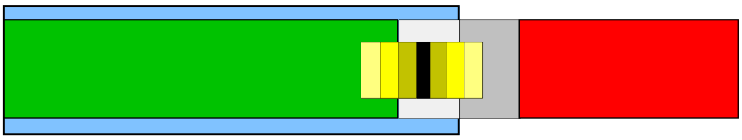
OFD 10
Version 09/2017

Gauges and masters for splines and gears

Acceptance or rejection of gauges and masters with regard to the tolerance limits of size and form variations



Modifications to prior version: Change-over to DAkkS – new uncertainties - JK

pure perfection

FRENCO

Summary of FRENCO document OFD 10

All measured values have a measuring uncertainty. Inspection certificates have to show the measuring uncertainty. If a gauge or master is measured to be slightly inside or outside the tolerance limit, the existing measuring uncertainty may make it impossible to decide whether the specimen is ok or not.

ISO 14253 gives 3 possibilities to accept a part or not:

1. Accept, if it is proven to be in tolerance
   (substract measuring uncertainty from tolerance)
2. Accept, if it is proven not to be out of tolerance
   (add measuring uncertainty to tolerance)
3. Agreements between supplier and customer

If no agreement between supplier and customer exists, the ISO 14253 advices:
The supplier shall prove to be in tolerance (1.), the customer shall prove not to be in tolerance (2.).

But this standard does not define a priority. Who has to prove first?

At gauges and masters for splines and gears, the relationship of measuring uncertainties to tolerances are too disadvantageous to work without agreements. OFD 10 defines percentages of this relationships and what to agree for which relationships. In general, the agreement B of OFD 10 reads to use possibility 2. for the supplier, if the relationship is too disadvantageous.

The measuring uncertainty may be defined in detail or just estimated.

If measuring uncertainties are just estimated, measuring results used to decide by agreement B of OFD 10 are senseless. The specimen will always be proven not to be out of tolerance if the measuring uncertainty is large enough.

The agreement B to OFD 10 is only allowed to be used, if the supplier can prove it's measuring uncertainty which has to represent best levels of accuracy.

Laboratories accredited by state institutions prove their measuring uncertainties with best levels of accuracy.

Frenco is accredited by the German state institution PTB for spline and gear measurements and explicitly shows the measuring uncertainties in OFD 10.

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1. Introduction

Any tolerance whatsoever has its tolerance limits. It is a matter of course that these tolerance limits are held. Strictly speaking, however, such clearly cut limits raise quite a number of questions. Every limit has various kinds of uncertainties. Some of the influence factors are:

The type of measuring method applied
Resolution of a measuring method
Human influencing
Rounding methods
Computing algorithms of replacement elements
Superposition of various deviations
Fluctuating environmental influences
Measuring uncertainties

So far, clearly cut tolerance limits were softened by a simple way of consideration and a habitual human acceptance. For analogue and visual evaluations measured values were rounded with the mechanisms of common sense. Then measured values just beyond the tolerance limit with one resolution unit, or often with 10 % measuring uncertainty were accepted. The consideration of tolerance limits has become subject to a strong change due to digital measuring technology, the dislocation of many processes, a changed legal position and a more detailed point of view. The DIN EN ISO 14253 is the result of such changes. It deals with the rules of decision making for accepting or rejecting work pieces with regard to their tolerance limits. In this context the measuring uncertainty plays a major role.

2. Tolerance and Measuring Uncertainty

There are single and bilateral tolerances. Single tolerances are known as minimum or maximum. Bilateral tolerances include both a minimum and maximum preset point. To simplify matters, we shall focus on a single tolerance limit, for example the total profile deviation of an involute gear and spline. The ideal shape of the involute is described by the value zero, the still permissible deviation from the ideal involute is defined by the value TG.

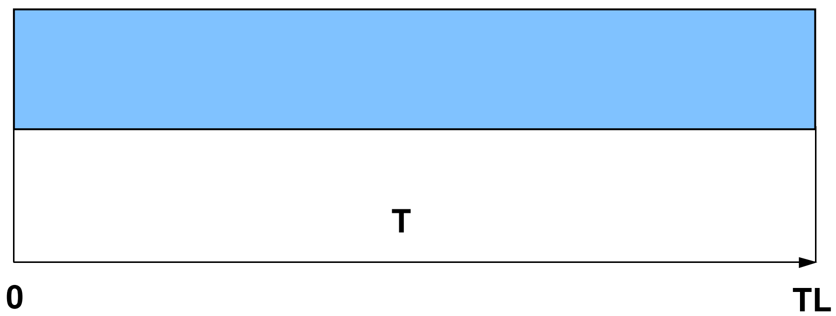


Illustration 1: Single tolerance

T	Tolerance
TL	Tolerance limit

If a specimen is supposed to be accepted as correct the actual value of a feature should not exceed the tolerance limit. The actual value, however, is only a theoretical one. In practice there is only a measured value which was determined with a certain measuring uncertainty.

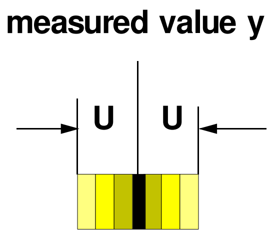


Illustration 2: Measured value and measuring uncertainty

y	Measured value
U	Measuring uncertainty

3. Various Measuring Value Positions

Within the measuring uncertainty range of 2·U, the actual value is unknown and can deviate by ± U from the measured value. As long as the measured value is clearly within the permissible tolerance, the measuring uncertainty is no problem. Everybody clearly agrees on the possible actual value being within the tolerance limits and accepting the specimen.

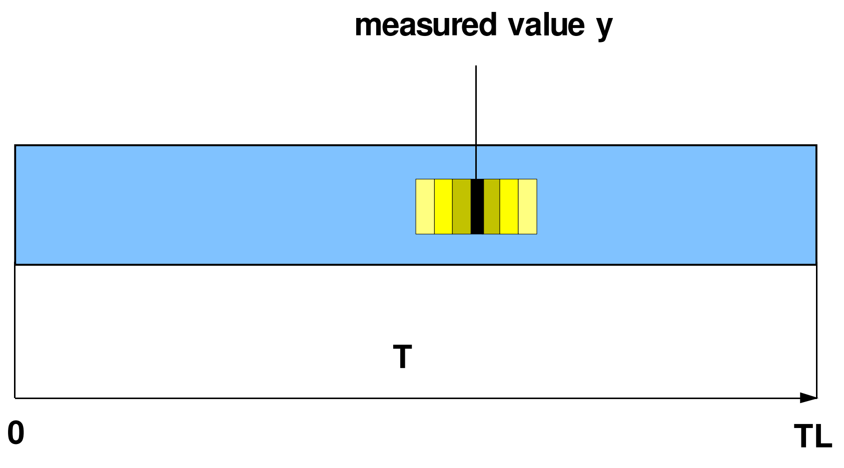


Illustration 3: Measured value y within tolerance

There is conformity with all measured values which are clearly within the tolerance limits. The area of conformity ends if the measured value and its measuring uncertainty U hit the tolerance limit. In this case there is only just the conformity that the possible actual value is within the tolerance limits, and the specimen is accepted.

