Instabilities in a Yarn balloon

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Introduction

The subject of yarn balloons has fascinated scientists throughout this century. The usual assumption is that the yarn is perfect and the balloon shape is invariable for a given set of boundary conditions/ Anyone who has observed yarn balloons in a staple-fiber spinning mill will have observed that this is not true. The balloons change shape and there is a lack of constancy in the angular position of the yarn in the balloon at a given rail height. This work seeks to demonstrate various relationships that control these changes.

As was mentioned in previous reports, disturbing faults in a yarn passing through a yarn balloon produce local distortions in the shape of the yarn in the balloon. The thick spots are heavier than average and the centrifugal forces drag the yarn in the vicinity of the thick spot to a radius that is larger than it was before. The thick spots also have a greater air drag than the normal yarn and a deviation in drag force is generated. The converse applies when a thin spot passes through. In addition, changes in hairiness or yarn diameter alter the balloon shape because of the associated changes in air drag. As the fault passes relatively slowly through the surface of the balloon, the local deviations in shape follows it. A possibility exists for other causes of deviation.

Measurements were made of the deviations in yarn geometry by using photography. The balloon shape was determined 10 times per second for a minimum of 60 seconds and the data are analyzed.

The Yarn Balloon

For convenience, parts of the theory from an earlier report are repeated here. in ring spinning, the yarn coming from the drafting system and passing down to the traveler forms a surface of revolution called a yarn balloon. The shape of the yarn that is the generator for this balloon is described by a hyperbolic equation and the factors are:

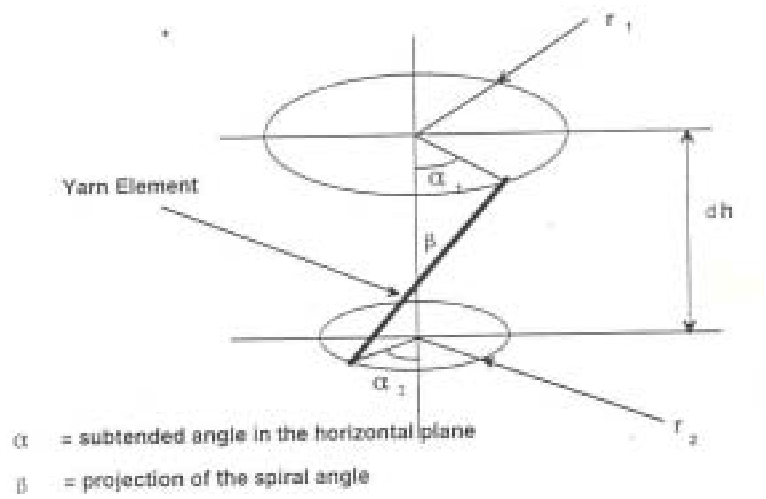
rotational speed of the generator	(ω)
radius of the yarn element	(r)
mass of the yarn element	(dm)
vertical tension component	(Tv)
air drag acting on the yarn element	(dD)
Coriolis component.	(c)

The Coriolis component in ring spinning is negligible because the linear velocity of the yarn along the generator is so slow.

Consider an element of yarn at radius r and distance h from the ring rail. Let the position nearest the observer be called the "front center" and that at 180^0 be the "back center". A line between the front and back centers is perpendicular to the length of the machine in the horizontal plane.

The air drag is a function of $(r)^2$ [and other factors as discussed later] and acts tangentially to the locus of the element. It might be noted that the centrifugal force equals (dm)r^2, and the forces acting on the element are also a function of r^2 but act radially. In other words, in an XYZ co-ordinate system, the forces in both the X and Z directions depend on r^2 and the force in the force in the Y direction for a given yarn count and traveler weight is more or less constant. The Y direction is vertical and parallel to the spindle axis. The height of the machine and Z is perpendicular to that (i.e., passing through the front and back centers).

The air drag acts tangentially to the locus of each element of yarn and provides a moment to tilt it so that the yarn forms a spiral of angle [used in previous reports]. In this report, the subtended angle α will be mostly used. The vertical height of the element is dh.



