EVALUATING THE GAUGE REPEATABILITY AND REPRODUCIBILITY FOR YARN STRENGTH SPINNING PROCESSES

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***Abstract*:** One precise method used in the industry for several years to think about measurement instrument repeatability and reliability across quite a lot of inspection agents is the Gauge Reproducibility & Repeatability (GR&R) tool. GRR Studies have become critical in process improvement projects in the manufacturing sectors. There are various methods to conduct GRR study. However, the most widely used is the Automotive Industry Action Group (AIAG) method, which was standardized after the recognition of the importance of measurement systems. In this study, AIAG method, variance component method, ANOVA method and Control chart method are compared for Twist per Inch (TPI), a quality characteristic of the yarn processes. Usually, the GR&R study wants to be conducted earlier to the process capability analysis for verifying the exactness of measuring equipments and helping organizations develop their product and service quality. Therefore, how to make sure the quality of measurement becomes a vital task for quality practitioners. In textile spinning industry, the quality measurement includes usually, Neps, Strength, Elongation, Evenness, Twist variation, Hairiness etc. Whereas the present study deals with the evaluation of accuracy of the yarn strength for the TPI data that leads to reliable decision concerning yarn quality. The measurement system analysis (MSA) is then used to observe the reliability of the data due to operators. Due to this, the yarn strength measurement system is inappropriate and need improvement regarding operators. Hopefully, the results of this study can supply a useful reference for quality practitioners in various industries.

***Intex terms*: ANOVA, Gauge R& R, measurement system analysis, spinning industry, yarn strength.**

I. INTRODUCTION

In textile, spinning industry's main requirement is to judge the yarn quality (Issa and Nagahashi, 2005). Textile products are manufactured for daily uses and ceremonial purposes. Products such as ropes, wicks and sailing cloth have been a part of our civilizations since years to years. Yarn holds a principal position for manufacturing textile products which is manufactured on the basis of cotton fibres. Cotton fibres cannot be used to make clothes in their raw form. For this purpose, cotton fibre must be converted into yarns (Raul, 2005). The process used for yarn formation is spinning. To produce good quality of fabric a high quality of yarn is needed. Yarn quality is measured by some parameters i.e. yarn count, yarn strength, yarn CLSP, TPI etc. As yarn quality is measured in terms of data and if data is not measured accurately, then our results concerning yarn quality testing are not reliable. For this purpose, we need some statistical measure to check the accuracy and precision of data, collected through different sources. Here we use measurement system analysis to test the quality of data for making better decision about yarn quality.

1.1 Measurement System Analysis (MSA): A measurement system is an important component for any quality improvement process. Quality of a product is measured through statistical quality control (SQC) and every method in SQC needs data. So if we have clear-cut and exact data, the results will be consistent and due to this, the quality of product is monitored correctly. Quality of a product is usually affected by material, method, men and machinery, the MSA is concerned with men method/technique.

Because these are the two sources that affect the data collection method. MSA is used to determine the precision and accuracy of data or to measure the quality of data due to operators and method (Mast & Wieringen, 2004). Sometimes the data may be accurate but not precise and vice versa. Main goal of MSA is to obtain data that are both precise and accurate (Mader et al., 1999; George et al., 2005; Mukhopadhyay, 2006 and Hoffa & Laux, 2007).

1.2 Components of MSA: The components of MSA includes, bias, stability, repeatability and reproducibility. Where bias is the difference between process average of industry and target (customer demanded value), also known as accuracy. Stability is the change in bias over time. Repeatability is the process variation which arises due to instrument error or same person, same thing being measured, same characteristics, same instrument and same environmental condition, also known as precision. Reproducibility is the variation which arises due to external sources, i.e. different persons, same part/sample, same characteristics, same instruments and same environmental conditions (Hoffa and Laux, 2007). MSA is studied by Gauge repeatability and reproducibility.