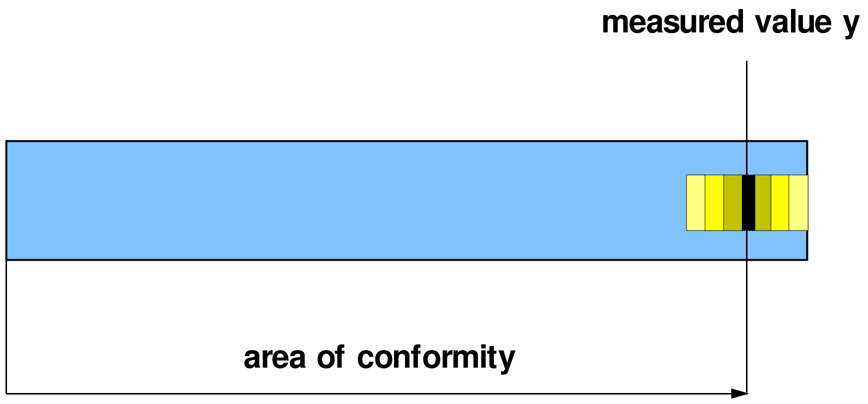


Illustration 4: Area of conformity

The difficulty of decision begins if a superposition of the measured value and its measuring uncertainty with the tolerance limit occurs. The measured value has left the area of conformity. It can no longer be decided whether the actual value is within or beyond the tolerance limit. This possible superposition is an area of uncertainty.

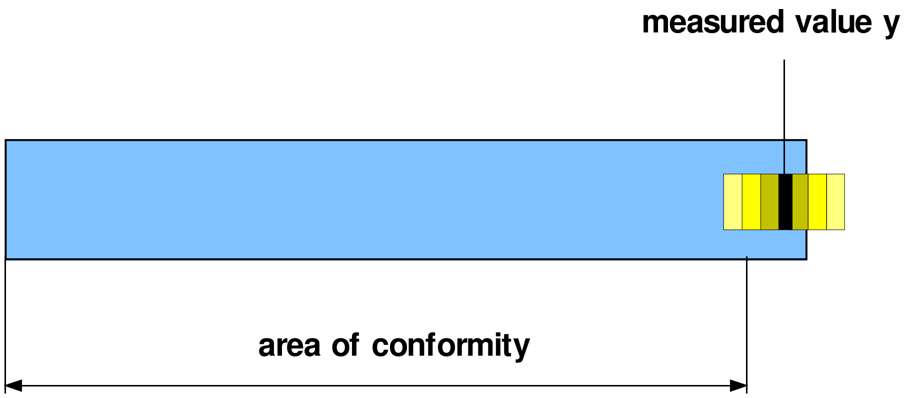


Illustration 5: Exceeding the area of conformity

The measured value y can only be clearly judged once it is within the area of non-conformity. Then a safe decision can be made as to the actual value being beyond the tolerance limit. Exactly from this position of the measured value onwards there is concord that the specimen does not correspond with the tolerance requirements. Such specimens are definitely rejected.

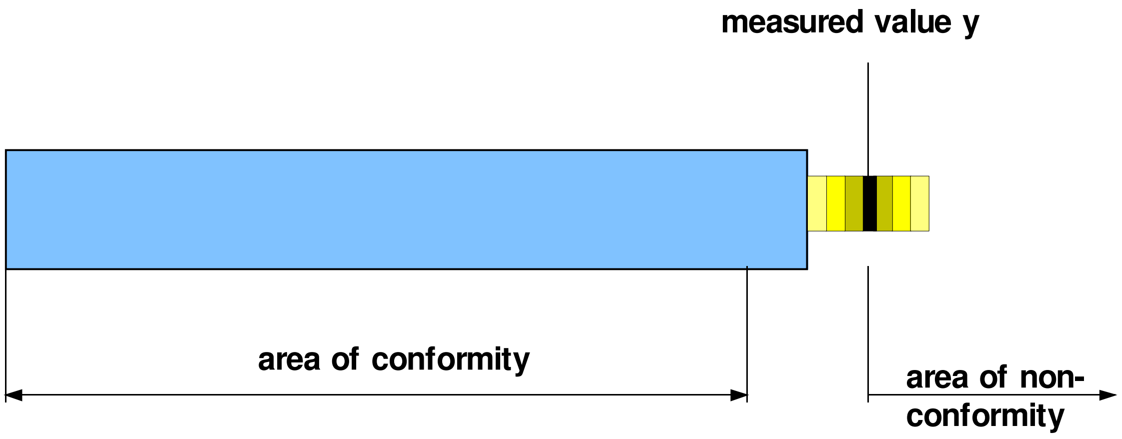


Illustration 6: Area of non-conformity

Neither measured values within the area of conformity neither those beyond the area of conformity create any decision problems. The possible actual value of measured values within the area of uncertainty, however, cannot be allocated within or beyond the tolerance limit.

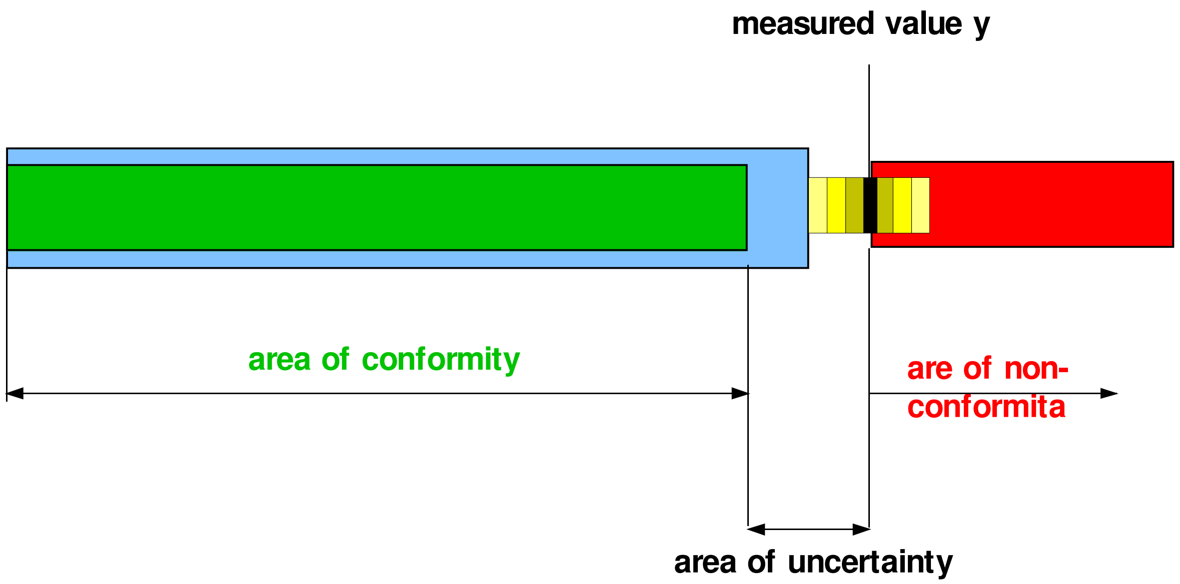


Illustration 7: Area of uncertainty

4. Grey Zone and ISO 14253

The area of uncertainty is the grey zone within which no clear decisions can be made as to whether the tolerance requirement has been met or not. The ISO 14253 proposes the following solution and puts an end to this subject:

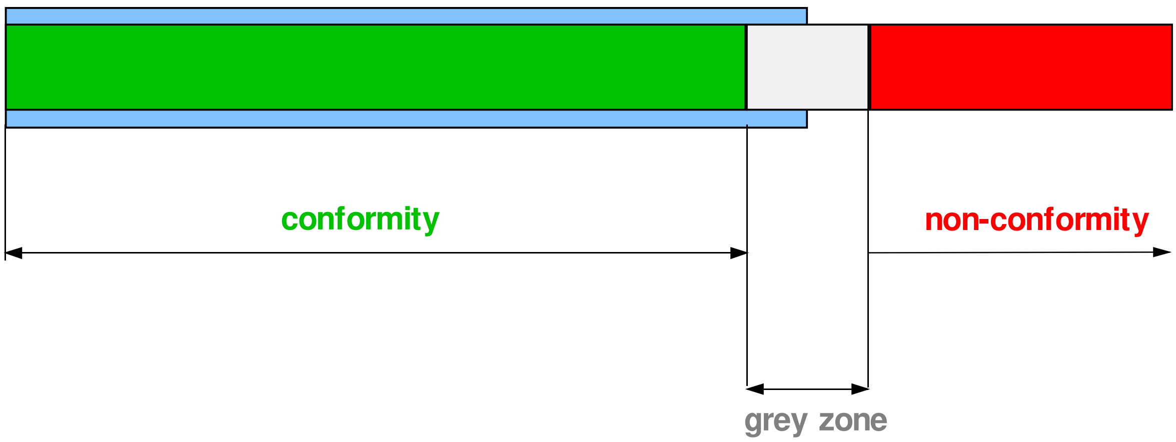


Illustration 8: Grey zone

- Somehow reduce the measuring uncertainty
- Define an prior agreement with the parties
- Reject the specimen

Before starting the measurement, the practical handling of specimen with a measured value within the grey zone should have been clarified. The ISO 14253 indicates that, if no arrangements have been made, work pieces with a measured value within the grey zone should be rejected. Therefore, the following two specimen would be rejected:

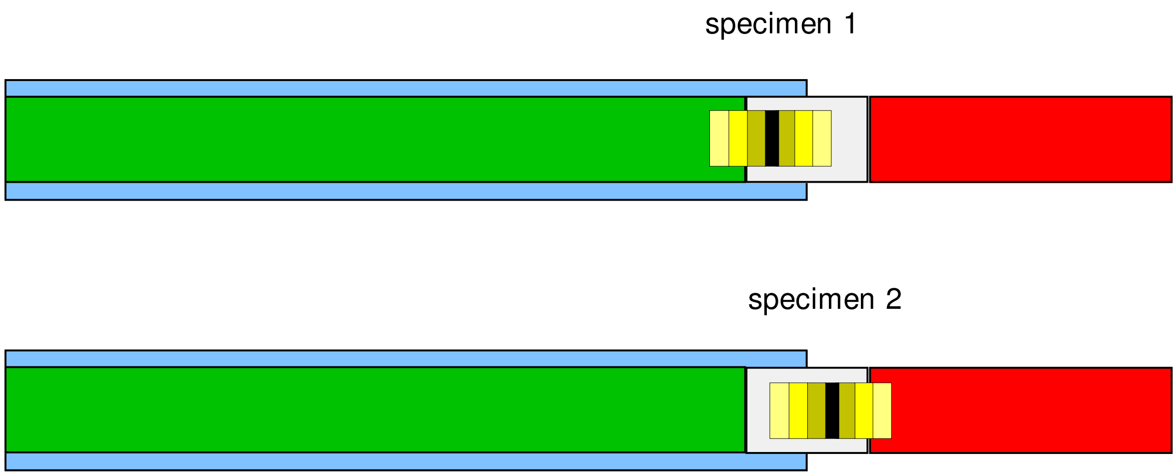


Illustration 9: Two specimen within the grey zone

5. Acceptance and Rejection Errors

This way of handling absolutely guarantees that specimen with a possible actual value beyond the tolerance limit are rejected. At the same time, however, one puts up with a specimen having a possible actual value within the tolerance limit being rejected. A specimen is rejected although its actual value can clearly be within conformity. Therefore, when absolutely avoiding specimen with possible actual values beyond the tolerance limits, one puts up with a rejection error.

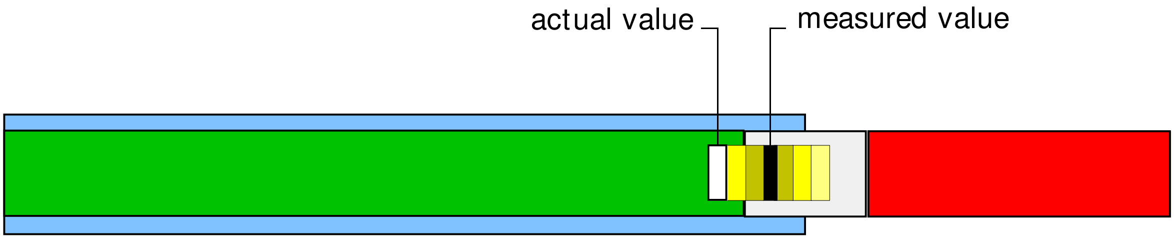


Illustration 10: Measured value and actual value

In terms of value this rejection error can be up to 2 U, but there is no acceptance error. Specimen with a possible actual value beyond the tolerance limit cannot be accepted by mistake.

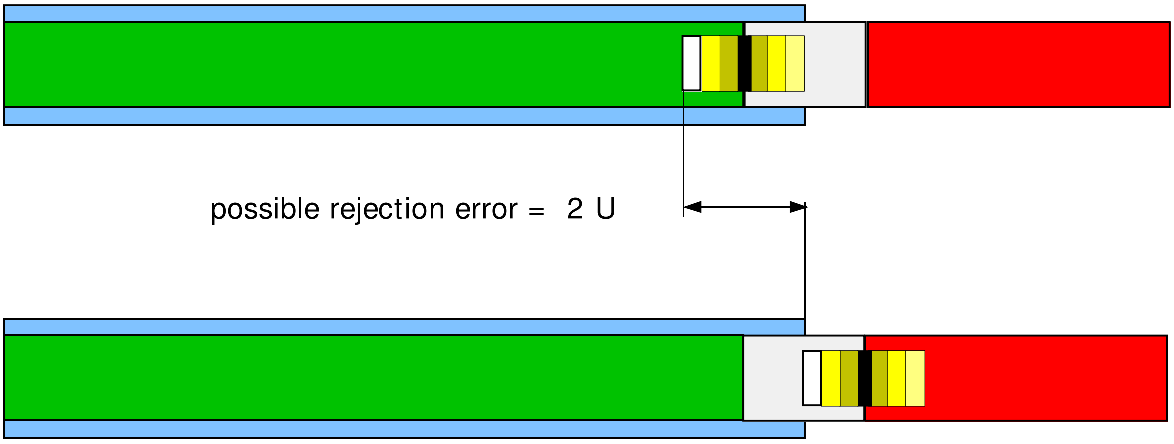


Illustration 11: Rejection error

In many cases, the acceptance of the relatively high rejection error and thus of the absolute security of accepted specimen with a possible actual value beyond the tolerance limits is appropriate, in many cases it is expensive and in some cases even impossible. For single tolerances the possible percentage of rejection errors ZI_1 is calculated from the relation of the measuring uncertainty U to the tolerance T:

$$ZI_1\,\% = 2U \cdot 100 / T$$

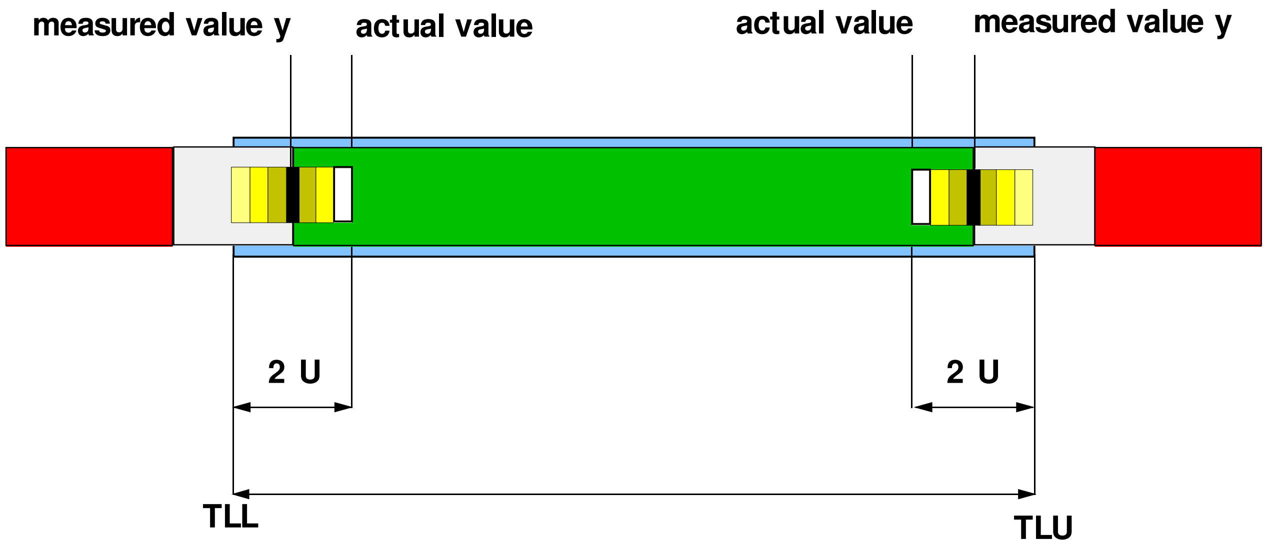
Examples for the Percental Rejection Error with Single Tolerance Limits:

Example 1: Runout Measurement of a Gear with Bore		
Clamp the gear:	on an arbour	
Clamp the arbor:	between fixed centres	
Measuring means:	Measuring stand with dial indicator and measuring ball insert	
Extended measuring uncertainty U:		0.004 mm
Specimen tolerance:		0.030 mm
Rejection error	**$ZI_1 = 2 \cdot 0.004 / 0.030 \cdot 100$**	**26.67 %**

Example 2: Measuring the Total Pitch Deviation of a Gear to the Bore		
Clamp the gear:	Three-chuck-jaw	
Measuring means:	3D - measuring machine	
Alignment:	Bore axis of the compensation cylindre	
Measuring method:	3-measuring axis	
Extended measuring uncertainty U:		0.004 mm
Specimen tolerance:		0.020 mm
Rejection error	**$ZI_1 = 2 \cdot 0.004 / 0.020 \cdot 100$**	**40 %**

Example 3: Measuring the Total Profile Deviaiton of a Master Gear to the Bore		
Clamp the master gear:	Hydraulic arbour	
Measuring means:	Gear and spline measuring machine	
Alignment:	Centres	
Measuring method:	4-measuring axis	
Extended measuring uncertainty U:		0.002 mm
Specimen tolerance:		0.005 mm
Rejection error	**$ZI_1 = 2 \cdot 0.002 / 0.005 \cdot 100$**	**80 %**

Often the possible rejection error is considerable and can even exceed 100 %. This is the latest point when it becomes obvious that arrangements between the parties are necessary. Bilateral tolerance limits shall not be dealt with in detail, just roughly. With bilateral tolerance limits the grey zones develop at both sides of the tolerance limits, and the possible rejection error is doubled.



Rejection error = 2 · 2 U = 4 U

Acceptance error = 0

Illustration 12: Rejection error with bilateral tolerance limits

The percentage of possible rejection error for bilateral tolerance limits ZI_2 is:

$$ZI_2\,\% = 4U \cdot 100 / T$$

If the rejection of specimen with measured values within the grey zone cannot be carried out and if the reduction of measuring uncertainty is not possible for economic or technical reasons, this dead-end situation can be solved by agreements. This will always be necessary if the relation of the measuring uncertainty to the tolerance is too large.

6. Graduation of the Grey Zone

If you take a close look at the grey zone you will notice that it consists of two portions. Grey Zone A is still within the tolerance, whereas Grey zone B is already beyond the tolerance.

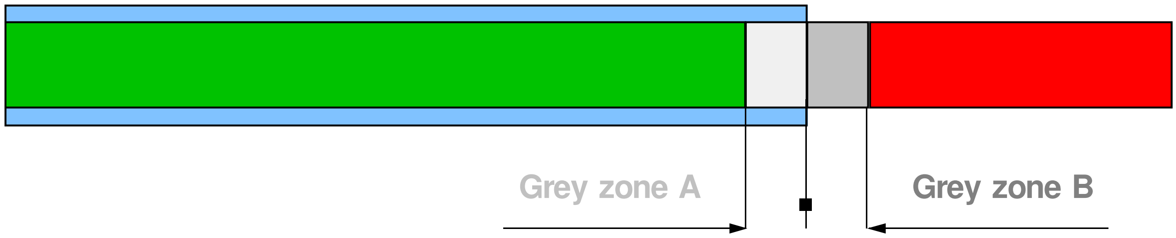


Illustration 13: Grey Zone A and B

The measured values of specimen can both be within Grey Zone A or in Grey Zone B. The measured value of specimen 1 is still within the tolerance, whereas the measured value of specimen 2 is already beyond the tolerance limit. Nevertheless, the actual values of both specimen could be either within or beyond the tolerance limit. The probability of the actual value being within the tolerance limit is clearly higher for specimen 1, compared with specimen 2.

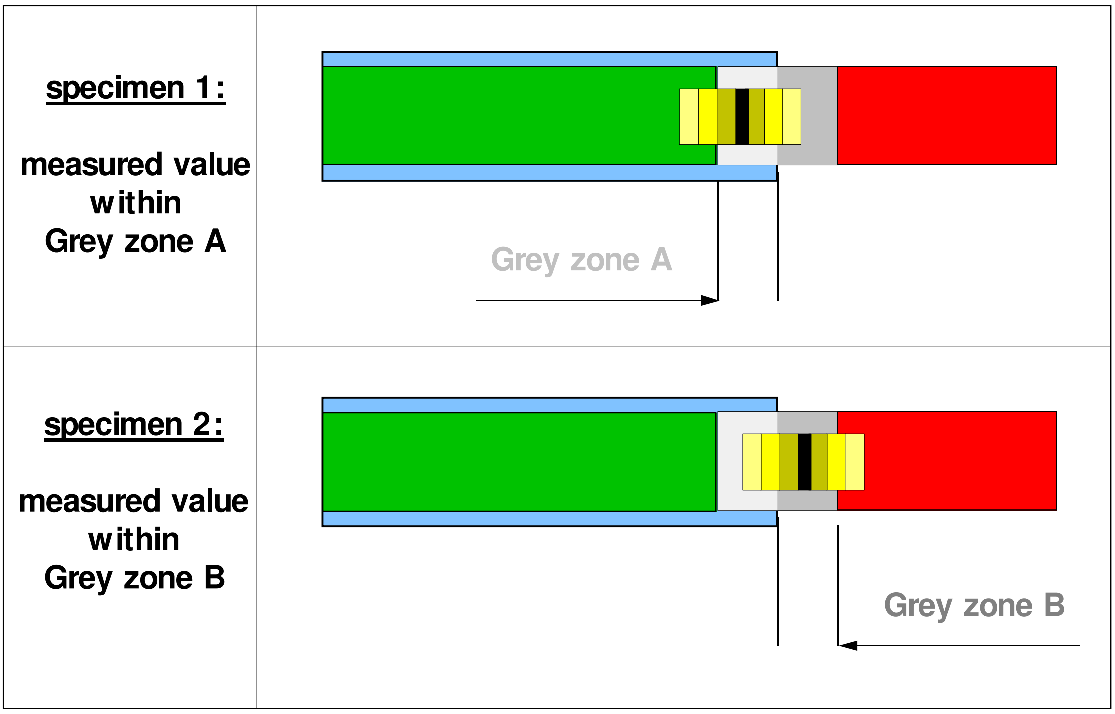


Illustration 14: Measured values within Grey Zone A and B

The actual values of specimen with measured values within **Grey Zone A** attach no risk of being allocated to the area of non-conformity. They even have the chance of falling within the area of conformity.

