Limits in Measurement Process Capability Analyses

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Depending on the standard, standard of technical associations or company guidelines, there are different statistics to evaluate test or measurement processes in measurement process capability analyses. These statistics are compared to specified limits in order to evaluate capability. The limits discussed in the following refer to quantitative characteristics. It is also assumed that the procedures and the calculation of statistics are known.

Do Limits Make Sense?

The first question that comes to mind is whether limits make sense. The clear answer is "yes" in case most of the measurement processes can be evaluated based on these limits since these limits provide clear conditions. Many practitioners confirm that the widely used procedures of the measurement process capability analysis can be applied to more than 50% of applications. This is a considerable amount. However, it is also clear that most measurement and test processes relevant in practice cannot be evaluated one-to-one with this procedure and these limits. It depends on the characteristic to be tested but also on the complexity of the measurement process under real conditions. In many cases you cannot even distinguish between a manufacturing and measurement process. For this reasons, it is important to evaluate the respective conditions in such cases and to establish them according to the current state of the art. You individually decide on capability by means of technological and economic aspects and by considering the respective risk.

Important Limits and their Meaning

By ignoring the procedure and calculation according to GUM (Guide to the Expression of Uncertainty in Measurement) in terms of measurement process capability, you may divide the evaluation procedures in three categories:

- Company guidelines for the evaluation of measurement processes
- MSA (measurement systems analysis) of the AIAG (automotive industry action group)
- VDA 5 Capability of Measurement Processes or ISO 22514-7 Measurement Process Capability

It is always the own guideline that is relevant to each company at first. If such a guideline does not exist, superior standards of technical associations or general standards will be used in audits. You may divide company guidelines in two categories. Some guidelines are based on the MSA for historical reasons because it has already existed since 1990 and most Anglo-American groups, such as GM, Ford or Chrysler, prefer the MSA. German companies, such as VW and their subsidiaries, Daimler or BMW, rather use the procedure described in the VDA 5 manual. The second edition of VDA Volume 5 published in 2010 is based on ISO 22514-7 (2012). For this reason, these procedures are likely to become more important on the international level in the next few years. Only time will tell if VDA 5 prevails against MSA.

However, this fact causes problems for the suppliers of the automotive industry. They might be obliged to evaluate their measurement processes according to MSA and VDA 5. Main suppliers thus have to apply the limits specified in these two guidelines.

Relevant Statistics and their Limits

Company Guidelines

Company guidelines first evaluate the resolution by means of the %RE value. It must be less than 5% of the tolerance. In addition, the company guidelines normally contain Type 1, Type 2 or Type 3 study. Type 1 study determines the C_g or C_{gk} value from repeated measurements on a reference part. This value has to exceed 1,33. Type 2 study evaluates the measurement process under real conditions. Thus the respective operator carries out the inspection at the operating location of the measurement process and takes measurements on the real test parts. The recorded data help to calculate the statistic %GRR (gage repeatability and reproducibility). The same requirements apply to this statistic as mentioned in the widely applied MSA:

- $\%GRR \leq 10\%$ capable
- $10 < \%GRR < 30\%$ conditionally capable
- $30 \leq \%GRR$ not capable

Please note that the limit for a "capable" process amounts to 20% instead of 10% in all OEM company guidelines, such as GM, Ford or Chrysler. Suppliers certified based on ISO/TS 16949 cannot avoid staying within the limits specified above, unless they are able to reach individual agreements with their customers.

These limits are quite an unfortunate choice since you distinguish between "capable" and "conditionally capable". Most measurement processes are rather conditionally capable than capable in practice. In this case you have to find technological and economic aspects or additional measures to give reasons for exceeding the 10% limit.

Statistics in the MSA Manual

The MSA effectively includes three relevant limits. It uses the ndc factor to evaluate whether the data categories are sufficiently small. This factor must exceed 5. Please find notes about how to determine the ndc value in the "Notes on MSA 4th Edition" PIQ article (published in PIQ 03/2010 on www.q-das.de). This statistic is comparable to the %RE value given in company guidelines.

The MSA uses the t-test to evaluate the systematic measurement error. This test checks the bias. The calculated statistic has to lie inside the confidence limits, otherwise the bias is significant and the measuring system is not capable. In terms of equipment variation, the MSA 4th edition just includes the general requirement that it has to be small. It does not provide any specific limit. You use the limits listed above in the calculation. Former editions of the MSA manual focused on the Average Range Method ARM in order to calculate %GRR. Since the 4th edition published in 2010, the MSA manual prefers the method of ANOVA for the calculation of %GRR.

