Measurement System Analysis

Definition:

Measurement System Analysis investigations are the basic requirement for carrying out Capability Studies. They are intended to ensure that the used measuring equipment is suitable.
Note: With destructive tests (e.g. tensile or bend tests), a "substitute normal" must be used that is not destroyed (such as a thicker part, etc.). If there is force measurement of destroying test specimens, the test specimen can, for example, be replaced by a spring whose characteristic is in the test specimen's force/stroke range.

Procedure:

Overall, a differentiation is made between the following influences:

1. **Repeatability** on a "**reference**" = constant master part
   (former process 1), pure test equipment deviation.
2. **Repeatability** on different **parts** (former process 3)
   Consideration of the value range to be measured.
3. **Reproducibility** on different parts and different **appraisers** (former process 2)
   Consideration of different appraisers.

Comparison with the classic methods

The overview below is a comparison with the old methods mentioned above:

Influences →

	Repeatability, reference standard		Repeatability, part to part	Reproducibility
	Tests with a reference standard (master)		Tests with several parts	Tests with several parts & appraisers
Former & classic methods	**Type-1 study** s_g Cg/Cgk ≤1.33		**Type-3 study** Range %R&R ≤ 20..30%	**Type-2 study** Range + mean diff. %R&R ≤ 20..30%
VDA 5 valid as of VA 4.4.7/1 V4	u_{EVR}; u_{RE}; u_{BI}	u_{cal}; u_{lin}	u_{EVO}	u_{EVO}; u_{AV}; (u_{IA})
	$Q_{MS} \le 15\%$		$Q_{MP} \le$ 20..30%	$Q_{MP} \le$ 20..30%

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According to VDA Volume 5 or the ISO 22514-7, measuring uncertainties are observed by means of the corresponding standard deviations that are expressed by the symbol *u* (measuring uncertainty budgets). The calculation is performed using an analysis of variance (ANOVA).
The overview below shows the most important measuring uncertainties:

Proportion	Calculation	Description
Resolution of the display	$u_{RE} = RE/\sqrt{12}$	RE Resolution of the equipment
Systematic deviation	$u_{Bi} = \lvert \bar{x}_g - x_m \rvert / \sqrt{3}$	$\bar{x}_g$ Disp. average val. of normal x_m Reference value of normal
Repeatability on normal	$u_{EVR} = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x}_g)^2}$	x_i Meas. val. of the repetition i n Number of repetitions

From this, the influence of the instrument (MS = measuring system) is formed as an intermediate result (simplified representation considering no linearity deviation):

$$u_{MS} = \sqrt{u_{Cal}^2 + u_{BI}^2 + max\{u_{RE}^2; u_{EVR}^2\}}$$

The calibration uncertainty of the normal u_{Cal} should be considerably less than the total measuring uncertainty (recommendation of $u_{cal} \leq 0.15\ u_{MS}$). Refer to the calibration certificate for the calibration uncertainty.

$$\%Q_{MS} = 100\% \cdot \frac{k \cdot 2 \cdot u_{MS}}{TOL}$$

$k = 2$ VDA Standard for confidence level 95.45 %
$k = 3$ for confidence level 99.73 %, if the application requires, or the specialist department has corresponding normative stipulations, e.g. threaded fastener technology.

Requirement: ***%Q$_{MS}$* ≤ 15%**

This corresponds to the older requirement:

$$C_g = \frac{0{,}2 \cdot TOL}{2\, k\, s_g} \;;\; C_{gk} = \frac{0{,}1 \cdot TOL - \lvert \bar{x}_g - x_m \rvert}{k\, s_g}$$

$\bar{x}_g$: mean of the measurements
x_m : mean of reference standard
s_g : standard deviation

In addition to the measurement uncertainties of the pure measuring system, influences from the part variation and the appraiser are also added. Overall, the measurement uncertainty of the entire measuring process is determined by:

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Measuring process = Measuring uncertainty of instrument +
Measuring uncertainty of equipment & appraiser

The scope of the equipment and the appraiser is:

Portion	Calculation	Description
Repeatability of test object	$u_{EVO} = \sqrt{MS_{EV}}$	MS_{EV} Variance repeatability
Reproducibility of appraiser	$u_{AV} = \sqrt{MS_{AV}}$	MS_{AV} Variance of appraiser
Interaction	$u_{IA} = \sqrt{MS_{IA}}$	MS_{IA} Variance Interaction

