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Research on Variations in Measurement System Analysis Based on Minitab

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Abstract: ***Measurement System Analysis (MSA) is widely used in the automotive industry, but most studies focus on which method to use when analyzing MSA. The research on positional and width variations is not thorough enough, and there is a lack of understanding of which gauges should study which variations. This article analyzes the influencing factors in the measurement of measuring tools, and uses Minitab software for practical application to obtain the variation research that various types of measuring tools should be carried out. Provide clear ideas for the future practical work of enterprises, save unnecessary work time, and improve work efficiency.***

Keywords: Measurement system analysis MSA; Variation; Minitab; Automotive components

1. Introduction

In the automotive industry, especially for enterprises implementing IATF16949, measurement system analysis is one of the five tools for quality management in automotive manufacturing enterprises [1]. It is required to implement and submit analysis and research on measurement systems, providing important basis for the stability of process capabilities in the later stage. MSA can ensure effective and reliable measurement results, and effectively monitor processes and products. In the early planning of product quality APQP, the MSA plan should be output during the process design and development phase. When submitting the production part approval process PPAP, the complete MSA should be submitted to the customer. In the remarks section 7.1.5.1.1 of the IATF16949 standard, it is described that "the priority of measurement system analysis research should focus on key or special product or process characteristics". Combined with the guidance of the fourth edition of the Measurement System Analysis Manual [2], a preliminary understanding of the implementation and methods of MSA has been gained, but a clear implementation process has not been formed. This article clearly points out how to conduct MSA variation research by analyzing the influencing factors, and uses Minitab software for practical application to obtain the MSA research that various gauges or instruments should conduct. To provide readers with clear ideas and improve work efficiency.

2. Concepts of measurement system analysis

2.1 Measurement System

A measurement system not only refers to measuring instruments, but also to a process that includes people (surveyors), machines (measuring equipment), materials (measured objects), methods (measurement methods), and environments (measurement environments), ultimately outputting measurement results. The collection of surveyors, measuring equipment, measuring methods, and measuring environments that assign values to the characteristics of the measured object is called a measurement system. The variation in the measurement system can be divided into positional variation and width variation. Position variation includes bias, stability, and linearity; Width variation includes repeatability and reproducibility [3]. The above characteristics are also known as the "Five Qualities". To study MSA, it is necessary to have a clear understanding of what these five characteristics specifically refer to. According to the measurement results, it can be divided into counting measurement systems and metering measurement systems [4-5].

Bias: also known as accuracy, refers to the difference between the measured mean and the true value. The larger the bias value, the greater the error between the measured value and the true value. Bias is generally eliminated through calibration. The method for verifying bias can use the independent sample method, which means that a person measures the same sample more than 10 times, calculates the confidence interval, and checks whether 0 falls within the confidence interval, indicating that the measurement system is unbiased.

Stability: refers to whether there is bias in the measurement system over time. Control charts are generally used to determine stability. Usually, one person periodically measures a sample, forming a subgroup of 3-5 measurements each time, and measuring 20-25 groups. Form a control chart to see if it exceeds the control limit.

Linear: refers to whether there is a difference in bias within the range or working range of the measuring equipment. Usually, a person measures 5 or more samples more than 10 times, lists the linear function, calculates the slope and intercept, calculates the upper and lower confidence lines, and checks whether 0 is completely within the confidence band, indicating that the linearity is acceptable.

Repeatability: can be understood as the variation of measuring equipment, without human influence. The variation caused by repeated measurements of measuring equipment. Can be used to verify automatic measurement equipment.

Reproducibility: can be understood as the variation caused by different surveyors using the same measuring equipment. Repeatability and reproducibility are collectively referred to as R&R, which can be analyzed using either the mean range method or the analysis of variance method. The analysis method will not be repeated here, but can be referred to in the manual.

If it is a counting measurement system, it means that the measurement result has no numerical value and can only be judged as qualified or unqualified. Here, Kappa consistency testing is required, including comparing between surveyors, comparing between surveyors and reference values, calculating kappa values, missed judgments, false positives, and validity.
If it is a metrological measurement system, it represents that the measurement result is numerical, and it is necessary to study the five characteristics. Measurement system analysis is not necessary to study all five aspects. It is necessary to comprehensively analyze the influencing factors based on the actual situation and develop a reasonable analysis plan.

