Planning Preventive Maintenance for Pumps

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List of Abbreviations

PM Preventive Maintenance
EHEDG European hygienic engineering & design group
Nitrile rubber (NBR)
Ethylene Propylene Diene Monomers rubber (EPDM)
Cleaning In Place (CIP)
MTFB Mean Time Between Failure

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ABSTRACT

The purpose of this thesis was to create preventive maintenance for pumps in a production process.

Thinkflow company was the commissioner of this thesis. The objectives of this thesis’s project were to create tools for preventive maintenance to prevent sudden stops in the production line and to reduce the ambiguity tasks of maintenance by doing the service at certain time.

Preventive maintenance will reduce the frequency of breakdown by servicing the products in the production line at one time according to the critical pump that causes the stop in the production line. This will lead to financial benefits.

Scheduled maintenance will reduce the storage area because service kits will be ordered in advance before the time of service therefor; there is no need to store service kits in their storage all the time.

This thesis provides a tool for preventive maintenance in general and a tool for preventive maintenance of the pumps which Valio uses as well as service kits with serial numbers for each pump.

At the end of this thesis project a preventive maintenance system was planned for Valio. Service kits, serial numbers and codes for each pump at Valio plant were provided in Excel-sheets in order to facilitate the ordering of service kits.

Keywords Preventive maintenance, Pumps, Nitrile Rubber, Mean Time between Failures.

Pages 29 pages + 12 appendices

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1 INTRODUCTION

Thinkflow company is Alfa Laval master distributor in Finland. Thinkflow takes care of the sales of hygienic fluid handling equipment in the food-, beverage and biopharma industries.

Thinkflow company wants to do entrepreneurship process with their customers, the goals of this process is to improve and facilitate services that are provided by Thinkflow to their customers and makes the products and its service kits selling process clearer and easier. Thinkflow offers a preventive maintenance tool to their customer which is one part of this process.

To do the preventive maintenance tool, we need at least one of Thinkflow's customers to see products performing in the production lines and to collect product's data. Valio company selected to be the main data resource for this research.

Valio is a food processing company. Food processing industry is a very sensitive process because it is concern people's health therefore, it requires hygienic-and high-quality equipment in the production line, the equipment should be in compliance with EHEDG criteria.

This thesis will give a preventive maintenance tool in general and preventive maintenance tool for pumps which Valio company uses, they have preventive maintenance for valves, but they do not have preventative maintenance for pumps.

In order to do the preventive maintenance for pumps, we should classify the pumps to groups according to the pump failure consequence. For example, how much area in the production line will be affected by the equipment failure?

2 MAINTENANCE

Maintenance is an activity to keep the assets as long as possible in their original condition because any machine/equipment is subject to tear and wear. There are four common maintenance strategies. (Wisdomjobs, 2018.)

2.1 Breakdown Maintenance

The breakdown maintenance strategy is known as run-to-failure maintenance. The repair/replacement performed after the machine / equipment failed. We can use this strategy for machine / equipment where the importance of it very low and has no effect on production breakdown. (Fiix, 2018.)

2.2 Preventive Maintenance Time-based

A preventive maintenance system is a time-based process whereby we prevent the failures and problems in the machines and equipment before those occur. The preventive maintenance makes the machine and equipment more reliable and efficient performance by doing the maintenance periodically. (Lean Manufacturing Tools, 2018.)

2.3 Predictive Maintenance Condition-based

A predictive maintenance system is a condition-based process. Predictive maintenance predicts when equipment failure may occur and prevents them. This can be done by monitoring the condition of the equipment and perform the maintenance in advance. Some ways of equipment monitoring are as follows: (Emaint, 2018.)

- Vibration analysis: The vibration can detect machine failures and determine the condition of equipment to scheduling the maintenance.
- Infrared: By Infrared cameras we can see the unusual high temperature.
- Acoustic analysis: We can do this analysis by using sonic or ultrasonic tests to find liquid or gas leaks.
- Oil analysis: By analyzing oil condition we can see the size of particles and by that we can know equipment condition.

2.4 Reliability Centered Maintenance RCM

The RCM maintenance preserves the system function and recognize the failure that have an effect on the system function (Anothny & Clenn 2003, 66).

The RCM prioritize function need by identifying failures and select the best and more efficient maintenance strategy for the high critical failures.

2.5 Comparison Between Maintenance Strategies

Here in the table (1) the deference between maintenance strategies.

Table 1. The deference between the maintenance strategies and their advantages and disadvantages (Common approaches, 2018).

Strategy	Summary	Cost of implement	Advantages	Disadvantages
Run to failure	The repair will be done after breaks	Low	The best strategy for low priority equipment	Lead to more cost than the failure requires
Preventive	The maintenance will be scheduled in advance	Medium	Best strategy to implement without expertise and easy to implement	PdM and RCM strategies are more efficient than PM
Predictive	Equipment condition based maintenance	High	Informed monitoring on time and give more knowledge about the reason of breakdown	It is worthy for the critical assets and it is expensive to initiate
RCM	Investigate failure mode, failure consequence and others to have best strategy	Highest	Provides the most efficient scheduled maintenance	Not reasonable for a lot of companies

3 PREVENTIVE MAINTENANCE-TIME BASED

3.1 Overview

The preventive maintenance system is a time-based process whereby we prevent the failures and problems in the machines and equipment before those occur. The preventive maintenance makes the machine and equipment more reliable and efficient performance by doing the maintenance periodically. (Preventive maintenance, 2018.)

Preventative maintenance is about regular maintenance checks and repairs in order to reduce the risk of equipment's breaking down (preventative maintenance, 2018).

Preventive maintenance keeps the machine running longer time as shown in figure (1) without breakdown by optimizing machine operating condition which leads to prevent unplanned breakdown in the production line (Preventive maintenance, 2018).

Preventive maintenance system can be costly and spending time but the benefit of it is more than the lose because it will reduce the number of big repairs and decrease the downtime of the machine and solve the small issue in the machine before they become bigger and eliminate the unnecessary maintenance task for example, we could replace an equipment which shouldn't be replaced (Services, 2018).

Prevention of machine breakdowns is very necessary because if you have an order from the customer with specified delivery time so, you are sure that you can deliver the order at the delivery time because all your machines operating perfectly without breakdowns, also the quality of the machine is ensured.

As an example of preventive maintenance is car maintenance. To be sure that the car is safe to use it should be serviced regularly, for example the oil must be changed every 10000 kilometres of driving to prevent the failure of the engine. (Lean Manufacturing Tools, 2018.)

Preventive maintenance includes a very wide of overhauls for example, inspecting, lubrication, cleaning, oil changes, adjustment, repairs and parts replacing partly or completely that are periodically scheduled (What is Preventive Maintenance, 2018).

There is maintenance management software whereby monitoring equipment condition, maintenance alerts and the inventory of spare parts.

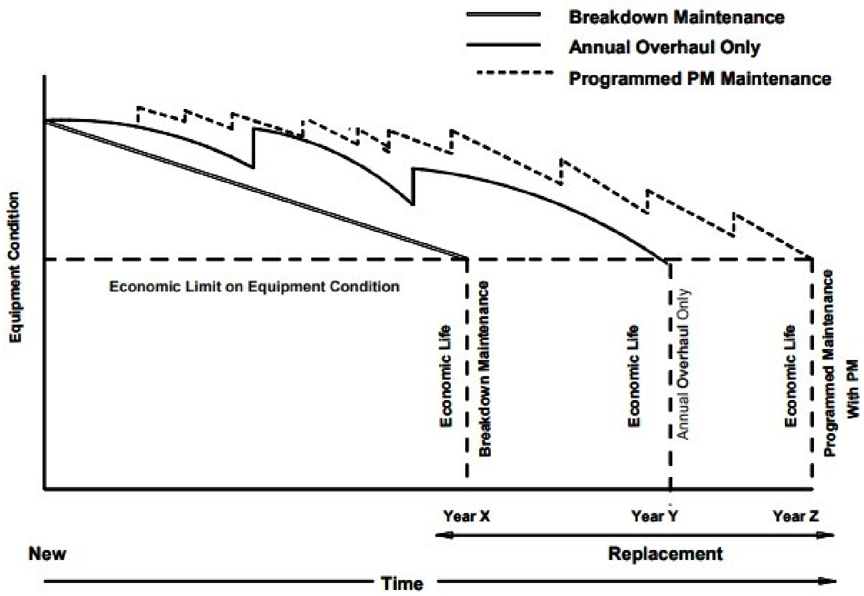

Figure 1. impact of Preventive maintenance (Lce.com, 2018)

3.2 **Mandatory Preventive Maintenance**

Mandatory maintenance is an activity pointed in the contract, law or regulation. For instance, the law requires making inspection and maintenance for some machines, so these machines should be inspected and maintained. Mandatory PM is usually required by insurance companies and even major customers. (Valtanen & perälä 2017.)