Overall, the measuring process is determined by (simplified view):

$$u_{MP} = \sqrt{u_{Cal}^2 + u_{BI}^2 + max\{u_{RE}^2;\ u_{EVR}^2;\ u_{EVO}^2\} + u_{AV}^2 + u_{IA}^2}$$

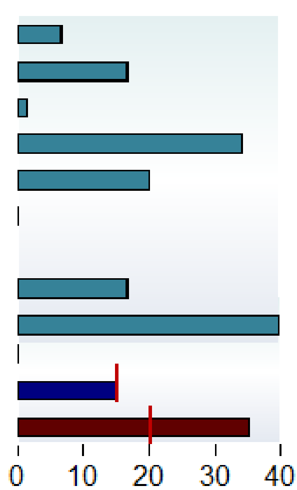
In a similar way to the repetition and comparability precision $\%R\&R$ reference is made to the tolerance and it yields the key figure:

$$\%Q_{MP} = 100\% \cdot \frac{k \cdot 2 \cdot u_{MP}}{USL - LSL}$$

The requirement is: $\%\boldsymbol{Q_{MP}} \leq$ **20 .. 30%**

Example:

VDA 5 / ISO 22514-7		values / 1000
Resolution of gauge	u_{RE}	0,0289
Repeatability Master	u_{EVR}	0,0738
Standard uncertainty (Bias)	u_{BI}	0,0058
Repeatability test-object	u_{EVO}	0,1513
Repeatability appraiser	u_{AV}	0,0892
Interaction	u_{IA}	0,0000
Uncertainty measurement	u_{MS}	0,0740
Uncertainty process	u_{MP}	0,1758
Measurement	$\%Q_{MS}$ (95,45%)	**14,8**
Process	$\%Q_{MP}$ (95,45%)	**35,2**

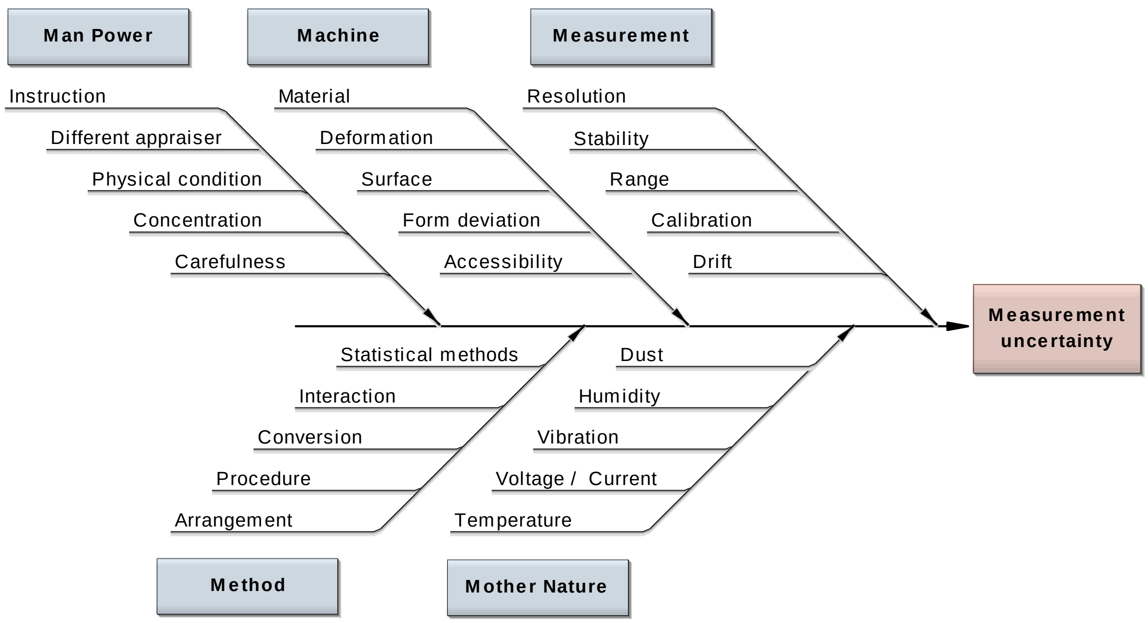


In this example, the requirement was met with $\%Q_{MS} \leq 15\%$, but the uncertainties from repeatability at different parts and appraiser are too high ⇨ $\%Q_{MP} = 35.2\% > 20\%$. The reason can be in an incorrect measuring range, which cannot cover the variation of the parts. The appraisers should be re-instructed ("operational definition"), so that all proceed in the same way.