Statistics of VDA 5 or ISO 22514-7

The ISO standard and VDA Volume 5 distinguish between measuring system and further components leading to the measurement process (see Figure 1). This distinction is based on the definition of VIM (Vocabulary of International Metrology) and the reason why there are two limits. One limit refers to the measuring system and the other to the measurement process. Both documents calculate two capability ratios respectively, Q_{MS} for the measuring system and Q_{MP} for the measurement process.

Recommendation:

$$Q_{MS} \leq Q_{MS\_max} = 15\%$$
$$Q_{MP} \leq Q_{MP\_max} = 30\%$$

Compared to company guidelines, the standard and the reference manual also assess the resolution in order to evaluate the measuring system. %RE must be less than 5%.

Tolerance as a Reference Size

The reference size is of utmost importance for the calculation of the described statistics because it affects the result considerably.

Since the MSA uses different reference sizes in order to determine the %GRR value, VDA Volume 5, ISO 22514-7 and all company guidelines always apply the tolerance as a reference size. This is reasonable since it is a decisive figure valid in specifications and agreements between customer and supplier.

This is the reason why it seems obvious to use the tolerance as a reference size even in measurement process capability analyses.

How Do We Achieve Limits?

Nowadays, we may only speculate about how statisticians achieved the one or other limit. Only the persons involved in defining these specifications more than 20 years ago know how they determined these limits.

