Master of science in Mechanical Engineering

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Standard vs. revolutionary sealing:

An investigative thesis on two methods of conceptual designing with regards to the root causes of failure mode in raw mill 7.

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Preface

This thesis is submitted to the Faculty of Engineering at Blekinge Institute of Technology in fulfillment of the requirements for the degree of Master of Science in Mechanical Engineering. The thesis was done in cooperation with Cementa AB in Slite, Gotland.

I, Karim Alamien, declare that I am the sole author of this thesis and that I have not used any sources other than those listed in the bibliography and identified as references. I further declare that I have not submitted this thesis at any other institution to obtain a degree.

Firstly, I would like to thank my supervisors Ansel Berghuvud, Magnus Pettersson and Henrik Stenegärd for their excellent guidance throughout this project.

I would also like to thank my brother Hassan, my sister in law Pamela and their kids Elias and Alicia for their warm hospitality and support during this project.

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I hope you enjoy your reading.

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Abstract

The grinding rollers of raw mill 7 operate in very harsh conditions and, because of this, suffer from excessive failure mode due to lip seal deterioration. Foreign material penetrates the deteriorated lip seal and enters the bearings resulting in bearing failure. Failure mode brings about high maintenance costs for the cement-producing company Cementa AB. This thesis aims to accomplish two things. 1- Hypothesize a set of root causes for failure mode and link them to existing literature studies to determine what actions should be taken to prevent or at least postpone failure mode. 2- Generate several new conceptual designs for the sealing mechanism by either creating a revolutionary sealing design or taking inspiration from standard seals currently on the market. The generated concepts aim to provide Cementa AB with a new perspective as well as mitigate some or all the root causes for failure mode if implemented.

The hypothesized root causes for failure mode are categorized through the creation of a problem tree and are defined as lip seal failure, lubricative pressure and contamination, tribologically improper friction, vibration, and finally very harsh conditions that are indigenous to raw mills in general and that are seemingly incompatible with the current sealing mechanism. Revolutionary concepts are brainstormed entirely from an experimental perspective, while standard concepts are inspired by established sealing technology on the market. Both alternatives are then conceptually adapted to the grinding roller of raw mill 7 and, with inaccurate scaling, 3D modelled with the aid of Autodesk Inventor.

7 concepts, revolutionary and standard combined, are generated as a result. The revolutionary concepts have been deemed non-viable due to the limited timeframe and scope of the thesis. Instead, the selected seal for the upgrade is a labyrinth seal, which is a non-contact standard seal that has the potential to mitigate many of the root causes for failure mode. The literature studies on the hypothesized root causes also indicate that there are actions that could postpone failure mode should Cementa AB chose to retain the original sealing mechanism for a longer period.

Keywords:

Failure mode
Mechanical seal
Tribology
Raw mill
Cement

Sammanfattning

Valsarna i råkvarn 7 arbetar under mycket tuffa förhållanden och på grund av detta lider maskinen av en överdriven mängd haverier till följd av läpptätnings försämring. Främmande material tränger igenom den försämrade tätningen och kommer in i lagren vilket resulterar i lagerhaveri. Detta medför höga underhållskostnader för det cementproducerande företaget Cementa AB. Denna avhandling syftar till att åstadkomma två saker. 1-Hypotesera en uppsättning av grundorsaker till lagerhaveri och länka dem till befintliga litteraturstudier för att avgöra vilka åtgärder som kan vidtas för att förhindra eller åtminstone skjuta upp lagerhaveri. 2-Generera flera nya konceptuella konstruktioner för tätningsmekanismen genom att antingen skapa en revolutionerande tätningsdesign eller hämta inspiration från standardtätningar. De genererade koncepten syftar till att ge Cementa AB ett nytt perspektiv såväl som att mildra några eller alla grundorsaker till lagerhaveri om de implementeras.

De hypotiserade orsakerna till lagerhaveri kategoriseras genom skapandet av ett problemträd och definieras som trasig läpptätning, smörjningstryck och förorening, tribologiskt felaktig friktion, vibrationer och slutligen tuffa förhållanden som är inhemska för råkvarn generellt. Revolutionära koncept är brainstormade helt ur ett experimentellt perspektiv medan standardkoncept är inspirerade av etablerad tätningsteknik på marknaden. Båda alternativen är sedan konceptuellt anpassade till valsen i råkvarn 7 och, med oegentlig skalning, 3D-modellerad med hjälp av Autodesk Inventor.

7 koncept, revolutionerande och standard kombinerat, genereras som resultat. De revolutionära koncepten har bedömts vara icke-livskraftiga på grund av avhandlingens begränsade tidsram och omfattning. Istället är den valda tätningen för uppgraderingen en labyrinttätning som är en icke-kontakt standardtätning som har potential att mildra många av orsakerna till lagerhaveri. Litteraturstudierna om de hypotiserade grundorsakerna tyder också på att det finns åtgärder som kan skjuta upp lagerhaveri om Cementa AB väljer att behålla den ursprungliga tätningsmekanismen under en längre period.

Nyckelord:

Lagerhaveri
Mekanisk tätning
Tribologi
Råkvarn
Cement

Table of contents

1 INTRODUCTION

It is tough to imagine a world without concrete. Concrete might be one of the essential materials in the process of building modern societies sustainable infrastructure. A key element in concrete is cement, and it is the cohesive ingredient for making robust concrete. This thesis is written in cooperation with Cementa AB. The studies and work were conducted on-site in the factory with the privilege of working during the annual maintenance stop of the factory. This created a one of a kind opportunity to mentally and physically dive into the subject and the machines in question while they were on standby. Much of the information about the topics presented in the thesis was gathered through interviews with managers and workers in the factory. As such, some of the information in the thesis belongs to manual interviewing. One example is the general cement-production process. Throughout the thesis, it is important to keep in mind that the expressions failure mode and bearing failure are referring to the same problem. Many of the figures and pictures in the thesis were apprehended through manual photography during the maintenance stop.

1.1 Background

1.1.1 Cementa AB

Cementa AB is one of the leading cement-producing companies in Sweden and in the world. The company is part of the international building-material group, HeidelbergCement, and has approximately 58 000 coworkers worldwide. Cementa AB has three cement plants in Sweden. They are located in Slite, Skövde, and Degerhamn. These plants are strategically placed near available limestone quarries. Limestone is one of the basic materials for producing cement [1]. This thesis will mainly focus on the plant in Slite, Gotland.

1.1.2 General Cement-production process

To be able to appreciate the importance and weight of the subjects presented in this thesis, a basic understanding of the cement production process is necessary. Below is a relatively short, generalized step by step introduction to the process from start to finish. The information was apprehended through a series of interviews with managers and workers in the factory.

Mining:

Cementa AB produces about 2-million-ton cement annually. To support the production rate, a large quantity of raw materials in the form of limestone and marlstone is extracted from the underlying limestone bedrock in the proximity of the factory. It is estimated that about 3 million tons of limestone and marlstone is mined annually. Marlstone being of lesser calcium carbonate content, which is what gives the limestone it's signature white color. Extraction is done by drilling holes around the open cast mine and injecting liquid explosives. Every explosion releases about 20-70 000 tons of stone. The stone is then transported to a crushing facility.

Crushing:

Stone from the mines arrives to be crushed. Since the rocks are relatively homogeneous, it is enough to fragment them once. The crushing takes place in a hammer-crusher, which breaks the material into fist-sized stones with an estimate of 2200 tons per hour. The dimensions of the rocks are adjusted for the later milling part of the process. The stones are then transported to the storage facility near the factory.

Stone storage:

The stone warehouse has two main functions. Firstly, it acts as storage for the crushed stones that will be further transported to the next step of the process in the factory. Secondly, it acts as a mixing station of different raw materials used in the production.

Raw mill:

This step Is considered to be a crucial part of the process for ensuring the quality of the cement production. Limestone and marlstone are transported separately via conveyers into a stone allocation tower where the material is stored in pockets, still separate at this point. The content is then fed into raw mills together with different essential additives such as quarts-sand and iron-ore. The purpose of the raw mill is to mill the stones into a fine raw flour. The flour is then transported to silos.

Raw flour silos:

The silos also act as a temporary storage space for the fine flour. However, in the silos, the raw meal is continuously mixed through homogenizing. Air is blown from below the silos, which turn the meal into an almost fluid state. This makes the mixing process more manageable and increases the quality of the flour. Homogenizing is also especially important to achieve a good combustion process in the upcoming furnace.

Cyclone system:

Before feeding the furnace with the material, the raw flour has to get preheated. This takes place in one of the cyclone towers, which connects to the rotary kilns. The meal is transported to the top of the tower, where it drops down stepwise through cyclone chambers. Usually, there are four steps or chambers. Hot gas is blown from the furnace upwards through the system, with the hottest chamber being the closest to ground level and the furnace.

Rotary furnace:

Once the flour is preheated, it is fed into the rotary furnace, which rotates with about 1,5-3 revolutions per minute. There are two of them in the factory, one 70 meters long and the other 80 meters. Both are slightly slanted to allow the material to travel along its axis. The furnace's inner temperature is about 1450 degrees Celsius, which is the optimum temperature for converting the raw flour into clinker. At the end of the furnace, the clinker is dropped into a clinker cooler.

Clinker cooler:

After the furnace, the clinker has to rapidly decrease in temperature to stop all chemical processes that occur during the clinker formation from resuming. When the clinker leaves the cooler, it has a temperature of about 100 degrees Celsius. It is then transported to clinker silos.

Clinker silos:

Storing the clinker in the right conditions is very important since it is easily damaged by moisture. This takes place in the clinker silos.

Cement mill:

Through the combustion process, the raw flour has converted into clinker shaped like small balls. To achieve the final product, another milling process of the clinker is required. This takes place in a cement mill. Clinker and other additives that help to get the right attributes in the different cement qualities are fed into the mill—the finer the flour, the better the reactions when introducing water for creating concrete.

1.1.3 Raw mill 7

There used to be three raw mills in the factory, but today only two are operational. Raw mill 7 and 8. Raw mill 8 is a Polysius mill while raw mill 7 is a Loesche mill. The Polysius mill is much larger and can handle more substantial quantities of raw material with a higher production rate. For this thesis, the focus will be on the Loesche mill, raw mill 7. But for comparison's sake, the size difference of the grinding rollers for each raw mill is shown in figures 1 and 2. There is a substantial difference in size between the two. Also, the design is different, meaning that the components within are various as well.

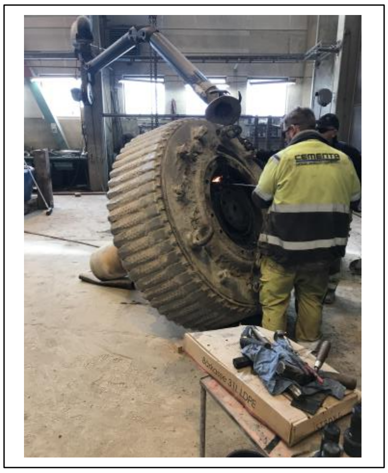


Figure 1. Raw mill 7 grinding roller.

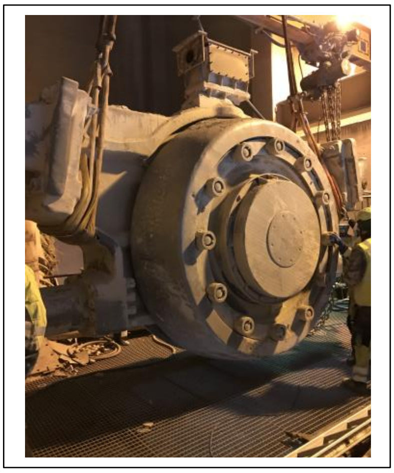


Figure 2. Raw mill 8 grinding roller.

The internal process of raw mill 7 starts when the raw material in the form of fist-sized stones are fed into the mill by a rotary feeder shown in figure 3.

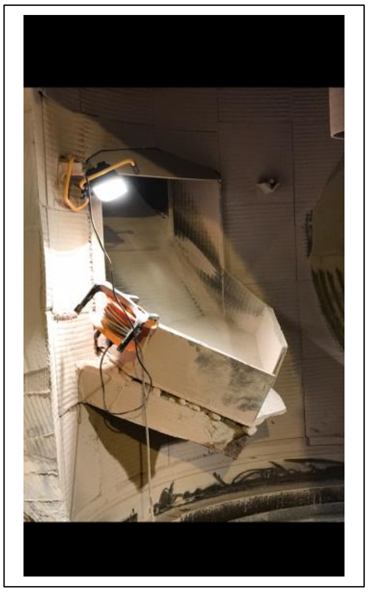


Figure 3. Stone feeder.

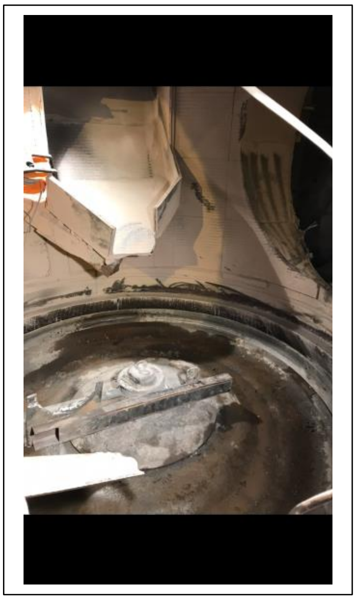


Figure 4. Milling table.

The stones then fall down to the center of the milling table, as shown in figure 4. In figure 4, the milling table isn't complete due to it being under maintenance. The outer layer of the table has been stripped for renovation. Before falling, the material is subjected to a powerful magnet that separates unwanted objects, mainly metals, from the raw material as not to damage the components within the mill. The milling table spins around its own axis by the aid of the motor below the raw mill and creates a centrifugal force that drives the raw material outwards toward the edge of the table where the grinding rollers operate. What makes the grinding rollers spin is the contact of raw material in between the rollers and the milling table. As such, the rollers do not need a motor and instead rely on the spinning force of the table.

Figure 6. Grinding roller (back view).

Figure 5. Grinding roller (front view).

There are two rollers inside the mill on opposite sides and are hydro-pneumatically spring-loaded since grinding is done by application of compressive force through the "holder" shown in figure 5. The rollers are mounted on the holders and are folded into the raw mill, as shown in figures 5 and 6.

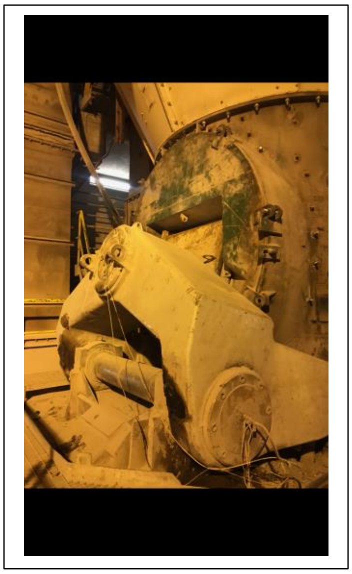


Figure 7. Grinding roller holder (folded in).

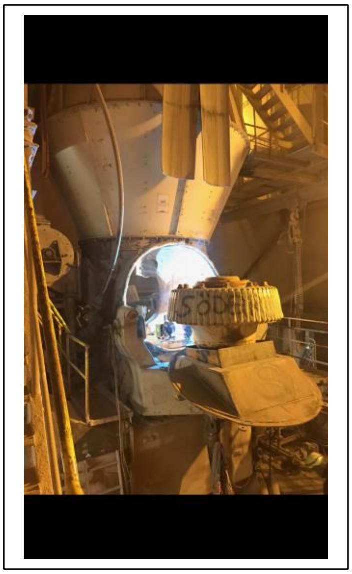


Figure 8. Grinding roller holder (folded out).

The rollers also spin around their own axis, and the material is ground in a material bed between the grinding track and rollers. The purpose of the gap is to eliminate metal on metal friction. Once ground, the material is once again subjected to the centrifugal force of the milling table and is driven further outwards toward the surrounding gas entries shown at the edge of the milling table in figure 4. Hot gas from the rotary furnace, as well as the cyclone system, is driven upwards through the entries around the milling table. This creates sort of a hurricane-like environment inside the raw mill. The stream of gas carries the ground material into a wind-sifter, also called classifier or separator shown in figures 9 and 10, where sufficiently ground fine flour passes through onto the next step of the process while not completely ground material is rejected. This material then falls into a return cone and afterward onto the milling table once again.

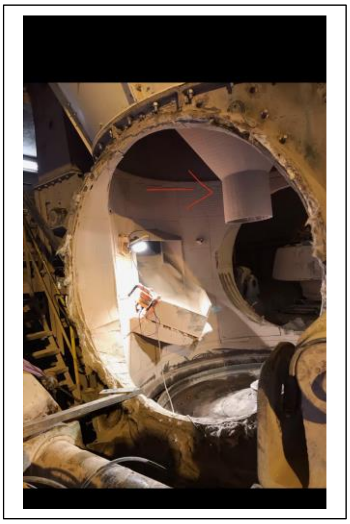


Figure 9. Wind-sifter above the milling table.

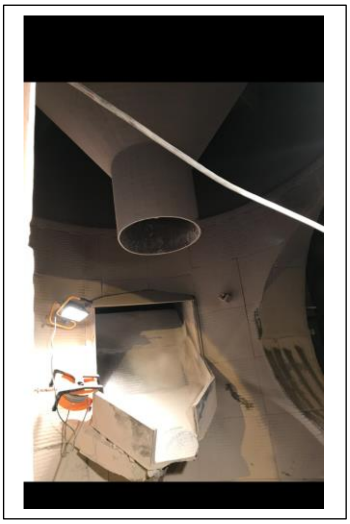


Figure 10. Wind-sifter.

Another essential purpose of the hot gas is to draw moisture out from the raw material. To achieve this, the gas needs to be around 100-110 degrees Celsius [2].

Figure 11 illustrates all the mentioned relations within a raw mill and is a relatively accurate representation of raw mill 7 as well. Figure 12 shows the outside structure of the actual raw mill 7.

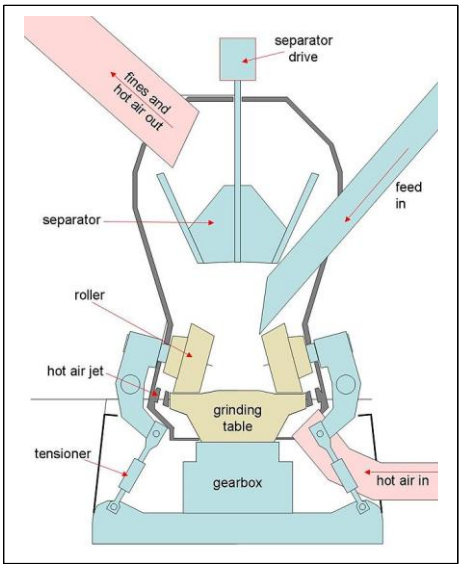


Figure 11. Typical roller mill layout. From [24].

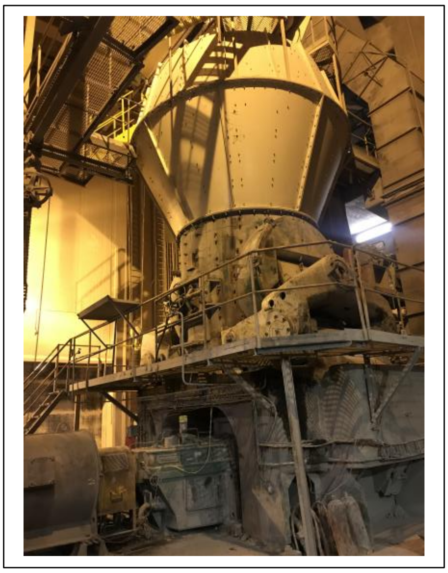


Figure 12. Structure of raw mill 7 from the outside.

1.1.4 Raw mill 7th grinding roller

The design of raw mill 7 and its inner structure as well as the inner structure of the grinding rollers and sealing mechanism date back to the year 1970 when the machine was first commissioned [3]. Figure 13 shows a cross-section of the grinding roller, and the design has mostly stayed the same throughout the years, with spare parts being swapped during renovations and when needed.

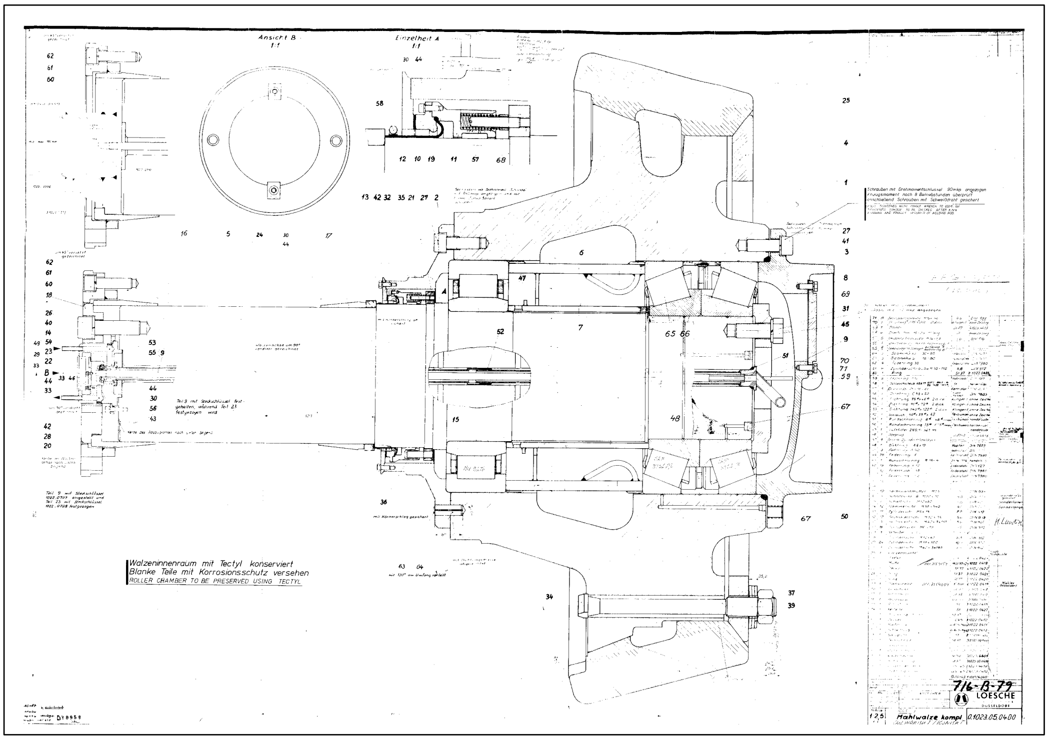


Figure 13. Cross section of raw mill 7th grinding roller.

For this thesis, the primary sealing area of the grinding roller shown in figure 14 will be the focus. The sealing mechanism is situated, as shown in Figure 15.

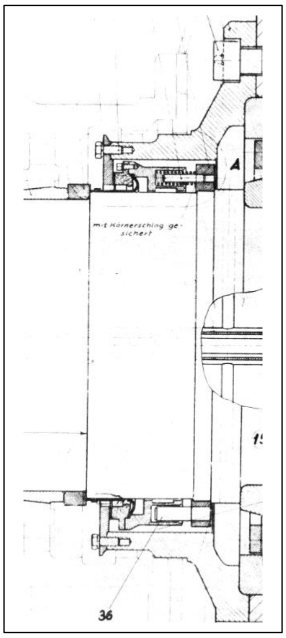


Figure 14. Cross section of the roller sealing area.