2.2 Timing of MSA implementation

Measurement system analysis is generally conducted during the trial production of new products or when there are changes in the inspection process, such as the deployment of new inspection gage or after the overhaul of inspection gage. The MSA conducted in the early stage of a new project generally requires a complete set of five characteristics research, followed by periodic MSA, which is usually implemented once a year. Periodic MSA can be targeted to study the five characteristics. If the customer has special requirements that are stricter than the MSA manual and standards, they shall be executed according to the customer's requirements. If the customer's request is lower than the standard, it shall be executed according to the standard.

2.3 Influencing factors

The five elements that affect product quality in Total Quality Management theory are human, equipment, material, method, and environment. The measurement system is affected by randomness and system variation. By analyzing the sources of variation that affect the measurement system through fishbone diagrams, it is possible to identify which factors affect the measurement system and develop MSA plans that meet production needs. The fishbone diagram of potential sources of variation is shown in Figure 1.

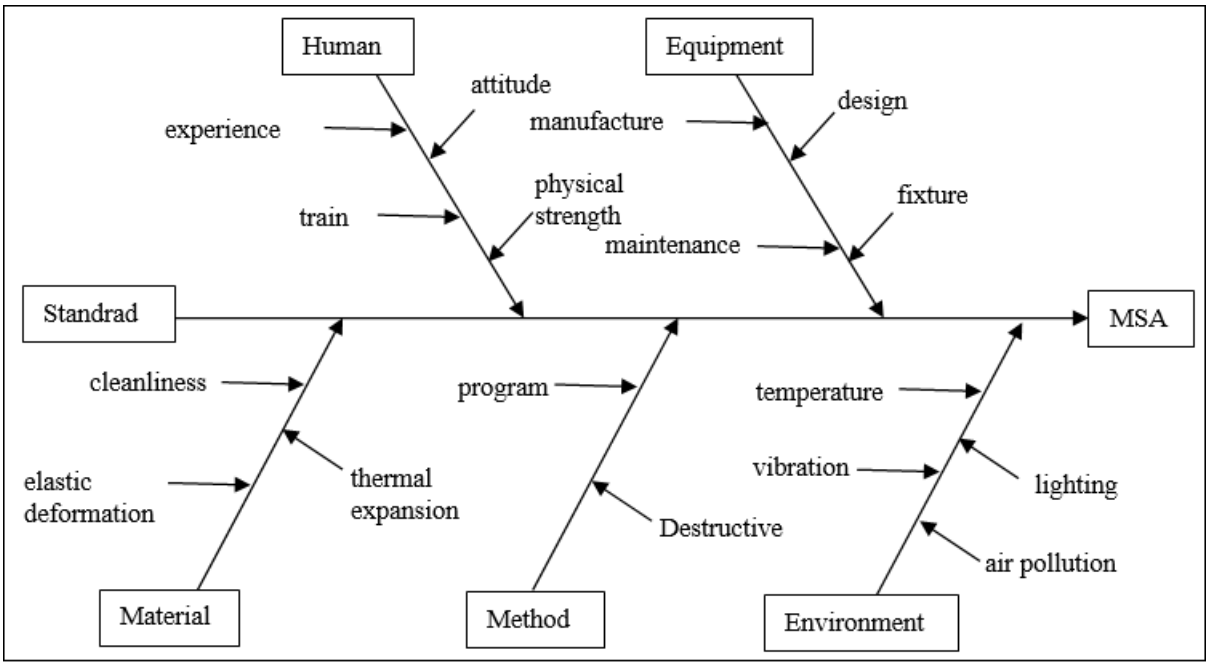

Figure 1: MSA element analysis fishbone diagram

3. MSA Element Analysis

3.1 Common measuring equipment

The commonly used quality inspection tools in the automotive industry include calipers, micrometers, depth gauges, go/no go gauges, chamfer gauges, coordinate measuring machine (CMM), profilometers, roughness tester, scales, as well as some destructive inspection instruments such as hardness testers and material strength testers. There are still some automatic measuring equipment on the production line. But all measurement equipment mentioned in the control plan needs to undergo MSA research. Due to different usage environments and operating methods, the study of MSA elements varies for each type of measuring equipment.

