ACC Fan Gearboxes:

Eskom's Experience in the Selection and Maintenance of ACC gearboxes.

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1) Introduction

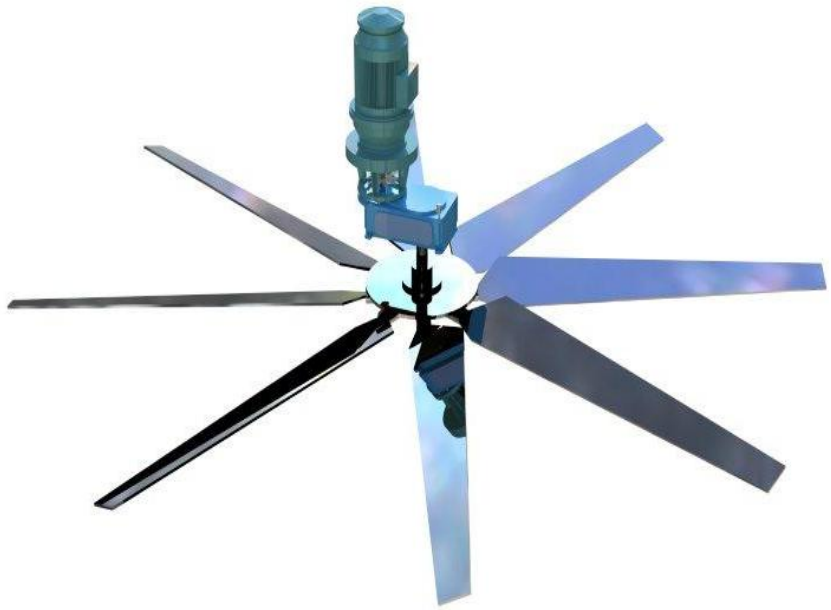
- The Matimba ACC's have 48 fans per Unit with 288 fan drives in total. Of the original split casing – splash feed type boxes that were commissioned 20 - 25 years ago, 235 are still in operation. The boxes run on mineral oil and are maintained and overhauled in the Matimba workshops.

- During 2009, 48 later generation monoblock- force feed type boxes were purchased. 45 were installed and 3 kept as spares. Also during that time, 6 monoblock boxes of a different manufacturer were installed for long term testing. All the monoblock boxes operates on synthetic oil.

- In addition Matimba has one other brand name, a split casing force feed box on test since 1994. This box run on mineral oil.

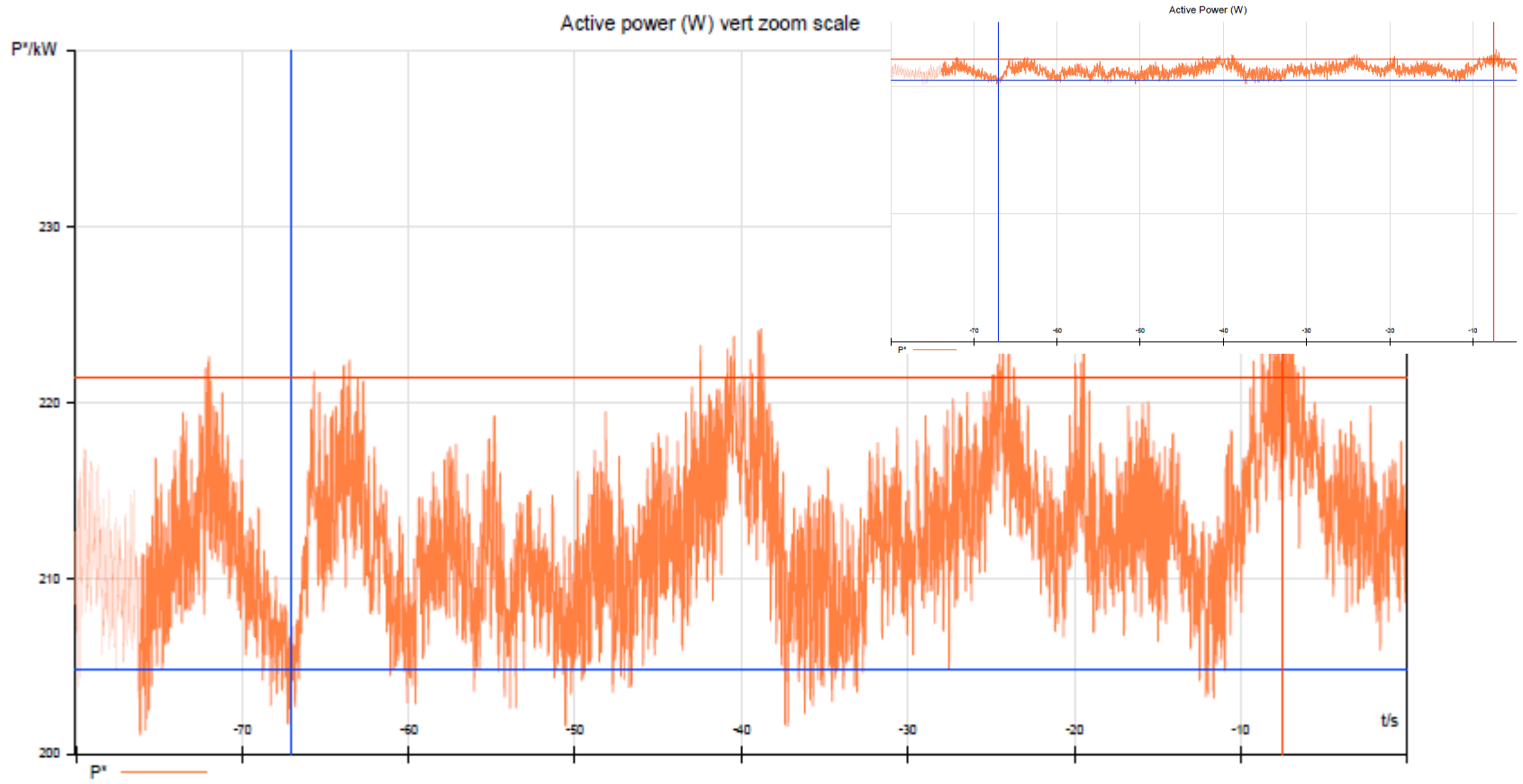
2) ACC Gearbox Working Conditions

- 1) Normally the fan blade angles are fixed and the gearboxes are likely to be continuously loaded at close to MCR capacity.
- 2) Gearboxes are subject to perpetual peak load fluctuations
- 3) Poor cooling air flow around box
- 4) Questionable oil change practices