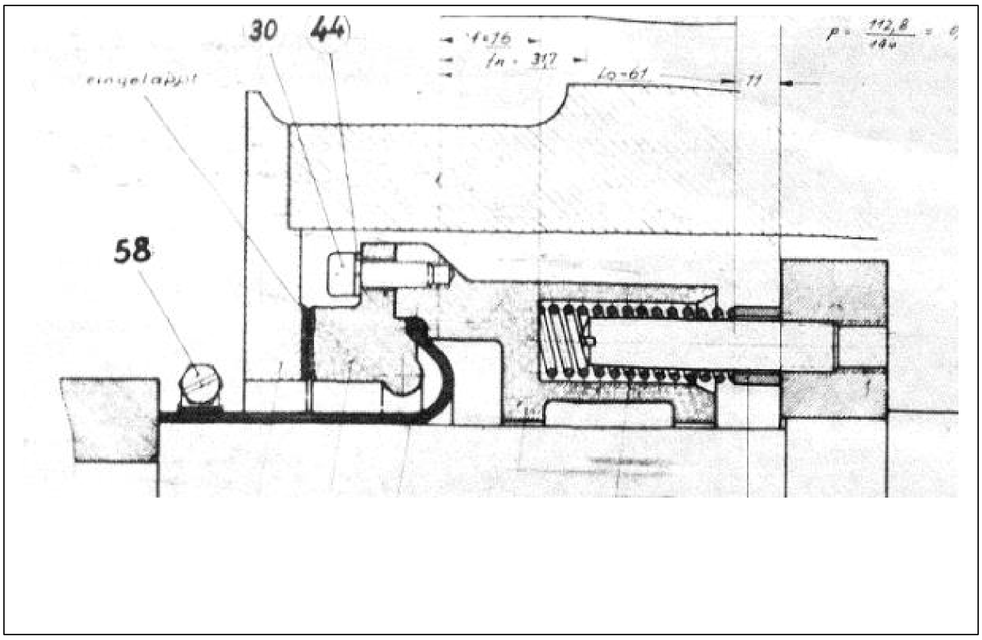


Figure 15. Cross section of the sealing mechanism.

Rotating and fixed components:

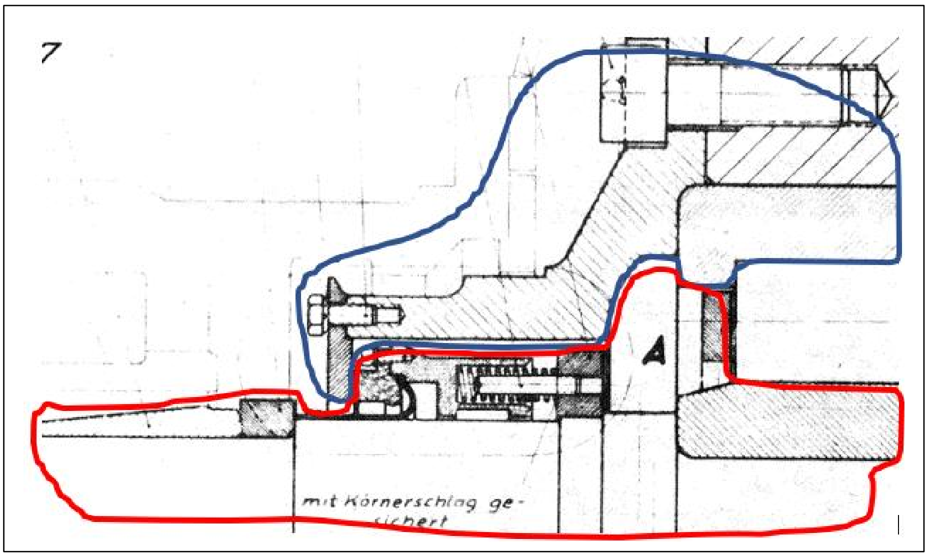


Figure 16. Rotating components in blue and fixed components in red.

Sealing components:

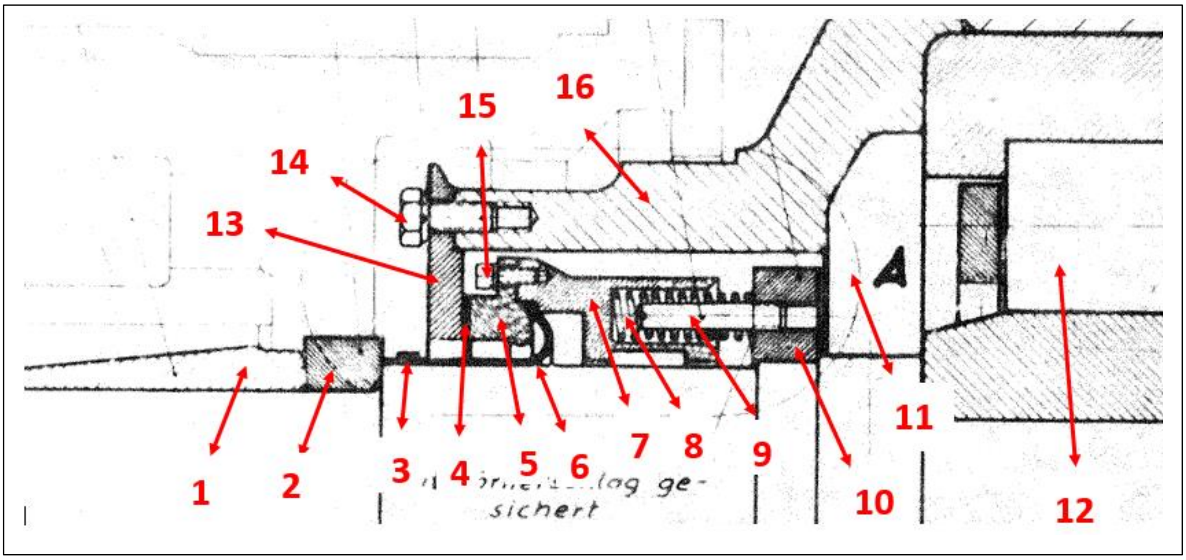


Figure 17. Sealing mechanism component identification.

Below is a list describing the function and purpose for each component shown in figure 17, within and in the vicinity of the sealing mechanism. All components, replacements and spare parts are made by and ordered from the original Loesche supplier. The terms used to describe each component are not the precise terms used by the supplier. The below list does not have to be read in any particular order.

1. <u>Outer ring 1.</u> The last ring mounted before mounting the grinding roller in the holder. The end of the mounting process mostly covers it. It acts as a layer between shaft and holder to hold the roller in place.
2. <u>Outer ring 2.</u> This outer ring is still visible once the grinding roller is mounted in the holder. It contributes to further sealing by protecting the lip seal (6) from the side in which it is situated. It also reduces the space in which foreign material may infiltrate.

3. Seal clamp. This clamp fastens the lip seal (6) in place.
4. Rubber seal. This is a piece of rubber placed in between the sealing ring (13) and the pinching ring (5) for additional sealing.
5. Pinching ring. This ring and the spring housing (7) pinch the lip seal (6) in place. It is lifted some distance above the shaft level to allow the lip seal to move under it.
6. Lip seal. The lip seal is an elastomeric ring of rubber and is pinched between the pinching ring (5) and spring housing (7). It then continued under the sealing ring (13) and clamped by the seal clamp (3).
7. Spring housing. This component contributes to the pinching process and houses the sealing spring (8).
8. Sealing-spring. The purpose of the spring is to give the lip seal (6) a degree of freedom to move. This is to not cause too high stress on the lip seal during axial and radial movement of the mechanism, which could cause premature wear.
9. Spring rod. The sealing spring is mounted on it.
10. Spring rod housing.
11. Free space.
12. Cylindrical roller bearing.
13. Sealing ring. This ring is the outer protection of the sealing mechanism. It is also lifted some distance to allow the lip seal (6) to move under it. However, the sealing ring does come in contact with the lip seal, which is the primary sealing action through constant friction.
14. Sealing-ring bolt. The sealing ring is bolted to the outer lid, which is why it is among the rotary components, as shown in figure 16.
15. Pinching-bolt.
16. Outer lid.

To assemble and mount the grinding roller, a set of steps provided by the supplier are followed. These steps are presented in appendix 1 in Swedish. The steps act as a guide for the workers in the workshop when renovating the grinding roller during a maintenance stop.

1.2 Main problem statement

1.2.1 Bearing failure: The main problem

What allows the cylindrical grinding rollers in raw mill 7 to rotate freely in a given direction around their axis are the bearings within. These bearings are periodically lubricated sufficiently enough to allow for efficient rotation. To protect the bearings and the lubricant inside from invasive material, seals are put in place. The primary seal is a lip seal made of elastomeric rubber, as shown in figure 19.

Figure 19. Rubber lip seal

Figure 18. Hardened lubricant pushing out the sealing gland.

Figure 20. Visible wear on sealing components.

The fundamental problem is that the chosen rubber lip seal deteriorates at a high rate. A big factor to this would have to be the fact that the lip seal operates in dry conditions for the majority of the running time. There exists little to no lubrication film between the rubber and outer sealing ring it is in contact with during rotation. When newly mounted, the grinding roller is packed with lubricating grease, as shown in appendix 2. Grease is then periodically and manually pumped through the shaft up into the bearing and out through the sealing mechanism. This creates a sort of positive pressure of lubrication that is meant to keep invasive material from entering. With this in mind, the lubricant does reach the space between the rubber seal and outer sealing ring due to the positive pressure. However, the high operating temperatures quickly dry out the immediate lubrication film, and the constant blowing of raw material hardens the lubricant to the point of almost a solid-state, and dry friction between the components occurs instead. This can visibly be seen in figure 18. Also, the wear on the lip seal is visible in figure 20.

The dry friction in conjunction with the seemingly unending harsh condition within the raw mill hastens deterioration. Furthermore, with the constant stress against the seal by lubricants, contaminated or otherwise, from within and among other factors, an endless stream of high-speed material from the outside in combination with high temperatures, the seals tend to give in and allow for unwanted materials to infiltrate the bearings they were meant to protect finally.

There are two routes in which invasive material can travel within the sealing mechanism to be able to reach the bearings. This is illustrated in figure 21.

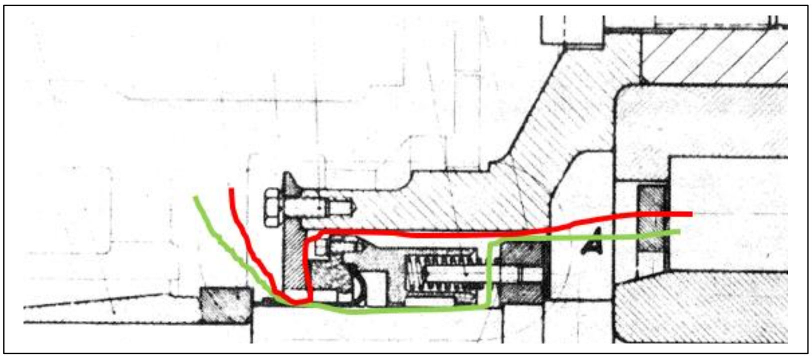


Figure 21. Invasive material routes.

Also, the lip seal has a thickness of barely a centimeter, which does not contribute to a longer lifecycle within these conditions. The invasive material then clogs the bearings by contaminating and eventually hardening the grease-based lubricant, which in turn adds to the pressure on the seals as well as the bearings. It doesn't take long for bearing failure to occur once this happens.

Bearing failure can look something like, as shown in figures 22 and 23.

Figure 22. bearing failure (cracking).

Figure 23. Bearing failure (clogging).

The factory has made countless so-called "root cause failure analysis" or RCFA, which supports the fact of the excessive frequency of failure mode and the conclusion of poorly performing rubber seals as well as sub-optimal lubrication. Examples of RCFA can be reviewed under appendix 2.

Today, the best-case scenario is replacing the seals periodically before further infiltration of material. The worst-case scenario is reaching failure mode or bearing failure within an unplanned timeframe, and as mentioned, seal deterioration is a frequently appearing issue. With this in mind, one can assume that failure mode can occur due to foreseen as well as, as of yet, unforeseen factors, which is what this thesis will research upon.

Also, the bearings within the grinding roller were initially meant to be oil lubricated when the machine was set into commission and, in fact, was operated as such at first. The factory had run it that way for a while, but due to seal deterioration that caused the oil to leak out onto the raw material, the method was quickly changed to grease-based lubrication, which is the current method today. The lubrication method works as intended when it is newly applied but encounters a range of problems, as previously mentioned. Because of the high viscosity of the grease, leakage was no longer an issue but proved itself to be a sort of double-edged sword in the long run due to the eventual hardening of the grease by invasive material.

1.2.2 Subsequent problems

Considering the crucial part that the raw mill plays in the production process, it is worth considering the subsequent problems of seal deterioration. Later on, in the methodology section, a problem-tree showcasing the cause and effects of failure mode will be presented with a more detailed study for each problem branch. But continuing on a range of problems arises in conjunction with seal deterioration.

First off, the inconvenience of having to maintain the grinding rollers by replacing the seals periodically. Of course, this can be considered a natural part of the sealing life cycle; however, when considering the consequences of unexpected or hastened seal deterioration, the problem becomes a lot more severe. Although the change of seals usually takes place during planned maintenance stops and has proven to be quite manageable but definitely not sustainable. This is why it is essential to have seals that at least hold up until the planned maintenance stop so that unnecessary stops in-between don't have to happen. Secondly, replacing the seals at a high frequency has become the norm for raw mill 7, and it costs the factory a lot of money in the long run.

The inconvenience is furthered by having to pump grease onto the bearings manually. Too much pumping of grease onto the bearing can lead to over-saturation prone to overheating the bearing. And too little pumping of grease does not contribute to the desired positive pressure of lubricant to keep out invasive material. By introducing a better seal, oil lubrication could once again be implemented if so desired. There are many advantages to having an oil-circulation system. Monitoring the oil level, temperature, and pressure are some of the benefits as well as not having to inject the lubrication manually, which saves valuable time and effort that can be put elsewhere.

When looking at further subsequent problems of bearing failure due to seal deterioration, the consequences become a lot more severe. The raw mill has to stop to be able to replace the failed components completely. To do this, the whole grinding roller has to be extracted. This process can take up to 5 or 6 days to complete, which causes production to halt to some extent. Usually, however, a spare roller has been renovated for such a time and can with relative haste be a replacement to the faulty one in commission. Of course, it can also be argued that the toll on the overall production isn't as detrimental as one could assume because of the continuously filled raw material silos that the raw flour accumulates in after the raw mill. However, in the case that the silo-usage isn't maximized at the time of the failure, then the consequences may become more severe. It has become quite reasonable to expect failure mode at some point due to the high frequency that it occurs, but the fact remains that it is challenging to foresee actual failure timing because of the unreliability of the current sealing method. The risk then becomes greater and should be mitigated as soon as possible.

1.3 Scope of the thesis

This thesis will focus on two separate aspects: a theoretical study phase and a practical conceptual designing phase.

The first aspect is in the form of a study and is part of the chosen methodology for the thesis. The study is in the way of an identification and examination process of the causes for failure mode within the grinding rollers of raw mill 7. The problem statement section of the thesis has already touched on some of the general causations extracted from the point of view of the workers that handle the maintenance of the grinding rollers in the factory. Identification of causes will be made through the creation of a problem tree. The problem tree will be based on the hypothesis surrounding the most likely reasons that failure mode occurs. This will also be in combination with the already established reasons presented in the problem statement section. Each problem hypothesis branch in the problem tree will be researched on the world wide web for the aim of confirming that the hypothesized problems in the tree are, in fact, contributing factors for failure mode. The problem branches will then be related to external literature studies for further confirmation. The purpose of this, first of two aspects of the thesis, is to give Cementa AB a relatively short basis to understand and potentially improve upon the problematic factors of failure mode. The studies conducted are not meant to yield any specific results but are intended to be discussed in the discussion section to further support the notion of a need for a significant upgrade to the sealing mechanism in the grinding roller of raw mill 7.

The upgrade of the sealing mechanism is the second of the primary aspects of the thesis and is the practical approach meant to yield the thesis results. This will be done through conceptual designing and modelling, which falls in line with Cementa ABs' expectations for the project. Namely, to present a number of concepts, either inspired or revolutionary, for the sealing mechanism. The freedom to generate any type of conceptual design has been given. The purpose of this is not necessarily to implement one of the generated concepts but to provide a new perspective on what could potentially be a good idea by an up-and-coming engineer. Cementa AB already has already acquired suggestions regarding new sealing mechanisms from external companies but is not inclined to share these as the purpose is, as mentioned, to provide a new perspective. It is, therefore, essential to once again emphasize the fact that the concepts that are eventually generated in the thesis aren't meant to be complete with regards to dimensional accuracy, scale, or implementational readiness. This includes both ideas inspired by established sealing standards and revolutionary concepts. Cementa AB has also forbidden contact with Loesche, the original supplier of the raw mill, since they hold one or more of the already suggested upgrades. All data concerning the dimensions of the grinding roller is gathered from the internal system of the factory. The bearings of the grinding roller will not be altered in any way. The generated concepts will assume that the lubricant used in the sealing mechanism is grease-based and will, as such, not be concerned with optimizations regarding the choice of lubricant. When generating the concepts, if chosen to implement, a sealing rubber used in a rubber-based concept will be assumed to be able to take on any shape demanded by the concept. This means that special orders of sealing rubber from external companies are a valid approach. Also, calculations on costs and savings for the potential upgrades will not be conducted.

Furthermore, catering to the conducted study and the concept generating towards Cementa AB does not mean that the concepts aren't applicable in other factories that have an operating Loesche raw mill as well. The conceptual data may then also be compared to other rollers or machines around the world that have similar or identical problems and, through this, aid them in the implementation of a more sustainable solution. They may then even be adopted in other types of rotary machines that have a need for a better performing sealing mechanism, other than raw mills provided that the potential solution is compatible.

1.4 Objectives

- Define a hypothesized problem tree and, through it, research into, present, and discuss existing information and studies linked to the hypothesized potential causes for bearing failure.
- Generate several conceptual designs to the sealing mechanism in raw mill 7^{th} grinding roller with the aid of either inspiration from standard seals or revolutionary thinking.
- Conclude by suggesting at least one of the generated concepts and briefly explain how the concept mitigates the discussed causes for bearing failure.
- Conclude by suggesting lifecycle extending measures, should Cementa AB chose to keep the original sealing mechanism for a more extended period.

1.5 Values of a potential upgrade

- Reduces maintenance costs
- Reduces spare-part usage
- Decreases time consumption during a maintenance shutdown
- Decreases the frequency of production stop due to failure mode.
- Decreases the overall risk of production stop due to failure mode.
- Continuous production rate

1.6 Thesis questions

- Can hypothesized root causes for failure mode within raw mill 7, related, and compared to literature studies concerning each contributing factor, help determine actions that could prevent or at least postpone total failure?
- Can upgrades through revolutionary conceptual designing with respect to the conducted literature studies on failure mode within raw mill 7, be as effective as selecting an already performance-tested and verified standard design?

1.7 Thesis outline

Cement is a critical component in concrete, which is the cornerstone of modern society's infrastructure. Cement is produced through a series of production steps. One of those steps is the crushing of limestone into a raw flour. The machine responsible for crushing is the raw mill. For this thesis, the focus will be on the company Cementa AB, raw mill 7. Within the raw mill, the crushing is done by feeding fist-sized limestones to a milling table where two grinding rollers crush the stone between themselves and the table. The grinding rollers rotate around their axis with the aid of roller bearings within. Roller bearings need to be sufficiently lubricated to function properly, which is why seals are put in place to protect the lubricant and the bearings from contamination that could lead to failure mode. The grinding rollers use a traditional rotational lip seal as a sealing mechanism. The conditions inside raw mill 7 are harsh with high temperatures. These conditions lead to premature lip seal deteriorating, which in turn allows for foreign raw material to penetrate its way into the bearings resulting in failure mode.

One of the thesis objectives is to hypothesize further potential causes for failure mode and relate them to literature reviews to either confirm or contradict them. The hypotheses, in conjunction with the literature studies, will then aim to determine what actions could be taken to prevent or postpone failure mode. The hypotheses are made through the creation of a problem tree. This methodology is suitable for the study since the subject of bearing failure and seal deteriorating is one that has been studied for almost a century with ongoing studies. Hypothesizing causes for failure mode could provide a new perspective that might contribute to the collective worldwide study on the matter.

Further thesis objectives are to generate conceptual designs with the aid of 3D modelling for a new sealing mechanism better equipped to handle the conditions within the raw mill. The concepts can either be revolutionary or they can be standard. Part of the objective is to determine if revolutionary designs can be as effective as selecting from a range of standard designs, and another part is to relate the concluded selected conceptual design to the literature studies on bearing failure by pointing out how the new concept mitigates the main problem, failure mode. This methodology is suitable for the thesis since it aligns with the expectations of Cementa AB.

The problem tree was accurately hypothesized, with many literature studies existing for each problem branch. Unfortunately, none of the hypotheses were revolutionary, and while failure mode prevention was too much to hope for, the gathered information has many implications on how Cementa AB could try and at least postpone failure mode should the original sealing mechanism continue operating. Seven concepts, revolutionary and standard-inspired combined, have been generated and modelled. Revolutionary designing, in conjunction with the limited timeframe of the thesis, resulted in non-viable concepts that, while potential exists, are in need of further development. Instead, a standard design was chosen, the labyrinth seal, which is a non-contact seal that, in theory, could mitigate many or all of the causes for failure mode within raw mill 7. For future work, contact with labyrinth seal suppliers will be the main priority in order to confirm combability and operability.

2 PROBLEM TREE

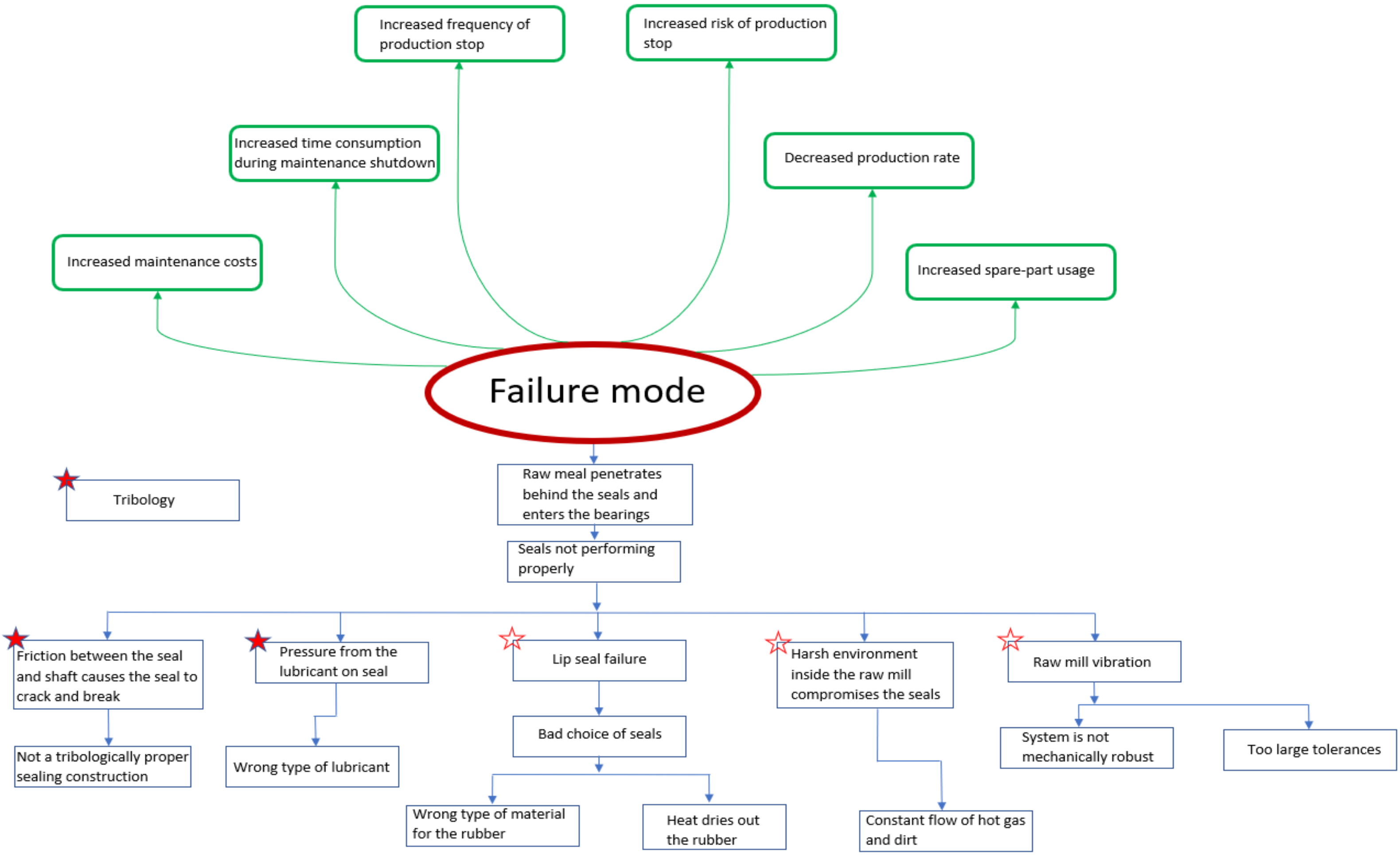


Figure 24. Problem tree.

