a quality control procedure to check yarn guides, lappets, sewing needles, knitting needles, etc.

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References

1 Hansen W W and Tabor D, Text Res J, 27 (1957) 300.
4 Kalyanaraman A R, J Text Inst, (accepted).
7 Schick M J, Surface characteristics of fibres and textiles, Part I (Marcel Dekker, New York) 1975, Chapter 1, Section 1.