3.2 MSA Element Impact

For metrological measurement equipment, in the initial design of the project, the stability, bias, and linearity of the measurement equipment should be considered first, followed by the study of repeatability and reproducibility. During annual periodic research, targeted analysis can be conducted based on specific influencing factors.

In the case of regular calibration of some universal measuring tools, such as calipers, micrometers, depth gauges, etc., it is possible to choose not to perform bias, stability, and linear analysis, and only perform R&R analysis. The coordinate measuring instrument, if used as a tool to verify the effectiveness of the measurement process, does not require MSA analysis and can be calibrated regularly. But if the coordinate measuring instrument is used as a measuring device to inspect whether the product is qualified, MSA analysis must be carried out. When analyzing, it is necessary to consider whether there is any variation when the measuring personnel place the workpiece. If there is, R&R analysis should be conducted. If there is no impact, repeatability can be analyzed; As an instrument for checking weight, if the placement of the measuring personnel does not actually cause any changes, the balance can analyze stability; For some measuring equipment with destructive tests, if the consistency of products in the same batch is good, alternative samples can be used for MSA analysis. If not, MSA analysis may not be performed.

For counting type measuring equipment, such as go/no go gauges, roughness comparison blocks, etc., Kappa consistency testing is required. When collecting samples, a certain number of ambiguous or out of tolerance parts must be included.

From the analysis of the five elements of human-machine, material, method, and environment, the interaction between personnel can affect the measurement results. Regular equipment calibration has little impact on the measurement results, and the variation caused by the workpiece is relatively large. Therefore, when conducting MSA analysis and research, the variation between personnel and workpiece is mainly considered, and then targeted research on the five characteristics is carried out.

4. Practical application of Minitab

The general Minitab software is used for practical application of R&R in MSA. The R&R research methods include mean range method and analysis of variance method. The advantage of analysis of variance method is that it considers the interaction between personnel and workpiece, which is more accurate. This article takes the analysis of variance method as an example.

4.1 Data Collection

Select k surveyors (k=3) and n parts (n=10), and each surveyor measures each part m times (m=2 or 3). This measurement is called cross measurement, and the analysis of variance performed is called cross analysis of variance. This article selects a coordinate measuring instrument for R&R analysis. The data is shown in Table 1.

Table 1: measured data

Parts	*Times*	*Operator 1*	*Operator 2*	*Operator 3*
1#	1	87.983	87.981	87.983
	2	87.981	87.981	87.981
	3	87.981	87.981	87.981
2#	1	88.009	88.009	88.009
	2	88.009	88.01	88.007
	3	88.01	88.009	88.009
3#	1	87.975	87.975	87.975
	2	87.975	87.974	87.975
	3	87.976	87.975	87.975
4#	1	87.991	87.991	87.991
	2	87.991	87.993	87.99
	3	87.992	87.991	87.991
5#	1	87.972	87.972	87.972
	2	87.972	87.972	87.972
	3	87.973	87.973	87.972
6#	1	87.989	87.989	87.989
	2	87.989	87.988	87.989
	3	87.989	87.989	87.99
7#	1	88.022	88.021	88.021
	2	88.022	88.022	88.022
	3	88.022	88.022	88.022
8#	1	87.973	87.973	87.973
	2	87.972	87.972	87.973
	3	87.973	87.973	87.973
9#	1	87.994	87.994	87.994
	2	87.994	87.993	87.993
	3	87.992	87.994	87.992
10#	1	87.981	87.981	87.981
	2	87.983	87.981	87.982
	3	87.981	87.981	87.981

4.2 Minitab calculation

Include the data in the software, select "Statistics → Quality Tools → Gauge Research → Gauge R&R Research (Cross over)", fill in the corresponding options according to the information in Figure 2, and fill in the upper and lower tolerances in the "Options".