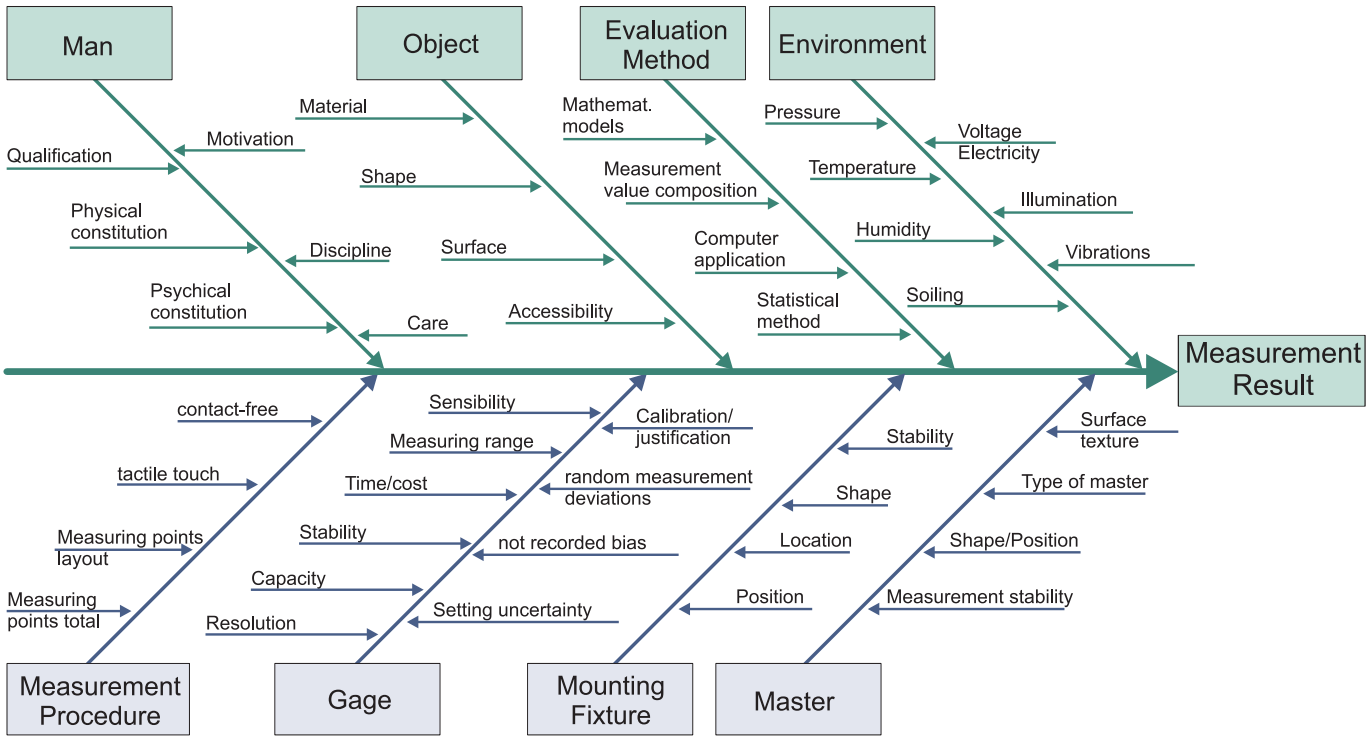

Figure 1: Important influences on the uncertainty of measurement results

Comments on single limits:

Resolution

The evaluation of the resolution based on %RE has proved to be particularly reasonable. This evaluation is quite easy on the one hand and very helpful on the other hand. In case you do not meet this requirement, you might effectively "classify" the measuring instrument in repeated measurements taken on a reference part, i.e. the measuring instrument always shows the same measured value. Actually the variation would be zero and the measuring instrument would be more than suitable in this case; however, this conclusion might be wrong since the resolution subject to the tolerance is too low.

C_g, C_{gk} Value

The limit for the C_g or C_{gk} value as used in company guidelines describing Type 1 study for the calculation of the equipment variation or the systematic error can be regarded based on the SPC procedure (statistical process control) introduced in the middle of the 1990s. Back then, statisticians introduced the capability indices C_m, C_{mk}, C_p, C_{pk} and later P_p, P_{pk}. These statistics are calculated by comparing the variation or offset of the process to the specification limits.

The C_g and C_{gk} values are comparable to these capability indices but the permissible range is logically restricted. Otherwise the entire variation within the tolerance would be considered to be the variation of the measuring instrument. In German-speaking countries and Europe, these statistics were first mentioned in the Bosch reference guide 10 and in the Ford guideline EU 1880. The limit for C_g or C_{gk} amounts to 1,33 in the Bosch reference guide and the tolerance as a reference size is restricted to 20%, whereas Ford demands a C_g or C_{gk} value of 1,0 and specifies a tolerance limit of 15%. It seems like Bosch wanted to compare the C_g or C_{gk} value to the requirement of 1,33 demanded in machine capability analysis. On the contrary, Ford obviously wanted to compare the C_g or C_{gk} value with the former C_p or C_{pk} value. At that time, these two values amounted to 1,0 instead of 1,33 as is customary today. However, please note that these explanations only reflect the interpretation or assumption of the author.

Note on C_g, C_{gk}

Since the Type 1 study for the calculation of C_g and C_{gk} as mentioned before is quite easy to handle, this method was established in many international company guidelines and not only in the MSA manual. Some examples are GM, Fiat, Ford, etc.

%GRR Value

The first edition of the MSA manual already included the fixed limits for the %GRR value. Whether these limits are reasonable - in particular the distinction between "capable" and "conditionally capable" - is a favorite subject of debate among statisticians. However, the applied procedures in order to determine the %GRR have been used for more than two decades now. Thus these limits seem to be written in the sky, i.e. they are unlikely to change in the foreseeable future.

Q_{MS} and Q_{MP}

The reason why VDA Volume 5 and ISO 22514-7 define a QMS_max value of 15% and a QMP_max value amounting to 30% is easy to explain. They wanted to take over the upper limit of 30% for the measurement process as specified in many company guidelines and in the MSA manual. The first edition of VDA Volume 5 pub-

