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your global specialist

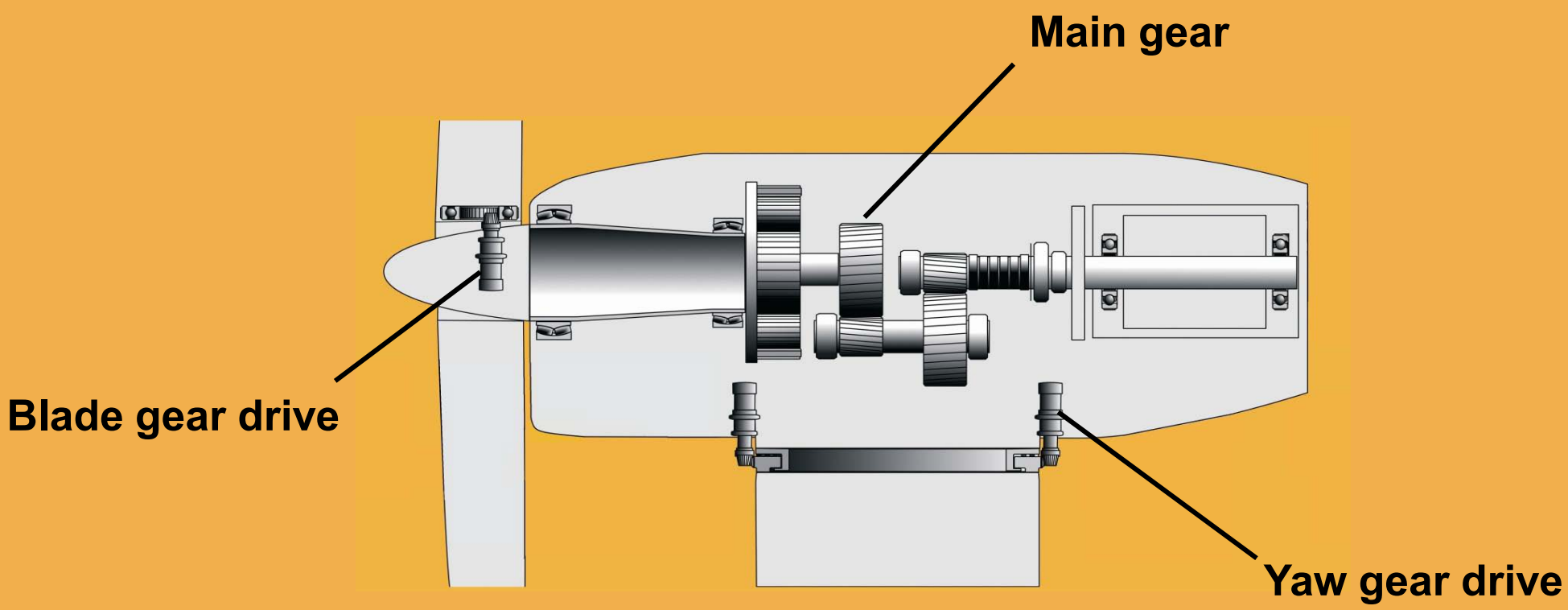
Selecting synthetic gear oil

National Renewable Energy Laboratory
Argonne National Laboratory
U.S. Department of Energy

Wind Turbine Tribology Seminar
November 15-17, 2011

Dennis A. Lauer, P.E.
Vice President – Engineering
Kluber Lubrication North America

Wind power turbines – Gear oil location



Industrial gears - Influences

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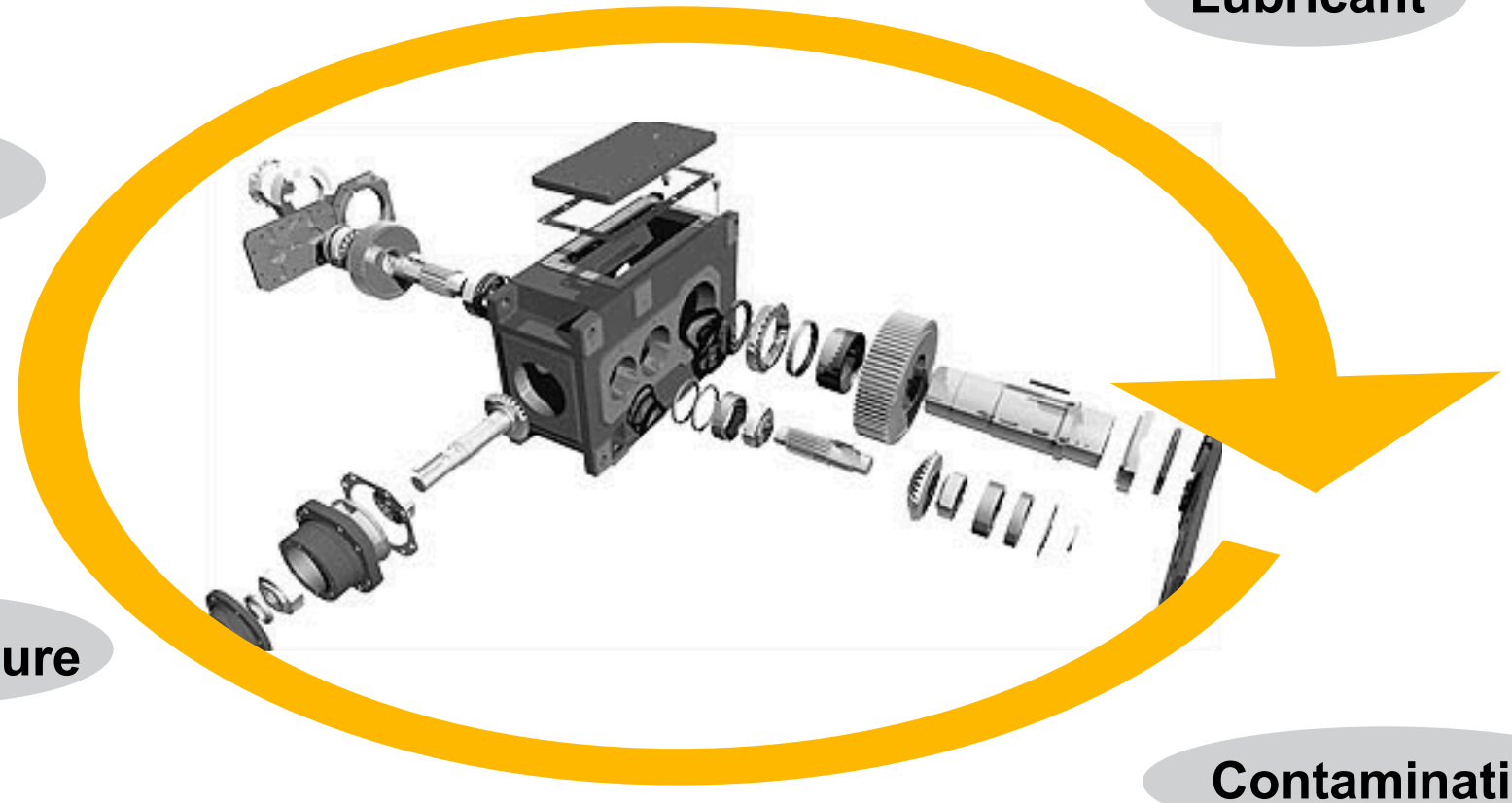
Load

Lubricant

Speed



Temperature

Contamination

Vibration

Influences on load-carrying capacity and efficiency

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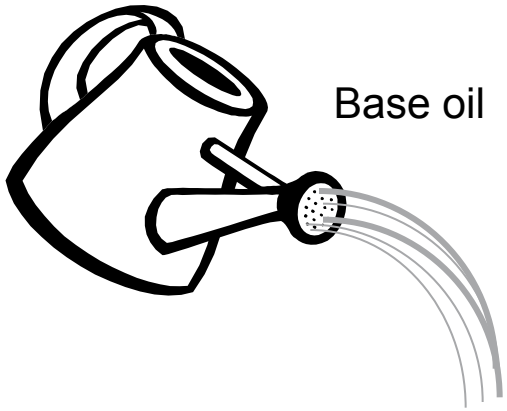
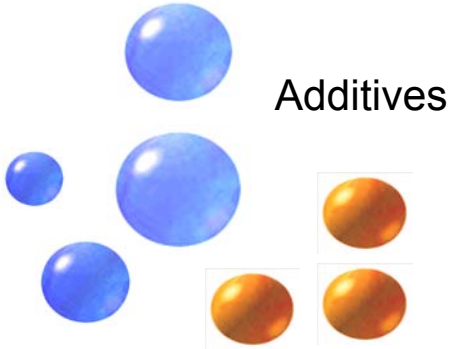
Gear failure	Material	Construction & operating conditions	Lubricant
Tooth root breakage (tooth root strength)	x	x	-
Scuffing load-carrying capacity (scuffing load)	(x)	x	xx
Wear bahavior (wear limit)	(x)	x	xx
Pitting (flank strength)	x	x	x
Micropitting	x	x	x(x)
Efficiency	-	x	x
Overheating	-	x	x

xx strong influence x influence - no influence

Industrial gear oils - Structure





Gear oil

- **Base oil**
  - Mineral oil
    - paraffinic
    - naphthenic
  - Synthetic oil
    - Polyglycol (PAG)
    - Polyalphaolefin (PAO)
    - Ester
- **Additives**
  - Corrosion protection
  - Oxidation resistance
  - Foam resistance
  - Extreme pressure (EP)
  - Anti wear (AW)
  - VI improver

Industrial gear oils

Requirements acc. to *DIN 51517-3* – CLP gear oils

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Designation	CLP 32	CLP 46	CLP 68	CLP 100	CLP 150	CLP 220	CLP 320	CLP 460	CLP 680	CLP 1000	CLP 1500
ISO viscosity grade	32	46	68	100	150	220	320	460	680	1000	1500
Kinematic viscosity at 40 °C, mm²/s	28,8 35.2	41,4 50.6	61,2 74.8	90 110	135 165	198 242	288 352	414 506	612 748	900 1100	1350 1650
Viscosity index	90	90	90	90	90	90	90	90	85	85	85
Density at 15 °C, kg/m³	Report										
Flash point, °C	≥ 180	≥ 180	≥ 180	≥ 200	≥ 200	≥ 200	≥ 200	≥ 200	≥ 200	≥ 200	≥ 200
Pour point, °C	≤ -12	≤ -12	≤ -12	≤ -12	≤ -9	≤ -9	≤ -9	≤ -9	≤ -3	≤ -3	≤ -3
Neutralisation number	Report										
Water content, %	< 0,1										
Foam behaviour, ml	100/10	100/10	100/10	100/10	100/10	100/10	100/10	150/60	150/60	150/10	150/60
Demulsibility	30	30	30	30	30	30	30	30	30	30	30
Copper corrosion	Rating 1										
Steel corrosion	Rating 0 - A										
Resistance to aging	Increase in viscosity < 6 %										
FAG FE8 wear test	roller wear < 30 mg, cage wear < 200 mg										
FZG scuffing test	Failure load stage ≥ 12										
Elastomer compatibility	SRE-NBR 28										

Wind turbine gear oils – Higher requirements

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High scuffing and micropitting load-carrying capacity