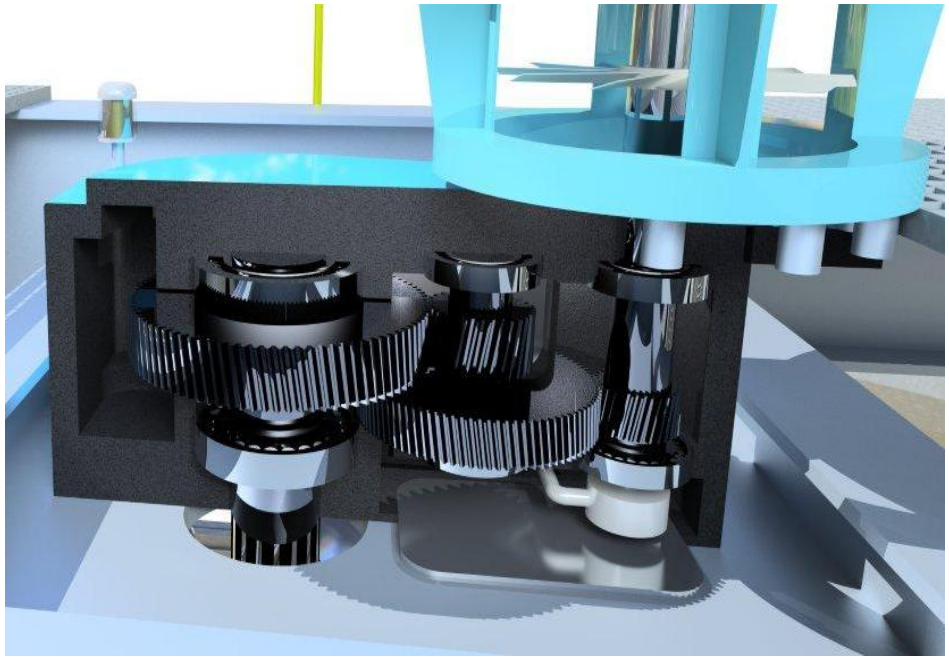
Working Conditions: Perpetual peak power fluctuations in ACC fan load

- Peak load variations occurring in 1 minute – up to 20kW (1.9 kNm of full load torque on output shaft) variation between peaks



Working Conditions: cooling air flow and maintenance

- The position of the ACC gearbox is normally between high profile IPE beams and onto a base plate which obstruct the already poor air flow in the centre of the fan



3) ACC Gearbox Maintenance

Matimba Workshop

- Time based maintenance
  - Oil changes & bearing grease
- Condition based maintenance
  - Quarterly vibration monitoring, oil sampling
  - Monthly walk-through inspections
- Breakdown maintenance
  - Consist mostly of broken shafts, oil pumps and back-stop failures

Condition Based maintenance: Typical oil sample reports

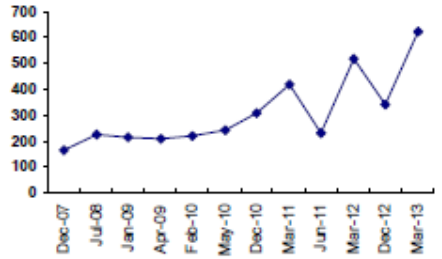
Customer: Matimba Power Station
Site: U2_ACC_FAN_GB
Machine: 20MAG24/20
Compart: GEARBOX

1405

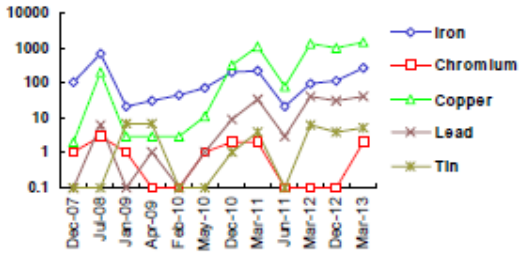
	Lab No	Sampled	Received	Oil Brand	Severity
1	4182207	20-Mar-13	25-Mar-13	SHELL RIMULA D 50	URGENT
2	4179397	20-Dec-12	27-Dec-12	SHELL RIMULA D 50	BORDERLINE
3	4170750	30-Mar-12	03-Apr-12	SHELL RIMULA D 50	CRITICAL
4	4162715	14-Jun-11	17-Jun-11	SHELL RIMULA D 50	NORMAL
6	4159514	03-Mar-11	07-Mar-11	SHELL RIMULA D 50	CRITICAL

