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IC-Gear Artefacts

The solution to determine the measurement uncertainty

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General Information

Artefacts should be geometrically similar to the test pieces. (= identity condition)

IC Artefacts

A new approach to gear artefacts or the solution to an old problem?

The design of conventional artefacts differs strongly from that of the actual test pieces. There is no similarity, let alone an identity condition.

IC artefacts can be constructed such that they have a similar gear profile to the test pieces. This is the precondition which is required to estimate the measurement uncertainty when measuring test pieces on gear inspection machines.

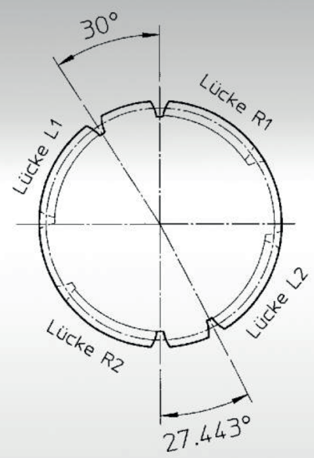
IC artefacts are feasible in all kinds of design. They can be made for running gears, external and internal gears with different modules and pitch circle diameters as well as for splines. Their geometric size can be matched to small plastic gears and HGV gears.

Artefacts should embody all important gear features

↓

Combination of artefacts

Normal A

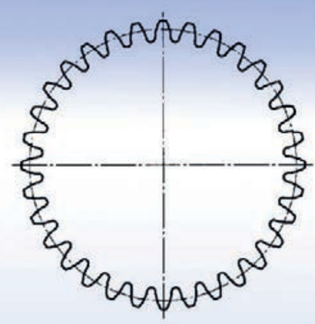


2 opposing tooth spaces R1 and R2 with a right hand helix angle based on z = 32

Two opposing tooth spaces L1 and L2 with a left hand helix angle based on z = 33

Certificate for:
Profile
Tooth trace
Dimension over balls R1 . R2
Dimension over balls L1 – L2

Normal B



Composite spur gearing

Certificate for:
Profile
Tooth trace
Runout
Single pitch
Total pitch
Dimension over balls

Spur gears	+	**Helical gears**
Sector gears	+	**Composite gears**
Left flank	+	**Right flank**
A tooth space	+	**Opposite tooth space**
Even number of teeth	+	**Odd number of teeth**

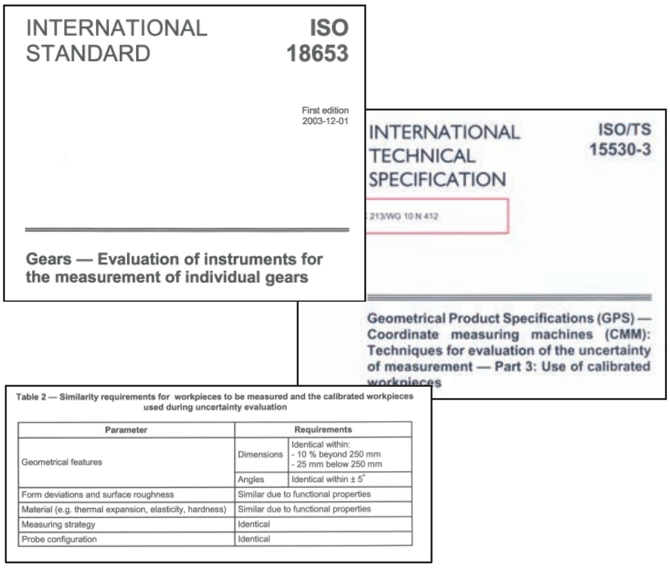
Combinations of IC artefacts provide a comprehensive evaluation of accuracy deviations for the features illustrated on the right.

Profile deviation:	Spur gears and helical gears with left and right hand helix angles
Tooth trace deviation:	Spur gears and helical gears with left and right hand helix angles
Pitch deviation:	Single pitch and total pitch
Runout deviation:	Runout, axial position and roundness
Dimension over two balls:	Odd and even number of teeth on straight and helical gearing

Determining the Measurement Uncertainty

Measurement uncertainty during gear measurements is mostly unknown in the industry. The theoretical calculation of the measurement uncertainty through budgets for industrial gear measurements has not yet been worked out.

ISO 18653 describes possible estimations of gear measurement uncertainty by means of workpiece-like artefacts. This procedure is applied on page 5 in this brochure.
Prerequisite of this method is the compliance of the identity condition between the artefacts and the workpieces to be inspected. The conditions are described in ISO/TS 15530-3.
The validity of the identity condition for gears and splines is not defined in the standards illustrated on the right. It could, however, be defined as follows:


INTERNATIONAL STANDARD — ISO 18653

First edition 2003-12-01

Gears — Evaluation of instruments for the measurement of individual gears

INTERNATIONAL TECHNICAL SPECIFICATION — ISO/TS 15530-3

213/WG 10 N 412

Geometrical Product Specifications (GPS) — Coordinate measuring machines (CMM): Techniques for evaluation of the uncertainty of measurement — Part 3: Use of calibrated workpieces

Table 2 — Similarity requirements for workpieces to be measured and the calibrated workpieces used during uncertainty evaluation

Parameter	Requirements	
Geometrical features	Dimensions	Identical within: - 10 % beyond 250 mm - 25 mm below 250 mm
	Angles	Identical within ± 5°
Form deviations and surface roughness	Similar due to functional properties	
Material (e.g. thermal expansion, elasticity, hardness)	Similar due to functional properties	
Measuring strategy	Identical	
Probe configuration	Identical	