1.3 Gauge Repeatability & Reproducibility (R & R): MSA is also called gauge capability analysis or gauge repeatability and reproducibility (Patki, 2005). Gauge R & R is used to check whether the measurement system is adequate or not? Gauge R & R initially based on control charts techniques but this technique is worn to weigh up the measurement system of operator and samples individually but their combined effect cannot be checked. That's why we have gauge ANOVA and Gauge R & R based on numerical computation to test combined effect. We use Gauge R & R when dissimilar people get the same measurements and when data is continuous.

II. REVIEW OF LITERATURE

The unique GR&R method proposed by the Automotive Industry Action Group (AIAG), the most accepted automotive industry technique nowadays, uses the Average Range Method. However, the ANOVA-based method seems to be acknowledged as well and is generally the chosen method. A complete and meticulous reconsider of the precise steps and calculations in a GR&R will not be obtainable in this paper as there are several great published sources for information on this topic including but not limited to (Automotive Industry Action Group, Automotive Division, 2002), (Wheeler, 2009), and (Minitab Inc., 2010). However, a quick review of key indicators of the GR&R will be discussed. MSA is based on the philosophy that measurement error masks true process capability; therefore, it is performed prior to any process improvement activities in order to quantify and minimize the measurement error (Harry & Lawson, 1992). According to Tsai's (1989) ANOVA model, it is a two-factor design of experiment under the same condition of measurement, where one factor is the inspector, the other factor is the product, and both are random effect. AIAG (1995, 1997) and DataMyte (1989) stated a method called Long Form, which is a standard form, designed by three major automobile manufacturers in the USA. Montgomery and Runger (1993a), Verdeman and Job (1999), Burdick et al. (2005), Hart (2005), and Pan (2006) discussed the Range method for conducting gauge R and R study. This method is based on range control charts to assess MSA and easier to compute. But this method does not use the effect of the interaction of operator and part (Hoffa and Laux, 2007, and Borror, 2009) MSA by ANOVA is discussed initially by Mandel (1972) and further discussed by Pan (2004 and 2006).

III. DATA ANALYSIS

AIAG standard (AIAG, 2002)-According to AIAG, 2002 the metrics of measurement error and methods of data analysis are as follows:

3.1 Metrics for AIAG Method

In Gage R&R study, the evaluation of measurement system is by manipulating the ratios of measurement variation from the collected data. If the measurement variation is condensed, the ratios differentiate between the parts that are out of specification, and increase the confidence of accepting or rejecting the parts. Therefore, the metrics used are as follows: **Equipment Variation (EV):** The variation caused by tools during replication of the measurements, is equipment variation. This is an estimation of repeatability attributed by the gage or equipment. **Appraiser Variation (AV):** This is the variation caused by the dissimilarity in the measurement by operators. This is an estimation or reproducibility attributed by operators. **Product Variation (PV):** The variation within a sample gives rise to product variation. This is attributed by variations in the process of manufacturing of the parts. **Combined Gage R&R:** The variation due to combined effect of Repeatability and Reproducibility. **Total Variation (TV):** It is an estimate obtained by combining Product Variation with the Repeatability &Reproducibility. After calculating the parameters or the estimates, the percentages of the estimates are calculated for the further analysis of data.

3.2 Methods for Conducting Gauge R and R Study:

The data measured or recorded for the study can be analyzed by three methods. They are Average Range method, Control chart method and Analysis of Variance (ANOVA) method. To estimate adequately reproducibility and repeatability there are two methods. One is Range or tabular method based on control charts and other is the ANOVA method (Borror, 2009). In this study both methods are adopted and then comparison is made for these methods.

3.2.1 Range Method

We considered the following points for estimating the reproducibility: (1)Calculate the average measurements for each operator (2)Find the range of operator averages denoted by R_0 (3)Calculate the standard deviation for reproducibility by the formula: $\hat{\sigma}_{\text{Reproducibility}} = \frac{R_0}{d_2}$ and variance component is $\hat{\sigma}^2_{\text{Reproducibility}} = \left[\frac{R_0}{d_2}\right]^2$. Following points may be considered for estimating the repeatability: (1) Calculate range for each part/sample (2) Calculate the average range of all samples let it represented by $\bar{R}$ (3) Calculate standard deviation for repeatability by using the relation: $\hat{\sigma}_{\text{Repeatability}} = \frac{\bar{R}}{d_2}$ and its variance component is $\hat{\sigma}^2_{\text{Repeatability}} = \left[\frac{\bar{R}}{d_2}\right]^2$.