Other influences on measurement uncertainties

Along with the proportions of measurement uncertainties described above, there is a series of other possible influences such as stability and temperature.

$$u_{MP} = \sqrt{\ldots + u_{Lin}^2 + u_T^2 + \ldots}$$



Here too, as regards calculation further measurement uncertainties $u_{\text{influence}}$ are cumulative in accordance with the Gaussian law of error propagation.

$$u_{MP} = \sqrt{\ldots + u_{E1}^2 + u_{E2}^2 + u_{E3}^2 \ldots}$$

Especially measuring equipment holding devices and their possible deformation may have considerable influence on measurement uncertainties, see example mentioned in Ishikawa diagram. These should be quantified by tests as far as possible. If this is not possible, the percentage shares shall be considered e.g. by rigidity calculations. Furthermore, manufacturers' specifications shall be considered, e.g. in case of electronic measurement sensors.

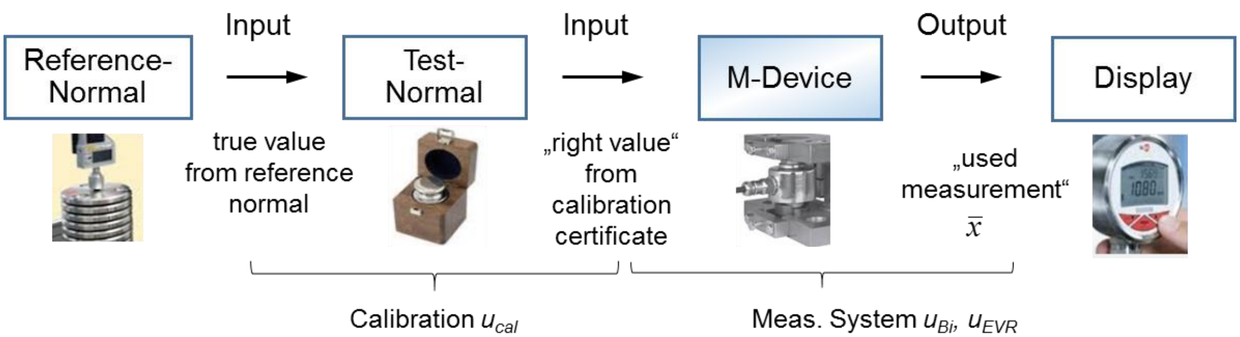
Reducing the measuring uncertainty by repetitions

In the event that the requirement is not met but no alternative measuring equipment is available, the possibility of repetitions exists. By multiple repeat measurements and averaging, it is possible to achieve a reduction in measuring uncertainty. It is possible to reduce random measuring uncertainties with m-repetitions by a factor $\sqrt{m}$. The proportion u_{EVO} then becomes

$$u^*_{EVO} = \frac{u_{EVO}}{\sqrt{m}}$$

If u_{EVO} is known from previous measurements, it is possible to determine the necessary number of repetitions to achieve the required measuring uncertainty.

Measurement chain



MSA for discrete characteristics

Discrete or attributive characteristics are measurements which can only deliver a result that is good or bad (two levels). This is often the case, e.g. in subjective observations.
In the **gauge R&R for discrete characteristics** process, to appraisers "measure" different parts twice each. That might for example be done on parts that are either intact or faulty. If there are deviations between the results of one appraiser, or between different appraisers, these are counted. The ratio between different results and the number of parts should not be more than 10%.

In what is called **Cohen's kappa method**, the appraiser is told to measure one part three times (result as 0 or 1). This doesn't detect deviations between appraisers, but also deviations from the actual values (reference measurements as the true status of the parts).
Score values are calculated based on the ratio between the deviations and the reference values, and must be tested against the confidence ranges from the binomial distribution. Because it relates to a reference value, this method is more meaningful than the gage R&R method. For more information, refer to MSA 4.