3.3 **Discretionary Preventive Maintenance**

Discretionary preventive maintenance is not a compulsory activity which is based on profit and loss. The company performs a preventive maintenance freely by its own will depending on the benefits of preventive maintenance. (Valtanen & perälä 2017.)

3.4 **Four Dimensions of PM**

The four dimensions of preventive maintenance are economic, engineering, psychological and management. We should know the impacts of these four in order to understand the benefits of a PM system. (Valtanen & perälä 2017.)

Economic

The preventive maintenance should be designed in such way that the cost of maintenance is less than the cost of breakdown maintenance. This means that the cost of preventive maintenance is less than the failure consequence cost. (Valtanen & perälä 2017.)

Engineering

In order to make failure detection easier and quicker, we should fully understand the failures and why they happen what causes them. By knowing those, we will use the right tool to the right with the right frequency and will not spend too much effort. (Valtanen & perälä 2017.)

Psychological

The people have different personalities, and everyone has own point of view therefore; we should make a system that applicable as much as can for all and make sure that everyone understands what should do, why, how and when. For example, two workers, one follows the instructions as guided when fixing something even doing the lubrication for small component in the machine and second one does not follow the instruction as guided and might neglect the lubrication for small component because he things that this task is not important. The preventive maintenance system could fail if the worker not follows the instructions as guided. Therefore, we must be sure that all workers follow the instruction as guided. (Valtanen & perälä 2017.)

Management

The management should keep preventive maintenance system up-going over time and improve it (Valtanen & perälä 2017).

4 PM ADVANTAGES AND DISADVANTAGES

4.1 Advantages of Preventive Maintenance

The preventive maintenance is the simplest maintenance strategy to implement and execute and here are advantages of it:

Decrease production downtime

The maintenance task will be easier, when the problem occur it will be solved quickly because the worker knows what he should do and what equipment should be replaced, so this will reduce the time for detecting the problem. Also, the parts will be ordered earlier rather than ordering them when the problem occur which is extends the downtime period.

Decrease the equipment breakdown

With preventive maintenance the equipment will be maintained regularly in scheduled time, so the equipment will be in its best condition.

Money saving

The preventive maintenance reduces the breakdown frequency. This means that you reduced the number of stops in the production lines which lead to financial benefits. Also, by doing the preventive maintenance you will solve the problem before becomes bigger which cost us more money and enhance the assets by increasing the uptime of the machine.

Increase the productivity

When the equipment downtime reduced that's mean the number of the stops in the production lines decreased which is leading to increase the productivity of the facility. Also, it can increase the uptime of the machine because the equipment is in the best condition.

Eliminate the ambiguity in the maintenance tasks

The preventive maintenance reduces the possibility of unnecessary repairs and create system where using the right tool to the right task.

Longer life and more efficient equipment

Because your equipment is checked regularly so these checks will extend the equipment lifecycle and keeps them in the best condition. The preventive maintenance enhances the performance of the equipment and increase the quality of the products because the machines are well-maintained, and the equipment performs efficiently.

Customer service and reputation

The preventive maintenance enhances company reputation because they deliver the customer order at the agreed time between them without delay because there is no unplanned breakdown in the plant. The reliable delivery time enhance company reputation because the customer wants from the manufacturer a good quality and reliable delivery

Decrease energy wastage

The preventive maintenance decreases the power cost because well-maintained equipment typically requires less electricity or fuel to run, if the equipment not in the best condition will drain more energy.

Enhance safety of facility

Equipment failures can have miserable consequences. Well-maintained equipment will improve worker safety, as well as those that work around equipment, so the well-maintained equipment leads to safer working environment

4.2 Disadvantages of Preventive Maintenance

Set-up costs

The preventive maintenance will save you money in the long-term but the costs to initiate it can be high.

Planning requirements

Preventive maintenance requires planning in detail and the creation of a system where all assets are included and observed in the system.

5 RELIABILITY METRICS OF EQUIPMENT

Equipment reliability measurement is an essential part in the maintenance system because by this measurement we schedule the maintenance.

There are seven main metrics whereby machine / equipment reliability can be assessed

5.1 Mean Time Between Failure (MTBF)

The MTBF is the average between two failures in machine / equipment.

By this measurement we can know how long the machine runs without failure. If we have along MTBF that is mean, we have long-life machine or equipment.

The MTBF can be calculated by dividing total uptime of machine by the number of failures during that period (Lubricants, 2018).
For example:

$$\frac{10\, years\ of\ service}{2\, failures} = 5\, years\ MTBF$$

5.2 Failure Rate

The failure rate is the opposite of MTBF where we divide the total number of failures by the total uptime of the machine and the result is the frequency of component fails (Lubricants, 2018).

For example:

$$\frac{2\,failures}{10\,years\ of\ service} = \ 1\,failure\ every\ 5\ years$$

5.3 Mean Time To Repair (MTTR)

This is the average time of repairing equipment / machine and that can be calculated by dividing total down time by number of breakdowns (calculator, 2018).

For example, we have four failures in equipment during two years and the total downtime of those failures is two hours

$$\frac{2\ hours}{4\,failures} = 0.5\ hour$$

The average time to repair one failure is 30 minutes

5.4 Mean Time To Failure (MTTF)

This is the average time to failure, it is same as the MTBF but the deference is that the MTTF is the right formula for the equipment / machine that are non-repairable and the MTBF is the right formula for the equipment / machine that are repairable (calculator, 2018).

For example, machine will be broken after 20000rpm.

5.5 Exponential Distribution and Projected Reliability

This method is the most common and reliable way to predict machine / equipment reliability, this is the best way when we have a constant failure frequency. This can be calculated by using the logarithms and failure rate for certain time. (Lubricants, 2018.)

The calculation as below:

$R_{(t)} = e^{-\lambda t1)}$

R(t) = Reliability estimation for a period (t) e = Base of logarithms (2.718281828)

λ = Failure rate (1/MTBF)

For example, we want to calculate the projected reliability for a machine after 5 years of use by using the failure rate.

Failure rate λ = 1/5=0,2

$R_{(5)} = 2.718281828^{-(0.2 \times 5)}$

$R_{(5)} = 0.367 = \sim 37\%$

5.6 Machine Availability and Unavailability

Machine availability means that the machine in use for a certain period and unavailability means that the machine out of use for a certain period.

By knowing machine availability and unavailability we can calculate the cost of machine downtime. This can be calculated by dividing total downtime by the total of uptime for the machine. (Lubricants, 2018.)

For example:

20 hours of downtime / 200 hours in service = 10% unavailability, 90% availability

5.7 Cost of Downtime

In order to calculate the cost of downtime we should know machine actual availability and compare it with the optimal availability (100% in use). The difference between machine actual availability and optimal availability of machine is the unavailability of the machine (downtime). When the down time has been calculated, we multiply the unavailability by expected production quantity from that machine per hour by the income for that quantity. (Lubricants, 2018).

For example:

We have a machine in 100% availability runs 8 hours/day and 300 days/year, the total running hours is 8*300 = 2400 hours/year and actual availability is 70% which means that the machine has been run 1411 hours/day, the downtime is 2400-1411= 989/year (unavailability) and expected production quantity/hour is 2 quantities and the income for one quantity is 20€

989 (downtime hours) *2 (expected production quantity/hour) *20 (income for one quantity) = 39560€

6 PREVENTIVE MAINTENANCE DESIGN

There is a several ways to design PM for example, based on previous experience, spare part consumption, machine operating mode or manufacturer recommendations. Some of these ways can cause a heavy PM or include unnecessary tasks that lead to expensive PM.