3.2.2 The Analysis of Variance (ANOVA) Method

In this study, we use ANOVA method to check the accuracy of measurements, in order to incorporate the joint effect of operators and parts. The ANOVA method tests the hypotheses of mean biases of the experiment and also provides estimates of the variance components attributed to gage and operator. The assumptions of ANOVA method involved in this analysis as stated by Tsai (1988) are as follows: The operator, part interaction and gage (error) effects are additive, The operator, part and gage effects are normally distributed with zero mean and variances, The gage errors must be independent of the operator, part and interaction effects of each other and The total variation is partitioned into operator, part, interaction between operator and part as shown in table 3.1. In a two-way ANOVA with interaction, three hypotheses are tested which are: H_{01}: All parts are similar Vs. H1: All parts are not similar, H_{02}: All operators are equally good Vs. H1: All operators are not equally good and H_{03}: Interactions between parts and operators are negligible Vs. H1: Interactions between parts and operators are not negligible. The data collected for ANOVA at random and graphical analysis is performed on the data. Graphical analyses are also generated.

Table 3.1: ANOVA Table

Sources of Variation	Sum of Squares	Degrees of Freedom	Mean Squares	Test Statistic
(A)Operator	SS_A	a-1	$MSA=\frac{SSA}{a-1}$	$F=\frac{MSA}{MSE}$
Parts/Samples	SS_B	b-1	$MSA=\frac{SSB}{b-1}$	$F=\frac{MSB}{MSE}$
(AB) Interaction	SS_{AB}	(a-1)(b-1)	$MSAB=\frac{SSAB}{(a-1)(b-1)}$	$F=\frac{MSAB}{MSE}$
Error	SS_E	ab(n-1)	$MSE=\frac{SSAB}{ab(n-1)}$	
Total	SS_T	abn-1		

Table 3.2: Gauge R & R Metric Sources of Measurement Error

Equipment Variation (Repeatability)	$EV = k\sqrt{MSE}$	Variation of multiple measurements due to same sample or part by same operator
Appraiser or Operator Variation (Reproducibility)	$AV = k\sqrt{\frac{MSA - MSAB}{bn}}$	Variation representing the measured value of same part or sample by different operator
Part or Process Variation	$PV = k\sqrt{\frac{MSB - MSAB}{an}}$	Variation measured values of multiple parts by the same operator
Interaction Variation	$IV = k\sqrt{\frac{MSAB - MSE}{n}}$	Variation by the average of the measured values from different sample by different operator
Combined Gauge R & R	$R\,\&\,R = \sqrt{(EV)^2 + (AV)^2 + (IV)^2}$	Representing the sum of undesirable variations

Where k is constant which depends on number of trials of each operator. For trials = 2, the value of k is 4.56 and for trials = 3, the value of k is 3.05 (Montgomery, 2003).

3.2.2Decision Making Criteria

In order to make a decision about the measurement system for the GRR study, AIAG has set up a criteria index for the practitioners shown in Table 3.3.

Table 3.3: Gage R&R Criteria

% R&R Criteria	
Error<10%	MS is acceptable
10%-errror-30%	MS may be acceptable
Error>30%	MS needs improvement

IV. RESULTS AND DISCUSSIONS

4.1 Gage R&R Study - XBar/R Method

Variance components: Minitab also calculates a column of variance components (VarComp) and uses the values to calculate %Gage R&R with the ANOVA method. The gage R&R table breaks down the sources of total variability: Total Gage R&R consists of Repeatability, the variability from repeated measurements by the same operator. Reproducibility, the variability when the same part is measured by different operators. Part-to-Part is the variability in measurements across different parts.