The actual values of specimen with measured values within **Grey Zone B** attach the risk of falling into the area of non-conformity. They have no chance of falling into the area of conformity.

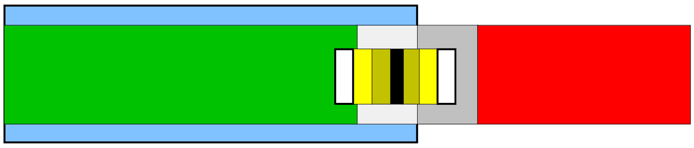
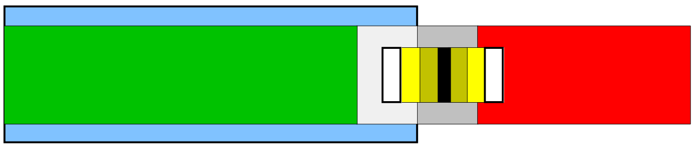
<u>specimen 1:</u> **measuerd value withinin Grey zone A, actual value from conformity to Grey zone B**	
<u>specimen 2:</u> **measuerd value withinin Grey zone B, actual value from Grey zone A to non-conformity**	

Illustration 15: Measured values and possible actual values

If, for technical or economic reasons, it makes no sense to reject specimen with measured values beyon conformity, argreements will be necessary. They can have different appearances, such as for example:

7. Agreeements A and B

Argreement A: Specimen shall only be rejected if the measured value is beyond Grey Zone A (= beyond the tolerance limit)

Agreement B: Specimen shall only be rejected if the measured value is beyond Grey Zone B (= beyond the tolerance limit extended by the measuring uncertainty)

Agreement A can create both a rejection error and an acceptance error:

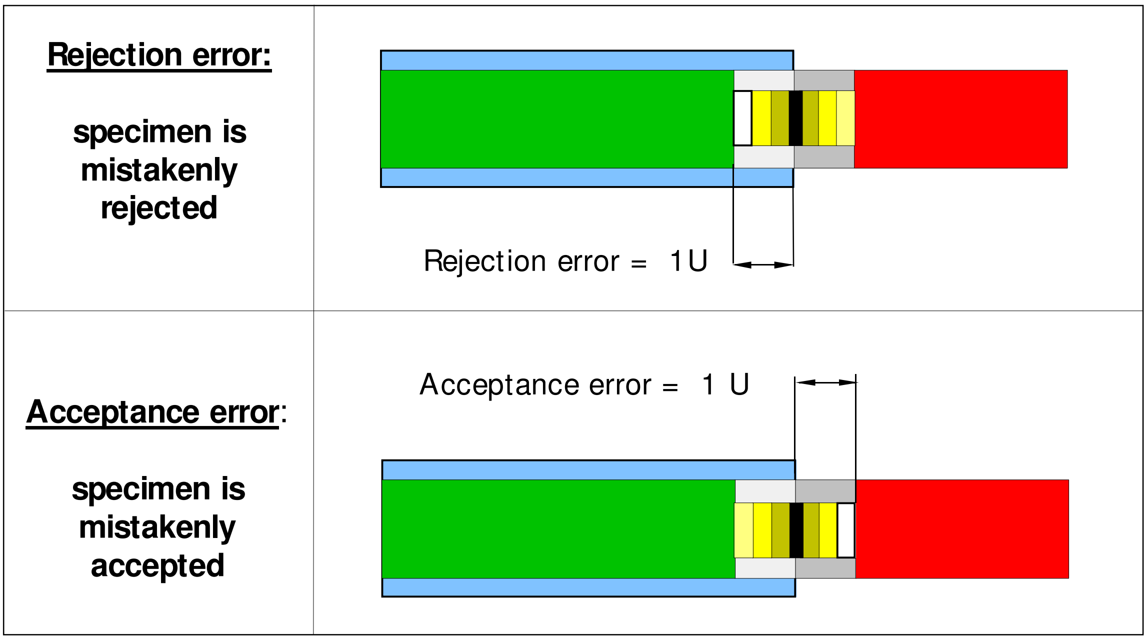


Illustration 16: Possible errors with arrangement A

Agreement B can create a possible acceptance error, only:

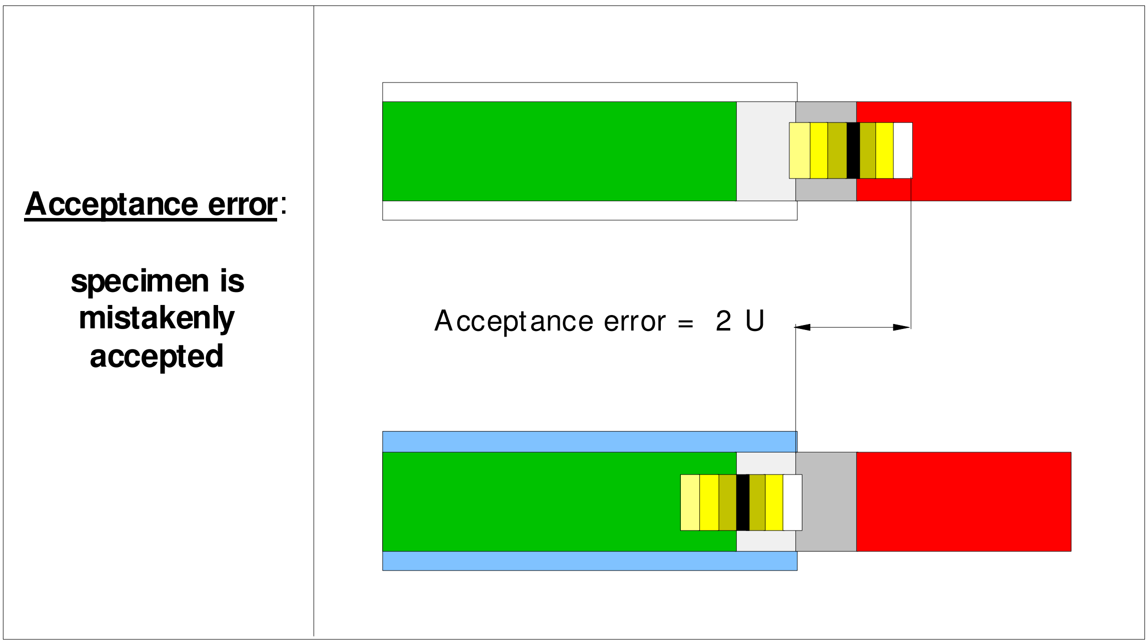


Illustration 17: Possible errors with arrangment B

Agreements always become necessary, if the possible rejection error becomes unjustifiable for technical or economic reasons, and if a possible acceptance error leads to no severe consequences.

