

MSA studies for electronics tester qualification

Version 2.0



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2 SCOPE

This requirement shall be used for all:

- Electronics
- Electronic components for example PCBs
- Assemblies, which host electronics.

manufactured and/or developed for Hilti.

3 GENERAL INFORMATION

A requirement for the quality release of production lines on which electronics, or electronic components are manufactured, all multi-functional testers must be evaluated. These testers shall be capable of delivering reliable results regarding:

- Resolution
- Reproducibility
- Repeatability

The characteristics stipulated above must be verified to meet the demands of this document by means of MSA capability studies.

The performance of MSA analyses is largely standardized in various literature sources. Nevertheless, there are differences, even if very minor, in the formulas to calculate key evaluation metrics. Beyond the MSA, other statistical tools enable the evaluation of processes within production lines. The illustration of all possible boundary conditions, initial parameters as well as limitations concerning an MSA analysis is not the aim of this document. Rather, individual aspects of MSA's are to be highlighted and standardized within this document and thus, represents the minimum scope of requirements Hilti demands for the execution of an MSA.

The aim of this document is that Hilti, as the addressee of MSA capability studies, receives them as much as possible in a unified and standardized method. Thus, able glean a clear statement about the capability of measurement processes.

Deviations, Exceptions shall be agreed upon by Hilti Quality. All deviations from general requirements shall be released by Hilti Quality.



4 APPLICABILITY

4.1 Test systems

MSA-studies 1, 2 and 3 are applicable in all types of measurement systems within a production line such as

- ICTs
- Functional testers
- End of line testers

4.2 **Properties of the measured values**

Moreover, MSA – studies are applicable to measurements, which deliver:

- physically quantizable measurement results which are classified as continuous characteristics.
- characteristics whose results are normally distributed.
- characteristics with a bilateral tolerance band.

4.3 Characteristics with unilateral specification limits

The calculation of capability indices such as Cg and Cgk requires measurement characteristics with bilateral specification limits. An upper limit (USL) and a lower limit (LSL), whereas the tolerance T = USL - LSL.

When a measurement characteristic only has a single defined specification limit (USL or LSL) and in addition to that a natural specification limit (USLN or LSLN), the tolerance TN is either TN = USLN - LSL or TN = USL - LSLN.

When a measurement characteristic only has a single defined specification limit and no additional natural limit, the supplier shall define an alternative acceptance criterion for it.



5 SOFTWARE – SUPPORTED ANALYSIS

MSA studies require the execution of mathematical calculations. These can either be done manually or automatically by means of software-supported analysis tools, which additionally offer the possibility to present the measurement results graphically. The representation of the measured values within a diagram simplifies the investigation on root causes for capability indices, which lie outside of the specified range such as:

- An unacceptably low long-term stability of the measurement system or the device under test
- A drift of the measurement results due to temperature as an example.
- Single measurement outliers / extreme values

6 WHEN ARE MSA 1, MSA 2 / 3 AND PROCESS CAPABILITY STUDIES REQUIRED?

6.1 Inside a HILTI TTM process

HILTI TTM PROCESS (Only sufficient information shown)						
B-Sample production	C-Sample production	Release for D-sample production	D-sample production	Release for SOP	Mass production	
	MSA 1		MSA 2/3			

Figure 1: Requirement for studies during a TTM process

The delivery of the **MSA type 1** capability study and its acceptance by Hilti shall be done during C-sample production phase, and its acceptance is:

- mandatory for the production line to achieve D-sample maturity.
- mandatory to start the MSA 2 or MSA 3.

The delivery of the **MSA type 2** capability study shall be done during D-sample production phase and its acceptance by Hilti is mandatory for the line testers to be released for mass production / SOP.

Should the **MSA type 3** capability study be required by Hilti and to be executed in place of the **MSA type 2** capability study, then its delivery and its acceptance by Hilti is mandatory for the line tester to be released for mass production / SOP.



