

A FAILURE MODE AND EFFECT ANALYSIS ON WATER RECIPROCATING PUMP FOR DRILLING INDUSTRY

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Abstract

Pumps have been designed for a variety of purposes that operate to move liquid on high elevation and high pressure. One of them is a positive-displacement reciprocating duplex power pump. In drilling industry, it is used to circulate clean water to the supply tank, and to mix mud while simultaneously drilling. A Failure Mode and Effect Analysis (FMEA) was carried out on these pumps to analyze potential failures. In this study, the data of pump's failures, occurrences, and detection methods were collected from PT Airtara Bekasi and interpreted on a criteria rank system to determine its Risk Priority Number (RPN). Discussions on recommended actions to decrease failure risks were conducted in brainstorming meetings. Of the whole RPN results, the highest score which was scored 224 was found in a Silicon-Controlled Rectifier. To reduce RPN score of this pump, several steps were applied, namely: installed bridge diode to reduce ripple wave on converted DC waveform, installed fuse current to prevent damage from shorting, improved the quality of drive current, and implemented proper installation circuit diagram. The FMEA was then repeated to determine the new score of revised RPN. It decreased significantly from 224 to 54 or it had about 76% reduction.

Keywords: *Failure Mode and Effect Analysis, FMEA, Positive-Displacement Pump, Power Pump, Reciprocating Pump*

INTRODUCTIONS

Pump is a mechanical device which is driven by a power source that is used to move liquid (fluid) from one place to another, where the liquid flows only when there is a pressure difference. Pump can be defined as device to convert dynamic force to move the fluids into high pressured vessel. Besides being able to move the fluid, the pump also serves to increase the speed, pressure, and level of fluid [1, 2].

Pumps may be classified on the basis of the applications they serve, the materials from which they are constructed, the liquids they handle, and even their orientation in space [3]. Pumps

may be divided into two major categories: Dynamic, and Displacement. A positive displacement pump causes a fluid to move by trapping a fixed amount on the suction side and forcing (displacing) that volume through the outlet. Positive displacement pumps have an expanding cavity, or area, on the suction side expands and a contracting cavity on the discharge side. Positive displacement pump produce the same flow at a given rotational speed regardless of discharge pressure [3, 4].

Positive displacement pumps divided into two main groups, that is rotary pumps and reciprocating pumps. Reci-

procating pumps include piston, plunger pumps, and diaphragm pumps. Reciprocating pumps cause the fluid to move using one or more oscillating pistons, plungers, or membranes (diaphragms). Reciprocating pumps require a system of suction and discharge valves to ensure that fluid moves in one direction. Reciprocating positive displacement pump is one in which a plunger or piston displaces a given volume of fluid for each stroke. The basic principle of a reciprocating pump is that a solid will displace an equal volume of liquid [3][4].

Failure Mode and Effects Analysis (FMEA) is one of the most popular methods for the systematic prevention of errors. The problem of early defect detection has become so important to result in developing a method for identifying errors in the design phase of the product [5]. A failure mode and effect analysis (FMEA) is an engineering technique used to define, identify, and eliminate known and/or potential failure, problems, errors, and so on from the system, design, process, and/or service before they reach the customer [5]. A failure modes and effects analysis (FMEA) is a methodology in product development and operations management for analysis of potential failure modes within a system for classification by the severity and likelihood of the failures [6].

A successful development of FMEA is very important for product manufacturers to deliver high quality products to their customers on time in turn the manufacturers will be able to compete in the global market [7]. FMEA helps the engineer to design reliable and safe product by mitigating the anticipated failure modes. The risk associated with each failure mode is evaluated using Risk Priority Number (RPN) which is calculated by multiplying severity (S), occurrence (O) and detection (D) ratings. Severity rating is assigned according to seriousness of an effect of a failure mode.

Occurrence rating is based on the failure probability during the product life. Similarly, detection rating is according to ability to identify a risk occurrence [8].

Rating scales usually range from 1 to 5 or from 1 to 10, with the higher number representing the higher seriousness or risk. After the ratings have been assigned, the RPN for each issue is calculated by multiplying Severity x Occurrence x Detection. In this study, the data of pump's failures, occurrences, and detection methods were collected from PT Airtara Bekasi and interpreted on a criteria rank system to determine its Risk Priority Number (RPN). Discussions on recommended actions to decrease failure risks were conducted in brainstorming meetings.