We use variance components to assess the amount of variation that each source of measurement error and the part-to-part differences contribute to the total variation. Ideally, differences between parts should account for most of the variability; variability from repeatability and reproducibility should be very small. Here from table 4.1, the total Gage R&R is 94.05, which is too big. Thus the measurement system needs improvement.

Table 4.1: Variance Components

Source	VarComp	%Contribution (of VarComp)
Total Gage R&R	0.104985	94.05
Repeatability	0.065809	58.95
Reproducibility	0.039176	35.09
Part-To-Part	0.006643	5.95
Total Variation	0.111628	100.00

Minitab also displays columns with percentages based on the standard deviation of each term. These columns, labelled percent Study Variance, typically do not add up to 100%. Because the standard deviation uses the same units as the part measurements and the tolerance, it allows for meaningful comparisons.

Table 4.2: Gage Evaluation

Source	StdDev (SD)	Study Var (6 × SD)	%Study Var (%SV)
Total Gage R&R	0.324014	1.94408	96.98
Repeatability	0.256533	1.53920	76.78
Reproducibility	0.197929	1.18757	59.24
Part-To-Part	0.081506	0.48903	24.40
Total Variation	0.334108	2.00465	100.00

Number of Distinct Categories = 1

4.2 Gage R&R Study - ANOVA Method:

Table 4.3: Two-Way ANOVA Table with Interaction

Source	DF	SS	MS	F	P
Parts	9	0.66114	0.07346	1.4328	0.246
Operators	2	2.36889	1.18444	23.1017	0.000
Parts * Operators	18	0.92288	0.05127	0.8362	0.652
Repeatability	60	3.67865	0.06131		
Total	89	7.63155			

α to remove interaction term = 0.05

Table 4.4: Two-Way ANOVA Table without Interaction

Source	DF	SS	MS	F	P
Parts	9	0.66114	0.07346	1.2452	0.280
Operators	2	2.36889	1.18444	20.0774	0.000
Repeatability	78	4.60153	0.05899		
Total	89	7.63155			

From Table 4.4, it is clear that operators are significant (p=0.000), which shows inadequacy of measurement system is due to operator only, also Table 4.6 below, on the basis of ANOVA method shows the inadequacy of measurement system as gauge R & R percent equals 99.18, which is much greater than 30 percent. Also number of distinct categories from Table 4.6 below supports the above statement. Furthermore, we may see that the ANOVA method provides more clarification about the factors that contribute in the adequacy of the measurement system.

Table 4.5: Variance Components (Var Comp)

Source	Var Comp	%Contribution (of Var Comp)
Total Gage R&R	0.0965090	98.36
Repeatability	0.0589939	60.13
Reproducibility	0.0375150	38.24
Operators	0.0375150	38.24
Part-To-Part	0.0016073	1.64
Total Variation	0.0981163	100.00

Table 4.6.: Gage Evaluation

Source	StdDev (SD)	Study Var (6 × SD)	%Study Var (%SV)
Total Gage R&R	0.310659	1.86395	99.18

Repeatability	0.242887	1.45732	77.54
Reproducibility	0.193688	1.16213	61.83
Operators	0.193688	1.16213	61.83
Part-To-Part	0.040091	0.24055	12.80
Total Variation	0.313235	1.87941	100.00

Number of Distinct Categories = 1

V. INTERPRETATION OF RESULTS

Minitab uses the ANOVA method to estimate variance components, and then uses those components to calculate approximately the percent variation due to the measuring system. The percent variation appears in the table 5.1. The two-way ANOVA table includes terms for the part, operator and operator by part interaction (part*operator). If the P- value is greater than 0.05, Minitab generates a second ANOVA table that omits the interaction term from the model. Here the P- value for parts * operators is 0.652, which is greater than 0.05, thus Minitab removes the interaction term from the model and generates a second ANOVA table.