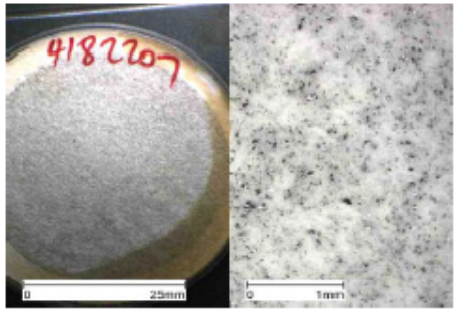
URGENT

Viscosity @ 40



Wear Metals





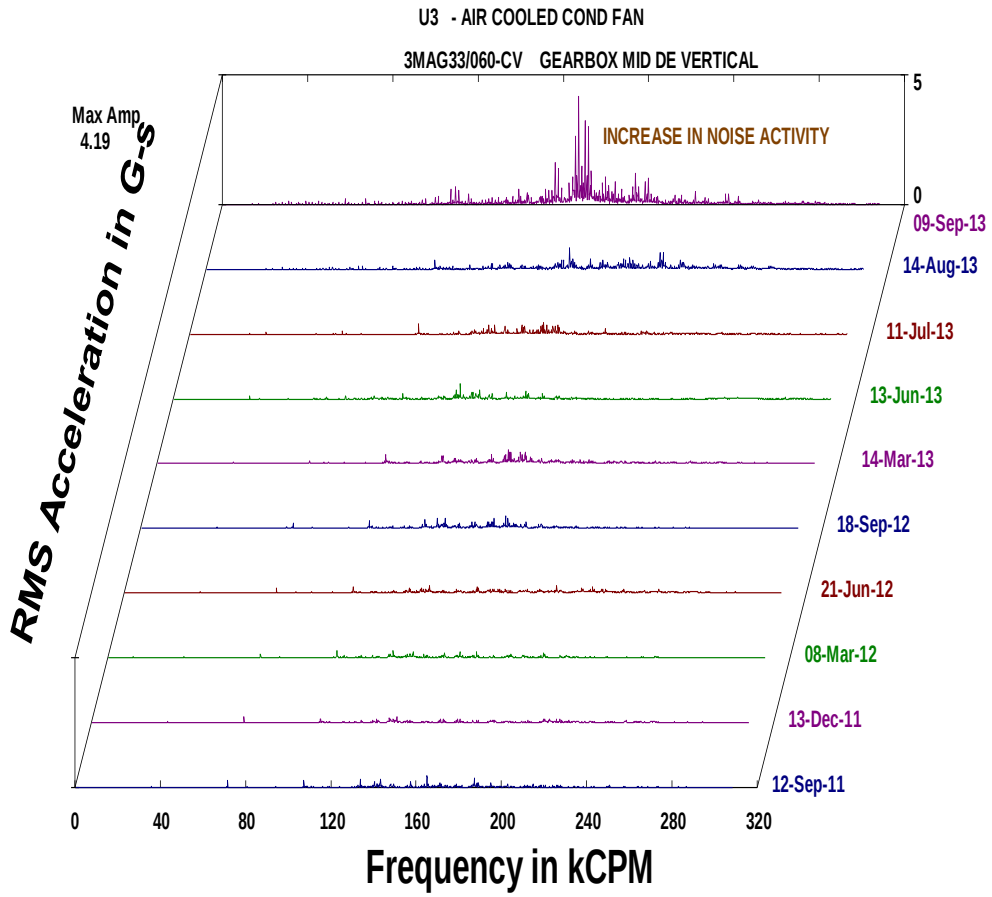
	KV 40	Water	TAN	ISO	MPE	WPC	Fe	Cu	Pb	Cr	Al	Si	Na	Mo	Sn	Ni	Ca	Ba	Mg	Zn	P	B	K	Li	S	Sb
1	621.1	ND	18.68	27/25	2111	253	266	1365	41	2	12	12	0	38	5	4	3383	0	13	1415	504	41		51	15000	0
2	343.1	ND	7.85	26/24	1111	62	114	971	29	0	10	9	0	49	4	4	4290	0	15	1288	601	39		43	16180	0
3	518.2	ND	16.72	/	2111	29	91	1251	39	0	11	9	0	44	6	4	3876	0	14	1499	550	56		74	17490	0
4	234.2	ND	1.43	/	1111	27	20	74	3	0	3	4	0	44	0	0	4022	0	12	648	501	7		8	17290	0
6	416.5	ND	13.76	/	1111	101	216	1071	33	2	8	9	0	38	4	3	3469	0	12	1345	506	40		53	14770	0

Comments

1	Viscosity appears high for this grade of oil. Bronze gear wear rates are high. Debris analysis revealed a light concentration of very small wear particles. Check for abnormal noise and vibration. Check oil operating temperature. Check shaft alignment. Increased viscosity and wear metal contamination makes the oil unfit for further use. Particle count is greater than the limit specified, recommend filtering/purifying the oil. Please return feedback. REPEAT PROBLEM wearx2. REPEAT PROBLEM oil-u/sx3.
2	Bronze gear wear rates remain higher than normal. A microscopic particle examination of particles filtered from the oil revealed no abnormal contamination. Check for abnormal noise and vibration. Particle count is greater than the limit specified, recommend filtering/purifying the oil. Please return feedback. REPEAT PROBLEM oil-u/sx2.
3	Bronze gear wear rates are high. Debris analysis revealed a light concentration of very small wear particles. Recommend removing cover plate and checking for abnormal wear particles inside housing. Viscosity appears high for this grade of oil. The Total Acid Number of the oil is 16.72. Increased acidity (TAN) indicates oxidation. Check oil operating temperature. The oil is not fit for further use due to contamination and degradation. Change the oil. Please return feedback.
4	Wear rates are normal and the sample provided appears free from unacceptable contamination or degradation. A microscopic particle examination of particles filtered from the oil revealed no abnormal contamination.
6	Viscosity appears high for this grade of oil. Copper level is critical, according to Eskom limits. A microscopic particle examination of particles filtered from the oil revealed no abnormal contamination. The Total Acid Number of the oil is 13.76. Increased acidity (TAN) indicates oxidation, possibly as a result of abnormally high operating temperatures. Increased viscosity and an increased TAN makes the oil unfit for further use. Change the oil. Please return feedback. REPEAT PROBLEM overheatingx2.

WearCheck, a division of the Setpoint Group(Pty) Ltd, Tel: +27 11 392 6322

Condition based maintenance:
Excerpt from typical vibration report



WEAR CHECK®
Leaders in Vibration Analysis

"Increase impact activity present in the waveform. Suspected bearing defect activity evident in the high resolution reading, indicating to possible input shaft bearing failure, oil pump failure or a broken / chipped gear tooth. Suggested to replace the gearbox asap and do a failure analysis on the gearbox, please give us feedback on the findings".

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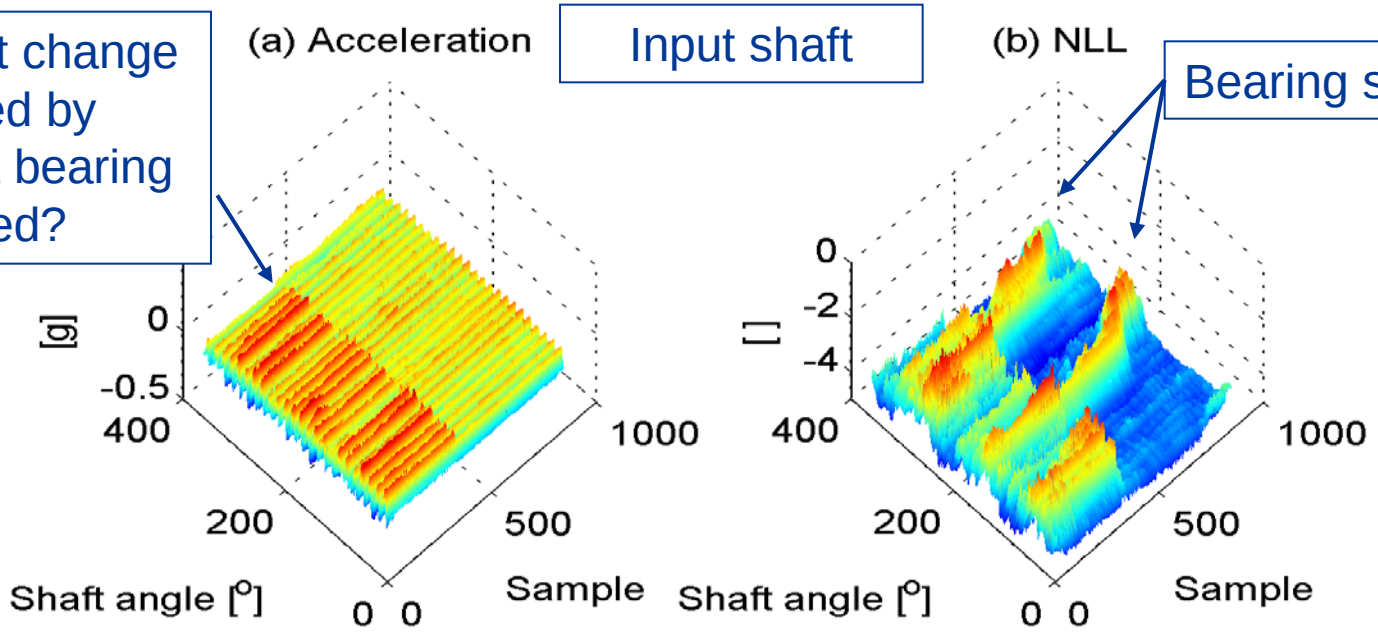
ACC fan gearbox long term vibration monitoring- University of Pretoria

