Research Report

Ultrasonic Condition Based Lubrication

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HZ University of Applied Sciences

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Abstract

Only nine percent of rolling element bearings operate long enough to achieve their design life. The leading cause of failure, by 43 percent, is improper lubrication. This includes over lubrication or a lack of lubrication. This will lead to unexpected failure of the bearings, which could result in a total shutdown of the system. This research will determine if the use of ultrasound can lead to a longer lifetime of the bearings on board the MS Rotterdam by comparing the difference between greasing the open bearings according to the maintenance schedule or by use of the Ultraprobe 15000.

For this research a main question is drafted. Main question:

“Will the lifetime of the open bearings on board the Rotterdam increase by using ultrasound detection during greasing?”

To find an answer on this question measurements are taken from the grey water units on the MS Rotterdam. These measurements are taken with an Ultraprobe 15000. For this research three methods are drafted. For this research three different inspection methods are used. The first is inspection method is “audible quality”. The second inspection method that has been used is “Comparative” and the third method is “Historical trending”. More information about the inspection methods is given in chapter 4: Results. To answer the main question, two sub questions have been answered in chapter 5: Conclusion. The sub questions can be found in chapter 1: introduction.

The Ultrasound Detector has shown that it is a fast and handy measuring tool to measure rolling element bearings. It is recommended to use the Ultraprobe during greasing of the bearings (from the moment they get installed). This method will prevent over lubrication and lack of lubrication, which could increase the lifetime of the bearings (other mechanical failures not included).

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1. Introduction

Holland America Line is a worldwide leader in cruising, with a fleet of 14 ships. (Holland America Line)
Each of these ships are running on a large engine room, filled with tons of technology's and a lot of bearings.
However only nine percent of rolling element bearings operate long enough to achieve their design life. The leading cause of failure, by 43 percent, is improper lubrication. This includes over lubrication or a lack of lubrication. This will lead to unexpected failure of the bearings which could result in a total shutdown of the system. (UE Systems Inc. training Division, 2014)

"Setting up a maintenance program is key to solving the problem of over greasing" (Machinerylubrication, 2016). Is this true? Also when speaking about a lack of lubrication?

The goal of this research was to determine if there is a difference between greasing open bearings according to the maintenance program and ultrasound detection. This research took place on board the Rotterdam, one of the cruise ships of Holland America Line.

For this research a main question is drafted.
<u>Main question:</u>
Will the lifetime of the open bearings on board the Rotterdam increase by using ultrasound detection during greasing?

<u>Sub questions:</u>
1. How often and how much grease is recommended according to the maintenance schedule to grease the open bearings on board the Rotterdam?
2. How often and how much grease is recommended by use of the Ultraprobe 15000 on board the Rotterdam?

By comparing how much difference was there between greasing the open bearings according to the maintenance schedule or by use of the Ultraprobe 15000 an answer could be given to the main question of this research.

2. Theoretical framework

2.1 Bearings

The purpose of bearings is to support shafts in axial and radial movements (see figure 1). There are two main groups of bearing types. The first group contains sliding bearings and the second contains rolling-element bearings. (Verbruggen)
For more explanation about different bearings see reference 9 in the list of references.

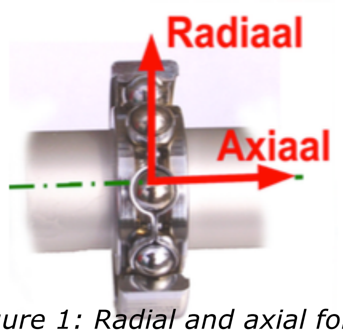

Figure 1: Radial and axial forces
Source: Lagertechnologie

This research will only comprise of rolling-element bearings.