Pitch circle ø in mm	from 10 to 40	from 40 to 80	from 80 to 120	from 120 to 180
Pitch circle ø	± 10	± 15	± 20	± 25
Number of teeth	± 40	± 30	± 25	± 20
Module	± 0,5	± 1,0	± 1,5	± 2,0
Pressure angle	± 10°	± 10°	± 10°	± 10°
Helix angle	± 15°	± 15°	± 15°	± 15°

The experimental estimation of the measurement uncertainty of gear measurements will be successful if these conditions are complied with:

- Geometrical similarity of artefacts and workpieces
- Material similarity of artefacts and workpieces
- Identical ambient conditions
- Identical measurement strategy
- Identical probe configuration

Limitation

The experimental estimation of the measurement uncertainty does not include influences of form deviations and surface roughness of the workpieces. The measurement uncertainty does therefore only apply to the precise position where the measurement was carried out and not to the gear as a whole.
In order for it to apply to the entire workpiece, the influences of form deviations and surface roughness must be determined separately and added to the measurement uncertainty.

Additional prerequisite

The artefacts to be used are calibrated with sufficient accuracy. The actual dimensions and actual form deviations and their measurement uncertainties are known. The exact positions on the artefact, where the actual values were determined, are also known. This data is given on the calibration certificate that is supplied with the IC artefact. DAkkS (Deutsche Akkreditierungsstelle GmbH - German Accreditation Body) calibration certificates are currently issued for IC artefacts A and B in line with the accredited parameters.

1. Determination of the standard uncertainty of a feature on the calibrated IC artefact u_c:

The artefact is measured under the same ambient conditions, with the same measurement strategy and probe configurations as the workpiece. All measurement values are documented. The measurement is repeated at least 10 times having regard to the normally occurring variations in temperature and other changes in the measurement conditions (e.g. clamping/unclamping).

$$u_c = \frac{U_c}{2}$$

U_c - Expanded measurement uncertainty of the calibration of the IC artefact

u_c - Standard uncertainty of the calibration of the IC artefact

2. Determination of the standard uncertainty u_p:

Determination of the arithmetic average of individual measurements

$$\bar{y} = \frac{y_1 + y_2 + \ldots + y_n}{n}$$

y_i - Measurement results during the evaluation of uncertainties

$\bar{y}$- arithmetic average of all measurement results y_i

n - Number of individual measured values

The standard uncertainty up is then calculated with the known formula of the standard deviation:

$$u_p = \sqrt{\frac{1}{n-1} \cdot \sum_{i=1}^{n} (y_i - \bar{y})^2}$$

u_p - Standard uncertainty of the measurement process

3. Determination of the systematic deviation b:

To calculate the systematic deviation, the actual value of artefact x_c is compared to the arithmetic average of all measurement results y_i.

$$b = \bar{y} - x_c$$

b - Systematic deviation, identified during the evaluation of uncertainties

x_c - Calibrated value of a parameter of the IC artefact

4. Determination the measurement uncertainty U:

The estimated expanded measurement uncertainty, determined by this experimental method, therefore is:

$$U = 2 \cdot \sqrt{u_c^2 + u_p^2 + b^2}$$

U - Expanded measurement uncertainty, determined experimentally

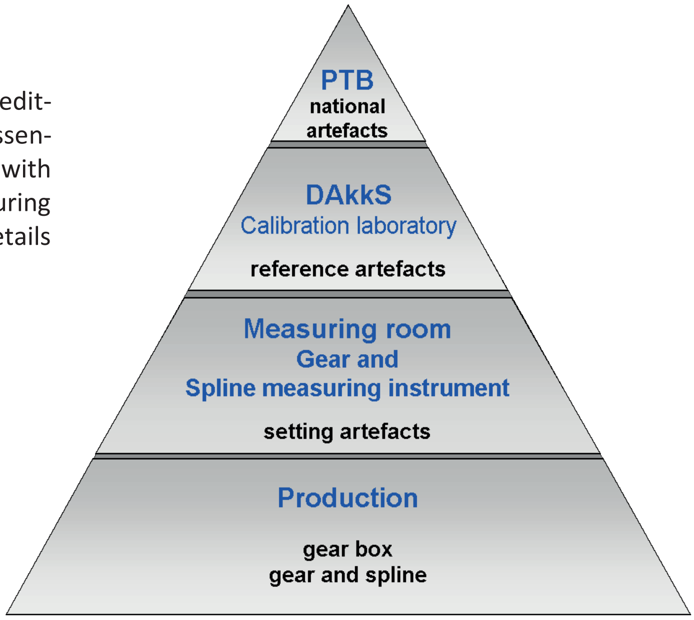
Notes:
The influence of the workpiece is ignored.
The systematic deviation is integrated into the quadratic summation in the form of measurement uncertainty contribution (Source: F. Härtig, M. Krystek; Correct treatment of systematic errors in the evaluation of measurement uncertainty; Proceedings of ISMTII-2009, Volume 1. St. Petersburg, p. 1-106 et sqq. Russia, 2009)

IC Artefacts with DAkkS Calibration Certificate

The calibration laboratory of FRENCO GmbH was accredited by DAkkS as conformity assessment body for all essential gear features (DK-15199-01-00), in accordance with DIN/ISO 17025. The accreditation is given for measuring zones, which are most commonly required. Further details on the scope of the accreditation can be viewed on

http://www.dakks.de/as/ast/d/D-K-15199-01-00e.pdf.