RESEARCH METHOD

The first thing to run FMEA is to select the process to analyse. The importance of the process in terms of the impact of potential failures is a parameter that has to be taken into account as selection criteria. Research Method must be processed step by step as shown on Figure 1.

Retrieving Information

An Information was gathered from personal communication with director, chief mechanic, and the entire staff of mechanic, then the process could be analysed and described in a flowchart.

Sorting Failure mode, Effect, and Higher Effect

The entire potential effects of each failure mode, the effect that caused, the higher effect for each component was listed. The potential effect of each failure was listed next to the failure.

Assign a Severity, an Occurrence, and a Detection Criteria

Severity, occurrence, and detection

rating for each failure mode was assigned; data on the failures of your product's competition was collected.

Calculate the risk priority number (RPN)

RPN was calculated from multiplying the severity rating by the occurrence rating by the detection rating. After doing that, the entire of RPN result was sorted

after calculate RPN and the highest number which makes that component will be prioritized was taken.

Brainstorming ways and Take Action

An action for prioritized the failure modes was taken, and the items that needs to be worked on right away was decided. Brainstorming was conducted to find the way how to reduce the severity,

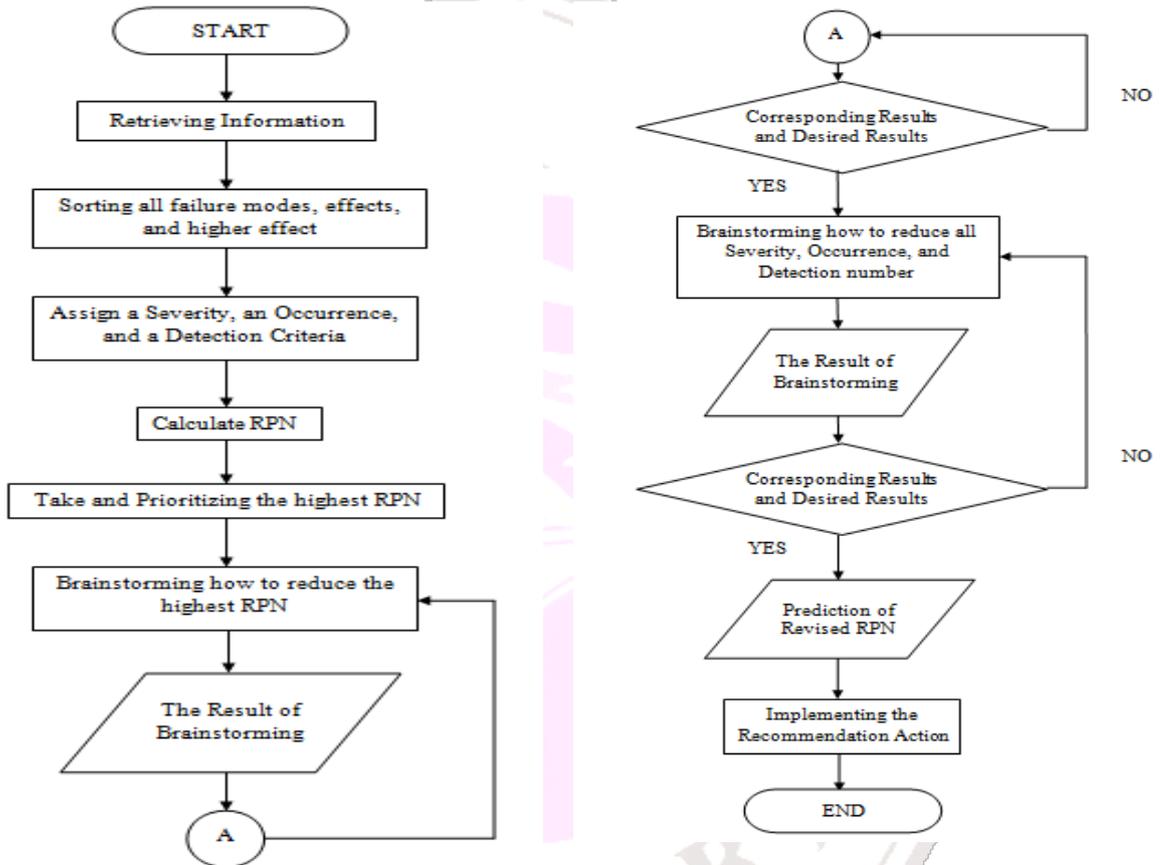


Figure 1. Flowchart of Research Method

occurrence, detection, RPN, and what action should be taken at recommendation. Each stage of the process was looked and the ways it could potentially fail, and things that might go wrong was identified after found the way what recommendation should be taken.