- Measure acceleration and shaft speed at 2.5 kHz over a period of 18 months
- Evaluate use of Gaussian mixture modeling
  - Negative Log Likelihood (NLL) indicator for out-of-normal behavior
- Evaluate synchronous averages
  - Mean and standard deviation

Abrupt change Caused by output bearing greased?

Input shaft

Bearing spall?



Oberholster, Heyns, Newby & Goldschagg

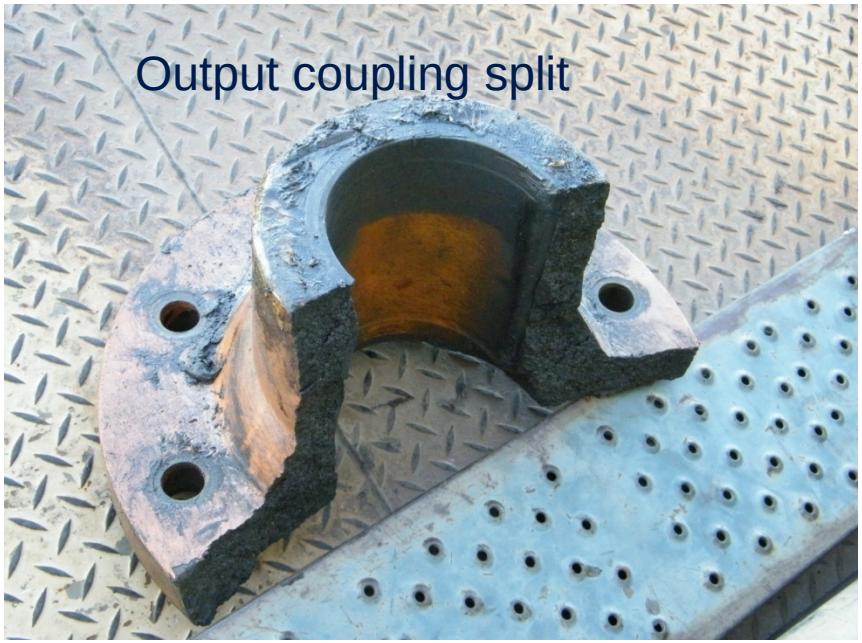
Condition based maintenance:
Gearbox overhauls

- Intermediate pinion failure – the most common failure of the old generation gearboxes.
- Dry wells working loose from the press fit into the casing is the most common and serious source of oil leaks.

Breakdown maintenance fatigue failure of gearbox output shaft – serious safety concern

Breakdown maintenance: Damage due to backstop malfunction and reverse rotation

Sticky backstop elements allow fans to windmill in reverse. If the fan is started or if the backstop suddenly operates while the fan windmills, it causes catastrophic failure either of the couplings or the input shaft. Output coupling failure may cause the fan to fall.



4) Lubrication Aspects

- The ACC gearbox user does not control the method and effectiveness of the lubrication design. The user however determines the cleanliness and can influence the properties of the oil, aspects that relate directly to the life expectancy of the bearings and gears.

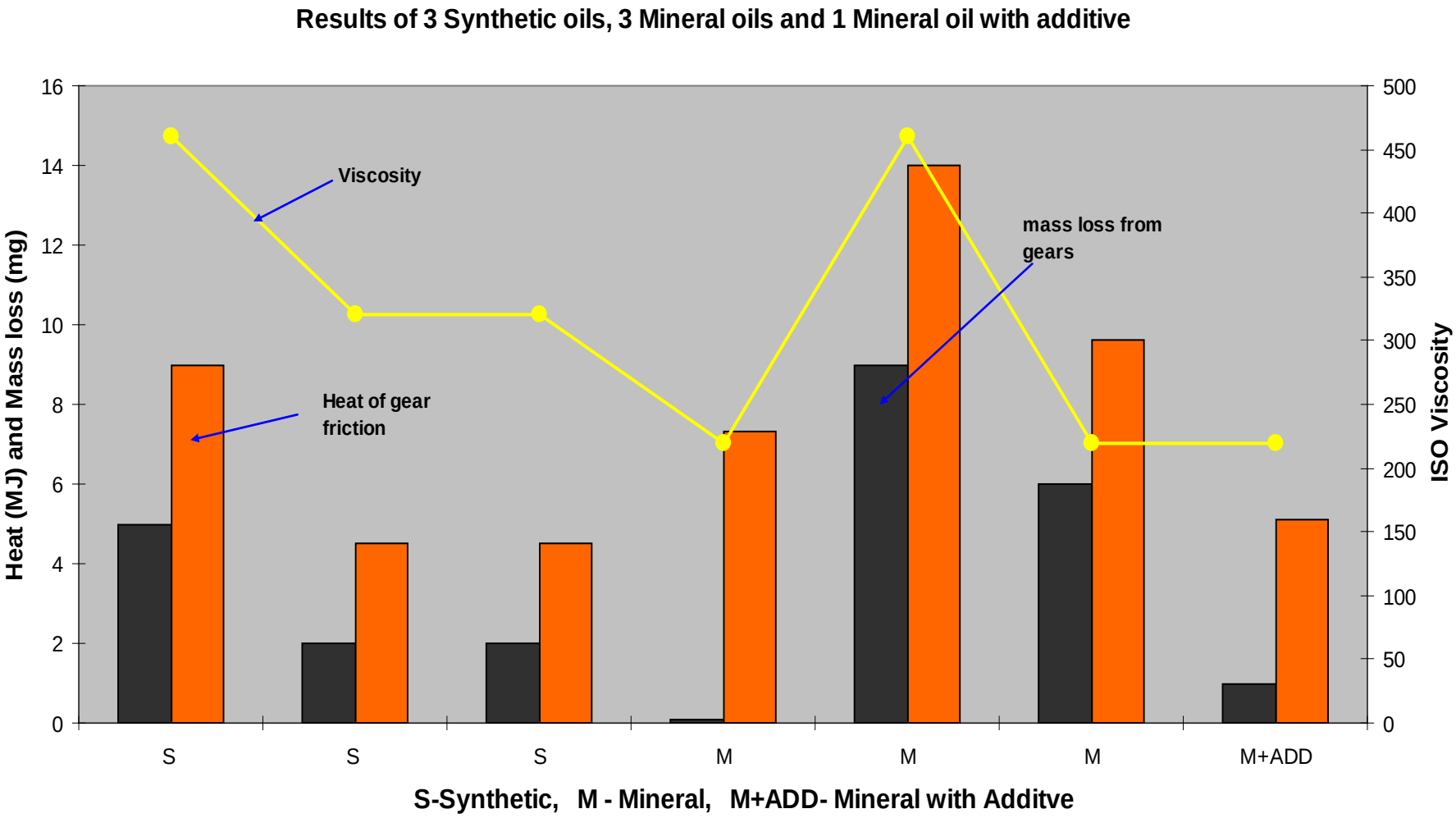
- Splash feed lubrication is simple and effective and requires minimum instrumentation such as only a basic C&I oil level protection. The large volume of oil allows some neglect as long as there is sufficient oil in the box. Matimba recorded only one seizure on a splash feed box in more than 20 years. The fan was started without oil and the level protection switch was not connected. Not surprising.

