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Dynamic oil compatibility tests for Freudenberg radial shaft seals to release the usage in FLENDER-gear units applications (Table T 7300)

FS PLM 111 0008

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Content

1 Introduction ... 2
2 Requirements ... 2
2.1 Approval ... 2
2.2 Oil ... 2
2.2.1 Information ... 2
2.2.2 Volume ... 3
2.3 Seal ... 3
2.3.1 Material properties ... 3
2.3.2 Seal properties ... 4
2.4 Shaft ... 4
3 Dynamic oil compatibility test ... 5
3.1 Test setup ... 5
3.2 Test procedure ... 6
3.3 Tolerances ... 6
3.4 Number of seals ... 7
4 Seal analysis ... 7
4.1 Procedure ... 7
4.2 Visual seal rating ... 7
4.3 Measurement of functional values ... 8
5 Evaluation ... 9
5.1 Outlier detection and treatment ... 9
5.2 Input value ... 9
5.3 Limits for NBR seals ... 10
5.4 Limits for FKM seals ... 11
5.5 Test result ... 12
5.6 Report and approval ... 12
6 Appendix ... 13
6.1 Contacts ... 13
6.2 Glossary ... 13
6.3 Shaft ... 14

1 Introduction

Depending on the application FLENDER-gear units use NBR- or FKM-compounds as sealing material for the Simmerrings (radial-shaft-seals). While in use, Simmerrings are affected by different ageing- and wearing processes of the tribological system (seal, shaft, lubricant and operation conditions) which essentially influence the lifetime of the seal and therefore of the FLENDER-gear unit. Furthermore, the seal material properties, such as hardness, density, volume, tensile strength and elongation at break are changed by the influence of the temperature and lubricant.

To ensure the reliability and lifetime expectations of the sealing system (tribological system) and therefore of the FLENDER-gear units it’s mandatory to know the influence of the lubricant on the Simmerring. Hence lubricants have to pass the dynamic compatibility tests with NBR- and FKM-compounds of Freudenberg Sealing Technologies according the FLENDER specification to be approved for the usage in FLENDER-gear units.

2 Requirements

2.1 Approval

In order to complete the full dynamic oil compatibility test the following original FST seals and seal materials have to be used:

Table 1 Required tests for FLENDER approval depending on oil type

Type Dimension	Item no.	Material	Mineral oil (API 1 & 2)	Mineral oil (API 3)	PAO (API 4)	PG/PAG (API 5)	syn. Ester (API 5)
BAU3X2 35-52-7	49408254	72 NBR 902	A	A	A	A	A
	49435125	75 FKM 585	A	A	A	**A**	x
	49435127	75 FKM 260466	x	**A**	**A**	A	A
	49435124	75 FKM 170055	B	B	B	B	B

Caption 1 A = required, B = by agreement, x = not necessary

2.2 Oil

2.2.1 Information

It is mandatory that the oil sample containers and material safety data sheet (MSDS) are labeled accordingly, which includes:

- Oil designation, name or sample code
- Nominal ISO VG viscosity information (at 40 °C) or SAE classification
- Base oil type (mineral, poly-α-olefin, poly-glycole or synthetic ester)
- API classification
- Purchase number and test conditions

In general each “single” viscosity has to be approved. To approve a homologous series of oils with different viscosity grades, preferably the viscosity grade ISO VG 320 or closest to VG 320 has to be tested.

Please ensure to provide a German MSDS for evaluation in advance of sending the oil sample and attached to the shipment. To guaranty a distinct assignment between oil sample and MSDS the oil name or code on the MSDS has to be identical to the one on the oil container.

2.2.2 Volume

Table 2 contains the required oil volume for each test depending on the number of seals used for the test (Table 10).

Table 2 Oil volume

Seals	Oil volume (liter)
3	4
6	8

2.3 Seal

The material and seal properties are measured and documented for each seal batch.