Single Tolerance	Rejection Error	Acceptance Error
To ISO 14253	2 U	0
Agreement A	1 U	1 U
Agreement B	0	2 U

Bilateral Tolerance	Rejection Error	Acceptance Error
To ISO 14253	4 U	0
Agreement A	2 U	2 U
Agreement B	0	4 U

8. The Relation of Possible Acceptance and Rejection Errors

The relation of a possible rejection error to the tolerance determines the technical and econcomical limits for the acceptance conditions with or without arrangement.

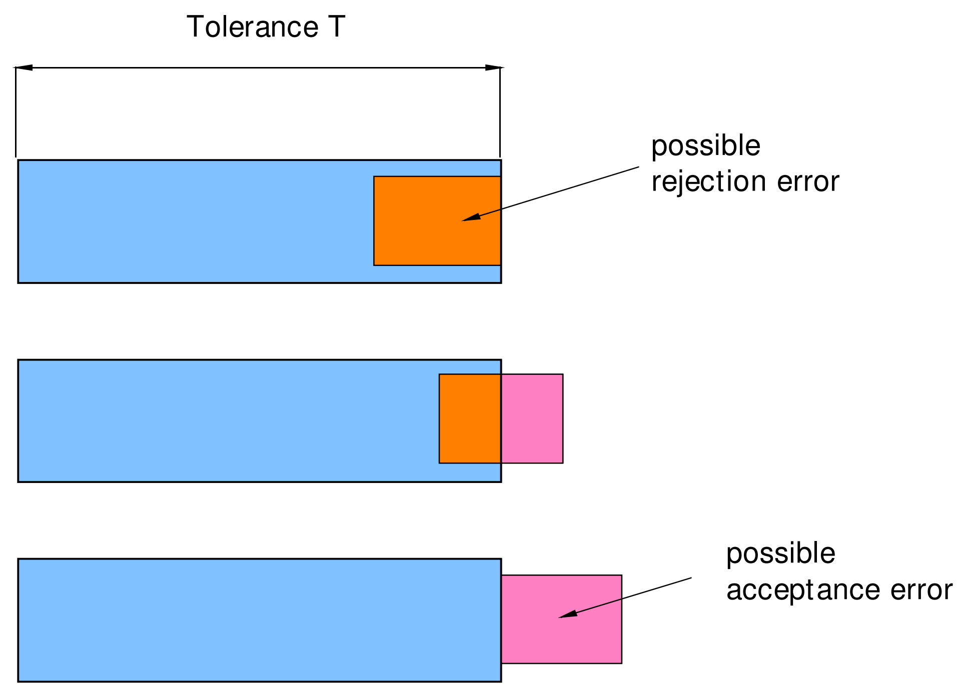


Illustration 18: Scaled representation of tolerance and error

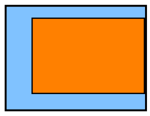
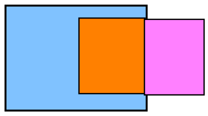
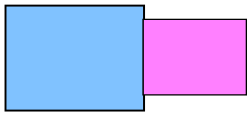
Example 1: Measurement of the Total Profile Deviation of a Master Gear to the Bore					
Measuring tolerance: 0.005 mm			Extended measuring uncertainty U.002 mm		
	Rejection error		Acceptance error		
	mm	%	mm	%	
To ISO without agreement	0.004	80	0	0	 manufacturing tolerance **0.0010mm**
Agreement A	0.002	40	0.002	40	 manufacturing tolerance 0.0030mm
Agreement B	0	0	0.004	80	 manufacturing tolerance 0.0050mm

Illustration 19: Scaled representation example 3

The possible rejection error can gain such an importance that the acceptance probability without arrangement drops towards zero, to the expenses, however, there is no end.

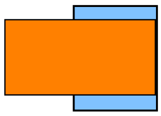
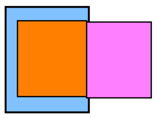
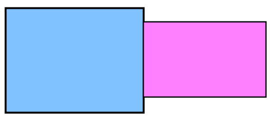
Example 3: Measurement of the Total Alignment Deviation of a Spline Gage					
Measuring tolerance: 0.0025 mm			Extended measuring uncertainty U: 0.002 mm		
	Rejection error		Acceptance error		
	mm	%	mm	%	
To ISO without agreement	0.004	160	0	0	 **no** manufacturing possible
Agreement A	0.002	80	0.002	80	 manufacturing tolerance **0.0005mm**
Agreement B	0	0	0.004	160	 manufacturing tolerance 0.0025mm

Illustration 20: Scaled representation of example 4

The dimension over balls or pins of a spline gauge serves as an example for a bilateral tolerance:

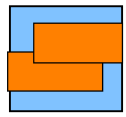
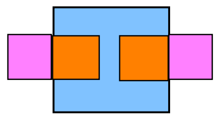
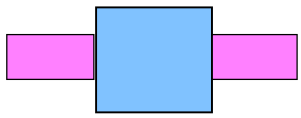
Example 3: Measurement of the Dimensions of a Spline Master Gauge					
Measuring tolerance: 0.0025 mm (ANSI B 92.1)			Extended measuring uncertainty U: 0.001 mm		
	Rejection error		Acceptance error		
	mm	%	mm	%	
To ISO without agreement	0.004	160	0	0	
Agreement A	0.002	80	0.002	80	
Agreement B	0	0	0.004	160	

Illustration 21: Scaled representation example 5

9. Priority Regulation

All toothed masters and gauges with close tolerances are manufactured as one part volume production and can only be economically measured under Agreement B. With Agreement B there is no possible rejection error, but a relatively large acceptance error. With Agreement B the probability of accepting a specimen within the area of non-conformity is given. This probability can be considerably reduced by a duplication check. If a duplication check is carried out with two similar measuring devices with identical measuring uncertainty, a priority regulation becomes necessary:

If Agreement B is applied, the latest moment of rejecting a specimen is when a second measurement shows a measured value within the range of non-conformity compared with the initial measurement.

Under Agreement B this specimen has to be rejected:

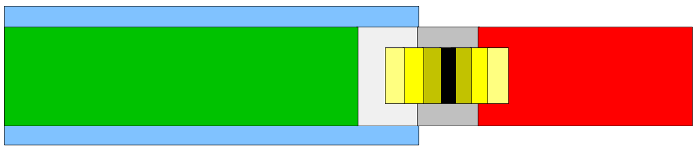
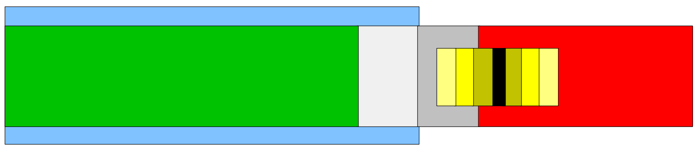
Initial inspection: Specimen is accepted	
Second inspection: Specimen is rejected	

Illustration 22: Initial and second measurement under Arrangement B

A similar procedure is also possible with Agreement A. With correct determination of the measuring uncertainty, in a second measurement with equal or less measuring uncertainty, no measured value is possible within the range of non-conformity. As a logical consequence the priority regulation under Agreement B must be:

If Agreement A is applied, the latest moment for rejecting a specimen is when a second measurement shows a measured value within Grey Zone B compared with the initial measurement.