- Force feed lubrication requires less bulk oil but renders the box more vulnerable to damage, especially in dry sump gearboxes where no part of a rotating component is submerged in oil. It also requires more components like pumps, filters, pressure switches and C&I timers

Lubrication: Mineral & synthetic oil tests

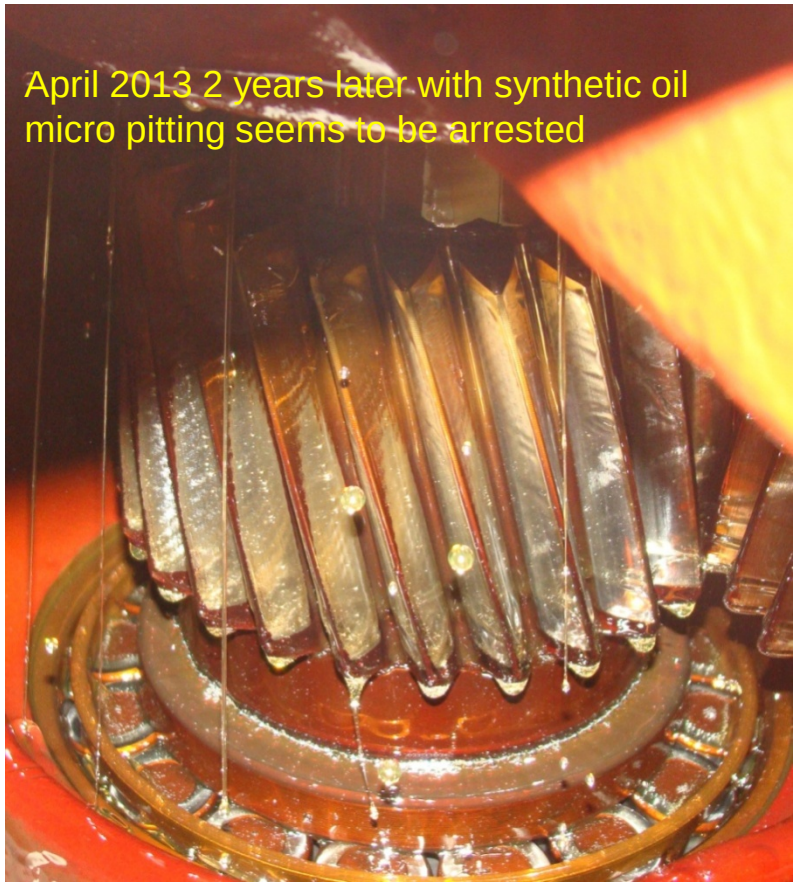
- Eskom commissioned the University of Pretoria to determine energy efficiency of selected mineral and synthetic oils. The test method measures the heat generated (friction) in the test gearbox and the mass loss from the gears under identical load conditions for all tests.
- The tests results showed that synthetic oils generally reduces friction more effectively than mineral oil, but also found that some synthetic oils performed worse than mineral oil. Both PAO and PAG synthetic were tested.
- Some relation between viscosity and heat generated was noted.
- The mass loss (wear) from the test gears after each test, showed no clear advantage of one type of oil above the other, possibly due to the relative short duration of the tests.
- Synthetic oils were also tested on the Matimba ACC. Decrease in bulk oil temperatures were observed as well as improved protection against micro-pitting of gears when mineral oil was replaced with synthetic oil