Low friction behavior

No negative influence on wear behavior and life time of rolling bearings

High oxidation stability

High upper operating temperature

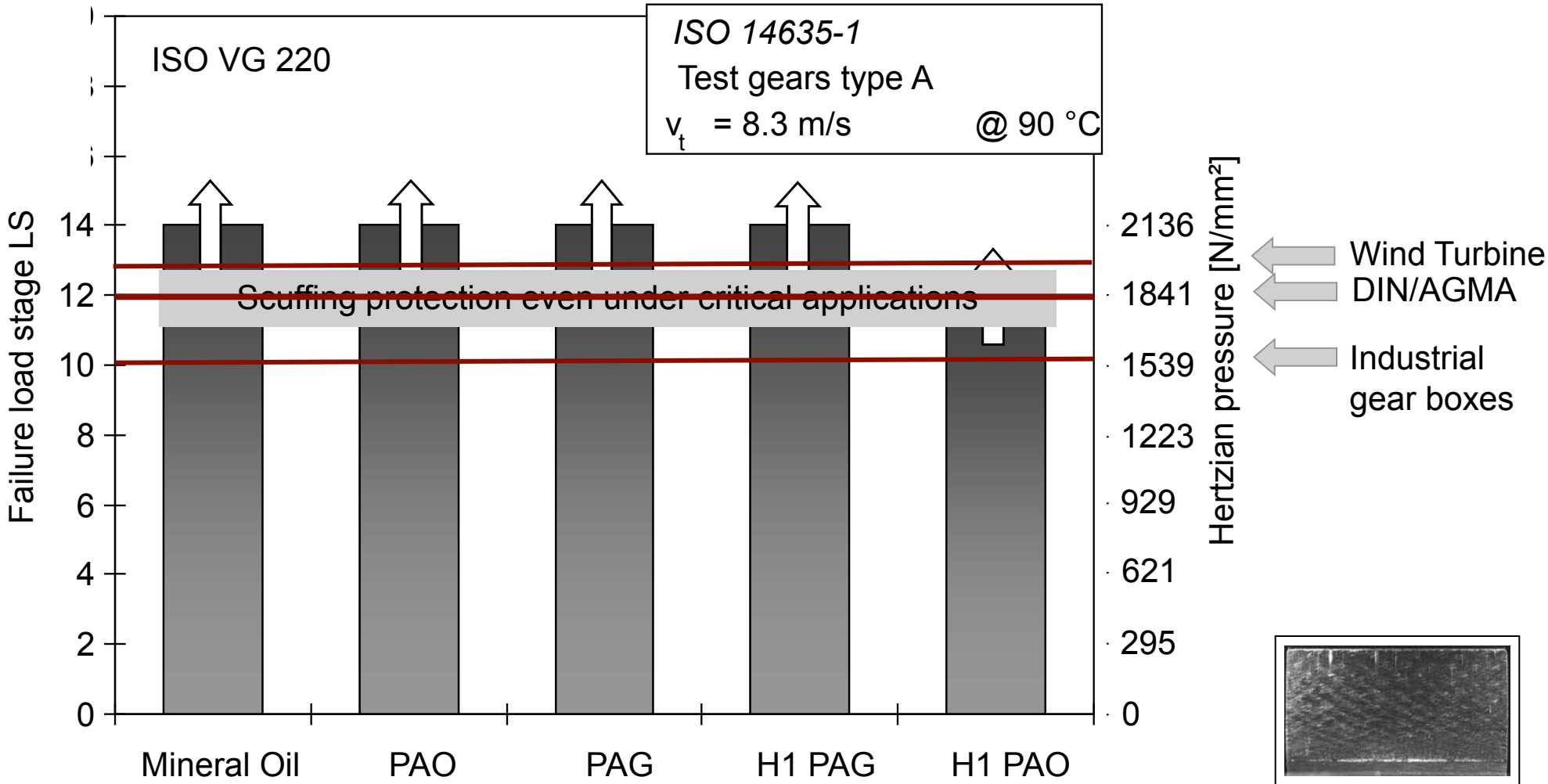
No residue formation

No negative influence on radial shaft seals (RSS)

Wind Mill Gear Oil Requirements

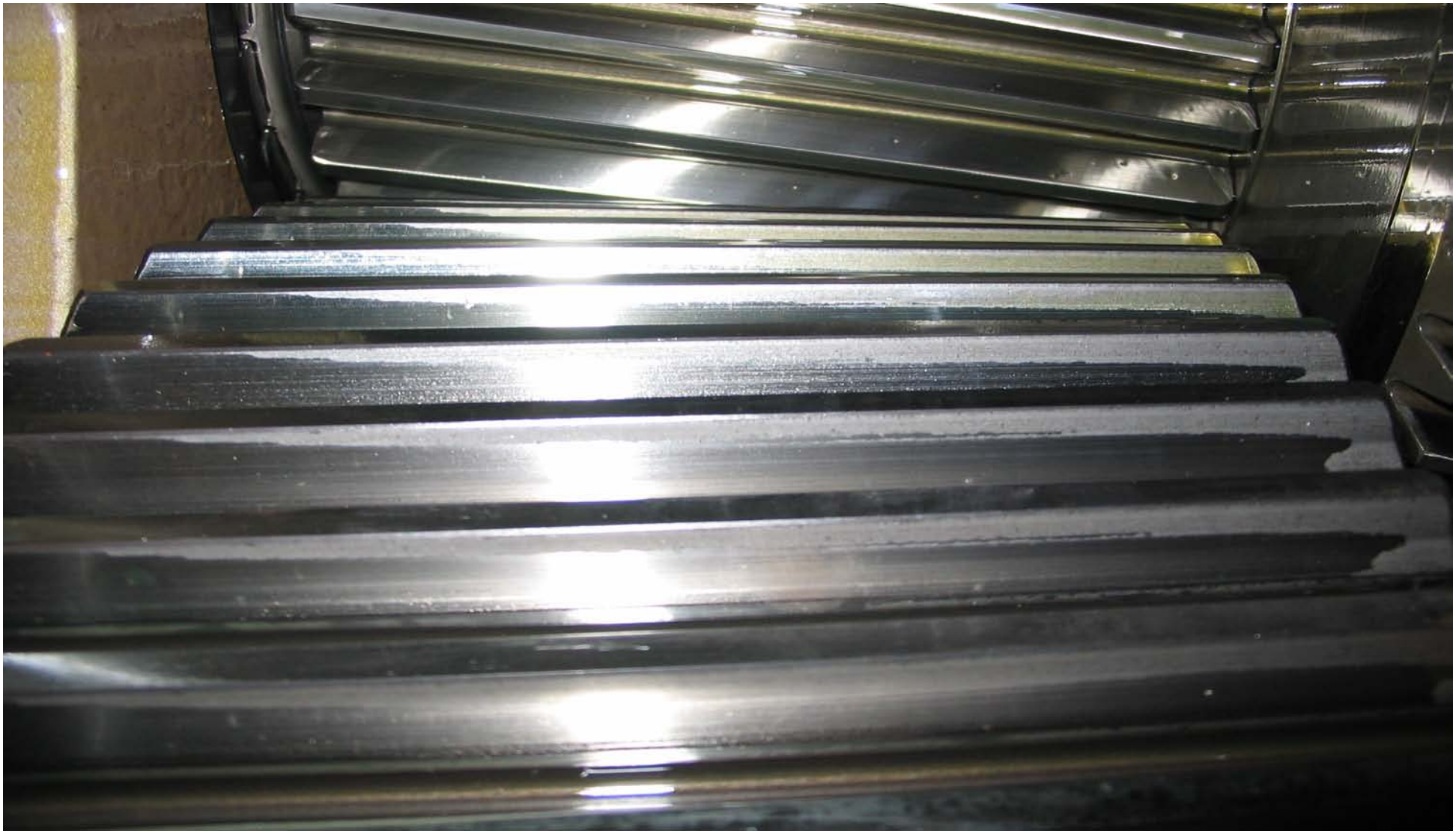
- Resistance to micropitting ≥ LS 10
- Scuffing load capacity > LS 13
- Suitable for rolling bearing lubrication
  FAG FE8 test
- Low residue formation
  t = 60 - 90 °C
- Resistance to hydrolysis

Scuffing load-carrying capacity High performance

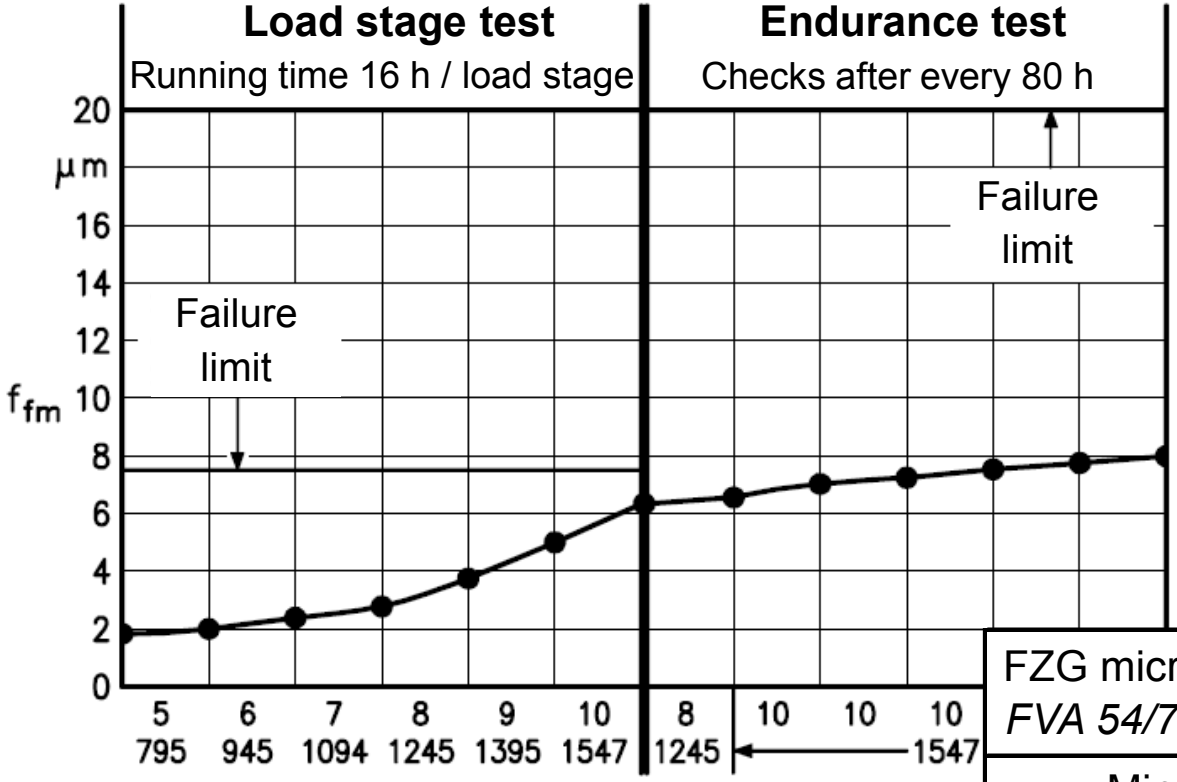


Exemplary flank photo

Micropitting failure



Micropitting load-carrying capacity High performance



Execution: Forschungsstelle für Zahnräder und Getriebebau (FZG)

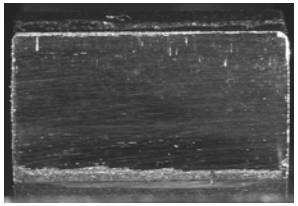
Test conditions:

Micropitting test:
C / 8,3 / 60

Lubricant:
Klübersynth GH6–320

Surface roughness:
$R_a \approx 0{,}50\ \mu m$

$R_a = (R_{a1}+R_{a2})/2$


Exemplary flank photo

FZG micropitting test *FVA 54/7*	Load-carrying capacity	
	ϑ_{Oil} = 90 °C	ϑ_{Oil} = 60 °C
Mineral Oil	*high*	*high*
PAO	*high*	*high*
PAG	*high*	*high*
H1 PAG	*high*	*high*
H1 PAO	*medium*	*medium*