Revising the RPN number

A revised RPN results could be calculated after found what recommendation should be taken. The Revised RPN result was acquired from predicting what happen after recommendation action was

implemented. Prediction what happen after recommendation action implemented was predicted while brainstorming meeting were being conducted.

RESULT AND DISCUSSION

Specification

These are the specification of pumps that most of customers are used. Even though the maximum pressure for duplex piston power pumps are up to 2,000 psi, the customers tuned in only up

to 1600 psi. The reason is because for water suction, the customers and company said it was the efficient pressure, and for long-lasting life-time of piping. If the pressure was too high, the life-time of piping will be shortening. The performance rating is show in figure 2.

SPECIFICATIONS:

- Maximum BHP:
 - Mud Service : 32 (24 kW)
 - Industrial Service: 42.5(32 kW)
- Maximum Jackshaft:
 - Mud Service : 354
 - Industrial Service: 472
- Number of Pistons : 2
- Stroke Length : 6 inch (152 mm)
- Piston Rod Load :6.122 lbs (2.777 kg)
- Oil Capacity :4.5 gallons (17 litres)
- Pump Weight : 2.300 lbs (1.043 kg)

Component List

This session explained about the components that use the duplex reciprocating pump piston, which have failed or have potential failure / damage. In Table 2, the data and information about the list of components, which is experiencing or has the potential failure modes of failure are taken based on the results of interviews and visits to the company.

Potential Of Failure and Effect, Severity, Occurrence, Detection, and Risk Priority Number (RPN)

This session explained about Failure modes, Effects, Higher Effects, Severity that is caused, occurrence, and detection for each component. From Table 3, Failure mode, effect, and higher effect are explained from each component parts. This session explained about Severity that is caused by the effect from failure mode. From Table 4, the severity that caused from each potential failure components are explained from each component parts.

In Table 5, the Occurrence that caused from each potential failure components are explained from each component parts. This session explained about detection level for each component. That means how much chance or level to detect the failure at each component part before it will occur a higher effect which is caused more severity. The Detection level for detect chance to cause failure or its potential from each components can be seen at Table 6.

This session explained about Severity, Occurrence, Detection, and Risk Priority Number (RPN) for each component. Based on Equation 1, RPN is gained from Severity number times Occurrence number times Detection Number. each component can be seen at Table 7.

FXG DUPLEX INDUSTRIAL PUMP for Oil Line, Mining and Industrial Service																
Model	Stroke	Liner Size Diameter		Normal Operation				** Maximum Recommended Operation				*** Maximum Working Pressure		Maximum Piston Load		
				Displacement		Max Pump RPM	Jack-shaft RPM	Input HP at Max. Speed	Displacement		Max Pump RPM				Jack-shaft RPM	Input HP at Max. Speed
		in.	mm	gpm	lpm				gpm	lpm		psi	kg/cm2			
FXG(*)	(152 mm)	5	127.0	150	568	75	354	32	200	757	100	472	42.5	310	21	6,122 lbs. (2,777 kg)
		4 ½	114.3	121	458				161	609				385	27	
		4	101.6	95	359				126	477				492	34	
		3 ½	88.9	72	272				96	363				646	45	
		3	76.2	52	197				69	262				895	62	
FXG DUPLEX MUD PUMP for Mud, Grout and Cement Service																
Model	Stroke	Liner Size Diameter		Normal / Maximum Recommended Operation				*** Maximum Working Pressure		Maximum Piston Load						
				Displacement		Max Pump RPM	Jack-shaft RPM				Input HP at Max. Speed					
		in.	mm	gpm	lpm			psi	kg/cm2							
FXG(*)	(152 mm)	5	127.0	150	568	75	354	32	310	21	6,122 lbs. (2,777 kg)					
		4 ½	114.3	121	458				385	27						
		4	101.6	95	359				492	34						
		3 ½	88.9	72	272				646	45						
		3	76.2	52	197				895	62						

Based on 90% mechanical efficiency and 100% volumetric efficiency.