6.2 Dependent on the tester environment

Independent from the maturity level of a TTM project or the release status of a production line, capability studies shall be executed, when:

- a tester is set up / built for the first time.
- an already existing tester is duplicated.
- the tester's hard- and / or software is changed.
- test systems are relocated inside a company.

As mentioned in Hilti's **"manufacturing specifications for electronics and switches vX-Y.docx"** in its newest version, changes to customer-specific test equipment must be reported to Hilti by official change request.

7 RESOLUTION OF THE MEASUREMENT DEVICES

The resolution RE of the measurement devices shall be checked prior to the measurements and shall be:

$RE \leq 5\% \cdot T$

The Tolerance T stands for the complete tolerance width.

Example:

When Resistor R = $50\Omega \pm 10\%$ shall be measured, where the 10% equals 5Ω and T equals 10 Ω , the resolution shall be: RE $\leq 0.05 \cdot 10\Omega = 0.5\Omega$.



8 MSA TYPE 1 CAPABILITY STUDY

8.1 Procedure of MSA type 1

MSA type 1 is carried out using a measurement standard, that is measured 50 times by a single operator.



Figure 2: MSA 1 Required resources

The measurements shall be made including all actions which will also be executed in the series production. If an ICT requires the operator to place a PCBA inside a fixture and remove it afterwards, these actions shall be done for each of the 50 measurement steps. If the PCBA is placed automatically inside the testers fixture, this placing process also must be executed for each single measurement. The MSA 1 is intended, for example, to detect excessive degrees of freedom in the positioning of PCBAs in the test fixture, which can lead to different results in repeated measurements. From the results of the measurements the capability index Cg shall be calculated.

8.2 Calculation of the potential capability index Cg

For the calculation of the potential capability index, the following formula shall be used.

Data type	Index / formula	Note
Tolerance of characteristic	T = USL - LSL	USL: Upper tolerance limit LSL: Lower tolerance limit
Potential capability index	$Cg = \frac{0.2 \cdot T}{6 \cdot s}$	s: standard deviation of measured values



The capability criterion is met when the index fulfills the following condition:

Cg ≥ 1,33

For capability indices smaller than 1,33, the supplier shall investigate on the root cause and take actions to improve the values. Logfiles or data sets, on which the calculations of the Cg characteristic values are based, shall be supplied to Hilti.

Deviations, Exceptions shall be agreed upon by Hilti Quality. All deviations from general requirements must be released by Hilti Quality.

8.3 Calculation of the critical capability index Cgk

For the calculation of the critical capability index Cgk the following formula shall be used.

Data type	Index / formula	Note
BIAS	$ \bar{x} - x_m $	 x_m: center of the tolerance band. x̄: arithmetic mean from 50 measurement repetitions of one PCBA.
Tolerance band T	T = USL - LSL	USL: Upper specification limit LSL: Lower specification limit
Standard deviation	S	s: standard deviation of measured values
Critical capability index	$Cgk = \frac{0,1 \cdot T - \bar{x} - x_m }{3 \cdot s}$	

The capability criterion is met when the index fulfills the following condition:

Cgk ≥ 1,33



Alternative for the reference value Xm

For the calculation of the critical capability index Cgk the reference value x_m must be known. It represents the value of the measurement standard. In general, this value is determined by using a calibrated measurement device and should be as close as possible to the real physical value of the component. But, doing this for PCBAs with hundreds of components is very time consuming, economically not feasible and thus, not done by suppliers.

For this reason, the center of the tolerance band should be used for Xm rather than the true physical value. Cgk will then be a metric for how close the mean value of all MSA 1 measurements is to the center of the tolerance band.



Figure 3: New definition of Xm

This method is only valid for characteristics, whose reference values are unkowable. Characteristics, whose reference values are determined by a calibrated measurement standard and remeasured inside an ICT or functional tester, these reference values shall then be used for Xm.



