**Please sign, date, and return this document as a record of your understanding of these requirements.**

Below are the minimum requirements to be incorporated into the manufacturing process for this specific commodity. This Part Specific SOR is in addition to and not intended to replace any requirements as outlined in the CG4338 GM 1927 03a Supplier Quality SOR. For example, CG4338 requires Full Compliance with CQI-27 for Castings. Leak Test requirements for Castings in CQI-27 take precedence over any potentially conflicting wording in this document. The expectation is for GM to receive parts that meet 100% of the specifications as defined by GM. It is understood that advances in technology may require modifications to the following requirements to ensure state of the art processing and testing. It is the responsibility of the supplier to ensure that the process meets or exceeds all requirements and that the GM Supplier Quality Engineer (SQE) and Supplier Quality Global Process Leader is informed and is in documented and in written agreement to any modifications of the requirements in Appendix CG3404 M7 Technical Issues List and approved by General Motors Supplier Quality prior to sourcing.

**Leak Test Requirements**

* 1. **Part Requirements:**
  2. All parts SHALL be clean and dry before leak test.
  3. Any leak test SHALL be qualified with appropriate Gauge R&R (Repeatability and Reproducibility) studies as specified in attached **Appendix A**: **“Types of approved Studies”** (Reference sections 5.0 thru 5.4 for further details).
  4. Parts SHALL be tested with clean, dry compressed air (industry standard), unless otherwise specified.
  5. The air leak rate for the part should be specified as XXX SCCM@XXX kPa, temperature SHALL be specified as Ambient +/- 1oC.
  6. All tracer gas leak specifications SHALL specify the helium leak rate in SCCS, in helium concentration, and in technology used (i.e., hard vacuum true mass spec, accumulation, sniffer etc.)
  7. If the GM part print does not specify a leak rate and if it is the supplier's responsibility to determine an appropriate leak rate, the supplier SHALL justify the leak rate selected for the given part and is subject to GM approval prior in accordance with CRV process and procedure.

1. **Testing Technologies:**

Appropriate test technologies SHALL be used for leak test. (Using incorrect test type will make it difficult to achieve a passing GM 1927 35 R@R or Gauge R@R as outlined in GM 1927 10 Fixture Standards. Following are the recommended application ranges based on allowable leak ranges:

* 1. Pressure/vacuum decay: >2.0 SCCM (Standard Cubic Centimeters Per Minute)
     1. For pressure/vacuum decay the pressure transducer full range should not be >4 times the test pressure range.
     2. Slope to offset ratio SHALL be 4 or higher.
     3. With differential Pressure: The total differential pressure transducer range should be 10 times larger than maximum differential pressure measured.
  2. Mass Flow (Hot wire anemometer): > 2 SCCM
     1. The ratio between the “0” master and the reject master should be 4 or higher (i.e., Reject Master/ “0” Master >= 4)
  3. Mass Flow (Laminar flow): > 0.5 SCCM
  4. Helium Accumulation at ambient pressure: < 1.0E-2 SCCS (0.6 SCCM)
  5. Helium Mass Spectrometer at vacuum less than 1 Torr: < 1.0E-4 SCCS (0.006 SCCM)