< Figure 1 >

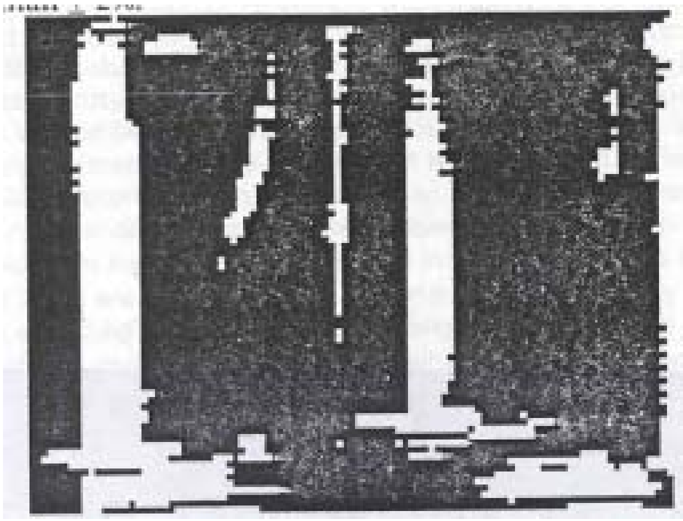
Air drag depends on the effective yarn diameter (d), incremental length (ŏ), yarn hairiness and, perhaps, inclination. Furthermore, it depends on the square of its speed through the air mass. As a practical matter, we do not know the rotational speed of the air mass in the vicinity of the balloon surface, but we do know that it is not zero. On this basis, the relative velocity is k and the air drag is a function of (r^2, ω d, k). Let the air drag=$k(r)^2$ where k is a modified air drag coefficient that takes into account changes in yarn hairiness, surface structure and inclination as well as the air movement within the balloon. Changes in any of these factors would produce changes in the geometry of the balloon. to reduce the number of variables, the rail position was fixed and the spindle speed was kept nominally constant. The fixing of the rail maintains the balloon height constant and the limiting of the amount of yarn spun in any series of observations, restrained the wind-on diameter of the yarn on the bobbin within narrow limits. Thus ω and k were restrained to be virtually constant and the parameter h was controlled. The remaining uncontrolled factors were m, d, k, r and α. Changes in mass (δm) reflect changes in linear density, and it is well known that staple yarn has quite a large variance in linear density. Changes in hairiness are also known to be large and there are also changes in diameter. Thus variability in δm, $\delta \kappa$ and δd would be expected to cause transient changes in yarn balloon geometry. The purpose of this investigation was to see what changes there were in r and α each of several heights over a period of a minute and to try to explain these in terms of the parameters δm, $\delta \kappa$ and δd.

The Test Method

In the present work, data has been gathered using a video camera with a line of sight in the Z direction and a stroboscope synchronized to hold the yarn in the balloon as nearly as possible at the side position so that is could be seen in a mirror which reflected the quadrature view. The video tape was then transcribed to a computer record using a Video spigot frame grabber that enable single frames a tenth of a second apart to be rendered as bit-mapped images. These images were processed using Adobe Photoshop software. This software could be set up to indicate the cursor position and thus it was relative simple to trace the coordinates of the yarn. Also the optical density of the image could also be enumerated and used to determine the presence of the yarn even when it was scarcely visible. The data were transcribed to a spreadsheet on a second computer and the calculations for r and were made automatically. The value of r was calculated from the value of was calculated from the equation Tan α = x/z. Various datum, points were recorded to serve as calibration benchmarks. This was successful but the magnitude of the task of measuring and recording many thousands of coordinates has to be pointed out and the need for an on-line system is emphasized.

Processing the Data

Some errors in measurement were inevitable, consequently care was taken to assess them. At high magnifications, the image became slightly pixelated which meant that continuous lines appeared stepped and this source was estimated to give an error band of less than ±0.5% in all three directions. The yarn was twisted and the helical fibers reflected light differently to give a staircase appearance at shown in Figure 2. The particular frame chosen for this figure was poor and was chosen to show the pixelation and other errors: it has been processed to enhance the contrast. There was also some speed blurring. However, it was possible to interpolate and the error from this source is not likely to exceed ±1%. A few frames had poor lighting and those frames were more susceptible to error. The vector sum of these errors is thought to be less than ± 2%.



< Figure 2 >

It was thought desirable to smooth the data to reduce the impact of random errors. It was estimated that none of the phenomena concerned would cause significant changes within 3 inches of yarn in the balloon. Consequently all data in the matrices other than those at the margins were averaged with their neighbors. In all cases every data point in the height (h) direction was averaged with the first neighbor on either side to make each point an average of three readings [when there was no neighbor on one side or the other, the process was not carried out]. The height intervals were 0.2 inches and the sliding average was over 0.4 inches. In the case of radius measurement, it was observed that there were no sudden changes and consequently each data point was averaged with the neighboring two data points on either side to give an average of five [when there less than four data points the process was not carried out]. During the time interval for five successive readings, about 2 1/2 inches of yarn would pass through the balloon. In the case of the matrix for alpha, there were some sudden shifts and it was thought undesirable to time average to smooth the data. The random error arising from faulty readings was in intervals of 0.1 second during which time 1/2 inch if yarn would pass through the balloon. The smoothing should have reduced the reading errors to under ±0.5%.