Lubrication: FZG test results



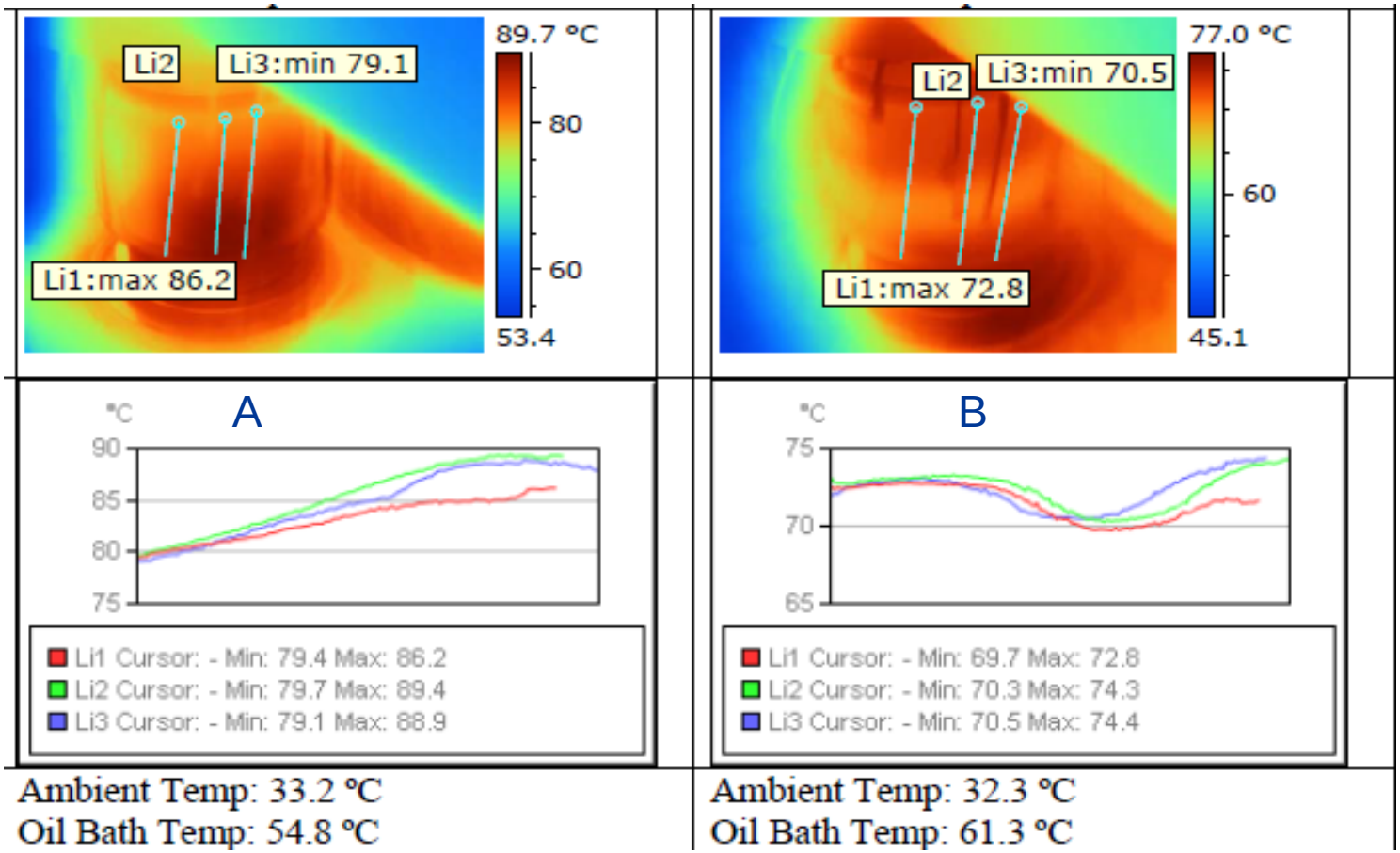
Micro pitting - Mineral vs Synthetic

Micro pitting in a dry sump gearbox where the thermal rating is lower than the absorbed power



Thermal images of the input pinion of a dry-sump gearbox in operation

- **A**: Normal: Oil cascading from top bearings only, **B**: Test: Cascading combined with jet lubrication



Lubrication: Oil change issues

- The position of gearbox drain plug or valve at the bottom of the gearbox makes oil draining cumbersome due to safety regulations and equipment needed to access the plug from underneath the box.
- It also prolong the standing time of the fan which may interfere with production. As a result oil is sucked from the box through the level standpipe with a gear pump which leaves some dirty oil at the bottom of the box . This contaminates the fresh oil
- If the gearbox is situated low below the walkway, like the installation shown on the right, is more arduous to reach the dipstick, filter, breather etc. It is also not possible to do an internal inspection through side covers or inspection plugs unless the fan is un-coupled and the box lifted.

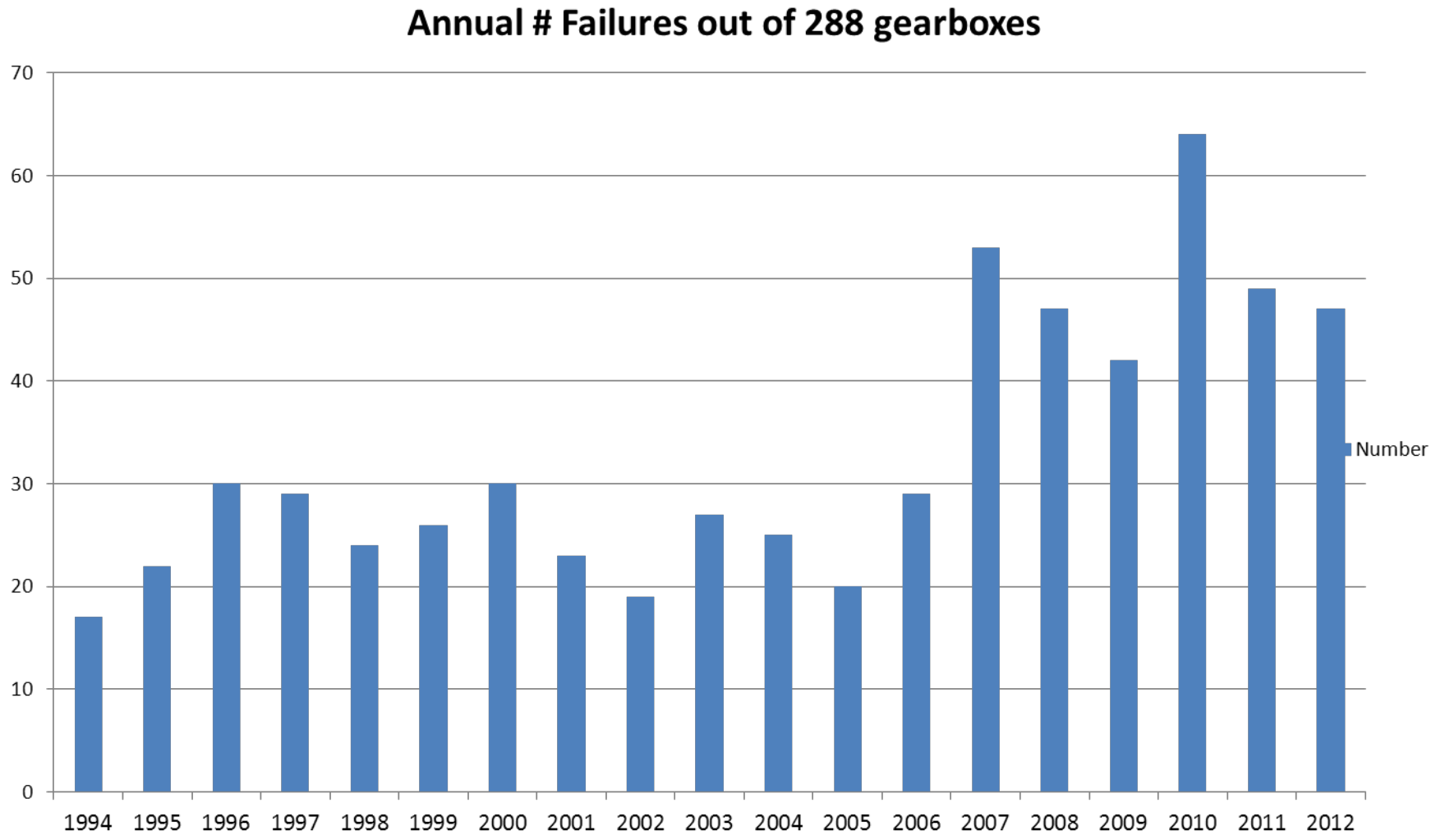
Oil Changes

- Mineral oils at Matimba are changed annually. Failure to observe oil change frequency, or acting timeously on sample reports result in rapid depletion of lubrication properties and oxidation of the oil at exponential rate. The damage to the gearbox is severe when the oil reach a state as shown in this splash feed box

