Additional Tension Caused by Bending of a Yarn Running on a Slender Cylinder

By Toshiro Sasaki and Katsuaki Kuroda, Members, TMSJ

Technical Research Laboratory, Kurabo Industries Ltd., Neyagawa, Osaka

Based on the Journal of the Textile Machinery Society of Japan, Transactions, Vol. 26, No. 12, T227-232 (1973)

Abstract

When a yarn runs on a slender cylinder, additional tension is brought in due to the bending energy (ΔT_1 , ΔT_2) of the yarn. In the previous paper, we proposed that the additional tension is shown as $\{\Delta T_1(e^{\mu\theta} - 1) + \Delta T_2\}$.

In this paper, an experiment was carried out by using a rotating slender cylinder to notice the existence of additional tension, and to get reasonable values of ΔT_1 and ΔT_2 . However, ΔT_1 , and ΔT_2 should be understood as components of deformation energy including bending energy.

1. Introduction

The frictional resistance of a yarn running on a slender cylinder is larger than the calculated value obtained by the usual capstan equation. For this reason, when a yarn runs on for example, a knitting needle, its tension becomes excessive, by high, and causes often troubles in knitting process. To solve these troubles, it is necessary to clarify this phenomenon and to estimate the value of this resistance from the yarn properties.

In our previous paper¹⁾, we proposed the following capstan equation under the presumption that the bending energy of the yarn would be required which would be added to the yarn tension:

$$T_2 = T_1 e^{\mu\theta} + \Delta T_1(e^{\mu\theta} - 1) + \Delta T_2 \quad (1)$$

where ΔT_1 is bending energy and ΔT_2 is hysteresis loss in bending. Both of them are obtained from bending test of a yarn. The value $\{T_1(e^{\mu\theta} - 1) + \Delta T_2\}$ is the additional tension compared with the usual capstan equation.

In this paper, we will prove this hypothesis from another view point. When a yarn running on a rotating slender cylinder, there will be no friction between the yarn and the cylinder, if there was no relative surface speed between them. Consequently, in this case the additional tension due to yarn running on a cylinder is caused only by the bending effect. In this way, we can make sure of the property of eq.(1), and can obtain some properties of ΔT_1 and ΔT_2 .

2. Theory

When a slender cylinder is rotated (surface speed: v) in

Fig. 1 Friction between a yarn and a rotating slender cylinder

the direction of yarn running (speed: V) as shown in Fig. 1, the final tension T_2 can be calculated from the initial tension T_1 by the usual capstan equation, as follows:

$$\text{if } V > v, \quad T_2 = T_1 e^{\mu\theta} \quad (2)$$

$$\text{if } V = v, \quad T_2 = T_1 \quad (3)$$

$$\text{if } V < v, \quad T_2 = T_1 e^{-\mu\theta} \quad (4)$$

The yarn tension along the yarn is shown in Fig. 2 schematically.

If the bending effect of the yarn is considered, eqs. (2), (3) and (4) are turned into eqs. (2)', (3)' and (4)' as follows:

$$\text{if } V > v, \quad T_2 = T_1 e^{\mu\theta} + \Delta T_1(e^{\mu\theta} - 1) + \Delta T_2 \quad (2')$$

$$\text{if } V = v, \quad T_2 = T_1 + \Delta T_2 \quad (3')$$

$$\text{if } V < v, \quad T_2 = T_1 e^{-\mu\theta} + \Delta T_1(e^{-\mu\theta} - 1) + \Delta T_2 \quad (4')$$

Equation (2)' is identical with eq. (1). Tension derived from eqs. (2)', (3)' and (4)' is shown in Fig. 3, respectively.

These equations are derived from the following considerations. The bending energy will be required when a yarn comes contact with a slender cylinder, and the unbending energy ($-\Delta T_1 + \Delta T_2$) will be required when the yarn

Fig. 2 Variation of yarn tension (1)

Fig. 3 Variation of yarn tension (2)

detaches from the cylinder, and both energy causes additional yarn tension on each position.

Hereupon, let us consider the change of T_2 when V is increased gradually with v fixed. Since the direction of the frictional force at $V > v$ is opposite to that at $V < v$, the change of T_2 against V will become discontinuous as shown in Fig. 4. As the friction between the yarn and the cylinder does not occur at $V = v$, the tension additional to T_1 is only due to bending hysteresis loss ΔT_2 as shown in eq. (3)' and Fig. 4(b). Therefore, ΔT_2 could be obtained immediately from this experiment.

Fig. 4 Variation of final tension against yarn speed. Surface speed of the cylinder was kept constant

Fig. 5 Experimental method

3. Experimental

In Fig. 5, the rotation of the cylinder was kept constant at 2,400 rpm and the yarn tension, T_1 and T_2 , was measured by increasing the yarn speed. Eight cylinders, 0.26–2.0 mm in diameter, were used. Initial tension was kept at 20.5 g, and the contact angle θ was 130°.