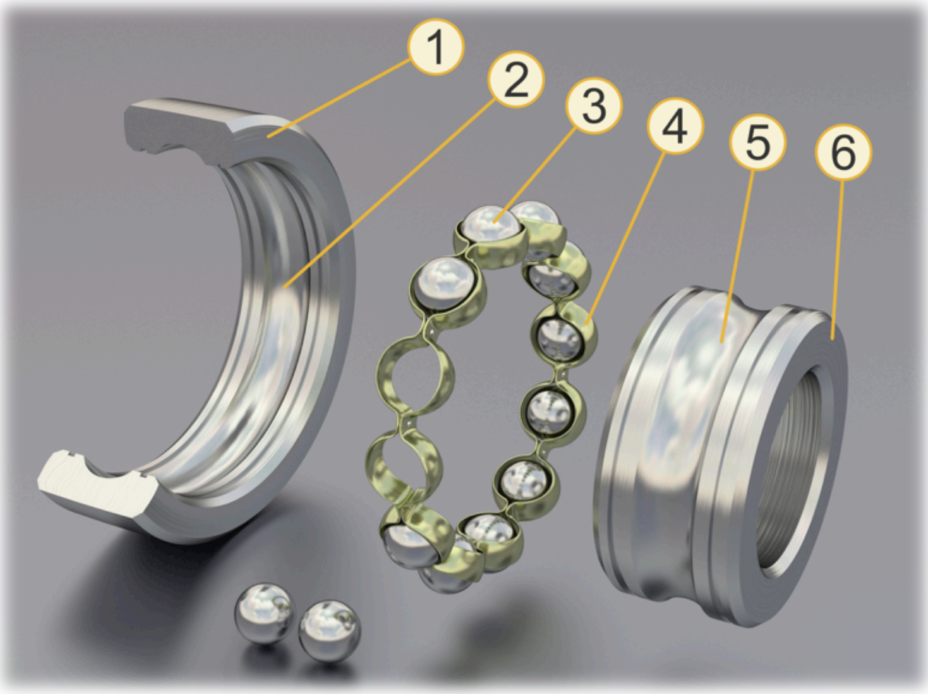

Figure 2: Ball-bearing *source: commons Wikimedia*

Figure 2 illustrates the components of a rolling-element bearing. Number 1 shows the outer ring. Number 2 and 5 are showing the ball race. Number 3 is showing the balls of the bearing. Number 4 the cage and number 6 the inner ring.
A load (e.g. shafts or axles) is attached to the inner ring. The inner ring will move with the motion of the load. The balls between the inner and outer ring will guide this process. The name bearing is coming from the verb "to bear" what means to carry/to support. This is what a bearing does. It is carrying the load en supports the movement to reduce friction.

Other examples of rolling-element bearings are: double row ball-bearings and cone bearings. For more different types of bearings see the book: Lagertechnologie by H. verbruggen.

Figure 3: double row ball-bearing
Source: Lagertechnologie

Figure 4: cone-bearing
Source: Lagertechnologie

For further information about bearing materials, wear and friction see the book: Applied Tribology: Bearing Design and Lubrication by Michael M. Khonsari and E. Richard Booser. There are some benefits of a rolling-element bearing comparing to a sliding bearing; through this there is less energy loss. A rolling element bearing has a small starting resistance comparing to the gliding bearing. The friction resistance also stays the same with every rpm and the lubrication consumption of a rolling element bearing is less than a sliding bearing due to a longer lubricating period. (Verbruggen)

2.2 Lubrication of Bearings

The purpose of lubrication is to separate two moving surfaces to reduce friction and wear by putting a lubricant between them. (Wytzes, 1998)
The secondary purpose of lubrication oil is to cool (engine internals). The oil will abduct a part of the heat. A cooler will separate the heat out of the oil again, so that the oil can be reused as a coolant. (Leaky Lugnut, 2016)
Another benefit of lubrication is that it has a cleaning function. Dirt, water and other contaminants will mix with the "clean" lubrication oil. The dirty lubricant gets filtered and reused again. Although the filter is supposed to filter out all the contaminants many get by anyway and remain in the lubricant. This will increase, as the filter gets older. (Leaky Lugnut, 2016)
Other properties of lubrication are: noise cancelling and that it can function as a seal.
There are three types of bearing lubrication:

1. Dry lubrication: The shaft is in direct contact with the bearing material, whereby no lubricant is added.
2. Boundary lubrication: The oil film is so thin that contact between the two metals is still possible. The lubricant will take a part of the friction heat away.
3. Full lubrication: Thereby a thick film layer separates two materials. (Verbruggen)

2.3 Over lubrication

Over lubrication may occur due to a short lubricating interval or due to excessive lubrication. "Overgreasing" can lead to high operating temperatures, collapsed seals and in the case of greased electric motors, energy loss and failures". (Machinerylubrication, 2016)
Over lubrication causes more damage in a bearing than a lack of lubrication. When a bearing is over lubricated and the seal is still intact, a high pressure will exist inside the bearing housing. The temperature inside the bearing casing will increase, which leads to chemical degradation of the lubricant. (UE Systems Inc. training Division, 2014)
The high temperature in combination with the chemical degradation eventually will make the lubricant thicker until it is hard. This will effect the proper lubrication or even block the new grease that comes in. As a result the rolling elements can wear out rapidly. Eventually the bearing will fail. (Machinerylubrication, 2016)

Damage of the seal is also a negative side effect of over lubrication. (Machinerylubrication, 2016) If the seal cracks: dirt, water and other contaminants will get access into the bearing housing. In case the seal to the motor cracks: lubricant can displace inside and reach the motor windings. (UE Systems Inc. training Division, 2014)
"Overgreasing can lead to high operating temperatures, collapsed seals and in the case of greased electric motors, energy loss and failures" (Machinerylubrication, 2016)

2.4 Lack of lubrication

Problems in bearings may occur due to a too long lubricating interval or due to a too small quantity of lubricant. (UE Systems Inc. training Division, 2014) When the surfaces of two materials slide over each other, the impurities of the two surfaces will make contact. Due to the friction heat these impurities will weld together (also known as friction welding) and break off again by the movement. The surfaces will become rougher and rougher, whereby the friction will increase and the material wear out. (Wytzes, 1998) This may lead to jamming of a bearing or problems with a motor.

