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Measurement System Analysis for the Dimensional Control of a Tooth Gear

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ABSTRACT

A measurement system can be qualified by measuring its accuracy, precision, and stability; this can be done by defining the measurement system's requirements, comprehending the quality features of measurement, and understanding the process for establishing measurement capabilities. The important performance indicators linked to the measurement system analysis will be examined in this study. A Gage R&R ANOVA study is developed for analyzing the measured parameters of a toothed wheel. The aim of the paper is to measure the dimensions of the teeth after the common normal tangent to the base circle, on a non-corroded toothed wheel, then comparing the actual values with the prescribed ones, interpreting the obtained results and highlighting the sources of errors that may occur during the measurement.

Keywords-metrology, quality management, industrial products, toothed wheel

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I. INTRODUCTION

Measurement System Analysis (MSA) is the first step of the measure phase along the DMAIC methodology (Define, Measure, Analyze, Improve and Control). A comprehensive MSA typically consists of six parts: Instrument Detection Limit, Method Detection Limit, Accuracy, Linearity, Gage R&R and Long-Term Stability [1]. A poor measurement system can make data meaningless and the improvement of a process impossible. Excessive measurement error may hinder efforts to continuously enhance manufacturing processes as well as the evaluation of process stability and capabilities. Measuring measurement error directly affects how stable and capable a process is evaluated. A capable process can appear incapable and a stable process can appear unstable due to poor methodology. [2].

Gage R&R study identifies and quantifies the sources of variation that influence the measurement system. R&R stands for repeatability and reproducibility. In Six Sigma methodology, this is a crucial issue because process improvement is impossible without controlling the measurement system's variability. Several of the individual tools, including control charts, plots, and analysis of variance ANOVA, must be used in order to conduct a complete R&R study. The two main study types are nested studies and crossing studies. It explains how to use each tool separately and offers an analysis of the results of the Six Sigma package for crossed studies [3].

This paper [4] offers an approach for choosing of methods for the proof of capability of measurement processes based on the risk associated with making a mistaken decision. Low risks permit the use of cost-effective techniques with reduced reliability, while high risks necessitate more expensive and hence more dependable approaches. This method, which will be included in the soon-to-be guideline VDI/VDE 2600-1, enables manufacturers to minimize the risks and expenses linked to the assessment of the measuring process in light of the potential implications of making incorrect decisions based on measurement results.

II. RESEARCH METHODOLOGY

There are statistical methods available to estimate the repeatability and reproducibility (R&R) components in destructive scenarios if a key, and perhaps controversial, assumption is made. The initial assumption is that it is possible to identify a batch of parts related and is reasonable to consider them the same part. This means the measurement characteristic of interest is identical for each part in the group. This assumption is important because the batch variability is used to estimate the repeatability of the measurement system [5]. When the batch size is sufficient to allocate at least two portions from each batch to each operator, a more conventional or crossed design and analysis might be suitable. This is due to the fact that each operator has the ability to test every batch several times. When the operator and batch can be crossed, this experimental design allows estimation via batch interaction. When working with a small batch, where it is not possible to distribute numerous components to each operator, a hierarchical model is a viable alternative.

In this paper, the key performance indicators that are tied to the measurement system will be investigated. A Gage R&R study is developed for analyzing the parameters of three toothed wheels made of cast iron. The cast iron is widely used for the manufacture of gears due to its good wearing properties, excellent machinability and ease of producing complicated shapes by casting method. The cast iron gears with cut teeth may be employed, where smooth action is not important. The aim of the paper is to measure the dimensions of the teeth after the common normal tangent to the base circle, on a non-corroded toothed wheel, comparing the actual values with the prescribed ones and interpreting the obtained results, highlighting the sources of errors that may occur during the measurement.

The equipment used is a micrometer for gears with a division value of v_{div} = 0,01 mm and a measuring range of 0-25 mm. The toothed wheels are into class 8 of precision and the angle of engagement $\alpha = 20°$. For measurement instruments, the precision and accuracy are important, but they do not need to be focused on simultaneously to get the best reading. However, the best reading has precision and accuracy aligned together. There are many factors that impact accuracy, but the skill of the user is the most important. If the micrometer is not calibrated enough, this will factor into the problem. The data should be: continuous, in time order, collected at appropriate time intervals, at least 5 individual observations that are not collected in subgroups and moderately normal.