Fig. 6 Relation between final tension and yarn speed

Fig. 7 Relation between final tension and yarn speed

Fig. 8 Relation between $(T_2 - T_1)$ and curvature of slender cylinders when $V < v$

4. Results and Discussions

Figure 6 shows the tension T_2 versus yarn speed for 60/2 cotton yarns. Symbol $\uparrow$ in the figure shows the position of $V=v$. T_2 varies steeply near $V=v$, but discontinuity does not appear contrary to our expectation. Besides, T_2 increases as the cylinder diameter becomes small.

Figure 7 is the result for dyed 30/2 cotton yarns. T_2 is larger on the whole than that for 60/2 yarn. Hereupon, we pay attention to T_2 when $V < v$. T_2 ought to be smaller than T_1 when only frictional effect acts upon the yarn. But it is evident that T_2 is larger than T_1 on cylinders having diameters of 0.26 and 0.32 mm. The value of $(T_2 - T_1)$ at $V < v$ was plotted against the curvature for 4 samples in Fig. 8. For each samples, $(T_2 - T_1)$ becomes positive when

the curvature is large. This means that there is tension not only by frictional effect but also by bending effect.

5. Calculation of ΔT_1 and ΔT_2

Discontinuity of T_2 was not obtained from Figs. 6 and 7. So, we could not obtain ΔT_2 immediately from the experiment described in Section 2. Then we would consider another means.

T_2 can be measured accurately in both regions of $V > v$ and $V < v$, because T_2 is almost independent of the yarn speed except the steep slope near $V=v$. Besides, such a state as $V=v$ in which the yarn friction does not occur ought to exist in the steep slope region.

The final tension at $V > v$, is put as T_2 , that at $V=v$ as T_2' , and that at $V < v$ as T_2'' , respectively. Then, eq. (5) is obtained from eqs. (2)'-(4)'.

$$T_2'' = \frac{T_2 + T_2' e^{\mu\theta}}{e^{\mu\theta} + 1} \quad (5)$$

If the frictional coefficient μ is measured by other experiments, it is able to calculate the value of T_2'' from eq. (5).

Measured μ for 60/2 mercerized cotton yarns is shown in Fig. 9. It decreases with the increase of curvature.

Figure 10 shows the change of T_2 against V for the same sample as used in Fig. 9. Solid circles in the figure are T_2'' calculated by eq. (5) using μ of Fig. 9. From eq. (3), it is evident that the difference between this T_2'' and the initial tension T_1 means the bending hysteresis loss ΔT_2 of the yarn.

The value of ΔT_2 obtained on the assumption that eqs. (2)'-(4)' should hold seems reasonable, because it is very small when the cylinder is 2.0 mm in diameter. Besides, ΔT_1 obtained by substituting ΔT_2 into eq. (1) had the similar tendency to ΔT_2 .

Fig. 9 Coefficient of friction μ of sample yarns

Fig. 10 Calculated final tension at $V=v$

Fig. 11 ΔT_2 of yarns with wax and without wax

Next, the same 60/2 mercerized yarn was passed through

wax treatment, and was examined by the same method. It is generally natural that the slippability of a yarn is changed by wax treatment but bending properties do not change. So, the value of ΔT_2 of a waxed yarn ought to be the same as that of the original yarn. Figure. 11 shows this clearly, although the values of T_2 of both yarns were different.

ΔT_2 obtained by this method, however, is larger than that estimated from bending hysteresis measurement of the yarn. At first, we defined ΔT_1 and ΔT_2 as the bending energy and the hysteresis loss of a yarn. But, it seems appropriate to consider that ΔT_1 and ΔT_2 are synthetic deformation energy containing bending energy. Deformation energy is required when a yarn contacts with a slender cylinder, and recovery energy from deformation ($-\Delta T_1 + \Delta T_2$) is required when the yarn detaches from the cylinder, and both energy changes into yarn tension on each position respectively.

In our previous paper¹⁾, we described that other effects were expected in addition to bending energy, because the difference of final tension, between calculated by eq. (1) and measured, increases with increasing of initial tension. But, the view point mentioned above will solve these problems.

It is the subject for further study to make clear the properties of ΔT_1 and ΔT_2 and to explore the method to measure them directly.

6. Conclusion

Additional tension caused by bending energy of a yarn was studied by using a rotating slender cylinder. Obtained results were as follows:

(1) Bending energy (ΔT_1 , ΔT_2) of a yarn was calculated by a previously derived capstan equation, $T_2 = T_1 e^{\alpha\theta} + \Delta T_1(e^{\alpha\theta} - 1) + \Delta T_2$. Bending test of the yarn showed that the equation holds good.

(2) It is appropriate that ΔT_1 and ΔT_2 mean synthetic deformation energy including bending energy.

Literature Cited

[1] T. Sasaki et al; Preprints presented at Annual Convention of Text. Mach. Soc. Japan held June, 1973. (p. 75).