A NEW ELECTRO-MECHANICAL METHOD FOR MEASURING YARN THICKNESS

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Abstract

Measuring the thickness of a wire using a micrometer is simple, but textile workers cannot use the same technique. The current report describes a possible method of measuring yarn thickness under lateral force using a range of loads. The effect of twist on thickness and compressibility of yarns is studied.

***Key words**: yarn thickness, yarn diameter, thickness tester, electro-mechanical thickness tester*

Introduction

Measuring yarn thickness and compressibility and their effect on fabric quality is important to both the fabric designer and the textile technologist. Oxenham [13] has reported that the dimensional and mechanical characteristics of fabrics are dependent on fabric thickness, thread spacing of warp and weft in woven fabrics, courses and wales per unit length and stitch length in knitted goods, and the properties of the yarns from which the fabrics are made. He and Baser [3] have mentioned that among the yarn properties of great importance are parameters such as flexural and torsional rigidity, both of which are influenced to some extent by yarn diameter and twist. Also, the yarn diameter and its compression impose certain geometrical restrictions on the structure which influence its dimensional and mechanical properties.

There are many different methods for measuring yarn thickness and yarn compression. These methods have undergone considerable change and development over the years. However, none of them has been accepted as a standard method. A typical classification of the methods is as follows: (I) measuring yarn diameter via mass and length, (II) measuring yarn diameter using optical methods and (III) measuring yarn diameter by employing mechanical methods.

The first two methods are basically for measuring the yarn diameter free from any forces, i.e. free from lateral forces in a non-compressed state. There is usually only a small longitudinal force (tension) on the yarn to keep it straight. Measuring the yarn thickness via a mechanical measuring head involves travelling the yarn between suitable feelers, one of which is fixed while the other can be displaced freely. The relative displacement of the movable element is magnified to give a clear trace of yarn diameter, which enables quantitative estimates of the diameter to be made.

There are several methods by which yarn thickness can be measured mechanically. Frenzel [6] used a rotating drum and feeler, in which the yarn thickness was measured by passing the yarn around the drum's circumference with the feeler pressed very gently against the yarn. The application of shoes or two flat-faced segments for measurement of yarn irregularity in continuous form is well known. Anderson et al. [1] and Oxley [14] used a device to measure the thickness of yarn compressed between two steel shoes by drawing the yarn between a fixed flat and a cylindrical shoe. Cavaney et al. [4] modified Anderson's device; in place of one pair of shoes, three pairs were used, which were separately mounted on independently moving arms. Using three shoes enabled Cavaney and his colleagues to evaluate the average thickness of half-inch samples each time the device was employed.

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Anderson & Settle [2,19] measured the thickness of 0.5 cm sample lengths of yarn compressed between two parallel steel plates (anvil and presser foot). The anvil was fixed, and the presser foot was mounted at the end of an arm supported by two steel needles. The arm oscillated vertically, and measured the diameter of the yarn, which is the separation between the two plates. Baser [3] measured the yarn thickness by compressing the yarn sample (fixed on the yarn sample holder) between two glass plates. The load was applied via a counter-weight method using a screw thread, and the major axis of the yarn was obtained by using a travelling microscope.

Oxtoby's [15] instrument was based on that of Anderson & Settle [2] with some improvement. Oxenham [13] made a further improvement to Oxtoby's apparatus by converting the manual method of raising and lowering the load lever which carries the saddle to an automatic process by employing a motor and gearbox.

The tongue and groove or grooved plunger technique has been used for the purpose of measuring thickness, but this has generally been restricted to assessment of the regularity of slivers and roving by measuring their thickness variation under load [10,11,18].

After a bulking process for worsted yarns [8,9], the core thickness of the yarns (original and bulk-treated worsted yarn) was measured under zero lateral force by using an optical method. However, since the optical method cannot provide information about the compression behaviour of yarns, it was decided to design and construct an electro-mechanical yarn thickness tester, which is the subject of this paper.