Variations in linear density and hairiness have well-known periodographic profiles and if the variations in balloon geometry are related, it might be expected that they would have similar profiles. Also if there is any periodic variation, it would be shown in a periodogram. Consequently the data was processed using fast Fourier transforms. This requires an uninterrupted time series, so the time series have the least number of unfilled data points was chosen and the vacancies were filled with values interpolated from the surrounding matrix. About 10% of the data points were filler values.

As a cross-check, some analyses were made using superpositioning method. In this the time series is divided into equal segments and the corresponding segmental values are averaged which reduces the random error and resonates with the periodic error when the segment length is a harmonic of the period.

In addition to the above various three dimensional graphs were used to view the data and some of these are described later.

Machine and Yarn Conditions

Two qualities of cotton yarn were produced. The first one was made with defective drafting rolls with the idea of ranging the measurement system and the second yarn was the best we could make with the equipment at hand without reconditioning the machine. These will be termed "good" and "bad" even although neither was of acceptable commercial quality. The yarns made were 16s count and 20 t.p.i. The good yarn had a short-terms CV of linear density of 4.24% and the bad yarn 10.24%. A #12 traveler was used which was deliberately on the light side of normal practice. In fact, at low rail positions the balloon collapsed, but once again an extreme value was used for these ranging tests. The roving was 0.80 N_e and 1.08 t.p.i.

A Spintester running at 7000 rpm was used to produce the yarns, The ring size was 3.85 inches and no balloon control ring was used. The rail was fixed in position and the frame was run for just over one minute to prevent the build up of yarn on the that would otherwise change the wind-on diameter. The overall draft used was 22, which means that error wavelengths arising from roving variability is likely to be in the range encompassing 110 inches. The linear speed of yarn through the system was 5.8 inches/sec. Assuming a fault length of about 3 inches, a yarn fault took less than 1/2 second to pass through whereas roving faults would take almost 12 seconds. One turn of roving twist took about 3 1/2 seconds to pass.

Preliminary data showed that the good yarn had a CV of balloon radio of 3.9% and the gad yarn 3.6%. The good yarn had a CV of balloon spiral angle of 10% whereas the bad yarn had a CV of 11%. There was very poor correlation between variations in balloon radius and balloon spiral angle.

Preliminary Test results

First, consideration was given to the CV's obtained with the so called "good" and "bad" yarns . The results given in Table 1 relate to sufficient yarn to get an acceptable value. In some cases this meant running the frame longer than the stipulated minute. The normal measurements of quality such a CV's of yarn tenacity and linear density were consistent with the labels (unless one quarrels with the definition of good yarn), however, the CV's of yarn angle and balloon radius were not.

< Table 1>

%CV's within Various Batches of Data

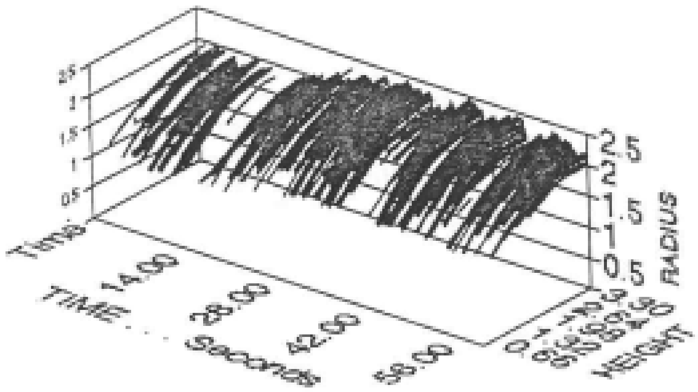
[Other quality data given in brackets]

	"Bad" yarn	"Good" yarn
CV of Yarn Tenacity	18.37	7.87
CV of Linear Density	21.50	17.00
[Uster Imperfections	48	12]
[Uster Hairiness	6.43	6.33]
CV of Yarn Angle β	9.52	7.67
	9.91	10.95
	7.83	9.61
	8.92	-
CV of Balloon radius r	3.80	3.51
at 1.75" above the rail	3.90	3.64
	3.51	3.83
	2.77	-
	2.26	-

These preliminary results showed considerable variation in r and β but provided no probable cause for the variations. The variability among the batches of data suggested that there might be some long term effects which might well come from changes in the roving used. It is well known that twist runs to the thin spots in the roving and that roving twist affects fiber migration in ring spinning, which in turn affects the hairiness of the yarn.