Percent Contribution: Percent contribution is based on the estimate of the variance components. Each value in variance component is divided by the total variation and then multiplied by 100. Total Gage R & R contribution is 98.36%, which is unacceptable and requires improvement. With repeatability at 60.13% and reproducibility at 38.24% Here 1.64% of the total variation in the measurements is due to the differences between parts. This low percent contribution is considered to be not good. When percent contribution for part- to –part is low, the system cannot distinguish between parts.

Using variances versus Standard Deviation: Because % contribution is based on the total variance, the column of values adds up to 100%

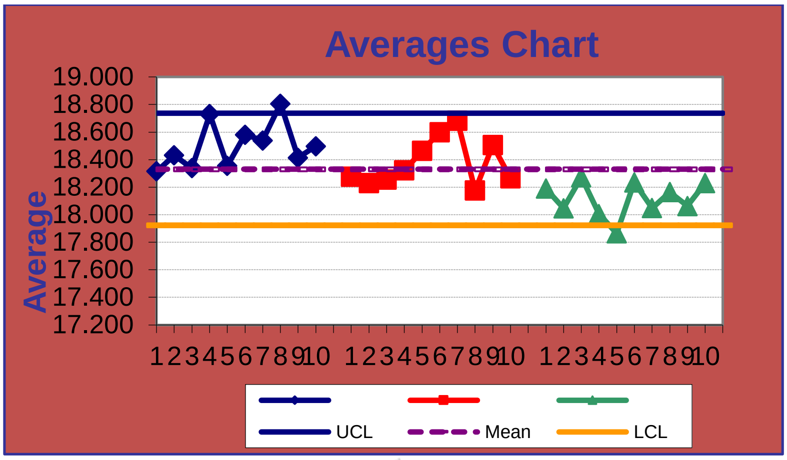
Number of distinct categories: The number of Distinct categories values estimates how many separate groups of parts the system can differentiate Minitab truncates this value to the integer except where the value calculated is less than one. In that case Minitab sets the number of distinct categories equal to 1. Here, the number or distinct categories is one, which indicates the system cannot discriminate between parts. Since AIAG recommends that the number of distinct categories is five or more.

Interpretation of GRR Study: The Repeatability and Reproducibility are compared from the results obtained for the study, in order to take necessary actions for the improvement of the measurement system.

Here, in this study Repeatability (60.13) is greater than Reproducibility (38.24), hence Gage needs maintenance, redesign, repairs or replacement, Improve clamping or location of the gage and Presence of excessive within-part variation. In ANOVA table, given above, we have found the significance of the operators. To locate the operators, which create significant problem for measurement system, we follow the graphical method.

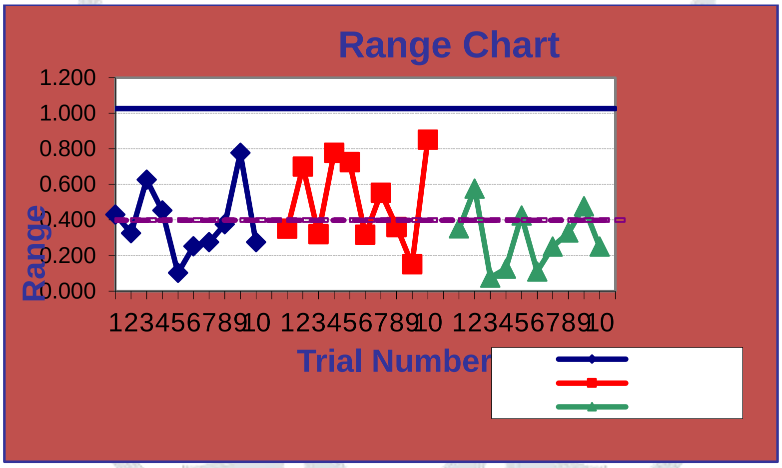
Graphical Analysis of Measurement System: The last acceptance of the measurement system should not be confined to a single set of indices.