Principle of the experimental device

After being deposited on a yarn accumulator, the yarn is drawn between two vertically mounted measuring rollers and a pair of take-up rollers. The bottom (grooved) measuring roller has an inner groove width of 34 mm and rotates about a fixed horizontal axis. The bottom take-up roller also rotates about a fixed horizontal axis, and these two rollers (bottom measuring and bottom take-up rollers) are connected together via a timing belt for transferring motion from the take-up to the measuring roller. In this way the surface speeds of the two rollers are kept equal. The top take-up roller is springloaded, and is therefore negatively driven.

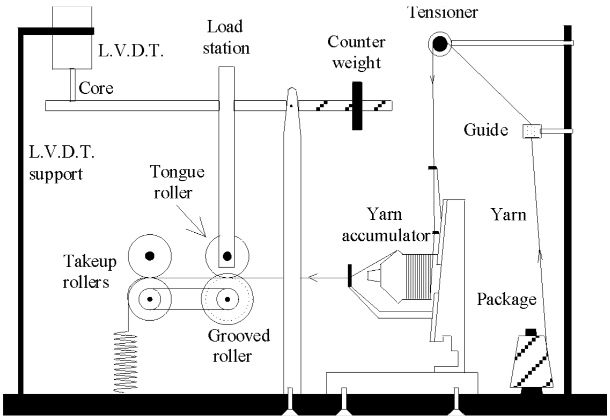

Figure 1. Electro-Mechanical Yarn Thickness Tester.

A stepper motor was found to be a suitable method for producing rotatory motion of the take-up roller. The stepper motor can be precisely controlled, as it moves in a definite step in a specific direction on application of an electronic pulse. The motor chosen has a step angle of 1.8^{o}, which means that it makes one revolution in 200 steps. The top measuring (tongued) roller is supported by an arm which is fixed to a balance lever. The latter has its fulcrum at its support and is free to oscillate vertically. The length of the balance lever was chosen so as to give sufficient magnification to the yarn thickness and its variation. At one end of the balance lever the measuring device, a linear variable differential transformer (LVDT), is placed. The LVDT core is free of load, i.e. there is no loading mechanism acting on the core apart from its own weight; the latter, being constant, can be balanced out on the measuring scale, so that every displacement of the lever caused by variation in yarn thickness can be detected. The counterweight, which is positioned at the other end of the balance lever, can be moved forwards and backwards on a screw. The counter-weight is moved to adjust the distance between tongue and groove roller nip according to the yarn thickness. It is also used to compensate for the weight of the tongued roller and its support and the weight of the LVDT core. In order to reduce the tension variation in the yarn during the measurement, an electrically controlled yarn accumulator is used. This device works independently, always carrying a fixed amount of yarn. An IBM personal computer was used to drive the stepper motor at the desired speed. It is also used to receive electronic signals which are proportional to the thickness of the yarn specimen under the test.

The effect of load on yarn thickness

It has been suggested [7,17] that the load applied during testing of yarn compression and thickness should be related to the load expected to be encountered in use. This latter load is often indeterminate [7], and the standards suggested depend to a large extent on the judgement of the investigator. The choice is also often governed by the measuring instrument available.

After the calibration of the Electro-Mechanical thickness tester, several spun yarns were tested. In order to assess their compressional characteristics, the yarn thickness was measured under different loads. The loads used ranged from 0.2 to 50 grams. Fig. 2 illustrates a typical result of the thickness tests on a ring spun yarn with 250 tpm.

The results exhibit the expected trend when measuring yarn thickness under different loads. At the initial stage, the rate of reduction in yarn thickness with increasing load is quite large. At higher loads the effect is much smaller; in the example shown an increase in load from 40 to 50 grams appears to have very little effect on the measured yarn thickness.