The most effective preventive maintenance can be designed by using critical analysis.

6.1 Critical Analysis

Equipment critical analysis is a quantitative analysis of equipment faults, and ranking them according to the consequences on safety, environment, production loss and maintenance cost. The critical analysis provides tools whereby we prioritize the maintenance tasks to high-priority, mid-priority and low-priority equipment. The critical analysis reduces the level of unnecessary tasks and focus on high-priority maintenance tasks. This analysis also helps to select the best and most economic maintenance strategy and prioritize work orders.

One essential part in critical analysis is how much area in the process will be affected if the equipment failed? If the affected area is big in the process, so this equipment will be subjected to high-critical equipment, if the equipment failure effect on the process partly, so this equipment will be subjected to mid-critical equipment, if the equipment failure has no effect on the process, so this equipment will be subjected to low-critical where we can do the maintenance for that equipment when break occur, no need to do preventive maintenance to low-critical equipment.

The high-critical equipment will be given number (1). med-critical equipment number (2). Low-critical number (3).

We can make the critical analysis based on three factors

- Safety risk: the equipment failure has effect on work environment/personnel.
- Production losses: the equipment failure effected-area in the production line.
- Maintenance costs: the cost of maintenance when the equipment breaks.

The machines/equipment that have higher safety risk, production lose, maintenance cost will be in high-critical level that means number 1 and so on.

The company can add or change the factors in critical analysis based on their situation and priorities.

7 PUMPS

7.1 Working Principle

The pump is a machine used to transfer fluids and/or gases, from one place to another. The figure below shows pump working principal where transferring fluid from tank A to nozzles B. Figure (2) shows the working principle of a pump where transferring the liquid from reservoir A to nozzle B

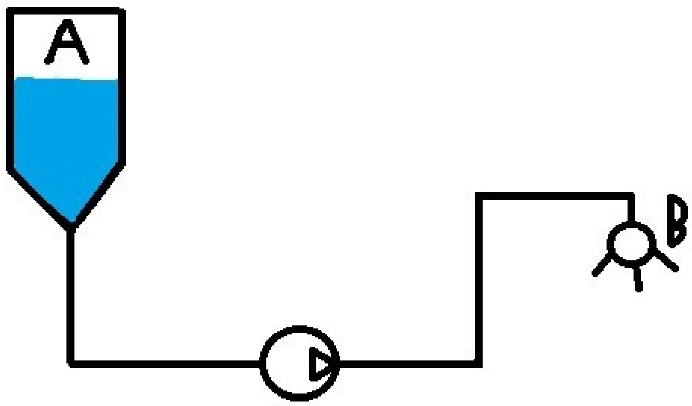

Figure 2. Working principle of a pump

7.2 Pump Types

Generally, there are two main categories of pumps, rotodynamic and positive displacement pumps. There are many forms of these as shown in Figure 3.

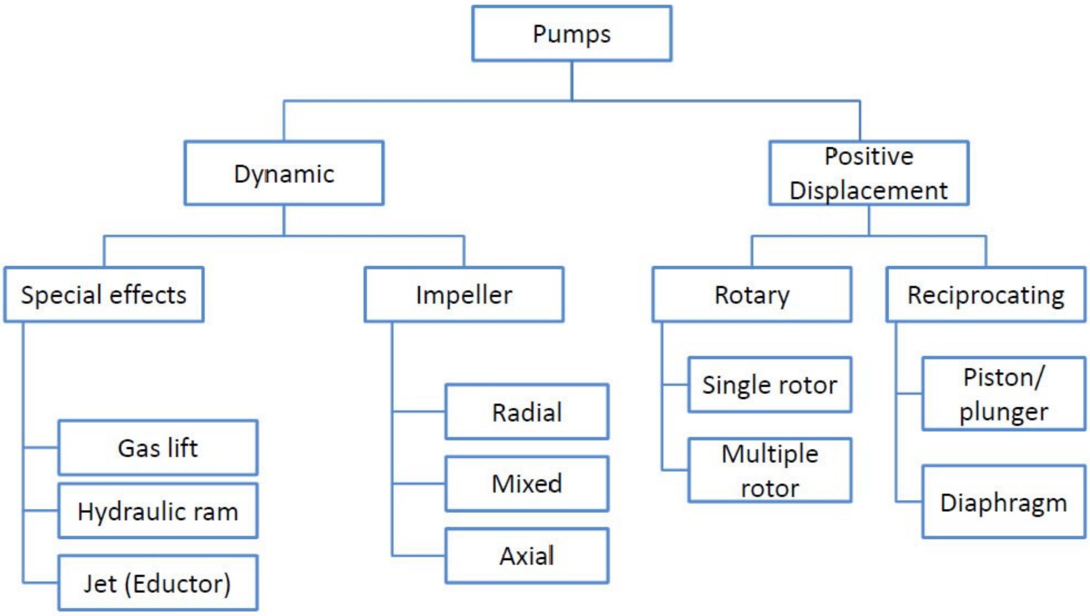

Figure 3. Pump classification (Zainbooks, 2018.)

7.2.1 Rotodynamic pump

A rotodynamic pump converts mechanical energy into kinetic energy in the form of fluid velocity and pressure. Rotating blades apply force to the fluid which is in contact with the blades and this force makes the fluid move. Centrifugal and liquid ring pumps are types of a rotodynamic pump, that use centrifugal force to transfer the fluid. (Pumps.org, 2018.)

There are basically two kinds of centrifugal pumps:

- Single Stage Centrifugal Pumps
- Multistage Centrifugal Pumps

Single Stage Centrifugal Pumps:

This pump is the most common centrifugal pump for fluid transfer in high flow rate and low pressure.

Single stage means that there is one impeller which is mounted on the shaft which rotates by electric motors or turbine (Castle Pumps, 2018).

The single stage centrifugal pumps can be used for Light fuel transfer, pressurized, water supply, inert gas cooling, washing and firefighting, air condition supply, sea water circulation, petrochemical, waste water transfer and sewage transfer. The maintenance cost for single stage pump is low comparing with others because it has a few moving parts in. (Castle Pumps, 2018.)

Multi Stage Centrifugal Pump:

Multi stage means that there are two or more impellers in the pumps and they could be mounted on the same shaft or different shafts and each impeller has own chamber (stage). The liquid enters first stage where the pressure increases and move to the second stage where the pressure increases more and so on depends on how much stages in the pumps. (Peters, 2018.)

By multi stage pump we can get higher and higher pressure depends on the number of stages because the more stages are the higher outlet pressure but, the flow rate remains same at a certain rpm (All Pumps, 2018).

We have a higher outlet pressure when the stages are mounted on the same shaft. For a higher flow rate the stages should be mounted in parallel. (Engineers Edge, 2018.)

There are two diverse types of multistage pumps: Horizontal shaft and vertical shaft. Each one of those shafts is suitable for specific applications. (Peters, 2018.)

7.2.2 Positive displacement pump

A positive displacement pump gives a constant flow at a fixed speed, although there are changes in pressure. This pump can give a higher flow, but it is not able to provide a high flow. (Positive displacement pump, 2018.)

This pump is able to pump viscous fluids and fluids that contain suspended or fragile solids (Positive displacement pump, 2018).

Principle of operation

The fluid enters the suction cavity and moves to the discharge side by trapping a certain quantity of that fluid. Some pumps have a suction cavity and decreasing cavity where the fluid enters the suction cavity when the cavity expands, and the fluid moves to discharge side when the decreasing cavity decreased. (Mechanical booster, 2018.)

This pump is not able to raise a fluids' velocity as the centrifugal pump does. The positive displacement pumps suitable for application where pumping viscous liquids and liquids that contain suspended or fragile solids. (Positive displacement pump, 2018.)

Diverse types of positive displacement pumps

There are several types of positive displacement and they are often classified according to the mechanism used to move the fluid. Here are the main types: (Mechanical booster, 2018.)

