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The study of a measurement system precision

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Abstract: The use of measurement system Repeatability and Reproducibility (R&R) studies is widespread in industry. Such analyses have become mandatory for many companies who supply the automotive industry and is now an integral part of the QS 9000 automotive industry standard. R&R study allow one to estimate the contribution of variation attributable to the measurement system itself and is used to ensure that a company measurement system is acceptable. If the measurement system R&R study indicate that the recorded measurements may be unreliable, this may impact all subsequent analyses, e.g. control charts, capability analyses etc. It is the aim of this paper to address such issues and to show a measurement system R&R case study that was made in a major automotive company. A measurement system used to measure a bore diameter of a part, having a specification of 18.1 to 18.3 mm was to be evaluated. Ten parts have been selected for measurements by three operators. Each part was measured twice with a dial bore gauge. Because R&R value was between 10% and 30%, it had required further analysis to find the sources of measurement error. The supposition was that the dial bore gauge was not adequate to measure this bore diameter, so it was replaced by an internal micrometer and another measurement system R&R study was made. The conclusion was that the new measuring system is excellent.

Keywords: Measurement system, Precision, repeatability, Reproducibility.

1. BACKGROUND

Measurement systems are used every day in manufacturing, research and development, sales and marketing. They are a critical component in the quality a company provides to its customers and they represent a significant investment. Measurements are the window through which we look at products and processes, and it is necessary to know whether the image we see are accurate or, perhaps, somewhat distorted. Often measurements are made with little regard for the quality of such measurements. Yet all too often, the measurements are not representative of the true value of the characteristic being measured. That might be because the measurement system is not accurate enough or not precise enough. The moral is that before one embarks on using a new measurement system for a characteristic which has not been previously measured on it, it should perform a measurement system analysis, because this is critical to the success of every measurement and ensure that future measurements will be representative of the characteristic being measured.

Measurement systems are essential to the quality of a manufacturing process because the measurement process itself is subject to variation, and excessive variation in the measurement systems can mask critical variation in the manufacturing process.

2. REPEATABILITY AND REPRODUCIBILITY CONCEPTS

There are number of factors that affect the ability of a measurement system to discriminate among the units it measures. These factors can be categorized generally into those that affect central location and those that affect the variability (spread) of the measurements. Variability factors measured by repeatability and reproducibility (these terms refer to the precision of a measurement system) are the more familiar, while factors related to the central location of the measurements: stability, bias, and linearity (they refer to the accuracy of a measurement system) are relatively new approaches. Both approaches may need clarification.

Accuracy is defined as the closeness of agreement between observed values and a known reference standard, whereas precision is a measure of the closeness between several individual readings. Accuracy is something that can be drastically reduced by measurement errors and precision can be reduced by mechanical means.

So precision, or measurement variation, is a measure of the degree of repeatability between measurements. Precision is often denoted by $\sigma_{R\&R}$, which is the standard deviation of the measurement system. The smaller the spread of the distribution, the better the precision. Precision can be separated into two components, which are related as follows:

- Repeatability or equipment variation refers to the variation in measurements observed when one operator repeatedly measures the same characteristic in the same place on the same part with the same measurement tool (i.e. variation in measurements under identical conditions); it is the inherent variation within the measurement tool and it is represented by $\sigma_{repeatability}$, which is the standard deviation of the measurement tool.
- Reproducibility or appraiser/operator variation refers to the difference in the average of the measurements observed when different operators measure the same parts using the same measurement tool and it is represented by $\sigma_{reproducibility}$; it is due to factors other than the machine variation, such as, but are not limited to, operators, temperature, humidity, and part fixturing technique.

Often, an evaluation of a measurement system should be performed using a measurement system repeatability and reproducibility study, so the amount of variability in a set of measurements taken on a single measurement tool that can be attributed to the measurement tool itself (repeatability) and to the entire measurement system (reproducibility) must be determined. A typically study utilizes one to three appraisers (m) for one measuring tool that is measuring a single characteristic. Each appraiser measures five to ten units (n) selected from a process two or three times (r). Before proceeding with the analysis of the study, the ranges for the replications of the measurements made by each appraiser on each part are determined and used to calculate control limits for the range chart. Then each range is checked to determine if it falls inside the limits. Those measurements that result in a range outside the limits should be excluded from further analysis or should be redone. Once the basic calculations are made, an analysis of repeatability and reproducibility can be performed.

To interpret the measurement system R&R study, we looked at the percentage of the part tolerance that measurement system error consumes or the percentage of total variation that's due to measurement system error. Generally, manufacturers accept percentages expressed as a percent of part tolerance and the following criteria for acceptance are: R&R as a percentage of the tolerance is under 10% error – acceptable; R&R as a percentage of the tolerance is 10% to 30% error – may be acceptable based upon the importance of the application, cost of measurement tool, cost of repair and so on; R&R as a percentage of the tolerance is over 30% - generally not acceptable and every effort to identify and correct the problem should be made.

