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QUALITY CONTROL IN COTTON SPINNING
YARN COUNT AND UNIFORMITY [1]

by

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INTRODUCTION

The ultimate object of the spinning process is to produce yarn of specified count and required quality at the lowest price. Yarn quality is important in two ways : firstly for ensuring that the yarn performs well in the subsequent processing it undergoes such as winding, warping, sizing, weaving or knitting etc.; secondly for ensuring that the end product made out of the yarn is acceptable, to the extent that it depends upon yarn quality. Naturally, therefore, there are many physical properties of a yarn that contribute to its quality. The more readily measurable among these are : its uniformity, tensile strength and elongation, and their variability. Besides these characteristics, yarn quality is also determined by its relative freedom from such imperfections and faults as hairiness, neps, foreign matter, slub, fly etc. The relative importance of particular aspects of yarn quality depends upon the final product made out of the yarn and also on the subsequent processing that the yarn undergoes in the making of the product. It may however be said that count and uniformity are basic characteristics of a yarn. The reasons for this are as follows : Firstly, a yarn is designated by its count. Secondly, count and uniformity strongly influence yarn strength and its variability, the performance of the yarn in subsequent process and the fabric appearance. The control of count and uniformity is, therefore, one of the primary functions of any scheme for quality control in spinning.

The uniformity of a yarn is commonly measured in terms of coefficient of variation (C.V.) of weight per unit length. Weight of the yarn, and not its thickness (diameter), is chosen as the basis for determining yarn uniformity mainly because the concept of weighing a yarn to determine its fineness has been conventionally used in the textile industry and also because measurement of such variability is easier in industrial practice. The coefficient of variation (C.V.) of weight/unit length of a yarn, does not, however, possess a unique value. In fact, the value of the C.V. depends upon the cut length used for determining the weight. In order to characterise the irregularity of yarn in total, therefore, a graph of C.V. or relative variance has to be plotted against the (logarithm of) cut length. In this graph, called the B(L) curve, the relative variance remains at a high level for short cut lengths of the order of twice the fibre length, then drops rapidly till the cut length becomes about 10-20 meters and thereafter decreases gradually upto and after the cut length becomes about 1[illegible] meters. Yarn count variation determined by cutting and weighing 120 yd. leas, and the yarn irregularity determined by using electronic testers where the cut length is about 1 cm. are but two points on the B(L) curve. The difference in the numerical values of count C.V. and yarn irregularity is solely due to the difference in the cut length chosen for weighing. In routine control of yarn uniformity, interest mainly centres around these two aspects namely count variation and irregularity. As the technological steps necessary to control the levels of nonuniformity at these two extremes of the B(L) curve would in general be also expected to keep the level of the entire B(L) curve low, this concentration of quality control efforts on these extreme points is understandable.

The control of count and uniformity, then, essentially aims at maintaining the average count at the specified level, and keeping count variation and the short-term irregularity at satisfactory levels There is one other aspect of yarn quality which is also conveniently considered along with irregularity, namely imperfections such as thin and thick places, and neps. This is because the search for causes of poor rating of a yarn for either irregularity or imperfections is along similar lines. This paper deals with all these four aspects of yarn quality. Besides giving a methodology for quality control in these areas, the technological rationale which led to the development of the methodology is also outlined. Specific points which require attention in the case of unsatisfactory performance are thus automatically brought to light.

Since 1950 A.T.I.R.A. has worked in the area of quality control in composite cotton textile mills and has been instrumental in the establishment of quality control sections in over 45 member mills. Besides, in the course of applied research, and the consultation work carried out on behalf of the member mills, A.T.I.R.A. has conducted numerous investigations in cotton spinning. Naturally, all this work was not carried out in isolation but in awareness of similar activity elsewhere. The present paper, then, is based on the totality of knowledge gained through extensive work in industrial quality control. An attempt is made to describe the integrated view that is used in A.T.I.R.A. today for quality control in these areas of spinning. No distinction has, therefore, been made in the text between work done at A.T.I.R.A. and elsewhere. The indebtedness of the authors to others who have worked in this field will be clear from the selected bibliography given at the end of the paper.

COUNT CONTROL

Nature of Problem

Until recently the universally accepted systems of cotton yarn count were the English and the metric. These systems define count as the number of certain ad hoc length units that go to make certain ad hoc weight units. The units of length and weight are respectively 840 yards and one pound in the English system and 1000 metres and 1000 grammes in the metric system. Attempts are now being made to encourage the adoption of the Tex system in which the count of yarn is defined as number of grammes weight of a kilometer of yarn. These definitions of count immediately make it clear that whatever the system of yarn count followed the determination of count involves the weighing of long lengths of yarn. In other words whatever the system of reckoning count, the problem of count control is essentially one of controlling the weight of long lengths of yarn; so that a discussion of the methodology of count control with reference to one system does not in any way restrict the generalisation of the principles enunciated. In the present paper the English system of count has been used, as this is the system almost exclusively followed in Indian mills.

Briefly stated, the effective control of count consists of three steps : (i) assessing process capability, (ii) improving this where possible, and (iii) specifying tolerance limits for routine check. The methodology of count control is therefore best discussed in terms of these steps.

Assessing Process Capability

Any mass manufacturing technique has what may be termed a process capability in terms of the minimum dimensional variability of the units. The process capability is generally determined by the raw material variations, the level of technology incorporated in the machines used for production, the mechanical condition of the machines and the competence of the plant personnel. In the case of yarn count the process capability is best measured in terms the coefficient of variation of the weight of leas (or of the count of leas*). The first step in setting up count control is, therefore, to determine the coefficient of variation of lea count. In ring spinning, the yarn is delivered in the form of bobbins, each bobbin containing a number of leas. The leas from one bobbin have a commonality in the sense that they are, in about 90% or more bobbins, spun from the same creel bobbin. The variation of lea count can be therefore said to have two sources, namely, variation between leas within a bobbin, and variation between bobbins. It is in fact possible to identify other sources of count variation such as between machines, between doffings, and between days. But a little reflection will show that these variabilities are of a different nature. For example, with a given feed hank, the average count of two machines can be made as close to each other, and to the nominal, as the gear wheels would permit. Once this is done, the doffing and daily averages of count can again be controlled to fairly close limits. On the other hand the variation in count of leas from the same bobbin cannot generally be minimised by action on the ring frame itself. In fact there is a minimum possible limit below which it is not possible to reduce the within-bobbin variability. The same is true of bobbin to bobbin variability. It should be here emphasized, that the between-bobbin variation almost invariably contributes a substantial amount to the overall variation in lea count. The limits of within - and between - bobbin variability can, therefore, be said to define the process capability as far as count control is concerned. In order to determine the within - and between - bobbin count variation, a suitable number of bobbins are collected every day from each of the group of frames working on the given count so that over a period

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* In the normal range of values of lea weight and count, and for the type of distribution applicable to these, the C.V. of a given set of lea weight values is sensibly the same as the C.V. of the set of lea count value derived from the former.

of about 10 days 50 to 60 bobbins have been accumulated. A sample of about 25 to 30 bobbins is then drawn from this lot and three consecutive leas are tested per bobbin. The data are used to calculate the C.V. between - and within - bobbins by carrying out a simple analysis of variance. (See Appendix I for illustration). The observed values are compared with the norms available. If after allowing for sampling errors, the observed values are higher than the norms, the causes for this are sought. Extensive mill yarn testing in A.T.I.R.A. has shown that over the range of 20s to 60s count, satisfactory values for within-bobbin and between-bobbin C.V.'s are 2.5% and 3.0% respectively. When the C.V.'s are estimated by testing 3 leas from each of 30 bobbins, the upper limits for the estimates can be considered as 2.9 and 3.8 respectively for the within-bobbin and between-bobbin C.V.'s.