Under Agrement A this specimen has to be rejected:

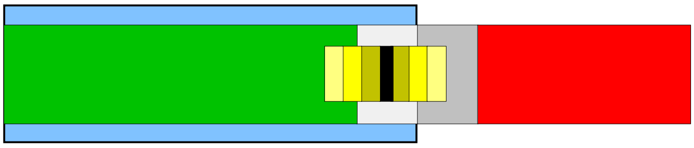
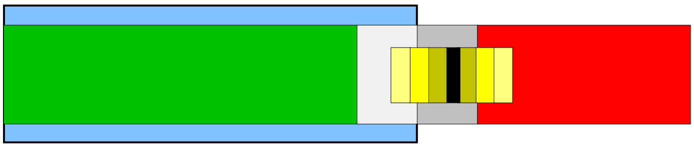
Initial inspection: Specimen is accepted	
Second inspection: Specimen is rejected	

Illustration 23: Initial and second measurement with Arrangement A

Using agreement A, the measuring uncertainty of the second measurement is very important, as the probability of finding a measured value within the greyzone B increases having larger measuring uncertainty. The measuring uncertainty, however, is without interest working with agreement B. If no agreements have been made, specimen are only accepted, if the are within the area of conformity. If the measuring uncertainty is correct, it is not possible to find a measured value in greyzone B by a second measurement. Therefore, the second measurement is not necessary.

10. Standard agreement

The manufacturing tolerances of gauges and masters for splines and gears are quite small. The smallest measuring uncertainties possible are large in relationship to the tolerances given. This relationship U / T regulates the technical and economical justifiable agreement of the rule of acceptance.

Rule of acceptance	Relationship U / T	
	One sided tolerance	**Double sided tolerance**
ISO 14253	≤ 10 %	≤ 5 %
Agreement A to FRENCO OFD 10	> 10 % ≤ 20 %	> 5 % ≤ 10 %
Agreement B to FRENCO OFD 10	> 20 %	> 10 %

At gauges and masters for splines and gears, the relationship U / T mostly is that large that only agreement B according to Frenco OFD 10 is possible. If supplier and customer have not agreed to any other rule of acceptance, the agreement B will be valid according to above table.

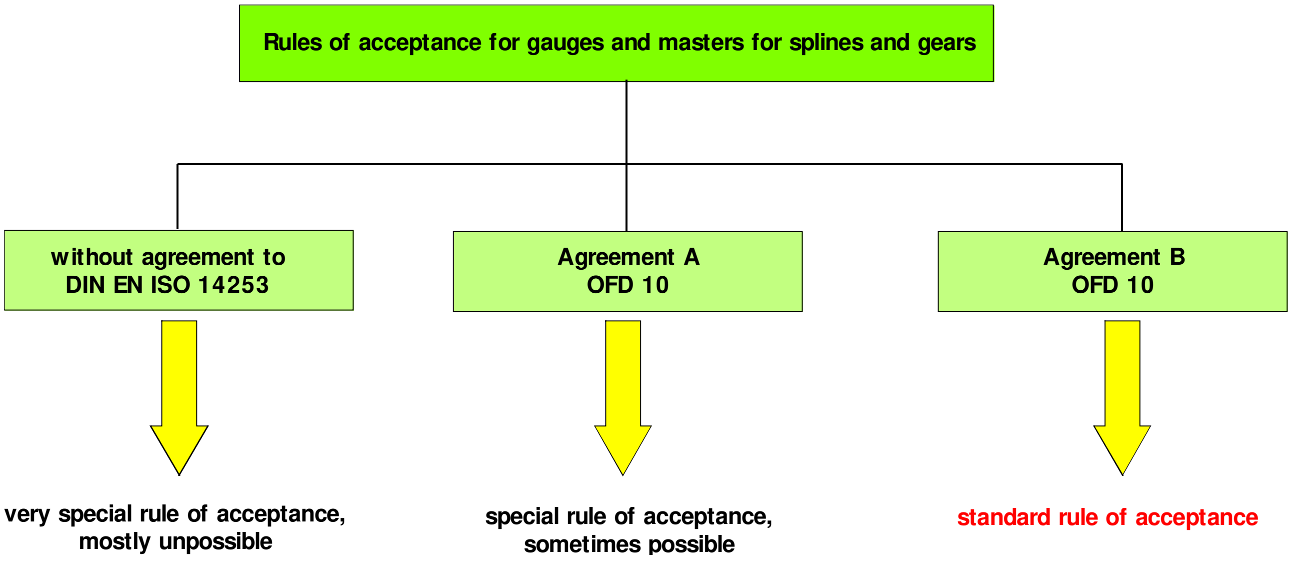
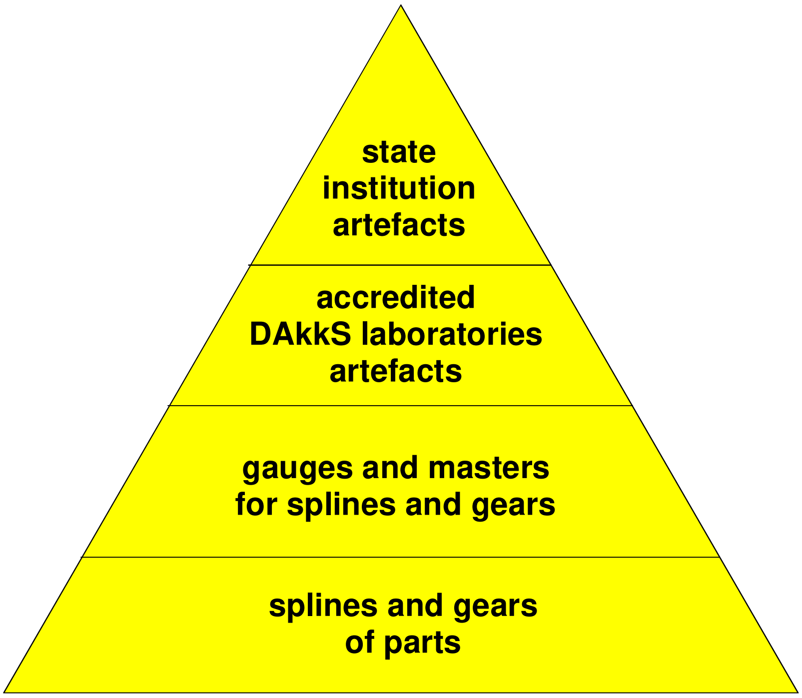


Illustration 24: Rules of acceptance

11. Determination of the Measuring Uncertainty

The procedure of determining the measuring uncertainty is defined in the GUM (Guide to the expression of uncertainty in measurement). Inspecting gears or splines, the complete theoretical calculaton of the measuring uncertainty is not possible. Artefacts are necessary as a reference. These artefacts have to be certificated by licensed laboratories. Certificates made by state institutions like PTB in Germany or NIST in USA show measured values having the smallest measuring uncertainty possible. Nobody can give smaller measuring uncertainties than these state institutions.

Using this basis, the measuring uncertainties are constructed with this row:



The calibration laboratories accredited to ISO 17025 are one step below the state institutions and the most accurate private places for measurements. They measure artefacts calibrated by the state institutions in their own facilities using their own equipment. The measuring values found are compared to those of the state institutions. The difference between both is added to the measuring uncertainty of the state institutions and gives the measuring uncertainty of the ISO accredited laboratory for this special artefact. When artifacts are measured having difference geometry a similarity value is added to the measuring uncertainty. This similarity value is calculated by the use of GUM and is prescribed for ISO 17025 accredited laboratories by the state institutions. This series of references is the basis for all given measuring uncertainties and accredited by the state institutions.