3. CASE STUDY

A measurement system R&R study was made in a major local company who supply the automotive industry. A measurement system used to measure the bore diameter of a part, having a specification of 18.1 to 18.3 mm, was to be evaluated. Ten parts have been selected for measurements by three operators. Each part was measured twice with a dial bore gauge. The repeatability and reproducibility study collected the data from table 1.

Table 1.
Repeatability and Reproducibility Report

General data					
Part:	B4-RAO-Z007A05	*Gage name:*	Dial bore gauge	*Date*	10.09.04
Characteristic:	Ø 18.1	*Gage number:*	UMF 135-74	*Prepared by*	
Tolerances:	0; +0.2	*Gage type:*	0.002 mm		Simion Carmen
Number of parts	10	*Number of operators*	3	*Number of trials*	3

Obtained values												
OPERATOR	*Trial*	*PART* 1	2	3	4	5	6	7	8	9	10	
1 *A*	1	18.152	18.160	18.170	18.152	18.150	18.270	18.198	18.202	18.220	18.232	18.191
2	2	18.152	18.158	18.172	18.156	18.158	18.268	18.198	18.210	18.224	18.220	18.192
3	3	18.154	18.160	18.172	18.154	18.152	18.270	18.198	18.200	18.220	18.220	18.190
4 Mean		18.153	18.159	18.171	18.154	18.153	18.269	18.198	18.204	18.221	18.224	X-bar A=18.191
5 Range		0.002	0.002	0.002	0.004	0.008	0.002	0.000	0.010	0.004	0.012	R-bar A= 0.005
6 *B*	1	18.154	18.162	18.168	18.152	18.158	18.270	18.214	18.212	18.224	18.240	
7	2	18.150	18.164	18.166	18.170	18.170	18.268	18.200	18.210	18.224	18.236	
8	3	18.162	18.160	18.172	18.160	18.168	18.260	18.208	18.202	18.220	18.250	18.196
9 Mean		18.155	18.162	18.169	18.161	18.165	18.266	18.207	18.208	18.223	18.242	X-bar B=18.196
10 Range		0.012	0.004	0.006	0.018	0.012	0.010	0.014	0.010	0.004	0.014	R-bar B= 0.010
11 *C*	1	18.158	18.164	18.170	18.168	18.158	18.276	18.208	18.202	18.230	18.248	18.198
10	2	18.168	18.162	18.170	18.158	18.166	18.260	18.212	18.200	18.240	18.230	18.197
13	3	18.168	18.160	18.180	18.170	18.158	18.270	18.210	18.200	18.232	18.248	18.200
14 Mean		18.165	18.162	18.173	18.165	18.161	18.269	18.210	18.201	18.234	18.242	X-bar C=18.198
15 Range		0.010	0.004	0.010	0.012	0.008	0.016	0.004	0.002	0.010	0.018	R-bar C= 0.009
												X-double bar=18.195
16 Range on the part		18.158	18.161	18.171	18.160	18.160	18.268	18.205	18.204	18.226	18.236	Rp= 0.110
		R-double bar=0.008				*X-bar Diff=0.007*			*Uper Control Limit for R=0.021*			

Results			
Repeatability	EV=0.025	%EV=13.7	The measuring system may be marginally aceptable based on the importance of the application, cost of the measuring tool, cost of repair and so on; it may require further analysis to find the sources of measurement error.
Reproducibility	OV=0.019	%OV=10.7	
Repeatability & Reproducibility	R&R=0.032	%R&R=17.4	
Part-to-part Variation	PV=0.179	%PV=98.5	
Total Variability	TV=0.182		

Operative assumptions included: the measuring tool stayed in calibration (central location did not change); operators used the same method of measurement; parts were measured in the same place. If the assumption that the parts are measured in the same place is incorrect, the possibility of within-part variation will need to be considered, too.

Because measurement system R&R value was between 10% and 30%, it had required further analysis to find the sources of measurement error. The supposition was that the dial bore gauge was not adequate to measure this bore diameter, because the cylindrical hole goes on with a conic surface and sometimes the contact point of the dial bore gauge (in gauges for measuring bores the head of the gauges has diametrically opposed holes with two measuring balls and two centering balls; centering takes place because the measuring balls are 0.01 mm greater in diameter than the centering balls) come in contact with the conic surface of the part not with the cylindrical part of the bore, and so the measurements are inexact.

The decision was to replace the dial bore gauge by an internal micrometer and another measurement system R&R study was made. The new results were:

- Repeatability - Equipment Variation=6.39%
- Reproducibility - Operator Variation=3.59%
- Repeatability and Reproducibility - Equipment & Operator Variation=7.33%

The conclusion was that the new measuring system is excellent.

4. CONCLUSION

To summarize, the purpose of the repeatability and reproducibility study was to allow the quality control engineer to assess the precision of the measurement system used in this quality control process. Identifying and reducing measurement variation was the whole reason for doing measurement system repeatability and reproducibility study.

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