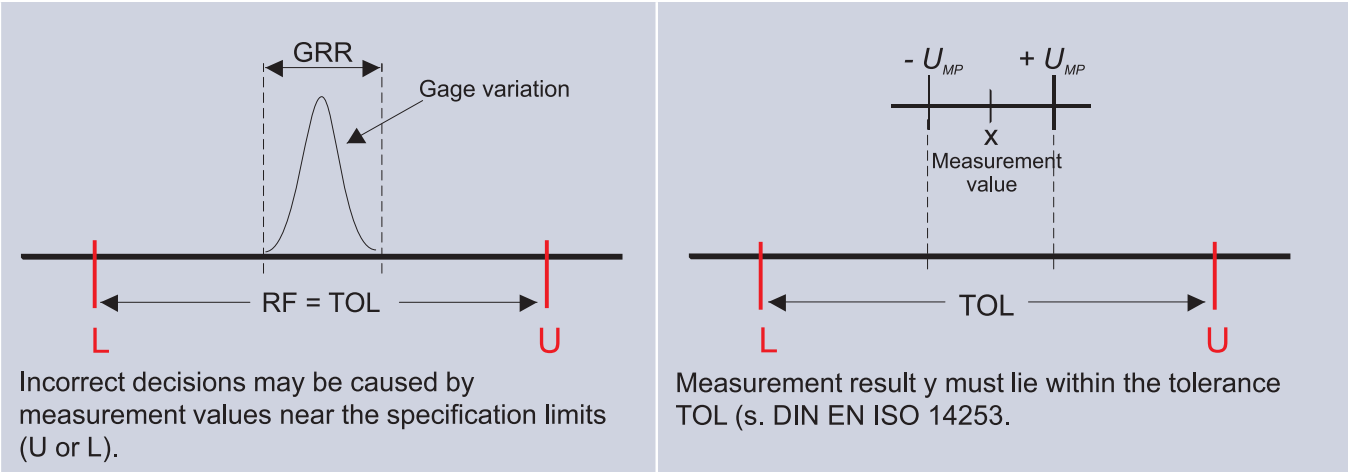

Figure 2: Comparison between %GRR and U_{MP}

In case you do not exceed the limits in the evaluation based on the %GRR (MSA), you assume that the measurement process is okay. By estimating the expanded measurement uncertainty as demanded by ISO 14253, you may consider this uncertainty at the specification limits.

lished in 2003 already contained the empirical assumption that the combined standard uncertainty of the measuring system amounted to about 50% of the combined standard uncertainty of the entire measurement process. It is more than obvious to define the limit of the QMS value as half of the QMP_max value so that it amounts to 15% in the evaluation of the measuring system.

International Meaning of these Limits

Particularly in a global, economic sense, manufacturers of measuring instruments or measuring systems have a high interest in the definition of standardized and binding procedures and limits. This is also helpful for the exchange of goods between customer and supplier. There is no other way manufacturers of measuring systems can be sure to meet the agreed specifications in selling and later acceptance of their products. The same applies to suppliers since they sign delivery contracts and agree to meet product characteristics. You may only check and evaluate this demand in a reasonable way by using a standardized measurement process capability analysis and by being able to consider the expanded measurement uncertainty as correct and binding at the customer's and the supplier's.

Summary

Measurement process capability analyses for the calculation of capability indices and ratios are important. You decide whether a measurement process is "capable" or "not capable" by comparing capability indices and ratios to specified limits. The better and the more frequently you are able to apply these procedures, the easier it is to perform a capability analysis.

However, you should be aware that you cannot measure everything by the same yardstick. You have to decide in each individual case whether the standards discussed in this article are applicable.

Q-DAS® offers a platform for the evaluation of these special cases.

Reducing the Uncertainty through Suitable Measurement Processes

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In industrial production, the applied measurement processes evaluate and assess the quality of manufacturing and production facilities as well as the produced parts, components and products. The results gained by the measurement processes and the statistical evaluation always include different uncertainties.

Quality Evaluation

Depending on the manufacturing or production process, selected quality characteristics are inspected in or after the different process steps. You may conduct a 100% inspection or an inspection based on a sample. You evaluate the manufacturing or production quality graphically by using various visualizations or numerically by calculating capability indices. The recorded measured values are evaluated statistically and the required statistics are calculated. These data are processed numerically and, depending on the respective application and the responsible user group, graphically, too. Only by succeeding in communicating the results quickly specifically to the respective task and user and in making them easily accessible, these results are applied in order to evaluate and assess processes and certain issues. In this case they contribute to the quality evaluation.

Uncertainty

The results or issues include, amongst others, uncertainties as a result of:

- measurement and test processes
- the application of statistical procedures
- erroneous data recording, transfer and management
- erroneous communication of results

You may solve the problems caused by the last two sources of error with organizational measures and IT support, e.g. by permanently checking the plausibility of data where relevant. The application of Q-DAS® products helps you to describe processes by means of validated statistical procedures specifying the confidence intervals for the single statistics. The uncertainty caused by statistical procedures becomes assessable now. However, the uncertainties from the measurement processes remain and thus we will have a closer look at them in the following.