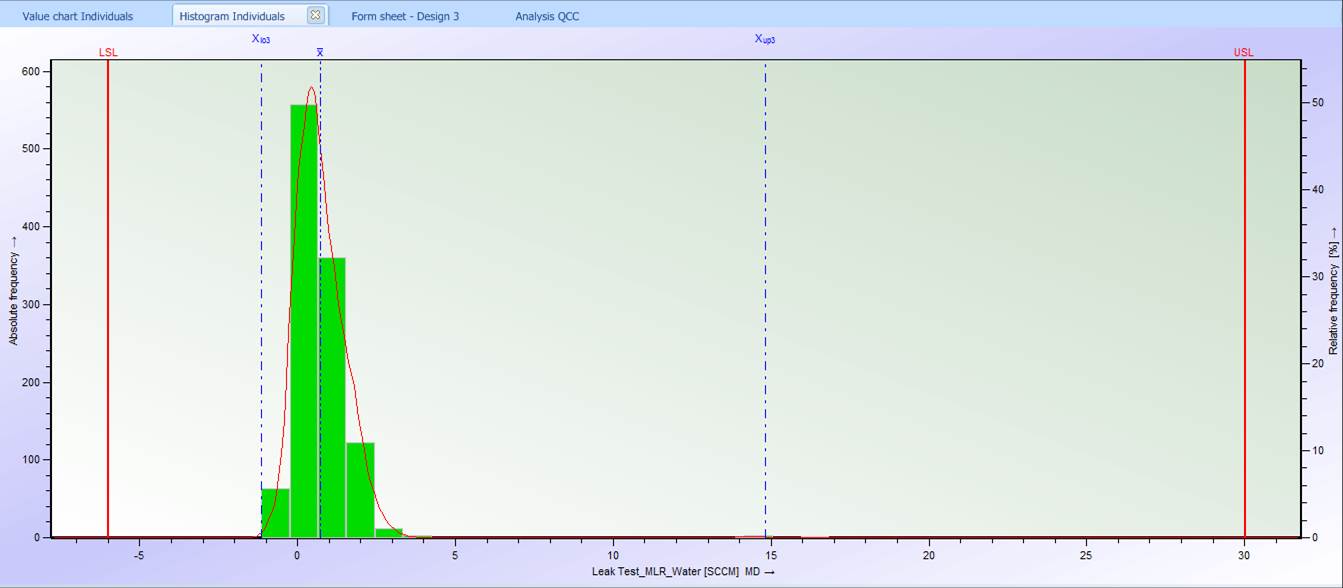
**Additional Test design considerations:**

* 1. Temperature compensation SHALL not be allowed.
  2. The test system SHALL recognize if the test temperature is outside of the temperature limit, then no test should be performed.
  3. The tester should have the ability to display leak rates in standard cubic centimeters per minute (SCCM, or SCCS (standard cubic centimeters per second for Tracer Gas Test).
  4. Leak Test Limits –
     1. The upper control limit SHALL not exceed the leak limit called out on the part print.
     2. The lower control limit should not be less than 20% of the upper limit. (Includes the “negative leak effect”).

**Machine and Fixture**

* 1. The leak test station SHALL be designed to utilize as many available product fill openings as deemed necessary and practical, all circuits are tested individually- or as required by print specification and protects against internal part blockages.
  2. The fixture design should have positive stop to a limit seal crush to 70% of the allowable range for assembly tested with captured seal. (*Captured Seal= Reused on leak test unit vs. One time use on part).*
  3. The fixture design should incorporate appropriate volume filler to minimize the test cavity volume.
  4. The leak test station seal SHALL seal to the design specified production part seal path.

1. **Operation:**
   1. The “0” Master should be a part leaking less than 5% of the leak test upper control limit (Gage R&R data SHALL be provided to substantiate).
   2. The “Reject Master” is a part that SHALL leak 0% to 5% above the leak test upper control limit (GR&R data SHALL be provided to substantiate). **NOTE: Reject master could be the “0” Master + a certified leak test orifice.**
   3. The error proofing verification of the leak test system SHALL be conducted at minimum, daily and preferably, every shift, utilizing the “0” master and the “Reject master”.  Leak test units SHALL not require daily re-calibration, except for helium or tracer gas leak test application.
   4. Serialized leak test data and overall result (Pass/Fail) with associated **Part Unique Number (PUN)** SHALL be recorded and saved if required by the part print.
   5. All leak test data SHALL be provided in excel readable format.
   6. Any rejected parts SHALL **NOT** be retested immediately following the initial failure. The part SHALL be vented, and sufficient time SHALL be allowed between retest for the part to come back to original condition (with exception of the tracer gas leak test).
   7. A part SHALL not be tested as a “FAIL” more than 3 times and then be allowed to be changed to a “Pass” status.
   8. All reject parts SHALL be identified with a stamp, marking, 3D Matrix, PUN, etc. and/or a traceable reference (where applicable/allowable per part print).
   9. Limits SHALL be set for a specific number of rejects i.e., Alarm Limits (in a row, in an hour/shift/day) based on data to determine “Out of Control” condition. If the limit is exceeded, a Root-Cause analysis SHALL be performed.
   10. If >10% of the parts are passing between at a rate of 50% to 99% of the reject limit, a root cause analysis SHALL be performed. (Example of a normal leak test distribution that would pass a Leak Test Gauge R&R below- If a high number of parts are grouped near the upper end of the limit, it is likely that a special cause would be present).