Artefacts outside the specified scope can be factory calibrated.



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akkreditiert durch die / *accredited by the*

Deutsche Akkreditierungsstelle GmbH

als Kalibrierlaboratorium im / *as calibration laboratory in the*

Deutschen Kalibrierdienst DKD

Kalibrierschein
Calibration certificate

Kalibrierzeichen
Calibration mark

000143
D-K-15199-01-00
2011-06

Gegenstand *Object*	IC-Normal Bm für Profil, Flankenlinie, Teilung, Rundlauf und M_{dK}
Hersteller *Manufacturer*	FRENCO GmbH, Jakob-Baier-Straße 3, 90518 Altdorf
Typ *Type*	d = 105.000 mm; ß = 0°
Fabrikat/Serien-Nr. *Serial number*	53872 00 01 00
Auftraggeber *Customer*	Muster GmbH, Messstraße 1, D-04711 Scheinheim
Auftragsnummer *Order No.*	20119999
Anzahl der Seiten des Kalibrierscheines *Number of pages of the certificate*	7
Datum der Kalibrierung *Date of calibration*	24.06.11

Dieser Kalibrierschein dokumentiert die Rückführung auf nationale Normale zur Darstellung der Einheiten in Übereinstimmung mit dem Internationalen Einheitensystem (SI).
Die DAkkS ist Unterzeichner der multilateralen Übereinkommen der European co-operation for Accreditation (EA) und der International Laboratory Accreditation Cooperation (ILAC) zur gegenseitigen Anerkennung der Kalibrierscheine.
Für die Einhaltung einer angemessenen Frist zur Wiederholung der Kalibrierung ist der Benutzer verantwortlich.
This calibration certificate documents the traceability to national standards, which realize the units of measurement according to the International System of Units (SI).
The DAkkS is signatory to the multilateral agreements of the European co-operation for Accreditation (EA) and of the International Laboratory Accreditation Cooperation (ILAC) for the mutual recognition of calibration certificates.
The user is obliged to have the object recalibrated at appropriate intervals.

Dieser Kalibrierschein darf nur vollständig und unverändert weiterverbreitet werden. Auszüge oder Änderungen bedürfen der Genehmigung sowohl der Deutschen Akkreditierungsstelle GmbH als auch des ausstellenden Kalibrierlaboratoriums. Kalibrierscheine ohne Unterschrift haben keine Gültigkeit.
This calibration certificate may not be reproduced other than in full except with the permission of both the Deutsche Akkreditierungsstelle GmbH and the issuing laboratory. Calibration certificates without signature are not valid.

Datum *Date*	Leiter des Kalibrierlaboratoriums *Head of the calibration laboratory*	Bearbeiter *Person in charge*
24.06.11	Dipl. Ing (FH) J. Kühl	J. Stellwag

Frenco GmbH Verzahnungstechnik
DAkkS Kalibrierlaboratorium für Verzahnungsmessgrößen
Jakob-Baier-Str. 3 – 90518 Altdorf
Tel. +49(0)9187 9522-0 – Fax. +49(0)9187 9522-40
Internet www.frenco.de – E-Mail info@frenco.de

DAkkS (Deutsche Akkreditierungsstelle GmbH - German Accreditation Body) calibration certificates are currently issued for IC artefacts A and B as well as for conventional artefacts type 100, in line with the accredited parameters.
DAkkS calibrated artefacts ensure the traceability to the SI unit "metre" and form part of the traceability chain to the national artefact.

The following parameters are calibrated, depending on the design:

- Profile deviation
- Tooth trace deviation
- Pitch deviation
- Runout deviation
- Dimension over two balls

The following details are described (explicitly and in form of an image) on the DAkkS calibration certificate:

- measurement conditions
- alignment planes for the determination of the reference axes
- measuring planes
- and the reference plane.

DAkkS calibration certificates are available in German and English.

Seite 2
Page

000143
D-K-15199-01-00
2011-06

1 Profil und Flankenlinie
1.1 Kalibrierverfahren
Das Verzahnungsnormal wurde auf einem Verzahnungsmessgerät kalibriert, dessen Abweichungen durch eine messaufgabenspezifische Kalibrierung mit PTB-kalibrierten Normalen ermittelt wurde, um die gemessenen Werte für F_α, $f_{H\alpha}$ und F_β und $f_{H\beta}$ zu korrigieren.

1.2 Messbedingungen
Bei der Kalibrierung des Verzahnungsnormales wurden die Referenzachsen durch die Mittelpunkte zweier Kreise bestimmt. Die Kreismittelpunkte wurden aus je einer Rundlaufmessung berechnet, deren Messebenen sich auf den Mantelflächen der beiden Zylinder mit den Durchmessern 58.0 mm befanden. Die Messebenen der Rundlaufmessungen lagen nach oben 24.5 mm und nach unten 148.5 mm von der Messebene entfernt. (siehe auch Bild 1 / Ausrichthöhen P1)

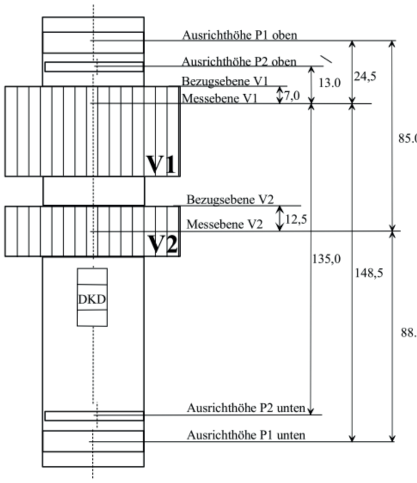

Bild 1: Lage der Bezugsebene und der Messebene (P= Prüfbund / V= Verzahnung)

Die Bezugsebene des Normales ist die Stirnfläche der Verzahnung, auf der die Zähne beschriftet sind (siehe Bild 1). Durch die Prüfkurven wurden Regressionsgeraden nach der Methode der kleinsten Fehlerquadratsumme gelegt.