2.3.1 Material properties

The material properties are measured by using standard test sheets (2 mm, acc. to DIN) produced out of the same material batch as the test seals. The seal material properties listed in Table 3 are measured according the specification named in the corresponding row.

Table 3 Material properties

Material	Physical	Values		Specification
72 NBR 902	Density	1.43 ± 0.02	g/cm³	DIN EN ISO 1183-1, 23 °C
	Hardness	75 ± 5	Shore A	DIN ISO 7619-1, 23 °C
	Modulus	6 ± 2	MPa	100 %, DIN 53504, S2, 23 °C
	Tensile strength	> 10	MPa	DIN 53504, S2, 23 °C
	Elongation at break	> 300	%	DIN 53504, S2, 23 °C
	Compression set	< 40	%	DIN ISO 815, 22 h, 100 °C
75 FKM 585	Density	2.05 ± 0.03	g/cm³	DIN EN ISO 1183-1, 23 °C
	Hardness	75 ± 5	Shore A	DIN ISO 7619-1, 23 °C
	Modulus	6 ± 2	MPa	100 %, DIN 53504, S2, 23 °C
	Tensile strength	> 10	MPa	DIN 53504, S2, 23 °C
	Elongation at break	> 175	%	DIN 53504, S2, 23 °C
	Compression set	< 40	%	DIN ISO 815, 22 h, 175 °C, 25 %
75 FKM 260466	Density	2.08 ± 0.03	g/cm³	DIN EN ISO 1183-1, 23 °C
	Hardness	75 ± 5	Shore A	DIN ISO 7619-1, 23 °C
	Modulus	10 ± 3	MPa	100 %, DIN 53504, S2, 23 °C
	Tensile strength	> 15	MPa	DIN 53504, S2, 23 °C
	Elongation at break	> 140	%	DIN 53504, S2, 23 °C
	Compression set	< 40	%	DIN ISO 815, 22 h, 175 °C, 25 %
75 FKM 170055	Density	2.05 ± 0.03	g/cm³	DIN EN ISO 1183-1, 23 °C
	Hardness	75 ± 5	Shore A	DIN ISO 7619-1, 23 °C
	Modulus	6 ± 2	MPa	100 %, DIN 53504, S2, 23 °C
	Tensile strength	> 10	MPa	DIN 53504, S2, 23 °C
	Elongation at break	> 175	%	DIN 53504, S2, 23 °C
	Compression set	< 40	%	DIN ISO 815, 22 h, 175 °C, 25 %

2.3.2 Seal properties

The seal properties need to be measured at the seal itself. For the radial load and interference 20-30 seals from each batch are measured and compared to the limits. Hardness and density are measured at one seal each (triple determination).

Table 4 Seal properties

Seal	Material	Seal properties	Values		Specification
BAU3X2 35-52-7	72 NBR 902	Radial load with spring	19 ± 4	N	DIN 3761
		Radial load w/o spring	13 ± 3	N	
		Sealing lip diameter with spring	33.70 ± 0.25	mm	
		Sealing lip diameter w/o spring	33.95 ± 0.20	mm	
		Density	1.43 ± 0.02	g/cm³	
		Hardness	72 ± 5	IRHD	
	75 FKM 585	Radial load with spring	19 ± 4	N	DIN 3761
		Radial load w/o spring	10.5 ±3	N	
		Sealing lip diameter with spring	33.70 ± 0.25	mm	
		Sealing lip diameter w/o spring	33.95 ± 0.20	mm	
		Density	2.05 ± 0.03	g/cm³	
		Hardness	75 ± 5	IRHD	
	75 FKM 260466	Radial load with spring	19 ± 4	N	DIN 3761
		Radial load w/o spring	10.5 ± 3	N	
		Sealing lip diameter with spring	33.70 ± 0.25	mm	
		Sealing lip diameter w/o spring	33.95 ± 0.20	mm	
		Density	2.08 ± 0.03	g/cm³	
		Hardness	74 ± 5	IRHD	
	75 FKM 170055	Radial load with spring	14.5 ± 4	N	DIN 3761
		Radial load w/o spring	11.5 ± 3	N	
		Sealing lip diameter with spring	33.40 ± 0.25	mm	
		Sealing lip diameter w/o spring	33.60 ± 0.20	mm	
		Density	2.05 ± 0.03	g/cm³	
		Hardness	75 ± 5	IRHD	