8.4 Flow chart of the MSA 1 process





9 USING WRONG FORMULAS OR INDICES FOR MSA TYPE 1 STUDIES

In the future, Hilti will **reject** MSA type 1 capability studies, where:

- results for Cp or Cpk are submitted instead of Cg or Cgk. Cp and Cpk are exclusively used for process capability indicators and are requested by Hilti later in the TTM process.
- formulas or methods are used to calculate Cg and Cgk that are not the formulas detailed in this document.

10 MSA TYPE 2 CAPABILITY STUDY

10.1 Precondition for the MSA type 2 capability study

The MSA 2 type shall reveal the capability of the measurement process to be reproducible as part of a serial production process. Therefore, it is mandatory to use serial parts, which were manufactured under serial production conditions. Sample parts or prototypes are not allowed to be used for MSA 2 studies. In addition, successful completion of the MSA 1 study is a prerequisite for completion of the MSA 2. Furthermore, the measurements shall be repeated under all environmental conditions which can also influence the measurement system in series production.

The MSA type 2 study is most effective when using parts, whose values cover the whole tolerance band. Of course, this can be challenging when measuring PCBAs with hundreds of components which a huge variety of tolerances.

10.2 Procedure of MSA 2

For the execution of the MSA 2 study, 10 parts and 3 operators shall be chosen. Each of these operators shall measure all 10 parts in a random order, which defines a series. Once a measurement series is started by an operator, it must be completed before another operator starts a new one. The test results of the single series shall be inaccessible for the other operators to avoid the inadvertent influence on results.

Each part is measured three times by each operator, which sums up to 90 measurements in total.





Figure 5: MSA 2 required resources

As with the MSA type 1, all actions which occur during the series production process like clamping and unclamping a PCBA shall be done for each measurement step during the study. So, the conditions under which the parts are measured, shall be as close as possible to the series manufacturing process.

Log files, on which the calculations of the %GRR characteristic values are based, shall be supplied to Hilti.



10.3 Flow chart of the MSA 2 process



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11 MSA TYPE 3 CAPABILITY STUDY

11.1 Precondition for the MSA type 3 capability study

The MSA 3 shall, as with the MSA type 2, reveal the capability of the measurement process to be reproducible as part of a serial production process. Therefore, it is mandatory to use serial parts, which were manufactured under serial production conditions. Sample parts or prototypes are not allowed to be used for MSA 3 studies. As well as for the MSA type 2, the successful execution of the MSA type 1 is a prerequisite for the execution of MSA 3. Furthermore, the measurements shall be done under all environmental conditions which can also influence the measurement system in series production.

The MSA type 3 study shall be performed <u>instead</u> of a MSA type 2 study when it can be ensured, that the measurement process is done without any operator influence. MSA 2 can be replaced by MSA 3 if:

- The position of the measuring object is adjusted completely automatically by the test setup.
- The MSA type 1 has proven, that tolerances of the automated positioning of the PCBAs inside the testers fixture do not influence the repeatability of the measurement.
- The operator cannot influence the force of clamping devices, which hold the measuring object inside the fixture.
- The measurement procedure (e.g., adjusting measurement probes, changing measurement ranges) and the data analysis are done fully automatic.

The execution of the MSA 3 makes the requirement for a MSA 2 obsolete. This shall be agreed upon by Hilti Quality in advance.



11.2 Procedure of MSA 3

For the MSA type 3 capability study one operator shall measure 25 parts in two independent measurement series. In both series, the devices shall be measured in a random order. The second series shall not be started until the first is completed.



Figure 7: Required resources for MSA 3

As with the MSA type 1 and 2, all actions which occur during the series production process like clamping and unclamping a PCBA shall be done for each measurement step during the study.

Log files, on which the calculations of the %GRR characteristic values are based, shall be supplied to Hilti.



11.3 Flow chart of the MSA 3 process



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12 GAGE R&R RESULT CLASSIFICATION FOR MSA TYPE 2 AND 3

It is recommended to use statistics software using the ANOVA method to have the %GRR values calculated automatically.