1. rotary positive displacement pump
2. reciprocating positive displacement pumps
3. linear positive displacement pump

Advantages of positive displacement pumps:

- In general, positive displacement pumps are a good option for applications where a constant flow is required and for applications where a combination of a low flow and high pressure is needed.
- These pumps can create medium to high pressure and they can pump viscous liquids (oils) and liquids that contain suspended or fragile solids (Positive displacement pump, 2018).

8 DESCRIPTIONS OF PUMPS AT THE VALIO PLANT

There are five diverse types of pumps at Valio’s plant. Each one is explained as follows.

8.1 Centrifugal Pump LKH

Centrifugal pump uses the centrifugal force to move the fluids. The centrifugal force will raise fluids’ pressure

Working Principle

The fluid enters the pump through the eye of the impeller and the impeller applies force as in figure (4) whereby fluids velocity and pressure increases and makes the fluid moves to outlet and that will create a vacuum at the eye of impeller which makes the fluid enters the eye continuously (Learnengineering.org, 2018).

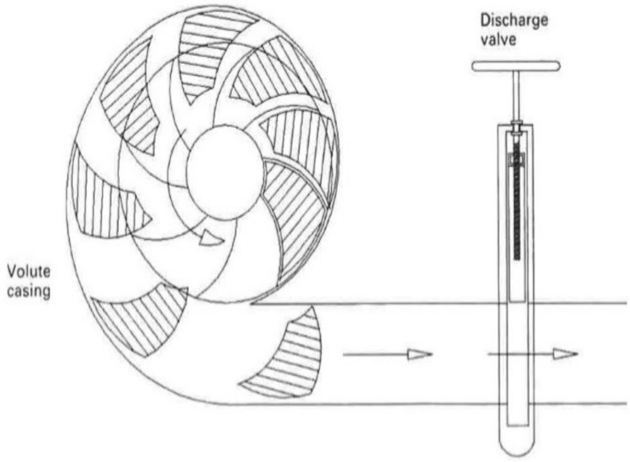

Figure 4. Working principle of centrifugal pump (Centrifugal pumps 2018)

Applications

"The LKH pump is a highly efficient and economical centrifugal pump, which meets the requirements of hygienic and gentle product treatment and chemical resistance. LKH is available in thirteen, LKH-5, -10, -15, -20, -25, -35, -40, -45, -50, -60, -70, -85 and -90. Standard design The LKH pump is designed for CIP with emphasis on large internal radii and cleanable seals. The hygienic version of LKH has a stainless-steel shroud for protection of the motor, and the complete unit is supported on four adjustable stainless-steel legs". (Close at hand, 2018.)

The pump flow depends on the height as shown in figure (5).

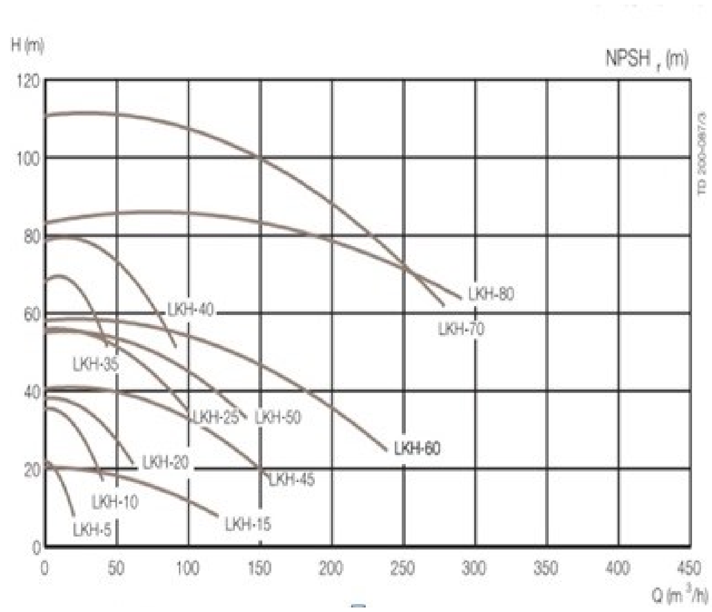

Figure 5. LKH flow chart (Close at hand, 2018)

8.2 **MR, Liquid Ring Type Pump**

Principle and application

"The MR range of pumps is specifically designed for pumping liquids that contain air or gas. These pumps are most commonly used for CIP return applications in the food, dairy, beverage and pharmaceutical industries". (Close at hand, 2018.) The pump flow depends on the height as shown in figure (6).

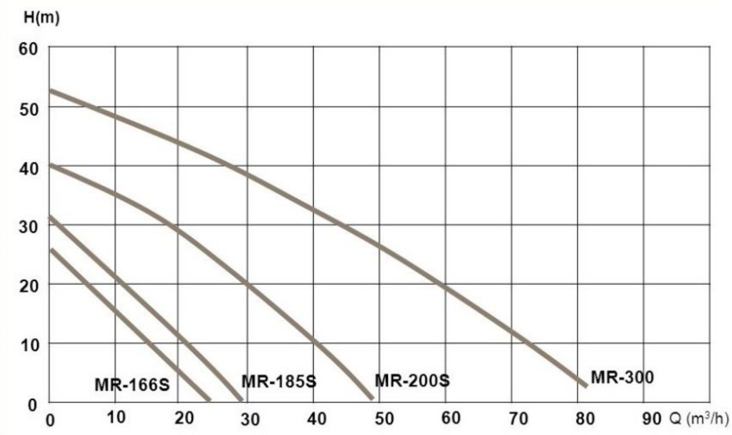

Figure 6. MR pumps flow chart (Close at hand, 2018)

8.3 **SX, Rotary Lobe Pump**

Working Principle

"The positive displacement of the SX pump is provided by non-contacting, contra rotating four lobe rotors within a fully swept pump chamber. All SX pumps are capable of bi-rotational flow without modification" as shown in figure 7. (Close at hand, 2018.)

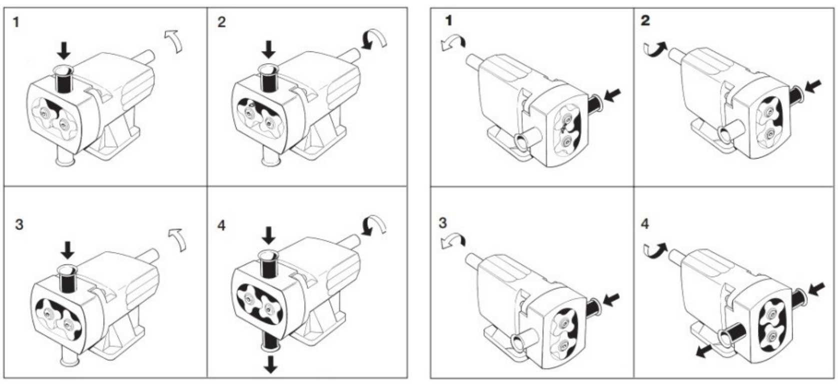

Figure 7. Working principle of SX (Close at hand, 2018)

Application

"The SX range of rotary lobe pumps has been designed for use on wide ranging applications within the Pharmaceutical, Biotechnology, Fine Chemical and Specialty Food industries. The SX range is ideally suited to applications where cleanability and corrosion resistance is paramount." (Close at hand, 2018.)

8.4 FM, Centrifugal Pump

Working principle

The working principle is same as the LKH pumps, but FM pumps are a multistage pump.

Applications

The FM pumps are specifically designed for food, chemistry, medicine and other industries, where the pumped liquids require stainless steel. FM pumps can be used for hard pressure conditions such as feed pump for heat exchangers and filters. The pump flow depends on the height as shown in figure (8).