Endurance test:
No further increase of micropitting compared with the step test

Micropitting load-carrying capacity High performance

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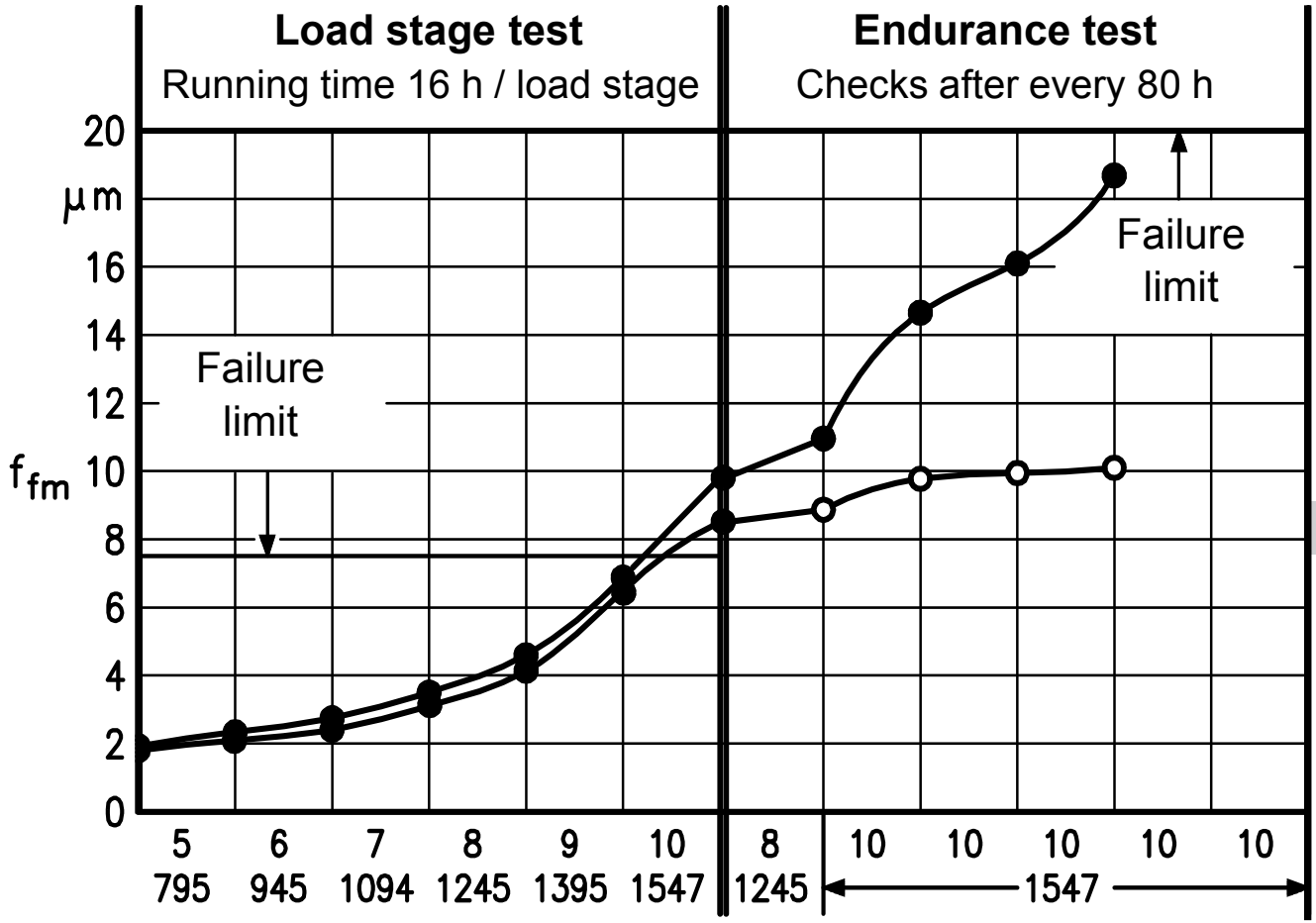
Stopping micropitting formation by using the right lubricant



Test conditions:

Micropitting test:

C / 8,3 / 60

Lubricant:

ISO VG 320 Mineral Oil

End of test due to pitting

PAO

Surface roughness:

$R_a \approx 0.50\ \mu m / 0.43\ \mu m$

$R_a = (R_{a1}+R_{a2})/2$

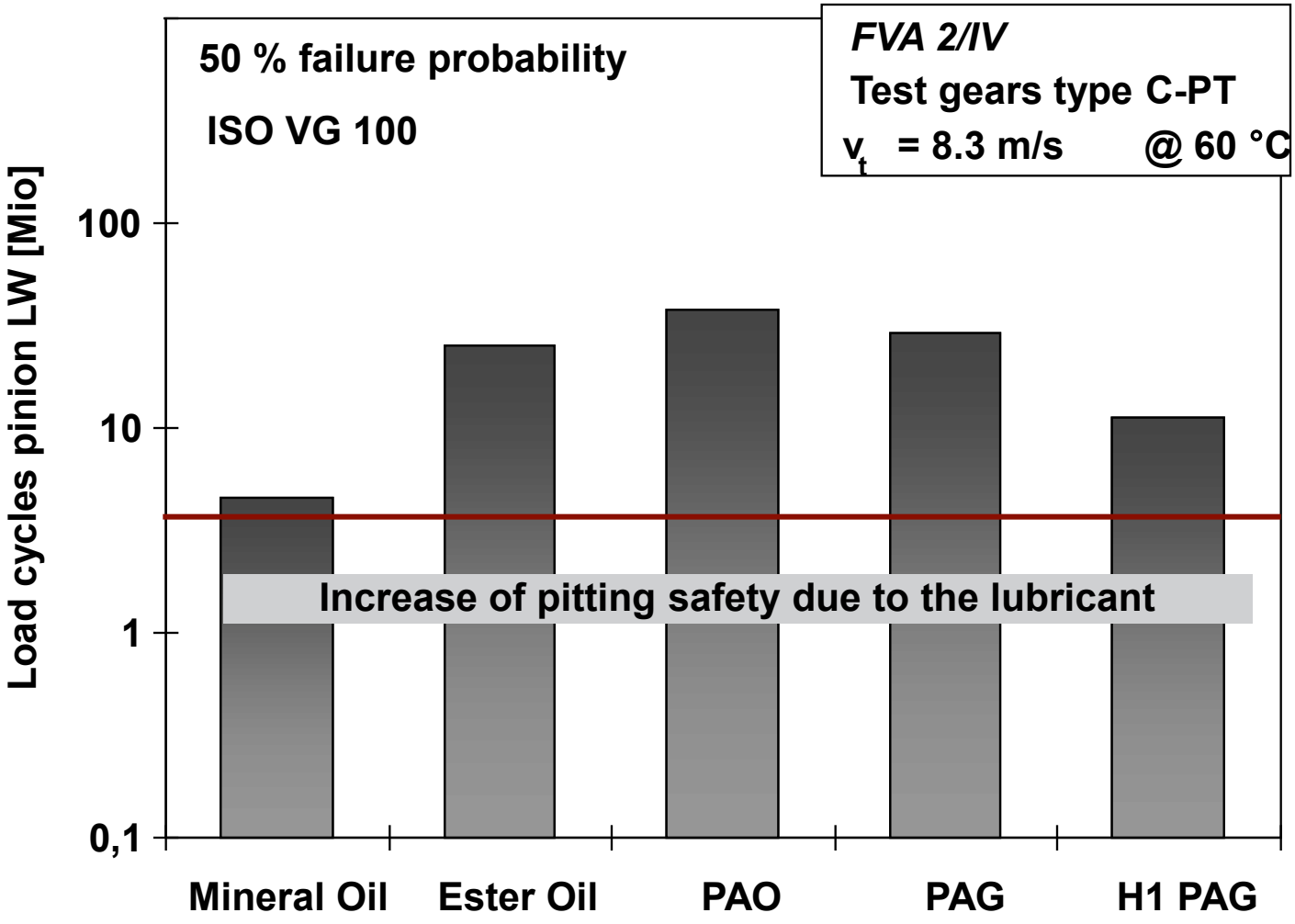
Load stage

p_C in N/mm^2

Execution: Forschungsstelle für Zahnräder und Getriebebau (FZG)

Pitting failure

Pitting load-carrying capacity High performance



Calculation of pitting load-carrying capacity:

DIN 3990 / ISO 6336

Execution: Forschungsstelle für Zahnräder und Getriebebau (FZG)

Bearing protection – High performance

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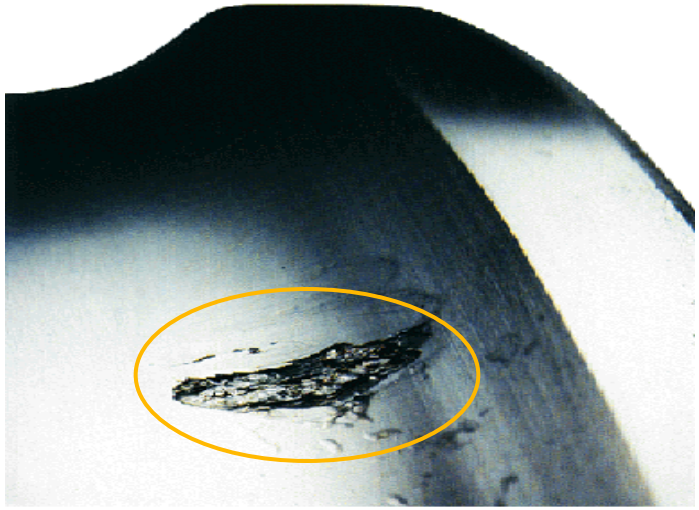
Wear or fatigue failure of rolling bearings is often the reason for gear failures

