Energy Efficiency Tests in a Full Scale Wind Turbine Gearbox

Mineral vs Synthetic (PAO) Gear Oils

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Objectives

Evaluate a group of 3 synthetic PAO (PAOF; PAOM and PAOX) wind turbine gear oils vs a reference mineral gear oil (MINS), with special focus on:

- Assessment of gearbox energy efficiency in a full scale test rig
- Condition monitoring during the test campaign allowing to verify the oil cleanliness

Gearbox: Echesa GE 850 PL (Gamesa G5X Wind turbine)

Lubricants:

- MINS: Mineral gear oil with Conventional EP Additives
- PAOF: PAO gear oil with Conventional EP Additives
- PAOM: PAO gear oil with Conventional EP Additives
- PAOX: PAO gear oil with Plastic Deformation (PD) Additives

Conventional EP Additives

Chemical reacting additives that form metallic salt on the surface of the friction parts

Positive: The direct Metal-Metal contact is avoided through the formation of a metal salt layer on the rubbing surfaces

Negative: The additives are permanently consumed. Then the oil has to absorb the used additives (in form of metallic salts) which causes aging. By the permanently returning formation of metallic salts abrasive wear has an effect on the metal surfaces

Examples: Sulphur, Phosphorus

Animation of Conventional EP Additives

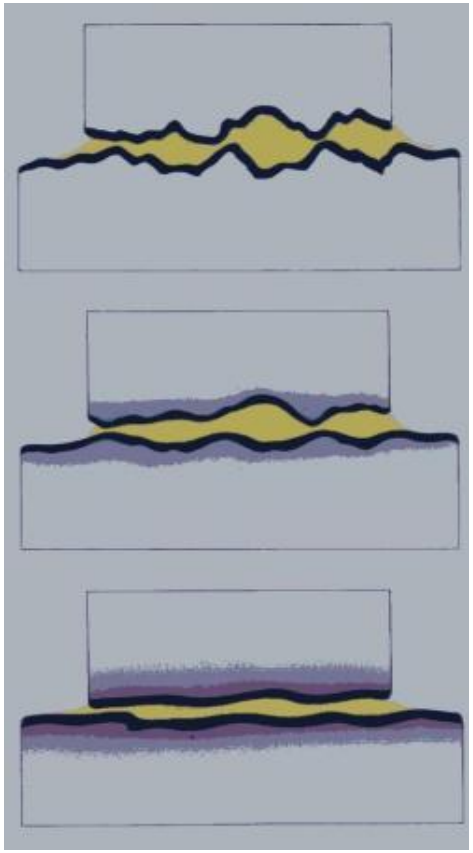
PD (Plastic Deformation) Additives Technology

THE TECHNOLOGY INSIDE

Step 1: Build up of a pressure resistant additive combination

Step 2: Compression of the protective layer at increasing loads. At the same time the coefficient of friction is improved

Step 3: During the flow smoothening the „peaks“ slide into the „valleys“ and this leads to an up to a higher contact area and subsequently to lower friction.



Advantages:

Better surface

↓

Lower Friction
Less Wear

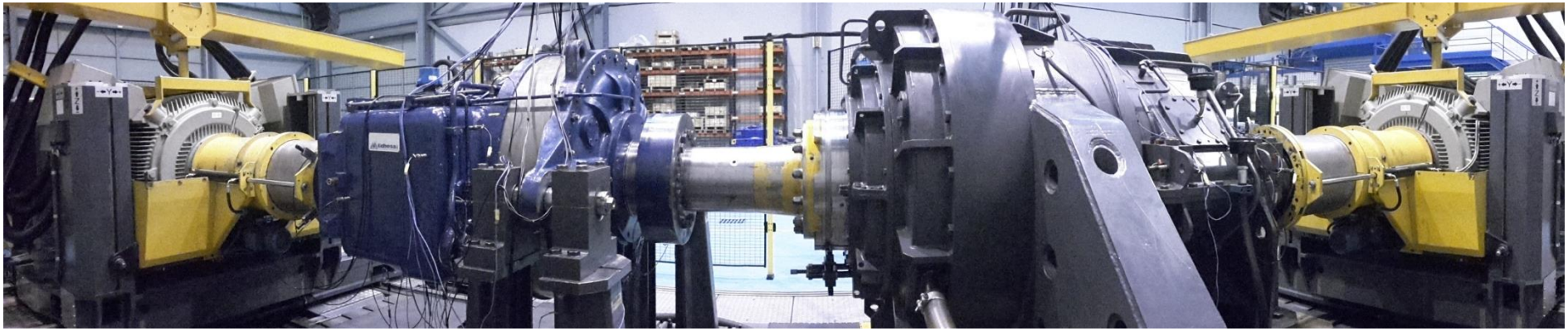
Lower Temperature

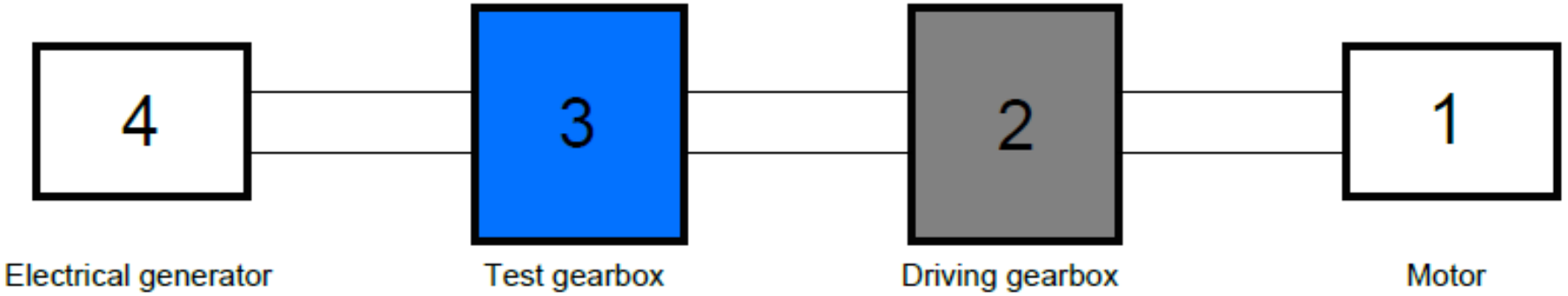
↓

Longer Life
Gear Life Time
Less energy loss

Animation of Plastic Deformation (PD) Additives

Gearbox Test Rig





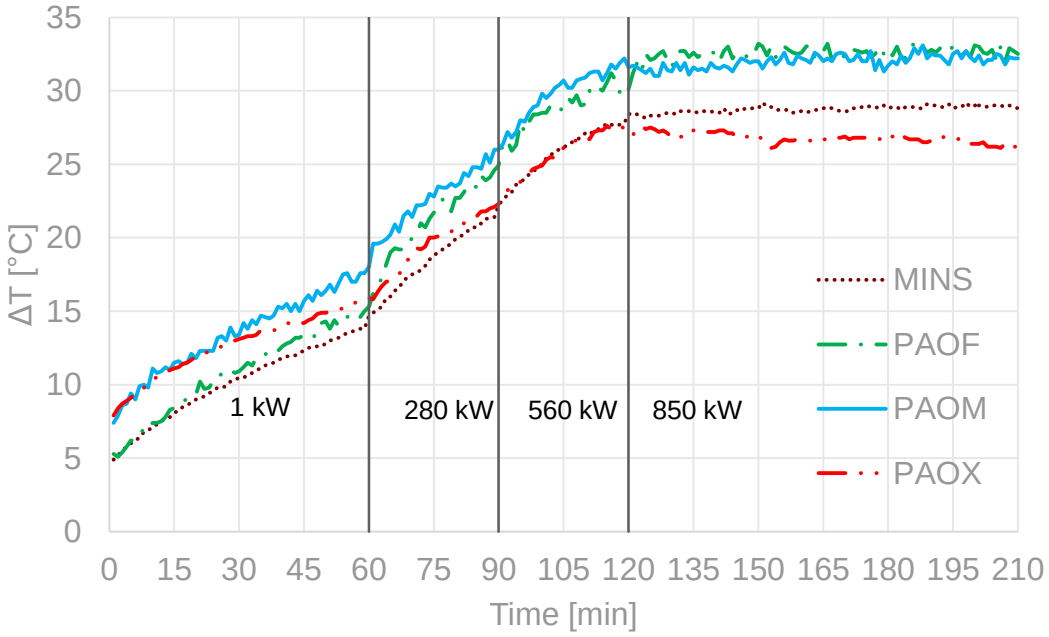
Test Procedure

Step	Speed [rpm]	Power [kW]	Step time [min]	Total time [min]
1	1620	1	60	60
2	1620	280	30	90
3	1620	560	30	120
4	1620	850	90	210

REMARKS:

- 560 kW is 2/3 of full power capacity (850 kW)
- A wind turbine gearbox is most of time working under 2/3 of full power

Experimental Results (1/3)



Max. Operating Temperature [°C]

P_{IN} [kW]	MINS	PAOF	PAOM	PAOX
280	45.8	48.7	48.9	46.3
560	52.2	54.5	55.1	51.7
→ 850	53.4	56.8	55.1	50.4

Operating Kinematic Viscosity [cSt]

P_{IN} [kW]	MINS	PAOF	PAOM	PAOX
280	228.2	213.0	212.2	235.5
560	161.8	165.9	163.1	184.2
→ 850	152.1	150.9	152.2	195.1

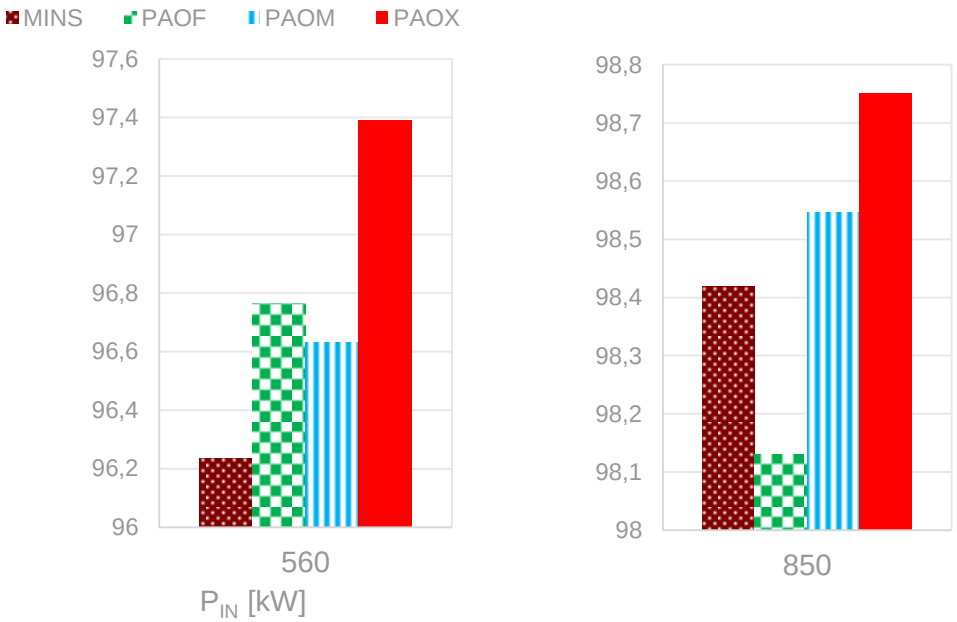
CONCLUSIONS:

- PAOX promoted the lowest operating temperature
  - Higher operating viscosity at full load

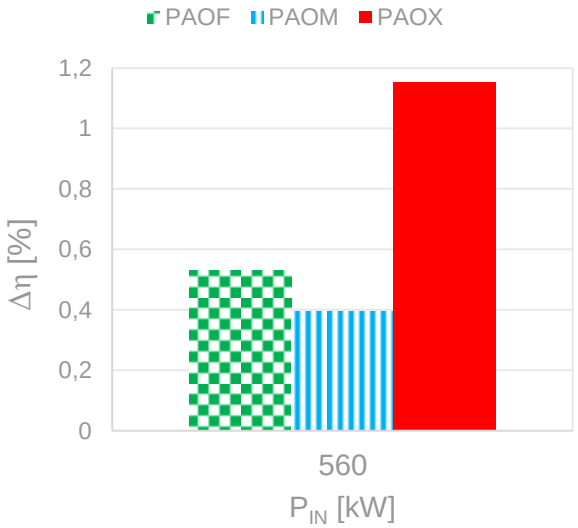
Experimental Results (2/3)

THE TECHNOLOGY INSIDE

Test rig efficiency [%]



PAO vs. MINERAL
2/3 OF FULL POWER CAPACITY



CONCLUSIONS:

- Under real load conditions (560 kW and 850 kW):
  - PAOX generated the highest gearbox efficiency (red bar)

Experimental Results (3/3)

Total energy consumption during each test [kWh]

Energy source	MINS	PAOF	PAOM	PAOX
Test rig	482.5	486.3	482.0	473.6
Oil pump	19.2	18.3	17.36	17.8

Max. Operating Temperature [°C]

P_{IN} [kW]	MINS	PAOF	PAOM	PAOX
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CONCLUSIONS:

- PAOX promoted the lowest operating temperature
  - Higher operating viscosity at full load
- PAOX generated the lowest total energy consuption

Oil Cleanliness (Inline)

Lower particle concentration will reduce the bearing and gear indentations and will contribute to increase the reliability of the gearbox:

Inline average oil cleanliness during each load step, according to ISO 4406.

Oil	280 kW	560 kW	850 kW
MINS	24/19/10	23/17/10	20/14/9
PAOF	18/16/12	18/16/12	18/15/11
PAOM	19/17/13	18/16/13	17/16/12
PAOX	14/11/7	14/12/7	15/12/8

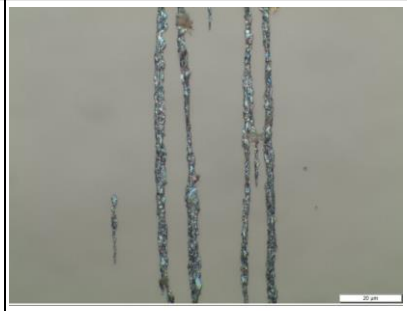
CONCLUSIONS:

- No matter the test condition, PAOX presented the better oil cleanliness, that is lower than the required value during service specified by ISO4406, i.e.18/16/12.
- The other PAO formulations still meet the ISO4406 specification but MINS does not.
- The filtering capacity of PAOX was far better than the other tested products.