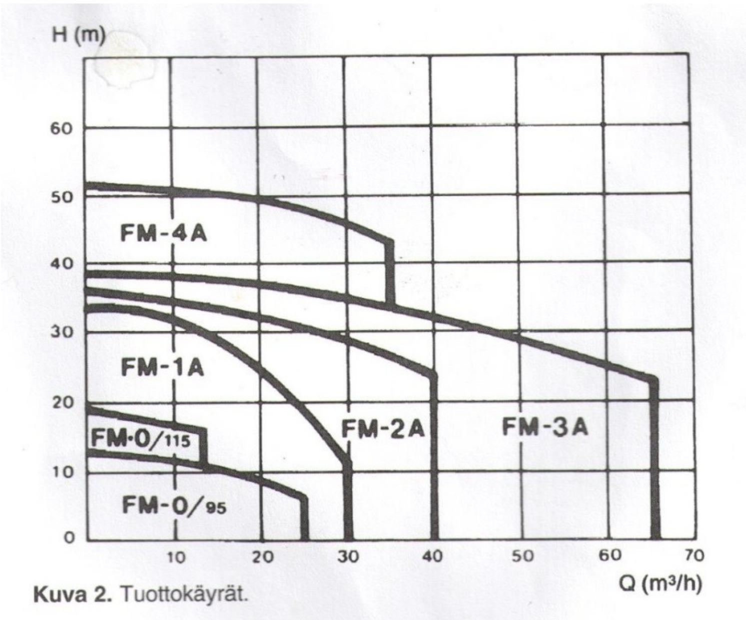

Figure 8. FM pump flow chart (Close at hand, 2018)

8.5 SRU, Rotary Lobe Pump

Working Principle

"The positive displacement of the SRU pump is provided by non-contacting, contra rotating tri-lobe or bi-lobe rotors within a fully swept pump chamber. All SRU pumps are capable of bi-rotational flow without modification" as shown in figure (9). (Close at hand, 2018.)

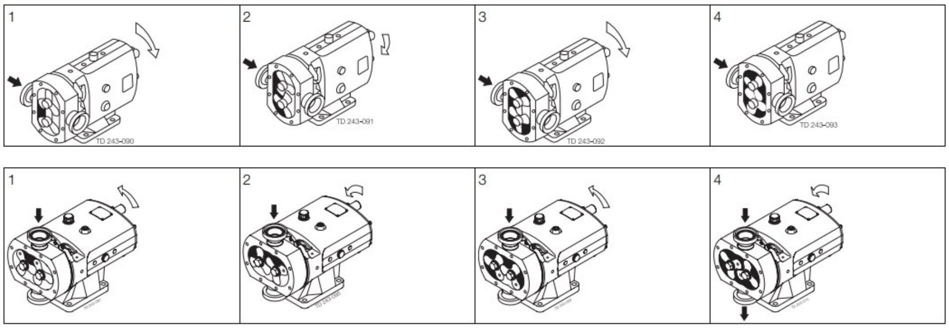

Figure 9. SRU working principal (Close at hand, 2018)

Application

"The SRU range of rotary lobe pumps has been designed for use on wide ranging applications within the Brewing, Dairy, Food, Pharmaceutical and Chemical industries. The SRU pump can handle from low to high viscosity media with its characteristic smooth, low shear pumping action being ideal for products such as creams, gels, emulsions, aerated mixtures, and delicate cells and organic solids in suspension. The SRU range is suitable for CIP (Cleaning in Place)." (Close at hand, 2018.)

9 FAILURES

9.1 Pumps Failure Factors

It is very important to know what the potential factors in equipment are cause failures. This makes the maintenance tasks easier, faster and to order the components in advance.

For the pumps, the sealing material and the motor are the factors that cause failures in the pump

9.1.1 Sealing material

The sealing material is the part which causes failure in the pumps which leads to leaking. Therefore, the working condition of the pump is very important aspect on the pump well-performing; we need to consider these factors to extend equipment lifetime and to do the right tool for the preventive maintenance.

Temperature

The temperature has a direct influence on the sealing material of the pumps because the higher temperature the shorter lifetime of sealing material. The temperature limitations for the sealing material EPDM is 140° maximum. For NBR sealing material the temperature should not be over than 90°.

Process

In the process there may occur pressure shocks. They may damage the shaft seals.

In order to avoid pressure shocks the control system of the process must be designed in the way that pumps never run towards closed valves.

product

The product which flow in the production line has influence on the sealing material. For example, cream, honey, milk or juice etc.

We should use NBR sealing material for the fat product because the fat influence on the EPDM sealing material.

Cleaning process

The cleaning frequency has also influence on the sealing material of the pumps, should be done according to the regulation. For example, in Valio should do the cleaning process every 8 hours.

9.1.2 Motors

The electrical motor that rotates the pump's shaft causes stop in the pump. The personnel should follow the manufacturer recommendation for motors and do the maintenance according to that recommendation.

9.2 **Failure Consequence**

There are a lot of consequences and here are some of them

9.2.1 Safety

The failure can influence on the work environment and personnel, some of equipment has a significant effect on both.

9.2.2 Production loss

Some failures in equipment cause stops in the production line totally or partly which lead to production loss. Production loss value depends on downtime and breakdown frequency.

9.2.3 Maintenance cost.

The costs depend on the failures and on the personnel whether are talented or not. Some of failures cause another failure to the equipment which make the maintenance cost higher. In order to reduce the maintenance cost, we should solve the issues before becomes bigger and this can be done by using PM whereby we do the repair to equipment before the failure occurs.

9.3 **Common Failures**

9.3.1 Common faults of centrifugal pump

There are many functional problems in the centrifugal pumps as in table 2. Each problem has one or more cause.

Table 2. The problems of centrifugal pumps and their reasons (Mobely 2002, 219).

The cause	The problem												
	Insufficient Discharge Pressure	Intermittent Operation	Insufficient Capacity	No Liquid Delivery	High Bearing Temperature	Short Bearing Life	Short Mechanical Seal Life	High Vibration	High Noise Levels	Power Demand Excessive	Motor Trips	Elevated Motor Temperature	Elevated Liquid Temperature
Bent shaft					●	●	●	●		●			
Casing Distorted from Excessive Pipe Strain Elevated					●	●	●	●		●		●	
Cavitation	●	●	●	●	●		●	●	●				●
Clogged Impeller	●		●	●				●		●			
Driver Imbalance						●	●	●					

Electrical Problems (Driver)						●	●	●		●	●	●	
Entrained Air (Suction or Seal Leaks)	●	●	●					●	●			●	
Hydraulic Instability					●	●	●	●	●				
Impeller Installed Backward (Double-Suction Only)	●		●							●			
Improper Mechanical Seal							●						
Inlet Strainer Partially Clogged	●		●					●	●				●
Insufficient Flow through Pump													●
Insufficient Suction Pressure (NPSH)	●	●	●	●				●	●				
Insufficient Suction Volume	●	●	●	●	●			●	●				●
Internal Wear	●		●					●		●			
Leakage in Piping, Valves, Vessels	●		●	●									
Mechanical Defects, Worn, Rusted, Defective Bearings					●		●			●			
Misalignment					●	●	●	●		●		●	
Misalignment (Pump and Driver)								●		●	●		●
Mismatched Pumps in Series	●		●			●		●		●			
Noncondensable in Liquid	●	●	●					●	●			●	
Obstructions in Lines or Pump Housing	●		●	●				●				●	●
Rotor Imbalance						●	●	●					
Specific Gravity Too High	●									●		●	
Speed Too High										●	●		
Speed Too Low	●		●	●								●	

Total System Head Higher Than Design	●	●	●	●	●		●					●	●
Total System Head Lower Than Design					●		●	●	●	●			●
Unsuitable Pumps in Parallel Operation	●		●	●	●			●	●		●		●
Viscosity Too High	●		●							●		●	
Wrong Rotation	●			●						●		●	

9.3.2 Common faults of rotary type, positive displacement pumps

Here in table 3 the common functional problem of rotary and positive displacement pumps and their causes.

Table 3. The common failures of rotary type, positive displacement pumps (Mobely 2002, 223.)