* 1. An appropriate diagnostic method (e.g., tracer gas sniffer or Water Dunk test) should be utilized to identify leak locations in rejected parts based upon the allowable leak rate per part print.
  2. The diagnostic station should have the same sealing strategy as the production machine.
  3. A part passing the diagnostic test SHALL not be a “Pass” part until it passes the production leak tester.
  4. The leak test station SHALL have a proactive, preventive, and predictive maintenance plan developed and followed appropriately to ensure valid results and continued system reliability.

1. **Plant:**
   1. The plant ambient air temperature (Tp.) SHALL be within the following range: 15oC >Tp.>35oC.
   2. Each leak test station should have its own air drop to leak test panel separate from any motion controlling air.
   3. Each leak test station should have its own power supply and isolated grounding.

Acronyms, Abbreviations, Definitions and Symbols

CG GM General Form/Template identifiers

CRV Component Readiness Valve

DRE Design Release Engineer

EP Error Proofing

EPC Early Production Containment

GPS GM Global Propulsion

R@R Run at Rate

R&R Repeatability and Reproducibility

SCCM Standard Cubic Centimeters Per Minute

SCCS Standard Cubic Centimeters Per Second

SQE Supplier Quality Engineer

Tp Plant Ambient Air Temp

Acknowledgement

Please sign, date, provide evidence (current and/or empirical) and return this document as a record of your understanding of these requirements:

Authorized Supplier Management:

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| **Change History** | | | | |
| **Date** | **Version** | **Change Summary** | **Approver** | **Approving Department** |
| 5/2012 | 1 | Initial Document | M. Cremer | SQ |
| 11/5/15 | 1.0 | Review of 1927-03a – Document deemed relevant by Owner and Global Process Team; Creating document CG for input into e-SOR. | Thomas Pougnet | Supplier Quality and Development |
| 10/30/17 | 2.0 | Major Revision of Format and Content | Thomas Pougnet | Supplier Quality and Development |
| 3/23/2022 | 3.0 | Changed Header to new standardized format, replaced SRV with CRV; updated name of CG4338 GM 1927 03 SQ SOR: added ref to CG3404: added ref to GM 1927 10 Fixture Standards and GM 1927 20 Process Capability Measurement System Analysis MSA Result Sheet /Gauge R&R Worksheet; added ref to GM 1927 35 R@R; Added additional Abbreviations Tp, PUN, SCCS and SCCM to list, added a note referencing CQI-27 compliance. | Craig Kirbitz | GPS Global Process |
|  |  |  |  |  |

**Appendix A - (Reference to MSS 3.0 specification)**

5.0 Types of Approved Studies

5.1 Gage Repeatability Study

A Gage Repeatability Study outlined in GM 1927 10 Fixture Standards and GM 1927 20 Process Capability Measurement System Analysis MSA Result Sheet should be preceded by a functional test of the gage. This should consist of an actual measurement cycle on a representative sample workpiece. This functional test should also include a preliminary review of the accuracy of the gage to eliminate gross errors and reduce wasted effort on studies that may need to be repeated after correcting these errors.

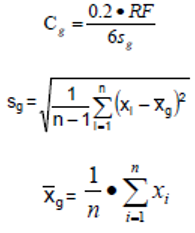
The Gage Repeatability Study is used to determine repeatability, accuracy, linearity and short-term stability. This study investigates the inherent variation behavior of the measurement system. The various capability indices are determined in this study. This study is carried out by the supplier/manufacturer during initial acceptance, before delivery, in order to recognize any deficiencies in the measurement system and avoid costly problems later. Measurement system performance in a Gage Repeatability Study is determined by having 1 operator measure the same sample (known value workpiece or appropriate master, other than those used to calibrate the gage system) at least 30 times (50 times is recommended). Part should be evacuated in between each test and maintained in ambient condition for a minimum of 1 minute.