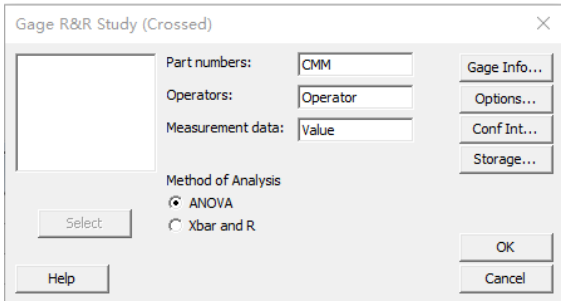

Figure 2: R&R Settings

The analysis results of the measurement system are shown in Table 2. The% research variation (% SV) of the total R&R of the measuring tool is the result of the measurement system analysis, which is% GRR=4.18%. This result is less than 10% [6], and the number of distinguishable categories, which is the number of grades NDC, is 33. This result is greater than

5, indicating that the measurement system is acceptable.

Table 2: measured data

Source	*Standard deviation (SD)*	*Research variation (6 × SD)*	*% Research variation (%SV)*	*% Tolerance (SV/Toler)*
Total measuring tools R&R	0.0006757	0.0040543	**4.18**	6.76
Repeatability	0.0006726	0.0040357	4.16	6.73
Reproducibility	0.0000646	0.0003878	0.40	0.65
Operator	0.0000646	0.0003878	0.40	0.65
Number of distinguishable categories = 33				

From Figure 3 of the analysis report, it can be seen that all points in the range plot are within the control limit, while the mean plot exceeds 50% outside the control limit, and the percentage of variation components is reflected between the parts.

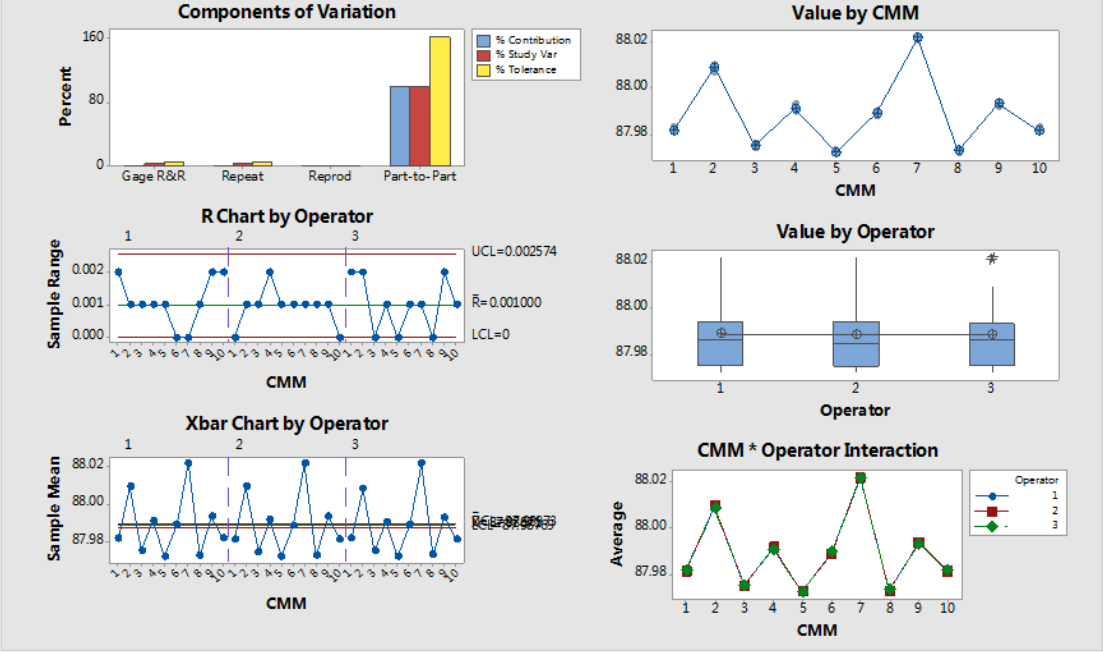

Figure 3: MSA analysis report

5. Conclusion

In summary, by analyzing the impact of the five elements of human-machine, material, method, and environment on the measurement system, identify which element will cause measurement variation, and then conduct targeted MSA research. Using Minitab software to analyze the R&R of the coordinate measuring instrument, using the analysis of variance method, the final result meets the requirements of the MSA manual. We also provide readers with clear ideas to improve work efficiency.

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Author Profile

Chen Zhang graduated from Tianjin University of Technology and Education with a master degree in mechanical engineering, and has been engaged in mechanical design and processing technology since 2016, currently engaged in APQP of auto parts products technology and quality.