One of the main steps of methodology for this project is creating the problem tree above. The problem tree illustrates the root cause and effects of failure mode based on educated hypotheses in combination with field studies in the factory where countless workers have been interviewed. The effects are marked in green and root causes in blue.

The root causes were formulated by a continuous *"Why"* based questions. For instance, why does failure mode occur? The question is answered by a hypothetical assumption. Subsequently and following the example, the answer is followed up by the question, *Why* do raw meal particles penetrate behind the seals and enter the bearings? And so on. This method creates a flowchart-like structure for the causations, which in turn will help in the categorization of them.

The main sections that will be focused on for this thesis and, in turn, related to existing information and literature reviews are the ones with stars placed above. The sections with filled stars are the ones related to the field of tribology and will, as such, be researched under one single headline, namely, tribology. The sections with un-filled stars will get their own. The following roots are mainly further hypotheses that may or may not be confirmed through the studies.

2.1 Lip seal failure

This thesis has already touched on the problem of lip seal deterioration in raw mill 7 since it is part of the main problem. It is, however, important to acquire a deeper understanding of the general reasons for seal failure apart from the obvious ones in the case of seal deterioration in raw mill 7 due to the already mentioned factors such as high temperatures. This is also to help with determining what actions should be taken or at least considered when generating a potential solution.

It has been established that above-average or excessive temperature spikes in a machine is the leading cause of seal deterioration. Once the temperature rises above a certain degree, the lubrication film between the seal and rotating component becomes very thin, which in turn leads to the seal operating in dry conditions. Subsequently, the elastomer starts to blister, crack, and eventually fail [4].

A study published by Eindhoven University of technology investigated radial lip sealing mechanisms and the temperature influence during sealing contact. The influence of temperature in the study covers contact distribution, stress, width, and force. These are considered to be so-called boundary conditions within a sealing mechanism. These boundary conditions are affected by reversible and irreversible effects from temperature differences. Some of the irreversible effects are rubber stiffness and thermal expansion of both rubber material as well as the shaft itself. The study then goes on to present the reversible effects, which in this case, aren't as relevant. The study then concludes that it should be the aim of the seal manufacturer to create a seal that is not too sensitive to temperature differences, be it increased or decreased changes. Also, it was concluded that for temperatures above 100 degrees Celsius, the rubber material in a rapid manner stiffens due to, and among other factors, physical aging. This is also an irreversible factor. It is worth mentioning that the study focused on nitrile rubber, which luckily is the same rubber used in raw mill 7. To summarize some of the findings of the study, beyond a certain temperature, an increase in seal wear will most likely occur, which will significantly lower the life expectancy of it. Also, to keep in mind, the temperature due to contact friction adds to the total heat in the machine when balancing all the heat sources within a given machine. Furthermore, due to the dynamic excitation of the lip seal, dynamic stiffness becomes an important consideration [5].

Among other already mentioned factors to seal deterioration in raw mill 7 are grease hardening and raw material invasion. Figure 25 shows the worn lip seal of raw mill 7^{th} grinding roller when disassembled.

Figure 25. Deteriorated lip seal of raw mill 7th grinding roller.

Furthermore, the mating surfaces play a crucial part in the longevity of the seals. The finish on the shaft is an essential component. Seals are easily damaged by, for example, sharp edges and imbalances in the shaft finish. The finish should, as such, match the material of the seal and seal type. Rough finishes will cause excessive wear on the seals, while a smooth finish will make it challenging to keep the lubricants from spilling out [6].

Any given machine that uses some type of bearing and shaft should take into account the shaft movement. The displacement of the shaft will put the seal under abnormal pressure. In this case and in the case of poor assembly, the seal will be subjected to unbalanced compression. One section of the seal will, by that, be more compressed than the other sections, which causes specific, and excessive wear on the compressed section while the uncompressed ones will experience a lot more lubrication leakage [6].

2.2 Harsh Environment

When active, the conditions within the raw mill are all but mild. Due to the constant upwards flow of hot gas and the amount of ground material being produced, a hurricane-like environment is created within. This is illustrated as an upwards red spiral in figure 26. With a large amount of material bouncing on and off the walls and components, one can, with near certainty, assume that this has a significant effect on the wearing of said walls and components. The seals of the grinding rollers are no exception since the seals are located very close to the gas inlet, as marked with green circles in figure 26. Furthermore, when examining the rollers, it is apparent that the sealing glands are very much exposed to the environment and, as such vulnerable to the hurricane-like material flow. This exposure can make it a lot easier to infiltrate the seals or at least attempt to do so. Figure 18 shows the exposed glands of the grinding roller, and the assumption can be made that it might not be sufficiently protected against incoming material.

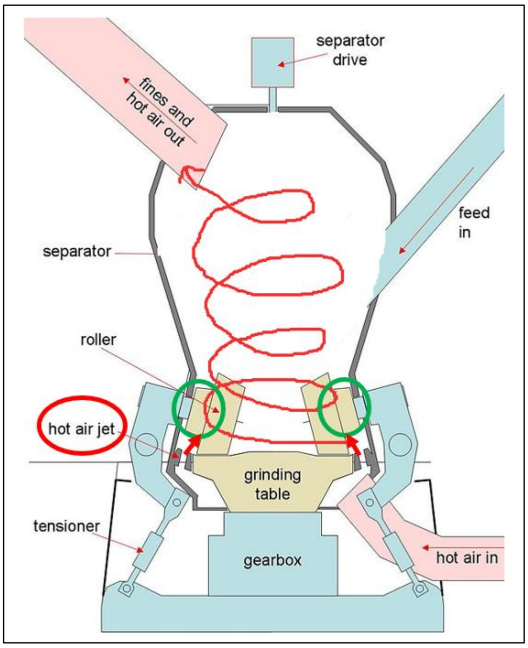


Figure 26. Typical roller mill layout. (illustration of inside hurricane-like environment). From [24].

A previous engineering thesis studied the different relations within the similarly functioning, but exceptionally larger Polysius raw mill, raw mill 8 in Cementa AB. The study examined wear due to abrasion and erosion within the mill. When producing the raw flour, materials such as limestone and marlstone, as well as adhesives such as quartz sand and iron ore are mixed together on the milling table inside the raw mill. The roller grinders then grind the material into a fine flour. The quartz sand is considered to be the hardest out of the material with the hardness of 810 Vickers. The quartz sand is often round and without cracks with a crystal-like structure as shown in figure 27, while, for instance, calcite, which is the main element in limestone, is relatively easy to break because of the nature of its structure as shown in figure 28. As such, the sand has a hard time getting ground by the rollers and tends to bounce between the mill walls with relatively high speed due to the constant flow of gas from below. Due to the sand being challenging to destruct and lack of plastic deformation, collisions of sand against the components within the raw mill causes erosion and abrasion in the form of micro-cuts and micro-failures. According to the study, the most prominent wear takes place around the milling table and at the entrance to the classifier, with erosion and abrasion being the primary factors for wear [7].

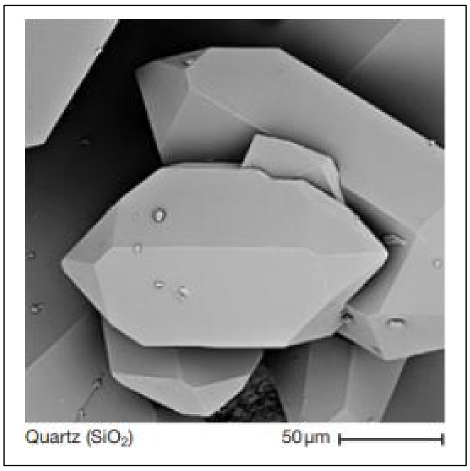


Figure 27. Quartz. From [25].

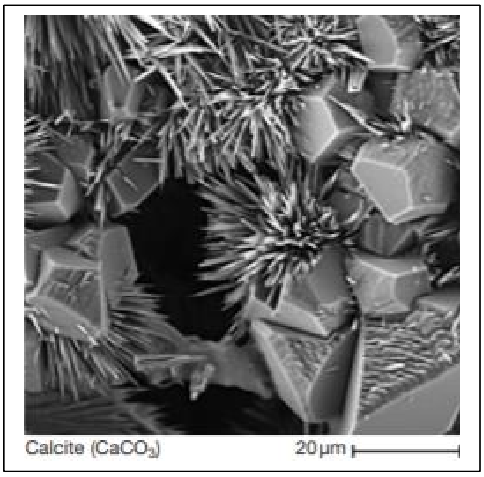


Figure 28. Calcite. From [25].

The study then aims to examine the possibility of maintenance cost reductions by selecting a new, more durable material for the raw mill 8 circuit. The choice of material is built on the wear resistance, life cycle, and price. The study then concludes that the best type of material, in that case, is a hard one with high resistance to erosion and selected material for the task being Triten T266X [7].

2.3 Tribology

Tribology studies can be dated back to 1493. It was then that Leonardo da Vinci created the first two fundamental laws of friction [8]. Methods for estimation of the magnitude of friction have been studied for the past 200 years as well [9].

Tribology is the study and science of the tribological behavior of applications. This includes lubrication, friction, and wear of interacting elements and contact surfaces of a given machine. How the machine system behaves in a dynamic or relative motion largely depends on the design and lubrication method of it. The science is very complex with countless research and researchers around the collaborating to further understand the mysteries of tribology. Figure 29 illustrates the main points of tribological optimization and design.

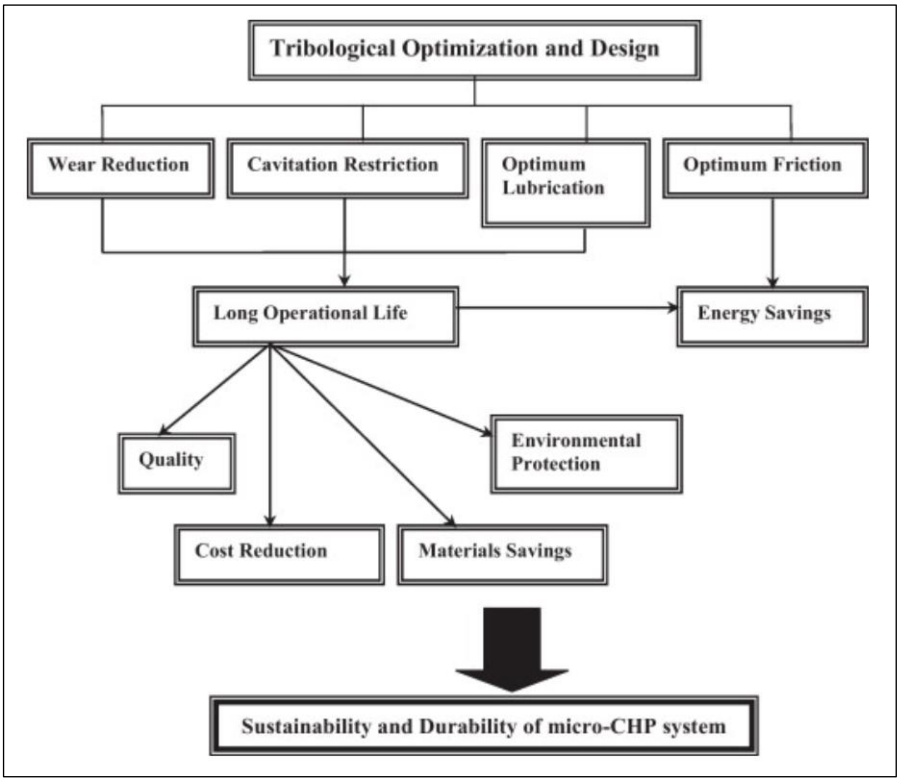


Figure 29. Schematic representation of tribological optimization. From [26].

Generally, lubrication acts as a barrier or film between two or more moving surfaces which allows for the reduction of friction, which is the key objective of any given lubrication, and is most commonly in a fluid state but can also, in some cases, be a solid substance. Apart from friction, lubricants help to prevent excessive wear, corrosion and can be used to regulate the temperature within the application by dissipating heat. Also, some lubricants have the ability to regulate contamination by transporting the foreign material to filers as not to wear down the components further. The most common of lubrication substances used in mechanical components are oil and grease. What determines the choice of lubrication is the application they are meant for [10].

A doctoral thesis studied the tribological behavior of elastomers used in different seals. The purpose of a sealing component is mainly to hinder forms of lubricants from accessing a delicate machine process. Leakage of lubricants can cause serious harm to whatever the process may be. When it comes to seals, elastomers have proven to be the most useful and reliable type of material. Since seals often are used in the presence of lubricants, the interaction between the lubricant and the seal elastomer can prove to be of utter importance when researching the tribological effects that can occur. Also, since seals often slide against a surface, they really need to be optimized for friction, which, when excessive, causes leakage and eventually failure. For some seals, such as the so-called reciprocating seals, contamination in the form of leakage can be minimized by increasing the pressure on the sealing surface and decreasing lubrication. However, when reducing the amount of lubrication, some risks can be aggravated due to vibrational factors of the machine. The study also thinks it is worth looking into the tribological performance of operation under dry conditions since the elastomers are affected by frictional wear at times. For instance, during the upstart of the machines.

Furthermore, the study researches the effects that age has on the elastomeric seals as well as how lubricants influence the wearing on seals due to abrasive wear. The study then concludes that lubricants do, in fact, play a major role in the abrasive wear on the seals due to them constantly being in contact with the lubricant, which in turn weakens the elastomer chosen for the seal. Also, the study showed that the worn particles on the seals where especially aggregated when in a dry state, and the lubrication did somewhat calm down the agitation process [11].

Lubricants are used in a wide variety of applications, but for the sake of this thesis, the focus will be on bearing lubrication. Figure 30 illustrates the lubrication action within a roller bearing.

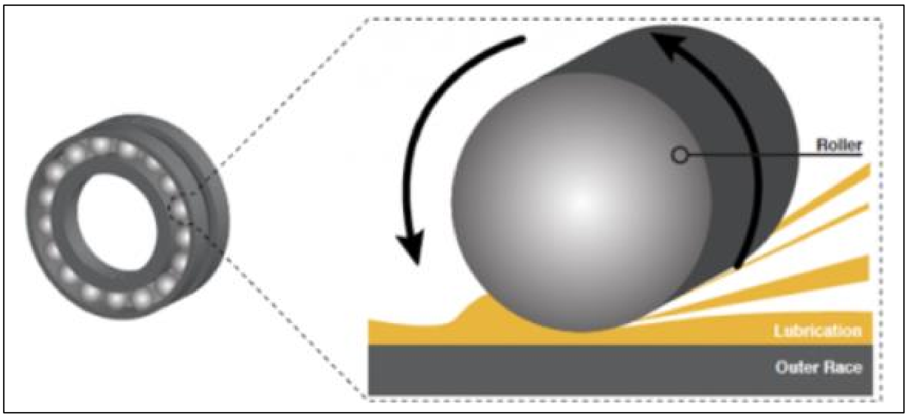


Figure 30. As bearing speed increases, lubrication is "pulled into" the contact zone. From [27].

A crucial factor when researching lubricants is viscosity and it is an important property of any lubricant to have understood when attempting to select one for a specific application. Viscosity is known as the measurement of internal friction within a given lubricant, or fluid in general. Contributing factors to the variation of viscosity in lubricants are pressure and temperature. In some cases, even the shearing rate of the lubricant. Furthermore, research of the tribological nature of any lubricant relies heavily on the viscosity properties of them [12].

Figure 31 shows the state of the grease inside the grinding roller bearings of raw mill 7 when disassembled after failure mode.

Figure 31. The state of the grease lubricant at failure mode.

Another doctoral thesis from Luleå university of technology studied the influence that grease-based lubrication has on the performance of bearings by examining and evaluating the so-called rheological properties of grease, which include the differences between normal and shear stress with regards to the sealing system in place. By this, the study focuses on the relations between grease-based lubrication, grease-lubricated bearings, and the sealing properties of grease. The aim of the project was to create models to understand better, predict, and analyze grease behavior and function when in operation and to understand better the overall conditions that the grease is operating within. The thesis then implies that it is not entirely clear how seals function in conjunction with grease despite the amount of theoretical as well as experimental research that has been conducted in the field of tribology the past few decades [13].

According to the thesis, about 80-90% of all bearing use some type of grease-based lubricant. This is due to the ease of which it can be applied and the minimal leakage. Also, the friction within the bearings is quite low once the component has been running for a while, and the grease is fully distributed throughout the bearing canals. Also, the oil within the grease is continually lubricating the contact surfaces of, for example, the seals in place. This property is called oil bleeding and is an essential factor for the performance of both the bearings and seals [13].

The thesis presented an extensive amount of literature study of grease lubrication, sealing and lubrication conditions with a lot more tribological research intertwined [13].

Due to the broad scope of the study, the thesis then goes on to present many conclusions related to each research concerning grease lubrication. Among them was a very interesting conclusion regarding the relationship between the grease lubricant and the sealing contact. The high shearing rates of grease near the sealing surface, in conjunction with the normal stresses of grease, may result in a lifting force on the sealing lip. However, the author stresses that the significance of this is inconclusive and that it needs more testing [13].

Applications or machines that operate in high temperature and speed generally benefit a lot more from oil-based lubricants since the oil helps to transfer heat away from the surfaces of the bearings. The oils are usually synthetic oils but often, and most commonly, mineral-based with a set of additives for the prevention of oxidation on the surfaces. Mineral and synthetic oils are quite different in regard to specific properties. One of the crucial characteristics kept in mind when selecting an oil-lubricant for a bearing is the viscosity of it. Specifically, for oil, there exists a correlation between the viscosity and the created film thickness of the oil. The thickness is a significant factor in the separation action of the elements within the bearings. The elements being sliding and rolling. Oil is common in some applications, but for the most part, grease is the preferred option for about 80-90% of all bearings [14].

When it comes to grease, the consistency is made up of about 85% oil, synthetic or mineral, and additives that act as thickeners to sort of round out the volume of the grease, which is what gives the grease its signature texture as opposed to oil that is in a more fluid state. Thickeners are mostly in the form of different kinds of metallic soaps, calcium, or lithium. The immediate benefit with grease is the high viscosity that helps it sit in the application with minimal leakage. Important aspects when selecting a grease for any given application is the viscosity of the base oil, oxidation prevention capabilities, and the range of operating temperature [14].

2.4 Vibration

It is usual for a mechanical gadget to vibrate. However, should the device have any sort of imbalance within its components, then seal failure is imminent due to the excessive vibrations that are produced by the imbalance. Almost any dynamic seal needs a lubrication film between itself and the surface of its sealing counterpart. Vibration, especially excessive vibrations, could prevent the lubricating film from settling. This increases the wear factor of the elastomer used and significantly contributes to an early seal failure. One way to detect and eventually limit the conditions that are created from vibration is periodic maintenance. This includes rinsing the gadget from invasive material that could potentially cause these imbalances that also have a significant negative effect on the bearings as well as the shaft when it comes it displacements and misalignments. Bearings can also play a crucial part in the vibrational aspects of a sealing mechanism. Poorly installed bearings that are loose contribute heavily to vibrations that carry over to seal failure. This also includes poorly adjusted or assembled components that have an effect on the dynamic system. Furthermore, it is essential to further touch on the importance of proper alignment of components. If two sealing surfaces aren't precisely matched, then uneven wear on each of them is the result, as well as the risk of excessive lubricant leakage. Uneven wear is when one part of a seal is being worn more than the other parts. Also, another type of misaligning other than the surrounding components is a misalignment of the sealing mechanism itself due to the excessive vibrations produced by the presented causes. The vibrations force the sealing mechanism out of alignment, which puts unnatural stress on the seal and is a significant factor for seal failure [15].

A study from 2004 researched the behavior of dynamic radial lip seals with the aid of numerical and experimental testing to determine the effects of radial vibrations in a rotary sealing environment. The study defined the parameters in which the behavior of dynamic seals could be characterized to achieve a correlation between the sealing conditions and vibrational effects. The parameters being: Rotating speed, machine operating cycles, temperatures, lubricant viscosity, elastic properties of the seal, static eccentricity, dynamic eccentricity, and assembly interference. The study suggests that the total effect of the parameters determines the stress distribution on the seal when influenced by vibrations in the machine, and that ultimately leads to displacements. The study then concludes with the suggestion that there does in fact exists a relationship between displacement due to, among other factors, vibration and lubricant leakages caused by seal wear and failure [16].

3 PROCESS FOR REDESIGNING THE SEALING MECHANISM

The process of redesigning a new sealing mechanism will undergo a set of steps. Firstly, data in the form dimensions of the grinding roller and the existing sealing solution will be gathered from internal sources. If needed, manual data gathering will be conducted on one of the rollers currently being maintained in the maintenance workshop. This data will be used to model the current grinding roller and its sealing mechanism first. This is to get a clear idea of the functionalities within the roller in a 3D environment. Furthermore, since raw mill 8 has a functioning sealing mechanism that supports oil-based lubrication, it will be worth comparing the two for inspiration. Of course, in the case that inspiration is found in raw mill 8, the measurements will have to be scaled down and adapted since the grinding roller of raw mill 8 is much larger. Further inspiration will be searched for from existing grinding that other companies manufacture and own. This will be done by researching the web as well as attempting contact with the companies. Furthermore, a short study on standard sealing mechanisms will be conducted to get a better idea of the range of standard selections that could either be implemented or drawn from inspiration-wise. Lastly, an idea-generating phase will ensue where the different inspirations and studies will come in play, and a decision will be made on how to proceed with the actual conceptual designing. The final designs might heavily draw from the presented inspirations and standards, or they might be utterly revolutionary as the freedom of such has been granted by Cementa. For designing the CAD software environment, Autodesk Inventor will be used.

3.1 Data collection

Throughout this project, field studies in the factory were conducted during the annual maintenance shutdown. This is a complete shutdown of all machines in the factory with planned succession. This created a valuable opportunity to observe raw mill 7 in a stationary state as well as the grinding rollers. Since the rollers that had been in operation for a time were extracted and sent for renovation, the chance to observe all the inner components within the roller arose. This includes the sealing mechanism. At first, the plan was to gather data and dimensions of the components with manual measuring as soon as the roller was disassembled in the renovation workshop. However, it was later found out that there exist drawings of the machine that could be apprehended through the internal system. This did not mean that the observations of the actual machine were made redundant since it gave a clearer picture and idea of the relations within that made it easier to visualize the relationships continuing forward.

Apart from the already presented cross-section of the grinding roller in figure 13, appendix 3 shows further internal drawings that were apprehended and worked with.

3.2 Modelling raw mill 7th original Grinding roller

To further visualize the current grinding roller and its sealing mechanism as well as visualizing what upgrades can be made later in the project, it was decided to 3D model it using Autodesk Inventor. The drawings in appendix 3 were used to some extent. However, due to some of the components not having a specified dimension within the drawings, it was also decided to create a rough model instead, which means that the model wasn't made to scale. In fact, many of the component modelling, such as the sealing mechanism, was basically free hand-drawn with the help of figure 13 as a guideline. In the case of this project, it is totally acceptable since it lines up with the scope of the project being the creation of a conceptual design. This will become the case for practically all final conceptual models in the thesis. Below figures 32-36 present the modelled original grinding roller.