The gage must be calibrated before starting the study and may not be adjusted during the study. 5.1.6 The sample must be removed and replaced for each measurement and should not be subject to changes during the study. Workpieces should be marked to ensure that the same place is measured each time to eliminate any measurement variation. Studies should be documented in order to maintain standards for capability of measurement systems, as required by AIAG IATF ISO/TS 16949 or QS-9000. Failure to pass the acceptance criteria specified for the Gage Repeatability Study (see subsequent sections) requires approval before proceeding with the Standard R&R/Operator Independent R&R Study or shipment of the gage.

5.1.1 Measurement System Repeatability

Repeatability is evaluated using Gage Potential Index Cg

Reference Figure



Using the Gage Potential Index formula, a region of 20% of the Reference Figure is compared to the spread of the measurement values. Here the spread of the measurement values is defined as 6sg. Figure 5.1.1-A illustrates this.

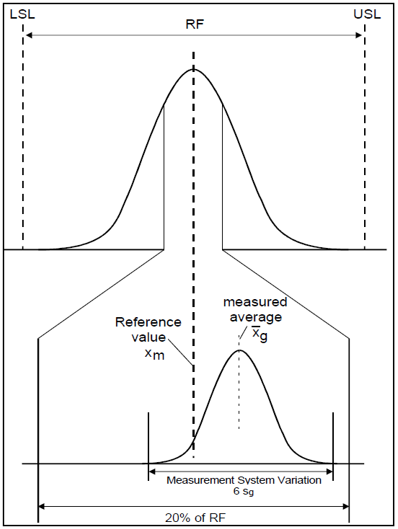


Figure 5.1.1-A Repeatability as a % of RF

The figure below illustrates the influence of the measurement system variation on the capability index Cg. As sg decreases, Cg increases (% of Equipment Variation, EV, decreases) proportionally.

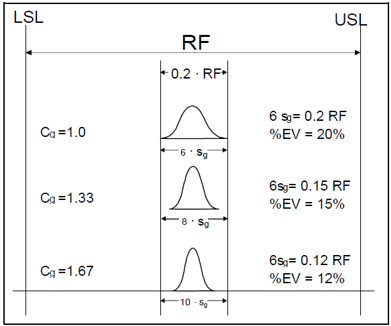
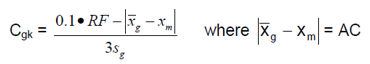


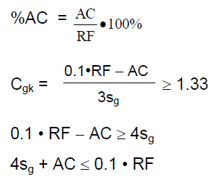
Figure 5.1.1-B Influence of measurement system variation on Cg.

This is based on the normal distribution of the measurement values. In the case of natural limit characteristics (those which cannot produce measurements below zero, e.g. runout) and bi-variate position characteristics (e.g. true position), the distribution is typically non-normal. In these situations, the software used for analysis must be capable of fitting the appropriate distribution and calculating the corresponding statistics. The Measurement System Analysis module of the qs-STAT® software can be utilized in determining the cage potential index.

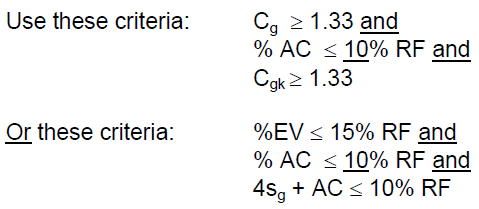
An alternative to using the Cg index is to use the EV index:



An alternative to using the Cgk is to use the AC and sg:



The following acceptance criteria apply for the above indices.



Either set of criteria may be used. The Measurement System Analysis module of the qs-STAT® (statistical analysis software) is capable of calculating both sets of indices.

If it is necessary to evaluate gage performance of 2 microns, use the (4sg + AC) term to do so. Therefore, if (4sg + AC) 2 microns, use the first fine tolerance criterion shown as 10% RF plus 30% of the difference between 2 microns and 10% RF. Mathematically, this criterion = 0.1 • RF + 0.3 • (2 – 0.1 • RF).