Figure 5.1: X-bar Chart



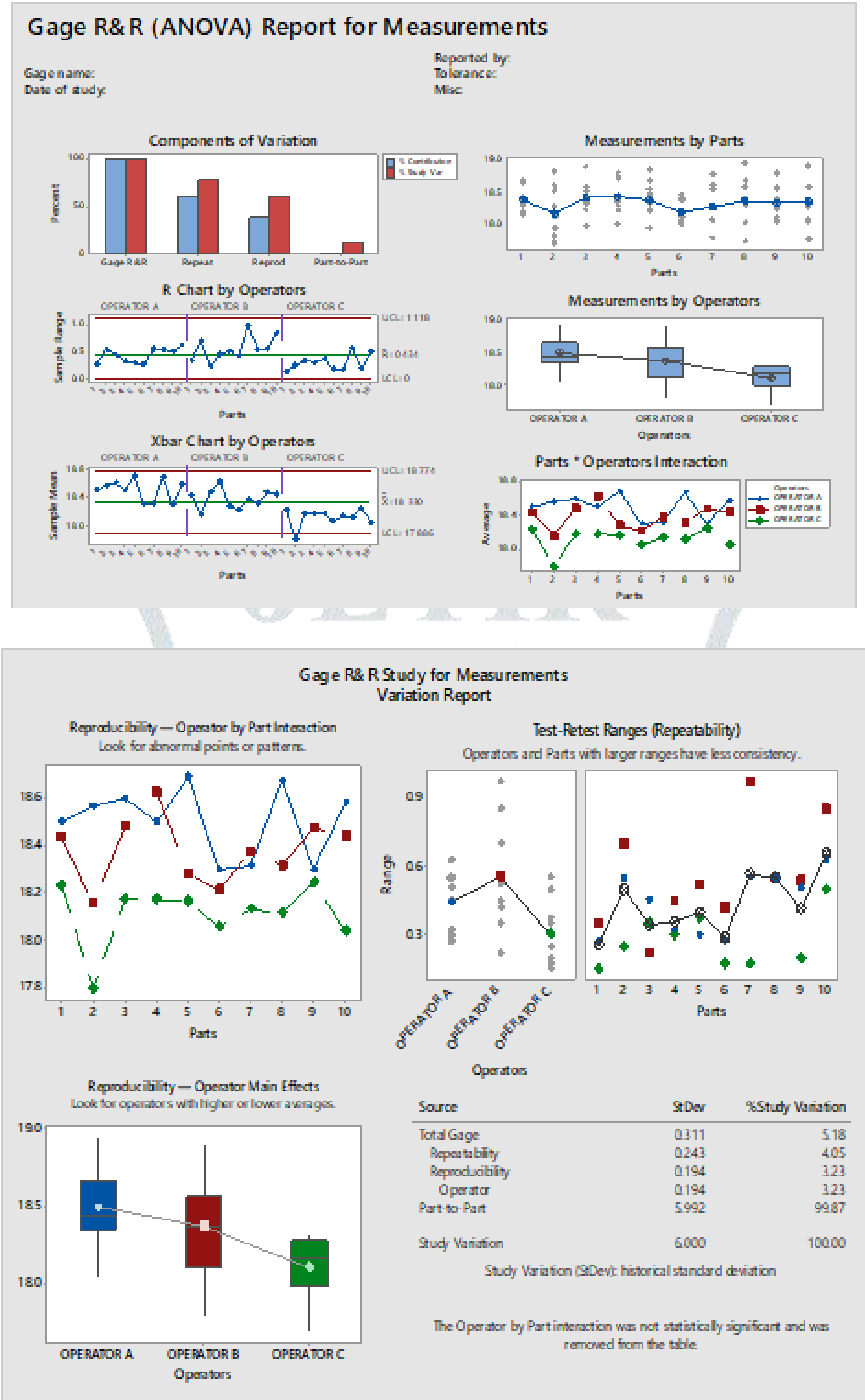
From the X bar chart in Figure 5.1, it is evident that most of the average points lie outside the control limits. This indicates that the measurement system is inadequate in detecting part-to part variation.

Figure 5.2: Range Chart



From the Range chart in Figure 5.2, all the ranges are within the control limits. This indicates that the operators followed the same method and were consistent in taking the readings.