Video Analysis

The second step was to analyze the data obtained from the individual sequential frames of the video described earlier. This video related to the so called "good" yarn. A three-dimensional graph relating the changes in balloon radius(r) and height above the ring (h) in inches in respect to time in seconds is given in Figure 3.

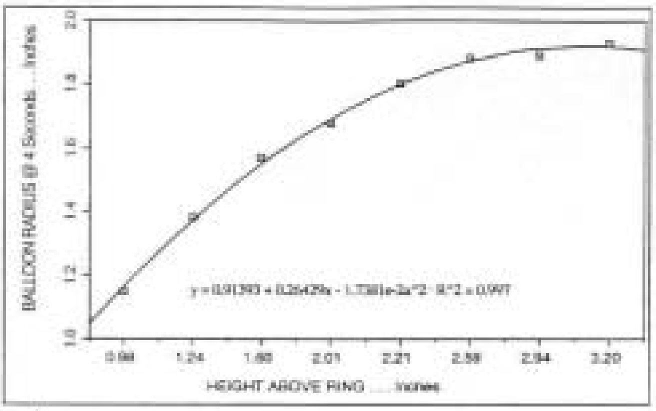


< Figure 3 >

It will be noted that there were periodic zones where incomplete readings are evident. These cases occurred when the yarn rotated out of view behind the bobbin, it being realized that this was really due to changes in speed of the yarn relative to the stroboscope flashes. It implies transient changes in the subtended angle α.

It turns out that the portion of the yarn balloon measured is quite accurately described as a parabola (even although this is still an approximation that can apply only over a part of the balloon and may not apply so closely for other running conditions). However it supports the assumption made in a previous report. As time progressed, the constants of the parabolas changed but the smoothed values consistently gave correlation coefficients (R2) better than 0.99. Most unsmoothed values consistently gave correlation coefficient around 0.75 and those cases where much of the yarn was obscured behind the bobbin were understandably lower still because the number of data points per curve was low. An example is given in Figure 4 but in this case the x direction referred to is the height (h) and the balloon radius is (r)

The data in table 2 gives an idea of how the parabolic constants varied. The first two lines relate to measurements smoothed over the moving block of 5 tenths of a second and 0.4 inches of height and were chosen arbitrarily: the second two relate to measurements smoothed over 30 seconds and 0.4 inches of height. The coefficient of h gives the slope of the balloon in a plane containing a radius and the spindle axis. The coefficient of h^2 relates to the curvature. It is evident that there are considerable variations in shape on a second to second basis.