2.4 Shaft

The dynamic oil compatibility test uses special FLENDER shafts. The shafts must fulfill the following requirements:

Table 5 Shaft specification

Characteristic	Specification	
Material	18CrNiMo7-6	
Machining process	plunge ground with rotating grinding disc	
Hardness	55 + 7	HRC
Roughness	$R_a = 0.5 \pm 0.3$	µm
	$R_z = 3 \pm 2$	µm
	$R_{max} \leq 6.3$	µm
Diameter	Ø 35 h11	mm
Roundness	IT 8	
Shaft lead	No shaft lead allowed	

More details as well as an exemplary drawing are in chapter 6.3.

3 Dynamic oil compatibility test

3.1 Test setup

The test procedure and parameters are mostly chosen in accordance to DIN 3761 part 10 and part 11 but also to be as closely as possible to the running conditions of FLENDER-gear unit applications. For the dynamic oil compatibility test original components from Freudenberg have to be used.

For the dynamic tests specifically designed test rigs (Figure 1) are used.

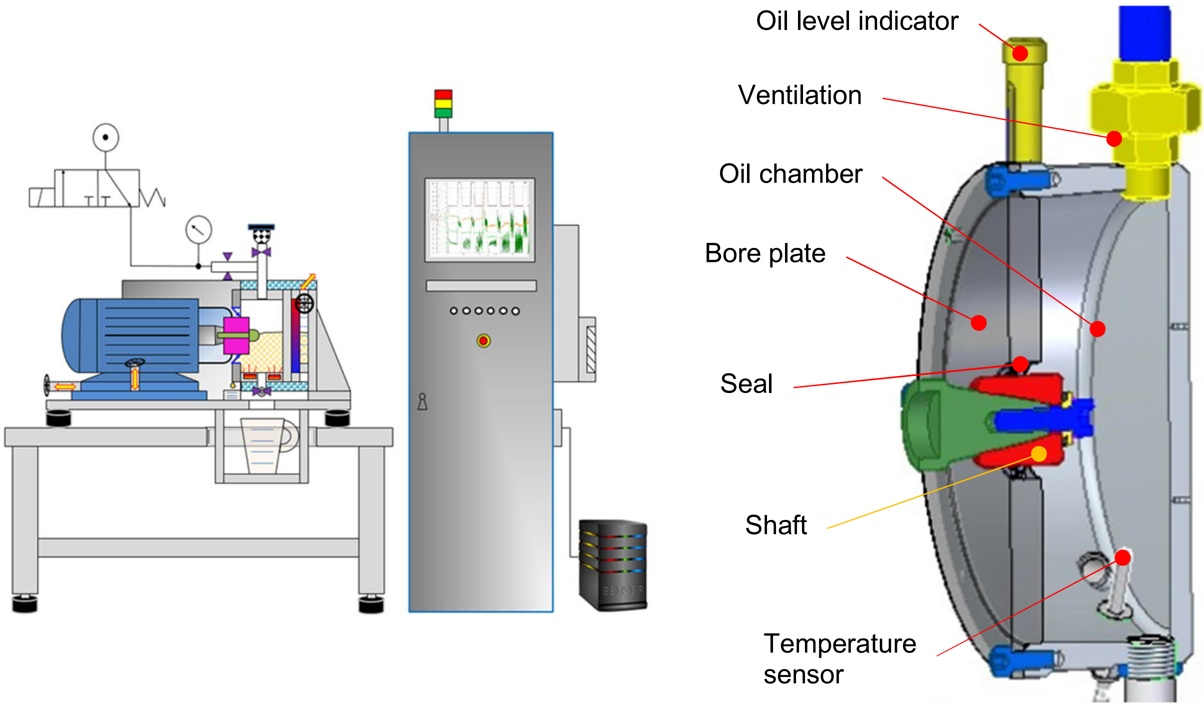

Figure 1 Test rig schema, left: basic test rig setup, right: detail of the oil chamber

The minimum oil volume must be 0.75 liter and the oil level must reach the shaft center line (measured in non-operating condition).