2.5 Wrong lubrication

Not only the right amount of lubrication is important, also the lubricant itself. Is the lubricant for the purpose? Is it the correct chemical formulation? The lubricant has to have the right viscosity. Also the chemical composition is very important. Some seals will react with certain kind of substances.
Additives can be added to the lubricant to strengthening properties or even add properties to the lubricant.
"Additives have three basic roles:
1) Enhance existing base oil properties with antioxidants, corrosion inhibitors, anti-foam agents and demulsifying agents.

2) Suppress undesirable base oil properties with pour-point depressants and viscosity index (VI) improvers.
3) Impart new properties to base oils with extreme pressure (EP) additives, detergents, metal deactivators and tackiness agents." (Machinerylubrication, 2016)

2.6 Ultrasound

Ultrasound technology is usually concerned with frequencies from 20 kHz and up. This is way higher than the audible sound rage (between 20Hz and 20kHz). Problems in bearings in an early stage will generate Ultrasound waves that can be detected by an Ultrasound detector. The detector generates the ultrasound waves into a sound that can be detected by ears. By listening to a bearing, it can be determined when to lubricate and when to stop lubricating. As a lubricant film reduces, the sound level will increase. When there is an 8dB reading above the base line, lubrication is recommended. The base line is the sound (dB) that a new and good working bearing will produce after installation. To determine if the condition of a bearing will deteriorate, the sound of the bearing of the first measurement can be taken as the base line. How to lubricate in a proper way, will be explained in chapter three. Visual faults begin at 16dB above the base line reading. (UE Systems Inc. training Division, 2014)
An Ultrasound detector is a receiver and cannot send out any sound waves. Ultrasound can hardly move through solid materials. By using the contact mode of ultrasound (structure borne), the ultrasound being generated from inside the bearings can be detected. (UE Systems Inc. training Division, 2014)
By measuring the bearings, a contact module is necessary. This metal probe acts as a wave-guide when touched against surfaces. (UE Systems Inc. training Division, 2014)
The Recommended Frequency of measuring structure borne (bearings/mechanical) is 30kHz. (UE Systems Inc. training Division, 2014)

3. Research method

This chapter describes the method that has been used to execute this research. The method contains: the way data has been collected, the way the measurements that has been taken and the way that is used to analyze the results of the measurements to form a conclusion and an answer to the sub- and main questions. For this research a qualitative experimental operational research took place.

The first thing that has been considered is; which bearings and how many bearings were part of this research. To determine the lubrication period of the bearings, information has been taken of the maintenance program on board the Rotterdam (AMOS). The amount of greasing and the interval that the maintenance program set has been noted (to compare with the ultrasound results). After having observed the maintenance program, the answer to the first sub question can be given. "How often and how much grease is recommended according to the maintenance schedule to grease the open bearings on board the Rotterdam?"

Ultrasound Equipment that has been used during this research:

- Ultraprobe 15000 in combination with headphones.
- Contact module (to guide the waves to the ultraprobe)
- Rubber focus probe (works as a shield for ultrasound background noise)

To reduce any high ultrasonic noise of the environment on board the Rotterdam the following actions has been taken: reduced sensitivity of the ultraprobe, placed the rubber focus probe over the contact module and tried frequency tuning.
Before measuring during lubrication the sound of the bearing has been identified with the ultraprobe to determine if the bearing was not broken. An irregular rattling noise is a sign of wear in the bearing. A uniform rushing sound indicates a good bearing that may need lubrication.

The headphone has been connected to the ultraprobe, which has been set on 30kHz. The contact module has been connected to the probe with (depended on the background noise) the rubber focus probe over it.
Before measuring the following actions should be taken:

1. Selected test points (There where the bearings are located) and tried to mark them.
2. Used the contact module.
3. Adjusted sensitivity until mechanical operation of equipment is heard clearly.
4. Established a test angle (90 degrees on the surface when possible).
5. Selected a test frequency (usually 30 kHz).

(UE Systems Inc. training Division, 2014)

Measurements have been taken by listening through the headphones while observed the meter during greasing. During the greasing period the intensity of the sound reduced. The lubrication was stopped when the sound did not decrease anymore. When there was no sound reduction when the greasing process started, lubrication was not needed. During lubrication notes has been taken of the quantities that has been used. The 24 measurements of bearings that have been taken, will form an answer to the second sub question "How often and how much grease is recommended by use of the Ultraprobe 15000 on board the Rotterdam?" the results of these measurements can be found in chapter 4: Results.

After the answers on both sub questions were found, the results has been compared with each other. By comparing the data with each other an answer has been found on the main question of this research.
"Will the lifetime of the open bearings on board the Rotterdam increase by using ultrasound detection during greasing?"

If the results of the two sub questions did show that there is more or less lubricant was needed during greasing than the maintenance program set, the lifetime of open bearings may increase when using ultrasound detection. If there was no deference shown in the results, no answer can be given to the main question of this research.