Improving Within-Bobbin Count Variation

It may at first sight appear that the detection of the causes for high count variation may need a complete investigation starting from raw material and going up to spindle point. But logical analysis and experience based on extensive investigations show that in a large majority of cases the causes of high within-bobbin or between-bobbin count variation are to be looked for in a few specific places. In order to appreciate this, let us consider three consecutive leas taken from a bobbin or carded yarn with drafts of 24 and 10 on ring and fly frames, and of 6 on each of two passages of drawing frames. Three consecutive leas from a bobbin would then correspond to three consecutive five-yard wrappings from an intermediate bobbin; half-yard wrappings from finisher drawing; 3-inch pieces from breaker drawing; half-inch pieces from card sliver. With a draft of 100 on card they would correspond to 0.005-inch pieces of blow room lap. Strictly speaking, the one-to-one correspondence between the consecutive leas from a bobbin and the consecutive intermediate and drawing wrappings does not apply at the card sliver and blow room stage - it is only from the breaker drawing stage onwards that the corresponding lengths can be said to be faithfully drafted out linearly into leas of yarn. A little reflection on the type of mechanisms involved in the formation of laps (or in chute feed) and sliver will show that there is nothing in the blow room or card which can at this stage control the variability which can directly be responsible for variation of lea count. Further, the doubling involved in drawing will greatly reduce the effect of variability of lap and card sliver on within-bobbin count variation. These considerations clearly show that lap and card sliver irregularity can not directly influence within-bobbin count variation. There is the possibility, however, that other factors in blow room and card which influence the drafting behaviour of card sliver at draw frames may influence the variation of 3-inch pieces of first head drawing sliver and subsequently the within-bobbin count variation. But data on count variation of mills with good and bad carding, and with varying rates of carding almost conclusively show that such differences do not materially affect the within-bobbin count variation though they have a profound effect on short term uniformity of yarn. The fact that carded and combed yarns from the same mixings differ significantly in yarn uniformity but not in within-bobbin variation also lends support to this argument. Similar considerations establish that, for a given yarn count, raw material differences that can normally be expected in practical mill situations can have very little effect on within-bobbin count variation. Further, changes in the level of relative humidity cannot be expected to influence within bobbin count variation. In fact, only such extremes of raw material or relative humidity which are likely to impair the draw frame drafting considerably can have an appreciable effect on within-bobbin count variation; but such changes are not likely in practical working. It must be mentioned here that in this discussion of within-bobbin variation, consecutive three leas from a bobbin have been considered. But the conclusions can be seen to be equally valid for leas taken at random from a bobbin : assuming about 40 leas in a bobbin, the total length of card sliver involved is only 20 inches, and of blow room lap 0.2 inches; control of variation of smaller lengths (0.5 inch in the case of card sliver and 0.005 inches in the case of lap) within these lengths is hardly feasible. In other words if the within-bobbin count variation is found to be higher than the norm the causes are not to be looked for in the raw material, in the blow room or in the card sliver.

The most important single cause of within-bobbin count variation is defective draw frame drafting, which introduces pronounced differences in the weight of 3-inch pieces of first head sliver or 18-inch pieces of finisher sliver. In the case of carded slivers processed on old draw frames of the 4-over-4 roller system with gradually increasing draft over the zones, slippage of the second top roller is a prolific source of such irregularity. On such draw frames bottom rollers with worn out flutes, and ineffective weighting add considerably to this defect. It is obvious that such a periodic irregularity of high amplitude in the breaker sliver will result in a marked variation in the weight of three-inch pieces in the breaker sliver and ultimately will result in high within-bobbin count variation. The measures for eliminating roller slip are : (i) use of bottom rollers with better and improved flutes (ii) avoiding the crowding of feed slivers by the use of special traverse guides and (iii) the re-distribution of the draft in the three zones according to the Shirley Institute recommendations, namely about 1.8 x 1.05 x rest, back to front;or the use of 3-over-3 roller system with drafts of 1.5 x rest on the first head, and 1.05 x rest on the second head. Along with the above measures, increased weighting on the top rollers of the order of 15 kg. per side and the use of weight hooks of suitable design to ensure the effectiveness of the weighting system also help in avoiding roller slip. On modern drawing frames, which are modified versions of the basic 3-over-3 system, the points to look for are whether the springs develop the stipulated pressure and whether weight pins are squarely acting on the rollers. Where special fibre control systems such as the Platts pressure bar or small diameter rollers are provided, their functioning and positioning have to be correct.

Another important cause of within-bobbin count variation attributable to drawing is excessive web draft. The minimum workable web draft should be employed. For combed counts, phasing (or the coming together) of piecing waves should be avoided by the use of single zone drafting or of a basically 3-over-3 system with a very low back-zone draft of the order of 1.05. Excessive creel draft can also be a source of within-bobbin count variation.

Sometimes, the irregularity of the comber sliver is itself high. In such cases it needs to be controlled by giving proper attention to the comber.

The contribution to within-bobbin count variation of fly frames can be from two sources : irregular drafting and irregular stretching. Of these, the effect of irregular draft is not much. This is because irregular drafting will introduce variability between small lengths of roving. Such variability will be averaged out in a 5-yard piece of roving which roughly corresponds to a lea of yarn. The effect of irregular stretching caused by improper regulation of bobbin speed can introduce differences in the weight of roving over different layers of roving bobbin. To the extent that different leas from a ring bobbin originate from different layers of the creel roving bobbin, therefore, the effect of irregular stretch can affect the within-bobbin count variation. But the first and last lea of a ring bobbin is normally separated by about 8 to 10 layers of roving. This means that irregular stretch at fly frame can affect within - bobbin count variation only if such irregularity is likely to introduce weight variation in consecutive 8 to 10 layers of roving. On old fly frames where cone drums are used for regulating the bobbin speed this is just possible. Where there is improper ratching leading to either a gradual increase or decrease of roving tension, a corresponding trend in the roving weight is introduced over the bobbin, generally with a steep portion towards the full bobbin or empty bobbin stage. To this extent, then, irregular stretch in fly frames is a contributor to within-bobbin count variation. Checking of intermediate bobbins for the presence of such trend is, therefore, necessary when within-bobbin count variation is found to be very high.

On the ring frame the sources that are likely to introduce within-bobbin count variation are stretch between creel and back roller, and irregular movement of self-weighted back top rollers where these are present. The effect of these has been found to be an increase in the within-bobbin C.V. from roving to yarn by about 0.5. Where this increase is more than 0.5, it is worthwhile to investigate the causes.

Table I shows, by way of example, two instances where the within-bobbin count variation was reduced by corrective action at the draw frame.

TABLE I

EFFECT ON WITHIN-BOBBIN COUNT VARIATION
OF IMPROVING DRAW FRAME DRAFTING

Within Can/bobbin C.V.%		Case 1			Case 2	
Stage	Cut Length(yds)	B	L	S	B	S
Finisher Drawing	½	*	3.3	2.5	6.8	2.7
Slubbing	2	4.1	3.1	2.9	5.0	2.1
Intermediate	10	3.9	2.7	2.2	4.5	1.7
Ring Frame	120 (Lea)	5.0	3.2	2.7	4.5	2.4

* Not observed

B : Before attention to draw frames L : After overhauling and setting
S : After re-distributing drafts according to Shirley Institute recommendations.