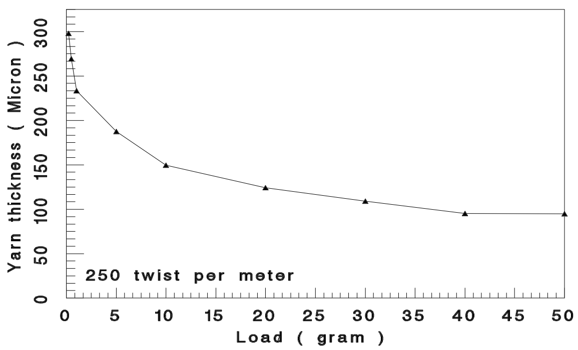

Figure 2. Typical result of a thickness test on ring spun yarn with 250 tpm.

It is known that a tongue and groove roller system measures the thickness of the yarn at the nip of the measuring rollers. This means that the length of the yarn specimen under test is not directly known. Thus, while Fig. 2 shows the effect of load on yarn thickness, it cannot be assumed that the graph represents the effect of pressure on the thickness, since the length of specimen under load may vary with the applied load.

Length of specimen under load

The tongued and grooved rollers adopted for the present work were originally developed for the measurement of sliver and roving irregularity. During the measurement of irregularity a fixed load was used; the load selected depended on the material under test (sliver, roving or yarn), the instrument and the investigator [5]. For the measurement of irregularity under a fixed load, the length of specimen under load has not been considered critical.

On the other hand, for the measurement of yarn thickness it is necessary to know the length of yarn specimen under the test. The yarn thickness testers used by previous researchers [2,15,13] were equipped with a saddle and anvil with a flat surface of half a centimetre. In the current device there is no immediate specimen length available, and therefore an estimate must be made of the length of the specimen under test. The specimen length (length of yarn under the measuring point) may be defined as the length of contact between the yarn under test and the bottom measuring roller, or the length of arc covered by the deformed specimen at the measuring point. The length of arc is dependent upon the diameter of the yarn, the size of the load on the system and the degree of deformability of the specimen.

Fig. 3 shows the geometrical construction of the system with and without material between the tongued and grooved rollers.

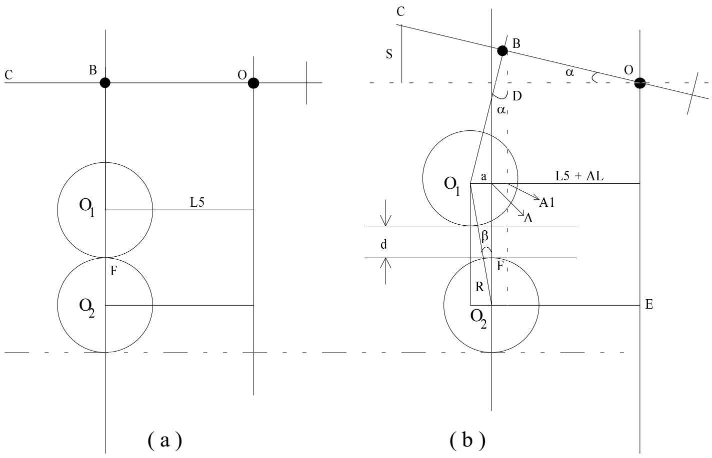

Figure 3. Geometrical construction of the system with (b), and without (a) material between the rollers.

Since F is a point fixed in space, it can be seen by comparing the two diagrams that BF in Fig. 3 (a) is equal to the vertical distance between F and D in Fig. 3 (b). Thus

$$O_1B + R = A_1B + R + d - BD,$$

or

$$O_1B = A_1B + d - BD\,, \qquad (1)$$

Now in Fig. 3 (b),

$$BD = OB\sin\alpha, \qquad A_1B = O_1B\cos\alpha$$

and therefore substituting these into (1), we get

$$d = O_1B(1-\cos\alpha) + OB\sin\alpha \qquad (2)$$

where d is diameter of the solid rod. However, this result would not apply when the rod is replaced with a yarn.