Procedure for determining the stability of a measurement system is: determine the expected range of results; select a part from production that falls in the center of the expected range; the sample found is tested over and over on a regular basis; the sample found results are plotted on an individual control chart over time; bring the measurement system into statistical control by finding and eliminating special causes. The data can be analyzed graphically using histogram, numerically by developing a confidence interval around the average and determining if the range contains zero. The activities that are done to analyze the characteristics of the wheel are: determination of the number of teeth "n" over which to measure the dimension W; control the the measuring instruments to find if they are correctly set to zero; the external micrometer measures the outer diameter of the gear wheel; calculate the gear module ($m = d_{ef} / (z + 2)$); the value found is rounded to the nearest standard; depending on the number of teeth “z” of the wheel, choose the number of teeth “n” and W_1 the theoretical dimension over teeth for m = 1 and $\alpha = 20°$; calculate the theoretical W by taking into account the calculated module and the determined value W_1 is: $W = W_1 \cdot m$.

Between the measuring surfaces of the gear tooth, "n" teeth are taken and the parameter W_{ef}measured over the teeth. In the same way, the parameters W are measured successively over the entire circumference of the toothed wheel. The values W_{ef}in millimeters obtained by measurement are given in **Table** 1.

Table 1.The measured parameter Wef of toothed wheel

1	13.47	***13***	13.46
2	13.48	***14***	13.45
3	13.47	***15***	13.46
4	13.48	***16***	13.46
5	13.47	***17***	13.47
6	13.47	***18***	13.46
7	13.46	***19***	13.46
8	13.47	***20***	13.46

9	13.47	***21***	13.47
10	13.47	***22***	13.46
11	13.48	***23***	13.47
12	13.46	***24***	13.47

The characteristics of the toothed wheel are then determined by the following equations [3].

$$F_{Wr} = W_{ef} - W \text{ [mm]} \quad (1)$$

$$F_{vWr} = W_{ef\ max} - W_{ef\ min} \text{ [mm]} \quad (2)$$

$$W_{mr} = (\sum_{i=1}^{n} W_{ef})/n \text{ [mm]} \quad (3)$$

$$E_{Wmr} = W_{mr} - W \text{ [mm]} \quad (4)$$

For this measurement process, using the formulas from the specialized literature, it is obtained that the piece is compliant: the technical parameters falling within the imposed limits (**Table** 2).

The tightening of the component between the measuring surfaces of the micrometer is made only by the force limiting device. The following inputs and outputs of the process are calculated: the actual deviations of dimensions measured against the theoretical or nominal, the variation of the W dimension, the average dimension over the teeth, the average dimension deviation over teeth.

Table 2. Prescribed values of precision indicators

Precission class	
Tolerance of the game between the flanks	
Angle of engagement α	0°
F_{vw}[μm]	8
F_{Ws} [μm]	60
T_W [μm]	0
T_{Wm}[μm]	0
-E_{Wms} [μm]	71

where$F_{vW}$is tolerance of variation of the dimension over the teeth; - F_{Ws} is maximum deviation of the share over the teeth, for external teeth; T_W represents tooth tolerance; T_{Wm} is average tooth tolerance over teeth; $E_{Wms}$is minimal deviation of the median height over teeth, for external teeth. The effective value of E_{wmr} is lower than the prescribed value E_{wms}, which means that the piece corresponds to the dimensional precision.

The toothed wheel is considered good only if the variation of the excess height falls within the allowance for the variation of the dimension over the prescribed F_{vW} teeth. In Minitab software, the type of data is defined, the analyzed objective of the study is chosen and the attributes of the Gage R&R are imposed.