5.1.2 Special Criteria for Measurement System Accuracy and Linearity

For any type of gage which uses HIGH / LOW or MAX / MIN masters to set both zero and sensitivity (air or electronic), if the sample workpiece / master used for the accuracy evaluation has a known value that is in the central 1/3 of the tolerance zone, the gage system linearity is acceptable if the %AC 10% RF. If the sample workpiece / master is not in the central 1/3 of the tolerance zone, it may still be used to evaluate accuracy, but not linearity. In this case, use the Optional Linearity Evaluation procedure is shown as 20% RF plus 30% of the difference between 2 microns and 20% RF. Mathematically, this criterion = 0.2 • RF + 0.3 • (2 – 0.2 • RF). The corresponding conditional fine tolerance criterion for gage performance of less than 2 microns would be 1.5 times the preceding formula.

For any non-air type of gage which uses a MEAN master to set zero (with or without the use of HIGH / LOW or MAX / MIN masters to set sensitivity), if the sample workpiece / master used for the accuracy evaluation (even if it was used to calibrate gage sensitivity) has a known value that differs from the MEAN master by at least ½ the workpiece tolerance in the direction of increasing clearance to the gage (e.g. a MAX master for an electronic plug or a MIN master for an electronic snap), the gage system accuracy and linearity are acceptable if the %AC 10% RF. If the sample workpiece / master does not differ from the MEAN master by at least ½ the workpiece tolerance in the proper direction and was not used to zero the gage, it may still be used to evaluate accuracy. In this case, or if the sample workpiece / master was used to zero the gage, use the Optional Linearity Evaluation procedure previously explained above.

If a master (not a sample workpiece) is used for the Gage Repeatability Study, it must be approved for its use in the linearity evaluation.

Where the features of form (e.g. runout, cylindricity, ovality) are calculated using measurement sensors which are also used for features of size (e.g. diameter), conformance to the above criteria for size will suffice to indicate conformance for the corresponding form measurements.

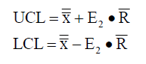
5.1.3 Measurement System Short Term Stability

All Gage Repeatability Study measurements must be plotted on an x (individuals) chart. All measurements must be inside the control limits. If the spread of the natural control limits is < 10% RF, you may increase the spread of the control limits to 10% RF (shown as xm +/- 0.1xT in example below) in order to avoid gage resolution causing a control limit violation.



Figure 5.1.3: Example of acceptable x chart

Formulae for x chart control limits:



5.2 Standard R&R Study

A Standard R&R Study is carried out to determine % Repeatability and Reproducibility (R&R) and Linearity in cases where operator influence may be present. Combined with the Gage Repeatability Study, this enables a statement to be made as to whether the measurement system is suitable, of limited suitability, or unacceptable. Studies should be documented in order to maintain standards for capability of measurement systems, as required by ISO/TS 16949 or QS-9000.

5.2.1 Measurement System R&R

The Standard R&R study determines Equipment Variation (EV, repeatability) and Appraiser Variation (AV, reproducibility) and combines them in an R&R parameter.

The number of measurements (trials) per operator and the number of operators must be stipulated in each individual case.

There must be a minimum of 2 operators (k) and 2 trials (r). There should be a minimum of 5 workpieces (n). Once the number of operators is selected, the number of workpieces and trials must be selected so that the product of is k • r • n 30. Use of fewer than 5 workpieces must have the appropriate approval to generate study. Workpieces must be numbered for the study. To eliminate the influence of measurement variation in static checks within the same workpiece (e.g. roundness), workpieces should be marked to ensure that the same place is measured each time. The gage must be calibrated before starting the study. The operator performing the measurements should not know the individual results of the other operators.

For the analysis of the measurement series, there are two options:

* ARM – Average and Range Method
* ANOVA – Analysis of Variance.

Although the ARM is mathematically simpler, the ANOVA is preferred. The ARM formula is found in section 5.4.1.1.