The cause	The problem										
	No Liquid Delivery	Insufficient discharge pressure	Insufficient capacity	Starts, But losses prime	Excessive wear	Excessive heat	Excessive vibration and noise	Excessive power demand	Motor trips	Elevated motor Temperature	Elevated Liquid Temperature
Air leakage into suction piping or shaft seal		●	●				●			●	
Excessive discharge pressure			●		●		●	●	●		●
Excessive suction liquid temperatures			●	●							
Insufficient liquid supply		●	●	●	●		●		●		
Internal component wear	●	●	●				●				
Liquid more viscous than design								●	●	●	●

Liquid vaporizing in suction line		●	●	●			●				●
Misaligned coupling, belt drive, chain drive					●	●	●	●		●	
Motor or driver failure	●										
Pump strain on pump casing					●	●	●	●		●	
Pump running dry	●	●			●	●	●				
Relief valve stuck open or set wrong		●	●								
Rotating element binding					●	●	●	●	●	●	
Solids or dirt in liquid					●						
Speeds too low		●	●						●		
Suction filter or strainer clogged	●	●	●				●			●	
Suction piping not immersed in liquid	●	●		●							
Wrong direction of rotating	●	●								●	

10 PM PROFITABILITY CALCULATION

The preventive maintenance main aim is to lead to financial benefits and to calculate that we should know these three things as below,

- Cost of production downtime
- Frequency of the breakdown in the production line for the last five years (can be less) before using the preventive maintenance and the frequency of the breakdown with the preventive maintenance (for example, if the preventive maintenance should be done every two years, so in the next five years will have 2.5 times of breakdown).
- Cost of maintenance tasks

The formula below calculates the finical benefit,

$$Cost\ of\ downtime * Cost\ of\ maintenance * breakdown\ frequency\ with\ PM\ -\ Cost\ of\ downtim * Cost\ of\ maintenance *\ breakdown\ frequency\ without\ PM$$

If the result of above formula is negative, the PM is financial benefited and better than the breakdown maintenance.

11 PREVENTIVE MAINTENANCE SOLUTION

The preventive maintenance will be designed according to Valio's critical analysis because they have already critical analysis in use which based on production area breakdown-effect (production loss).

The Valio company has four level of criticality based on pump affecting area in the production:

1. Breaking effect: the pump cause stops in the production line
2. Partly effect: the pump cause partly stops in the production line
3. No effect: the pump has no effect on the production line
4. No effect: the pump has no affect and the replace it when the have the new one.

According to the criticality analysis we will do the preventive maintenance and it will be applicable just for the equipment that cause full stop and partly stop in the production line.

11.1 Pumps in Critical Level 1 and 2

The preventive maintenance created based on MTBF method.

11.1.1 Reliability measurements (MTBF)

The product reliability measurements specify the frequency of the maintenance for that product (Industrial Wiki, 2018).

The reliability measurement is the average time between the failures, it's calculated by dividing total operating hours by the total failures number as the equation below: (Wiki, 2018).

$$\frac{total\ operating\ hours}{total\ failure\ number} = Mean\ time\ between\ failures\ (MTBF) \tag{4}$$

11.2 **Pumps in Critical Level 3**

For those pumps does not matter whither doing PM for them or doing the maintenance after pump breaks.

11.3 **Standby**

In this solution we can repair the critical pump without stopping the production by using the standby pump as shown in figure 10. This is can be costly but in long term is efficient and it is more comfort and reliable.

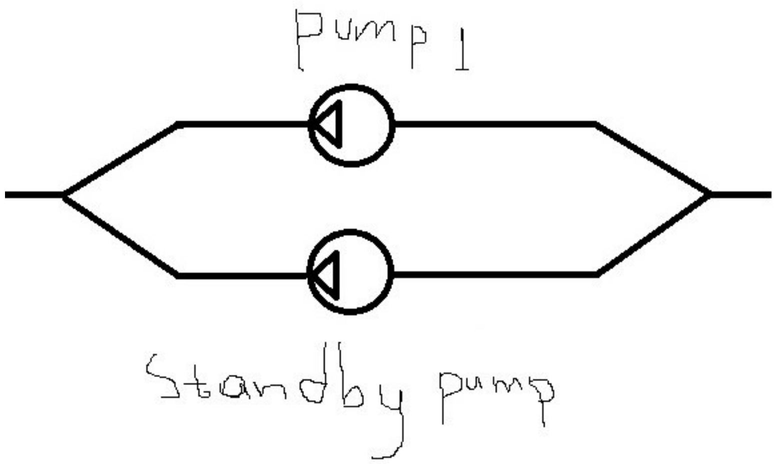

Figure 10. Standby pump figure

11.4 **Spare Parts**

Service kits for each pump has been provided in excel sheet, but it is kept confidential according to Valio's request.

12 **RECOMMENDATIONS**

I recommend conducting maintenance to all the pumps in the same production line to reduce breakdown in the production line, and to change all the maintainable components in the pump, for example the pump shaft seal and the pump casing O-ring at the same time.

Valio has PM for valves, Valio repairs some valves every year and some valves every three years and the actuators every six years. These valves have a connection with the pumps and their maintenance also causes breakdown in the production line, therefore, I would recommend doing

PM on the pumps and valves at the same time, if applicable, to reduce breakdown.

Alfa Laval stopped producing pumps type FM for over 20 years ago and Valio still has FM pumps in use. I recommend replacing these pumps with alternative pumps.

13 CONCLUSION

A preventive maintenance system for pumps was created in this thesis's project. The technical data, serial numbers, codes, service kits (shaft seal, O-ring) for about 100 pumps were provided which will facilitate maintenance tasks and makes the ordering of spare parts easier. By these codes and serial numbers, right components can be ordered.

There is a possibility to optimize the created PM system by finding such way where the maintenance tasks can be done for pumps, valves, valve actuators and motors at the same time (if applicable) in order to have further reduce with production breakdowns.

I hope that Alfa Laval innovates such a sensor whereby can monitor pump condition to transfer form time-based maintenance to condition-based maintenance which is more efficient.

The author himself has learned a lot about pumps and maintenance tasks during this project. This was a great opportunity for me to gain a deep knowledge of pumps and their significant role in production process.

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Appendix 1 LKH Pumps technical data

Shaft seals

The LKH pump is equipped with either an external single or a flushed shaft seal. Both have stationary seal rings made from stainless steel AISI 329 with sealing surface in silicon carbide and rotating seal rings in carbon. The secondary seal of the flushed seal is a long-lasting lip seal. The pump may also be equipped with a double mechanical shaft seal. (Close at hand, 2018 January ESE00361EN).

TECHNICAL DATA

Materials

Product wetted steel parts: . . . . W. 1.4404 (316L).

Other steel parts: . . . . Stainless steel.

Finish: . . . . Standard blasted

Product wetted seals: . . . . EPDM rubber.

Connections for FSS and DMSS:

6mm tube/Rp 1/8"

Motor sizes

50 Hz: . . . . 0.75 - 110 kW.

60 Hz: . . . . 0.9 - 125 kW.

Motor

Foot-flanged motor according to the IEC metric standard, 2 poles = 3000/3600 rpm at 50/60 Hz, 4 poles = 1500/1800 rpm at 50/60 Hz, IP 55 (with drain hole with labyrinth plug), insulation class F.

Min/max motor speed:

2 poles: 0,75 - 45 kW . . . . 900 - 4000 rpm

2 poles: 55 - 110 kW . . . . 900 - 3600 rpm

4 poles: 0,75 - 75 kW . . . . 900 - 2200 rpm

(Close at hand, 2018 January ESE00361EN).

OPERATING DATA

Pressure

Max. inlet pressure:

LKH-5: . . . . 600 kPa (6 bar).

LKH-10 - 70: . . . . 1000kPa (10 bar).

LKH-70: 60Hz . . . . 500kPa (5 bar).

LKH-85 - 90: . . . . 500kPa (5 bar).

Temperature

Temperature range: . . . . -10°C to +140°C (EPDM).

Flushed shaft seal:

Water pressure inlet: . . . . Max. 1 bar.

Water consumption: . . . . 0.25 -0.5 l/min.

Double mechanical shaft seal:

Water pressure inlet, LKH-5 to -60: . . . Max. 500 kPa (5 bar).

Water pressure inlet, LKH-70 and -90: Max. 300 kPa (3 bar).

Water consumption: . . . . 0.25 -0.5 l/min.

(Close at hand, 2018 January ESE00361EN).

Warranty

Extended 3-years warranty on LKH pumps. The warranty covers all non-wear parts on the condition that genuine Alfa Laval Spare Parts are used. (Close at hand, 2018 January ESE00361EN).