The ultraprobe can store dB and sound waves what can be analyzed with DMS (data management system) and Spectralyzer software from UE systems for more information about the bearing conditions. This is not included in this research but may be recommended for the future.

4. Results

This chapter contains the results of the measurements of the research.

For this research three different inspection methods are used. The first is inspection method is “audible quality”: just by identifying the sound of the bearing, the inspector can quickly assess if the bearing is good, in an early stage of failure or failed. If the bearing is in an early stage of failure, the bearing may need: 1. More grease, if the sound will reduce during lubricating the bearing. 2. Less grease, if the sound does not change during lubrication. The second inspection method that has been used is “Comparative”: by comparing similar pieces of equipment, the inspector can obtain a good idea of what the normal sound of the equipment should be while identifying anomalies. The third method is “Historical trending” by obtaining readings over time and setting a base line for a piece of equipment, the inspector can realize when a bearing is healthy, in need of lubrication, in an early stage of failure or complete failure. The third method is used on the bearings with auto greasing to see if the condition of the bearings will change in time. If not the auto greasers are working efficiently. It would have give a better result if the baseline for historical trending was taken from a new bearing instead of the bearings that already have been in operation. All 24 bearings that have been measured for this research are SKF bearings (6206 and 6205) with an operating speed of 3450 rpm. These bearings are chosen for this research because they were easy accessible for measuring and they have a lubrication interval of a month. The 12 pumps of the grey water units on board the MS Rotterdam are Flomax 15 pumps (see figure 7 and 8)

Figure 7: Flomax 15 pump

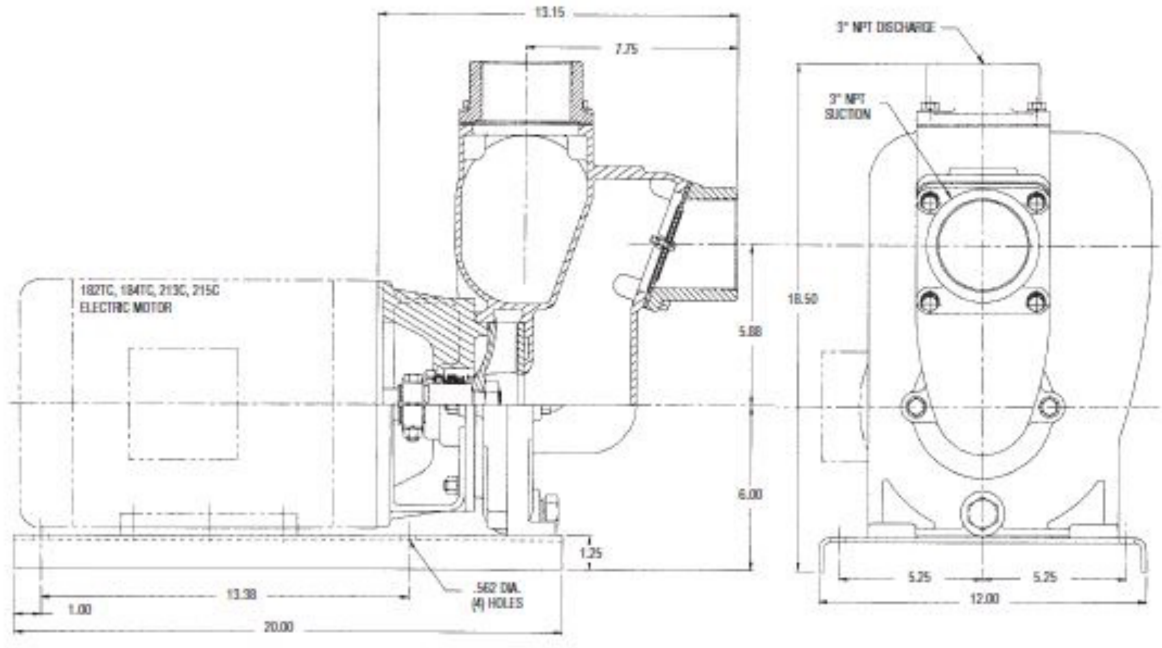

Figure 8: Flomax 15 pump drawing

Lubrication of the bearings of the grey water units is a monthly job and has to be done by job description L511 of AMOS, however the job description of AMOS only says "Lubricate bearings".
These results are the results of the grey water units on board.