Specifications subject to change without notice.

Figure 2. Performance Rating

Table 2. Component list

No.	Component	Component Parts Image
1	Rolling Type Bearing	
2	Rolling Type Bearing	
3	Sleeve Type Main Bearing	
4	Rubber Piston	
5	Rubber Piston	
6	Rod	
7	Valve	

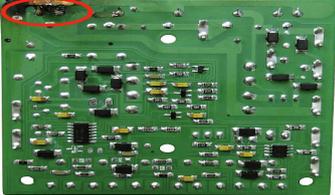
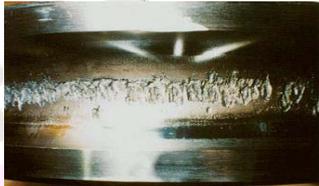
No.	Component	Component Parts Image
8	Valve	
9	SCR (DC Motor)	 [15]
10	Bearing (DC Motor)	 [14]
11	Gasket (DC Motor)	

Table 3. Potential of failure and effect sheet

No.	Component	Failure Mode	Effect	Higher Effect
1	Rolling Type Bearing	Overspeed/ Exceeding the speed limit	Overheat	Damaged
2	Rolling Type Bearing	Run out of Lubricant	Overheat	Damaged
3	Sleeve Type Main Bearing	Run out of Lubricant	High Pressure	Pressure has been returned
4	Rubber Piston	Damaged on the rubber parts	Compression loss, Pressure Loss	-
5	Rubber Piston	Failure on Strainer	Pressure Loss	-
6	Rod	Gland Packing has Burned / Dried	Leakage	Pressure loss
7	Valve	Stoppage by foreign material	Pressure loss	-
8	Valve	Seal became Brittle	Damaged	Water loss
9	SCR (DC Motor)	Failure on Input Power	Damaged on Coil	-
10	Bearing (DC Motor)	Run Out of Lubricant	Overheat	Damaged
11	Gasket (DC Motor)	Damaged	Oil Leakage	Pressure loss

Table 4. Severity Sheet

No.	Component	Severity	Description
1	Rolling Type Bearing	Extreme	Product performance is severely affected but functions. Operate the system may not operate
2	Rolling Type Bearing	Major	Product performance is degraded. Comfort or convince functions may not operate.

No.	Component	Severity	Description
3	Sleeve Type Main Bearing	Major	Product performance is degraded. Comfort or convince functions may not operate.
4	Rubber Piston	Major	Product performance is degraded. Comfort or convince functions may not operate.
5	Rubber Piston	Major	Product performance is degraded. Comfort or convince functions may not operate.
6	Rod	Low	Irregularities can be seen, but the vehicle can operate, but in a safe condition and can be seen by customers above 50%.
7	Valve	Significant	Moderate effect on product performance. The product Requires repair.
8	Valve	Moderate	Small effect on product performance. The product does not Require repair.
9	SCR (DC Motor)	Extreme	Product performance is severely affected but functions. Operate the system may not ope-rate
10	Bearing (DC Motor)	Major	Product performance is degraded. Comfort or convince functions may not operate.
11	Gasket (DC Motor)	Low	Irregularities can be seen, but the vehicle can operate, but in a safe condition and can be seen by customers above 50%.

Table 5. Occurrence Sheet

No.	Component	Occurrence	Description
1	Rolling Type Bearing	Low	Isolated failures are only dealing with almost the same design or the design simulation and/or testing.
2	Rolling Type Bearing	Low	No failures were observed associated with almost the same design or the design simulation and/or testing.
3	Sleeve Type Main Bearing	Moderate	Isolated failures associated with the same design or the design simulation and/or testing.
4	Rubber Piston	Moderate	Sometimes related failures occur because of the same design or the design simulation and/or testing.
5	Rubber Piston	Moderate	Sometimes related failures occur because of the same design or the design simulation and/or testing.
6	Rod	Moderate	Failure frequency associated with the same design or the design simulation and/or testing.
7	Valve	Low (Depend on Condition)	No failures were observed associated with almost the same design or the design simulation and/or testing.
8	Valve	Low (Depend on Condition)	Isolated failures are only dealing with almost the same design or the design simulation and/or testing.
9	SCR (DC Motor)	Moderate	Isolated failures associated with the same design or the design simulation and/or testing.
10	Bearing (DC Motor)	Low	Impreventive Control/Maintenance Process
11	Gasket (DC Motor)	Low	Impreventive Control/Maintenance Process