The ANOVA method is a more precise method and is capable of showing the components of variation separately, i.e.:

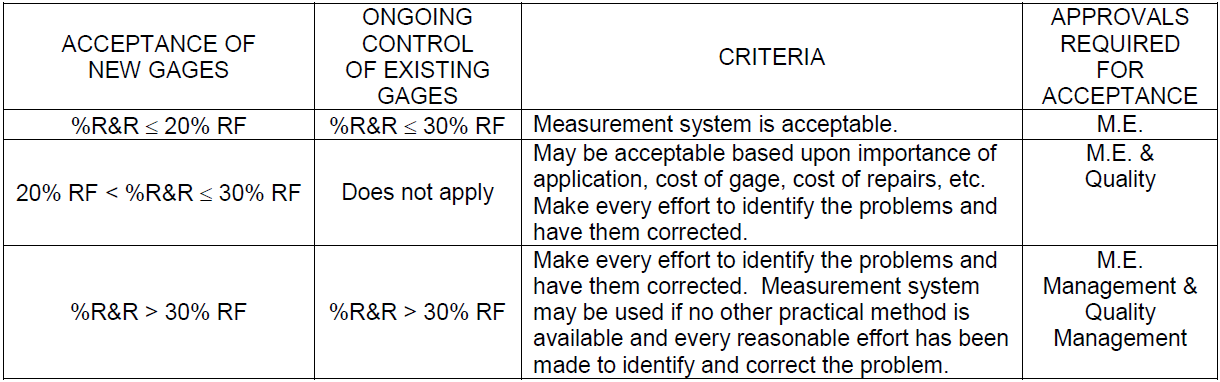
* Repeatability (EV)
* Reproducibility (AV)
* Piece/operator Interaction (IA)
* %R&R
* Piece Variation (PV)

Explanation and formulae for the ANOVA method can be found in the AIAG MSA manual.

The ANOVA method requires the use of appropriate computer software (e.g. qs-STAT® statistical analysis software).

This preceding listing of the individual components of variation enables more precise conclusions regarding error causes and thus aids the identification of appropriate corrective action. Refer to "Measurement Systems Analysis" by AIAG for further explanation.

When using the ANOVA method, the following acceptance criteria apply:



All non-conforming gages SHALL have the discrepancies documented and clearly explained on the gage acceptance forms and supporting documents.

When using the ARM method, the following acceptance criteria apply:

%R&R 10% RF: Measurement system is acceptable.

%R&R > 10% RF: Re-evaluate using ANOVA method.

5.2.2 Optional Linearity Evaluation

If the sample workpiece / master used in the Gage Repeatability Study is not in the central 1/3 of the tolerance zone, the simple linearity evaluation explained in the Gage Repeatability study is not permissible. In this situation, the more complete linearity evaluation approach explained in this section should be used. This approach may also be used as a diagnostic tool for gage performance investigations.

If this type of linearity evaluation is required, it is conducted on the same data acquired during the Standard R&R study. At least 5 of the workpieces used in the Standard R&R study should have known values (n samples). The supplier/manufacturer is responsible for providing these known values. These samples should have variation that approximates the RF. Linearity calculations are shown in section 5.4.2.

The results of the analysis are: a = slope

b = intercept

R2 = Correlation coefficient

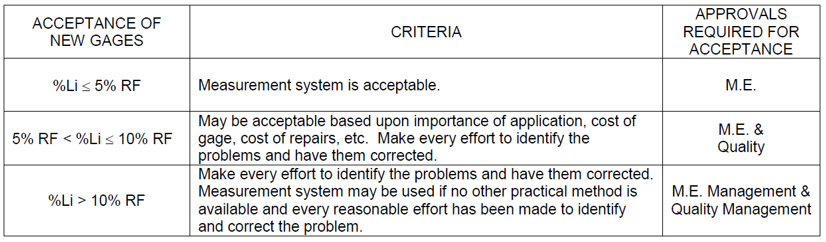
In order for a valid linearity assessment to be made, two conditions must be met:

* Variation of n samples must be 50% RF, and
* Correlation coefficient R2 must be 0.95 RF.