Improving Between-Bobbin Count Variation

There are mainly three sources which can cause the average count to vary from one bobbin to another : (i) any difference in the average hank of one creel bobbin to another (ii) any pronounced trend in the hank over a creel bobbin, and (iii) any difference in the effective draft from one spindle to another of a group ring frames spinning a given count. These will now be considered.

Differences in the average hank of inter bobbins can originate from : differences in blow room lap weight over such long periods as are unlikely to be evened out by subsequent doubling; draft (or waste) differences between groups of cards, the slivers from which tend to get processed in isolation without inter-doubling; similar differences at combers; hank differences between draw frames, slivers from which tend to get channelized; draft differences between fly frames; excessive hank differences between front and back row of bobbins on fly frames; marked trends in hank over a fly frame bobbin (see example in Table II) caused by irregular bobbin speed control. This list of causes immediately suggests also the remedies for high between-bobbin count variation : namely, control of blow room lap weight over intervals of half days or so; ensuring uniformity of waste levels and drafts on cards and combers, ensuring uniformity of draft over draw frames and fly frames; ensuring that trends in the hank of intermediate over a bobbin are avoided; keeping the hank difference between front and back row bobbins at a minimum level, and the creeling of ring frames entirely with front or back row bobbins with a suitable change in ring frame draft (or, where double creeling is used, of ensuring the use of one front row and one back row bobbin from fly frames).

TABLE II

EXAMPLES OF TREND IN WRAPPING WEIGHTS AT FLY FRAMES

Stage of Build	Weight of 10 Yds. (grains)	
	Case 1	Case 2
1	120.1	150.1
2	117.8	150.3
3	115.4	149.2
4	115.3	149.4
5	114.4	147.8
6	114.8	146.6
7	114.3	146.1
8	114.2	144.5
9	114.3	143.1
10	112.4	141.3

Note: The doff was divided into ten equal stages, and at each stage the average wrapping weight at that stage of build was determined by weighing 10 wrappings.

At ring frames it is necessary to make sure that the draft constant of a group of frames considered identical be kept the same. Where this is not possible it is necessary to make sure that suitable pinions are used taking into account the differences in draft constants. A periodic checking of the draft constants to see that these are as per records is useful. Intermittent slippage of back top rolls where these are of the self-weighted type have to be avoided.

Routine Control of Count

Once the within-bobbin and between-bobbin coefficients of variation have been brought down to the lowest possible level, the next step is to establish a suitable procedure to ensure that the average count is maintained as close as possible to the standard or nominal count. For this, routine wrapping checks are necessary at the ring frame and at earlier stages of processing. The methods of establishing an adequate programme for this will now be discussed. In establishing a routine wrapping programme three questions are involved. These are : (i) at what stages have wrappings to be checked (ii) how often have wrappings to be checked and (iii) how many wrappings have to be checked every time ?

The answers to the first two questions are in our experience as follows: In the blow room the normal practice of weighing all the laps is a good one. These data should be recorded or exhibited in such way as to bring out effectively any pronounced trend, and to ensure that hourly averages of lap weight are within the limits

$$" \text{Nominal} \pm \frac{2 \times \text{C.V. of Lap Weight}}{\sqrt{\text{No. of Laps Processed}}} "$$

Routine wrapping checks are not needed at cards and combers. It is only necessary to ensure uniformity of waste and mechanical draft on machines running the same count. At drawing, wrapping checks are better made every four hours. On fly frames it is sufficient to ensure that the geared drafts of machines on the same count are equal. If daily wrapping checks are in vogue, pinion changes should be made on the basis of proper limits, and the checks gradually discontinued as it becomes obvious that with the improved count control system these become unnecessary. In fact, examination of mill records show that pinion changes on fly frames are extremely rare. At the ring frame the present 8-hourly checks which are commonly practised may be continued and the frequency reduced to daily checks as more confidence is gained.

The number of wrappings taken at any given time needs to be such that unnecessary pinion changes are kept at a minimum and that significant hank changes are not left uncorrected. It is a good practice to make sure that the probability of making an unnecessary pinion change is 1 in 20; in other words, the probability of an observed average hank differing, solely due to sampling variation, from the nominal hank by an amount equal to the specified tolerance limit is 1 in 20. Similarly, it is good to make sure that only once in twenty times is a real shift in the average hank by an amount equal to that corresponding to one tooth of the pinion left undetected. It can be shown, that, if the percentage change in hank caused by one tooth of the pinion is K, then the number of wrappings to be checked in a given test is given by

$$n = \frac{13(CV\%)^2}{K^2}$$

where, C.V.% refers to the over all $C.V. = \sqrt{(C.V.within)^2 + (C.V.between)^2}$, and it is assumed that only one wrapping per bobbin (can) is taken. (The statistical basis for this formula is explained in Appendix II, Case 1). The inspection plan then reduces to one of taking n wrappings, one from each of n bobbins or deliveries and making a pinion change when and only when the average hank is beyond the tolerance limits of

$$\text{"Nominal Hank} \pm 1.96 \frac{\text{Standard Deviation}}{\sqrt{n}}\text{"} \quad .$$

In drawing, it is necessary that frames are inspected individually. The required number of wrappings is taken from as many deliveries as possible. Where the number of deliveries per frame is less than the required number of wrappings, the required number of wrapping is taken nearly equally from the available deliveries. In ring spinning, one bobbin per frame is drawn from as many randomly chosen frames as the calculated number of wrappings. Where the number of frames is less than the calculated number of wrappings, as many bobbi as the required number of leas are collected nearly equally from the frames and one lea per bobbin is tested. If for any reason it is found convenient or expedient to test two leas per bobbin, then, in order to ensure that the two aforesaid requirements are met, the number of bobbins sampled should be $= \frac{4}{5}n$ (See Appendix II, Case 2). This means that in this case 60% more leas have to be tested than when one lea per bobbin is taken. It is not advisable to test more than two leas per bobbin.

In determining the average hank care must be taken to see that fluctuations in relative humidity do not introduce errors. In Indian mills, in a wrapping room where no control is provided for relative humidity, the moisture regain of yarn can differ by as much as 5% between a dry day and a day during monsoon. A count of 20s maintained at such uncontrolled humidities will, when tested in a standard atmosphere of 70°F and 65% R.H., result in counts of 19.63 and 20.56 respectively in summer and monsoon. In winter months the relative humidity in the wrapping room may, in the absence of any control, differ by anything upto 20% between morning and afternoon. The control of the atmosphere inside the laboratory where wrapping weights are determined and the conditioning of the samples before weighing are therefore important.

YARN UNIFORMITY

Assessment

Yarn uniformity is measured by electro-mechanical or electronic instruments. The results are usually expressed as either the Percent Mean Deviation or the percent Coefficient of Variation - in short P.M.D. (or U%), or C.V.% . As in count control, the basic technological considerations involved in uniformity control remain the same irrespective of the instrument used and of the mode of expression. In this paper, U% as determined by a linear integrator attached to the Uster Evenness Tester will be used as the measure of yarn uniformity, as this is the measure used in most of the work done at A.T.I.R.A. Uster Evenness Testers are in fact very widely used in mills also.

In order to assess the existing level of yarn uniformity it is first necessary to determine the average U% of yarn spun on a group of apparently similar ring frames, creeled with rovings obtained from comparable preparatory sequences. From each of any such group of frames, an equal number of bobbins is collected to make up a total of about 16. Where the number of frames in a group is more than 16, one bobbin is taken from each of 16 randomly chosen frames. One test of U% at a speed of 25 yds. per min. is taken per bobbin, following the manufacturers recommendation regarding checking of calibration and operating procedure. The average U% is then worked out and compared with the norms. Such a norm is arrived at on the basis of inter-mill surveys or on past performance when extensive data on similar yarns from competitors are not available. A difference of 0.5% can be taken as indication of deviation from the norm, and any difference of more than 1% calls for investigation. The following table gives two sets of norms, one set up by A.T.I.R.A. on the basis of annual surveys of yarns from member mills, and the other set up by Uster on the basis of international surveys.