To create accredited inspection certificates is time consuming and expensive. These certificates are only made for artifacts used to calibrate inspection machines. The inspection of gauges and masters for splines and gears is made by the standard inspection laboratory. The certificates are not accredited and show measuring uncertainties not being accredited. The traceability of these measuring uncertainties is only possible, if the producer of these certificates has an accredited laboratory. Frenco has a DAkkS accredited laboratory. The shown measuring uncertainties and the relationship of U / T are shown in simplified way below:

One sided tolerances

	Feature	**U state PTB**	**U Frenco DAkkS**	**U Frenco not acc**	**tolerance DIN 3962 Q3**	**relationship U /T of U FRENCO not accr. To DIN 3962 Q3**
m=1,5 ∅ 50 mm	F_α	1,4	1,8	2,0	3,0	60 %
m=2,5 ∅ 100 mm	F_α	1,4	1,5	3,0	4,0	38 %
m=1,5 ∅ 50 mm L=40	F_β	1,5	1,9	2,0	5,0	38%
m=2,5 ∅ 100 mm L=60	F_β	1,4	1,7	3,0	6,0	28 %
m=1,5 ∅ 50 mm	F_p	0,5	0,7	2,0	7,0	10 %
m=2,5 ∅ 100 mm	F_p	0,5	0,7	2,5	10,0	7 %
m=1,5 ∅ 50 mm	f_p	0,5	0,6	2,0	2,5	24 %
m=2,5 ∅ 100 mm	f_p	0,5	0,6	2,5	2,5	24 %
α=20°-30°	F_r	0,9	1,0	2,0	6,0	17 %

* is worked on

1) estimated

The measuring uncertainty exists for both tolerance limits at double sided tolerances. This has been considered in below table.

Double sided tolerances

	feature	U PTB	U Frenco DAkkS	U Frenco not acc	Gauge tolerance ISO 4156	U FRENCO not accr. to guage tolerance ISO 4156
m=1,5 ∅ 50 mm	Tooth thickness	1,0	*	1,5[1)]	4,0	37 %
m=2,5 ∅ 100 mm	Tooth thickness	*	*	2,0[1)]	6,0	33 %

* is worked on
1) estimated

The given measuring uncertainty und the relationship to the tolerance T define the rule of acceptance. Only by using the shown basis, the series of measuring uncertainties can be designed and the suitable rule of acceptance can be found.

The existing measuring uncertainties of Frenco not accredited certificates can be shown for gauges and masters for splines and gears in simplified way:

Measuring uncertainty	0 bis 50 mm	>50 bis 150 mm	>150 bis 250 mm
Diameters	± 0.002	± 0.003	± 0.004
Size over/betw. Balls +pins	± 0.002	± 0.003	± 0.004
Form variations:	± 0.002	± 0.003	± 0.003

12. Features of individual form variations

Gauges and masters for splines and gears often are looked at like simple parts. The classes of quality are just taken from the most accurate classes for parts. Tolerances of gear standards are not valid for spline gauges. If spline standards do not show tolerances for spline gauges, those of ISO 4156 are valid. Single form tolerances needed for geared parts are not valid for master gears, just the total tolerances.

Short term	valid form variations	Not valid Form variations
F_α	Total profil variation	
F_β	Total helix variation	
F_p	Total index variation	
f_p	Single index variation	
F_r	Runout variation	
$f_{f\alpha}$		Profile form variation
$f_{H\alpha}$		Profile angle variation
$f_{f\beta}$		Helix form variation
$F_{H\beta}$		Helix angle variation
F_u		Tooth to tooth index variation

The single form variations are within the total variation. The single form variations are calculated values and just needed for geared part, not for the masters.

For master gears to DIN 58420, the tolerances of DIN 58420 cannot be used due to their crazy numbers. Those of DIN 3962, module1, Q3 are used instead.

DAkkS Deutsche Akkreditierungsstelle

Deutsche Akkreditierungsstelle GmbH

Entrusted according to Section 8 subsection1 AkkStelleG in connection with Section 1 subsection 1 AkkStelleGBV
Signatory to the Multilateral Agreements of
EA, ILAC and IAF for Mutual Recognition

Accreditation

The Deutsche Akkreditierungsstelle GmbH attests that the calibration laboratory

Frenco GmbH, Verzahnungstechnik, Messtechnik
Jakob-Baier-Straße 3, 90518 Altdorf

is competent under the terms of DIN EN ISO/IEC 17025:2005 to carry out calibrations in the following fields:

Dimensional Quantities
 Length
 - **Gear Quantities**

The accreditation certificate shall only apply in connection with the notice of accreditation of 07.03.2012 with the accreditation number D-K-15199-01 and is valid until 06.03.2017. It comprises the cover sheet, the reverse side of the cover sheet and the following annex with a total of 4 pages.

Registration number of the certificate: **D-K-15199-01-00**

Braunschweig, 07.03.2012

Dr. Michael Wolf
Head of Division

This document is a translation. The definitive version is the original German accreditation certificate.

See notes overleaf.

DAkkS Deutsche Akkreditierungsstelle

Deutsche Akkreditierungsstelle GmbH

Anlage zur Akkreditierungsurkunde D-K-15199-01-00
nach DIN EN ISO/IEC 17025:2005

Gültigkeitsdauer: 07.03.2012 bis 06.03.2017

Urkundeninhaber:

Frenco GmbH, Verzahnungstechnik, Messtechnik
Jakob-Baier-Straße 3, 90518 Altdorf

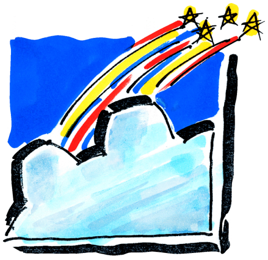
Leiter:	Dipl.-Ing. (FH) Jan Kühl
Stellvertreter:	Dipl.-Ing. (FH) Thomas Peter Jürgen Stellwag

Akkreditiert als Kalibrierlabor seit: 17.04.2000

Kalibrierungen in den Bereichen:

Dimensionelle Messgrößen
 Länge
 - **Verzahnung**

FRENCO Product Lines



Gear and spline high precision

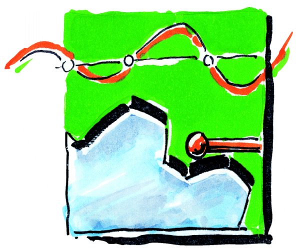
Spline Gages
Master Gears and master wheels
Setting masters
Punches, dies and electrodes
Gear and spline clamping systems
Gear and spline manufacturing

Instruments for size inspection Series V

VK Measuring ball inserts and pins
VA Instruments for rocking
VP Instruments with face stop
VM Indicating Gages with guiding profile
VS Customized solutions
VD Variable 3-Disc Gages

Universal Rotation Measuring Systems URM

URM - K with balls and pins
URM - R with master wheels
URM - WE for single flank gear rolling
URM - WZ for double flank gear rolling
URM - WS Gear Rollscan



Gear and spline inspection

DAkkS Calibrations of artefacts
Inspection of parts
Analysis of deviations
Wear inspection of gages and masters

Know-how Transfer

Software
Training, seminars and workshops
Consulting and calculations
Literature and documents
National and international standards work

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gear + spline technology
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