Verwendete Verzahnungsdaten und Auswertebereiche

Schrägungs -winkel ß [°]	Teilkreis-durchmesser d_0 [mm]	Grundkreis-durchmesser d_b [mm]	Zahnfuß-Wälzlänge L_f [mm]	Zahnkopf-Wälzlänge L_a [mm]	Profil-Prüfbereich L_α [mm]	Flanken-linien-Prüfbereich L_β [mm]	Auswerte-bereich $f_{H\beta}$ [mm]
0	84.000	80.112	9.2	18.2	9.0	28.0	28.0

1.4 Messergebnisse
In den nachfolgenden Tabellen sind die Messergebnisse aufgeführt. Es sind Mittelwerte aus mehreren Messungen.

Flankenlinie

Schrägungswinkel ß [°]	Flanke Nr.	Flankenlinien-Gesamtabweichung F_β [µm]	*Flankenlinien-Winkelabweichung* $f_{H\beta}$ [µm]	Flankenlinien-Formabweichung $f_{f\beta}$ [µm]
Verzahnung V1				
0	1R	1.3	R1.2	0.6
0	2L	1.2	R0.9	0.5

1.5 Messunsicherheit
In der nachfolgenden Tabelle sind die erweiterten Messunsicherheiten für die vorgenannten Messergebnisse aufgeführt.

Flankenlinie

Schrägungswinkel ß [°]	Messunsicherheit U für F_β [µm]	Messunsicherheit U für $f_{H\beta}$ [µm]	Messunsicherheit U für $f_{f\beta}$ [µm]
0	2.1	1.8	1.0

The gear data, calibration values and measurement uncertainties used for the calibration are presented in tabular form.

The inspection records / graphical representation of the measuring results are given in the appendix of the calibration certificate.

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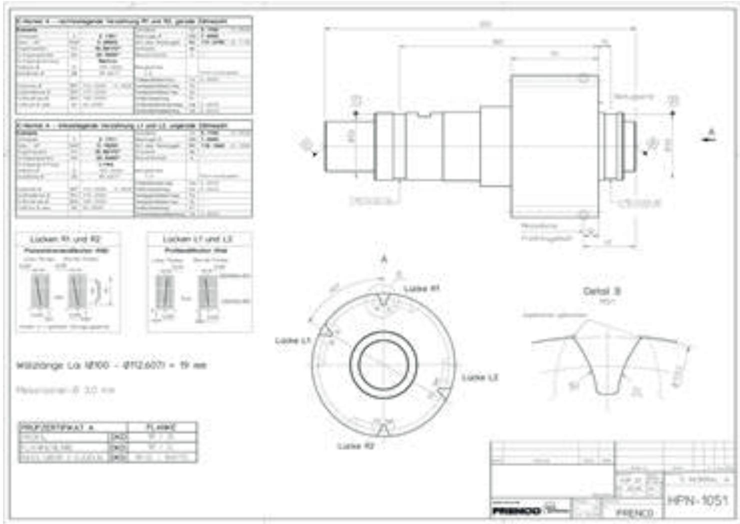
Artefact A



Example

Normal module:	3.5
Base circle:	98.6677
Pressure angle:	20°
Helix angle:	20°R/20°L
Number of teeth:	30/31

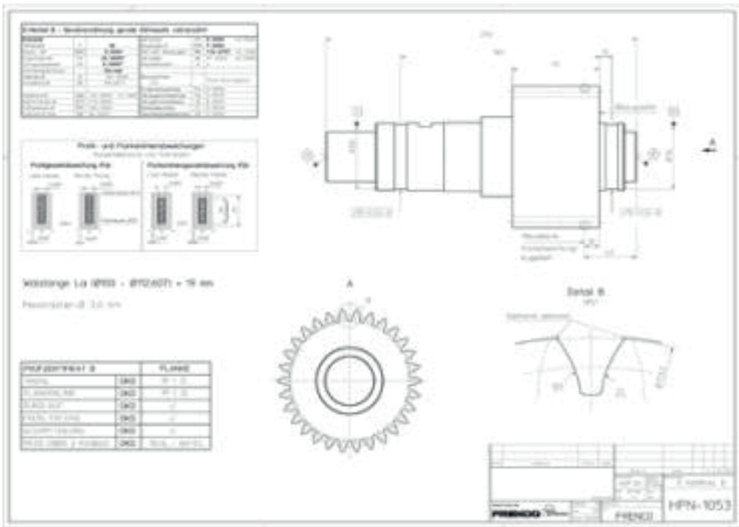
3 helix angles (in addition to 0°) are possible.