Figure 5.3: Gauge R &R ANOVA Report for Measurements



In Figure 5.3 different graphs are studied for Gauge R & R analysis, we conclude the following results: In the Components of Variation bar graph, the variation from part to part is smaller than the both total process variation (variance of yarn strength) and the study variation (the sum of gauge R & R and part variation). This indicates that the measurement system is inadequate.

The $\overline{X}$ and R charts of Operators are used to check the consistency of operators. If both charts are in statistical control then MSA is acceptable. $\overline{X}$ chart seems to be out of control. This indicates that any non random pattern may be due to operator technique, or instrument inconsistency. So the measurement system of the spinning process for yarn strength is unacceptable.

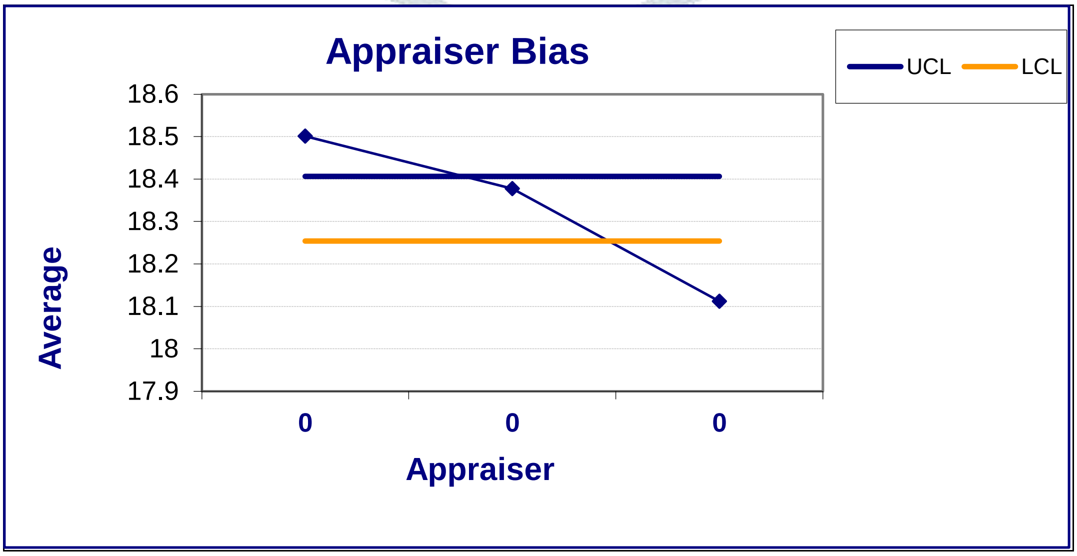
Yarn Strength by Operator: From the figure 3, it is clear that "operators" are significant. As the box plot of the yarn strength of operator shows individual interpretation of each operator, these operators cause the unacceptability of spinning measurement system because the yarn strength averages of each operator are not looking horizontal.

Table 5.1: Measurement Unit Analysis by AIAG and Component Variance Method.

Measurement Unit Analysis	AIAG Method	Component Variance Method
	% of Total Variation	% of Total Variation
Repeatability-Equipment Variation(EV) EV=0.2354	%EV=74.1%	% EV=54.9%
Reproducibility-Appraiser Variation(AV) AV=0.19897	%AV=62.7%	%AV=39.3%
Repeatability & Reproducibility(GRR) GRR=0.3082	%GRR=97.0%	%GRR=94.2%
Product Variation (PV) PV= 0.07666	%PV=24.1%	%PV=5.8%
Total Variation(TV) TV=0.31758	$\sum = 100$	$\sum = 100$