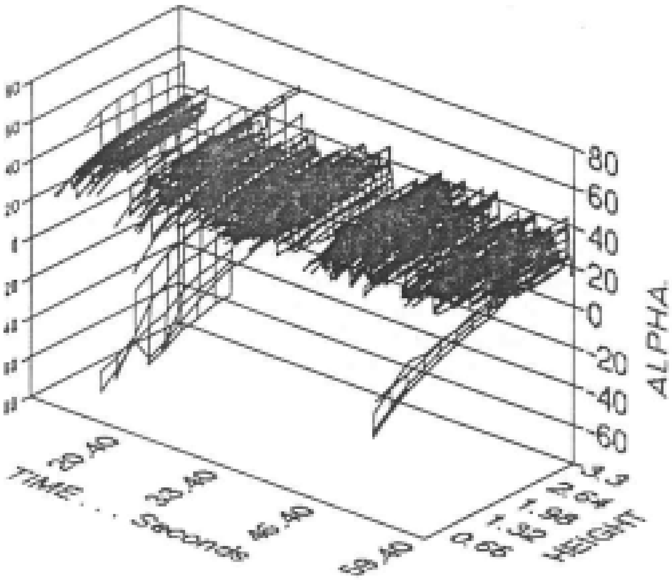


< Figure 4 >

< Table 2 >

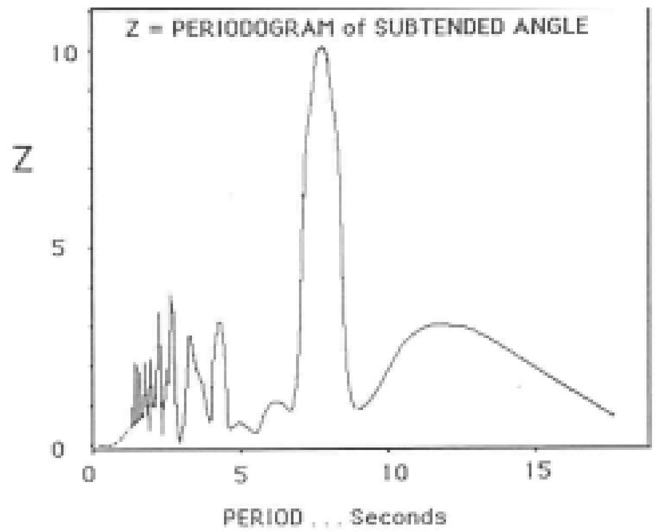
Time	coeff. of h	coeff. of h^2	Corr. Coeff. R2
1second	0.23	0.010	0.991 +
4second	0.26	0.107	0.997 +
30seconds	0.77	0.107	0.997 *
60seconds	0.74	0.107	0.996 *

The corresponding data relating the subtended angle time in seconds and height above the ring (h) in inches are given in Figure 5.



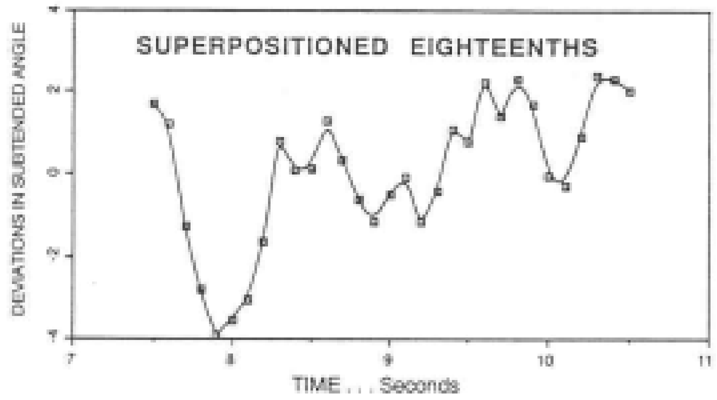
< Figure 5 >

It is obvious that much larger variations occurred in the subtended angle than had been experienced with the radius, but this is consistent with the periodic disappearance of the yarn behind the bobbin. There were two episodes when there were massive deviations from the mean position of alpha but there was also an appearance of repetitive deviations from the mean. Consequently fast Fourier transforms (FFT) of the data were used to produce periodograms of angle, it is clear that there was a strong periodic component between 7.5 and 8 seconds. Harmonics would be expected at about 4, 2.6, and 2 seconds if the disturbance was non-sinusoidal. Higher harmonics would be expected to be lost in the noise. These component are evident and it seems reasonable to assume that there was periodic component that strongly deviated in waveform from a pure sine wave.