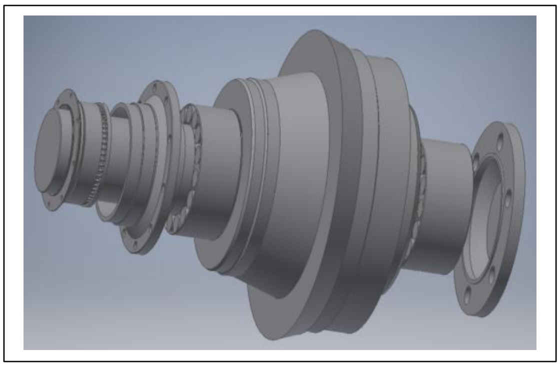


Figure 35. Original grinding roller 3D model.

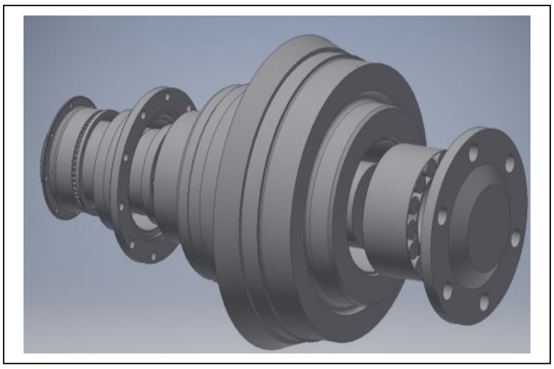


Figure 36. Original grinding roller 3D model.

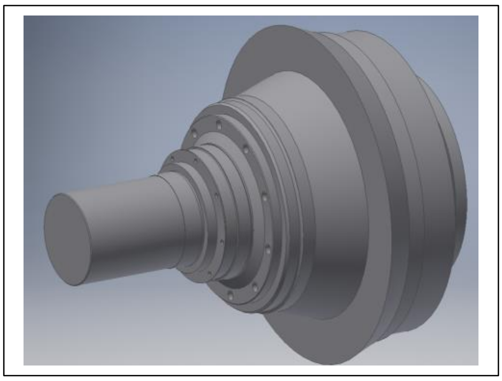


Figure 34. Original grinding roller 3D model.

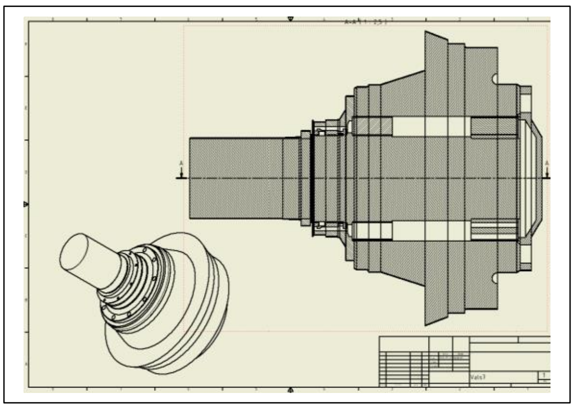


Figure 32. Original grinding roller Cross section.

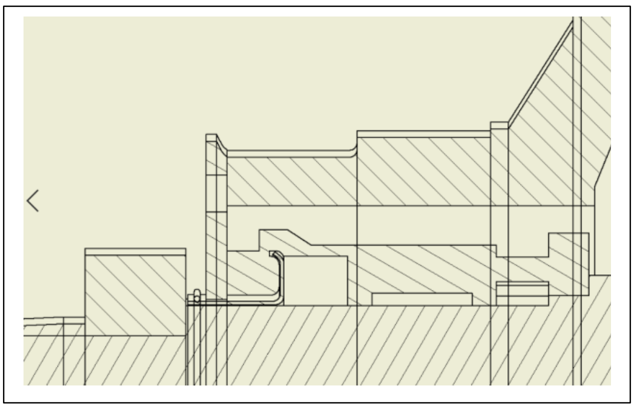
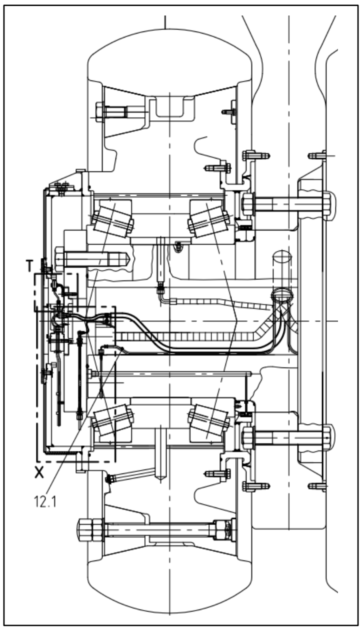


Figure 33. Original grinding roller cross section of sealing mechanism.

3.3 Inspiration from raw mill 8

Since the grinding roller of raw mill 8 has a functioning sealing mechanism that supports oil-based lubrication, it seemed like a good idea to compare the two in the hopes of at least finding inspiration when generating ideas for a concept regarding raw mill 7. Figure 38 shows a cross-section of raw mill 8th grinding roller. Figure 39 shows a cross-section of the sealing mechanisms in place. Roller 8 is, however, very different from roller 7. It should also be noted the number of O-rings used in different sections of the roller as presented in table 1. This means that the roller most likely has more than one sealing mechanism. The differences are by that too broad and inspiration will have to be found elsewhere.



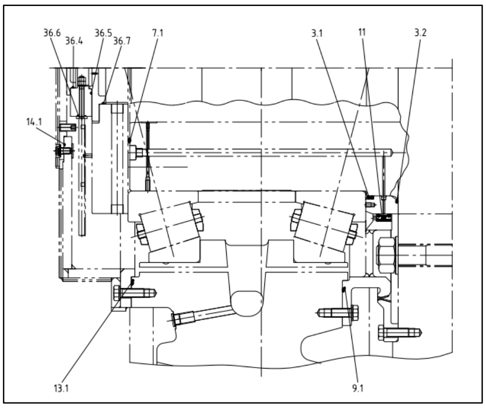


Figure 37. Raw mill 8 grinding roller cross section.

Table 1. Part designations for raw mill 8

Item	Designation
3.1	O-ring (slide ring)
3.2	O-ring (slide ring)
7.1	O-ring (bearing tension cover)
9.1	O-ring (inner bearing cover)
11	Radial shaft seal
13.1	O-ring (outer bearing cover)
14.1	O-ring (bearing cover plate)
36.4	O-ring (cover for oil probe)
36.5	O-ring (cover for oil probe)
36.6	O-ring (cover for oil probe)
36.7	O-ring (sealing flange)

Figure 38. Raw mill 8 grinding roller cross section.

3.4 Inspiration from other companies

Another alternative for finding inspiration was exploring other companies' websites that specialize in roller seals or raw mills in general. It stood to reason that many of these companies would have relatively modern grinding rollers implemented in their plants. It was, however, later apparent that they don't post descriptions of their products, at least not the necessary details for the concept generating phase, online for everyone to see and eventually copy. This made a lot of sense, so contacting them personally seemed fitting. However, this idea was also scrapped since the chances of the companies handing over product specifications to a rival company were slim. In the end, the concept of taking inspiration from other raw mill manufacturers was ultimately scrapped.

3.5 Examples of standard seals

The next step was researching established standard sealing mechanisms to get a better understanding of the range of rotary seals that could be applicable in raw mill 7. Below are three types of rotary seals that inspiration could be drawn from. The choice of the three specific types of seals was made through research on what would be considered the best alternatives on the market for rotary type equipment in need of sealing and as such would fit the needs of raw mill 7.

3.5.1 Rotary shaft seals

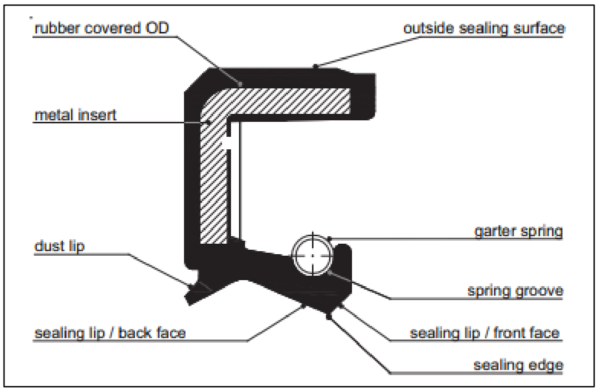


Figure 40. Rotary shaft seal. From [17].

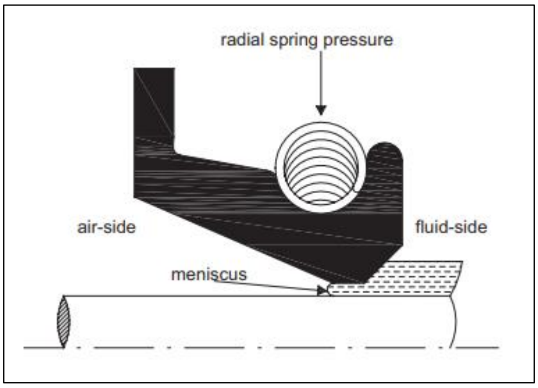


Figure 39. Rotary shaft seal. From [17].

The lower edge of the seal, or sealing edge, is considered to be the most important since it is also the contact point between the seal and the shaft. The rotary shaft seal is also known as one of the many versions of lip seals that exist. The internal diameter of the rotary seal is a bit smaller than the diameter of the shaft, which creates a natural pressure from the seal on the shaft. Furthermore, a garter spring mounted on the seal makes it so that constant pressure is generated onto the shaft. This action also somewhat flattens the sealing edge. As with almost all lip seals, a lubrication film, preferably oil, is created between the flattened sealing edge and the shaft. This creates a sort of surface tension. To avoid leakage of oil, the choice of viscosity has to be carefully made with regards to the sealing environment [17].

3.5.2 Dynamic rotary gland seals with O-rings

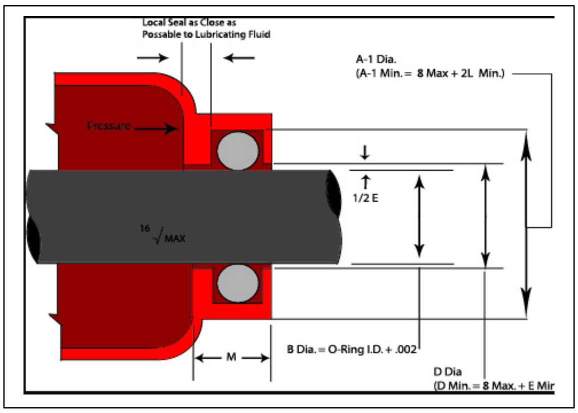


Figure 42. Dynamic rotary gland design. From [18].

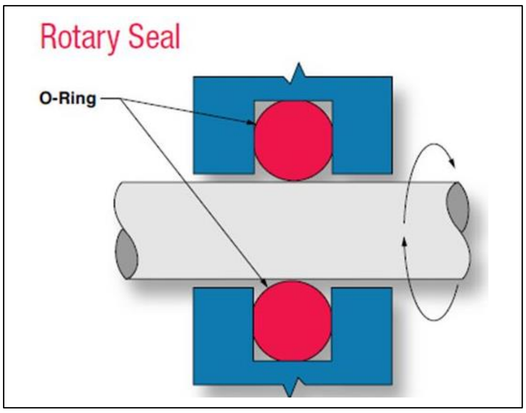


Figure 41. Dynamic rotary seal. From [28].

A dynamic rotary gland seal utilizes the O-ring as a sealing entity. However, because of the many interacting forces that, due to the bigger surface tensions that are generated, it is recommended that the choice of elastomers for the O-ring be carefully investigated with regards to the sealing environment [18].

It is, therefore, essential to conduct a short study about the O-ring and its functionality.

The most common of sealing components is the O-ring and is the most basic type of seal that is widely used in the industry. The O-ring is like a doughnut-shaped ring and comes in many sizes. Some O-rings are made of thermal plastic, but for the most part, most O-rings are made of elastomers, which are basically rubber. A rubber seal can be seen as an incompressible, extremely viscous fluid that is put under constant high pressure. Figure 44 illustrates the seal when newly installed. Figure 45 shows the seal having to start flowing towards the grooves due to added pressure from fluids. Figure 46 illustrates the seal at a pressure limit. Figure 47 illustrates the failed seal [19].

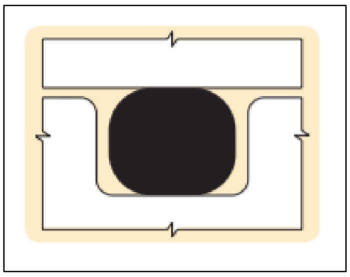


Figure 44. From O-ring installed. From [19].

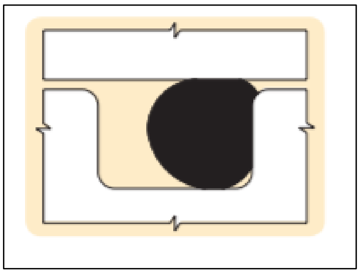


Figure 43. O-ring under pressure. From [19].

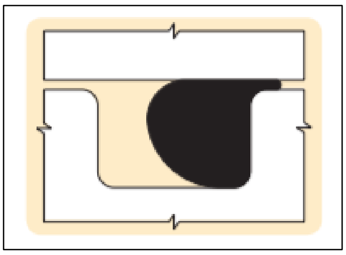


Figure 45. O-ring extruding. From [19].

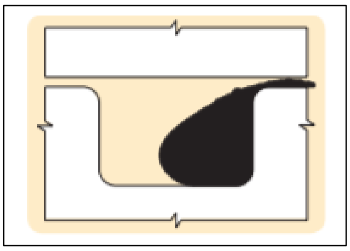


Figure 46. O-ring failure. From [19].

The primary usage of an O-ring is to conveniently seal off and prevent leakage of lubricants as well as keep foreign material from entering. Substantial research funds have been dedicated to studies on the sealing capability of O-rings. Institutions like NASA are among the many organizations that have realized the importance of performance studies on the sealing technology. The seal is used in a wide variety of mechanical structures in the conditions of both dynamic and static contact [20].

The design of a dynamic and a static O-ring is different in some ways. A dynamic O-ring seals between two or more moving parts, often in a rational motion. It is then especially important to choose a material that is relatively hard-wearing. Also, a crucial aspect when selecting a dynamic O-ring is the design of the environment that it is placed in. The situation that the O-ring is positioned within should take into consideration the wearing inducing factors of shearing and abrasion that most likely will deteriorate and destroy the O-ring prematurely because of the near-constant movement of the surfaces. This is certainly less of a hindrance for static seals since basically the only force they will have to endure is that of static compression, which they have been proven to be quite resilient towards. Proper maintenance is still required, though. Furthermore, a dynamic O-ring requires more lubrication with more frequent application than its counterpart, and for optimal sealing performance, the quality and type of material need to be determined when manufacturing them based on the dynamic movement they are meant to perform within [21].

Below table 2 shows some examples of material-performance for O-rings.

Table 2. Material for O-ring and advantages/disadvantages. From [20]

Material	Advantage	Application example
Nitrile rubber (NBR)	Compatible with oil; wear resistance & heat resistance are good and molding is easy.	Oil seal, packing, O-ring & diaphragms
Polyacrylate rubber (ACM)	Compatible with oil & heat resistance and in particular, compatibility with gear oil is good.	Oil seal for high temperature, high speed & for gear oil
Silicone rubber (VMQ)	Heat resistance, cold resistance & squeeze resistance are excellent	Oil seal for high speed, O-ring & diaphragms
Fluorocarbon rubber (FKM)	Heat resistance & chemical resistance are excellent	High-temperature oil seal, medical packing
Polyurethane-Ester (AU)	Strength & hardness are high and wear resistance & cold resistance are excellent	Packing, diaphragms for high pressure

The structure design of the environment around the O-ring in which it is situated enables compressive sealing. Within the seal, the housing mechanism is a groove that the O-ring completely and entirely covers. The groove allows for the insertion of the O-ring in a circumferential direction in either an inner or outer diameter side of a given shaft, provided that the sealing is of rotational nature. The sealing design then performs with the help of repulsive elasticity due to the deformation that is generated because of the compression. The rubber materials restoration force is then taken advantage of during the sealing action [20].

Below figure 47 illustrates the compressive force.

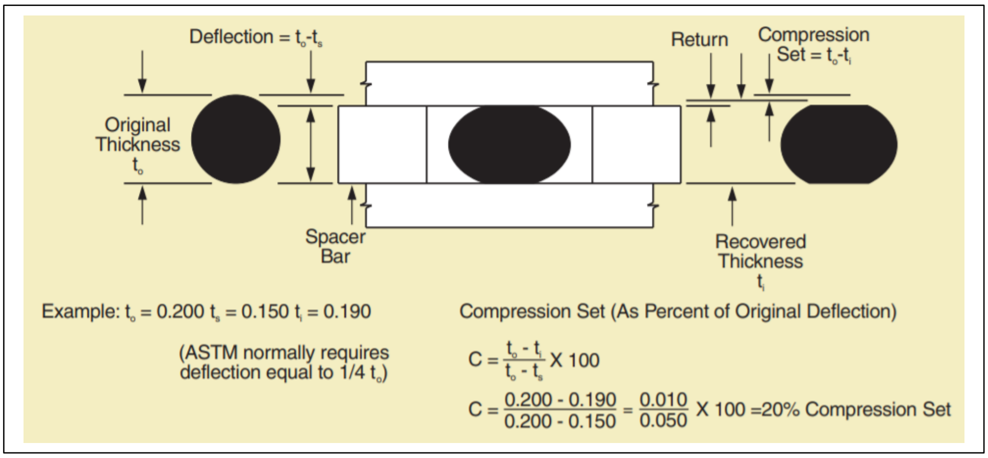


Figure 47. Illustration of compression. From [19].

Examples of common O-ring failures:

- Compression set
  This happens when an O-ring loses its elasticity and by that loses its previous ability to go back to its original shape. This is both a chemical and physical change and is permanent once it happens. The reason this happens is because of the common elevation of temperature within a given machine. The temperature causes the seal to be unable to relax once the temperature goes down. The result of the compression set is lowered contact sealing force due to the reduced amount of space that the seal at that point occupies. Apparent in the cross-section of figure 49. This, in turn, significantly increases the risk of leakage in a system that relies on high temperatures and dynamic movement [22].
- Extrusion and nibbling
  This often happens during high stress on the O-ring. Visual indication of this is the edges having been nibbled or chipped, and the surface of the seal can sometimes even appear to be completely peeled. The high stress forces the O-ring to extrude beyond the groove or clearance gap. Due to vibration and pressure, the clearance gap can get smaller and more prominent. This leads the extruded part of the material to become trapped. The pinching of the edges then results in damage on the seal. Figure 50 illustrates this [22].
- Abrasion
  Abrasion is most commonly the result of friction between the O-ring and, for example, the surface of a shaft. Very common in a dynamically moving apparatus. The repetitive contact of surfaces in conjunction with insufficient lubrication will increase the risk of abrasion. Also, the finish of the environment in which the seal is mounted has a detrimental effect on abrasion when suboptimal. Another factor that increases the risk for abrasion is contaminating or foreign material, which, when introduced to the process, shortens the lifetime and increases abrasion risk. Visual indication of abrasion is that of the seal having a grazed surface, visible wear and tear, and breakage in some areas. Can be seen in figure 51 [22].
- Thermal degradation
  When the temperature of a given apparatus or machine has exceeded the maximum allowed temperature of a chosen O-ring, an increase in density in the elastomeric material occurs. This causes the elastomer to have an increased hardness due to the decrease of elasticity. Common effects of thermal degradation are cracking on the surface of the seal and eventually breakage. Can be seen in figure 52. Another unwanted factor of thermal degradation is thermal extrusion, which goes hand in hand with the compression set. The elevated temperatures then cause the seal to extrude outside of the groove, as previously mentioned [22].

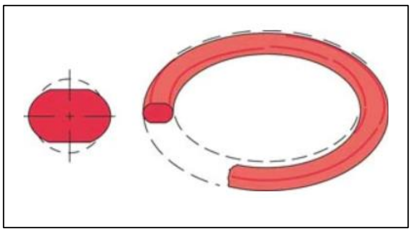


Figure 48. Compression set. From [29].

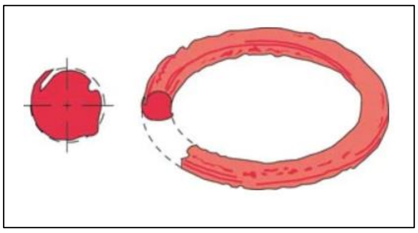


Figure 49. Extrusion and nibbling. From [29].

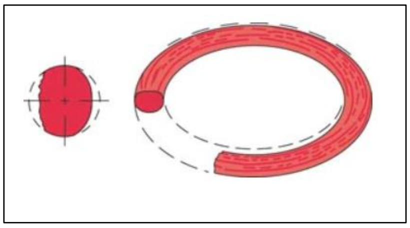


Figure 50. Abrasion. From [29].

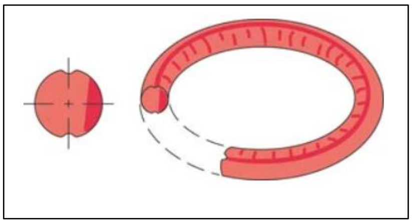


Figure 51. Heat hardening and oxidation. From [29].

Elastomers and rubbers are all bound to deteriorate at some point when high enough temperatures are introduced. The compression and volume of the seals are almost entirely dependent on the amount of heat that they are exposed to since the heat, at first, softens the rubber, which causes physical change. This is acceptable since the rubber will eventually return to its original form once the temperatures drop. However, adding on the pressure from the machine in question, deformation becomes a lot more detrimental because of the permanence of it [19].

Below is, therefore, a list of known elastomers that can withstand relatively high temperature that is worth looking into as the study report goes forward [21].

- Nitrile: anywhere from -50 C to 120 C
- Hydrogenated nitrile: anywhere from -45 C to 150 C
- Polyacrylate: anywhere from -25 C to 175 C
- Ethylene-propylene: anywhere from -50 C to 135 C
- Chloroprene: anywhere from -40 C to 120 C
- Butyl (petroleum compound): anywhere from -55 C to 205 C
- Fluorosilicone: anywhere from -60 C to 205 C
- Fluorocarbon: anywhere from -25 C to 205 C

3.5.3 Non-contact seal - labyrinth seal

Another type of standard seal is the labyrinth seal. Also, called the non-contact seal. It doesn't rely on any kind of friction during operation as opposed to lip seals, for instance. The concept of the labyrinth seal is to minimize the clearance in which invasive material can enter and travel through and, at the same time creating a turbulent flow of lubricant that has the purpose of excluding the invasive material. Figure 52 illustrates a basic labyrinth seal. When comparing labyrinth seals with standard lip seals, it is apparent that wear is much higher on the lip seal due to the constant rubbing contact. This makes it hard for this type of seal to exclude invasive material in the long run. That is not to say that the lip seal doesn't do a relatively good job of retaining lubricants, at least at the beginning of its life cycle. Once the life cycle comes to a close, both lubricant retention and material exclusion are practically nonexistent. The labyrinth seal, however, has a longer life cycle and will not have the same wear factors in identical conditions due to its non-contacting nature. It is certainly more expensive but will last a lot longer in harsh conditions. The labyrinth seal is built so that two pieces, one stationary and one rotary, interlock with a level of clearance between. Lubricants are meant to travel through this clearance, making it almost impossible for contaminants to enter. Should material particles succeed in entering, then a long intertwining path will make it difficult for them to reach the bearings [23].

The non-contact labyrinth seal was developed to be used as a sealing method for machines operating in harsh and extreme environments at high speeds where a regular lip seal isn't sufficient enough for the task due to the risk of overheating and contamination that causes wear on the rubber. High speeds contribute to a controlled laminar flow that ejects contaminates [24].