If both these conditions are met, conclusions may be drawn on linearity behavior using the slope of the regression plot. The values used for this purpose are:



The following acceptance criteria apply:



In the case where a linearity assessment is not valid, the largest accuracy value (ACi) must be compared to the above acceptance criteria and reported.

5.3 Operator Independent R&R Study

The Operator Independent R&R Study is carried out to determine repeatability and linearity in cases where operator influence is not present (e.g. automatic workpiece handling). The Operator Independent R&R Study is similar to the Standard R&R Study. Combined with a Gage Repeatability Study, this enables a statement to be made as to whether the measurement system is suitable, of limited suitability or unacceptable. The gage must be calibrated before starting the study. In an Operator Independent R&R Study, numbered workpieces corresponding to the appropriate process stage are measured in multiple measurement trials. The Standard R&R study’s requirement to use multiple operators does not apply to an Operator Independent R&R study. Marking of measurement points and manual repositioning of workpieces to optimize repeatability is not allowed (unless trying to replicate automation that is not available during gage trials but will be used in the production Buyer manufacturing facility). A minimum of 5 workpieces (n) and 5 trials (r) should be used. However, the number of trials must be set so that the n • r product of is 50. Use of fewer than 5 workpieces must have the appropriate approval to generate study.

Studies should be documented in order to maintain standards for capability of measurement systems, as required by AIAG IATF ISO/TS 16949 or QS-9000.

5.3.1 Measurement System Repeatability

As in the Standard R&R Study, the ANOVA technique is preferred and appropriate computer software is required to complete the analysis (qs-STAT®). The ARM formula is found in section 5.4.1.2.

Since there is no operator influence, AV = 0 and R&R = EV = K1 •.

Therefore, %R&R = %EV = 100 • %

Acceptance criteria are the same as for the Standard R&R Study (see section 5.2.1).

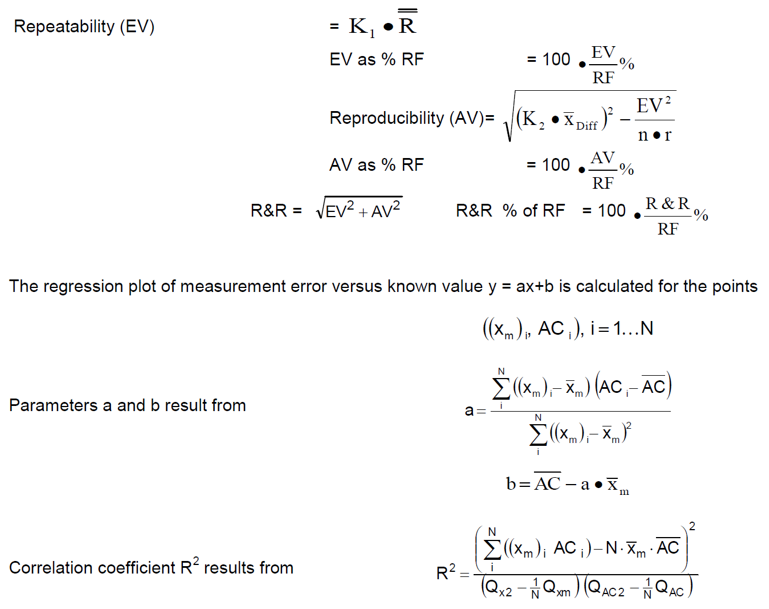
5.3.2 Optional Linearity Evaluation

The Linearity Evaluation analysis is the same as for the Standard R&R Study.

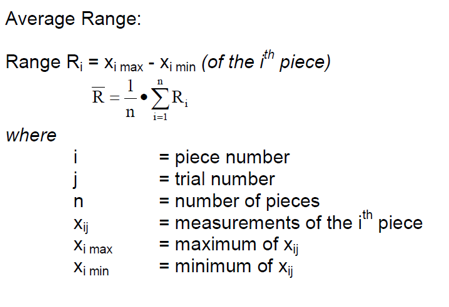
5.4 Supplemental Formulae

5.4.1 ARM Method Formulae

5.4.1.1 ARM Method for Standard R&R Study



5.4.1.2 ARM Method for Operator Independent R&R Study



5.4.2 Linearity Evaluation Equations