In what is called the **Bowker process**, three types can be taken into account, e.g. good, bad and additionally, the "non-uniform" result. At least 40 different test objects are tested by 2 appraisers, 3 times each. Each of the 40 results is allocated to three classes:

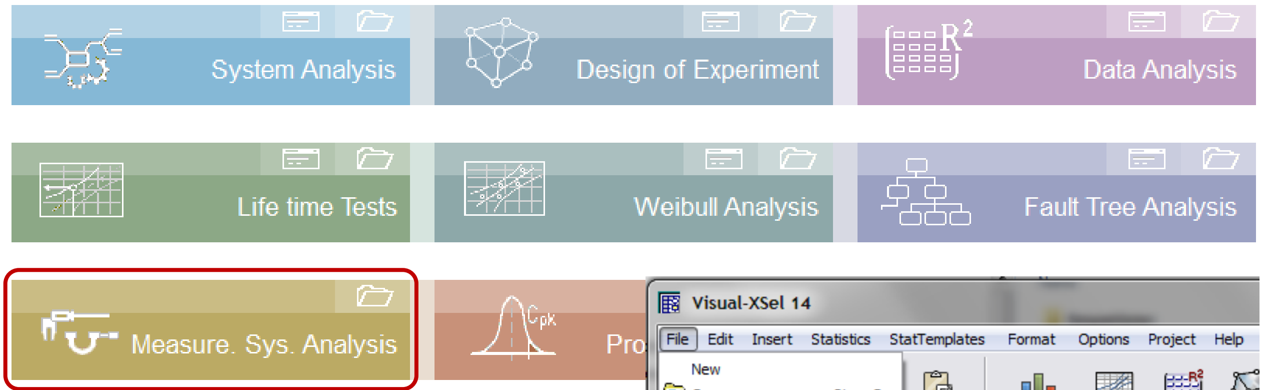
Class 1: All 3 repetitions produced the good result
Class 2: Different results within the 3 repetitions
Class 3: All 3 repetitions produced the bad result

The result in the form of a cross table is tested for symmetry using the χ^2 distribution. See VDA 5 for more information.