- Significant influence of the additives
- Consequential failures



Investigation of the bearing wear behavior

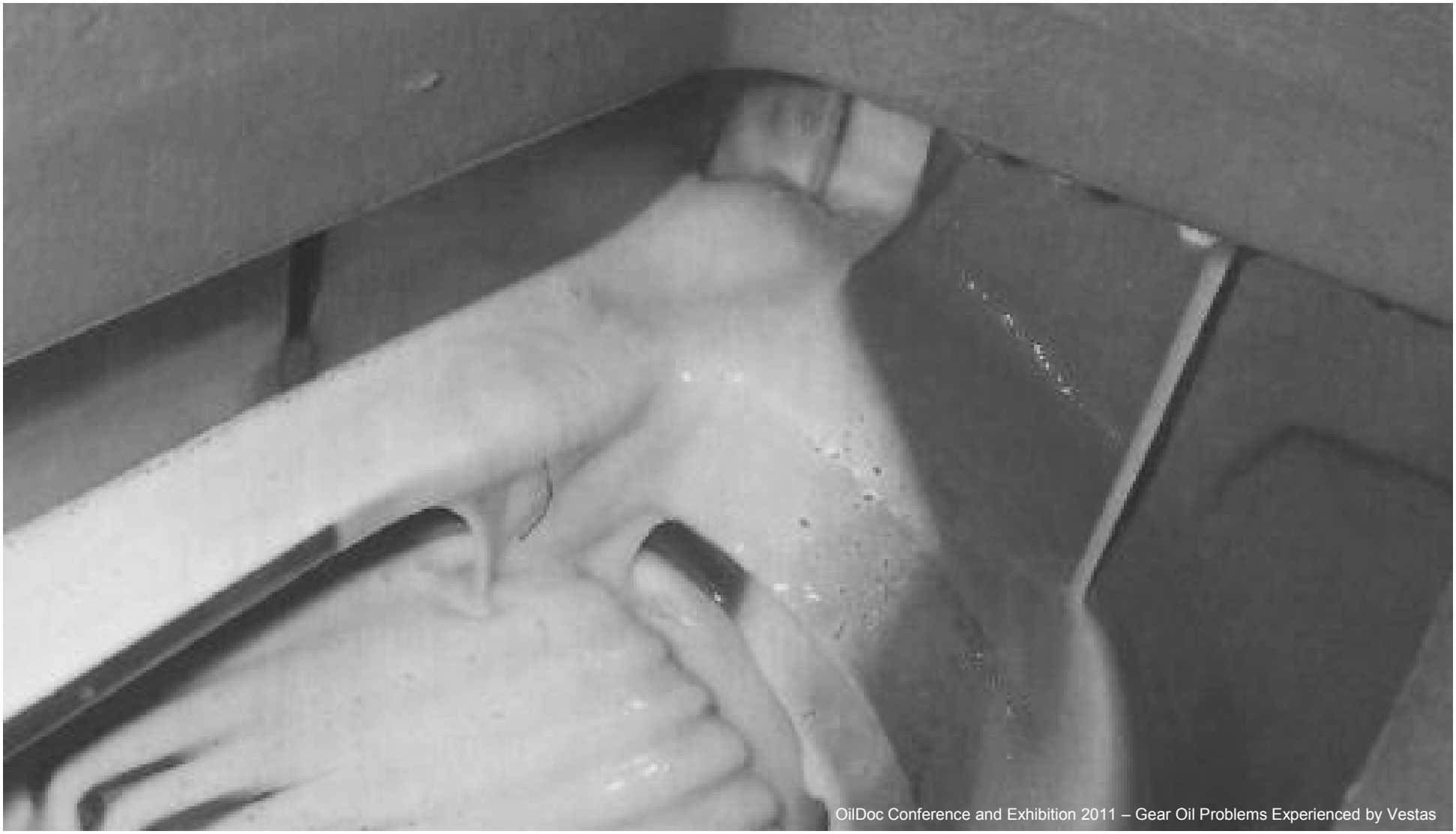
- FE8 wear test D 7.5/80-80 according to *DIN 51819-3*
- Maximum roller wear <= 10 mg, maximum cage wear <= 100 mg
- FE8 endurance test D 75/80-80 according to *DIN 51819-3*
- Double calculated bearing life time of 1500 h

Bearing load-carrying capacity FAG-FE8 bearing test rig

Bearing protection
High performance

Test	FE8 wear test D 7.5/80-80		FE8 endurance test D 75/80-80		
ISO VG 320	Roller wear [mg]	Cage wear [mg]	1500 h	Roller wear [mg]	Cage wear [mg]
Mineral Oil	0	87	passed	1	43
Ester Oil	1	22	passed	1	30
PAO	0	37	passed	1	50
PAG	0	22	passed	1	35
H1 PAG	1	44	passed	1	12
H1 PAO	1	128	passed	1	68

Foam behavior



FLENDER foam test
Test procedure acc. to *FLENDER report GG-V 425*

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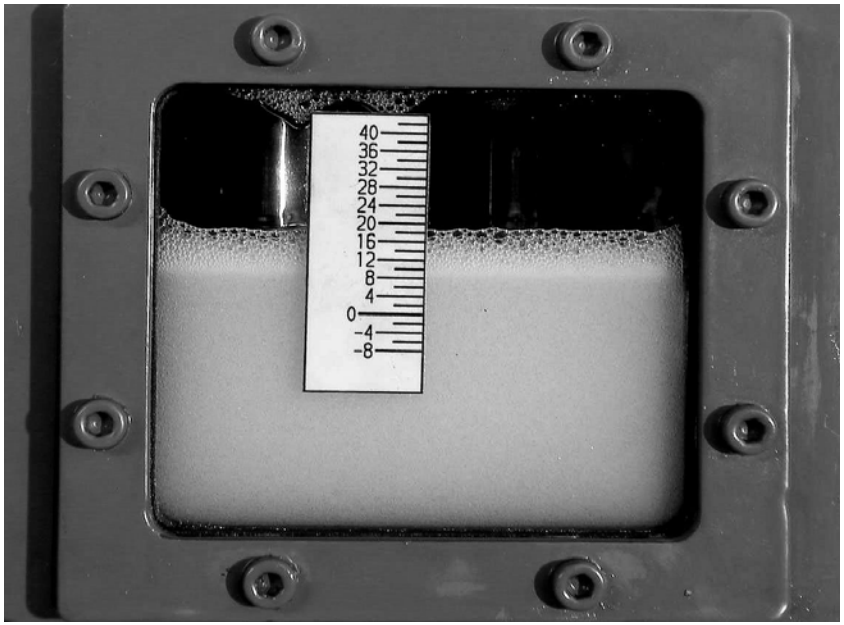
Test conditions

- P_{Motor} = 0,55 kW
- n_{Motor} = 1450 rpm
- $\theta_{Oil,Start}$ = 25 °C
- Oil volume of 1 Liter



Execution of the test

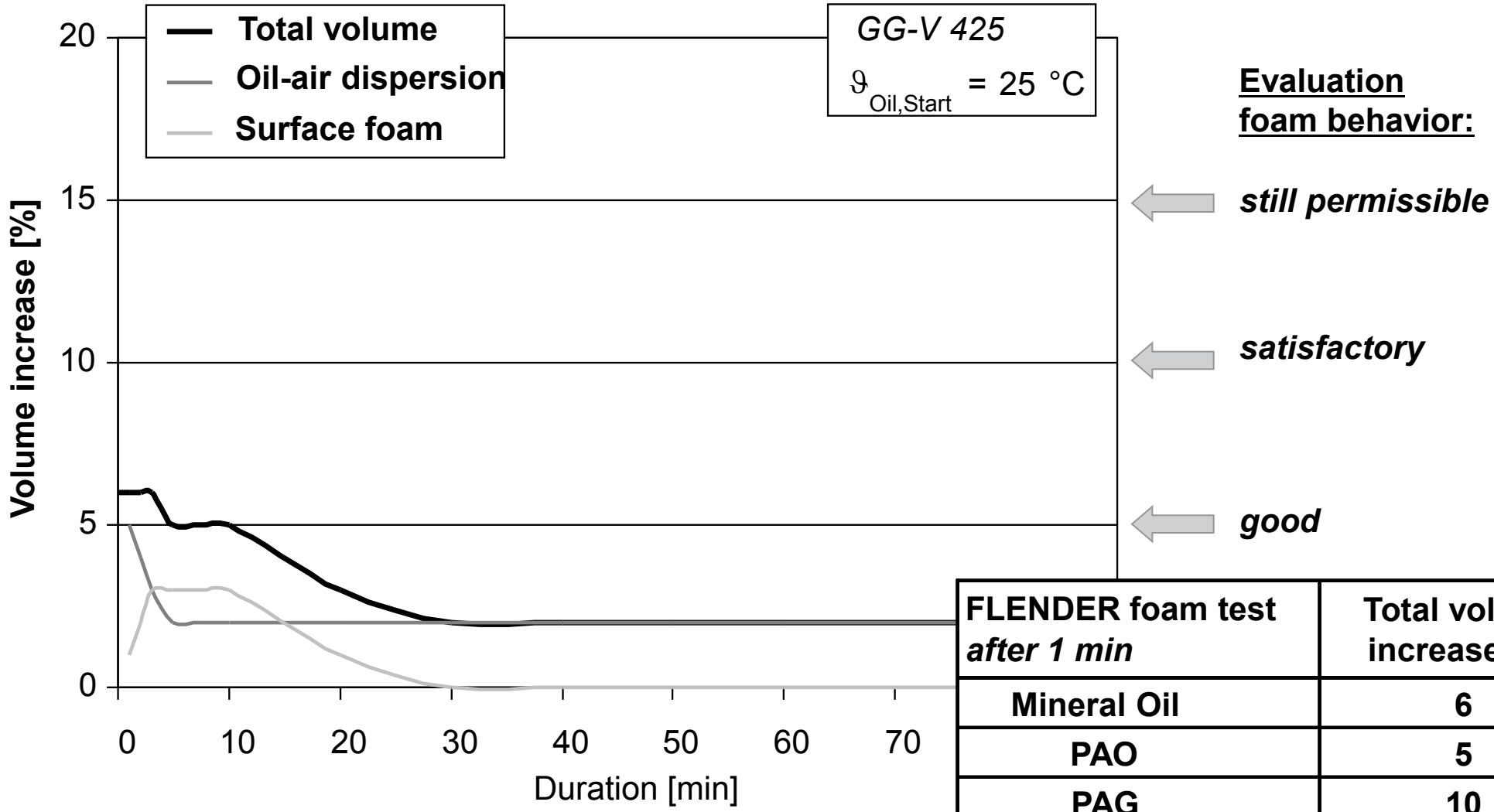
- Running time 5 min, standing time 1 min
- Observation of the foam behavior for 90 min

Test result

- Measurement of the foam behavior
  - Total volume increase
  - Oil-air dispersion
  - Surface foam
- Evaluation of the foam behavior 1 min after stopping the motor

Evaluation foam behavior	Totol volume increase
good	up to 5 %
satisfactory	up to 10 %
still permissible	up to 15 %
excessive	over 15 %

Foam behavior – High performance



FLENDER foam test *after 1 min*	Total volume increase [%]
Mineral Oil	6
PAO	5
PAG	10
H1 PAG	6
H1 PAO	10

Elastomer compatibility High performance

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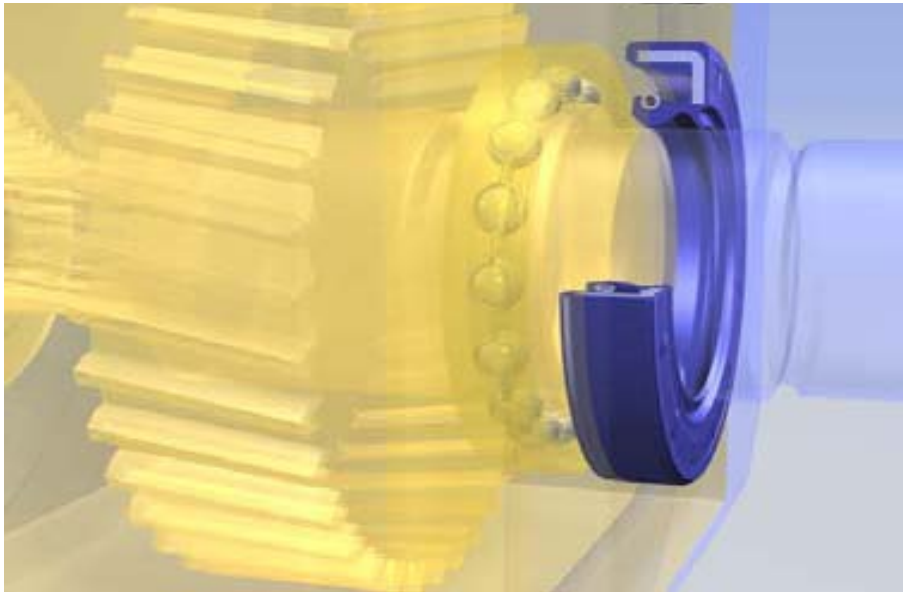
Perfect harmonization of lubricant and seal

- Protection of seals against friction and wear
- Avoidance of leakages, extensive oil filtering, and gear box repairs



Investigation of the elastomer compatibility

- Static elastomer compatibility according to *DIN ISO 1817*
- Dynamic elastomer compatibility according to *DIN 3761*
- Elastomer materials 72 NBR 902, 75 FKM 585, and 75 FKM 170055
- Limits according to *Freudenberg FB 73 11 008*