Table 6. Detection Sheet

No	Component	Detection	Description
1	Rolling Type Bearing	Almost Sure	Design control will almost certain detect a potential cause/mechanism and Subsequent failure mode
2	Rolling Type Bearing	Almost Sure	Design control will almost certain detect a potential cause/mechanism and Subsequent failure mode
3	Sleeve Type	Almost Sure	Design control will almost certain detect a potential

4	Main Bearing Rubber Piston	High	cause/mechanism and Subsequent failure mode Detection of failure modes in the station with automatic safety controls that would detect the detected part, and automatically lock the station to prevent further proceedings
5	Rubber Piston	High	Detection of failure modes in the station with automatic safety controls that would detect the detected part, and automatically lock the station to prevent further proceedings
6	Rod	Almost Sure	Design control will almost certain detect a potential cause/mechanism and Subsequent failure mode
7	Valve	High	Detection of failure modes in the station with automatic safety controls that would detect the detected part, and automatically lock the station to prevent further proceedings
8	Valve	High	Detection of failure modes in the station with automatic safety controls that would detect the detected part, and automatically lock the station to prevent further proceedings
9	SCR (DC Motor)	Very Low	Detection of the cause / potential mechanism and subsequent failure mode on the control design has a very low chance
10	Bearing (DC Motor)	Almost Sure	Design control will almost certain detect a potential cause/mechanism and Subsequent failure mode
11	Gasket (DC Motor)	Almost Sure	Design control will almost certain detect a potential cause/mechanism and Subsequent failure mode

Table 7. RPN Sheet

Component	Failure Mode	Effect	Severity	Occurrence	Detection	RPN
Rolling Type Bearing	Overspeed/ Exceeding the speed limit	Overheat	8	3	1	24
Rolling Type Bearing	Run out of Lubricant	Overheat	7	2	1	14
Sleeve Type Main Bearing	Run out of Lubricant	High Pressure	7	4	1	28
Rubber Piston	Damaged on the rubber parts	Pressure loss	7	5	3	105
Rubber Piston Rod	Failure on Strainer Gland	Pressure Loss Leakage	7	5	3	105
Valve	Packing has Burned/Dried Stoppage By foreign material	Pressure loss	5	2	3	30
Valve	Seal became Brittle	Damaged	6	3	3	64
SCR (DC Motor)	Failure on Input Power	Damaged on Coil	8	4	7	224
Bearing (DC Motor)	Run out of Lubricant	Damaged	7	1	1	7
Gasket (DC Motor)	Damaged	Oil Leakage	4	1	1	4

Where:

Severity	Rank	Occurrence	Rank	Detection	Rank
Hazardous	10	Very High	10	Almost impossible	10
Serious	9		9	Very limited	9
Extreme	8	High	8	Limited	8
Major	7		7	Very low	7
Significant	6	Moderate	6	Low	6
Moderate	5		5	Moderate	5
Low	4		4	Moderately high	4
Minor	3	Low	3	High	3
Very Minor	2		2	Very high	2
Not Affect	1	Very Low	1	Almost Certain	1

From Table 7, the highest number on RPN can be seen, that is SCR component on DC motor. The second one is Rubber Piston component. The highest number that on SCR component is 224, then RPN number on Rubber Piston is 105. In this case, the highest number has to prioritize for recommendation action first. The prioritized components are SCR and Rubber Piston component.

Analysis And Recommendation

Based on result of interview and RPN table above, it can be concluded that all customer use curative maintenance method on the most components. Curative/corrective maintenance is a maintenance task performed to identify, isolate, and rectify a fault so that the failed equipment, machine, or system can be restored to an operational condition within the tolerances or limits established for in-service operations.