Artefact A and B can be customised to meet specific requirements:

...as gears, module 1.2

...as gears, module 2

Artefact B



Example

Module:	3.5
Base circle:	98.6677
Pressure angle:	20°
Helix angle:	0°
Number of teeth:	30

...as gears, module 3

...as splines, module 1.5

Combination Artefact A/B

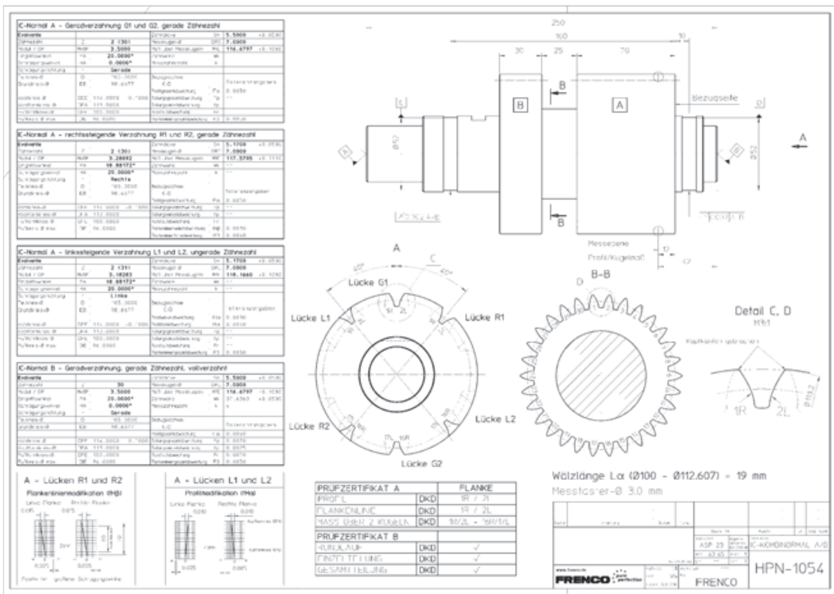
Subject to the space available, three helix angles can be machined to artefact A. The artefact will then feature six spaces with three helix angles (0° / +X° / -X°) to calibrate the parameters profile, tooth trace and dimension over balls.

Artefact B is then only required for monitoring the pitch and runout and only requires a narrow profile width. Artefact B can be attached “piggyback” to artefact A, if the latter has been prepared accordingly.

Users are provided with a complete gear artefact which embodies all essential gear features in one artefact.

Example

Module:	3.5
Base circle:	98.6677
Pressure angle:	20°
Helix angle:	0°/20°R/20°L
Number of teeth:	30/31



The combination artefact A/B can be customised to meet specific requirements:

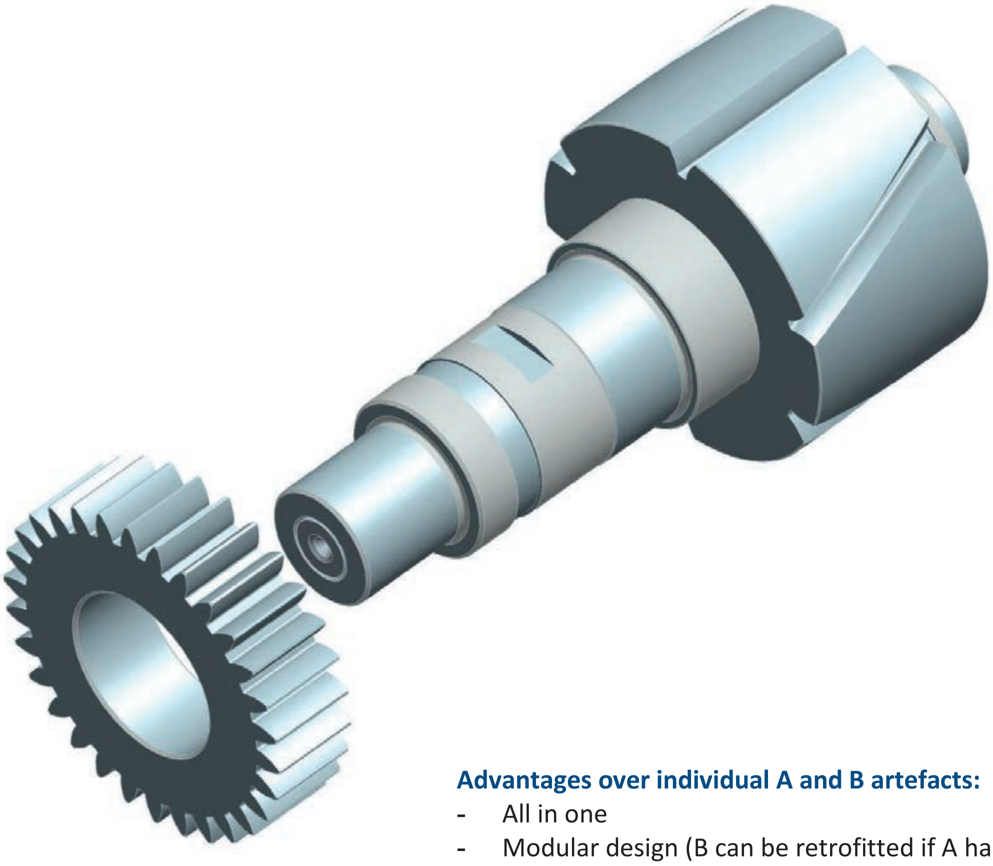
IC concept:

The combination artefact is, with regard to the gear data, adapted, as far as possible, to the customer base (Identical Conditions).