Static elastomer compatibility High performance

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Investigation of elastomer compatibility

- **Static elastomer compatibility of gear oils for 1008 h at 100 °C bzw. 110 °C / 130 °C according to *DIN ISO 1817***
- **Elastomer materials 72 NBR 902, 75 FKM 585 and 75 FKM 170055**
- **Limits according to *Freudenberg FB 73 11 008***

Stat. elastomer compatibility *DIN ISO 1817*	Change [%]			
	Volume	Shore-A-hardness	Max. stress	Elongation
Mineral Oil	> -2 … 5 <	> -5 … 5 <	> -50 … 20 <	> -60 … 20 <
PAO	> -2 … 5 <	> -5 … 5 <	> -50 … 20 <	> -60 … 20 <
PAG	> -2 … 5 <	> -5 … 5 <	> -50 … 20 <	> -60 … 20 <
H1 PAG	> -2 … 5 <	> -5 … 5 <	> -50 … 20 <	> -60 … 20 <

(72 NBR 902, 75 FKM 585, and 75 FKM 170055)

- **Protection of leakages, extensive oil filtering, and gear box repairs**

Dynamic elastomer compatibility High performance

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Investigation of elastomer compatibility

- **Dynamic elastomer compatibility of gear oils for 1008 h at 80 °C bzw. 90 °C / 110 °C nach *DIN 3761***
- **Elastomer materials 72 NBR 902, 75 FKM 585 and 75 FKM 170055**
- **Limits according to *Freudenberg FB 73 11 008***

Dyn. elastomer compatibility *DIN 3761*	Leak-age [ml]	Change			
		Width of running marks at sealing edge [mm]	Run-in depth of shaft [µm]	Interference with spring [mm]	Interference with-out spring [mm]
MIN GEM 1 N	0	≤ 0.5	≤ 5	≤ -0.6	≤ -0.7
PAO GEM 4 N	0	≤ 0.5	≤ 5	≤ -0.6	≤ -0.7
PG GH 6	0	≤ 0.5	≤ 5	≤ -0.6	≤ -0.7
PG UH1 6	0	≤ 0.5	≤ 5	≤ -0.6	≤ -0.7

(72 NBR 902)

- **Protection of leakages, extensive oil filtering, and gear box repairs**

Dynamic elastomer compatibility
Maximum performance

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Investigation of elastomer compatibility

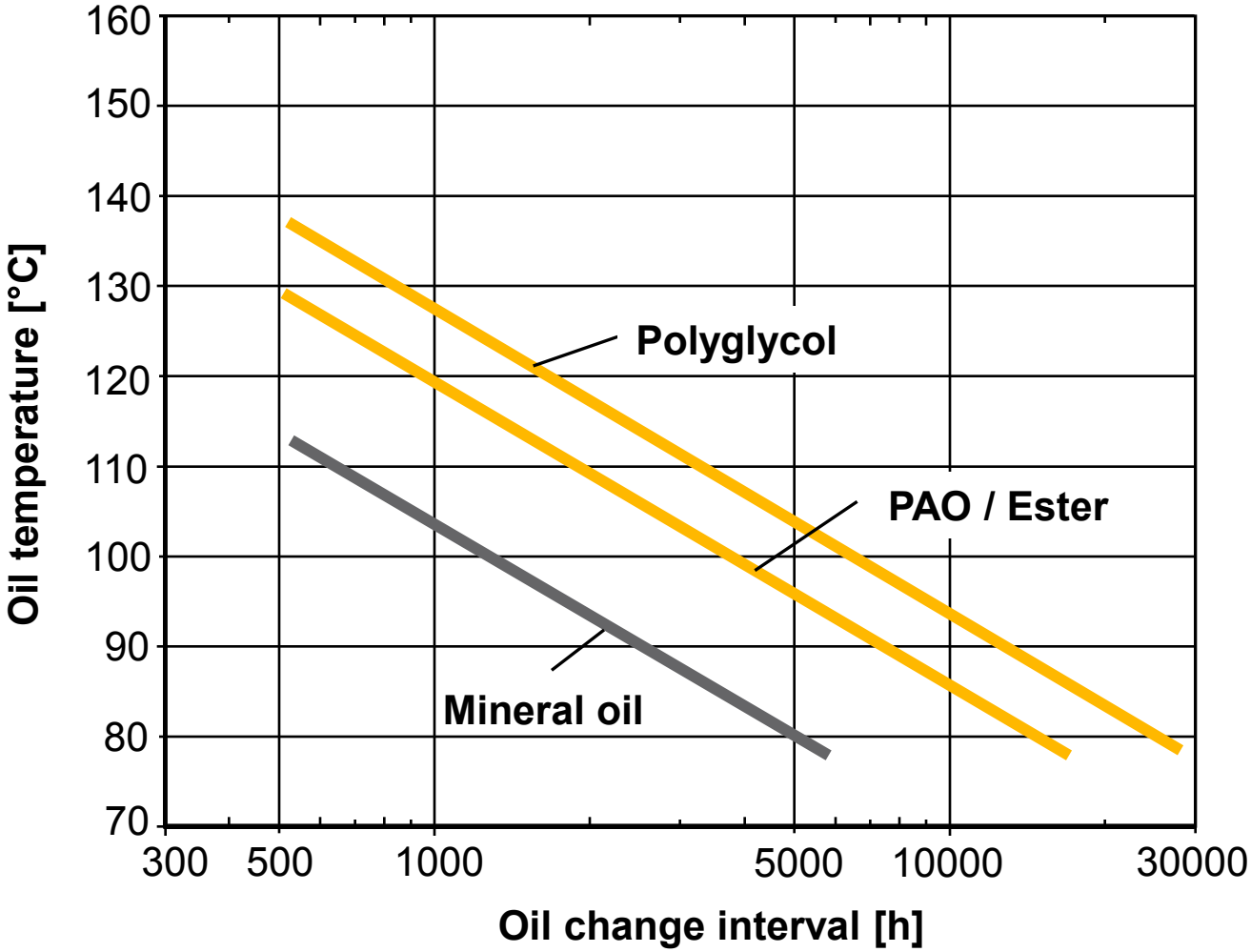
- **Dynamic elastomer compatibility of gear oils for 1008 h at 80 °C bzw. 90 °C / 110 °C nach *DIN 3761***
- **Elastomer materials 72 NBR 902, 75 FKM 585 and 75 FKM 170055**
- **Limits according to *Freudenberg FB 73 11 008***

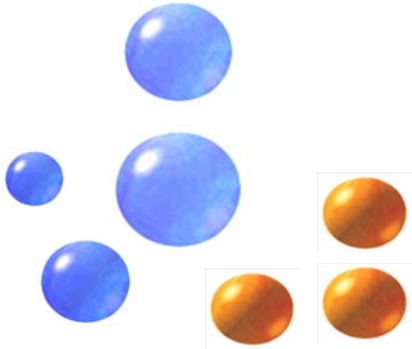
Dyn. elastomer compatibility *DIN 3761*	Leak-age [ml]	Change			
		Width of running marks at sealing edge [mm]	Run-in depth of shaft [µm]	Interference with spring [mm]	Interference with-out spring [mm]
MIN GEM 1 N	0	≤ 0.4	≤ 10	≤ -0.5	≤ -0.6
PAO GEM 4 N	0	≤ 0.4	≤ 10	≤ -0.5	≤ -0.6
PG GH 6	0	≤ 0.4	≤ 10	≤ -0.5	≤ -0.6
PG UH1 6	0	≤ 0.4	≤ 10	≤ -0.5	≤ -0.6

(75 FKM 585 and 75 FKM 170055)

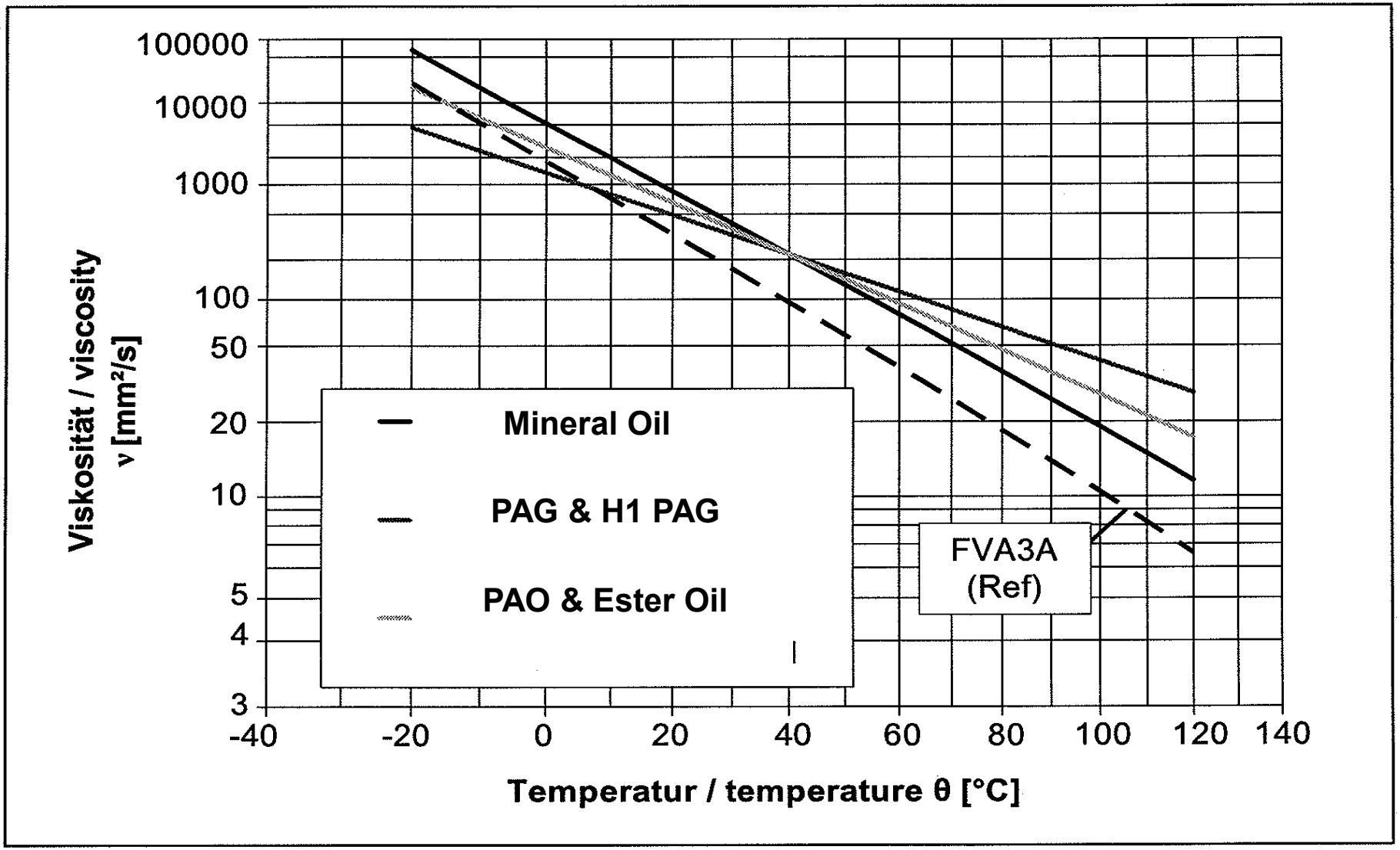
- **Protection of leakages, extensive oil filtering, and gear box repairs**