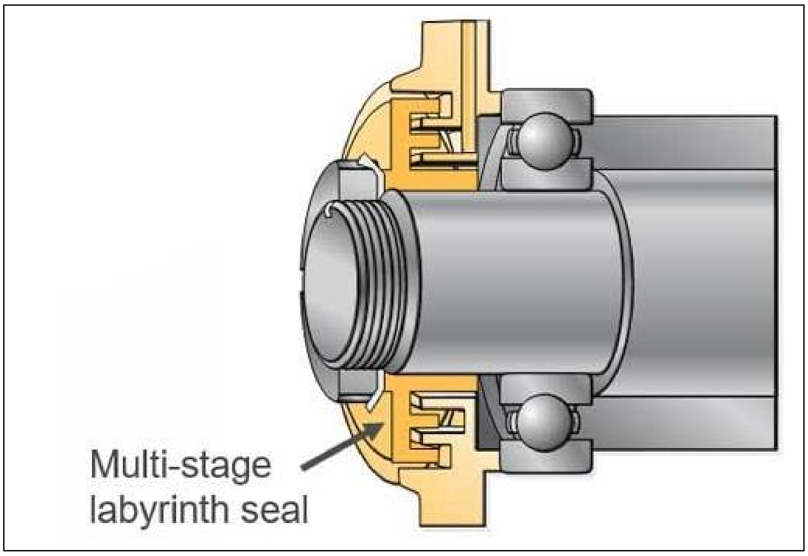


Figure 52. Multi-stage labyrinth seal. From [23].

3.6 Concept generating and modelling

A decision has been made that an attempt at designing revolutionary conceptual designs for sealing mechanisms will be made. To align with the scope of the thesis, the designs will remain conceptual with no further testing until a decision by Cementa AB has been made that one or few should be tested to see if they indeed work as intended. Of course, there are no guarantees that they will function as intended in their eventual conceptual state. It is, therefore, important to emphasize the conceptual aspect of the ideas, and more work will likely have to be done for them to function correctly. Apart from revolutionary conceptual designs, an attempt at upgrading the current sealing mechanism while keeping the integrity of it will also be conducted. This means that the surrounding environment will be improved to prolong the life cycle of the current sealing mechanism. Furthermore, some inspiration will be taken from one or more mentioned standard sealing concepts in the previous section of the thesis.

3.6.1 Concept criteria

The concept criteria below were formulated in cooperation with supervisors in Cementa AB.

- No change will be made to the overall construction of the grinding roller apart from the sealing mechanism itself and its surrounding components such as the outer lid, as seen in figure 15.
- It should be relatively easy to assemble if implemented.
- Should keep foreign material from entering the bearings.
- Should be able to withstand the high heat within raw mill 7.
- Should prolong the life cycle of the sealing rubber if rubber lip seals or O-rings are implemented.
- Upgrades to the current sealing mechanism should prolong the life cycle.

3.6.2 Idea generating process

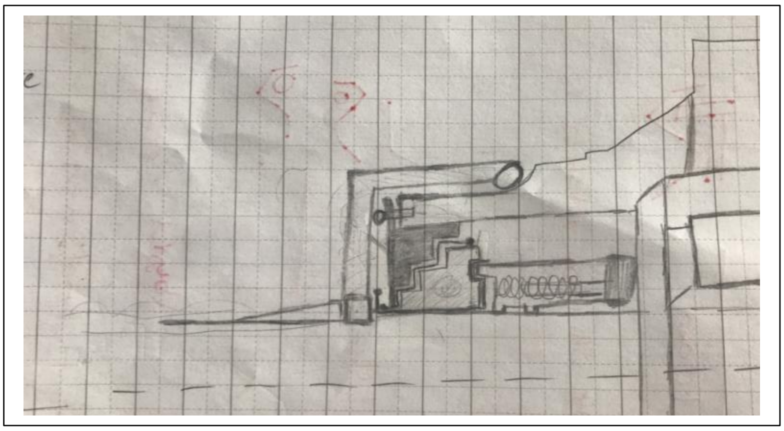


Figure 53. Brainstorming sketch session.

During the idea-generating phase, several brainstorming sessions were conducted where many ideas, potentially ridiculous or genius, were sketched by hand. Figure 53 illustrates one of those sketches. The purpose was to get a feel for what could potentially or possibly work but also to exclude ideas with lesser potential. All ideas began with a hand drawn sketch and some were instantly scrapped for being to ambitious and some were presented to supervisors for feedback and constructive criticism. Only the idea with some potential were then transferred onto a 3d-model. The reason for sketching by hand first before 3D-modeling was to save time and basically come up with as many ideas as possible without having to commit to any one of them.

3.6.3 3D modelling process

The modelling phase was done by firstly sketching the entirely new concept, be it revolutionary or otherwise, as seen in figure 54. Every concept emanated from the original sealing mechanism and its relations to the shaft and bearing housing. The original sealing mechanism was simply deleted and replaced by the new sketch. All components within the sketch were then revolved around a single axis. The components were then assembled in the Autodesk Inventors assembly module. Figure 55 shows an example of the number of components for a single concept; some had more and some less. However, the final concept results will not present each and every one of the new components as not to make the thesis too large.

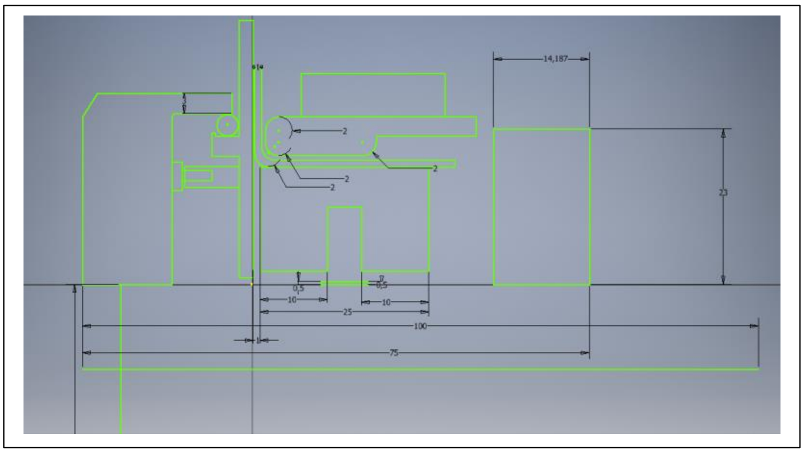


Figure 54. Concept sketch in Autodesk Inventor.

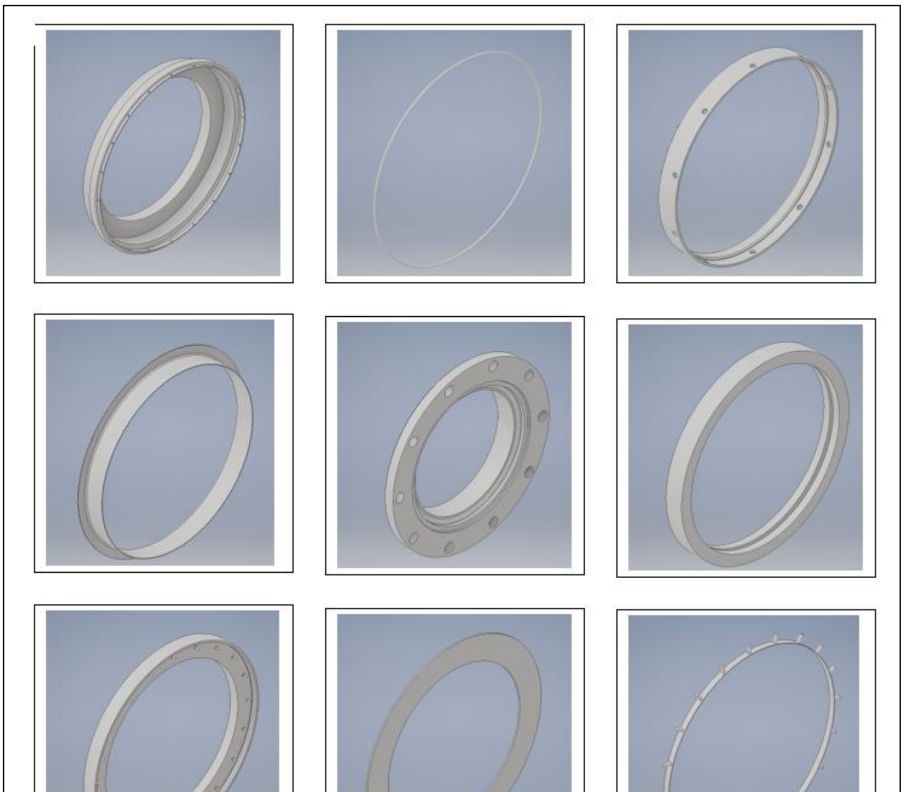


Figure 55. Concept components in Autodesk Inventor.

4 RESULTS

4.1 Concept 1

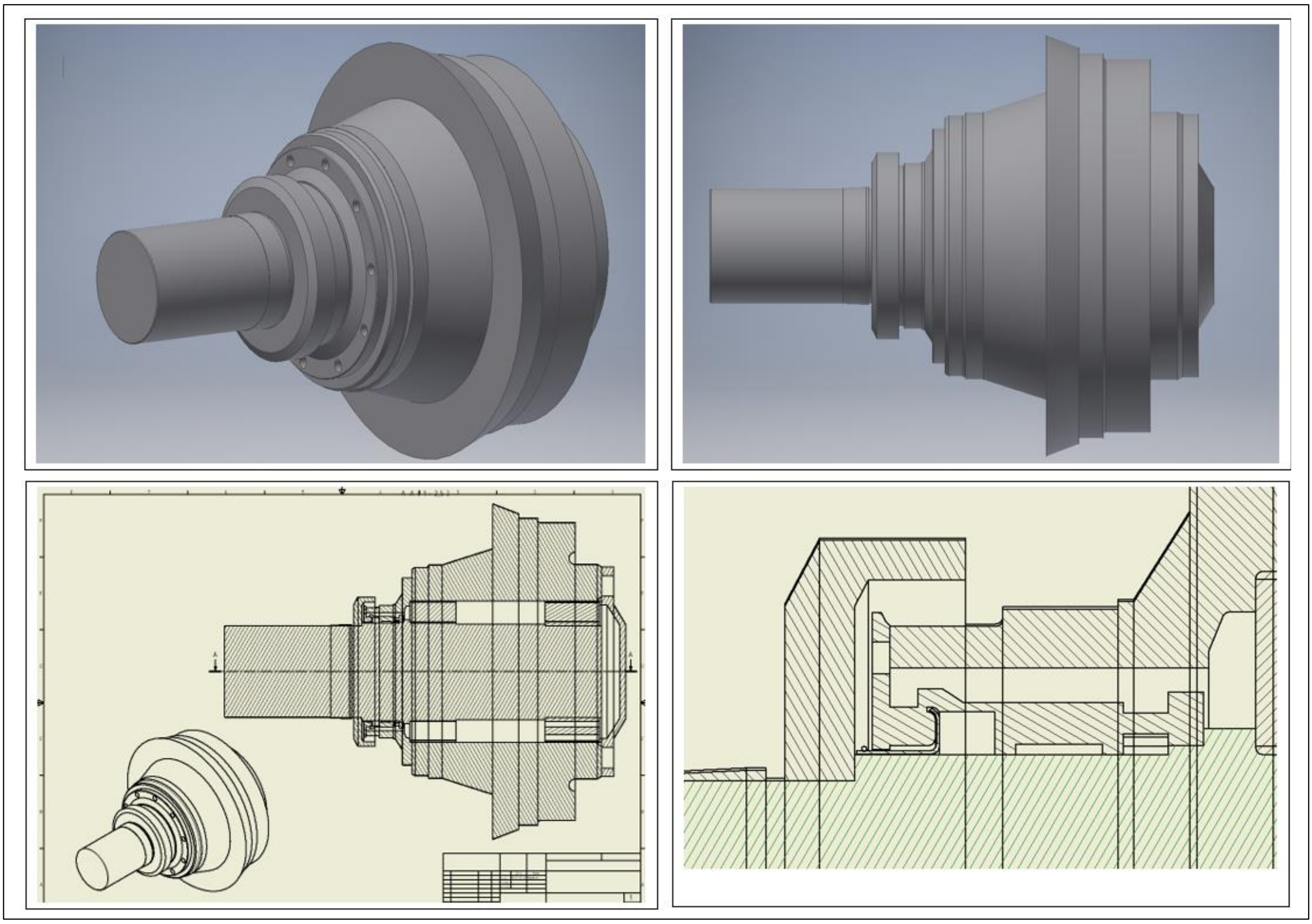


Figure 56. Concept 1 - Protective barrier.

Concept 1 is purely an upgrade for the original sealing mechanism. The idea takes advantage of the unutilized component 2, outer ring 2, from figure 17. The outer ring is stretched above and over the sealing gland, as shown in figure 56. The idea is to put a protective barrier in place for the sealing gland that protects against the direct heat produced by the milling tables gas entries. This should at least slow down the thermal degradation of the lip seal and prolong the lifecycle of the rubber. The barrier is fixed with no contact areas.

4.2 Concept 2

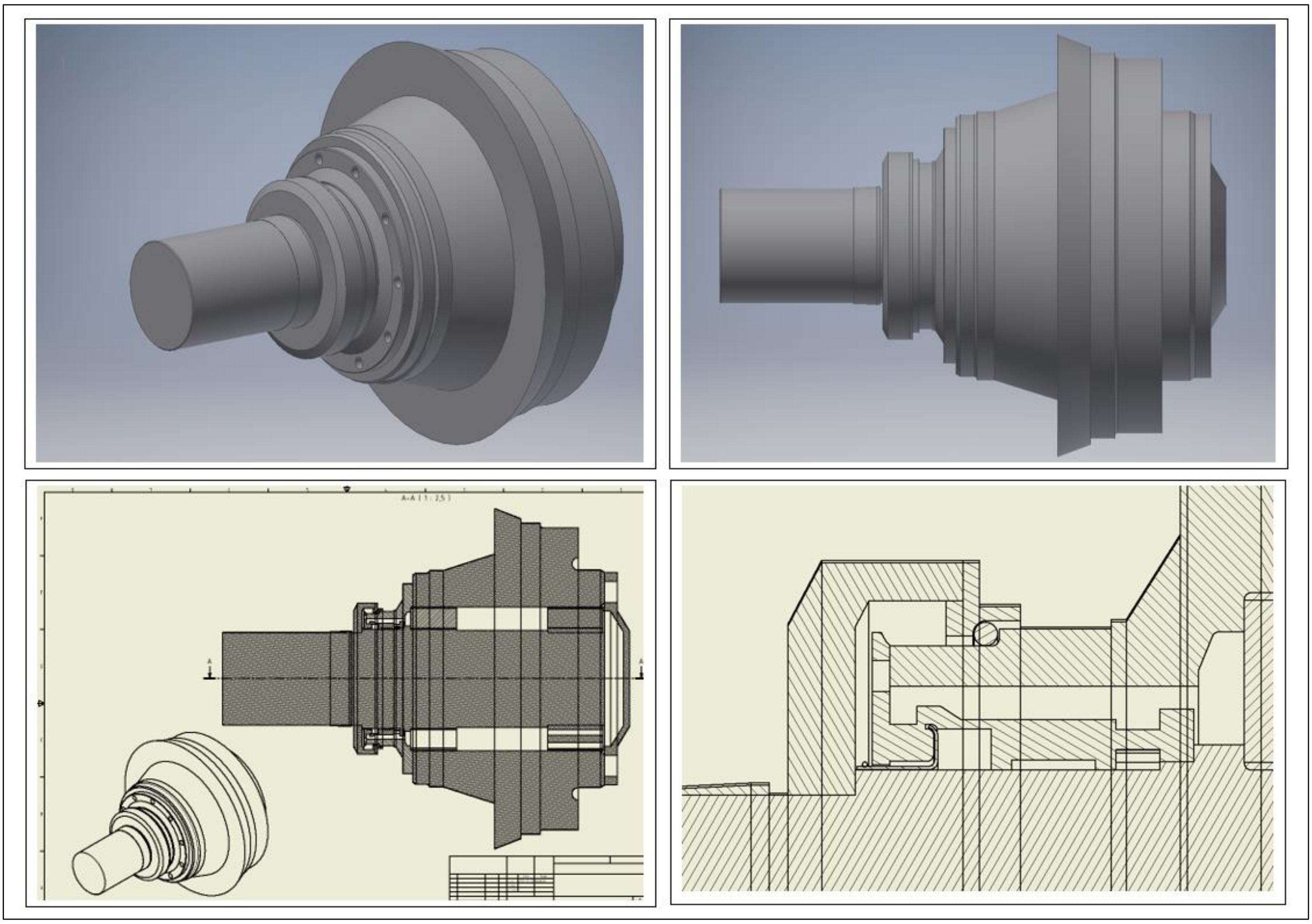


Figure 57. Concept 2 - Protective barrier with O-ring.

Concept 2 is also an upgrade for the original sealing mechanism. It is also meant as a protective barrier, however, with one defining difference. The clearance under the barrier is sealed by an O-ring, as shown in the lower-left figure of figure 57. The barrier and the O-ring are fixed, with the O-ring being the only contact against the outer lid. Of course, the area on the lid where the O-ring makes contact will have to be adapted and sufficiently lubricated to fit the tribological capabilities of the chosen O-ring.

4.3 Concept 3

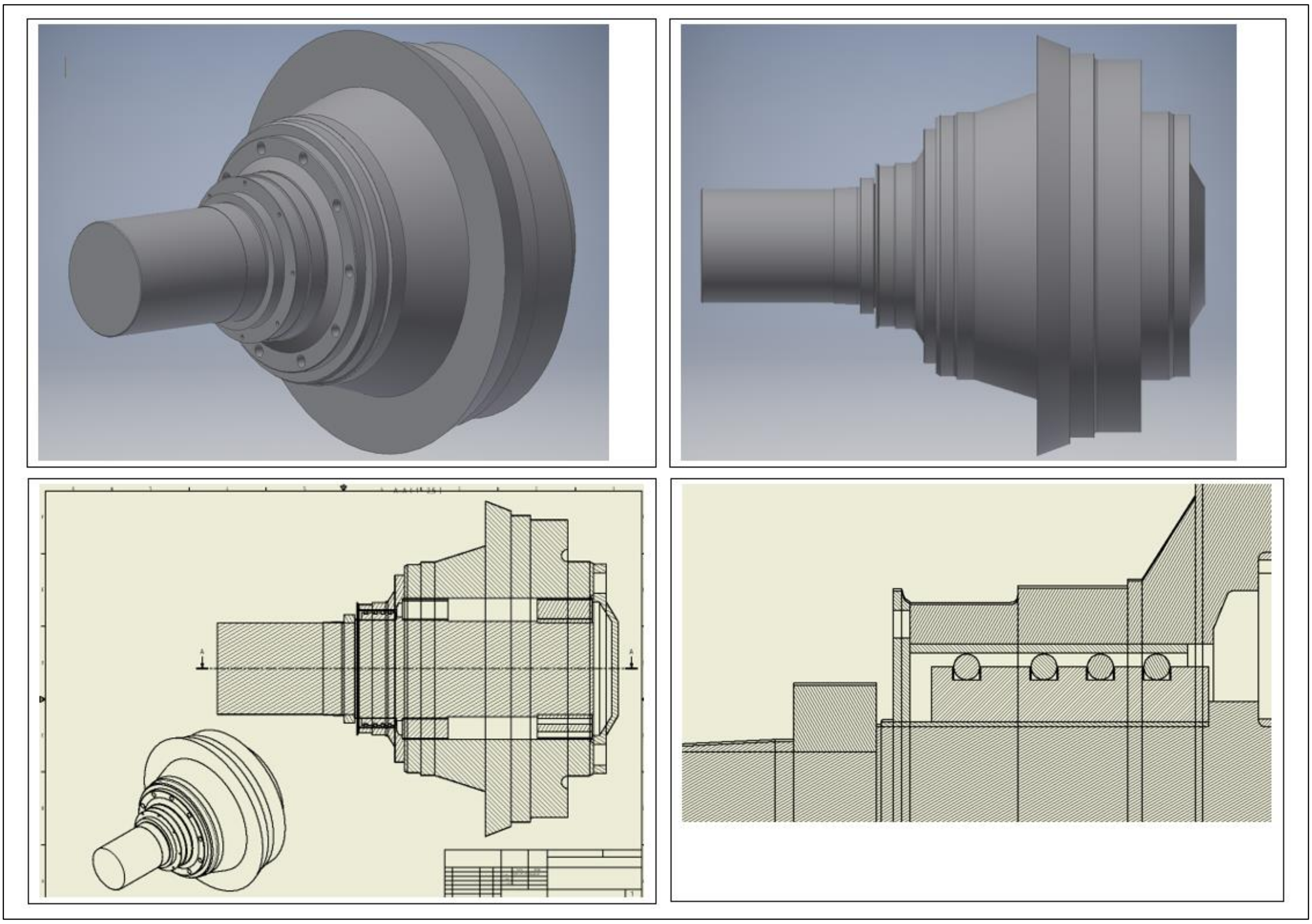


Figure 58. Concept 3 - Continuous O-rings.

Concept 3 is the first concept that departs from the original sealing mechanism. Instead of a single lip seal, the idea is to implement a number of O-rings. A ring with fitted glands is slid onto the shaft and mounted. The O-rings position themselves in the glands. A plate made of a material that supports the frictional requirements of the chosen O-rings and lubrication is mounted on the "roof" inside the sealing mechanism where the O-rings contact the lid. Apart from the O-rings, a single strip of rubber seal long enough to cover the base of the sealing mechanism is slid under the O-ring gland ring all the way out to where the original lip seal made contact with component 13 from figure 17, the sealing ring. The strip of lip seal is by that punched between the shaft and the O-ring gland ring, as seen in the lower left figure of figure 58.

4.4 Concept 4

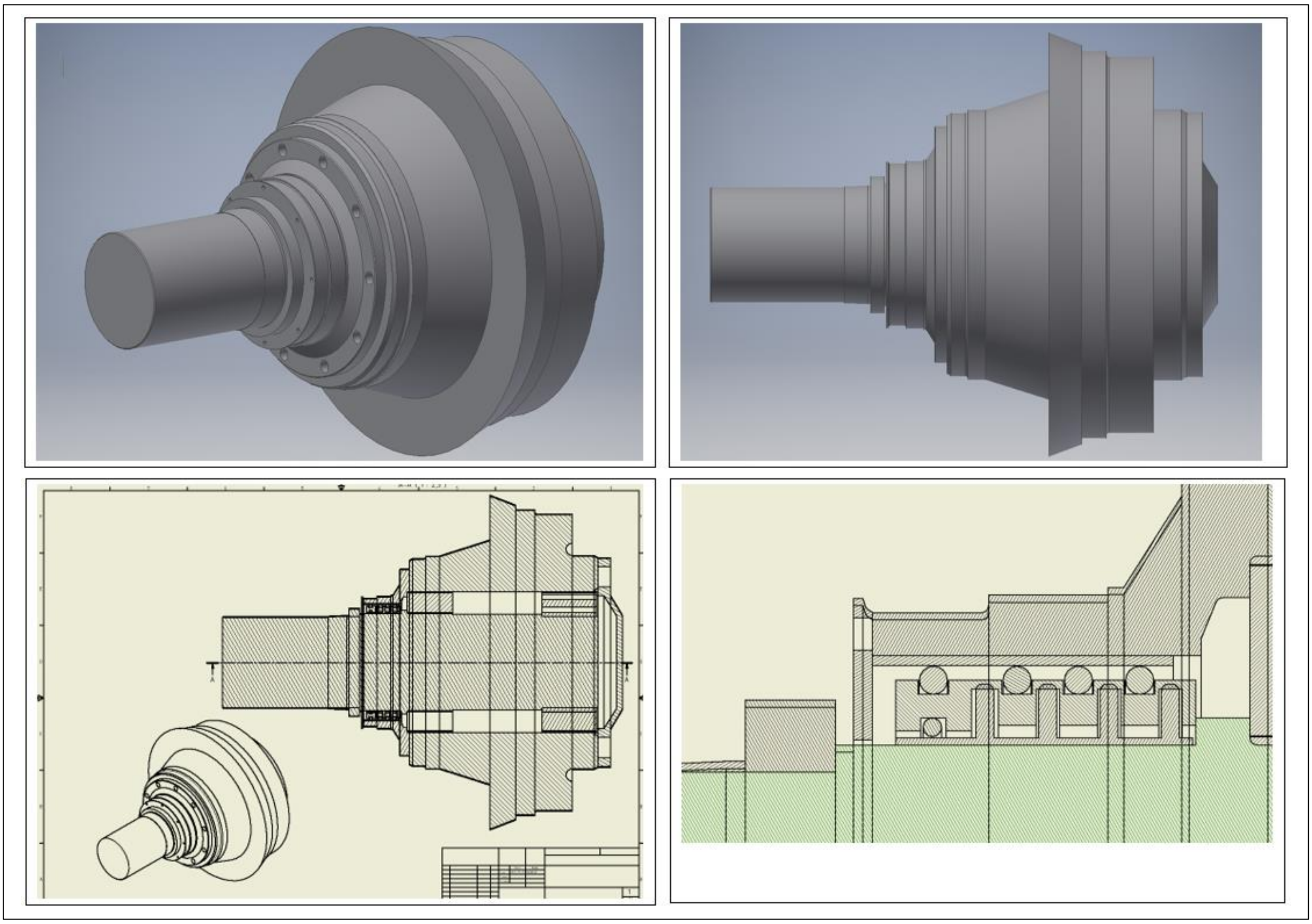


Figure 59. Concept 4 - Continuous O-rings with a spring system.