In the case of compressible material such as spun yarn, the geometry of the yarn at the contact point is slightly different, (Fig 5). The condition of the compressed yarn and the grooved roller can be visualised as in Figure 4;

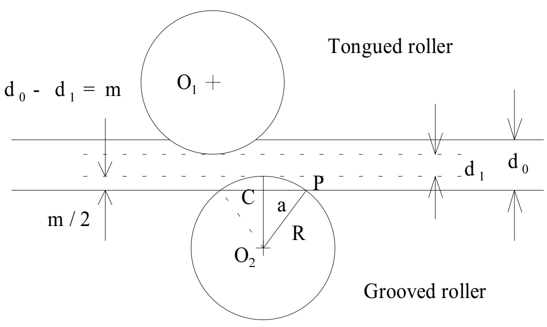

Figure 4 The compressed yarn between the tongued and the grooved rollers.

The length of chord 2a is assumed to be equal to the length of yarn being compressed. It should be emphasised that the actual length of yarn under the test at contact point is not straight but rather an arc of a curve. The explanation for this is that the total load on the yarn is not evenly distributed along the contact arc. However, to enable an estimate of contact length to be made, it was necessary to assume that the load was distributed equally along the length of yarn under the test. Thus the length of chord 2a was chosen as the yarn length under the test, because the length of the contact arc and its chord are very close to each other. The length of arc can be obtained from triangle Co_2P in Fig 4. Letting

$$m = d_0 - d_1$$

we get

$$R^2 = a^2 + (R - \frac{m}{2})^2$$

which leads to

$$2a = \{m(4R-m)\}^{1/2}$$

In order to present the yarn thickness as a function of load per unit length, the total load on the system was divided by the length of chord 2a.

Load-thickness relation

The electro-mechanical thickness tester was used to measure the thickness of worsted yarns spun at different twist levels. The results of yarn thickness at different twist levels under different loads are listed in tables 1 to 5. It can be seen from Fig. 5 that the length of chord or contact length increases as the yarn twist per unit length decreases at a load of 50 grams; a similar trend is found at other loads. Thus for a given total applied load, the load per unit length W/2a acting on the yarn is higher for yarn with higher twist. The results (Tables 1 to 5) of the yarn thickness measurement obtained from the electro-mechanical device show that the yarn thickness at the minimum load of 0.2 gram decreases with increase in the yarn twist level. This trend agrees with the result obtained from the same yarn sample using an image analysis device [8]. The results obtained by the two methods are shown in Table 6. It should be noted that the image analysis method measures the yarn core thickness under zero lateral force, while the results of yarn thickness using the electro-mechanical device at 0.2 gram load include a contribution from the surface hair.

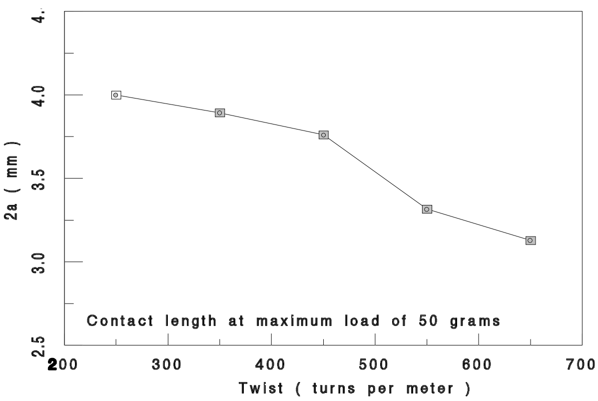

Figure 5 Contact length at maximum load of 50 grams in dependence of twist.