Industrial gear oils
Achievable oil change intervals



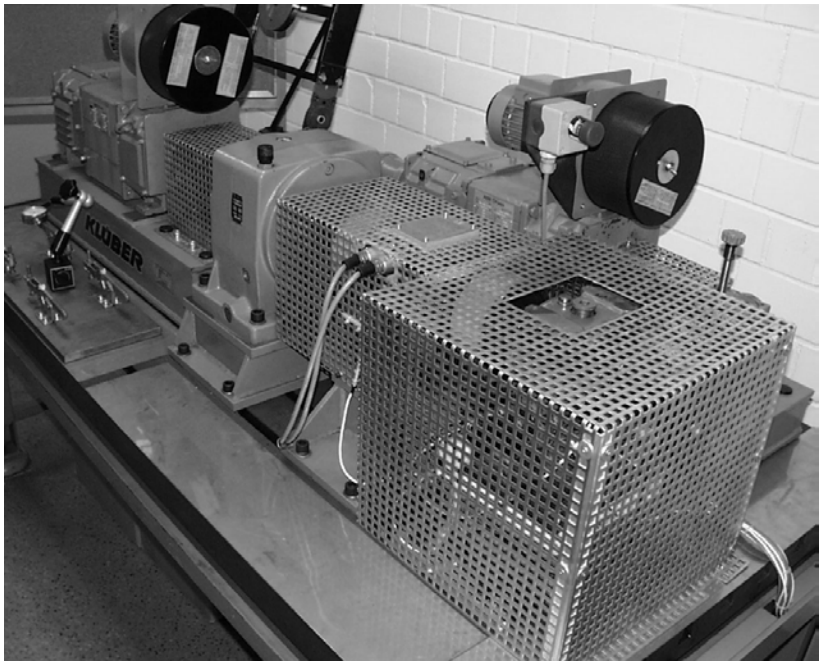


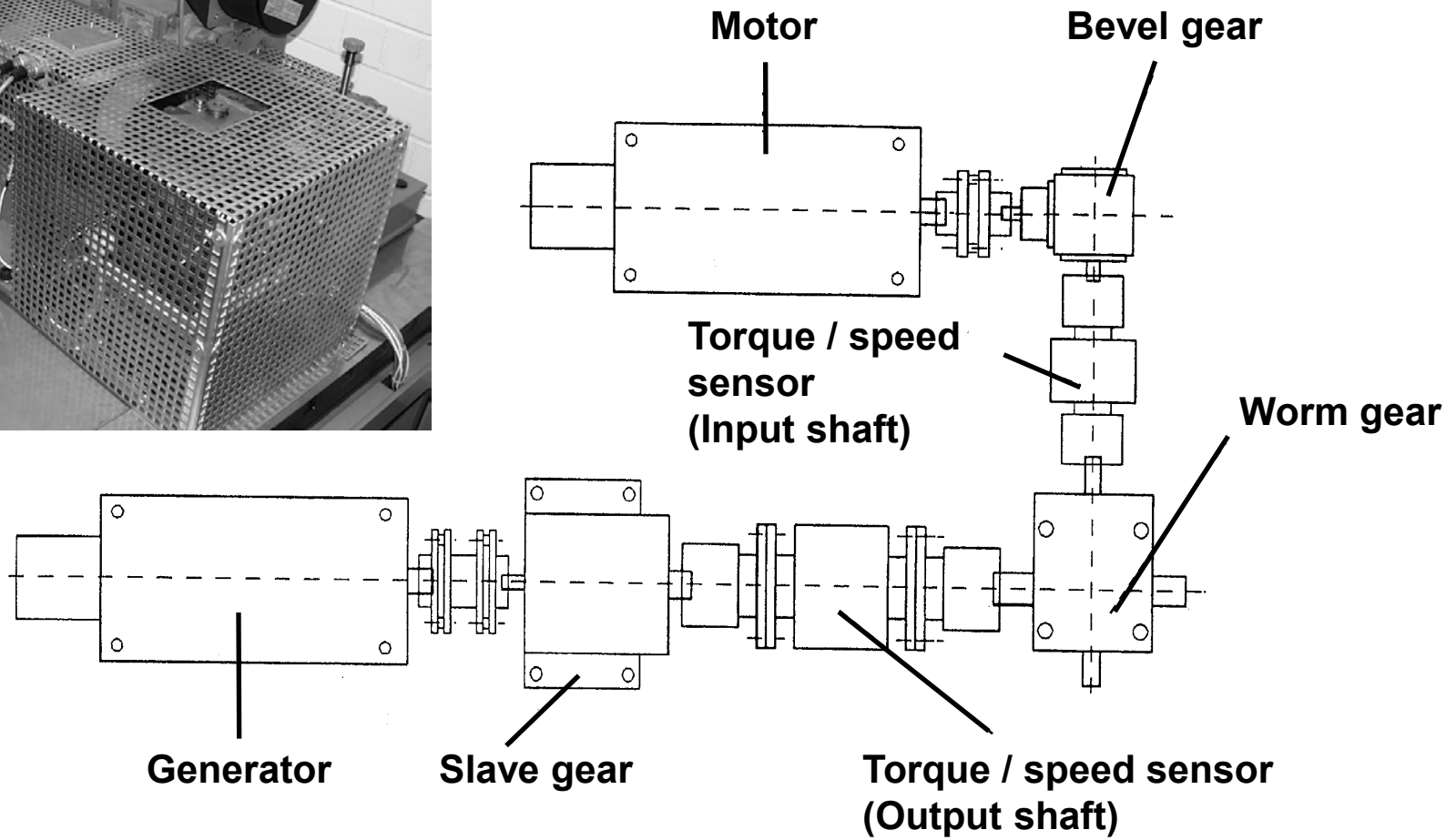
Viscosity-temperature behavior



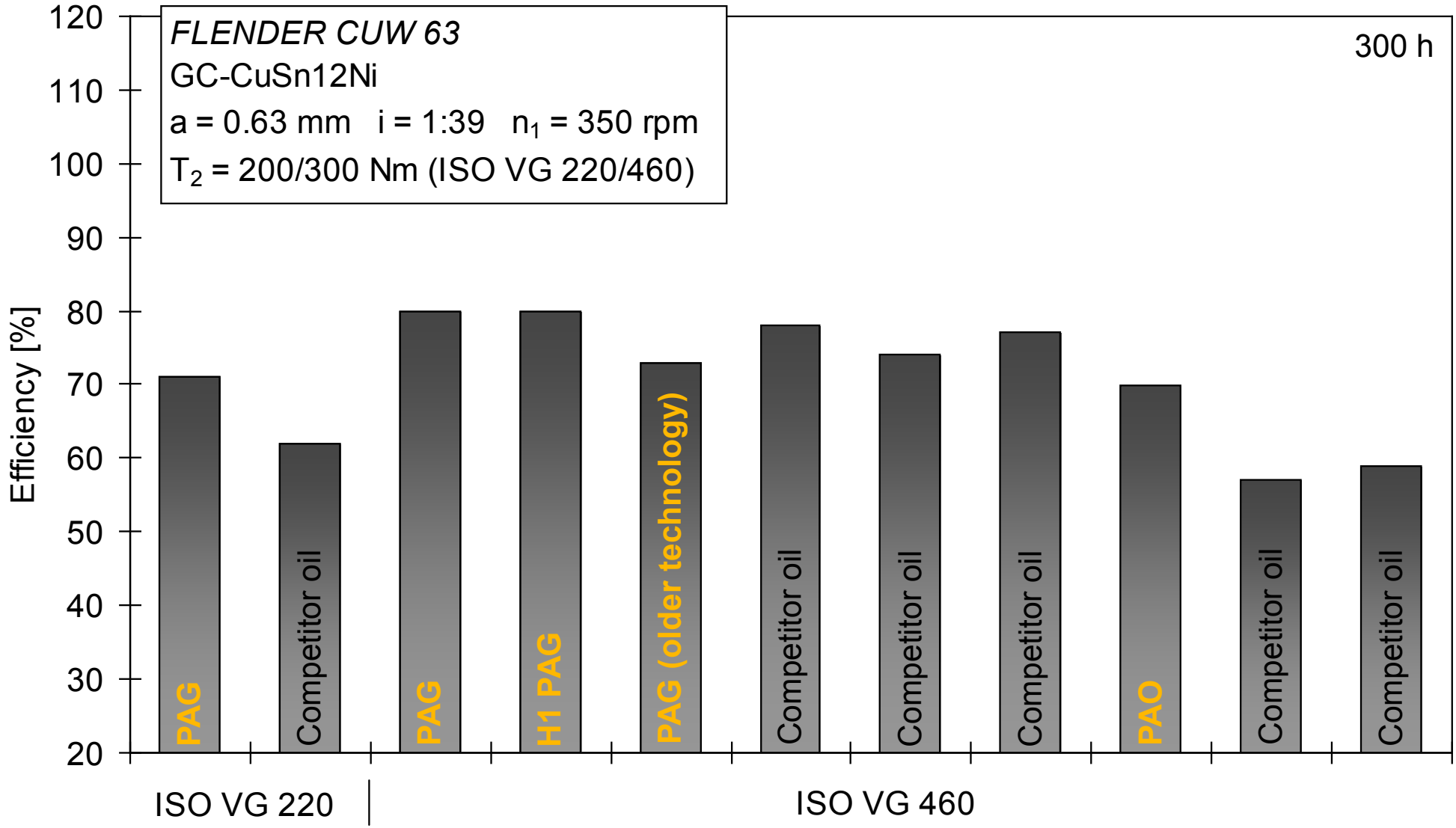
Worm gear load-carrying capacity