Each test starts with a new position (1-3) of the sealing lip on the shaft surface (see Figure 2), where the new position on the shaft has not been in contact with any other lubricant during testing before.

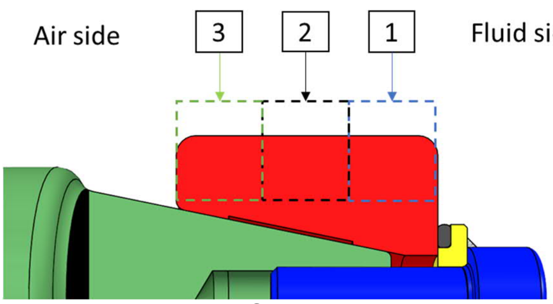

Figure 2 Sealing lip position

This procedure avoids that possible tribological coatings on the shaft surface could influence the test results. Each shaft can be used three times at most.

3.2 Test procedure

The test procedure is defined according to Table 6 (NBR) and Table 7 (FKM):

Table 6 Test procedure - NBR material

Step	Time (h)	Acceleration (1/min/s)	Shaft speed (1/min)	Sliding speed (m/s)	Temperature (°C)	e_{stat} / e_{dyn} (mm)
Step 1	20	1000	2000	~ 3.7	Table 8	0.05 / 0.05
Step 2	4		0	0	passive cooling down	
Test procedure: 32 repetitions of step 1 and 2 = total time 32 days (**768 h**)						

Table 7 Test procedure - FKM material

Step	Time (h)	Acceleration (1/min/s)	Shaft speed (1/min)	Sliding speed (m/s)	Temperature (°C)	e_{stat} / e_{dyn} (mm)
Step 1	20	1000	3000	~ 5.5	Table 8	0.05 / 0.05
Step 2	4		0	0	passive cooling down	
Test procedure: 42 repetitions of step 1 and 2 = total time 42 days (**1008 h**)						

The test temperature (oil sump temperature) depends on the used lubricant type and elastomer material (Table 8).

Table 8 Oil sump temperature

Material	Time (h)	T_{oil} (°C) Mineral oil (API 1 & 2)	Mineral oil (API 3)	PAO (API 4)	PG/PAG (API 5)	syn. Ester (API 5)
NBR	768	80	80	80	80	80
FKM	1008	90	100	100	110	90

3.3 Tolerances

Table 9 Test procedure tolerances

Feature	Tolerance	Specification
Shaft speed	± 3 %	ISO 6194-4 3rd Edition 2009-03-15
Temperature	$= \begin{cases} +5, & t < 2h \\ \pm 3, & t \geq 2h \end{cases}$ for each repetition of step 1	ISO 6194-4 3rd Edition, 2009-03-15 DIN 3761 Part 10, January 1984
e_{dyn}	± 0.015 mm (DRO ± 0.03 mm)	ISO 6194-4 3rd Edition 2009-03-15
e_{stat}	± 0.015 mm (STBM ± 0.03 mm)	ISO 6194-4 3rd Edition 2009-03-15
Oil level	− 3.5 mm	DIN 3761 Part 10, January 1984

3.4 Number of seals

The necessary number of seals for the dynamic oil compatibility test depends on the lubricant type and elastomer material (Table 10).