Table 1. Yarn thickness (dia.) at different load (W) for: 37 tex worsted untreated yarn 250 tpm; d0, d1, a – as in Figure 4.

load gram	dia. mm	d0-d1 mm	2a mm	W/2a g/mm	(d0-d1)/d0
Initial thickness	0.3309	--------	--------	--------	--------
0.2	0.2981	0.0328	1.493	0.134	0.099
0.5	0.2693	0.0616	2.046	0.244	0.186
1.0	0.2334	0.0975	2.573	0.389	0.295
5.0	0.1874	0.1435	3.120	1.603	0.434
10.0	0.1496	0.1813	3.506	2.852	0.548
20.0	0.1242	0.2067	3.743	5.343	0.625
30.0	0.1092	0.2217	3.876	7.740	0.700
40.0	0.0954	0.2355	3.995	10.013	0.712
50.0	0.0948	0.2361	4.000	12.500	0.714

Table 2. Yarn thickness (dia.) at different load (W) for: 37 tex worsted untreated yarn 350 tpm; d0, d1, a – as in Figure 4.

load gram	dia. mm	d0-d1 mm	2a mm	W/2a g/mm	(d0-d1)/d0
Initial thickness	0.3287	--------	--------	--------	--------
0.2	0.2908	0.0379	1.605	0.125	0.115
0.5	0.2682	0.0605	2.027	0.247	0.184
1.0	0.2307	0.0980	2.580	0.388	0.298
5.0	0.2054	0.1233	2.893	1.728	0.375
10.0	0.1561	0.1726	3.422	2.922	0.525
20.0	0.1309	0.1978	3.662	5.461	0.602
30.0	0.1165	0.2122	3.793	7.909	0.646
40.0	0.1128	0.2159	3.826	10.455	0.657
50.0	0.1052	0.2235	3.892	12.847	0.680

Table 3. Yarn thickness (dia.) at different load (W) for: 37 tex worsted untreated yarn 450 tpm; d0, d1, a – as in Figure 4.

load gram	dia. mm	d0-d1 mm	2a mm	W/2a g/mm	(d0-d1)/d0
Initial thickness	0.3191	--------	--------	--------	--------
0.2	0.2848	0.0343	1.527	0.131	0.107
0.5	0.2663	0.0528	1.894	0.264	0.165
1.0	0.2267	0.0924	2.505	0.399	0.290
5.0	0.2013	0.1178	2.828	1.768	0.369
10.0	0.1537	0.1654	3.350	2.985	0.518
20.0	0.1296	0.1895	3.585	5.579	0.594
30.0	0.1249	0.1942	3.629	8.267	0.609
40.0	0.1187	0.2004	3.686	10.852	0.628
50.0	0.1106	0.2085	3.760	13.298	0.653

Table 4. Yarn thickness (dia.) at different load (W) for: 37 tex worsted untreated yarn 550 tpm; d0, d1, a – as in Figure 4.

load gram	dia. mm	d0-d1 mm	2a mm	W/2a g/mm	(d0-d1)/d0
Initial thickness	0.2786	--------	--------	--------	--------
0.2	0.2673	0.0113	0.877	0.228	0.041
0.5	0.2641	0.0145	0.993	0.504	0.052
1.0	0.2452	0.0334	1.507	0.664	0.120
5.0	0.2236	0.0550	1.933	2.587	0.197
10.0	0.2063	0.0723	2.216	4.513	0.260
20.0	0.1723	0.1063	2.686	7.446	0.382
30.0	0.1431	0.1355	3.032	9.894	0.486
40.0	0.1171	0.1615	3.310	12.085	0.580
50.0	0.1165	0.1621	3.316	15.078	0.582

Table 5. Yarn thickness (dia.) at different load (W) for: 37 tex worsted untreated yarn 650 tpm; d0, d1, a – as in Figure 4.