Klüber worm gear test rig

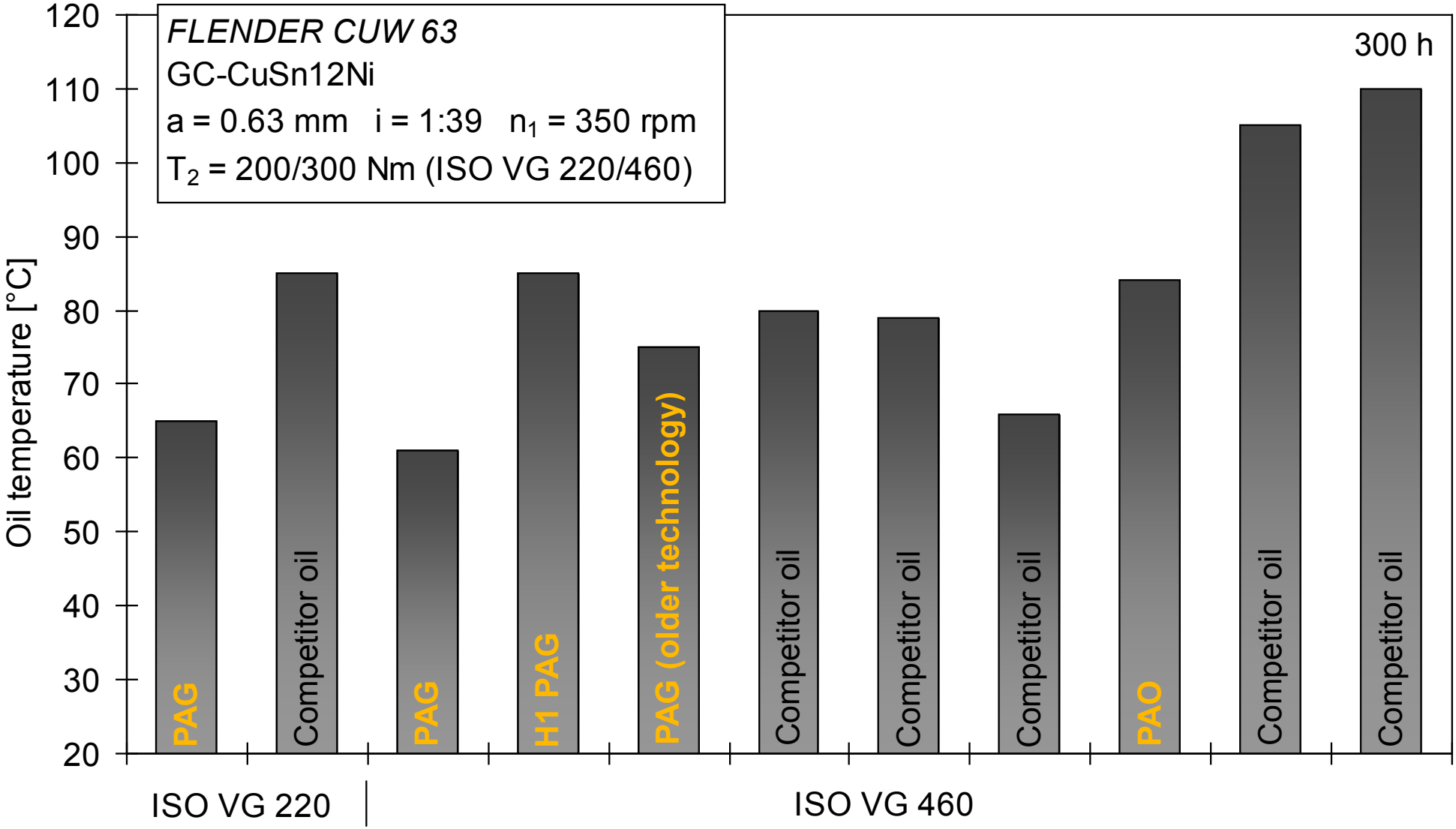




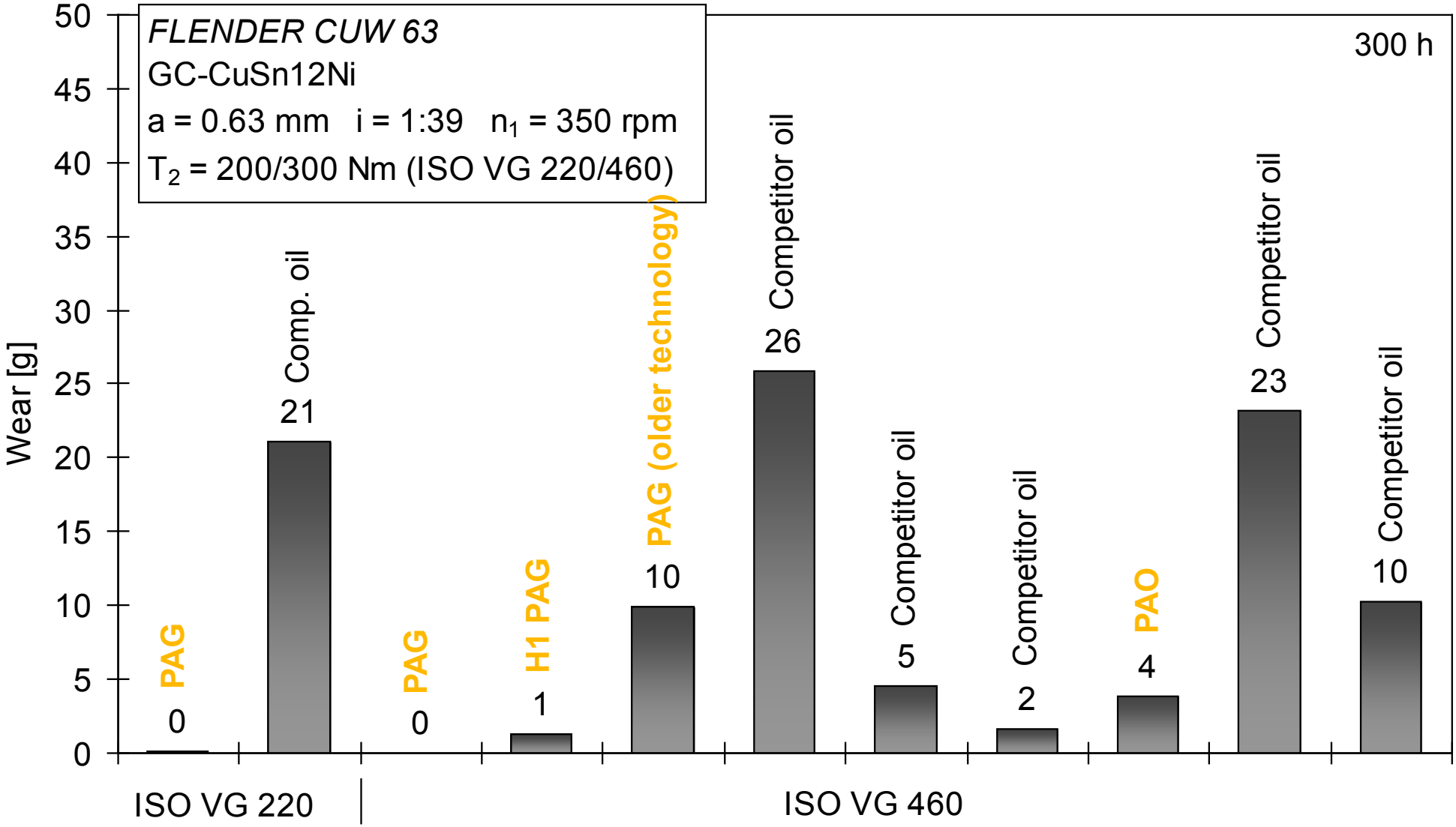
Worm gears – High performance Efficiency



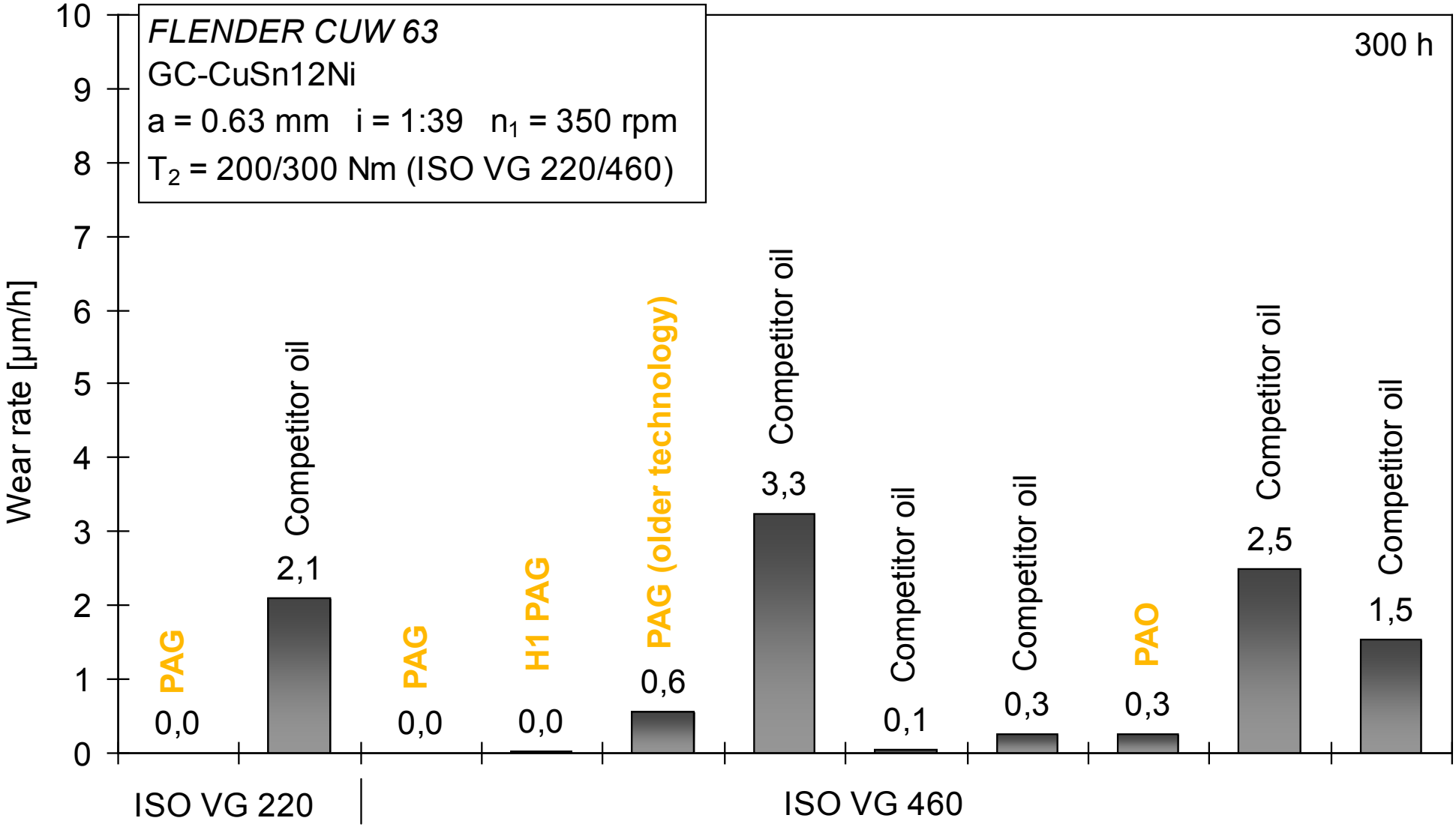
Worm gears – High performance Sump Temperature