Aft sewage room	Auto greasing	Added Grease	Needed Grease	Remark Bearing
Pump 1	Yes	-	-	Soft uniform sound
Pump 1	Yes	-	-	Soft uniform sound
Pump 2 (SB)	No	3 x	Non	No sound change
Pump 2 (SB)	No	3 x	Non	No sound change
Pump 3 (SB)	No	5 x	Non	No sound change
Pump 3 (SB)	No	5 x	Non	No sound change
Pump 4	No	3 x	3 x	Sound reduced to soft uniform sound
Pump 4	No	2 x	2 x	Sound reduced to soft uniform sound

Grey water Unit 4	Auto greasing	Added Grease	Needed Grease	Remark Bearing
Pump 1	Yes	-	-	Soft uniform sound
Pump 1	Yes	-	-	Soft uniform sound
Pump 2 (SB)	No	3 x	Non	No sound change
Pump 2 (SB)	No	3 x	Non	No sound change

Grey water Unit 3	Auto greasing	Added Grease	Needed Grease	Remark Bearing
Pump 1	Yes	-	-	Soft uniform sound
Pump 1	Yes	-	-	Soft uniform sound
Pump 2 (SB)	No	3 x	Non	No sound change
Pump 2 (SB)	No	3 x	Non	No sound change

Grey water Unit 2	Auto greasing	Added Grease	Needed Grease	Remark Bearing
Pump 1	Yes	-	-	Soft uniform sound
Pump 1	Yes	-	-	Soft uniform sound
Pump 2 (SB)	Yes	-	-	Soft uniform sound
Pump 2 (SB)	Yes	-	-	Soft uniform sound

Grey water Unit 1	Auto greasing	Added Grease	Needed Grease	Remark Bearing
Pump 1	Yes	-	-	Higher Intensity uniform sound
Pump 1	Yes	-	-	Higher Intensity uniform sound
Pump 2 (SB)	Yes	-	-	Higher Intensity uniform sound
Pump 2 (SB)	Yes	-	-	Higher Intensity uniform sound

The bearings of the standby pumps of the units generated a lot more sound with an irregular rattling noise in it. The greasing progress of the bearings on pump 4 of the grey water unit in the aft sewage room went as it supposed to go. There was a uniform rushing sound, whereby the intensity of the sound reduced during greasing. After three pumps of grease on one bearing and two pumps on the other bearing, the sound did not reduce anymore, so the greasing progress was stopped.

The Bearings that did not require any lubrication are the bearings of the standby pumps of the units (without auto greasing). If the pumps are on standby (not many running hours), than they don't require as much lubrication as a bearing of a pump that runs for example 24/7. If every month the bearings of the standby pumps get at least three pumps of grease, the conclusion can be made that the bearings are over lubricated. The irregularities in the sound can be a sign of beginning wear in the bearings. This is probably also happening to the bearings of the pumps of grey water unit 1. Because the intensity of the sound if higher comparing to the other grey water pumps with auto greasing units on the bearings.

The bearings with auto grease pods on it have been observed for a month by the use of the historical trending method. The dB values of the bearings stayed the same after measuring every week. This is a sign that the grease pods give the right amount of grease. However these grease pods are only applied on the bearings are running more often than the bearings of the standby pumps. Also these measurements cannot predict what the bearing condition will be after a couple of months.

The following information is taken from vibration reports of 2016 and 2012. This gives an indication of the failures that happened in the past to the pumps.

Vibration report of 2016 of the E-motors, pumps.

Unit/pump:
Unit 6 pump 2
Founding:
Elevated vibration at 1x operating RPM. This is an indication of unbalance and/or mechanical looseness.
Recommendation:
None

Unit/pump:
Unit 6 pump 1
Founding:
The dominant vibration is 1x-running speed indicating an unbalance condition or alignment.
Recommendation:
None

Unit/pump:
Unit 2 pump 2
Founding:
The primary fault vibration is 1x running speed and its multiples indicating excessive bearing clearances, mechanical looseness, misalignment or unbalance.
Recommendation:
Change the motor bearings. Pay attention to the clearances in the bearing housing and end bells.

Unit/pump:
Unit 4 pump 1
Founding:
The dominant vibration is 1x- running speed its multiples indicating an unbalance condition, mechanical looseness or misalignment.
Recommendation:
Check for mechanical looseness and misalignment.

Vibration report of 2012 of the E-motors, pumps.

Unit/pump:
Unit 2 pump 1
Founding:
There are indications of late stage 2 bearing defect frequencies in the motor bearing.
Recommendation:
1. Continue to monitor for any increase in noise, temperature and vibration. 2. Consider replacing the pump bearings. The fault vibration has remained the same since 11/2008.

Unit/pump:
Unit 2 pump 2
Founding:
There is a late stage 2 bearing defect on the motor bearings.
Recommendation:
Consider overhauling the pump. The fault vibration has remained the same since 11/2008.

Unit/pump:
Unit 3 pump 1
Founding:
Elevated vibration at 1x operating rpm and its harmonics. This is an indication of mechanical looseness.
Recommendation:
Replace pump bearings. The fault vibration has remained the same since 11/2008.

Unit/pump:
Unit 3 pump 2
Founding:
Elevated vibration at 1x operating rpm and its harmonics. This is an indication of mechanical looseness.
Recommendation:
Replace pump bearings. The fault vibration has remained the same since 11/2008.

Unit/pump:
Unit 4 pump 2
Founding:
There are indications of stage 3 bearing defect frequencies in the pump bearings.
Recommendation:
Replace pump bearings.

Unit/pump:
Unit 6 pump 2
Founding:
There are late stage 2 bearing defect on the pump bearings. The dominant vibration is 1x running speed and its multiples indicating an unbalance condition, mechanical looseness or excessive bearing clearances.
Recommendation:
Replace or rebuild unit.