Bearing Recommendation

First recommendation for lubricant failure is lubricant selection. Lubrication obviously plays a vital role in the performance and life of a bearing. Without lubrication, bearings can be expected to fail early and possibly cause other equipment to fail. The three main concerns with bearing lubrication are: (1) Specifying the right amount, (2) Specifying the right. and (3) Keeping the lubricant

clean. For reciprocating duplex pump case, Oil lubricant is the most preferred because it is suitable for medium-high speed or operating condition. Non-detergent oil SAE 30 to 50 is used for bearing lubrication. The second recommendation is re-lubrication.

Re-lubrication is to apply some oil or grease substance to a machine, parts of a mechanism, etc. in order to diminish friction. Relubrication is necessary because of grease degradation. Grease degradation is a gradual process; grease does not abruptly cease to be an effective lubricant.

Valve Recommendation

The first recommendation action that must be taken is to change curative maintenance method into predictive, periodic or preventive maintenance method. It is important because there are so many factors that can cause valve failure, especially on water lose problem/failure. To prevent broken valve springs, valve and seats wear-out, and relief of bypass valve(s) leaking factor, periodic maintenance can be applied. For applying predictive or preventive maintenance method, volumetric efficiency, suction pressure, pump speed, and cylinder operating status factor can be used as a benchmark.

The second recommendation is to choose valve type correctly. In this case,

plate and wing type are the best option. Depend on customer's pump, for plate type, it is the best when the pressure pump is 5,000 PSI, and for wing type is 10,000 PSI. If not choose valve type correctly, it will cause excessive suction lift, low volumetric efficiency, and not enough suction pressure that cause valves and seats wear-out, and its effect is water loss failure.

Rubber Piston Recommendation

Because of the close tolerances between the pistons and the cylinder walls, reciprocating pumps cannot tolerate contaminated liquid in their suction-supply system. If the customer does not install strainer and foot-valve (non-return type) on the pump, the first recommendation is install it. If the customer only install strainer, adding the foot-valve is recommended. The foot-valve allows water to flow only in the upward direction in the suction pipe. It helps for the strainer to filter foreign material on the best condition.

The second recommendation is to change curative/corrective maintenance method become periodical and preventive maintenance method. For cleaning filter, strainer, and valve check, it should be done in the daily checks. Then for water leaks check, it should be done in the daily checks too. For seal, strainer, and valve change, each system's maintenance cycle will differ. If system performance decreases, check immediately. If no wear at 1,500 hours, check again at 2,000 hours and each 500 hours until wear is observed. Valve typically requires changing every other seal change. Checking and changing the time can vary according to the evaluation, and reference from each manufacturer. It is important to follow the manufacturer's recommendations for valve, seal, and strainer maintenance and replacement.

The third recommendation is to choose strainer correctly. The strainer

should be chosen depends on customer desire, environmental, liquid type, pressure, mesh/filtration size range, filtration area, piping shape and size, and how long the customer want to use strainer (temporary or permanent).

Rod (Gland Packing) Recommendation

The first recommendation is lubrication of packing selection. There are two type of lubricant; it is grease and oil lubricant. Under conditions of heavy use and at the recommendation of some manufacturers, packing is lubricated and cooled with grease or oil. Various types of grease cups and auto motor oiling arrangements are used. Regardless of the type of installation, care should be taken to obtain the proper type of grease or oil. The second recommendation is the customer have to learn and know how to proper packing installation. One cause of packing failure is improper packing installation.

This recommendation is to prevent it. To ensure proper installation, first measure the packing for consistent width. Don't rely on what's printed on the spool or box. Next, inspect the old rings as discussed above, and look at the stuffing box and sleeve. Don't ignore gouges or burrs, as they will gradually destroy any packing. Also, many packing rings will shrink over time, and misdirected cooling water will seep outside the rings, causing them to become hard and fail. Replacing damaged equipment now will eliminate more serious problems later on.

The third recommendation is packing selection. By selecting the proper packing, making sure there are no equipment problems, and installing the packing correctly, the customer will be able to rely on this packing until the next scheduled packing replacement. Normal periodic inspections are all that should be required along the way. Packing is selected for the pump operating pressure,

shaft speed, pumped fluid temperature and type of fluid being pumped.

SCR (DC Motor) Recommendation

The first recommendation is to reduce ripple wave. This waveform has a small unwanted residual periodic variation of the direct current (DC) output of a power supply which has been derived from an alternating current (AC) source. To reduce ripple wave, Diode Bridge can be used. See at this Figure 2.