Table 10 Number of seals

Material	**Time (h)**	***n* (-)** Mineral oil (API 1 & 2)	**Mineral oil (API 3)**	**PAO (API 4)**	**PG/PAG (API 5)**	**syn. Ester (API 5)**
NBR	768	3	3	3	3	3
FKM	1008	3	3	**6 !**	3	3

Furthermore it is possible to run all tests with 6 seals instead of 3 seals. In this case it is possible to discard an outlier result (see chapter 5.1). However, this is only possible if the set of 6 seals are part of one test. It is not possible to combine two separate tests of 3 seals.

4 Seal analysis

4.1 Procedure

The post-test seal analysis is performed according to the following order:

1. Visual seal analysis
2. Measurement of the functional seal values

4.2 Visual seal rating

The visual seal rating consists of the evaluation of the following characteristics of the sealing lip:

- Discoloration
- Grooving
- Hardening
- Cracking
- Blistering
- Softening
- Soft deposits
- Hard deposits

For the visual seal rating a numeric system is used to quantify the seal condition for each visual characteristic. With increasing level, from 1 to 5, the appearance intensity of the visual characteristic is increasing (see Table 11).

Table 11 Legend for the evaluation levels of visual seal assessment

Level	**Legend**
1	without
2	little
3	medium / moderate
4	high
5	very high / severe

The visual assessment of the sealing lip is done by using a microscope and a preferred magnification of 16x and 25x. If not available deviating magnifications can be used but must be as close as possible to the specified and must be documented.

Table 12 Microscope magnification

Magnification	Legend
16x	Uncleaned seal
25x	Cleaned seal

For the visual seal assessment it is fundamental to have a wide-range of experience and deep knowledge base about the sealing and tribological mechanisms of radial-shaft-seal systems.

4.3 Measurement of functional values

The functional values which must be measured and documented are:

Table 13 Functional values

Functional value			Unit
Leakage			ml
Wear band width		min max	mm
Shaft wear depth			µm
Radial-load	with spring w/o spring	pre-test post-test pre-test post-test	N
Interference	with spring w/o spring	pre-test post-test pre-test post-test	mm
Radial-load change Interference change	with spring w/o spring with spring w/o spring		%

The measurements are done according to DIN 3761. The radial-load and interference change is the relative change between the pre- and post-test values of the radial-load and interference. For the calculation of the relative change the radial-load F_R and sealing lip diameter d_i have to be measured first, with and without spring as well as pre- and post-test. The interference Δd_1 is defined as:

$$\Delta d_1 = d_{1_{(nominal)}} - d_i$$

The wear band width of the sealing lip is measured with a microscope or another appropriate measuring system. For each seal the maximum (max) and minimum (min) wear band width around the circumference has to be documented. The shaft wear depth (or shaft run-in) has to be measured with a contacting or non-contacting surface measuring device.

5 Evaluation

5.1 Outlier detection and treatment

The outlier detection and treatment is only valid for tests with $n = 6$ seals. The purpose is, to find and exclude a single seal from the evaluation which shows a noticeable difference in

- Leakage,
- Shaft wear depth or
- Grooving

compared to the other seals of the same test. Therefore, if the measurements leakage and shaft wear depth as well as the visual characteristic grooving from one or more seals are exceeding the limits (Table 15, Table 16, Table 17 and Table 18),

$$x_i \geq max\{\text{limit}\}^1$$

and the absolute difference between the individual value x_i and the median $\tilde{x}$ is greater than the median absolute deviation (MAD)

$$|x_i - \tilde{x}| > \text{MAD}$$

with

$$\text{MAD} = \frac{1}{2}\left(D_{\frac{n}{2}} + D_{\frac{n}{2}+1}\right)$$

and

$$D_i = |x_i - \tilde{x}|$$

the seal is defined as outlier. If one seal meets the outlier definition in one or up to all listed categories (leakage, shaft wear depth and grooving), this seal is removed from the evaluation and the process continues with $n = 5$ seals. But if more than one seal meets the outlier criteria none is considered as outlier and the process continues with all $n = 6$ seals.