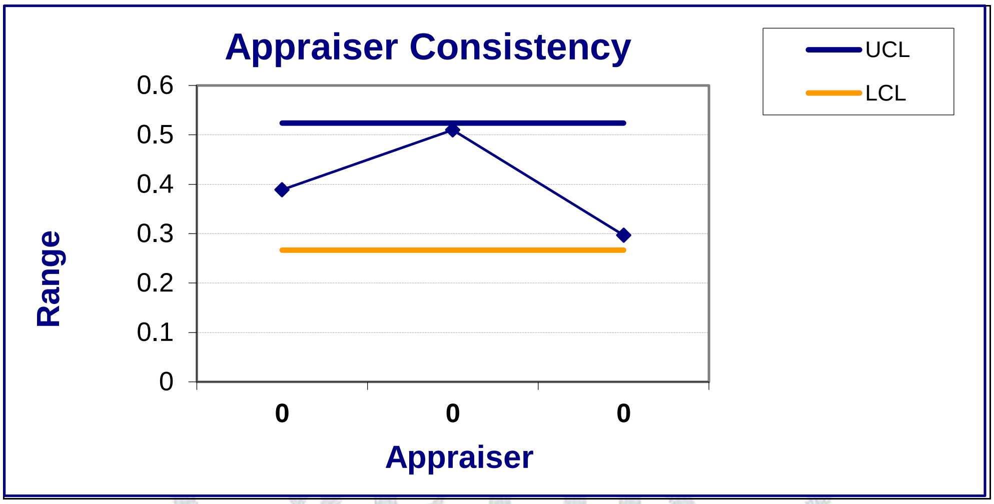
Interpretation of Results for the Component Variance Method: In this study, the gauge R&R percent is 98.36, which is very much larger quantity that refers to the inadequacy of the measurement system for yarn strength data. Table 4.5 shows the observation of gauge R&R towards the data. As a rule of thumb the measurement system is adequate if the percent total R&R is less than 10 percent and for marginal acceptance, it may be 30 percent. Relative Utility: Goal- at least 80% of measurement is error attributable to the product. The measurement system is not acceptable for measurement and will not be able to quantify process improvement since our actual percentage PV is 5.8% which is less than 20%. Bias: Goal - all appraiser averages within Bias Chart control limits, if all the data points are within the control limits, there is a 95% probability that there is no operator bias present. But here 2 appraisers have at least one average value outside the Bias Chart control limits. Hence there may be appraiser bias present.

Figure 5.4: Bias Chart



Consistency: Goal - all appraisers ranges within Consistency Chart control limits. From figure 5.5, if all data points are within the control limits, there is a 95% probability that there is no inconsistency of measurement across appraisers. Here all appraisers' ranges are within the Consistency Chart control limits. Thus the results are consistent across appraisers.

Figure 5.5: Consistency chart



Interpretation of Results for the AIAG Method: Relative Utility: Goal - gauge R&R% is less than 10%. Actual GRR% is 97.0% which is greater than 30% which means the measurement system needs improvement. Make every effort to identify the problems and have them corrected. System Resolution: Goal - all appraisers have at least 50% of average values outside the Averages Chart control limits 3 appraisers have less than 50% of the averages outside the Averages Chart control limits. The measurement system may not have adequate resolution to detect part-to-part variation. If 50% or more of the averages for each appraiser are outside the control limits, the measurement system has adequate resolution to detect part-to-part variation. Consistency: Goal - all appraisers have all range values below the Range Chart upper control limit. Since all data points are within the control limit, there is no inconsistency of measurement across appraisers. All appraisers' ranges are within the Range Chart control limits. The results are consistent across appraisers.

VI. CONCLUSION

Since yarn quality decisions are based on yarn quality measurements. Therefore quality department first assess the quality and the yarn quality characteristics are measured. As this is the fault in the measurement system due to operators, then yarn quality characteristics may lose industry faith for knitters. From the results of MSA, we have found that measurement system is not acceptable and needs improvement in their measurement system and operators may be trained according to the requirements or may be changed accordingly. The variation that is due to the measuring system, that is percent of study variation is greater than 30% which is not acceptable according to AIAG guidelines. If the industry not improves their measurement system, then the yarn product quality is not reliable. Due to this, the yarn strength measurement system is unacceptable and need correction concerning operators.

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