TABLE III

NORMS FOR IRREGULARITY OF WARP YARNS (U%)

Yarn Count	A.T.I.R.A.[1]	Uster[2]
30s Carded	17.5	16.2
30s Combed	16.0	12.0
36s Combed	16.0	12.5
40s Combed	15.0	12.8
70s Combed	15.0	14.5
100s Combed	16.0	15.5

1. These values refer to the averages of a number of yarns tested from member mills of A.T.I.R.A.

2. 50% of yarns from all over the world attain U% so good or better than these values.

A comparison of the two norms given in the table immediately shows that, except in the very fine counts, the A.T.I.R.A. values are much higher than the corresponding Uster values. The reasons for this can be differences in the following : 1) raw material, 2) level of sophistication of available machinery, 3) condition of machinery and 4) processing parameters employed. In fact, whenever a mill finds that its yarn is more irregular than the norm, these are the causes it will have to look into. A discussion of these will, therefore, be taken up in order to assess the relative importance of these factors as was done in the case of count variation. But before doing so, it is better to briefly describe the three important types of irregularities, because each type can be broadly related to certain aspects of raw material and processing factors.

Classification of Yarn Irregularity

The total irregularity, or the variation in the weight of centimetre pieces of yarn can be said to be made up of three basic types. These are : (i) irregularity of the type that does not exhibit any periodicity but is of a random nature, (ii) irregularity of a markedly periodic nature and (iii) irregularity that is in between the two, that is, irregularity which is not entirely random but has a discernible pattern.

Random Irregularity

Any continuous long length of yarn is composed of fibres which are themselves of very short lengths. In a perfectly uniform yarn, therefore, the number of fibres at any cross section should be the same, and also, the weight per unit length of the fibre should be the same over the length of a fibre and from fibre to fibre. Now, cotton fibres obviously vary in weight per unit length, both within a fibre, and from fibre to fibre. Also, it is impossible to assemble the fibres into a yarn in such a way that their number remains the same at any cross-section over a length of yarn. The utmost that can be done is to ensure that the variation in the number of fibres per cross section is the barest minimum. This minimum possible variation is what would be expected if the number of fibres per cross section were to follow the Posison distribution. The variability of weight per unit length, both within and between fibres, and the minimum conceivable variability in the number of fibres per cross section in a yarn, together, set the minimum limit for yarn irregularity. This limit, expressed as the coefficient of variation is $= \frac{106}{\sqrt{N}}$, where N is the average number of fibres per cross section. Given the yarn count, the average number of fibres per cross section is inversely proportional to the average fibre weight. Roughly speaking, the average number of fibres per cross section in a yarn of C's cotton count is

$$= \frac{15,000}{\text{C x microgms/inch of fibre}}$$

The minimum attainable C.V. of yarn is therefore

$$= \frac{106 \text{ x } \sqrt{\text{C x microgms/inch}}}{\sqrt{15,000}}$$

$$= 0.865 \sqrt{\text{C x microgms/inch}}$$

The following table gives the minimum C.V. of some yarns, each spun from three cottons differing in fibre weight.

TABLE IV

THEORETICAL MINIMUM IRREGULARITY OF YARNS

Yarn Count (English)	% C.V. of Yarn Spun from Fibre of		
	3 microgms/in.	4 microgms/in.	5 microgms/in
20s	6.7	7.7	8.6
40s	9.5	10.9	12.2
80s	13.4	15.5	17.3

The above table brings out clearly the effect of spinning different counts of yarn from cotton of given fibre weight, as well as that of spinning a given count from cottons differing in fibre weight. It is particularly to be noted that an increase in fibre weight of 1 microgm/inch increases the minimum C.V. of 20s yarn by 1%, of 40s yarn by 1.5% and of 80s yarn by 2%. The effect of fibre weight as a cotton characteristic determining the irregularity of yarn is, therefore, clear. It is, however, to be remembered that seldom do two cottons differ only in fibre weight. In practice finer fibres are generally also longer. The combined effect of fineness and length on irregularity will naturally be more than that anticipated here.

Periodic Irregularity

Drafting on the ring frame is carried out by means of rollers and aprons, where the rollers are kept rotating by a train of gears. Again, roller drafting (with or without aprons) is used extensively from drawing onwards for preparing the roving. Now any deficiency in the rollers or gears, which is likely to come in the way of constancy of roller speed, or which causes the distance between roller nips or between apron and roller nips to vary, will naturally impair the drafting of the material passing through. More particularly there are some factors which introduce thick and thin places at regular intervals in the material going out or which cause the ultimate yarn to exhibit irregularity of a periodic nature. Examples of these are roller eccentricity at ring frame, roller vibration at fly frame, roller slip at draw frame. It must be noted that a yarn which has an acceptable U% may possibly exhibit defects such as a discernable barriness in the fabric, if the yarn had a sufficiently pronounced periodic component in its irregularity. This is because the presence of a periodic irregularity may not - and often does not - result in high U%, because the contribution of other components of irregularity is sufficiently low. In fact, fabrics made from yarns which have a feeble periodic irregularity, but which are otherwise very regular, can exhibit objectional patterns of thick and thin places.

There are two characteristics of a periodic irregularity which are worth noting : (i) the amplitude and (ii) the wave length. The amplitude refers to the differenc in weight between the thickest or the thinnest place and the average weight per unit length. The amplitude is usually expressed as a percentage of the mean weigh By wave length is meant the distance between any two successive thick places, or between any two successive thin places. Other things being comparable, the wave length of a periodic irregularity tells us what type of defect the yarn is likel to give rise to and the amplitude how serious the defect is likely to be. The wa length is also useful in tracing the source of the periodic irregularity. By dividing the wave length by the drafts introduced onwards of any stage one can check whether the particular stage is likely to be the cause of the periodic irregularity in question. In carrying out the analysis it must be borne in mind that any eccentric roller will give rise to a periodic irregularity of wave len equal to the roller circumference. Similarly, a faulty gear will give rise to a wave whose length will depend upon its position in the train of gears used to drive the roller. For example, pronounced periodic irregularity of the order o 3 to 4 inches in the yarn is most likely to be caused at thr front roll of the ring frame itself. Waves with lengths exceeding the circumference of the back roller on ring frame x ring frame draft are unlikely to be caused by roller defects on the ring frame itself. There is, however, one exception to this ge rule. Pronounced front roller vibration in fly frame introduces periodic irre of wave length less than one inch in the roving and finally shows up in yarn waves a few inches long. In general if f is the frequency of vibration and the delivery in inches per second of the front roller of the fly frame, then wave length of the periodic irregularity will be $\frac{v}{f}$ inches in the roving.

With a ring frame draft of d the wave length in yarn will be $d \times \frac{v}{f}$.

There are two methods available for locating periodic irregularities in yarn. These are black-board tests and electronic wave length analysers provided as supplementary equipment with evenness testers. Wave lengths of the order of 3 to 5 inches can conveniently be located by winding the yarn on tapered black boards, 12 inches long, and 6 inches and 10 inches wide at the two sides. The exact length of the wave is given by half of width of the board at the middle of any U-shaped pattern discernible. Wave lengths of 5 inches or more are better looked for with the help of electronic instruments like the Uster Spectrograph.