Artefact B can be furnished with defined pitch errors in order to test probe deflections.

Modular Design:

The basic body of an A artefact can be designed in such a way that artefact B can be retrofitted at a later date. This is an option for customers whose current focus is on the profile and tooth trace but may, in future, require a pitch artefact.



Advantages over individual A and B artefacts:

- All in one
- Modular design (B can be retrofitted if A has been prepared accordingly)
- Lower acquisition costs compared to two individual artefacts

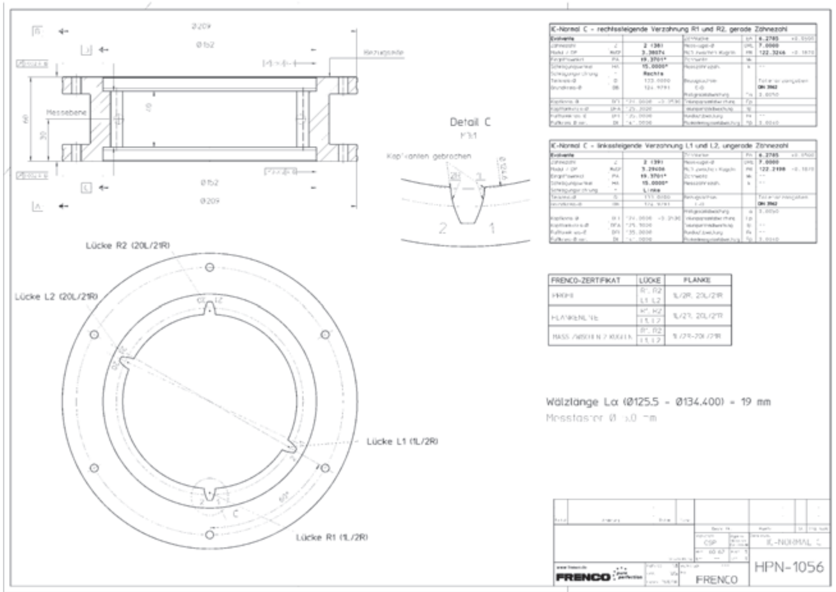
Disadvantages:

- Cannot be reground
- Higher weight

Artefact C

Example

Normal module:	3.5
Base circle:	124.9791
Pressure angle:	20°
Helix angle:	15°R/15°L
Number of teeth:	38/39



Internal gear artefacts are virtually unknown. FRENCO can manufacture high precision internal gear profiles with helix angles.
This makes it possible for the first time to compare the quality of gear inspection machines when measuring internal gearing.

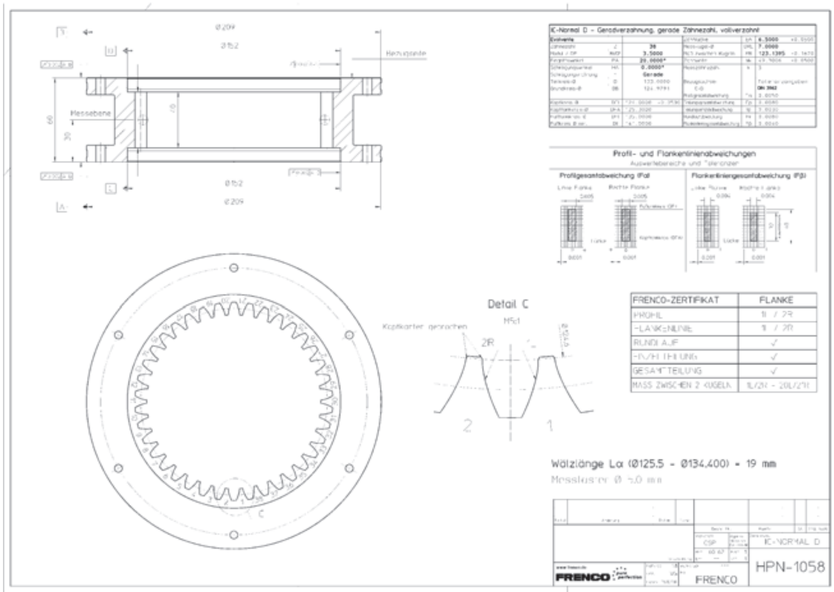
Artefact C:

With two helix angles in four spaces for the calibration of profiles, tooth traces and the internal dimension over balls. Odd and even numbers of teeth are taken into consideration.
three helix angles (in addition to 0°) are possible.

Artefact D

Example

Normal module:	3.5
Base circle:	124.9791
Pressure angle:	20°
Helix angle:	0°
Number of teeth:	38



Internal gear artefacts are designed symmetrically and can be used for simple reversal measurements.
The gear profile is designed such that a 1.5 mm probe can be used to measure using the gear-generating method or the track measurement method (coordinate method).