5.2 Input value

The limits and resulting points are defined for 16 measurements and visual characteristics. The input value $\overline{x}$ which is compared against the limits is the mean value for each measurement and characteristic:

$$\overline{x} = \frac{1}{n}\left(\sum_{i=1}^{n} x_i\right)$$

The decimal places of the mean values need to be rounded according to Table 14:

Table 14 Decimal places of the mean value

Functional value	**Decimal places**
Leakage	1
Wear band width	2
Shaft wear depth	1
Radial-load change	1
Interference change	1

All visual characteristics are rounded to the nearest integer with $\lfloor \overline{x} + 0{,}5 \rfloor$. The input value $\overline{x}$ for each measurement and visual characteristic will then be compared to the limits to obtain the resulting points. Chapter 5.3 and 5.4 contain the limits and resulting points for the mean value $\overline{x}$ for each measurement and visual characteristic.

[1] The maximum limit $max\{\text{limit}\}$ is listed in Table 14, Table 15, Table 16 and Table 17 and defines the limits which lead to zero points.

5.3 Limits for NBR seals

Table 15 Measurements: limits and points for NBR seals

	Functional value		Limit	Points
Measurements	Leakage	ml	$\bar{x} = 0$	2
			$0 < \bar{x} \leq 2$	1
			$\bar{x} > 2$	0
	Wear band width[2]	mm	$\bar{x} \leq 0.5$	2
			$\bar{x} > 0.5$	0
	Shaft wear depth	µm	$\bar{x} \leq 5$	2
			$5 < \bar{x} \leq 10$	1
			$\bar{x} > 10$	0
	Radial-load change with spring	%	$-45 \leq \bar{x} \leq +10$	2
			$\bar{x} < -45$ or $\bar{x} > +10$	0
	Radial-load change w/o spring	%	$-50 \leq \bar{x} \leq +15$	2
			$\bar{x} < -50$ or $\bar{x} > +15$	0
	Interference change with spring	%	$\bar{x} \geq -45$	2
			$\bar{x} < -45$	0
	Interference change w/o spring	%	$\bar{x} \geq -70$	2
			$\bar{x} < -70$	0

Table 16 Visual characteristics: limits and points for NBR seals

		Average rating level $\bar{x}$					
	Characteristic	**1**	**2**	**3**	**4**	**5**	
Visual characteristic	Discoloration	2				1	Points
	Grooving	2			0		
	Hardening	2			1	0	
	Cracking	2	1	0			
	Blistering	2	1	0			
	Softening	2	1	0			
	Soft deposits	2				1	
	Hard deposits	2		1	0		
	Deposits shaft	2			0		

[2] The mean $\bar{x}$ of the wear band width is calculated by using the maximum (max) and minimum (min) values from all seals of the test

5.4 Limits for FKM seals

Table 17 Measurements: limits and points for FKM seals

	Functional value		Limit	Points
Measurements	Leakage	ml	$\bar{x} = 0$	2
			$0 < \bar{x} \leq 2$	1
			$\bar{x} > 2$	0
	Wear band width[3]	mm	$\bar{x} \leq 0.4$	2
			$\bar{x} > 0.4$	0
	Shaft wear depth	µm	$\bar{x} \leq 10$	2
			$10 < \bar{x} \leq 15$	1
			$\bar{x} > 15$	0
	Radial-load change with spring	%	$-35 \leq \bar{x} \leq +10$	2
			$\bar{x} < -35$ or $\bar{x} > +10$	0
	Radial-load change w/o spring	%	$-40 \leq \bar{x} \leq +15$	2
			$\bar{x} < -40$ or $\bar{x} > +15$	0
	Interference change with spring	%	$\bar{x} \geq -40$	2
			$\bar{x} < -40$	0
	Interference change w/o spring	%	$\bar{x} \geq -60$	2
			$\bar{x} < -60$	0