Concept 4 is much like concept 3 in regard to implementing a number of O-rings instead of a single lip seal; however, with a couple of major differences. Instead of having the O-ring gland ring be solid, the under part of it will be drilled to fit a set of springs going around the shaft. A plate with springs attached is fitted under the O-ring gland ring instead of the long lip seal from concept 3 and sealed using another O-ring.

4.5 Concept 5

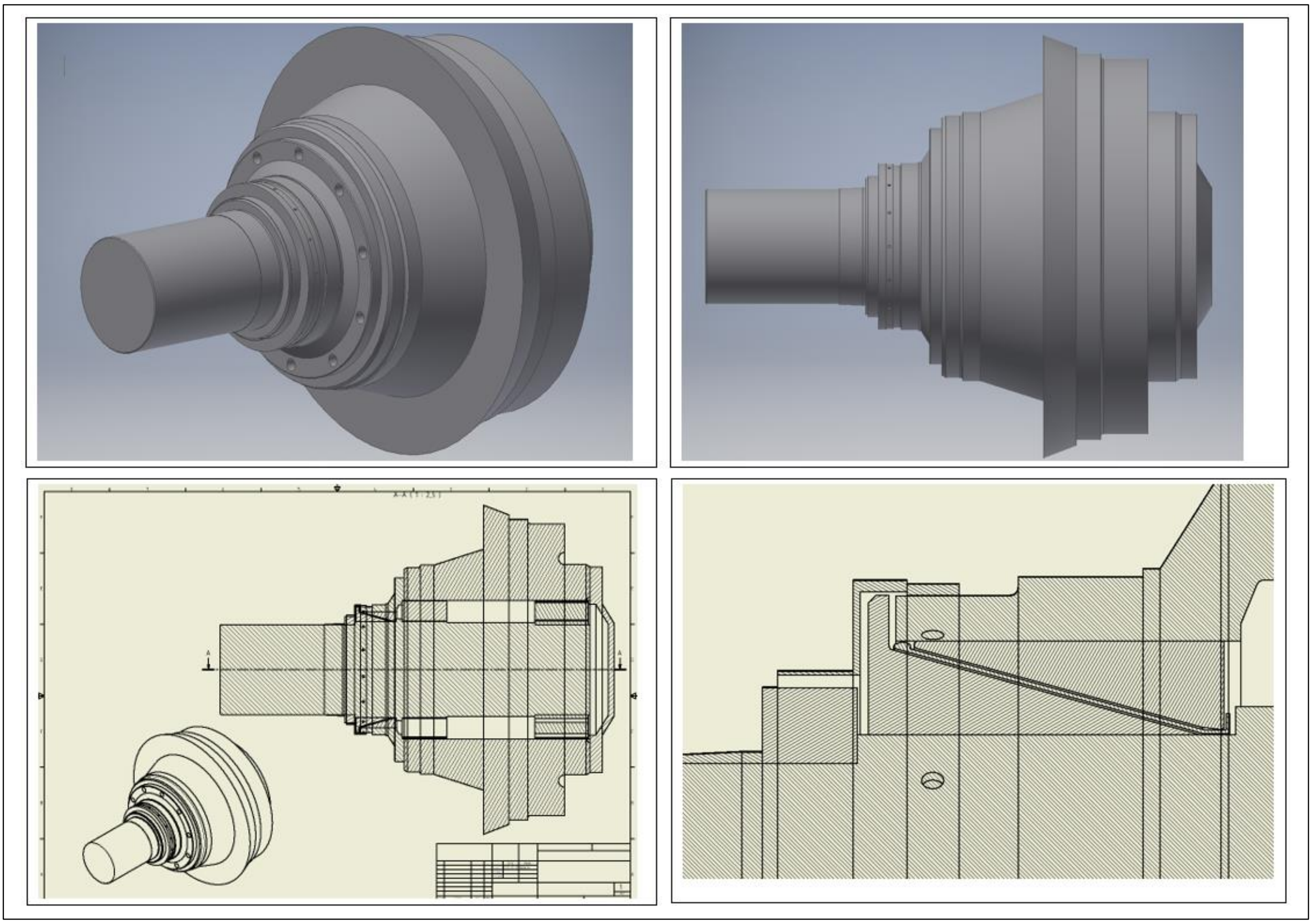


Figure 60. Concept 5 - Diagonal lip seal

The idea for concept 5 is placing a very fine rubber strip diagonally between two fine surfaces with a small clearance that allows lubricants to travel. Once again, a positive pressure of lubricant is necessary for this concept to function properly. The difference here is that there is a larger contact area, which, in theory, should make it difficult for invasive material to penetrate all the way into the bearing. Also, a protective barrier is mounted on the lid, as shown in the lower-left figure of figure 60, to protect the rubber from thermal degradation further. The top end of the rubber strip is formed like an O-ring to act as the first layer of sealing.

4.6 Concept 6

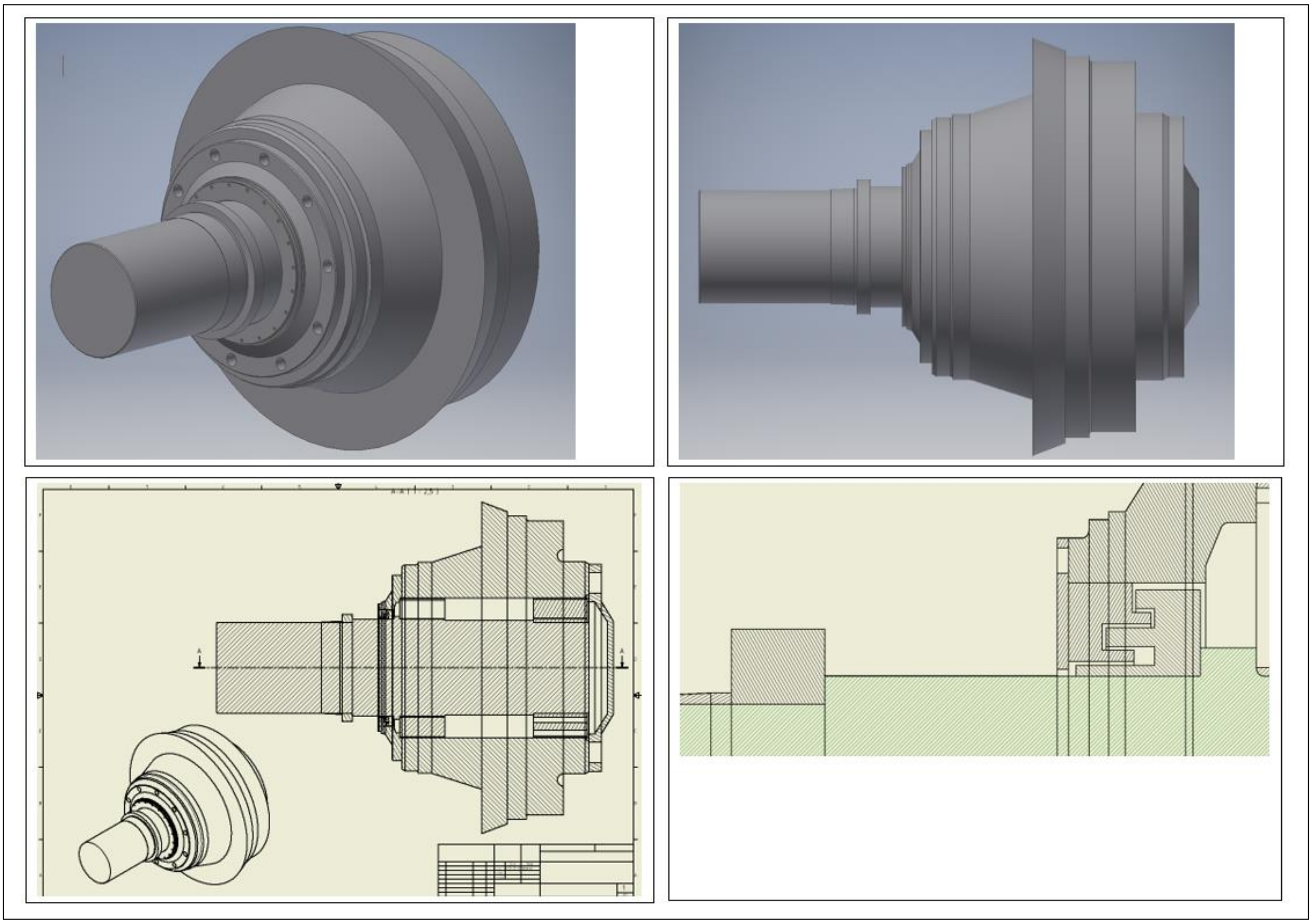


Figure 61. Concept 6 - Labyrinth seal.

Concept 6 is heavily inspired by the standard sealing mechanism of the non-contact labyrinth seal, as seen in figure 61. The outer lid of the grinding roller had to be shortened and adapted to fit the new seal.

4.7 Concept 7

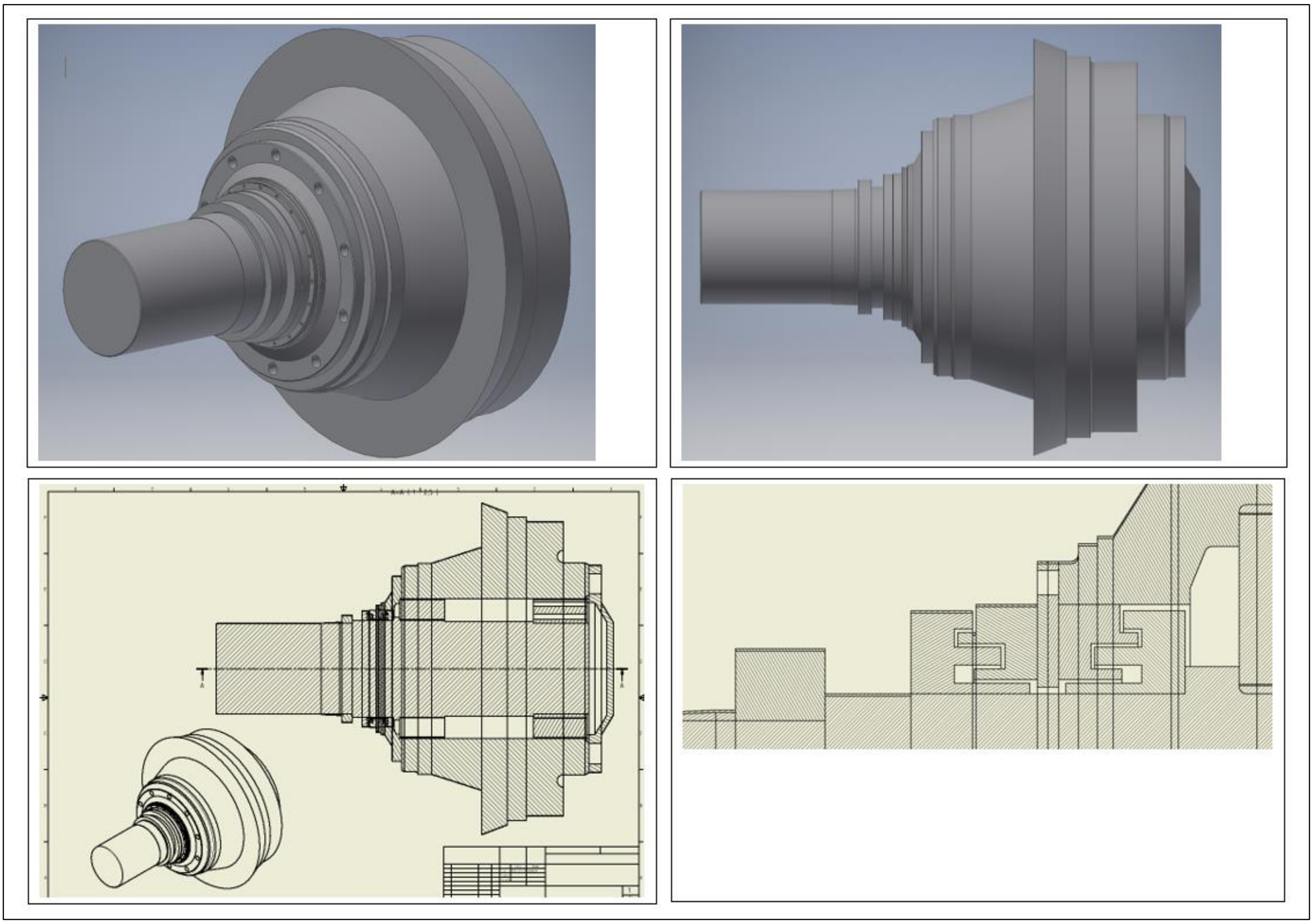


Figure 62. Concept 7 - Two-layer labyrinth seal.

Concept 7 also draws heavily from the standard labyrinth seal. However, in this version, the seal is mirrored to create another layer. This makes the path in which invasive material has to travel a lot longer while maintaining the integrity of the functionality of the non-contact aspect of the seal.

5 ANALYSES OF THE CONCEPTS

5.1 Concept 1

This concept might be considered simplistic as it is not very revolutionary. It is a simple change that could potentially have major benefits to the prolonging of the seal's life cycle while not sacrificing the integrity of the original sealing mechanism. The clearance inside the barrier, when perfectly adapted to the actual dimensions of the roller, could be filled with lubricating grease and, with continuous pumping of grease, create a positive pressure of lubricant from outside the grinding roller. The bearings would, in this case, not have to be overly filled with lubricants for the purpose of positive pressure, as this creates further problems with the functionality of the bearings when the temperature is heightened, as mentioned in the problem defining sections of the thesis. The positive pressure of lubricant is limited to the relative outside section of the sealing mechanism. This should make it harder for invasive material to penetrate the lip seal as they would have to penetrate the flow of lubricating grease first, which in theory should be impossible due to the continuous pumping. Also, the lip seal will then almost always be sufficiently lubricated, both from the inside and the outside, and continuously cooled by the new lubricants being pumped. A problem with this concept, however, is maintaining a proper pumping action not to promote excessive leakage. It is worth noting once again that minor leakage is acceptable since the high temperatures and the conditions within the raw mill basically evaporate the leakage.

5.2 Concept 2

Concept 2 also acts as a protective barrier for the original sealing mechanism. However, instead of the pumping action from concept 1, the idea is to introduce another layer of sealing. It was chosen to implement an O-ring in this case as the first line of defense to take advantage of the curved groove already existing on the outer lid, as seen in figure 56. Of course, the groove would have to be processed accordingly in order to function correctly with the O-ring. The process would include smoothing out the rough edges to make a fine surface for the O-ring to operate as to reduce friction and maintain a proper lubricating film. When it comes to lubrication, a similar approach to concept 1 will be taken. By filling and pumping grease inside of the clearance to create a positive pressure of lubricants, a similar effect to concept 1 will be achieved, but in this case, with reduced leakage due to the intentional sealing. A problem with this concept, however, is that since the barrier and O-ring are fixed and are making contact with a rotating surface, the outer lid, potentially big stress on the part, could arise if the assembly diameters aren’t perfectly fitted. This stress could result in breakage of the part. The broken material would then be accidentally ground under the grinding roller together with the raw material resulting in raw material contamination.

5.3 Concept 3

This concept is a full departure from the original sealing mechanism. The first line of defense would be the rubber strip on the bottom of the mechanism that would act very similarly to the lip seal in the original version. However, a problem with this could be the fact that there are no springs that will give the rubber strip the same level of flexibility during operation. This will, with time, most likely result in significant wear on the rubber strip, which is why there are O-rings implemented. The idea for having multiple O-rings is that if the rubber strip should fail or if one of the O-rings should fail due to any reason, then there would be a number of them left to keep up the sealing. This would, in theory, at least postpone total failure until the next maintenance session. Another potential problem is the increased friction surfaces due to the number of seals in place. However, the idea is also to pack the clearances inside the mechanism with a lubricant which should keep the O-rings properly lubricated. This, in conjunction with the “roof plate” made of a material that decreases friction, could make a significant impact on the lifetime of the mechanism. Another essential factor for this concept to function correctly is that every component has to be perfectly fitted in order to eliminate unwanted clearance gaps that could result in negative consequences such as increased vibration. Also, even though the O-rings are free to move axially, a perfect fit will aid in, with the O-rings being fixed with no flexibility, relieving the pressure from the rotating outer lid that could otherwise result in irreversible compression of the O-rings.

5.4 Concept 4

Concept 4 is, as mentioned, very similar to concept 3 except the rubber strip being replaced by a spring system. The purpose of the spring system is to give the O-rings an increased level of flexibly when being pressured by the rotating outer lid in a radial direction while having the same freedom of movement in an axial direction. The pressure on the O-ring sealing surface would not be determined by the outer lid but by the pressure determined by the spring system. This would, of course, have to be carefully researched and calculated to achieve optimal pressure between the O-rings and the sealing surface of the sealing plate. A problem with this concept, however, is the sealing of the spring system itself. It was opted to use another O-ring to seal the system from below, as seen in figure 59, but this isn’t the most optimal since it would interfere with the functionality of the springs closest to the spring-sealing O-ring. The spring system would, in this case, tilt inwards as the O-ring would be somewhat in the way resulting in an uneven sealing mechanism. This could be mitigated by applying a more substantial spring force at the back of the mechanism to compensate for the O-ring being in the way at the front. This would, however, mean that the spring system might be made redundant as it perhaps would become as rigid as its counterpart in concept 3. It is tough to tell how these relations might behave in a real situation. Further testing is required.

5.5 Concept 5

Concept 5 is unlike any standard sealing mechanism and is as such completely revolutionary. This, in turn, means that it can be considered as extremely unreliable due to it not having gone through any type of testing before. The idea behind it is creating a more extended contact area to make it more difficult for invasive material to penetrate their way into the bearings. A long piece of rubber strip is placed between the diagonal surfaces. The larger contact area, however, means more friction and heat buildup inside the sealing mechanism. This would have to be mitigated by applying an increased amount of lubricants. Which luckily is the main selling point of the concept. A small clearance between the contact surfaces would continuously be lubricated by once again promoting a positive pressure of lubricants. This will maintain a steady lubricating film while cooling down the contact surfaces from the frictional heat buildup. The increased rubber volume would then compensate for the potential wear that could occur in some points of the sealing area while the outer barrier protects the rubber from outside heat and blasting from invasive material.

5.6 Concept 6

The idea for concept 6 is, as mentioned, inspired by the standard labyrinth seal. It is unsure about how a non-contact seal would act in an environment such as raw mill 7th. Since the labyrinth seal is mainly implemented in high-speed rotational equipment, it is unclear how it would adapt to a relatively slower and bigger machine as raw mill 7 and if it will perform adequate sealing action. The clearance inside the seal should, in this case, be further calculated to compensate for the axial and radial movement caused by the grinding operation. This would preferably have to be tested in a digital environment first to see if it could hold up before testing it physically. Since the labyrinth seal is designed to withstand harsher environments, with little to no wear on the components because of the lack of physical contact during rotation, it stands to reason that this standard sealing mechanism could be a great upgrade to the grinding roller of raw mill 7 if adequately tested. Furthermore, as seen in figure 61, the labyrinth seal would take up a lot less space than the original sealing mechanism. This leaves some room to actually build upon the concept by, for example, implementing some sort of regular rubber-based sealing mechanism in the front area. The grinding roller would then have room for two sealing mechanisms acting in conjunction with each other.

5.7 Concept 7

Concept 7 is also a labyrinth seal, but as mentioned, it's a different take on the non-contact seal. The mirrored labyrinth is a purely hypothetical concept with no basis in reality. However, when keeping the dimensions of the grinding roller as close to the original sealing mechanism as possible as not to interfere with the integrity of the grinding roller, it stands to reason that a larger machine such as raw mill 7 could benefit from a larger labyrinth seal. And as the seal is a non-contact seal, then there would be no frictional problems or otherwise. The idea would also be doubling the distance that invasive material has to travel in order to reach the bearing, which is highly unlikely since the cavities within the seal would be filled with lubricants keeping the material invasion at bay through the controlled laminar flow of lubricants.

6 DISCUSSION

6.1 Lip seal failure

The study published by Eindhoven university of technology, presented in the literature section of the thesis, was made in 1988, and one would expect that a significant technological advancement has been made since then when it comes to many mechanical achievements other than the specific field of sealing technology. However, these findings still have implications in today's sealing mechanisms since, for example, raw mill 7 was commissioned in 1970 and hasn't changed much since then. This could be the case for many similar machines around the world and, as such, could potentially benefit from the information until a significant upgrade is made that would make the information redundant. The information in the study doesn't come in surprise since it's all more or less common sense. But none the less, the data is essential for understanding the parameters in which the sealing mechanism has to operate within to become more reliable and efficient.

When it comes to the cruciality of applying proper mating surfaces in order to increase the longevity of the lip seal, it is crucial to conduct appropriate maintenance not only on the sealing mechanism but the shaft on which it is situated and make sure there are no misalignments when installing. Other than improper installation, shaft and component imbalances could be the effect of inaccurate manufacturing. It is, therefore, essential to keep track of future changes that could arise in dimensions of the part due to thermal expansion or other factors when ordering new spare parts.

When looking at the findings in the literature section, it becomes apparent that a change in sealing rubber is a smart way to at least prolong the life cycle of the mechanism. The rubber might not be holding up due to incorrect estimations of operating temperatures in the machine and should, as such, be replaced with a more durable one. It is, however, not smart to assume that a change in rubber will solve the problem. It is essential to explore all angles of the problem to at least assume with acceptable accuracy. This is why a problem tree has been drawn up. Merely changing the rubber material could prove to be insufficient when looking at the broader picture. Perhaps today's sealing mechanism as a whole isn't the most efficient? It was commissioned in the early 1970s, after all. Maybe a new type of sealing mechanism is needed instead of merely changing one single component in the hopes of solving the problem.

When speaking to factory managers and workers, the most common topic of conversation with regards to failure mode is that the lip seal isn't enduring as long as it's needed. The problem seems to always shift in the direction of the lip seal, and all of the blame is put upon it. However, it must be realized that it isn't as simple as that. That no matter the change in lip seal material in the hopes of mitigating the problem will result in increased longevity and with a high likelihood will just result in the same issues happening over and over again. This is mostly due to the nature of the design of the grinding roller, which seemingly didn't take into account the hot gas flow that is situated right under the sealing glands. This all points toward the need for a completely different design in the sealing mechanism.