Appendix 2 MR, Liquid ring pumps

Standard design

All product wetted parts including the pump casing, casing cover and impeller are built with AISI 316L stainless steel. Shaft seal the mechanical single seals have stationary seal rings of stainless steel AISI 329 and rotating seal rings of carbon.

Technical data

Materials Surface finish: . . . . Ra 32 µin.

Product wetted steel parts: . . . . Stainless steel AISI 316L and AISI 329L.

Other stainless-steel parts: . . . . Stainless steel

Adaptor: . . . . Mild steel grade.

Product wetted seals: . . . . EPDM (acc. to FDA).

Motor

Standard C-faced, foot mounted motor according to NEMA standard.

1750 RPM. Class F.

Voltage and frequency

3~, 50 Hz, 230/460V.

Motor sizes

166 50 Hz: 2,2, kW - 1450 RPM, 185 50Hz: 5.5 kW - 1450 RPM, 200 50Hz: 7,5 kW - 1450 RPM

OPERATING DATA

Pressure

Max. inlet pressure: . . . . .60 psi (4 bar).

Temperature

Temperature range . . . . 14 ° F to 284° F (EPDM)

Appendix 3 **SX, Rotary lobe pumps**

Standard Design

Pump Gearbox

The SX pump with its conventional lobe pump design concept has a robust cast iron gearbox, which provides maximum shaft rigidity and easy oil seal replacement. The SX range in series 1 - 4 has a universal gearbox design. This gives the flexibility of mounting pumps with the inlet and outlet ports in either a vertical or horizontal plane, by changing the foot and its position. The SX range in series 5 & 6 has dedicated gearbox castings, which also allows the inlet and outlet ports to be in either the vertical or horizontal plane. The SX series 7 has a dedicated gearbox casting allowing inlet and outlet ports in a vertical plane only. (Close at hand, 2018 January ESE00361EN).

Pump head Construction

The SX pump has hygienic design full bore inlet and outlet ports to International Standards, maximising inlet and outlet port efficiency and NPSH characteristics. Vertical porting and unique rotor case internal profile enhances self-draining and self-venting while maintaining optimum volumetric efficiency. The SX pump has four lobe rotors, designed using CFD (Computational Fluid Dynamics) to develop the optimum rotor geometry - possibly the first rotary lobe pump to be developed using this technology. All rotors are rated to 150°C facilitating use with CIP/SIP processes. (Close at hand, 2018 January ESE00361EN).

Maximum Solid Size Capability

Pump size	Max. Size of Spherical Solids (mm)
SX1	7
SX2	10
SX3	13
SX4	16
SX5	19
SX6	25
SX7	28

Materials of Construction

Pump gearbox - high quality grey cast iron.

Pump head - product wetted components in 316L.

Product wetted elastomers of EPDM, MVQ, FPM all FDA conforming.

All media contacting elastomers are controlled compression joints, the latest technology where static and dynamic elastomer seals are used to prevent pumped media leaking to atmosphere.

All product wetted rubber parts are in compliance with FDA section 21 CFR 177.2600 & section 21 CFR 177.1550 (PTFE). EPDM Elastomers are furthermore in compliance with USP Class VI section 88 biological reactivity test, in Vivo. (Close at hand, 2018 January ESE00361EN).

Weight

Model	Bare Shaft Pump (kg)	
	Horizontal porting	Vertical porting
SX1/005	15	16
SX1/007	16	17
SX2/013	32	33
SX2/018	33	34
SX3/027	57	59
SX3/035	59	61
SX4/046	107	110
SX4/063	113	116
SX5/082	-	155
SX5/115	-	165
SX6/140	-	278
SX6/190	-	290
SX7/250	-	340
SX7/380	-	362

Shaft Seal Options

- Single or single flush/quench (steam barrier for aseptic application) R00 type mechanical seals.

- Double R00 type mechanical seal for flush.

All sealing options are fully front loading and fully interchangeable without the need for additional housings or pump component changes. Specialised seal setting of the mechanical seal is not required as the seal is dimensionally set on assembly. This feature further enhances fast and efficient on-site seal interchangeability. (Close at hand, 2018 January ESE00361EN).

Materials for Mechanical Seals

Carbon/Stainless Steel, Silicon Carbide/Silicon Carbide or variations of these materials to suit fluid being pumped and/or application requirements. The seal seat and face material combinations are all EHEDG compliant. (Close at hand, 2018 January ESE00361EN).

Pump Sizing

In order to correctly size a rotary lobe pump some essential information is required. Provision of this information listed below enables our

Technical Support personnel to obtain the optimum pump selection. (Close at hand, 2018 January ESE00361EN).

Product/Fluid Data

- Fluid to be pumped
- Viscosity
- SG/Density
- Pumping temperature, minimum, normal and maximum
- Cleaning in Place temperature(s), minimum, normal and maximum. (Close at hand, 2018 January ESE00361EN).

Performance Data

- Flow rate, minimum, normal and maximum

- Discharge head/pressure (closest to pump outlet)

- Suction Condition. (Close at hand, 2018 January ESE00361EN).

Standard Specification Options

- Screwed male inlet and outlet ports to DIN11851, SMS, ISS/IDF, RJT or Tri-clamp.

- Heating/Cooling Jacket for Rotor Case Cover.

- Electropolished product wetted components.

- Full material traceability on request to EN 10204.3.1.

- ATEX compliance.

- Complete pump unit comprising: Pump + Baseplate (mild or stainless steel) + coupling with guard + Geared electric motor suitable for (or supplied with) frequency speed control or manual variable speed drive (advise motor enclosure and electrical supply). (Close at hand, 2018 January ESE00361EN).

Flows/Pressures/Connections

SX Series	Build Selection		SX Model	Displacement			Inlet and Outlet Connection Size		Differential Pressure (see note 1)		Maximum Speed
	Pumphead Code	Gearbox		Litres/rev	Imp gall/100 rev	US gall/100 rev	mm	in	bar	psi	rev/min
1	005 007	H or U H or U	SX1/005/H or U SX1/007/H or U	0.05 0.07	1.11 1.54	1.32 1.85	25 40	1 1.5	12 7	175 100	1400 1400
2	013 018	H or U H or U	SX2/013/H or U SX2/018/H or U	0.128 0.181	2.82 3.98	3.38 4.78	40 50	1.5 2	15 7	215 100	1000 1000
3	027 035	H or U H or U	SX3/027/H or U SX3/035/H or U	0.266 0.35	5.85 7.70	7.03 9.25	50 65	2 2.5	15 7	215 100	1000 1000
4	046 063	H or U H or U	SX4/046/H or U SX4/063/H or U	0.46 0.63	10.12 13.86	12.15 16.65	50 65	2 2.5	15 10	215 145	1000 1000
5	082 115	H H	SX5/082/H SX5/115/H	0.82 1.15	18.04 25.30	21.67 30.38	65 80	2.5 3	15 10	215 145	600 600
6	140 190	H H	SX6/140/H SX6/190/H	1.40 1.90	30.80 41.80	36.99 50.20	80 100	3 4	15 10	215 145	500 500
7	250 380	H H	SX7/250/H SX7/380/H	2.50 3.80	55.00 83.60	66.05 100.40	100 150	4 6	15 10	215 145	500 500

H - Vertical Port (EHEDG approved)
U - Universal mounting (non EHEDG approved)

Note: These pressure ratings may vary for pumps with certain threaded connection.

Appendix 5 FM, Centrifugal pump

Standard design

All product wetted parts, ie. pump casing, impeller and pump shaft, are made of acid-resistant steel 1.4404 (316L). Screws, yoke, nuts and adaptor are made of stainless steel. Seals are made of Nitrile (NBR).

Shaft seal

Mechanical single or flushed seal with stationary seal ring of acid-resistant steel AISI 329 with sealing surface of silicon carbid and with rotating seal ring of carbon.

TECHNICAL DATA

Motor

Standard foot-flanged motor acc. to IEC metric standard, 2 pol = 3000/3600 rpm. at 50/60 Hz, IP55 (with drain holes with labyrinth plug), insulation class F.