Table 18 Visual characteristics: limits and points for FKM seals

		Average rating level $\bar{x}$					
	Characteristic	**1**	**2**	**3**	**4**	**5**	
Visual characteristic	Discoloration	2			1		**Points**
	Grooving	2			1	0	
	Hardening	2		1	0		
	Cracking	2	1	0			
	Blistering	2	1	0			
	Softening	2	1	0			
	Soft deposits	2				1	
	Hard deposits	2		1	0		
	Deposits shaft	2			0		

[3] The mean $\bar{x}$ of the wear band width is calculated by using the maximum (max) and minimum (min) values from all seals of the test

5.5 Test result

The final test result depends on the achieved total points $TP = \sum Points$. Each measurement and visual characteristics are within the limits or not. Therefore, for each of the 16 measurements and visual characteristics an rating of 2, 1 or 0 points is possible (see Table 15 to Table 18).

Table 19 Final result

	Total points TP	Test result TR		Information
$\boldsymbol{TP} = \sum_{i=1}^{16} Points(\overline{x}_i)$	$= 32$	**2**	**Approved**	All results within the limits
	$= 31$	**1**	**Borderline**	One result is slightly exceeding the limits
	< 31	**0**	**Failed**	One or more limits exceeding the limits

If all 16 results $\overline{x}$ are within the limits each of them gets rated with 2 points and a maximum of 32 total points is achieved. Once a result $\overline{x}$ exceeds slightly a limit it gets rated with 1 point but as long as only one limit is affected, the total sum will be 31 points the oil is approved as borderline. Is more than one result rated with 1 point or at least one result with 0 points the total will be less than 31 points and therefore the oil fails the FLENDER test. Table 19 summarizes the procedure to receive the final result.

5.6 Report and approval

The test result, the single measurement values of each seal as well as a photo of each seal in cleaned and uncleaned condition after test has to be documented in the report along with the test conditions.

The final evaluation of the results and therefore the final approval is made by FLENDER after submitting the application for approval of the oil. For a release by FLENDER, a minimum of 1 point in the final test result ("Borderline") of all tests is required.