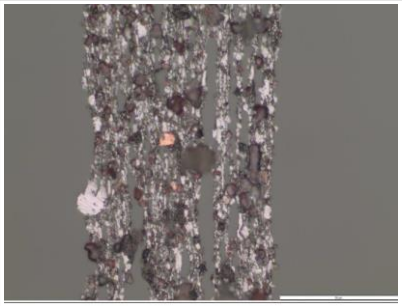
Ferrographic Analysis

THE TECHNOLOGY INSIDE

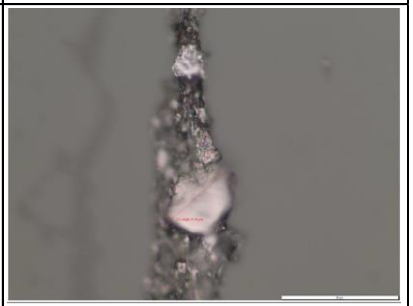
			Results		
FERROUS PARTICLES	Method	Unit	PAOX	PAOM	PAOF
Normal rubbing wear (FW-NR)	ASTM-D7690	µm max.	< 15	< 15	<15
Normal wear - Severity index (FW-NRI)	ASTM-D7690		4	4	4
Severe sliding wear (FW-SS)	ASTM-D7690	µm max.		25	40
Severe sliding - Severity index (FW-SSI)	ASTM-D7690			3	3
Abrasive wear (FW-AW)	ASTM-D7690	µm max.	15	25	40
Abrasive wear index (FW-AWI)	ASTM-D7690		1	2	4
Fatigue chunks (FW-FC)	ASTM-D7690	µm max.	15	25	30
Fatigue chunks index (FW-FCI)	ASTM-D7690		1	2	4
Fatigue flakes (FW-FF)	ASTM-D7690	µm max.	15	30	35
Fatigue flake index (FW-FFI)	ASTM-D7690		1	3	3
Spheres (FW-S)	ASTM-D7690	µm max.		<5	<5
Spheres - Severity index (FW-SI)	ASTM-D7690			1	1
NON-FERROUS					
White metal alloy wear (NFW-WM)	ASTM-D7690	µm max.	< 15	15	15
White metal - Severity index (NFW-WMI)	ASTM-D7690		1	1	1
Copper alloy wear (NFW-Cu)	ASTM-D7690	µm max.	< 10	20	20
Copper alloy index (NFW-CuI)	ASTM-D7690		1	1	1
Non ferrous - Severity index (NFW-SI)	ASTM-D7690		1	1	1



Ferrous wear particles after heat treatment @ 330°C.



ferrous wear, oxides, small copper alloy particle



larger ferrous wear particle

Final Conclusions

- The total power loss is lower for PAOX.
- The power loss measurements are consistent with oil temperature measurements, i.e. PAOX promoted also the lowest oil temperature under stabilized conditions. At full power (850 kW) operating conditions there are differences up to 6ºC between PAOX and the other gear oils.
- In the PAOX, the combination of a PAO base oil together with the plastic deformation additive technology can increase efficiency of the gearbox more than 1% vs MINS and more than 0,5% vs PAOF and PAOM.
- The total energy consumption of PAOX during the test was the lowest one, 1.8% lower than for MINS and 2.6% lower than PAOF.
- The oil ferrographic analysis are in agreement with inline oil cleanliness measurements. Regarding oil performance, PAOX promotes lower quantity and size of wear particles.

Economic Benefits for a Winfd Farm Operator

Example: Increase of Energy Efficiency on Gamesa G8X Wind Turbines

Financial Projections per Wind Turbine/Year on Gamesa G8X - 2 MW with Castrol Optigear Synthetic X 320 vs Mineral Gear Oil:

- Load factor: 30%
- Wind Turbine Power: 2 MW
- Increase of Energy Efficiency (percentage of running time): 50%
- Increase of Energy Efficiency (Castrol Optigear Synthetic X 320 vs mineral gear oil): Up to 1,2%

Economic Benefits:

Best Case Scenario: 30% (load factor) x 365 (days) x 24 (hours) x 2 (Power) x 100 (average MWh price) x 50% (% running time with energy efficiency increases) x 1,2% (increase of energy efficiency)

3154 € / Wind Turbine per Year

Average Scenario: 30% (load factor) x 365 (days) x 24 (hours) x 2 (Power) x 50 (average MWh price) x 50% (% running time with energy efficiency increases) x 1% (increase of energy efficiency)

1314 € / Wind Turbine per Year