Unit/pump:
Unit 1 pump 1
Founding:
Elevated vibration at 1x operating rpm and its harmonics. This is an indication mechanical looseness.
Recommendation:
Replace or rebuild unit.

In AMOS the history of the E-motor, pump of grey water unit 1 pump 1 shows the following information in 2012: *Changed bearing of E-motor pump 1. Pump 1 was vibrating a lot. Pump 2 is ok. After bearing change, pump was still vibration and has been changed and overhauled. The shaft was damaged.* This was written in 2012. According to the measurements the pump is vibrating a lot again, may be the same cause.

Unit/pump:
Unit 1 pump 2
Founding:
Elevated vibration at 1x operating rpm and its harmonics. This is an indication mechanical looseness or misalignment.
Recommendation:
Overhaul the unit.

The information about the history of the grey water units is not saying anything about improper lubrication. However the faults that have been determined can be a result of improper lubrication. Also AMOS does not show if any maintenance has been done on the bearings since the vibration report. Therefore it is unclear how long the bearings will hold after the vibration surveys.

According to the manual of SKF bearings, rolling bearings have to be re-lubricated if the service life of the grease is shorter than the expected service life of the bearing. The time at which the bearing should be re-lubricated depends on many related factors such as: bearing type and size, speed, operating hours, operating temperature, grease type, space around the bearing and bearing environmental.

The re-lubrication intervals (tf) for bearings with a rotating inner ring on horizontal shafts under normal and clean operating conditions can be obtained from diagram 1. Thereby is the speed factor a multiplied by the relevant bearing factor (bf).

Where:

A	=	n • dm (mm/min)
bf	=	Bearing factor dependent on bearing type and load conditions (see diagram 2)
dm	=	Bearing mean diameter (mm)
n	=	Rotational speed (rpm)