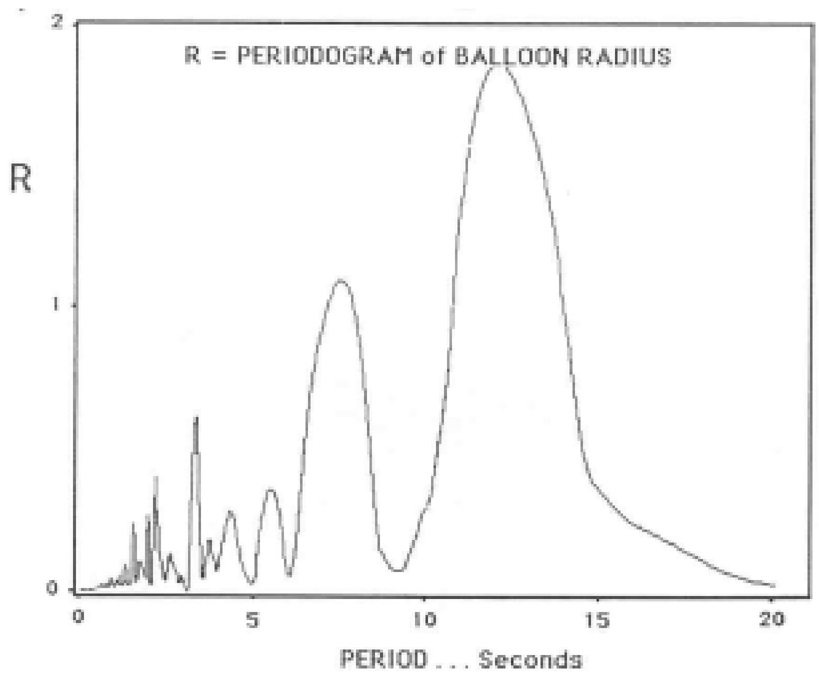
< Figure 6 >

There are also component at about 3 and 12 seconds that might be independent from the other series. The collection of peaks below 5 seconds is reminiscent of a spectrogram with too small an amount of data. The length of yarn processed in 5 seconds is about 30 inches which is too long to be associated with the main drafting zone of the ring frame. The actual roving used had a "hill" on the spectrogram over the range of 3/4 to 4 inches. This translates to 2.8 to 15 seconds of yarn passing through the balloon and this is the range of the periodograms given here. Variations correlated with the twist in the roving would be sub harmonics of 3 1/2 seconds (i.e., 7, 10.5, 14, etc., seconds). There is some evidence for the fundamental and first sub harmonic of the 3 1/2 second periods but values beyond 15 seconds become of doubtful value due to an insufficiency in the length of the time series.



< Figure 7 >

It was mentioned earlier that a cross-check of the FFT was carried out using the superpositioning technique. An example of this when the data was divided into 18 equal parts and superimposed is given in Figure 7. The period at 8 seconds is very evident and the shape of the superimposed curve suggests a pulse rather than a sinusoidal variation.



< Figure 8 >

The principal peaks in the periodogram for radius (Figure 8) show large changes at 12 seconds and there is a related harmonic series at 6,4 and 3 seconds. This could be caused by the passage of slubs generated in the bread draft zone from each 3 inch length of roving passing through. There is also evidence of the 8 and 4 seconds series noted earlier. A sharp spike existed at about 3 seconds that looks to be independent of the others by virtue of its sharpness but no correlation can yet be found apart from being part of a harmonic series. As mentioned earlier, periods below 1/2 second cannot be detected because of the smoothing techniques used but the data shows little sensitivity even for periods below 1 second (which relates to 5.8 inches of yarn) and it should be noted that this zone of low sensitivity includes the major error activity from the main drafting zone of the ring frame.

Discussion

The set of results presented represent little more than a snapshot of the performance of a laboratory machine under one specific set of conditions. Thus it is not possible to regard them as representative of any commercial operation. Nevertheless the variability confirms what has been observed qualitatively over many years in commercial practice.

The results indicate that the balloon is variable in geometry and quite clear harmonic components were seen that demonstrates how important the quality of the roving can be. It is interesting that the largest effect was on the angular changes which implies that it is the air drag components which are most significant. This is important because the factors involved are changes in diameter, hairiness and surface of the yarn, and this relates to variability in yarn appearance rather than the traditional CV of linear density. The smaller variation in balloon radius implies that the variability in linear density is smaller than that associated with yarn appearance.

The variations in angle are thought to be associated with variations in roving twist. Fiber migration is related to roving twist because the twist determines the frequency with which fibers move to and from the selvages of the twist triangle. Fiber migration determines the tightness or otherwise of the yarn (i.e., the yarn diameter) and possibly affects the hairiness. Roving is are places in the roving with significantly higher twist than average. These portions do not draft well and produce yarn of a different character from the average. It is likely that the known variations in twist are related to the observed variations in angle discussed above.

In addition to the periodic components discussed, random changes also occur. It was observed that the injection of a single massive slub caused a very large change in spiral angle and some change in balloon diameter as it passed through. When the slub was particularly massive, it caused balloon collapse followed by end breakage. When there is poor drafting in the break-draft zone due to high roving twist, a "street" of slubs can be produced in the yarn that have the appearance of a necklace. In other words the slubs have a characteristic period. It is thought that the observed phenomena is related to this behavior.

Conclusions

The tests have demonstrated that a yarn balloon in short-staple spinning is not stable and that there are continuous changes in shape. Much of the activity was long-term and associated with variations in the roving. It was expected that the periodograms might show period distributions similar to those seen in spectrograms of linear density and hairiness. However strong harmonic components were evident that seemed to be associated with the roving passing through the break-draft zone, and in particular, it is thought that variations in twist in the roving might be a large factor.