Quasi-periodic Irregularity

In between the two extreme types of irregularity, namely random and periodic, is the quasi-periodic irregularity. Such irregularity is periodic but has a varying wave length and amplitude so that it is just discernible as periodic. The most important source of quasi-periodic irregularity in ring spun cotton yarn is irregular drafting. In roller drafting, fibres which are much shorter than the roller nip-to-nip distance in any sone get pulled out of turn by contact with other fibres positively gripped by the forward roller nip, and this results in lengths of laternatively thick and thin yarn. The length of the drafting wave caused in any one drafting depends upon the fibre length, the roller setting and the total draft, but for practical purposes it is accurate enough to consider the average wave length as 2.5 inches. The amplitude of the drafting wave depends upon the proportion of fibres which are shorter than the nip to nip distance, the total draft, the roller setting and the degree of effectiveness of fibre control in the drafting system. Fibre control is sought to be introduced by preventing fibres free of the grip of back roller nip from accelerating to the forward roller speed out of turn, but at the same time allowing fibres positively gripped by the forward roller nip to be pulled by this nip. Given the raw material, the intensity of the drafting wave, therefore, depends very much upon the efficiency in fibre control achieved by the drafting system. Other examples of quasi-periodic irregularities are the stretch waves introduced in the web at drawing, the piecing waves introduced in combing.

Causes of Yarn Irregularity

The brief discussion of the types of irregularity has already highlighted the sources of yarn irregularity, namely, i) raw material quality, ii) level of sophistication of machinery, iii) suitability of the processing parameters employed and iv) condition of machinery. A more detailed consideration will now be given to these.

Raw Material Quality

The first consideration in the choice of cotton for spinning yarn of a given count is the end use for which the yarn is meant. Where the end use requires a minimum tensile strength in the yarn this will itself limit the choice of cotton. The second consideration in the choice of cotton is the price that can be realised for the end product. Thus different mills making poplins of specified construction and yarn count may use widely different cottons depending upon the market in which they are selling. Differences in relative costs of cotton and of processing can also lead to different cottons being used for the same count of yarn. Thus inferior cottons may be used to the extent that the resulting high end breakage rate is permissible at the prevailing low machine allocation made possible by a low labour cost per hour. The difference noticed between the Indian and the Uster norms for yarns in the range of 30s to 40s is to be ascribed mainly to differences in cotton quality. For counts of 30s to 40s, Indian mills generally use mixings very much inferior to those used in continental, American and British mills. Even among mills selling in the same market, and therefore constrained to use cottons of comparable price, the quality of cotton itself can cause significant differences in the irregularity of yarn. Table V illustrates the extent of difference in yarn unevenness caused by differences in quality of cottons which are comparable in price.

TABLE V

QUALITY OF YARNS SPUN FROM COTTONS COMPARABLE IN PRICE

30S CARDED

Cotton	Price	Fibre Properties					Yarn Quality	
	Rs/kg.	Effective Length mm	Mean Length mm	Short Fibres %	Bundle Strength (O") g/tex	Fineness Micro-gm/in.	Unevenness U%	Lea Strength lbs
Digvijay	5.00	26.6	21.8	12.2	45	4.1	15.8	67
L 147	4.95	28.4	20.2	27.5	40	3.9	17.5	59

Note : Length parameters from Baer Sorter Diagrams

The L 147 cotton which has more short fibres than the Digvijay cotton, gives a substantially weaker and more irregular yarn than Digvijay cotton. The price of these two cottons, however, is almost the same when both crops come into the market and are readily available. The reason for L 147, which is weaker and less uniform in the length, being priced at about the same level as Digvijay lies in the fact that the cotton prices are greatly influenced by the effective length of cottons.

Level of Sophistication of Machinery

It has already been pointed out earlier that the level of sophistication of machinery can cause substantial differences in yarn unevenness. In seeking for causes of high yarn unevenness the type of machinery available has, therefore, to be kept in mind. The question that arises is what relative importance should be given to machines in the various sections.

The total irregularity in the yarn is made up of the random irregularity and the periodic and quasi-periodic irregularities. The latter are introduced in ring spinning as also in earlier processes. The irregularities introduced in processes prior to spinning are, however, drafted out into longer wave lengths. It is also possible that under favourable circumstances the waves introduced in any process are reduced in amplitude by the doubling in subsequen processes. It might appear that a variance analysis can be carried out to estimate the contribution of individual processes to yarn irregularity. For example the added variance at ring spinning could be thought of as

$$= (\text{Yarn Variance}) - \frac{\text{Roving Variance}}{\text{Doubling in Ring Spinning}} .$$

Such an analysis would show that the contribution of irregularities introduce in processes prior to the fly frame to yarn irregularity are insignificant. But such an analysis is valid only for materials free of periodic irregularit Secondly, the assumption implied in the above analysis that the added varianc is independent of the input variance is not true. It has been demonstrated th the rate at which drafting adds irregularity is higher when the irregularity the input material is high. Also, it is well-known that some of the periodic and quasi-periodic irregularities introduced at one process can, under certa circumstances, get re-inforced during subsequent drafting by the phenomenon 'phasing' or the coming together of thick or thin places of the input materi Thus the second head drawing sliver is often more uneven than the first hea sliver and the draw box sliver of a comber more uneven than the individual sliver. Again the contribution to yarn 'irregularity' of processes like blo and card are not essentially through the unevenness of the lap or the sliv view of these considerations variance analysis is not a sufficiently reliable method for assessing the contribution of individual processes to yarn irregularity. This can better be assessed by considering how the machinery from opening to ring spinning can affect yarn irregularity, and also by examining empirical evidence.

In the blow room, the machinery is mainly expected to open the bales, blend the cotton from various bales, clean the cotton of impurities, and present it in the form of a sheet made of small tufts. No attempt is made to individualise the fibres. It can therefore be expected that the type of machinery in the blow room will have very little impact on yarn irregularity as measured by the U%. In fact, extensive experiments show that, over a fairly wide range, the sequence, number and type of cleaning and opening points in the blow room do not significantly effect the yarn irregularity. This is not to say that no progress has been made in the design of the blow room machinery. The progress has been mainly in improving the blending, opening, cleaning and tuft formation and possibly in minimising waste. But these improvements have not so far reached a stage where they make a significant contribution to yarn irregularity. The sophistication of blow room machinery is, therefore, of no relevance in looking for causes of yarn irregularity. Table VI illustrates this point.

TABLE VI

EFFECT OF BLOW ROOM PROCESSING ON YARN QUALITY

Count (Cotton)	Blow Room Treatment	Unevenness U%	Lea Strength lbs.
30s Carded (R.A.Laxmi)	Bale Cotton opened by hand	18.5	57.3
	Bale Cotton twice opened on a 3 Bladed Beater	18.9	57.9
30s Carded (Indian Mixing)	Blow Room No.1 : 3 Beating Points	18.5	48.9
	Blow Room No.2 : 7 Beating Points	18.3	49.4
30s *Carded (American Middling)	Blow Room No.1 : Ultra Cleaner-Porcupine- Ultra Cleaner-Airstream Cleaner	15.5	14.3**
	Blow Room No.2 : Ultra Cleaner-Airstream Cleaner	14.9	13.9**

* Source : Platts Bulletin, Vol.11, No.5
** Breaking Load, g/tex

Note : None of these differences is statistically significant

The major functions of the card are cleaning, near-individualisation of fibres and delivering the material in a sliver form. Of these the function of individualisation, or the carding proper, has so far eluded instrumental evaluation. But sufficient empirical evidence is available to show that on conventional cards, beyond a certain level of production the carding action is impaired, and substantial increase in end breaks, some reduction in yarn strength and a marginal increase in yarn irregularity, usually in that order, ensue. The major break-through in carding has been to raise this threshold level of production to anything upto ten times that of conventional cards. In other words, developments in carding have resulted in improving the carding efficiency to levels that are needed to make the higher outputs possible rather than to improve the carding efficiency at conventional rates. To this extent, then, the type of card again is not expected to contribute significantly to yarn evenness.