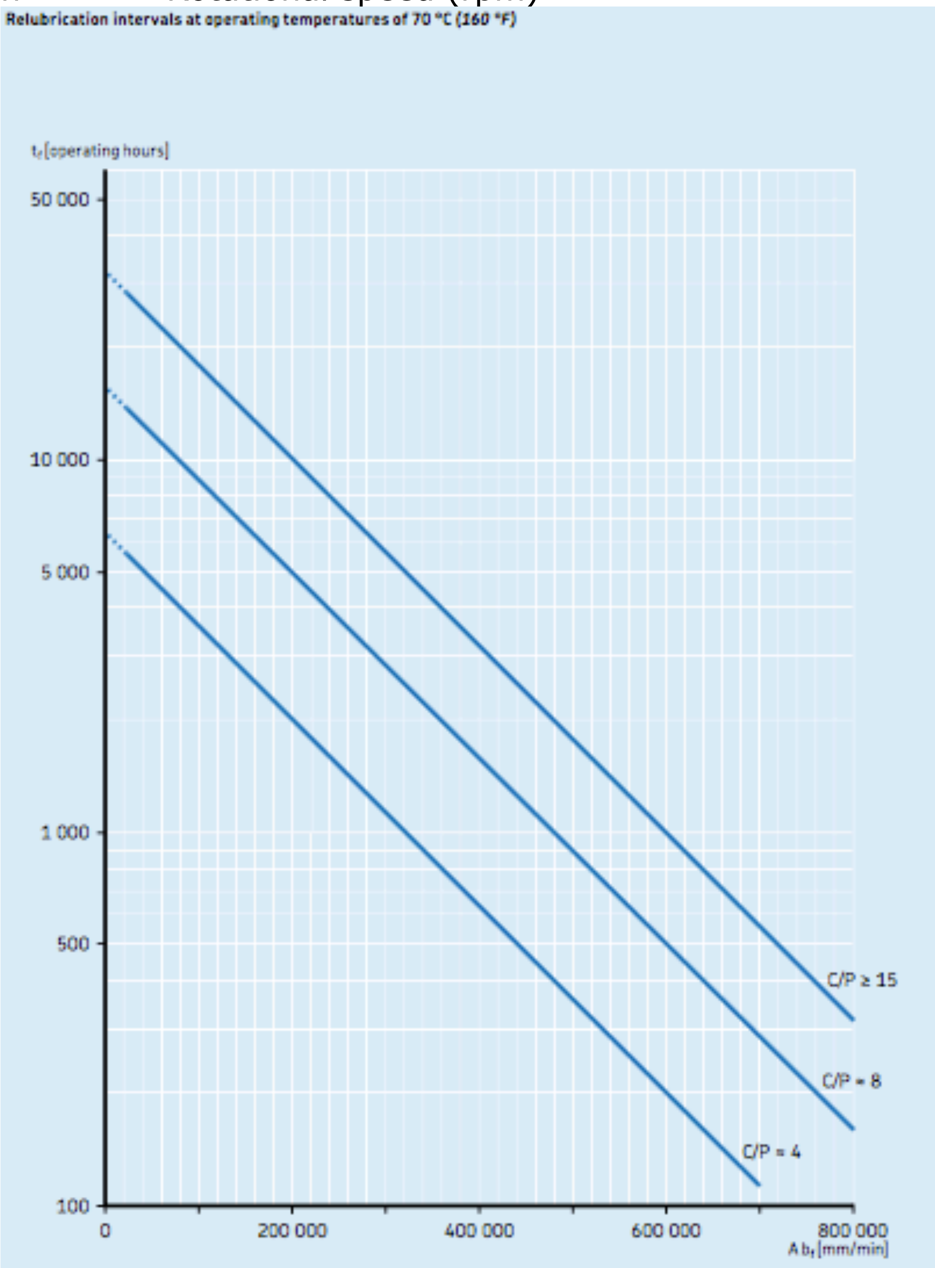

Diagram 1, source: SKF bearings

The re-lubrication interval tf is the estimated number of operating hours that high-quality grease, consisting of mineral oil and a lithium base thickener, can perform adequately when the operating temperature is 70 degrees. The grease that has been used to lubricate the bearings is Energrease MM-EP 2. The substance/mixture of MM-EP 2: Highly refined mineral oil (IP 346 DMSO extract <3%). Soap. Proprietary performance additives.

Bearing factors and recommended limits for speed factor A

Bearing type[1]	Bearing factor b_f	Recommended limits for speed factor A for load ratio C/P ≥ 15	C/P ≈ 8	C/P ≈ 4
–	–	mm/min		
Deep groove ball bearings	1	500 000	400 000	300 000
Y-bearings	1	500 000	400 000	300 000
Angular contact ball bearings	1	500 000	400 000	300 000
Self-aligning ball bearings	1	500 000	400 000	300 000
Cylindrical roller bearings				
– non-locating bearing	1,5	450 000	300 000	150 000
– locating bearing, without external axial loads or with light but alternating axial loads	2	300 000	200 000	100 000
– locating bearing, with constantly acting light axial load	4	200 000	120 000	60 000
– without a cage, full complement[2]	4	NA[3]	NA[3]	20 000
Needle roller bearings				
– with a cage	3	350 000	200 000	100 000
– without a cage, full complement	Contact the SKF application engineering service.			
Tapered roller bearings	2	350 000	300 000	200 000
Spherical roller bearings				
– when the load ratio $F_a/F_r \leq e$ and $d_m \leq 800$ mm				
series 213, 222, 238, 239	2	350 000	200 000	100 000
series 223, 230, 231, 232, 240, 248, 249	2	250 000	150 000	80 000
series 241	2	150 000	80 000[4]	50 000[4]
– when the load ratio $F_a/F_r \leq e$ and $d_m > 800$ mm				
series 238, 239	2	230 000	130 000	65 000
series 230, 231, 232, 240, 248, 249	2	170 000	100 000	50 000
series 241	2	100 000	50 000[4]	30 000[4]
– when the load ratio $F_a/F_r > e$				
all series	6	150 000	50 000[4]	30 000[4]
CARB toroidal roller bearings				
– with a cage	2	350 000	200 000	100 000
– without a cage, full complement[2]	4	NA[3]	NA[3]	20 000
Thrust ball bearings	2	200 000	150 000	100 000
Cylindrical roller thrust bearings	10	100 000	60 000	30 000
Needle roller thrust bearings	10	100 000	60 000	30 000
Spherical roller thrust bearings				
– rotating shaft washer	4	200 000	120 000	60 000
Track runner bearings	Contact the SKF application engineering service.			

Diagram 2, source: SKF bearings

Diagram 2 is used to determine the bearing factor (dependent on bearing type and load conditions).

5. Conclusion

To give an answer on the main question of this research “Will the lifetime of the open bearings on board the Rotterdam increase by using ultrasound detection during greasing?” the answers must be given on the two sub questions.

Sub question 1: How often and how much is recommended according to the maintenance schedule to grease the open bearings on board the Rotterdam? The maintenance program AMOS says that all bearings of the grey water pumps have to be lubricated every month. All means also the standby pumps. About the amount the job description does not say anything, except: *grease bearings.*

Sub question 2: How often and how much is recommended by use of the Ultraprobe 15000 on board the Rotterdam? How often have the bearings to be greased recommended by the use of the Ultraprobe 15000 is hard to say for this research. The amount of time that was available for this research was to short to find a good interval period. However this depends on the running hours and the temperature of the pump units. The amount is easy to determine with the use of the Ultraprobe 15000, as long as the bearings are not over greased. When the bearing is over greased it needs at least one pump of grease to establish with the ultraprobe that the sound of the bearing is not changing. If the sound does not reduce, no grease needs to be applied.

After giving an answer to the two sub questions an answer can be given on the main question of this research: Will the lifetime of the open bearings on board the Rotterdam increase by using ultrasound detection during greasing? The condition of the bearing will be in most of the cases much better when greasing the bearing with the use of Ultrasound detection.