6.2 Tribology

The bearings of the grinding rollers in raw mill 7 are originally designed to operate with oil-based lubrication. However, this was changed to grease after the oil had leaked out onto the raw meal in the machine. This is most likely due to the poorly performing seals, so it is hard to draw the conclusion that the oil used had been wrongly selected. Especially since, and according to workers operating raw mill 7, the original oil had been recommended by the supplier of the machine, namely Loesche. The change to grease proved to be quite efficient for a while, but a negative trend started to appear not long after. The foreign material infiltration the seals and entering the bearings began to thicken the grease beyond the thickness; it was meant to have causing pressure on the seals and clogging the bearing till failure occurs. Cementa AB does have aspirations to be able to change back to oil-based lubrication if a functioning concept is implemented.

Figure 31 shows the state of the grease lubricant once the roller had been disassembled during a maintenance session. However, this does not mean that grease should be put aside. Perhaps the grease that is used isn't the correct type of grease for the application? Maybe the factory opted to use a cheap kind of grease instead of selecting one that can handle the situation? At least for a more extended period of time.

When reviewing the information in the study from the literature review section of the thesis, the question arises on whether or not grease-based lubrication actually needs to be replaced in the roller bearings within raw mill 7. The study described grease as such an excellent lubricant and makes an arguably great case for it, keeping in mind that not all information was presented above to respect the already established scope of this thesis. With raw mill 7 in mind, is it merely a matter of wrong selection of grease type? Perhaps the grease that is used is actually of good quality, but the performance is hindered due to the excessive amount of foreign material that is infiltrating the bearing? If this is the case, then once again, the design of the grinding rollers sealing mechanism is at fault for allowing the material to infiltrate. Assuming that the grease today is of standard performance or better, one could assume that upgrading the design of the sealing mechanism would benefit and benefit from the lubricant used, be it grease or otherwise. So why would one choose to change to oil-based lubrication apart from the established problems and potential benefits presented in the introduction chapter of this thesis? To answer this, understanding the difference between oil and grease is important, which is why this was studied.

With the main problem in mind, the choice of grease or oil can seem irrelevant at this point due to the problem causing issues for either lubricant when implemented. If a solution is generated that rounds out the problem and mitigates foreign material infiltration within the bearing, a selection process of optimal lubricant might be a good step in ensuring the maximum operating optimization of the grinding rollers of raw mill 7.

6.3 Harsh environment

The study on wear for raw mill 8 has very strong implications in this thesis as well, because of the similarities of environments in which raw mill 8 and raw mill 7 operates. Just as in the case of raw mill 8, abrasion could very well be a contributing factor for the wear on the sealing glands in the grinding roller as well as the seals themselves. This could perhaps mostly be due to the layout of the grinding roller in relation to the milling tables' gas entries. As mentioned, the constant flow of gas continuously attacks the sealing glands and makes it easy for the invasive material to attempt penetration of the seals.

Once again, it seems that the design of the grinding roller, or more specifically, the grinding roller sealing mechanism might be a factor for failure mode in regard to the harsh environment within the raw mill. Since the glands are exposed, it begs the question if the design really is as optimal as one might think. It is, however, difficult to draw this conclusion based on an assumption with the indicator being the visual representation of figure 18, for example. The assumption is, however, an educated one and very likely to be accurate just by imagining the situation within the raw mill and in conjunction with the already confirmed problem of material infiltrating the seals. So, how does one attempt to verify that the design flaw exists?

Well, there might be some ways that one could attempt to try and confirm a design flaw I the grinding roller. The idea is to conduct an experiment while the raw mill is active. One could spray some dissolvable, non-contaminating paint into the raw mill. The material within would then get coated with the paint. When ground, the material flows upwards in the previously mentioned hurricane, and the painted material would then move and bounce as it naturally does, but this time, leave paint stains all over the insides of the machine. After a while, the machine is stopped and examined. The areas where most paint is located are then the areas that are most vulnerable to wear and abrasion. But in the case of the seals, the only thing needed through this experiment is confirmation that the grinding roller glands aren't protected enough. In theory, this might be a good experiment. But there is a range problem with this idea as well. Because of the high temperature inside, the paint might end up completely evaporating and leave no trace at all. Also, with a high probability, a large amount of paint would have to be injected to make a significant mark provided that the temperature isn't an issue. So even if the paint is non-contaminating, the sheer amount could result in fluctuation in batch quality. It is, however, an interesting thought.

On the other hand, the problem with the sealing glands being exposed to the harsh environment could also perhaps already be confirmed without having to experiment since failure mode is reoccurring at a high rate. It does, at this point, not have to be an assumption anymore that the sealing mechanism and the grinding roller both have an impending need for redesigning if the failure mode is to be eliminated or at least postponed.

6.4 Vibration

One would assume that vibrations could be a contributing factor to failure mode in raw mill 7. However, as it stands, very little information about the vibration in the machine could be apprehended throughout the project. Based on the studies conducted, the age of the raw mill could play a significant role in vibrational aspects that could be considered unacceptable or detrimental. It is unclear, however, if the vibrational fluctuations that contribute to failure mode are because of the surrounding complementary equipment to the grinding roller, such as the grinding roller holders and the milling table, or due to the inner components of the grinding roller, such as the bearings. It is naïve to assume that the problem has to lie in one or the other, without considering the fact that the problem could lie in the combination of all factors. Simply put, that the design of the grinding roller as a whole could be significantly inefficient at this point due to its age when comparing to newer models on the market. When it comes to the sealing mechanism, it is also unclear if an upgraded mechanism will halt vibrational fluctuations or if the grinding roller generally is in need of an upgrade.

Another important factor is, as previously studied if the assembly of the grinding roller is as accurate as one might expect. It stands to reason that a machine such as raw mill 7 and its grinding rollers that have been around for some decades must have maintenance workers that know all the ins and outs of its components. These workers, by experience, surely have the ability to detect if, say, the bearings aren't correctly aligned within their chambers or if there are imbalances on the shaft that could potentially be harmful to the operation of the machine.

Furthermore, it is interesting to note that the factory has a system in place that monitors vibration in the raw mill. Figure 63 illustrates a vibrational anomaly in raw mill 7 before an impending failure mode. In this case, it was detrimental damage to one of the inner-ring components. What component was, in fact, damaged was concluded after the fact as there is no way to tell while the machine is in operation.

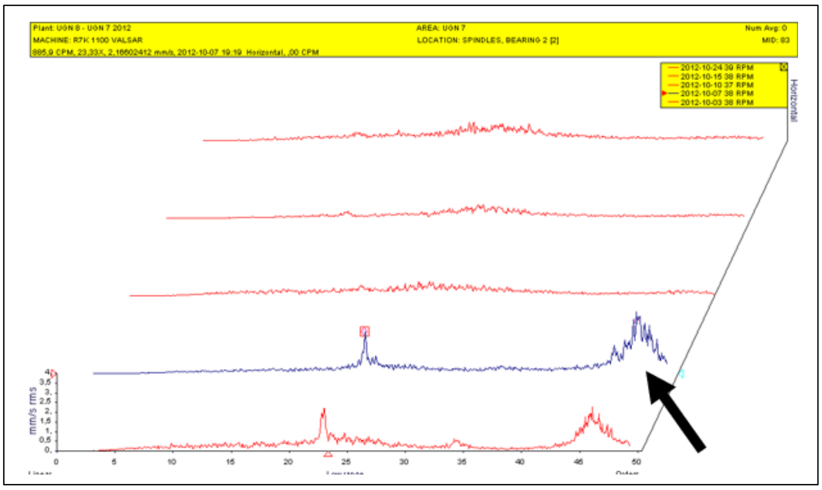


Figure 63. Vibrational anomaly in raw mill 7.

6.5 Bad overall sealing construction

Because of the frequency of failure mode, the assumption was drawn up during the formulation of the problem tree that the overall sealing construction of the grinding rollers within raw mill 7 is insufficiently optimized. The machine, as previously mentioned, was designed and commissioned in 1970, which by today's standards and technological advancements, might be considered outdated. As backed up by the conducted literature studies and analysis of the problem branches, most of the underlying problems seem to stem from a sort of design flaw or a lack of mechanical robustness needed to be able to handle the conditions within the raw mill. The tolerances might be too high with poorly fitted details that do not allow for efficient sealing. This, however, would have to be further researched in a focused environment in order to achieve proper confirmation of faulty construction with detailed data suggesting the former or proving otherwise. Either way, it is safe to assume that a significant change is needed in the overall construction to be able to uphold a sustainable sealing environment for a longer period of time since, for example, changing only the Lip seal rubber material might prove to be a fruitless endeavor if the environment it is placed within remains identical. It would be like changing the tiers of a car that can barely reach a couple of miles before breaking down. There is no point. It is at that point just better to upgrade or buy a new car instead.

The studies made on the problem tree and its problem branches all point towards the need for significant change in sealing mechanism. This does align with Cementa ABs' expectations for the project, as mentioned in the scope defining section of the thesis. A simple change of rubber material for the lip seal is simply not enough in this case, as presented in the study. Therefore, the decision for an attempt at redesigning or upgrading the current sealing mechanism was made and conducted.

6.6 Failed concepts

When conducting the practical modelling of the revolutionary conceptual designs, many of the concepts generated were deemed as failed or insufficiently designed. This was due to many different reasons depending on the concept that was generated. For example, in figure 64, where a horizontal labyrinth seal was created but later found to be a bad idea. There seemed to be no realistic way to mount the pieces and components of the seal, as seen in figure 64 in an actual real-life assembly. Since the labyrinth texture is of an overlapping nature, it is practically impossible to slide the components in place without interfering with the other, and in this case lower, components.

Another example is seen in figure 65. The idea was to create a spring-based sealing system where a "club-like" components made of rubber would be mounted on the inside top part of the outer lid. The club would then, in conjunction with the outer lid, have a rotational contact with two separate surfaces. One surface below the club and one surface to the left of the club with a spring system radially and axially respectively. This would, in theory, have made the rubber club extremely flexible with respect to shaft and lid movements in radial and axial directions while always maintaining proper contact with the rubber club since the springs in from both directions would force the contact. It's worth noting that the radial spring system is naturally protected against invasive material by the rest of the mechanism, while the axial spring system is sealed by an O-ring. Furthermore, as a protective measure, an extra piece of the protective layer would be mounted on the outer lid with a small clearance that would act as a non-contact protective barrier for the whole sealing mechanism. This, in theory, seemed like a good idea but is way too demanding dimensional-wise with a lot of factors that could potentially go wrong. The risk was then higher than the reward, and finally, the idea was scrapped on the basis of having too many non-accounted risk factors.

There were more revolutionary ideas like these two that were created but ultimately scrapped for similar reasons. One of the primary reasons being an overly ambitious take on a sealing mechanism with no real basis on realistic implementational potential.

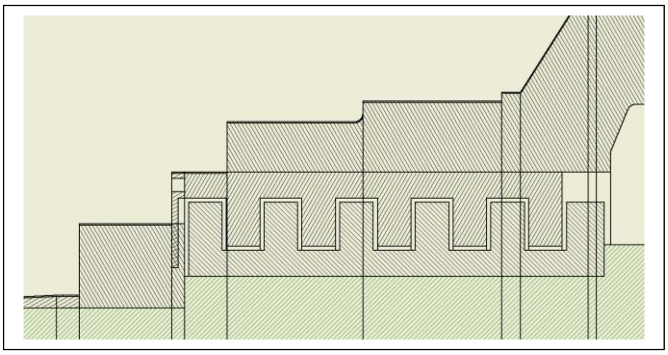


Figure 64. Horizontal labyrinth seal. (failed concept).

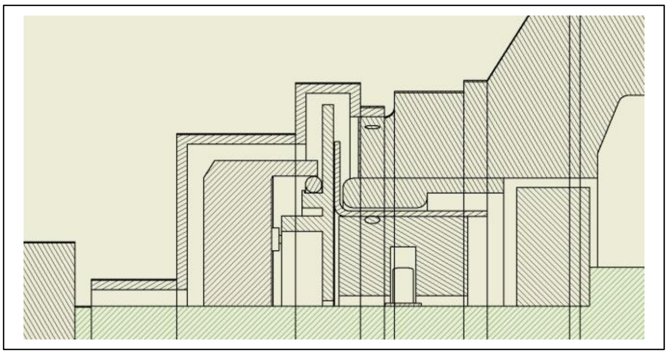


Figure 65. Spring powered sealing mechanism (failed concept).

6.7 Canceled research

During the project, many ideas for research were initially planned but ultimately were canceled due to many different reasons. One major research that was canceled was a field trip to the annual maintenance summit in Göteborg. Which is one of the largest maintenance summits in Europe were many different suppliers and manufacturers of, among other many things, sealing equipment. This was very relevant for the thesis study at the time of project planning. However, this field trip was canceled due to the outbreak of the novel coronavirus, Covid-19. The purpose of the field trip would have been speaking and interviewing the suppliers and manufacturers that specialize in sealing technology. Some of the companies that were attending are LockTech, Lundgrens Sverige AB, Nomo, Erasmis AB and protoma. All these companies specialized in mechanical sealing. The interviews would have given a broader understanding of the selection of sealing mechanisms that exist in the world, and perhaps some tips could have been gathered for the conceptual generating phase of the project. What defines a suitable sealing mechanism? Which is the central question that was aimed to be formulated in different ways in the hopes of receiving constructive answers that would aid in both the study phase of the project and the practical phase.

6.8 Revolutionary vs. standard

It was at first a very overwhelming task to make a choice with such a level of freedom as to when given the freedom to choose between either generating revolutionary concepts, being inspired by standard concepts, or merely selecting from a range of standard concepts. Because of the problem of failure mode being of this magnitude with real consequences for the company, it was imperative to explore both options, not to actually implement one of the generated concepts, but to give a perhaps much-needed inspiration towards the upgrading of the sealing mechanism that eventually constructors could potentially benefit from when taking on the task of replacing the older sealing mechanism.

When exploring the strengths and weaknesses of both revolutionary and standard concepts, it is clear that both have somethings, all be it different things, to offer in terms of technological advancements. Revolutionary concepts cater to creative thinking and invention. The inventing process could potentially have led to a solid concept that, if functioning, could have been patented, implemented, and eventually sold. Standard concepts cater toward immediate viability when perfectly adapted to the machine in need if an upgrade, in this case, raw mill 7.

Further strengths of a revolutionary concept are the interest peaking factors that all new inventions have in common. A uniqueness that could be capitalized upon and redistributed. Of course, Cementa AB is not a redistributor of that sort, but still, the concepts could have been passed over to the responsible people. Another strength is the privilege to explore new ideas and contribute to the technological advancement within this genre. Since the art of sealing has been studied for over 100 years, it stands to reason that it should be investigated further with the hopes of contributing to the advancement. Inventing a mechanism is then a good way of contributing. The most underlying weakness of generating a revolutionary concept is the fact that it's extremely unreliable due to the lack of testing and experience. It is, therefore, hard to foresee the viability of the invention and might, with all rights, even be considered a waste of time if the established given problem needs immediate mitigation, which unluckily is the case for raw mill 7^{th} grinding rollers.

When looking further at both the strengths and weaknesses of standard sealing concepts, it is apparent that the strength largely outway the weaknesses. The concepts have been tested and verified with perhaps years of experience in the field, which has deemed the concept viably in most cases. Or else, the concept would have been discontinued a long time ago. The standard concepts would most likely also have had years of development before hitting the market, which is a crucial factor in any given invention. Standard is also relatively easy to implement since the sealing mechanism would be ready to be shipped, assembled, and mounted on the grinding roller by the distributor in a very short amount of time. Provided, of course, that the standard mechanism is compatible with the specific machine such as raw mill 7. Compatible in the way that it takes into consideration all factors that could have an effect on performance, such as all the problems presented in this thesis. Weakness wise, it seems as though there are no immediate weaknesses since even if the new standard should fail, Cementa AB would simply contact the distributor and troubleshoot the problem.

It is important to remember that all standards have been revolutionary at one point in time or another. This means that revolutionary thinking shouldn't be discouraged but enforced.

7 CONCLUSIONS

7.1 Actions that could potentially aid in postponing failure mode

As is stands, the original sealing mechanism has a lot of flaws in the sense that it doesn't seem compatible with the environment in raw mill 7. Some flaws are inherent, while some are situational. Expecting an action that would completely prevent total failure is futile when excluding the potentials of upgrading the sealing mechanism to more sustainable design. However, just because prevention is out of the question doesn't mean that certain actions won't potentially be able to aid in postponing failure mode. Some failure postponing actions could be:

- Check that mating surfaces are aligned.
- Check for misalignments in components when disassembling as well as assembling.
- Check if dimensions are changed each time the mechanism is renovated so that proper proportions can be ordered for spare parts.
- Since the shaft isn't replaced during maintenance, check if there are shaft imbalances.
- Change the rubber material for the lip seal to a material more resistant to heat.
- Check with grease supplier if there are more heat resistant types of grease lubricants.
- Check to see if the temperatures inside the raw mill are up to standard.
- Check to see if there are better overall types of lubricants that can be used.
- Check to see if the chosen grease is sufficiently malleable enough with regards to bearing movement and if the lubrication routes inside the roller aren't clogged up.
- Examine the grease in the bearing once renovations are ongoing to research the level of contamination.
- Check to see if the amount of grease applied is over the limits.
- Check to see if the raw flour is already contaminated with foreign material that aids in seal penetration.
- Check to see if the bearings are correctly installed and aligned with the right tolerances.
- Mount some sort of protective barrier on the sealing glands to protect from dust and heat.
- Reexamine the quality of the grinding roller holders to determine if it is contributing to excessive vibration.
- Check to see if the milling table is correctly aligned with the grinding roller so that metal on metal friction isn't an issue and a contributing factor to vibrations.

Through the hypothesized problem tree in relation to literature studies, it can be confirmed that some failure postponing actions can be undertaken. These are, however, just suggestions, and reexamining the choice of sealing mechanism will most likely prove to be a more fruitful endeavor when aiming to achieve a semblance of total failure prevention.

7.2 Suggesting a concept for Cementa AB

While a revolutionary design might be a good idea if enough time and effort are put into perfecting it, it does not mean that it is the best idea for implementation within a machine that is desperate for an upgrade a soon as possible. In this case, raw mill 7th grinding roller. The timeframe for the thesis did not allow for thorough testing, theoretical or practical, and since the revolutionary concepts presented in the thesis have little to no basis in reality, the conclusion can be drawn that they are not an effective alternative for upgrading the sealing mechanisms. The case might be different in other applications, but in this specific one, a standard sealing mechanism is the most practical upgrade to implement right away. Of course, there are many factors that should be considered when attempting to implement a standard seal as for example, dimensional compatibility and so on.

The standard sealing mechanism suggested for implementing in the grinding roller of raw mill 7 is the labyrinth seal, as seen in figure 66.

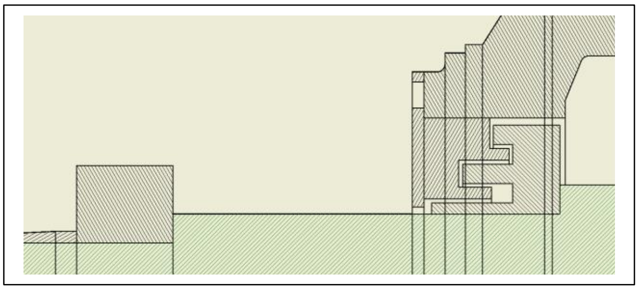


Figure 66. Standard labyrinth seal fitted to the grinding Roller of raw mill 7.

This is purely a suggestion for a standard design. There are many types of labyrinth seals the can be selected form on the market. With respect to the conducted literature studies on failure mode for raw mill 7, the labyrinth seal strengths compared to the original lip seal are:

- No rubber seal deterioration.
- Effectively retains lubricants with minimal leakage.
- Excludes invasive material.
- No frictional heat build-up.
- Clearance inside the seal remains non-contacting even with vibrations.
- Long life cycle due to minimal wear.

Some potentially negative aspects with the labyrinth seal are the fact that it is generally more expensive than a conventional lip seal. This is, however, made up by the long lifecycle of the seal. Also, since the labyrinth seal was invented with high rotation speed machines in mind, it is still unclear whether or not it is compatible with the grinding roller in raw mill 7.

8 FUTURE WORK

- Contact labyrinth seal manufacturers and start a discussion regarding the grinding rollers in raw mill 7
- Contact with other seal suppliers and manufacturers and ask their opining on the matter and if they have better suggestions than the labyrinth seal.
- Contact with Loesche and ask for their opinion on the matter.
- Determine what type of lubricant is best suited for the grinding roller while operating a labyrinth seal.
- Determine what to do with the freed space on the grinding roller, as seen in figure 66.
- Research about types of labyrinth seals that exist and determining what type is compatible with the grinding roller and its operating environment.
- Conduct theoretical experiments with the aid of computer software such as FEM and simulation-based programs.
- Create physical prototypes of the grinding roller with a labyrinth seal implemented.
- Once a standard labyrinth seal is chosen, adaptation in terms of dimensional accuracy with acceptable tolerances is conducted.
- Further research about seals in general.
- Continue with the revolutionary designing of concepts for sealing mechanisms. Not necessarily catered toward the grinding roller.
- If a labyrinth seal proves to be incompatible, research on better types of rubber material for the original sealing mechanism is conducted.
- Cost, budget and savings calculations for the potential upgrade.
- Try and implement oil-based lubrication once again.
- Design and implement a functioning oil-circulation.
- Implement an internal temperature thermometer to keep track of temp-spikes.
- Conduct experiments to determine where the wear inside the raw mill is highest.
- Full component check of every component in the grinding roller to see if there are inconsistencies.
- Find out what suggestions Loesche has for the upgrading of the sealing mechanism.

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APPENDICES

8.1 Appendix 1

3. Utförande

RKV 7 Renovering malvals

När valsen ligger i monteringshallen. Börja med att skära bort låsningarna till insexbultarna och demontera bultar och det inre lagerlocket. Montera låsklackarna mot lagret och montera lyftöglan axeländen.



Lyft sedan med bägge telfrarna och lyftkättingar för att vända valsen med axeltappen uppåt. Placera valsen på slipers över smörjgropen. Demontera axeltätningen. Skär bort låsningarna och bulta loss det yttre lagerlocket och demontera det. Fira ner en kätting genom hålet i axeln och lås lagerlocket. Bulta sedan loss locket och fira ner det i gropen.

3. Utförande



Lyft ur axeln ur valsen. Lyft bort valskärnan från smörjgropen och lägg den på slipers på golvet. Lyft ur den inre distansen. Skär ut bitar ur NU-lagret och skrota ur samtliga rullar.

Svetsa ordentligt runt i ytterbanan för att krympa lagret. Klyv sedan ytterbanan på flera ställen försiktigt med gas och vinkelslip.

Koppla lyftkättingar i öglorna i den yttre distansen och lyft försiktigt så att ytterbanan lossnar.


Ta bort låsklackarna från det koniska rullagret. När distansen är ur lägg i en plåt på ytterbanan på det koniska rullagret. Applicera två domkrafter och balk för att pressa ur lagret



(vid svåra haverier behöver ibland rullagret skäras ur med gas). Värm av inneringen och tätningsringen på valsaxeln. Rengör både axeln och valskärnan och kontrollmät lagerlägen innan montering påbörjas.

3. Utförande

Ihopmontering av malvals

Bulta ihop det yttre lagerlocket med NU-lagret och lägg i frysboxen i c:a 24 tim. Montera 2 gängstänger i valskärnan för styrning av locket vid monteringen. Stryk på kontaktytan på valskärnan med Hylomar universaltätning. Lyft lagret på plats och dra lätt emot bultarna.