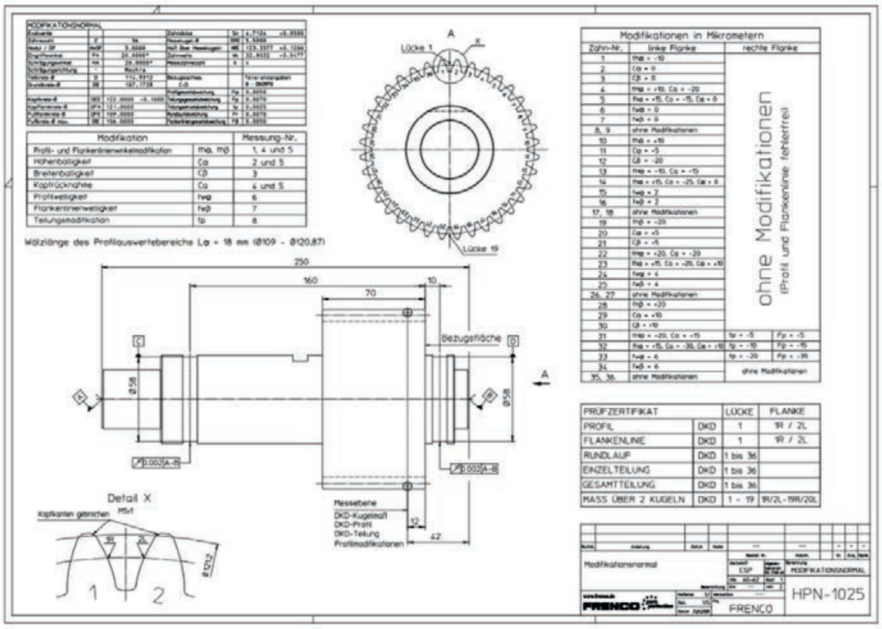
The DAkkS accreditation for internal gearing is still in preparation.

Artefact D:
Composite and spur toothed for the calibration of profile, tooth trace, internal dimension over balls as well as pitch and runout.

Modification Artefact M

2/80/17.5°

Modul:	2.25
Base circle:	90
Pressure angle:	17.5°



How are modifications displayed at the measuring machine?
How are relieves analysed?
What does a pitch error look like?
Which filters react how to waviness on the profile and the flank?
How do measuring systems of different manufacturers react?

Questions that even we may not always know the answers to. The modification artefact (M) can help you in finding the answers. Different modifications such as crowning, relieves, angle errors, waviness and pitch errors have each been applied to one flank. Modification artefacts can be manufactured as described, or in accordance with your individual requirements. They are used for comparative measurements, long-term monitoring and for training purposes.

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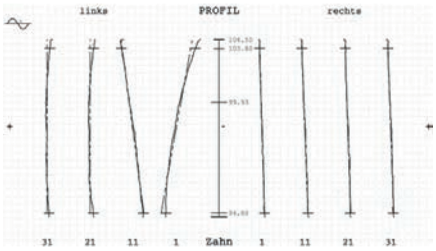
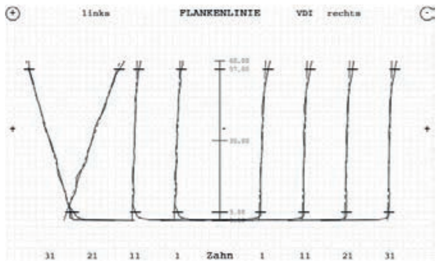
Measurement Results M

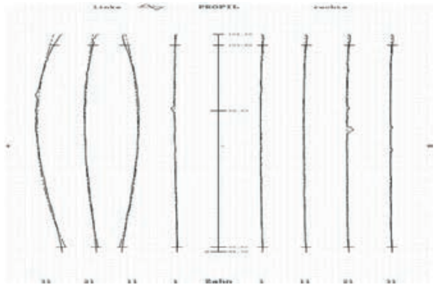
Messung 1	Modifikation	Zahn-Nr.	fHα, µm
	Profilwinkelabweichung (fHα) fHα, Kopfformkreis (DFA), Fußformkreis (DFE), Zahn, − 0 +	1	-10
		11	+10



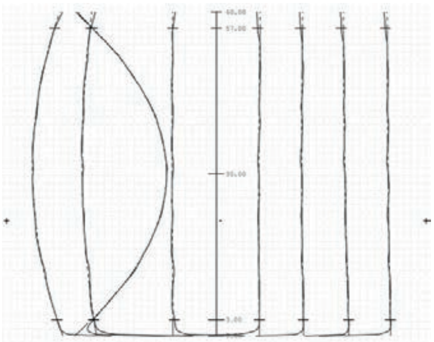
Messung 1	Modifikation	Zahn-Nr.	fHβ, µm
	Flankenlinienwinkelabweichung (fHβ) fHβ, Zahn, 50, Auswertebereich, Zahnbreite, + 0 − *) Positiv (+) = größerer Schrägungswinkel	21	-20
		31	+20



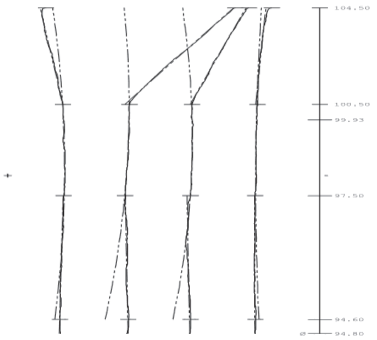
Messung 2	Modifikation	Zahn-Nr.	Cα, µm
	Höhenballigkeit (Cα) Cα, Kopfkreis (DEE), Fußformkreis (DFE), Zahn, − 0 +	2	0
		12	-5
		22	+5
		32	+10