Combing aims primarily at removing a certain amount of short fibres, and at parallelising and individualising. Incidentally, some neps and trash particles are also removed. Here again modern developments have been directed towards achieving higher speeds and minimising the loss of long fibres. As a result conventional combers and new combers operating at their rated levels of production give rise to yarns of comparable evenness. Table VII gives results typical of experiments conducted to study the effect of yarn quality or the type of comber, conventional or modern.

TABLE VII

EFFECT OF TYPE OF COMBER ON YARN QUALITY

Characteristic		Modern Comber	Conventional Comber
Fibre Mean Length, Lap	mm	20.7	20.7
Fibre Mean Length, Comber Sliver	mm	22.1	22.0
Yarn Irregularity	U%	14.1	14.5
Lea Strength	lbs	65.5	67.7
Single Thread Strength	gm/tex	14.3	14.4

The draw frame is essentially meant to parallelise the fibres and to reduce medium and long term irregularities present in the sliver fed to it. Modern developments on draw frames have been concerned mainly with engineering aspects. The consequent improvements have enabled the production to be increased to anything upto ten times that of conventional draw frames. Admittedly, there have been modifications to the drafting system also, but these are of a marginal nature as far as their effect on yarn irregularity is concerned. In any case old draw frames can be converted to the 2-over-2, 3-over-3 or Shirley drafting systems at very nominal costs, and the benefits that would be obtained by using modern drafting systems can be realised to a large extent. The drafting systems on fly and ring frames have been considerably improved in the past five decades. Economic considerations have ruled that part of these improvements be aimed at increasing the level of draft in any one stage with a resulting shortening of the sequence of machinery after drawing. Even so, a certain improvement has been achieved particularly in the ring spinning. This has enabled a definitely more regular yarn to be produced on a modern top arm system than on any of its precursors.

To sum up then, as far as yarn irregularity is concerned, the level of sophistication of machinery is most important in ring spinning, somewhat so in fly frame and to a marginal extent in drawing frames.

Processing Parameters

The foregoing discussion regarding the functions of the various machines in spinning and their impact on yarn quality suggests that the processing parameters that are likely to have an impact on yarn irregularity are : production rate and settings in carding in so far as these affect fibre separation; level of waste and production rate at combing to the extent these affect short fibre removal and fibre parallelisation; fly frame and ring frame drafts. Any search for causes of high yarn irregularity should, therefore, include an assessment of the correctness of these parameters. Besides, the earlier discussion of the importance of fibre control brings out the need for checking the following aspects on fly and ring frames also : the break drafts, the spacers or platforms that determine the space between the aprons, the settings between roller where these are variable and the twist in the ingoing material.

It must be mentioned here that it is not possible to set universally applicabl norms for all the parameters enumerated above. However, inter-mill comparison and empirical studies provide broad guide lines. A few key points may therefore be discussed by way of illustration.

A.T.I.R.A.'s experience has shown that the following production rates are reasonably safe for the following counts when processed on conventional flexible fillet cards.

Warp Count (English)	16s	30s	40s	60s
Reasonable Carding Rate at 100% Efficiency (kgs)	5.2	4.0	3.5	3.0

In particular instances, depending upon the condition of the card, slightly higher or lowerer carding rates may be found optimum. In the case of combed counts, with good combing, higher carding rates may be feasible. One of the important experimental observations is that, in order to obtain small increases in carding rates, it is safer to increase the doffer speed keeping the sliver hank unaltered, rather than to make the hank coarser at the given doffer speed. On cards converted to high production, the optimum carding rate has to be experimentally determined and in doing so the permissible cylinder speed has to be taken into consideration. On new high production cards also the maximum carding rate possible in a given set up has to be ascertained by experiments.

The rate at which yarn irregularity decreases with increasing comber waste, and the level of comber waste beyond which there is no substantial gain in regularity (or in any other yarn quality), are both dependent on the fibre length distribution of the cotton. For cottons like Digvijay, with relatively uniform fibre length, the optimum level of comber waste is reached at relatively low values of waste. For cottons like LSC 67 containing a high percentage of short fibres (defined as fibres shorter than half the effective length), successive increases in comber waste result in improved regularity of yarn. In the case of long staple cottons like Giza 45, however, inspite of a high percentage of short fibres successive increases in comber waste do not bring about a corresponding improvement in the uniformity of yarn. This is mainly because it is not useful to remove fibres longer than 12 mm - 15 mm, even though they may be defined as short fibres in the fibre array of long staple cottons.

The optimum levels are best determined by mill experimentation. Table VIII gives typical results of such experiments.

TABLE VIII

THE EFFECT OF INCREASING COMBER WASTE ON YARN IRREGULARITY

Cotton and Count	Fibre Properties			Comber Waste %	Uster U%
Digvijay (Indian) 28s	E.L.	mm	27.0	8	14.0
	M.L.	mm	22.3	11	13.8
	S.F. (< E.L./2)	%	12.5	14	12.6
				17	13.5
	S.F. (< 12 mm)	%	10.3		
ISC 67 (Indian) 36s	E.L.	mm	33.0	6	17.2
	M.L.	mm	21.0	8	16.0
	S.F. (< E.L./2)	%	36.0	11	14.8
				17	13.7
	S.F. (< 12 mm)	%	27.8	22	13.5
				28	13.8
Giza 45 (Egyptian) 100s	E.L.	mm	37.0	4	15.2
	M.L.	mm	26.5	8	14.6
	S.F. (< E.L./2)	%	25.2	12	14.4
				14	14.3
	S.F. (< 12 mm)	%	9.4	19	14.2
				21	14.4

E.L. : Effective Length; M.L : Mean Length; S.F. : Short Fibre

In combing, the weight per unit length of the lap, the feed per nip and the time of entry and depth of top comb can have an affect on yarn irregularity, when these are very much away from the optima.

The levels of total draft in fly and ring frames beyond which yarn irregularity increases depend on the drafting system and the cotton. Extensive mill experience is usually available to provide guide lines for choosing the total drafts. But individual mills may have to experiment to arrive at the optimum in terms of back zone draft and setting, and apron spacing where these are variable. The general principle is to use the narrowest spacing that gives trouble-free working. Where the ingoing twist is high the back zone setting is made wider and increased back draft is tried.

Optimum conditions for fly frame drafting should be arrived at by testing the irregularity of not only the roving but also of the yarn. This is because instances are known wherein large changes in the back draft on fly frame result in substantial differences in yarn irregularity though not in roving irregularity.

One other important processing parameter is the relative humidity inside the various sections of the spinning department. The limits of relative humidity beyond which roller drafting as well as the operations of carding and combing suffer are well known and these should not be exceeded.

Condition of Machinery

By condition of machinery is meant the relative state of fitness of the machinery for carrying out the functions expected of it. In assessing the condition of a card, for example, one examines the wire points. On the comber one looks at the needles, on the draw frame the flutes of rollers and so on. The various mechanical faults leading to specific drafting faults, and the analysis of the contributions of the various processes to yarn irregularity, suggest the following check-list for locating causes of high yarn irregularity:

Ring Frames : Roller Eccentricity, Apron Condition, Top Roller Weighting, Wall Thickness of Cots

Fly Frame : Roller Eccentricity, Roller Vibration, Apron Condition

Draw Frame : Roller Condition, Roller Slip

Comber : Condition of Needles, Efficiency of Brush

Card : Condition of Wire Points and Uniformity of Settings.