Motor size

50 Hz: . . . . 1.1 kW.

60 Hz: . . . . 1.3 kW.

OPERATING DATA

Pressure

Max. inlet pressure: . . . . 400kPa (4 bar).

Max. outlet pressure: . . . . 700kPa (7 bar).

Max. water pressure, (flushed seal): . . Normally atmospheric (max. 1 bar)

Temperature

Temperature range: . . . . -10°C to +140°C (EPDM).

Water consumption

Flushed seal: . . . . 0.25 - 0.5 l/min.

Impeller diameter

Impeller diameter: . . . . 115 mm.

Weight

Weight: . . . . 20 kg.

Appendix 4 SRU, Rotary lobe pumps

Standard Design

Pump Gearbox

The SRU pump with its conventional lobe pump design concept has a robust cast iron gearbox, which provides maximum shaft rigidity and easy oil seal replacement. The SRU range in series 1-4 has a universal gearbox design. This gives the flexibility of mounting pumps with the inlet and outlet ports in either a vertical or horizontal plane by changing the foot and its position. The SRU range in series 5 & 6 has dedicated gearbox castings, which also allows the inlet and outlet ports to be in either the vertical or horizontal plane.

Pump head Construction

The SRU in standard specification has sanitary design full bore inlet and outlet ports to International Standards, maximising inlet and outlet port efficiency and NPSH characteristics. Enlarged diameter and rectangular ports are also available to handle very high viscosity products. The SRU in standard specification has tri-lobe rotors with the option of bi-lobe rotors for handling fluids containing large delicate solids. All rotors are available in three temperature ratings allowing the pump to be operated at maximum process temperatures of 70°C, 130°C and 200°C for both fluid pumped and CIP.

Maximum Solid Size Capability

Pump size	Max. size of spherical solids (mm)	
	Bi-lobe rotors	Tri-lobe rotors
SRU1/005	8	6
SRU1/008	8	6
SRU2/013	8	6
SRU2/018	13	9
SRU3/027	13	9
SRU3/038	16	11
SRU4/055	16	11
SRU4/079	22	15
SRU5/116	22	15
SRU5/168	27	18
SRU6/260	27	18
SRU6/353	37	24

Materials of Construction

Pump gearbox - high quality grey cast iron. Pumphead - product wetted components in 316L. Product wetted elastomers of EPDM, NBR, FPM all FDA conforming. Also, PTFE for chemical applications.

Weight

Pump size	Bare Shaft Pump (kg)	
	Horizontal porting	Vertical porting
SRU1/005	15	16
SRU1/008	17	18
SRU2/013	28	30
SRU2/018	29	31
SRU3/027	53	56
SRU3/038	56	59
SRU4/055	105	111
SRU4/079	110	116
SRU5/116	152	152

SRU5/168	160	160
SRU6/260	260	260
SRU6/353	265	265

Shaft Seal Options

- Single or single flush/quench (steam barrier for aseptic application) R90 or Hyclean type mechanical seals.

- Double R90 type mechanical seal for flush.

- Packed gland (unflushed or flushed versions).

Note: EHEDG compliance only for Hyclean type mechanical seals.

Materials for Mechanical

Seals Carbon/Stainless steel, Tungsten Carbide/Tungsten Carbide, Silicon Carbide/Silicon Carbide or variations of these materials to suit fluid being pumped and/or application requirements. (N.B. Material variants are not available on all R90/Hyclean seal types)

Pump Sizing

In order to correctly size a rotary lobe pump some essential information is required. Provision of this information listed below enables our Technical Support personnel to obtain the optimum pump selection.

Product/Fluid Data

- Fluid to be pumped

- Viscosity

- SG/Density

- Pumping temperature, minimum, normal and maximum

- Cleaning in Place temperature(s), minimum, normal and maximum

Performance Data

- Flow rate, minimum, normal and maximum

- Discharge head/pressure (closest to pump outlet)

- Suction condition

Standard Specification Options

- Specification of inlet and outlet ports (Screwed male to BSP, DIN11851, Rdg, SMS, ISS/IDF, RJT, IAMD/3A, Tri-clamp and other standards, or Flanged to BS4504/DIN2533, ASA/ANSI 150, BS10E and other standards).

- Rotorcase Cover with integral Pressure Relief Valve.

- Heating/Cooling Saddle Jackets for Rotorcase and Jacket for Rotorcase Cover (not available when relief valve fitted).

- Bi-lobe Rotors in stainless steel and non-galling alloy.

- Electropolished product wetted components.

- Full material traceability on request to BS EN10204 3.1

- Electroless nickel plated gearbox.

- ATEX compliance.

- Complete pump unit comprising: Pump + Baseplate (mild or stainless steel) + coupling with guard + Geared electric motor suitable for (or supplied with) frequency speed control or manual variable speed drive (advise motor enclosure and electrical supply).

Flows/Pressures/Connections

SRU Series	Build Selection			SRU Model	Displacement			Inlet and Outlet Connection Size				Differential Pressure (see note 1)		Maximum Speed
	Pump Head Code	Gear-box	Shaft		Litres/rev	Imp gall/ 100 rev	US gall/ 100 rev	Sanitary		Enlarged		bar	psi	rev/min
								mm	in	mm	in			
1	005	L or H	D	SRU1/005/LD or HD	0.053	1.17	1.4	25	1	-	-	8	115	1000
	008	L or H	D	SRU1/008/LD or HD	0.085	1.87	2.25	25	1	40	1.5	5	75	1000
2	013	L or H	S	SRU2/013/LS or HS	0.128	2.82	3.38	25	1	40	1.5	10	145	1000
	013	L or H	D	SRU2/013/LD or HD	0.128	2.82	3.38	25	1	40	1.5	15	215	1000
	018	L or H	S	SRU2/018/LS or HS	0.181	3.98	4.78	40	1.5	50	2	7	100	1000
	018	L or H	D	SRU2/018/LD or HD	0.181	3.98	4.78	40	1.5	50	2	10	145	1000
3	027	L or H	S	SRU3/027/LS or HS	0.266	5.85	7.03	40	1.5	50	2	10	145	1000
	027	L or H	D	SRU3/027/LD or HD	0.266	5.85	7.03	40	1.5	50	2	15	215	1000
	038	L or H	S	SRU3/038/LS or HS	0.384	8.45	10.15	50	2	65	2.5	7	100	1000
	038	L or H	D	SRU3/038/LD or HD	0.384	8.45	10.15	50	2	65	2.5	10	145	1000
4	055	L or H	S	SRU4/055/LS or HS	0.554	12.19	14.64	50	2	65	2.5	10	145	1000
	055	L or H	D	SRU4/055/LD or HD	0.554	12.19	14.64	50	2	65	2.5	20	290	1000
	079	L or H	S	SRU4/079/LS or HS	0.79	17.38	20.87	65	2.5	80	3	7	100	1000
	079	L or H	D	SRU4/079/LD or HD	0.79	17.38	20.87	65	2.5	80	3	15	215	1000
5	116	L or H	S	SRU5/116/LS or HS	1.16	25.52	30.65	65	2.5	80	3	10	145	600
	116	L or H	D	SRU5/116/LD or HD	1.16	25.52	30.65	65	2.5	80	3	20	290	600
	168	L or H	S	SRU5/168/LS or HS	1.68	36.95	44.39	80	3	100	4	7	100	600
	168	L or H	D	SRU5/168/LD or HD	1.68	36.95	44.39	80	3	100	4	15	215	600
6	260	L or H	S	SRU6/260/LS or HS	2.60	57.20	68.70	100	4	100	4	10	145	600
	260	L or H	D	SRU6/260/LD or HD	2.60	57.20	68.70	100	4	100	4	20	290	600
	353	L or H	S	SRU6/353/LS or HS	3.53	77.65	93.26	100	4	150	6	7	100	600
	353	L or H	D	SRU6/353/LD or HD	3.53	77.65	93.26	100	4	150	6	15	215	600

L - Horizontal Porting
H - Vertical Porting
S - Stainless Steel
D - Duplex Stainless Steel

Note: These pressure ratings may vary for pumps with certain threaded connection.