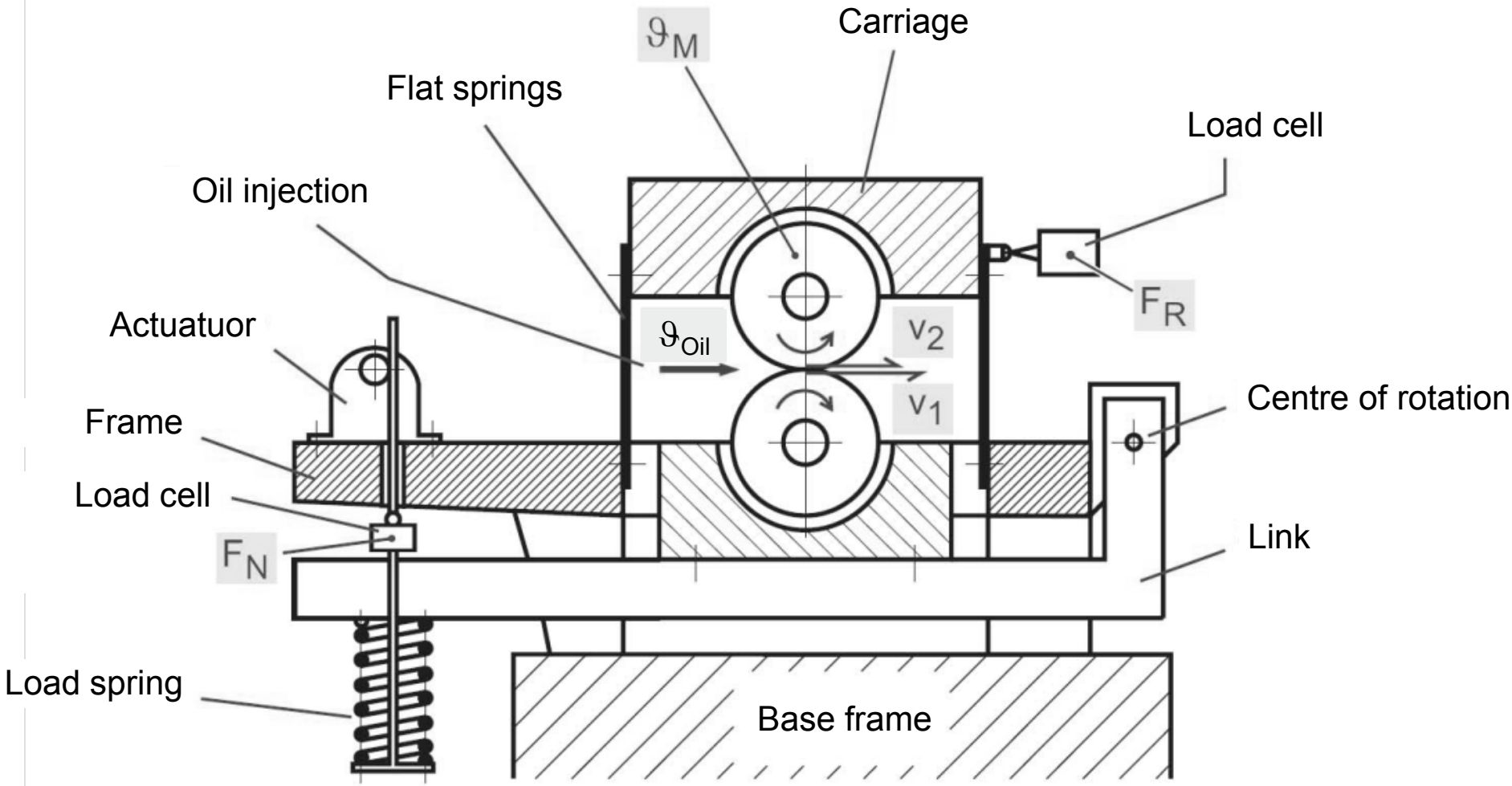
Worm gears – High performance Wear



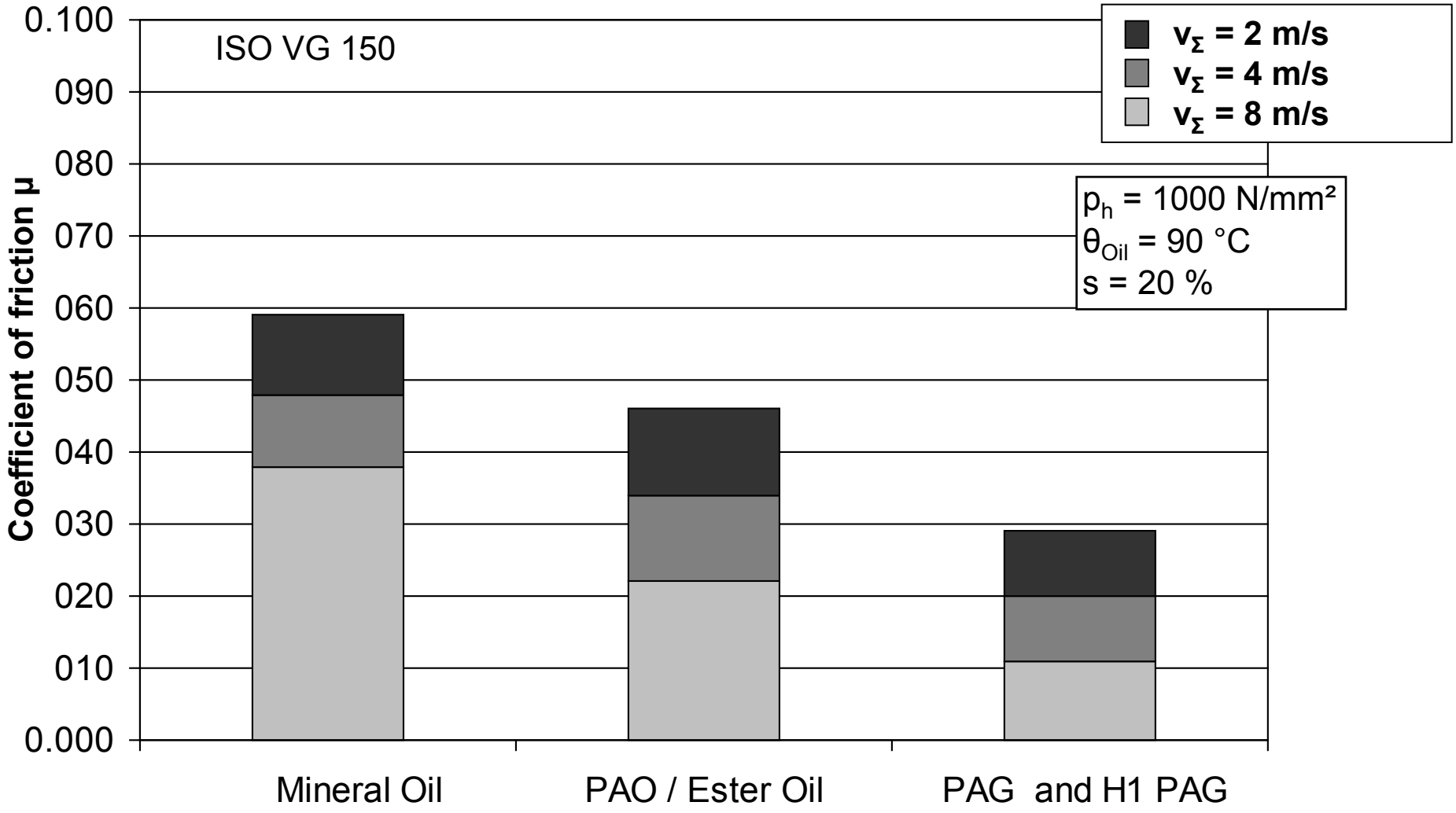
Worm gears – High performance Wear Rate



Friction behavior
Twin disk machine (FZG)



Twin disk machine – Friction behavior



Practical Experience with High Performance PAO Temperature and Sludge Problems

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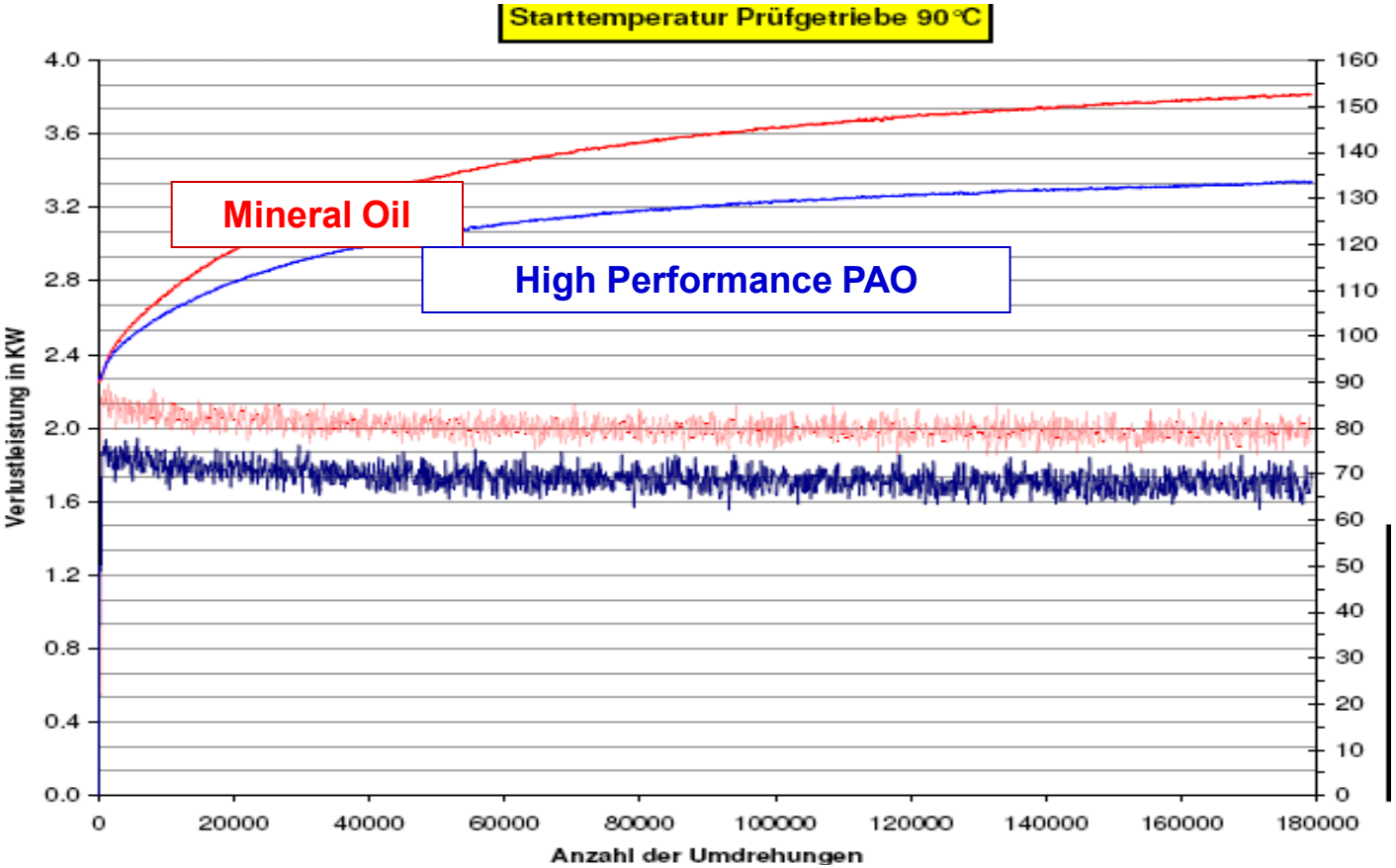
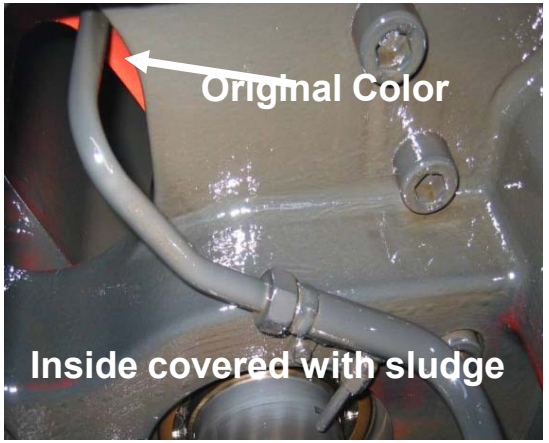
Applicaton: Various gearboxes

Problem: The used mineral oils and PAOs had a sludge and temperature problem. Too many oil changes and too high cleaning costs.

Solution : Changeover to High Performance PAO

Value : Reduction of the oil temperature down to 10 to 15°C, no residue formation, prolonged oil change intervals, maintenance and cost reduction





Clean Gearbox after changeover

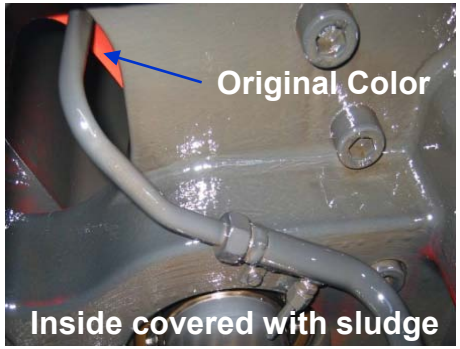
FE 8 Test Machine - bearings after test

Clean appearance after the test with:

High Performance PAO

Brownish discoloring after the test with:

Standard PAO



<u>Test conditions</u>:

Temperature: 80°C **Axial load: 80 kN** **Speed: 7.5 1/min** **Test duration: 80 h**

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