Roller eccentricity, roller vibration and roller slip can be measured by instruments developed by the Shirley Institute and front top roller weighting on ring frames by the instrument developed by A.T.I.R.A. However, most other aspects of machinery condition have to be assessed visually. The following table gives instances where differences in one or other aspect of machinery condition caused a significant difference in yarn irregularity.

TABLE IX

EFFECT OF MACHINE CONDITION ON YARN QUALITY

Machine	Condition	Yarn Quality		
		Count Ne	Unevenness U%	Lea Strength lbs.
Card	Good	30s K	16.4	65.7
	Poor	30s K	19.7	61.8
Card	Good	30s C	13.4	72.7
	Poor	30s C	15.9	72.0
Comber	Good	30s C	17.0	65.0
	Poor	30s C	18.5	60.0
Canfed Inter	Good Rollers	30s C	15.8	-
	Vibrating Rollers	30s C	16.7	-
Ring Frames	Good Top Rollers (Ecc: 0.002")	28s K	16.8	55.6
	Bad Top Rollers (Ecc: 0.007")	28s K	18.1	51.2

K : Carded; C : Combed; Ecc.: Eccentricity

CONTROL OF IMPERFECTIONS IN YARNS

The control of yarn count variation and yarn irregularity discussed in the first two parts of the paper represent the control of long and short term uniformity of yarn. The steps outlined for the control of these two types of irregularities will generally also lead to a control of medium term and very long term irregularity. Control of these yarn qualities, however, does not imply a complete control of yarn uniformity. An aspect of yarn uniformity which cannot be measured by the usual statistical indices of expressing variability is the incidence of imperfections and faults in the yarn. Imperfections like thin places, thick places and neps occur much more frequently than faults such as slubs or bad piecings. While the faults occur once in 3,000 m to 10,000 m, imperfections can occur even as often as once in a metre. Presence of faults and imperfections can lead to poor yarn and fabric appearance and presumably also to difficulties in processing, especially on knitting machines. Until recently mills did not have suitable equipment to determine the frequency of the incidence of faults and therefore no quantitative information is available regarding the relative importance of various aspects of processing on the incidence of the faults. In view of this, only the control of the level of imperfections in yarns is explicitly discussed below. Steps taken to control imperfections like thick and thin places may also, to some extent, help to reduce the occurrence of slubs.

As in the case of yarn irregularity, the commonly used instrument for determining the extent of occurrence of thin places, thick places and neps is an Uster instrument; namely, the Imperfection Indicator. Since most of the experience gathered at A.T.I.R.A. is based on testing with this instrument, all references to imperfection in this part imply the use of Uster Imperfection Indicator. The sensitivity levels used were : -50% for thin places, 3 for thick places and 3 for neps.

Technical considerations suggest that fibre properties as well as processing factors can be important contributors to the imperfections in yarns. The Uster Manual on the other hand, states that "For the frequency of thick places as well as of thin places, the influence of the raw material is, however, of minor importance. Principally, these values are influenced by the processing of the raw stock, particularly the ring spinning machine. On the other hand, the number of neps is influenced to a large extent by the raw material used." Investigations conducted at A.T.I.R.A. to confirm whether these observations hold good under Indian conditions of spinning have indicated that both the quality of raw material, as well as the processing, can influence imperfections in yarn. These differences in conclusions about the relative effects of factors on the incidence of imperfections in yarn may have resulted from the large differences in the quality of mixings used for coarse and medium counts in India and Europe, and also perhaps from differences in machinery and conditions of mill working.

As in the case of yarn irregularity, therefore, the quality of the raw material and the processes of carding, combing and ring frames are important in controlling the level of imperfections in yarn. In addition to this, the blow room can assume a place of importance in controlling the imperfections in yarns, particularly the neps.

The fibre properties most likely to influence the imperfections in yarns are the uniformity of the fibre length, the proportion of half-mature and immature fibres, and the amount of trash contained in the raw cotton. Cotton mixings which have a poor uniformity of fibre length, that is, those which contain more short fibres, give rise to more thick and thin places in yarns. With increasing proportion of immature and half mature fibres, the extent of nep formation during processing also increases. Dirtier cottons do get cleaned more in blow room as well as in cards, but even so, often leave more trash in the finisher sliver than cleaner cottons. Trash particles get counted as neps on the Uster Imperfection Counter.

The blow room treatment can affect the nep count on the Imperfection Indicator in two ways; through creating more neps, which are essentially immature fibres rolled into small balls, and through insufficient cleaning, which would result in more particles of foreign matter going into the yarn. Bot neps and the particles of foreign matter are counted as 'neps' by the Uster Imperfection Indicator. Evidence has been offered to show that the modern blow room systems which achieve cleaning without recourse to severe beating, and then feed the cards through chutes, may prove useful in improving the appearance grade of the resultant yarn. Technologically, the methods for keeping the nep formation at a minimum level and for improving the cleaning efficiency of the blow room line are well known.

At the stage of carding, the important factors to control are the sharpness of wire points and the closeness and uniformity of settings, especially of the setting between the cylinder and doffer. Combing and better drafting at ring frames considersbly reduce the imperfections in yarns. As in the case of yarn irregularity, the reduction in yarn imperfections with increasing comber waste depends on the nature of fibre length distribution and on the nep count in card sliver. The type of drafting at ring frames influences mainly the thick and thin places. Data are given in Table I to illustrate the effects of various factors on imperfections in yarns.

TABLE I

INFLUENCE OF COTTON QUALITY AND PROCESSING ON IMPERFECTIONS IN COTTON YARNS

30S COUNT

Factor or Machine	Factor Levels	Imperfections/100 Metres		
		Thin Places	Thick Places	Neps
Cotton Quality	Digvijay (good)	10	27	6
	L 147 (poor)	19	62	91
Cards	Good	15	39	44
	Poor	30	66	76
Combing	Carded	15	39	44
	Combed	3	10	14
	Combed at 8/32" S.G.	4	16	35
	Combed at 10/32" S.G.	5	13	28
Ring Frame Drafting	Top Arm Drafting	15	39	44
	Conventional Double Apron Drafting	43	79	46

S.G. : Step Gauge

THE IMPORTANCE OF DIRECT PROCESS CONTROL

From the foregoing discussion of the control of yarn count, uniformity and imperfections it is very clear that the causes of poor performance are often to be sought in processing parameters and machinery condition. It is, then, evident that rather than waiting for test data to reveal the need for looking into these aspects, an inspection of the key parameters and machinery conditions listed above should be made a useful routine. In fact there are other reasons which make such an examination a very important step in quality control in spinning. Defects such as roller eccentricity, roller vibration, etc. assume fairly large magnitude in degree and extent before test data would reveal their presence. Routine inspection of machinery, on the other hand, helps in locating such troubles at a very early stage even when the extent of the defect is very small. It is also to be noted that inspection of machinery is useful in detecting the causes of yarn faults like slubs, fly etc. which generally occur at such long intervals as to be practically left undetected in the normal imperfection tests, but which can significantly influence the performance of the yarn in subsequent processes of winding, warping, sizing, weaving or knitting.

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APPENDIX I

CALCULATION OF BETWEEN-BOBBIN AND WITHIN-BOBBIN C.V.'s.