load gram	dia. mm	d0-d1 mm	2a mm	W/2a g/mm	(d0-d1)/d0
Initial thickness	0.2855	--------	--------	--------	--------
0.2	0.2697	0.0158	1.036	0.193	0.055
0.5	0.2601	0.0254	1.314	0.381	0.089
1.0	0.2450	0.0405	1.659	0.603	0.142
5.0	0.2288	0.0567	1.963	2.547	0.199
10.0	0.2077	0.0778	2.299	4.350	0.273
20.0	0.1733	0.1122	2.760	7.246	0.393
30.0	0.1641	0.1214	2.871	10.449	0.425
40.0	0.1499	0.1356	3.034	13.184	0.475
50.0	0.1413	0.1442	3.128	15.985	0.505

Fig. 6 shows that at low loads the yarn thickness decreases with increasing yarn twist, whereas at higher loads increasing twist is accompanied by increase in thickness. This trend agrees with the results of Onions et al., and Anderson & Settle [12,2], and can be explained by the decrease in the amount of compression obtained by increasing the twist per unit length.

Table 6. Comparison of yarn thickness from two methods

twist per metre	optical device core dia. mm.	mechanical device yarn dia mm.
250	0.2730	0.2981
350	0.2680	0.2908
450	0.2510	0.2848
550	0.2430	0.2673
650	0.2390	0.2697

Increasing twist reduces the air space in the yarn, therefore reducing yarn diameter and making yarn more difficult to compress.

Under low loads, little compression takes place; therefore the trend reflects the reduction in yarn diameter as twist increases. Under high loads the behaviour is more complex. The yarns with low twist have relatively high diameters but are easily compressed, so the application of a high load therefore reduces the diameter greatly. Yarns with high twist may have lower initial diameters than their low twist counterparts, but are difficult to compress even under high loads. A contest between the effects of load and twist therefore occurs. The effect of load is thus greater at low twist than it is at high twist, which is reflected in the results as shown in Fig. 6.

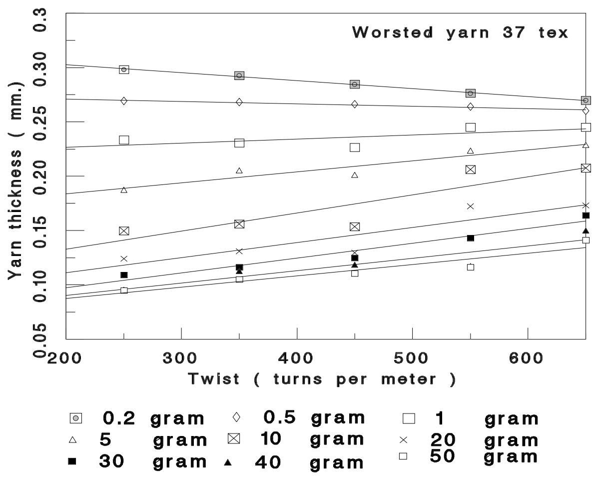

Figure 6. Dependence of yarn thickness on twist and load.

Relationship between thickness and applied load

Direct measurement of yarn thickness under zero load is not practical because of the ease with which the yarn is distorted. One approch to overcoming this difficulty is to fit to the compression results a theoretical trend which can then be extrapolated to zero load in order to estimate the yarn diameter.
A typical experimental trend is shown in Fig. 7.

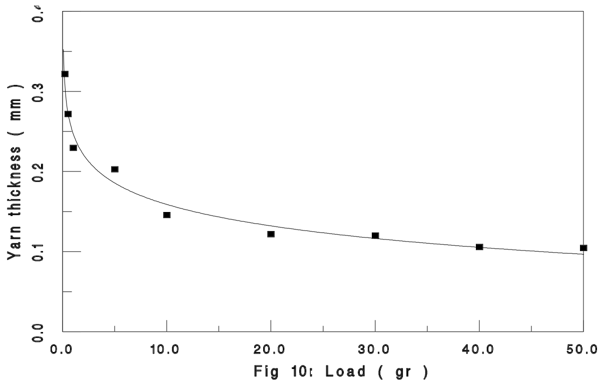

Figure 7. Dependense of yarn thickness on load at constant twist.