6 Appendix

6.1 Contacts

Company	Contact
Flender GmbH	Dr. Alexander Furtmann Flender GmbH Alfred-Flender-Str. 77 46395 Bocholt, Germany Tel.: +49 2871 92-2387 Mobile: +49 174 6926919 Email: alexander.furtmann@flender.com
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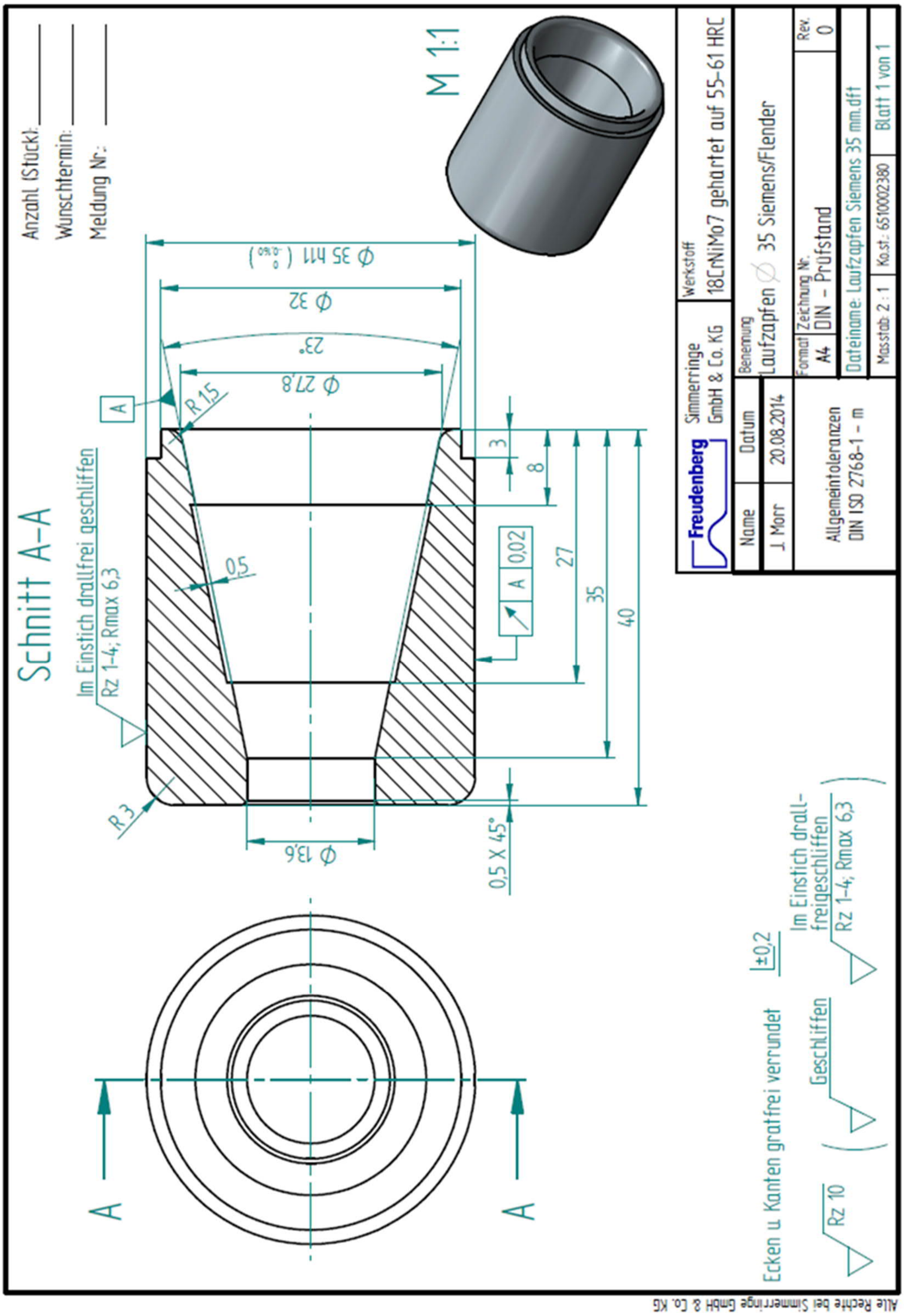
6.2 Glossary

Term	Definition
Δd_1	Sealing lip interference
D_i	Absolute difference to median
d_1	Shaft diameter
d_i	Sealing lip diameter
e_{dyn}	Dynamic shaft eccentricity to simulate dynamic (shaft) run-out (DRO)
e_{stat}	Static bore eccentricity to simulate shaft to bore misalignment (STBM)
MAD	Median absolute deviation
MSDS	Material safety data sheet
n	Number of seals
F_R	Radial-load
t	Time in h
T_{Oil}	Oil sump temperature
TP	Total points
TR	Test result
$\overline{x}$	Average value of visual characteristic or measurement

6.3 Shaft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Meldung Nr.:
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Ø 35 h11
Ø 32
23°
Ø 27,8
R 1,5
A
0,5
0,02
3
8
27
35
40
R 3
Ø 13,6
0,5 X 45°
Freudenberg
Simmerringe GmbH & Co. KG
Werkstoff
18CrNiMo7 gehärtet auf 55-61 HRC
Benennung
Laufzapfen Ø 35 Siemens/Flender
Name
J. Morr
Datum
20.08.2014
Format
A4
Zeichnung Nr.
DIN - Prüfstand
Rev.
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DIN ISO 2768-1 - m
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Masstab: 2 : 1
Blatt 1 von 1
Ecken u. Kanten gratfrei verrundet
Rz 10
Geschliffen
±0,2
Im Einstich drall-freigeschliffen
Rz 1-4; Rmax 6,3
A
A
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