5) Selection and Replacement of gearboxes

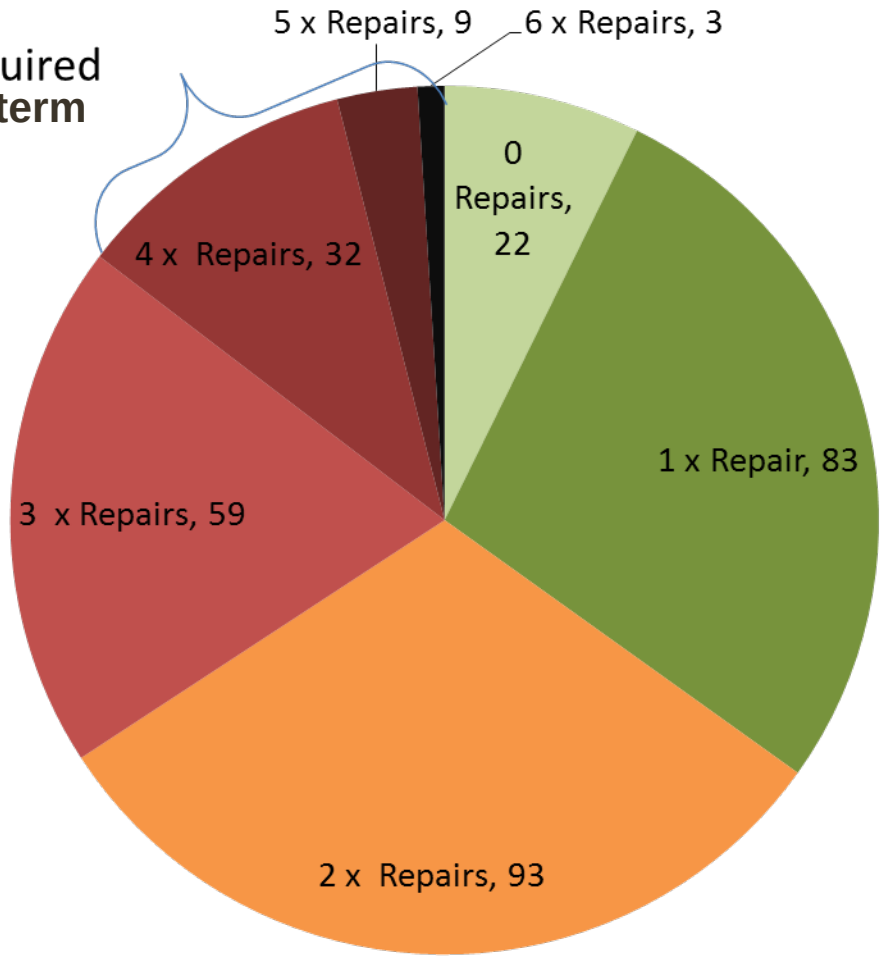
- Gearboxes casings & components do not have an infinite life. excluding boxes with casing failures, at a certain stage one has to consider to replace instead of repair,.
- A blanket replacement of all gearboxes is not always feasible because:
  - At Matimba gearboxes are repaired on site with locally manufactured gears, repair costs are therefore relatively cheap
  - The risk of production loss if the wrong choice of gearbox is made and simultaneous large numbers of failures occur
- Question: Which boxes are to be to replaced and which gearbox does one select as replacement box?