The following information is showing how to calculate the lifetime of a bearing in normal operations, when also following the re lubrications interval/amount that is described in the previous chapter.

The basic lifetime in operating hours of a bearing when the speed is constant can be calculated with the following formula:

$$\mathbf{L_{10h} = (10^6/60n)\, L_{10}}$$

L_{10h} = Basic rating life (at 90% reliability) in operating hours.

n = rotational speed (r/min)

L_{10} = Basic rating life (at 90% reliability) in million revolutions.

Where:

L_{10} = $(C/P)^p$

C = basic dynamic load rating

P = equivalent dynamic bearing load (kN)

p = exponent of the life equation

- for ball bearings p = 3
- for roller bearings p = 10/3

The equivalent dynamic bearing Load (P) can be calculated by the following formula:

P = X F_r + Y F_a

X = Radial load factor for the bearing (see figure 9).

Y = Axial load factor for the bearing (see figure 9).

F_r = Actual radial bearing load (kN)

F_a = Actual axial bearing load (kN)

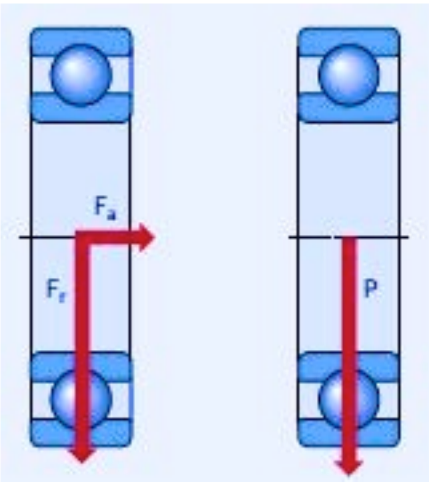

Figure 9: Source SKF Rolling Bearings

In appendix I the guideline values of the specification life can be found. The table shows that the specification life (operating hours) for pumps will be around 40 000 – 50 000 hours.
(SKF Group, 2013)

Bearings should be maintained according to the SKF manual. However the use of ultrasound for lubrication of the bearings is a more efficient way to re-lubricate the bearings and to condition monitor them. Using the ultraprobe will save time during a greasing job. Instead of calculating the amount of grease it tells you by the sound when to stop greasing. When using ultrasound it also immediately gives you an indication of the condition of the bearing.

To keep a better condition of the bearings, the bearings should be greased following the SKF manual with the right type of grease. To easy determine the right amount of grease that has to be applied to the bearings and also to determine the condition of the bearings, the use of ultrasound detection is recommended. When analyzing new bearings with the historical trending method, the condition of the bearing can easily be determined. To get more accurate answer on the main question of this research, more measurements on different bearings over a longer time period are recommended.

6. Discussion

The measurements of this research are taken of 12 pumps (24 bearings). For more reliable results, more measurements should be taken for different bearings and different pumps/electro motors. The measurements of this research are taken within a time window of six weeks. The results would be more accurate if measurements would be taken over a longer time period, therefore was not enough time during this research.

The results of this research did not meet with my expectations. During the execution of the research I found out that the bearings where not in the condition I thought they would be. I expected that the bearings would have a lack of lubrication and that by using the ultraprobe the right amount of grease could be applied to the bearings (until the sound would not reduce anymore). However I found the bearings over lubricated (except the bearings of one pump) so the use of ultrasound for this research lost part of its value. Because I followed a one-week course about the use of ultrasound detection (included lubricating of bearings), I know how efficient the use of ultrasound detection can be while greasing bearings. If chosen different bearings on different pumps/electro motors different results may came out of this research.

7. List of References

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Appendix I

Guideline values of specification life for different machine types

Machine type	**Specification life** Operating hours
Household machines, agricultural machines, instruments, technical equipment for medical use	300 ... 3 000
Machines used for short periods or intermittently: electric hand tools, lifting tackle in workshops, construction equipment and machines	3 000 ... 8 000
Machines used for short periods or intermittently where high operational reliability is required: lifts (elevators), cranes for packaged goods or slings of drums etc.	8 000 ... 12 000
Machines for use 8 hours a day, but not always fully utilized: gear drives for general purposes, electric motors for industrial use, rotary crushers	10 000 ... 25 000
Machines for use 8 hours a day and fully utilized: machine tools, woodworking machines, machines for the engineering industry, cranes for bulk materials, ventilator fans, conveyor belts, printing equipment, separators and centrifuges	20 000 ... 30 000
Machines for continuous 24 hour use: rolling mill gear units, medium-size electrical machinery, compressors, mine hoists, pumps, textile machinery	40 000 ... 50 000
Wind energy machinery, this includes main shaft, yaw, pitching gearbox, generator bearings	30 000 ... 100 000
Water works machinery, rotary furnaces, cable stranding machines, propulsion machinery for ocean-going vessels	60 000 ... 100 000
Large electric machines, power generation plant, mine pumps, mine ventilator fans, tunnel shaft bearings for ocean-going vessels	> 100 000

(SKF Group, 2013)