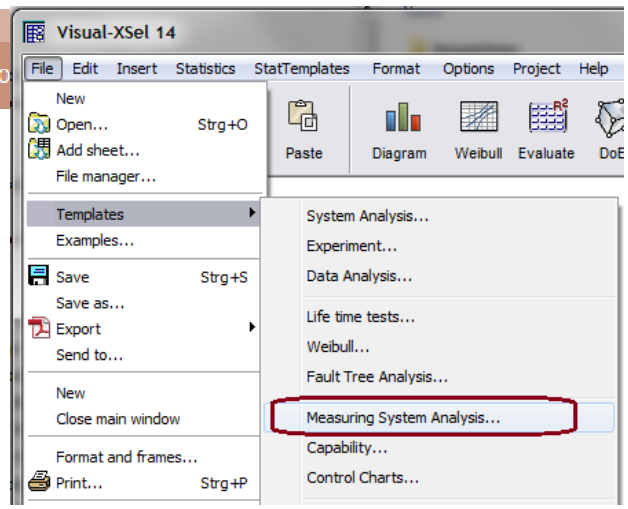
Measurement System Analysis

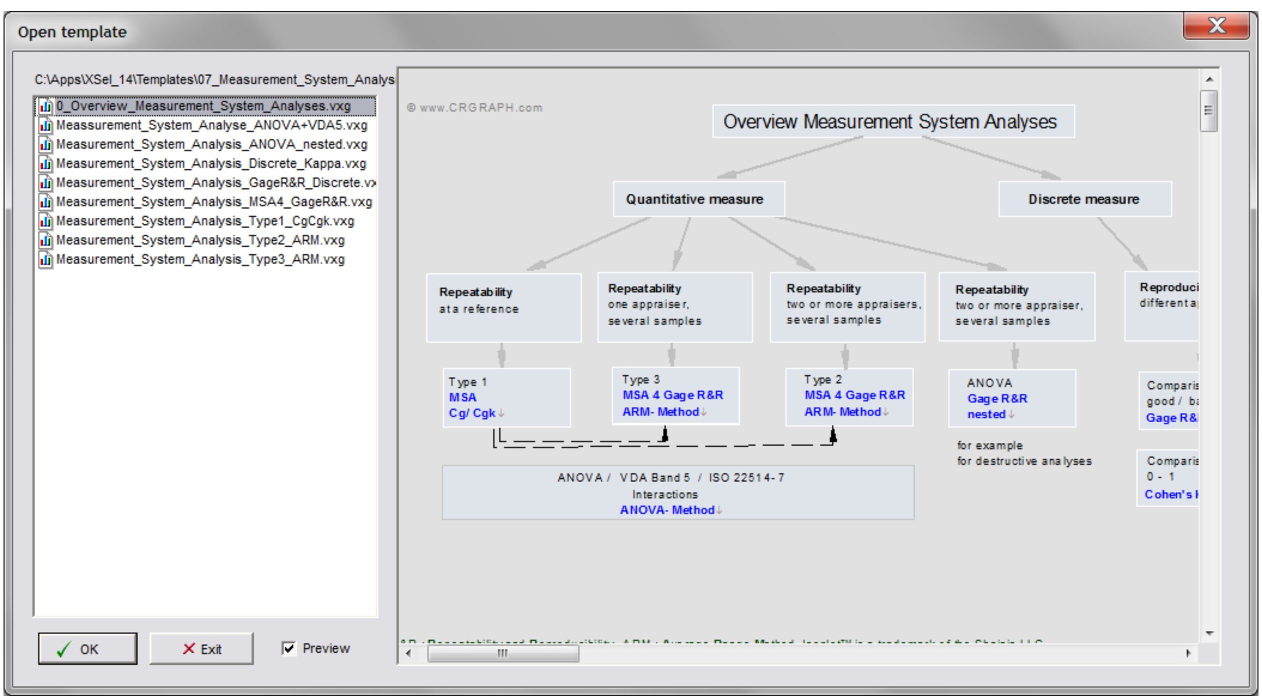
Using Visual-Xsel 14.0

Start Visual-Xsel or use menu ***File/New***. Select the ***Measurement Systems Analysis***



or open via ***File/Templates*** - ***Measurement Systems Analysis***





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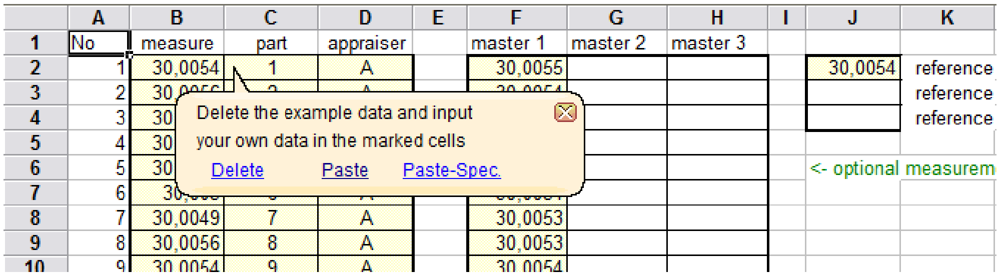
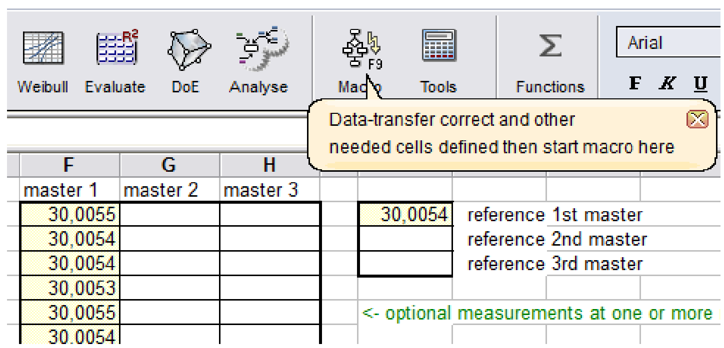
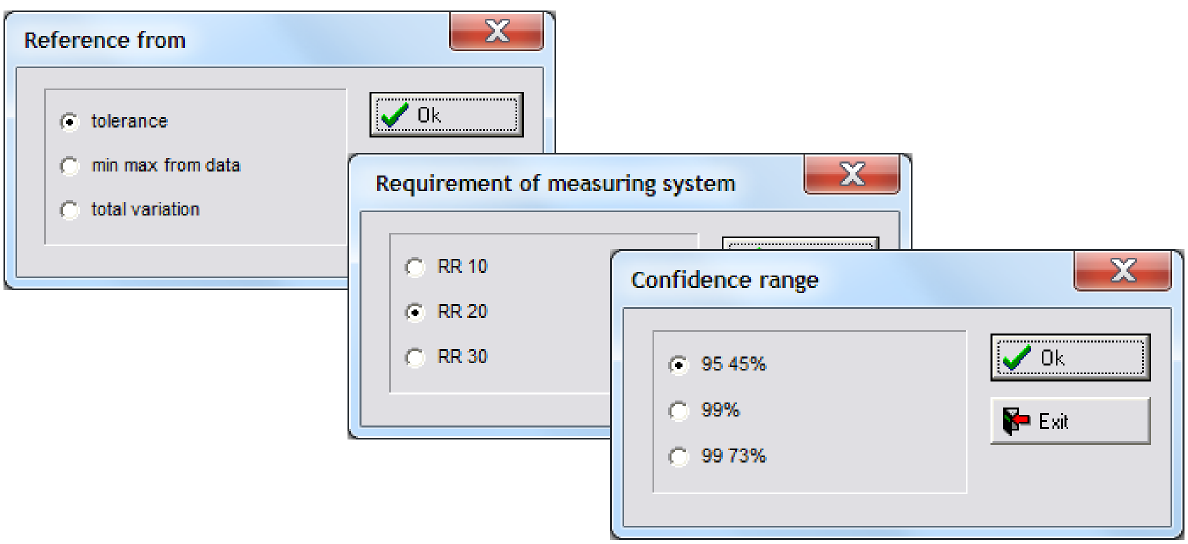
After you load the template, data can be pasted from the clipboard. Use the "Paste" function in the floating bubble for this purpose!