Replacement Criteria: Trend of repairs required 1994 - 2012



Replacement criteria: Number of repairs per gearbox . 1994 - 2012

44 Replacements required
In short to medium term

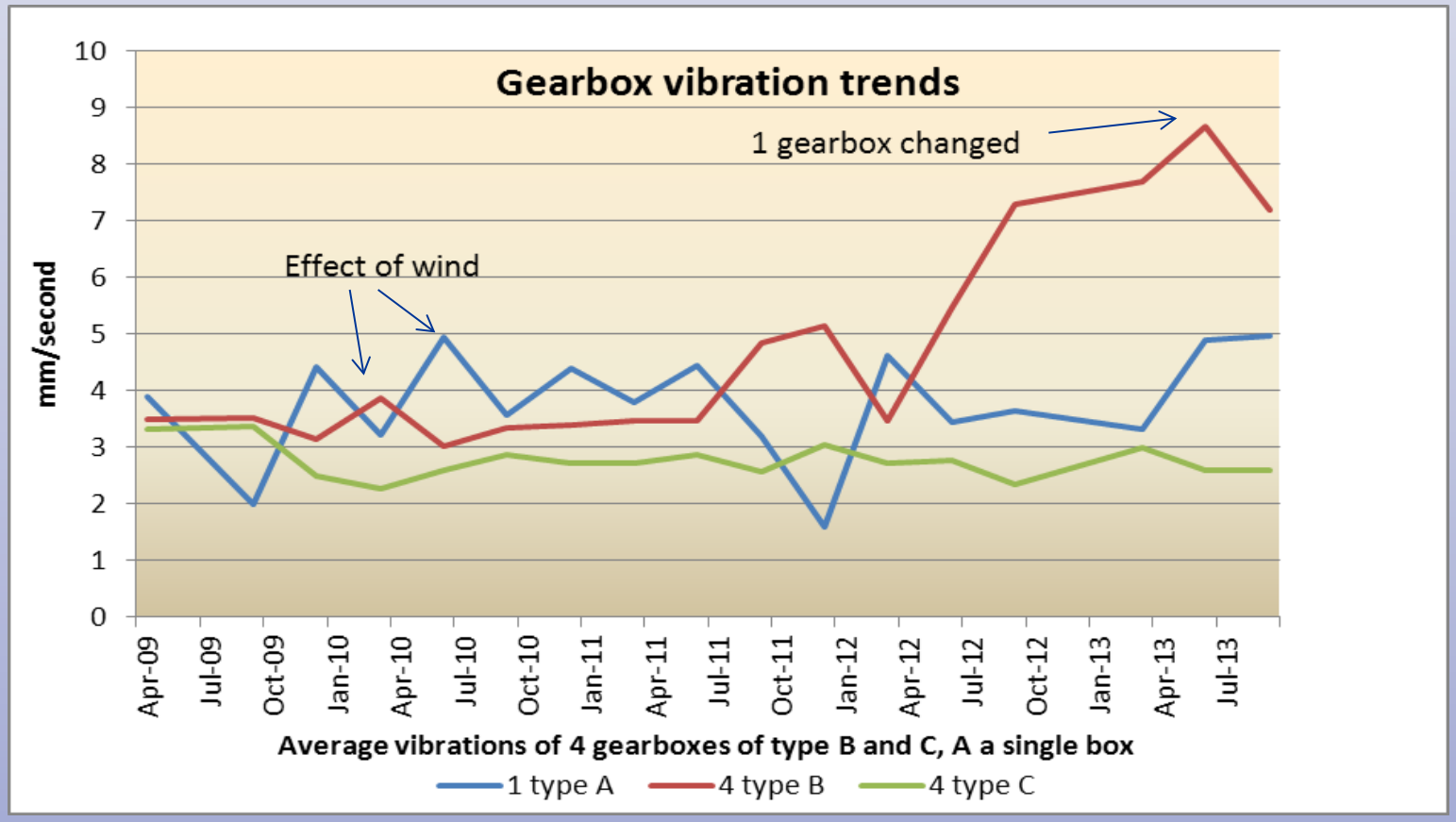


Selection Criteria for new boxes

- *Power rating*: ACC gearboxes normally has a service factor of 2 and mechanical failure due to start-up or load conditions is unlikely.
- *Thermal rating*: This limits the continuous load the box can transmit without exceeding temperature limits of components and lubricant. It determines the choice of lubricant and operating cost
- *Split casing or monoblock*: mono blocks are cheaper than split casings but require more specialized equipment and skill to overhaul. No significant difference in oil leakage between the two casing types is noted
- *Backstop position*: Back stops situated at the bottom of the box tend to clog up and malfunction more than backstops in the roof of the box

micro pitting on a dry sump box with cascade lubrication and thermal rating too low for the absorbed power. The oil sump temperature is however quite low

Long term vibration trends of 3 different manufacturer's gearboxes



Life Cycle Cost comparison using Matimba's investment model

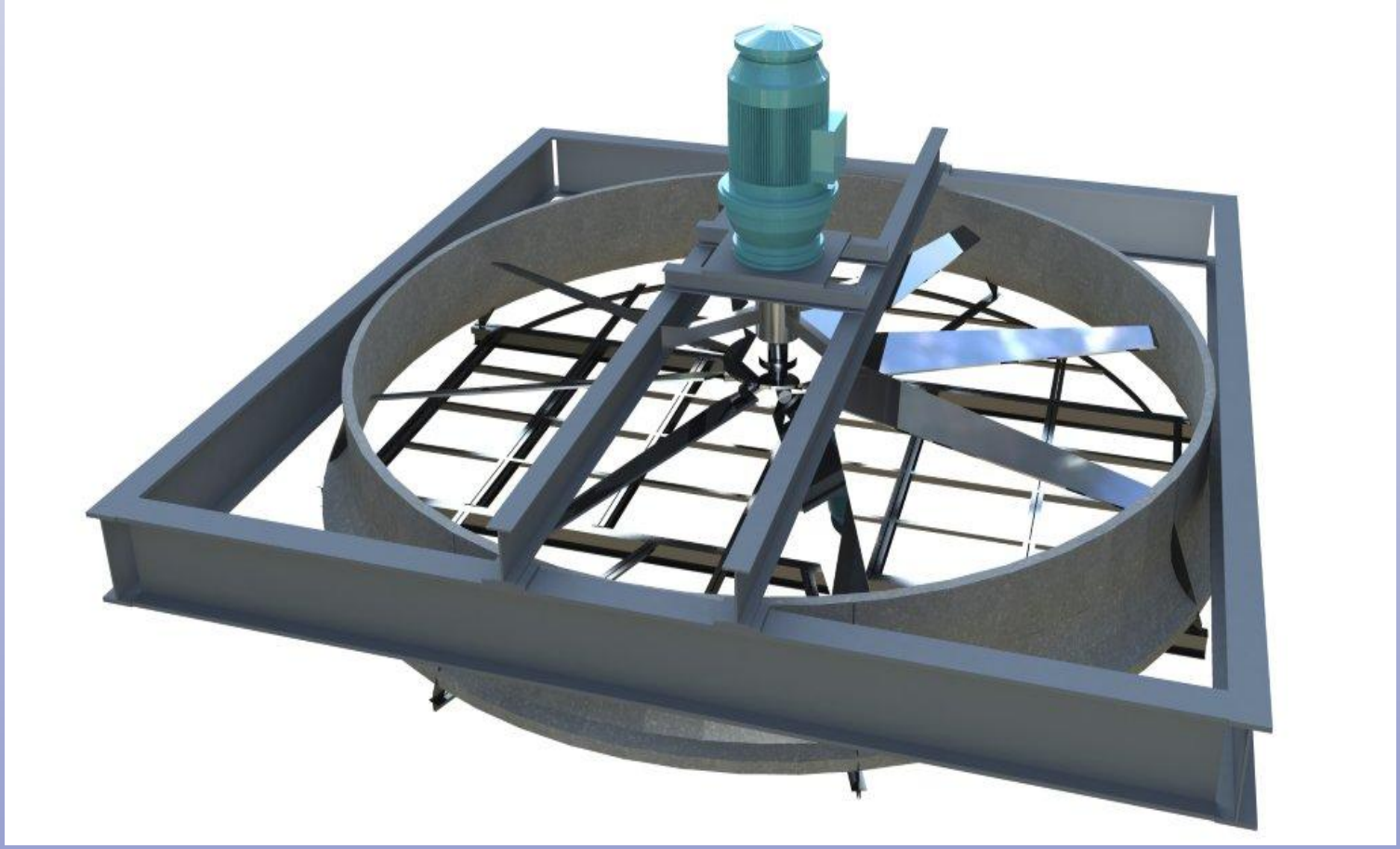
Investment period 25 years

Economic Model inputs	Original Box	Box A	Box B	Box C
Capital	R 0	R 410,000	R 280,000	R 276,000
Oil type	Mineral	Mineral	Synthetic	Synthetic
cost/litre	R 23	R 23	R 123	R 123
Capacity/litre	160	90	35	80
Cost /oil change	R 3,680	R 2,070	R 4,305	R 9,848
oil change frequency	1Y	1Y	2Y	2Y
oil cost 25 years	R 92,000	R 51,750	R 53,812	R 123,100
cost of repair	R 140,000	R 260,000	R 200,000	R 240,000
Estimated # repairs	4	1	4	2
PV life cycle cost Rmio	**0.28**	**0.39**	**0.55**	**0.38**

Recommendation: Capital cost should not be the major consideration to select replacement ACC gearboxes.

Future for ACC Fan Gearboxes?

Advances in the development of permanent magnet motors may soon eradicate the need for gearboxes



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