If the measurement process is capable will be judged by the %GRR – value and is regulated by the following classification:

GRR	Classification	Hilti validation	
≤ 10%	Measurement process is capable to be a test process	Result OK	
10% < GRR ≤ 30%	Measurement is conditionally capable to be a test process	Result OK Further investigations on these values can be demanded by Hilti	
GRR > 30%	Measurement is not capable to be a test process	Result not OK	

12.1 **Results** ≤ 10%

These results indicate that the measurement process is fully capable to be a test process.

12.2 Investigation on $10\% < GRR \le 30\%$

Is the result of the Gage R&R analysis between 10% and 30%, the measurement process is conditionally capable of being a test process. Hilti reserves the right to comment on these results and to demand further investigations on them.

Deviations, Exceptions shall be agreed upon by Hilti Quality. All deviations from general requirements shall be released by Hilti Quality.

12.3 Investigation on GRR > 30%

GRR – values above 30% are not accepted by Hilti. The supplier shall investigate the root cause and provide and inform Hilti about the results. Changings to the measurement process to improve the GRR-value are mandatory.

Deviations, Exceptions shall be agreed upon by Hilti Quality. All deviations from general requirements shall be released by Hilti Quality.



13 WHAT IF THE TESTER CHANGES THE CHARACTERISTICS OF THE DUT?

MSA studies require repeated measurements of one single DUT. Depending on the type of measurement or DUT it cannot be excluded, that the tester or the test process itself has a certain effect on the test sample, which leads to different starting conditions in repeated measurements. For example, functional tests can lead to a significant increase in temperature or charged capacitors that persist for a certain time after the test. If another test is carried out immediately afterwards, the test sample is in a different initial situation.

If the initial conditions in repeated measurements change in such a way, that the result of each following measurement is directly influenced, these results shall not be used for MSA capability studies. Especially when this leads to insufficient capability indices.

Each supplier is therefore requested to identify possible influences of each tester on the DUT and the influence on results of tester capability studies and take actions to grant equal initial conditions. This can be:

- Appropriate wait times between test runs to grant a sufficient decrease of temperature.
- Discharging of capacitors

This can lead to huge efforts doing MSA capability studies. In such cases the procedure of proofing capability shall be aligned with Hilti (Verification Team or Quality).

14 UNSUCCESSFUL CAPABILITY STUDIES

14.1 MSA 1 – Cg / Cgk values too small

For the case, that MSA 1 delivers insufficient capability indices, the supplier shall investigate the root cause and take actions for improvement **without any additional request** from Hilti - side. Possible reasons for too low capability indices could be among others:

- A tolerance band that is too tight*
- A weak contact resistance of the needles inside an ICT or functional tester due to worn contacts or contaminated contacts.
- A fixture, that is too inaccurate, which makes the movement of the PCBA or Panel possible.
- Unstable power supplies
- Unstable or insufficient acquisition timings



*For further information on how to define measurement tolerances see the document *"manufacturing specifications for electronics and switches vX-Y.docx" in its newest version*, which is part of Hilti's general requirements for electronic suppliers.

14.2 MSA 2 – %GR&R too high

In the case, that MSA 2 delivers insufficient capability indices, the supplier shall investigate the root cause of it and take actions for improvement **without any additional request** from Hilti - side.

Whenever it is not possible for the supplier to decrease insufficient capability indices below 30%, it is mandatory to comment on each specific case. Capability studies with insufficient capability indices, left without a corresponding comment are considered incomplete and can be rejected by Hilti.



15 ABBREVATIONS

- RE: Resolution of the measurement device
- DUT: Device under test
- T: Tolerance
- Cg: Potential capability index
- Cgk: Critical capability index
- Xm: Reference value / true physical value
- Cp: Potential capability index
- Cpk: Critical capability index
- USL: upper specification limit
- LSL: lower specification limit
- Xm: Reference value
- s: standard deviation



16 REVISION HISTORY

Version	Author	Date	Comment
1.0	Gleich	19.07.2022	Initial release
2.0	Gleich	24.01.2024	General update of all chapters; Cgk calculation method changed; Flow charts updated; Abbrevation section added;