Oxtoby assumed a relation of the kind $d = d_0 P^{-C}$ where d is yarn diameter, P is the compressive pressure applied, and d_0 and c are constants.

However this equation suggest that d tends to infinity as the load decreases, which is unrealistic. A more satisfactory equation is

$$d = A + Be^{-kP}$$

In order to check whether this is a reasonable equation we proceed as follows. Noting that at high loads d tends to the value A, an estimate of A may be found from the experimental results at the highest load applied. For example, for the yarn with 650 tpm in Table 5, the estimate of A is approximately 0.141 mm. Hence a test of equation (1) is to plot ln (d-0.141) against P, when a straight line should result

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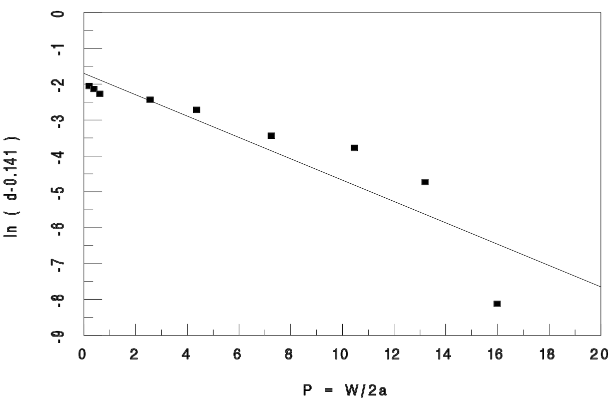

Figure 8. The measuring results from Figure 7 transformed into the co-ordinates ln(d-0.141) and W/2a.

Fig. 8 shows the results of such a plot and reveals that there appear to be two distinct regions. This suggests, following Oxenham [13], that the more general equation

$$d = A + B_1 e^{-k_1 P} + B_2 e^{-k_2 P} \qquad (1)$$

may be suitable. To estimate the parameters of this equation the method of least squares was used. giving the values in Table 7.
The appropriate curve when twist = 650 tpm is drawn on Fig. 7, which shows an excellent fit to the data. This is compared by the R^2 values in Table 7, which would be equal to 1 if the fit was perfect.

The thickness of the yarn at zero load, i.e. the initial thickness, can be determined from the relationship (1) by putting the load P equal to zero; this gives

$$d_0 = A + B_1 + B_2 \quad (2)$$

Table 7. Parameters of equation (1).

Yarn twist/m	A	B_1	K_1	B_2	K_2	R^2
250	0.092	0.106	-1.654	0.134	-0.074	0.998
350	0.106	0.085	-2.524	0.138	-0.086	0.993
450	0.114	0.079	-2.324	0.126	-0.097	0.990
550	0.070	0.029	-1.695	0.180	-0.029	0.995
650	0.130	0.034	-2.644	0.121	-0.046	0.997

The initial rate of compression (i.e. the rate of change of thickness with load about the zero gram load position) can be determined by differentiation of the equation with respect to the load P,

$$(dd / dP) = - B_1K_1e^{-k_1P} - B_2K_2e^{-k_2P}$$

and then introducing the condition P = 0 into the equation. Thus the initial rate of compression is determined by:

$$(dd / dP)_{P=0} = (-B_1K_1) + (-B_2K_2)$$

Summary

The electro-mechanical yarn thickness tester utilised a tongue and groove roller unit. The device incorporates an LVDT to sense the tongue roller displacement proportional to the yarn thickness. The use of a stepper motor provided accurate interval length of yarn between tests. The measurement of yarn thickness under lateral pressure revealed that the yarn thickness under light load decreases with increasing twist, and the opposite trend is obtained under heavy load. The use of the general equation form of the type $d_0 = A + B_1e^{-K_1P} + B_2e^{-K_2P}$ provides a good fit to the experimental data, and hence yields a realistic estimate of yarn thickness under zero load.

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