The following tasks are designed to provide a thorough analysis: evaluate the requirement for the research (% Tolerance - for product control, % Study - for process control), ascertain the study's specifics (such as the number of trials and appraisers), choose the appraisers who will use the gauge in production, choose the sample parts to be utilized in accordance with the study's determined needs, confirm that the gage resolution is appropriate, Measure the components in a random order to avoid measurement memory; all users should follow the standard measurement procedure; and the research should be watched to guarantee data reliability.

Parts ought to be gathered gradually and should utilize the whole spectrum of process variation. This does not refer to the full tolerance of the product. In variable Gage R%R Graphical Metrics, are defined the following: components of variation (indicates repeatability/reproducibility/parts and must be obtained a low Gage R&R), R Chart (indicates repeatability, helps unusual measurements, steps indicate resolution limitation) and Xbar& Chart (reproducibility/sensitivity, similar patterns can be seen for each operator). In Gage R&R (ANOVA) Report are illustrated the following charts (Fig. 1):

components of variation, R chart by operators, Xbar chart by operators, results by parts, results by operators, parts and operator interaction.

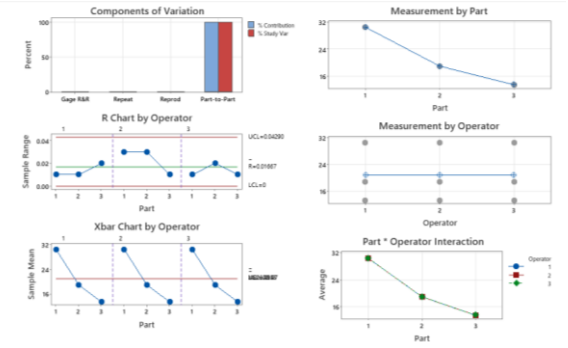


Fig. 1. Gage R&R (ANOVA) Report for Results

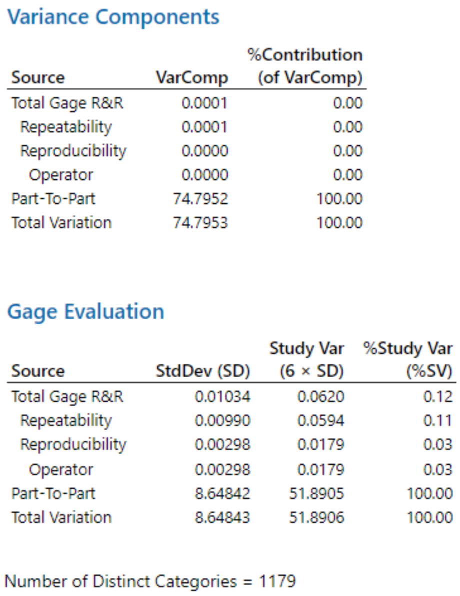
III. RESULTS INTERPRETATION

The R-chart indicates that the consistency of variance within each bar remains relatively steady. This chart helps identify if certain operators struggle with preparing and testing specimens consistently and pinpoint specific ingots that were not homogeneous by showing the combined variability from the repeatability and variability in the range. The R-chart is a control chart of ranges that graphically displays operator consistency. The operator is not consistently measuring the parts if any points on the R-chart are over the upper control limit. When operators measure consistently, the points fall within the control boundaries and the ranges are minimal in relation to the data.

The repeatability components and part-to-part variance are contrasted in the Xbar chart. This graph should ideally demonstrate a lack of control since the components selected for a Gage R&R study should represent the whole range of potential parts. Numerous points in these data are either above or below the control boundaries. According to these findings, measuring instrument variation is far smaller than part-to-part variation. In order to evaluate procedurally what the operators might do differently with relation to the crucial parts of obtaining the measurement, another study should be designed.

The By Operator Plot can help to determine whether measurements and variability are consistent across operators. Here, the operators appear to be measuring the parts consistently, with approximately the same variation [6]. The Interaction Plot displays the average measurements by each operator for each part. Here, the 3 operators seem to be measuring parts similarly. An operator’s ability to measure a part depends on which part is being measured (an interaction exists between Operator and Part).