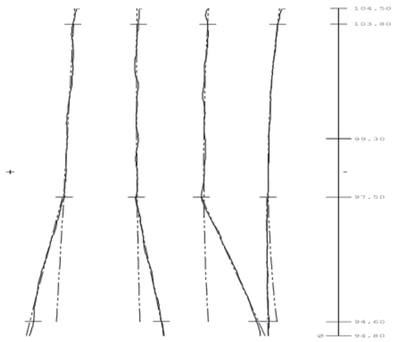
Messung 3	Modifikation	Zahn-Nr.	Cβ, µm
	Breitenballigkeit (Cβ) Cβ, Zahn, Zahnbreite, − 0 +	3	0
		13	-35
		23	+5
		33	+10



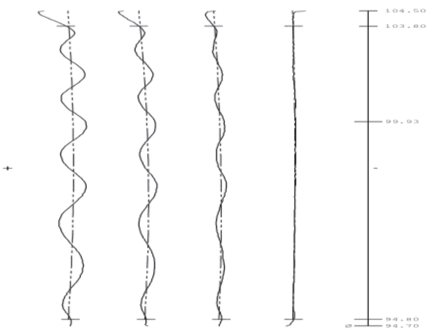
Messung 4	Modifikation	Zahn-Nr.	Ca, µm
	Kopfrücknahme (Ca) Ca, Kopfformkreis (DFA), Ø100.5 (Beginn Kopfrücknahme), Fußformkreis (DFE), Zahn, − 0 +	4	0
		14	-10
		24	-20
		34	+5



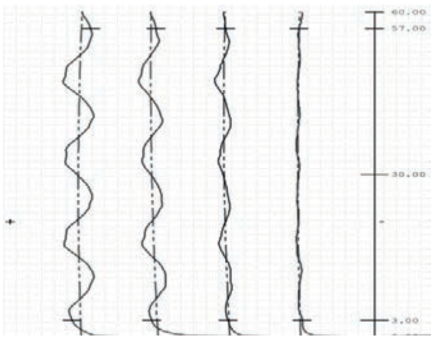
Messung 5	Modifikation	Zahn-Nr.	Cf, µm
	Fußrücknahme (Cf) Cf, Kopfformkreis (DFA), Ø97.5 (Beginn Fußrücknahme), Fußformkreis (DFE), Zahn, − 0 +	5	0
		15	-10
		25	-5
		35	+5



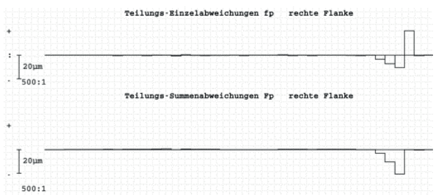
Messung 6	Modifikation	Zahn-Nr.	fwα, µm
	Profilwelligkeit (fwα) fwα, Kopfformkreis (DFA), 2, Fußformkreis (DFE), Zahn, − 0 +	6	0
		16	2
		26	4
		36	6



Messung 7	Modifikation	Zahn-Nr.	fwβ, µm
	Flankenlinienwelligkeit (fwβ) fwβ, 15, Zahnbreite, Zahn, − 0 +	7	0
		17	2
		27	4
		37	6



Messung 8	Modifikation	Zahn-Nr.	fp, µm
	Teilungsmodifikation (fp) linke Flanke, rechte Flanke, 35, 36, 37	35	-5
		36	-10
		37	-20



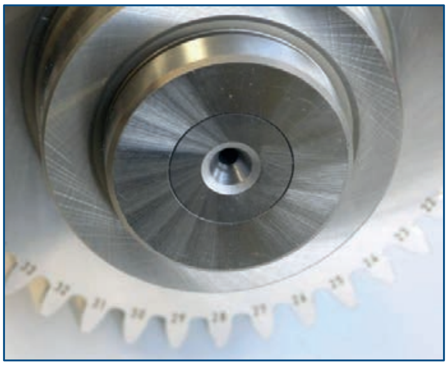
Special Features

Protected inspection / aligning collars

- It is hence apparent where the reference axis will be generated
- High precision concentricity of approx. 1...2 µm ensures very high repeatability.

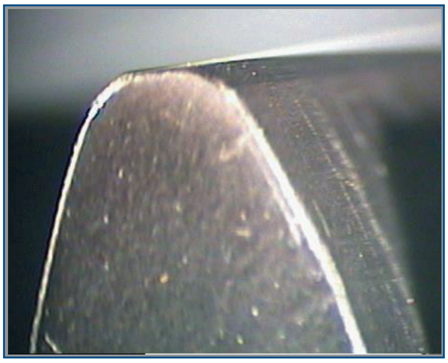
Carbide centres for long-term stability

- Frenco recommends single-end clamping in a chuck
- If the workpiece is clamped between centres, the carbide centres will ensure high repeatability



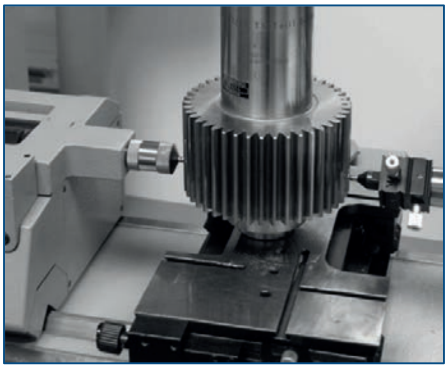
Chamfered tips

- Protecting the involutes in the tip area - to avoid having to recalibrate the artefact after each small knock.



Measured dimension over balls

- The dimensions over balls given in the inspection certificate are not the results of some calculations, but have actually been measured on the length measuring instrument.



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FRENCO GmbH
Gear + Spline Technology
Jakob-Baier-Str. 3 • D - 90518 Altdorf
www.frenco.com

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