Vänta tills kärna och lock har samma temperatur innan bultarna dras (900Nm). Vänd sedan valskärnan och lyft i den yttre distansen


Lägg ytterbanorna till det koniska rullagret i frysen under c:a 1 dygn. Var uppmärksam på placeringen i frysen då ytterbanor och rullager är märkta A och B. Montera sedan ytterbana A därefter rullagret och ytterbana B. Lägg i den inre lagerdistansringen och lås lagret med 3st låsklackar.


3. Utförande


Vänd runt valskärnan över smörjgropen. Fyll i fett i det koniska rullagret och lyft sedan i den inre distansen. Fyll sedan NU-lagret med fett.



Värm försiktigt innerbanan till NU-lagret och tätningsringen och montera på axeln. Smörj in axeltapp och lagerbana med fett och montera axeln i valskärnan.

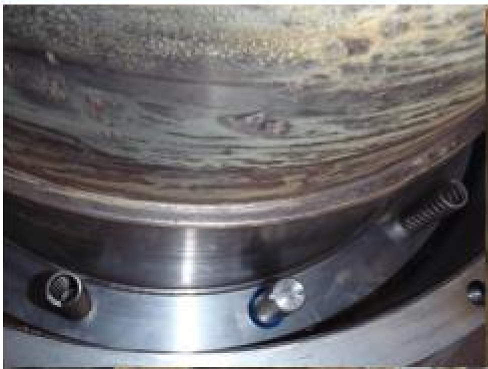


Sänk ner kättingen och fäst i korset och lyft upp axellocket på plats. Dra lätt fast locket. Vänd runt valsen över smörjgropen. Dra sedan axellocket med moment 500 Nm. Fyll upp lagret med fett och montera det inre lagerlocket med O-ring. Dra sedan locket med moment 900 Nm och lås bultarna med rundjärn. Spelet mellan lock och kärna skall ligga mellan 2-7 mm.



Lyft upp valsen ur smörjgropen och vänd den med axeltappen uppåt. Montera styrbultar och fjädrar i axeltätningen. Montera sedan hållarring, manschett, slitring och klammer.

3. Utförande



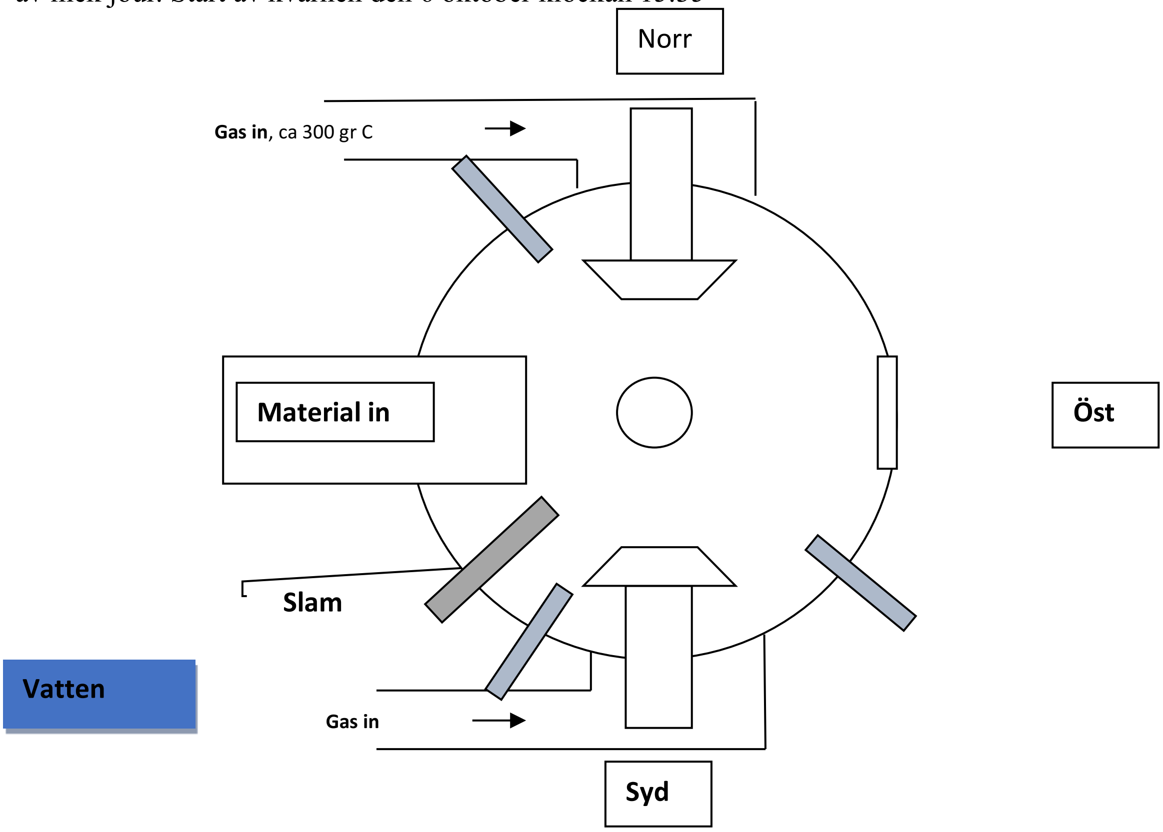
Tillverkning av distans/skyddsring

Skär ut en plåtring 500*385 mm i 50mm plåt. Ringen mäts in och bearbetas till rätt mått då varje vals är unik. Ringen monteras och valsen placeras i transportställningen.

8.2 Appendix 2

Sammanfattning

Klockan 01:30 morgonen den 6 oktober gjordes ett försök att starta kvarnen efter ett kortstopp, södra gick inte att snurra på, så beslut togs om urtagning och byte av vals, då denna hade fastnat, påbörjades av mek jour. Start av kvarnen den 6 oktober klockan 15:35



Incidentrapport / Fakta / Data

Maskindata

Råkvarnen av märket Loeche är från 1969.
KONISKT RULLAGER SKF 332 298 Kostnad; 165 947 kr

CYLINDRISKT RULLAGER NU 2276 ECMA/VA454 Kostnad; 88 204 kr

Vibrationsmätning

Vibrationsmätning av råkvarn 7's växellåda* görs både med on-line mätning som dokumenteras i IP21'an och med manuell vibrationsmätningsutrustning som mäts med TRIO portabla instrumentet. Man har på försök gjort mätningar på axeltapp med gott resultat som medförde ett byte av norra valsen innan haveri (år 2012), vid demontage upptäckte lagerskador som stämde med mätningen. Nya försök skall göras av SPM under hösten 2014.

*Obs att vibro från växellådan inte speglar vibro på råkvarnen på ett bra sätt. Vibrationsgivaren mäter ca 1 mm/s för litet jämfört med våra portabla instrument samt frekvensområdet troligen mellan 10 och 2000 Hz som var vanligt på de gamla. Vilket innebär att när det vibrerar från råkvarnen så tar inte givaren dessa vibrationer då de är av lägre frekvens, dock kommer övertoner från det lågfrekventa med men de är av lägre amplitud. Betyder ändå att de faktiska slagen som genereras från malbord leder sig ned till växellådan och på sikt kan förstöra oljefilm och därmed lager.

Senast byte till befintliga i drift TACKE växellåda år 2011-06 pga. ett haveri på RENK-lådan

Process

Om temperaturen stiger till över 110 gr C så dyser vatten in, om det inte hjälper trippar kvarnen vid 140 gr C. Denna temp är efter kvarn på gasledning uppåt.

Kvarnen värms upp till 90 gr vid uppstart, vid stopp kan tempen vara upp till 150 gr (Temp efter kvarn). Temp in till kvarn vid drift upp till ca 350 gr. C.

Kvarnen går ca 6300 h/år i snitt (Hämtat från åren 2007-2013. Se IP 21 tagg; R7K1100_HY)

Mekaniskt

Drifttid på södra vals från montage till detta haveri; ca 1340 h.
Ny rek. fettmängd efter att tidigare RCFA utredning gav att det var för mycket fett, är ca. 400 gram varje månad, eller var 14 dag ca 200 gram. Man bytte fett från Limona LX 2 till Stamina HDS 2 som är ett mera tåligt fett gällande slag, vattentåligt samt tål max 160 gr C. Fettanalys 2014-05 gav att det var som väntat förorenat med mjöl, samt vatten, i kombination inget vidare. Man bör ta fettanalys innan haveri inträffar.

Orsak & Verkan

Troliga orsaker till detta stopp kan vara, var för sig eller i kombination;

Föroreningar; Tidigare RCFA gav att det vid demontage var kraftigt överfyllt med fett som tryckte sönder tätningen därav bestämdes det att gå ned med mängd vid smörjning. Fettanalyser har tagits efter haveri vilket inte är bra då man inte vet om föroreningar kommit in före eller efter haveriet, men de visade på kraftigt förorenat fett, både från råmjöl men även från vatten, detta i kombination ger en gegga som fettet inte tycker om även om Stamina är vattentålig till viss gräns. Gummit i tätningen är av vanlig kvalité som inte tål större temperaturer, torkar upp. Eftersom dessa lagerhus saknar evakueringshål så till slut fyller man lagerhus och måste då tömmas annars koksar fettet och blir hårt pga. höga temperaturer.

Vibrationer: Vibrationer är i längden inte bra för ett lager, när bädden inte är tillräckligt hög eller för låg eller för lite slam så slår dämparna i ordentligt, uppmätt vibrationer ca 20-30 mm/s, dämpare har bytts ganska ofta på senare tid. Svängarmslager går också sönder pga. vibrationer. Vibrationerna leder sig nedåt via växellådan till marken. Främmande föremål som snurrar med runt kan också orsaka höga vibrationer.

Temperaturer: Gasen som är ca 300 grader kommer in underifrån via stövring/dysring och slår emot valsar, stenen som är betydligt kallare i kombination med slam och vatten kyler gasen och minskas till ca 120 ut. Om av någon anledning valsen står still ett kort tid kanske beroende på järnskrot kan snedbelastning ske pga. hög värme samt kan oljan i fettet kokas ur. Vattendysningen (3 dysor) är viktig att kollas då vattnet inte direkt bör träffa valsmantel som kan spricka utan vattnet skall dysas in försiktigt.

Diskussion

Bör tätningen bytas ut? Mera temptåligt gummi.
Skall vi byta mot ett ännu mera tåligt fett, Shell har ett fett som heter Steelrol EPH 2 som har ett högre basoljeviskositet vid 40 gr C (1000 cSt) mot staminans 480 Centistoke. Samt bör man diskutera att med ökad temperatur så måste intervall också ökas, ex vid 80 grader så 4 dubblas intervallet. Det som framkommit från oljebolagen grundar sig på 40 grader C vilket är standard. Å andra sidan hjälper det inte hur bra fett man har, huset måste tömmas ibland.

Eftersom evakueringshål saknas måste gammalt fett bytas/tömmas, skall man byta var 6 månad en vals så alla valsar rensas på gammalt fett minst 1 g/året?

Produktionen bör se över körsätt då dessa vibrationer är oacceptabla ur vibrationssynpunkt. Om bädden är för hög kan detta också orsaka höga vibrationer. Kalkstenen är hårdare och kan ge hårdare slag.

Magnetet på inmatarbandet är inte 100 % ig, hur ofta den töms är nog väldigt olika på hur mycket de har att göra på skiftet, men bör kollas upp, alernativt en bandmagnet som kör bort skrotet kontinuerligt. Hade biten till malbordet lossnat tidigare men inte hittats och gjort att valsen stannat och kvarnen vibrerat extra mycket?

Dysor skall kollas var 14 dag, inspektörens jobb.

Enligt tidigare erfarenheter så går valsen utan att någon misstänker ett fel till det stoppar, vid uppstart igen låser det sig, beror det på att fettet stelnar då föroreningar inkommit eller beror det på att varma gaser vid uppstart gör att fettet koksar?

Hade biten till malbordet lossnat tidigare men inte hittats och gjort att valsen stannat och kvarnen vibrerat extra mycket?

Felaktigt hydraultryck? Kan också orsaka vibrationer.....

Bilaga 1. Bilder med kommentarer

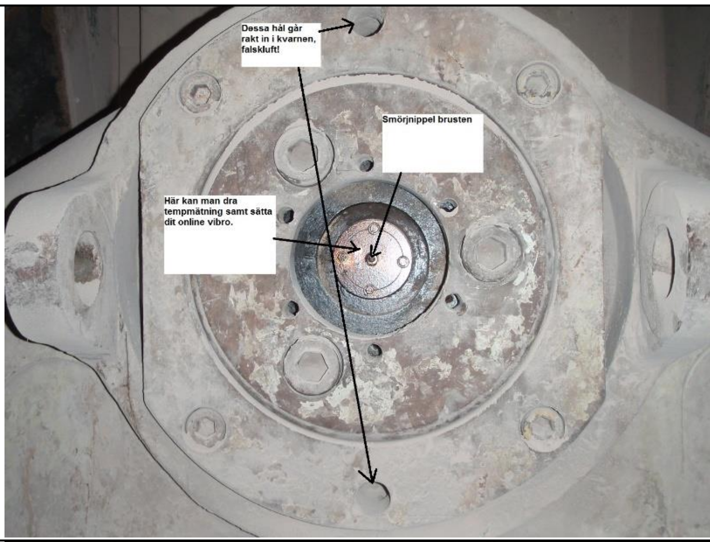
Bild 1 visar södra axeltapp utåt	
Bild 2 visar hål där fett fanns i hålet, är detta utrett till 100 %? Finns det möjlighet att råmjöl kommer in till lager någonstans? Tätningar var enligt Lasse Hansson ok. Lager och tätningssätena ej ok, repigt och slitet. Troligen fett som tryckts in vid montering för att skydda gängor?	

Bild 3 visar slam som bakar på är väldigt hårt, valsarna går i tuff miljö, med turbulens, undertryck, damm, vattenånga, hög belastning och hög temperatur.	
Bild 4 Ena sidan av det inre sfäriska rullagret, spräcktes vid demontering	
Bild 5 Cylindriska rullagret, yttre	

Bild 6 Alla lagerdelar tyder på varmgång	
Bild 7 Innerring till cylindriska lagret	
Bild 8	

Bild 9 Axel samt lagersäte till det inre lagret till vänster och yttre till höger. Skada på lagersäte, gammal sprutlagning hade lossnat på några ställen	 
Bild 10 Är tätningen verkligen bra?! Om hög temp förloras gummits egenskaper fort och blir hårt och drar sig alternativt spricker och därmed kommer föroreningar in. Gummit hålls på plats mha slangklammer mot axeln samt ringen har tryckfjädrar som gör tätningen flexibel axiellt.	

8.3 Appendix 3

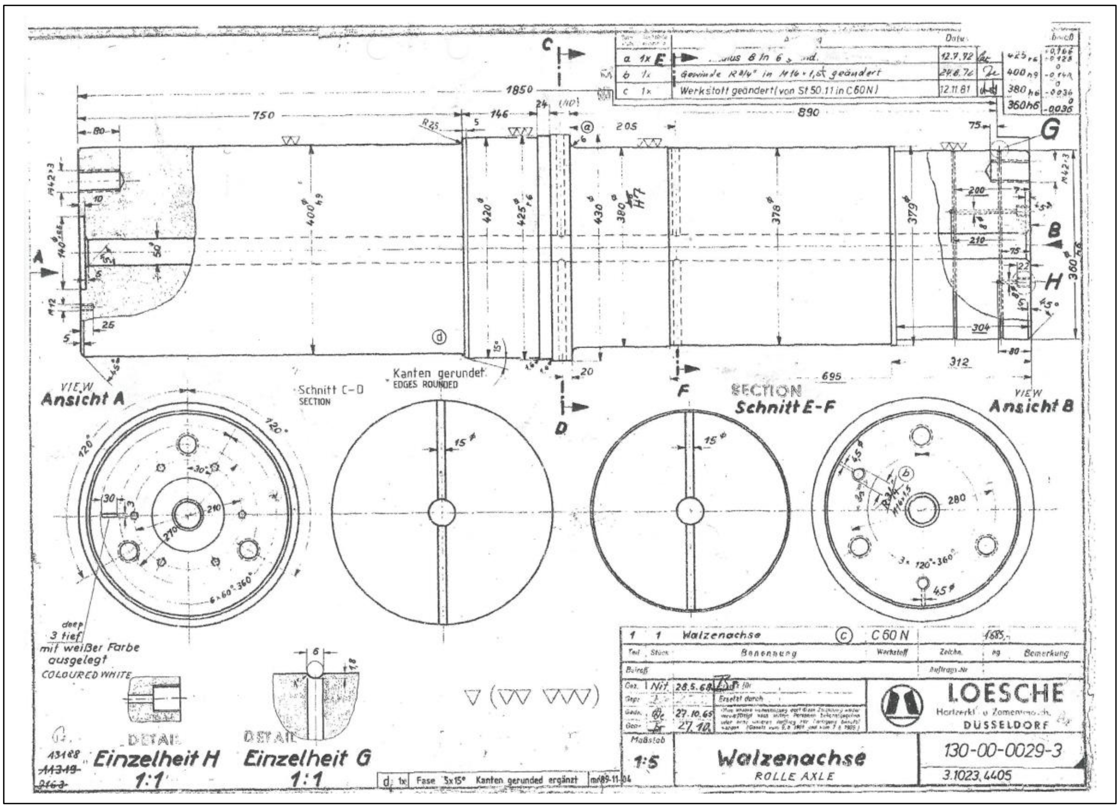


Figure 67. Grinding roller shaft.

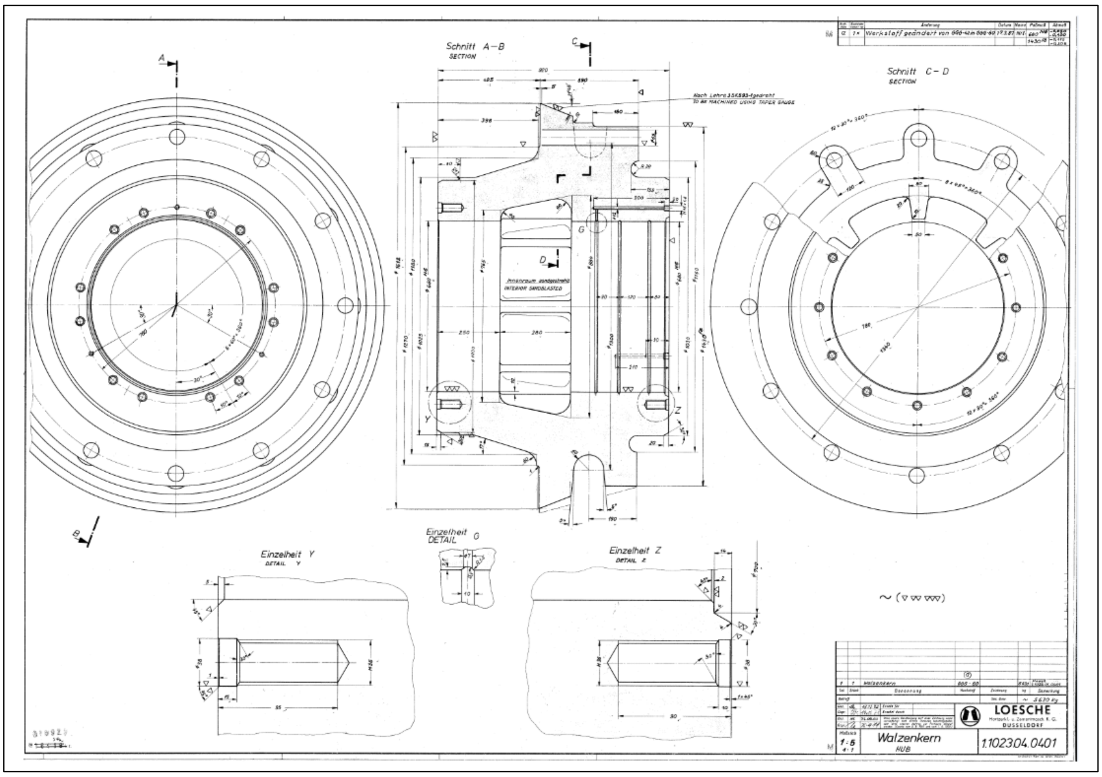


Figure 68. Bearing housing in grinding roller.

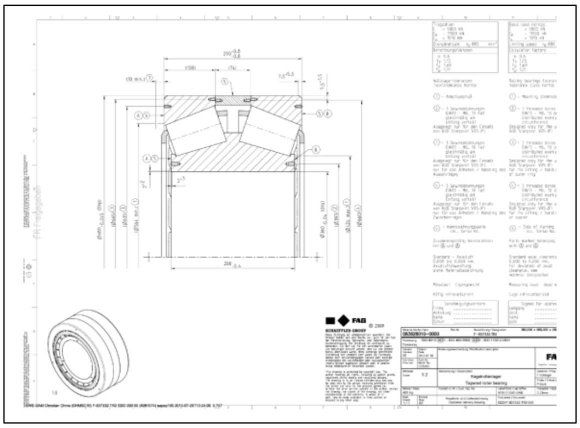


Figure 71. Roller bearing.

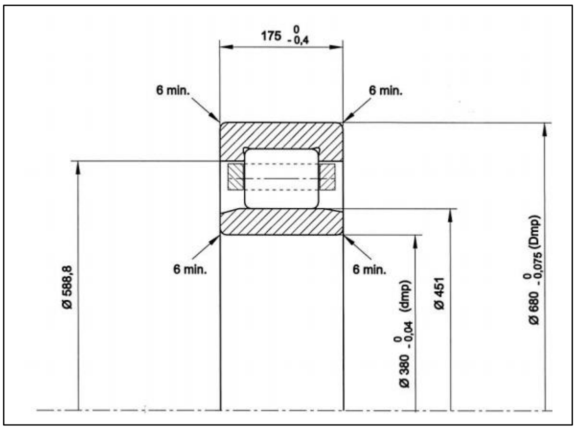


Figure 70. Roller bearing.

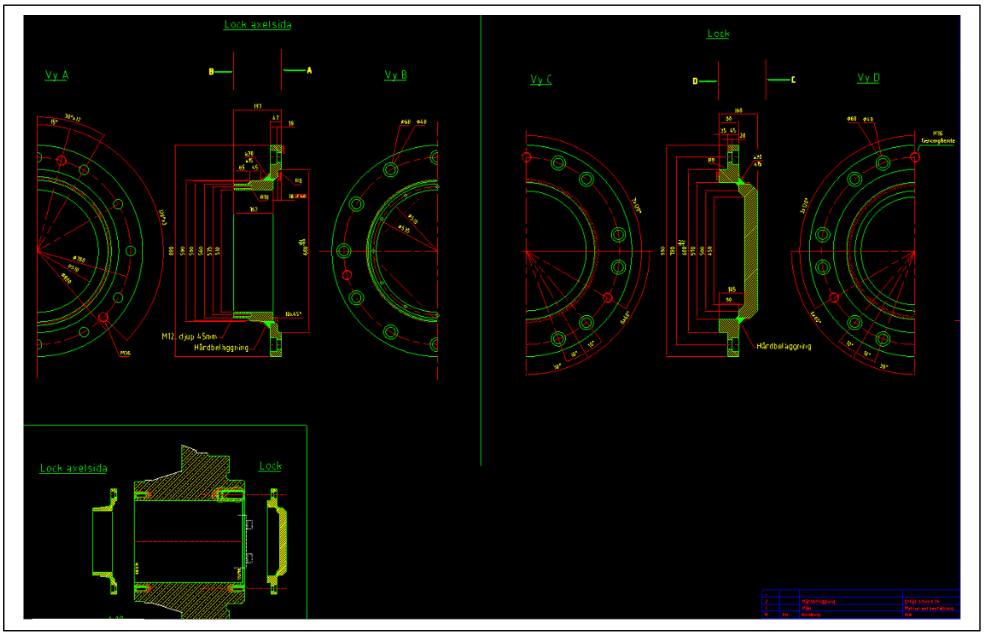


Figure 69. Drawings of grinding roller components.