One metric used to determine a measurement system's capacity to recognize a variation in the characteristic being measured is the number of unique categories. This indicator, which is a ratio of the variability in the measured components to the variability in the measuring system, needs to be at least 5. There are 1179 different categories in this instance. The measurement system is acceptable if the Total Gage R&R is less than 1 %. A measurement system is suitable if Total Gage R&R is between 1% and 9%, depending on the application, cost, and other factors. If the Total Gage R&R exceeds 9%, the measurement technique needs to be modified. The example under analysis has a total gauge R&R of less than 1%. (Fig. 2). Depending on the application, cost, and other considerations, a measurement method is suitable if the percentage of Study Var is between 10 % and 30 %. A measuring method is unsatisfactory and needs to be upgraded if the percentage of % SV exceeds 30 %. In the analyzed case, Total Gage R&R is 0,12 %. In the Components of Variation graph, the percent contribution from Part-to-Part is larger than that of Total Gage R&R, telling that the largest component of variation is due to Part-to-Part variation. The strategy is considered effective if the overall R&R gauge is less than 30%. Each process's mean must have a 95% confidence level.



Variance Components

Source	VarComp	%Contribution (of VarComp)
Total Gage R&R	0.0001	0.00
Repeatability	0.0001	0.00
Reproducibility	0.0000	0.00
Operator	0.0000	0.00
Part-To-Part	74.7952	100.00
Total Variation	74.7953	100.00

Gage Evaluation

Source	StdDev (SD)	Study Var (6 × SD)	%Study Var (%SV)
Total Gage R&R	0.01034	0.0620	0.12
Repeatability	0.00990	0.0594	0.11
Reproducibility	0.00298	0.0179	0.03
Operator	0.00298	0.0179	0.03
Part-To-Part	8.64842	51.8905	100.00
Total Variation	8.64843	51.8906	100.00

Number of Distinct Categories = 1179

Fig. 2. *Gage R&R Study – ANOVA Method*

The overall sample range must be analyzed to understand the scale of error. Part-to-Part variation should be the largest contributor. R Chart should have all points in control. Xbar& Chart should be 50% out of control. This indicates each operator can differentiate a good part from a bad part. The same data can be used for both quality Gage R&R studies, Xbar& R and ANOVA. The only difference is the method used to analyze the gage. The Xbar& R method ignores operator to part interaction and as a result can appear to increase gage performance.

Tolerance is the measurement error as a percent of the product specification. % Tolerance determines if the gage can be used for product control (determining a good part from a bad). If the gage cannot pass % Tolerance it cannot determine if a part within specification. % Study is the measurement error as a percent of total variation (standard deviation). % Study determines if the gage can be used for process control. If the gage cannot pass % Study, it cannot distinguish one part from another within normal process variation, monitor process improvements or process changes.

IV. CONCLUSION

Measurement System Analysis is established through the application of measurement system analysis. For precise and reliable data to be obtained, a measurement system that is in good working order is essential. When performing an examination of a measuring system, there are numerous aspects to take into account.

The gage is good for product control (evaluates part relative to specifications), but not for process control such as stability monitoring. If the samples do not represent the entire production operating range, the % Study Variation and % Contribution must be ignored in the assessment. Indicator % Process can be used to replace % Study Variation and % Contribution to access the adequacy of measurement system for process control. Generally, precision is the principal concern, inaccuracy due to constant bias can typically be corrected through calibration. Measurement error is the statistical summing of the error generated by repeatability (the variation within an appraiser) and reproducibility (the variation between appraisers).

An adequate experimental design structure can be used to evaluate a measuring system's performance. When homogeneous batch sizes are constrained and each batch can be tested more than once by a single operator, a nested technique is required. The findings of evaluating a destructive measuring system using an R&R approach are not as obvious as those obtained in a nondestructive scenario. To be more precise, there is no difference between within-batch variance and repeatability variation. The homogenous batch assumption needs to be questioned if a destructive measuring system is shown to be inadequate in terms of repeatability. Similar to other measurements system analyses, getting meaningful results depends heavily on how the experiment is planned and carried out. Validation of the method of measuring the dimension between the teeth of a wheel is made using a software package. The process variation is under control and the test method used is effective. The same methodology can be used for measuring the dimensions of other industrial products. All the criteria required have been reached.

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