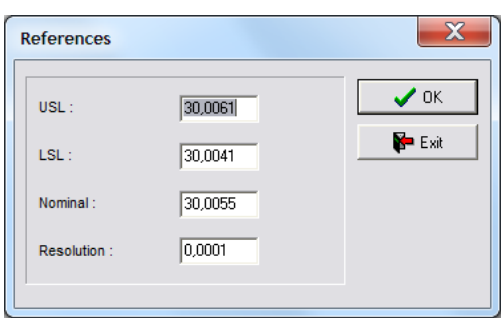


Of course, this is possible only if the data is formatted as shown in columns B-D. Otherwise all source columns have to be copied one by one. Use Ctrl-V to do this. You will usually have to do this in any case to paste the data of the master in column F. Once you have populated all the fields, start the macro by pressing F9 to start analysis. Or click on the 'Macro' button:



Next, several queries appear that shall be answered as follows:





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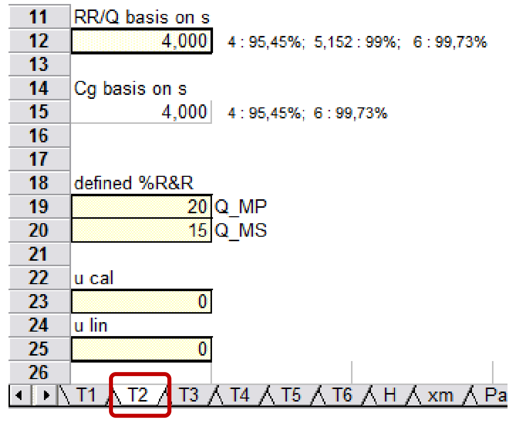
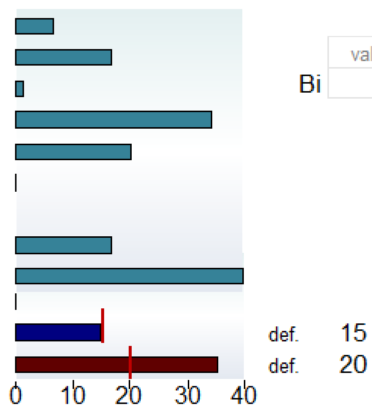
You can set the uncertainties for calibration and linearity later in sheet T2. You have to restart the analysis again with F9.



The next Figure shows the case-related results calculated by Visual-XSel by way of examples, refer to page 2 in the program

VDA 5 / ISO 22514-7		values / 1000
Resolution of gauge	u_{RE}	0,0289
Repeatability Master	u_{EVR}	0,0738
Standard uncertainty (Bias)	u_{BI}	0,0058
Repeatability test-object	u_{EVO}	0,1513
Repeatability appraiser	u_{AV}	0,0892
Interaction	u_{IA}	0,0000
Uncertainty measurement	u_{MS}	0,0740
Uncertainty process	u_{MP}	0,1758
Measurement	%Q MS (95,45%)	**14,8**
Process	%Q MP (95,45%)	**35,2**
Capability index	C_g	1,355
(reference to 4s, or 95,45%)	C_{gk}	1,287



	value / 1000
Bi	0,0100

Further characteristics (optional)		values / 1000
Calibration	u_{cal}	0
Linearity	u_{lin}	0