(ILLUSTRATIVE EXAMPLES)

1. **Data:**

Bobbin Number	Lea Number 1	2	3	Bobbin Total (T)
1	26.0	26.0	26.4	78.4
2	27.3	28.2	26.8	82.3
3	28.0	27.4	27.4	82.8
4	26.0	28.4	27.6	82.0
5	26.7	27.0	26.9	80.6
6	25.9	27.4	26.9	80.2
7	27.5	27.6	27.5	82.6
8	27.4	28.8	28.5	84.7
9	26.4	27.1	25.9	79.4
10	27.0	26.4	24.8	78.2
11	28.3	29.3	28.8	86.4
12	27.8	29.1	27.5	84.4
13	27.6	26.6	26.2	80.4
14	25.7	27.6	27.7	81.0
15	29.0	27.7	26.9	83.6
16	27.5	27.3	26.0	80.8
17	26.2	25.7	25.5	77.4
18	29.8	27.8	28.2	85.8
19	24.7	26.1	26.8	77.6
20	23.2	23.7	24.1	71.0

2. **Calculations for Analysis of Variance :**

1) Find $\Sigma 1^2$

$$= (26.0)^2 + (26.0)^2 + (26.4)^2$$
$$+ (27.3)^2 + \dots\dots\dots\dots\dots\dots$$
$$+ \dots\dots\dots\dots\dots\dots\dots\dots$$
$$+ (23.2)^2 + (23.7)^2 + (24.1)^2$$
$$= 43621.18$$

2) Find ΣT^2

$$= (78.4)^2 + (82.3)^2 + \dots + (71.0)^2$$
$$= 131390.78$$

3) Find ΣT

$$= 78.4 + 82.3 + \dots\dots + 71.0$$
$$= 1619.6$$

4) Find total sum of squares $= \Sigma 1^2 - \frac{(\Sigma T)^2}{n}$

$$= 43821.18 - \frac{2623104.16}{n}$$
$$= 43821.18 - 43718.40$$
$$= 102.78$$

5) Find between-bobbin sum of squares

$$= \frac{\Sigma T^2}{3} - \frac{(\Sigma T)^2}{n}$$
$$= \frac{131390.78}{3} - \frac{2623104.16}{60}$$
$$= 43796.93 - 43718.40$$
$$= 78.53$$

6) Find within-bobbin sum of squares

$$= \text{Total sum of squares} - \text{Between-bobbin sum of squares}$$
$$= 102.78 - 78.53$$
$$= 24.25$$

TABLE OF ANALYSIS OF VARIANCE

Source	Degrees of Freedom	Sum of Squares	Mean Sum of Squares
Between-bobbins	19	78.53	4.1332
Between leas Within-Bobbin	40	24.25	0.6062
Total	59	102.78	-

5. Calculation of Between- and Within-Bobbin C.V.'s.

Within-bobbin Variance = Mean within-bobbin sum of squares

$$= 0.6062$$

Between-bobbin Variance

$$= \frac{\text{Between-bobbin m.s.s.} - \text{Within-bobbin m.s.s}}{\text{Number of leas tested per bobbin}}$$

$$= \frac{4.1332 - 0.6062}{3}$$

$$= 1.1757$$

$$\text{Average} = \frac{T}{n}$$

$$= \frac{1619.6}{60}$$

$$= 26.993$$

$$\text{Between-bobbin C.V.\%} = \frac{\sqrt{\text{Between-bobbin Variance}}}{\text{Average}} \times 100$$

$$= \frac{\sqrt{1.1757}}{26.993} \times 100$$

$$= 4.02$$

$$\text{Within-bobbin C.V.\%} = \frac{\sqrt{\text{Within-bobbin Variance}}}{\text{Average}} \times 100$$

$$= \frac{\sqrt{0.6062}}{26.993} \times 100$$

$$= 2.88$$

APPENDIX II

STATISTICAL BASIS FOR CALCULATING THE NUMBER
OF
WRAPPINGS AND TOLERANCE LIMITS

CASE 1 : Only one wrapping per bobbin

Let A be the actual wrapping weight

M be the nominal wrapping weight

s^2 the overall variance of wrapping weight

(Note that overall variance = Between-Bobbin Variance
+ Within-Bobbin Variance)

K the percentage change in wrapping weight brought about by change of one tooth in pinion

n the number of wrappings to be tested (taking one per bobbin)

Then the sampling plan should ensure that :

(i) When $A = M$, pinion is changed only once in 20 checks.

(ii) When $A = M\left(\frac{100+K}{100}\right)$ or when $A = M\left(\frac{100-K}{100}\right)$,

pinion is not changed only once in 20 checks.

The first condition is fulfilled by setting the tolerance limits for sample average as $M \pm 1.96\frac{s}{\sqrt{n}}$.

Now when the actual wrapping weight, A, is equal to $\frac{M(100+K)}{100}$, the decision of not changing the pinion will be taken only if the observed average weight is equal to or less than $M + 1.96\frac{s}{\sqrt{n}}$. In order that the first half of the second condition is fulfilled, therefore,

$$\frac{M(100+K)}{100} - 1.645\frac{s}{\sqrt{n}} \text{ must be } = M + 1.96\frac{s}{\sqrt{n}} ,$$

where 1.645 is the lower 5% point of a standardised normal distribution. Similarly for the second half of the second condition to be fulfilled

$$\frac{M\,(100 - K)}{100} + 1.645\frac{s}{\sqrt{n}} \text{ must be } = M - 1.96\frac{s}{\sqrt{n}}$$

. Both these would lead to the equation,

$$(1.645 + 1.960)\frac{s}{\sqrt{n}} = \frac{MK}{100}$$

$$\text{or } \sqrt{n} = \frac{(3.605)s}{MK} \times 100,$$

$$= \frac{(3.605)\,C.V.}{K}$$

$$\text{whence } n = \frac{(3.605)^2\,(C.V.)^2}{K^2} = \frac{13 \times (C.V.)^2}{K^2}$$

CASE 2 : Two wrappings per bobbin

In ring spinning when the within- and between-bobbin C.V.'s are at satisfactory levels, the $(\text{between - C.V.})^2$ is roughly $1.5 \times (\text{within-C.V.})^2$. Now, the standard error of the average Count determined by testing 2 leas from each of b bobbins is

$$= 1.96\sqrt{\frac{\text{Between Variance}}{b} + \frac{\text{Within Variance}}{2 \times b}},$$

which under the above condition

$$= 1.96\sqrt{\frac{1.5 \text{ Within Variance}}{b} + \frac{\text{Within Variance}}{2 \times b}}$$

$$= 1.96\sqrt{\frac{4 \text{ Within Variance}}{2\,b}}$$

$$= 1.96\sqrt{\frac{2 \text{ Within Variance}}{b}}$$

In order that the requirements of the sampling plan be met, this standard error should be equal to that of the average determined by testing one lea per bobbin from each of n bobbins.

In other words,

$$1.96\sqrt{\frac{2\ \text{Within Variance}}{b}} = 1.96\sqrt{\frac{\text{Overall Variance}}{n}}$$

$$\text{i.e.}\qquad \sqrt{\frac{2\ \text{Within Variance}}{b}} = \sqrt{\frac{\text{Between Variance} + \text{Within Variance}}{n}}$$

$$= \sqrt{\frac{2.5\ \text{Within Variance}}{n}}$$

$$\text{i.e.}\ \sqrt{\frac{2}{b}} = \sqrt{\frac{2.5}{n}} \qquad \text{or} \qquad b = \frac{2\,n}{2.5} = \frac{4n}{5}$$

A sampling plan in which two leas are tested from each of b bobbins can, therefore, be considered equivalent to that in which one lea is tested from each of n bobbins when $b = \frac{4}{5}n$. The total number of leas tested in the first plan is $2b = \frac{8}{5}n$. This is 60% more than the number of leas tested in the second plan, namely n.

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