A Diode Bridge is an arrangement of four or more diodes in a bridge circuit

configuration which provides the same output polarity for either input polarity. It is used for converting an alternating current (AC) input into a direct current (DC) output. A Diode Bridge provides full-wave rectification from a two-wire AC input.

The purpose for installing Diode Bridge is to reduce ripple wave and smoothing converted DC waveform (see Figure 3).

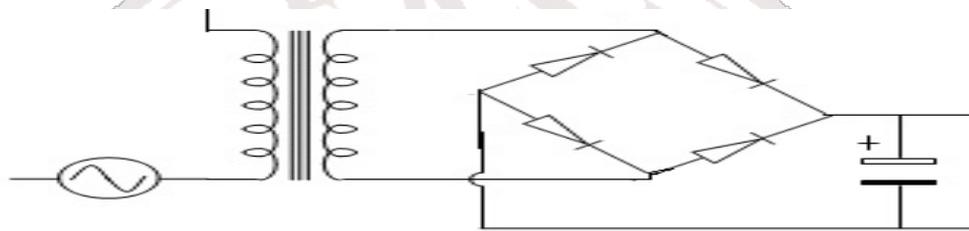


Figure 2. Circuit Diagram with Bridge Diode

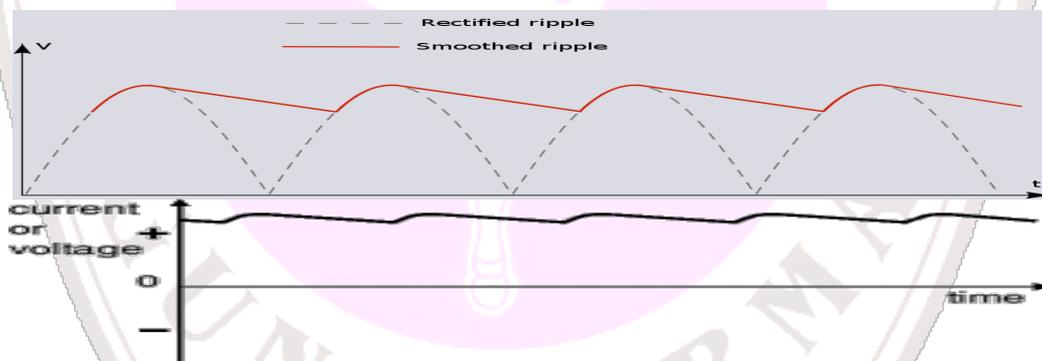


Figure 3: Smoothed Converted DC Waveform

SCR works like a faucet, when the faucet opened, the water was flowing from faucet. It is same as SCR principle, when SCR received a signal, SCR the current was flowing. The signal that are used to SCR is called Drive Current (I_{drive}) (see Figure 4).

If the Drive current quality is having shorting, it will cause failure on SCR component. The second recommendation is preventing Drive Current shorting. To prevent Drive Current shorting, Fuse Current or Circuit Breaker can be

used. If shorting happens there, the fuse will break and drive current will be disconnected. This method is proposed to prevent SCR get burned from shorting effects. The Circuit Breaker can be installed after switch and before SCR component (see Figure 5).

From overall recommendation for SCR component, this diagram is recommended for SCR installation (see Figure 6). There are 3 Fuse Currents. Each Fuse has each role. The first one is for AC shorting breaker, the second one

is for Drive Current shorting breaker, and the last one is for prevent diode bridge, capacitors, and SCR have shorting. Lamp has purpose for help detecting where is the shorting happens. Diode is installed

to help DC Motor release its residual voltage. Residual voltage can cause failure on DC motor. This circuit diagram is purposed to prevent and reduce failures on DC motor and SCR Component.



Figure 4. Drive Current

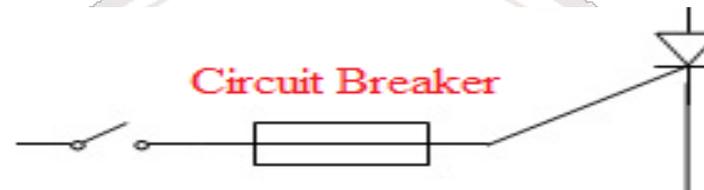


Figure 5. Installation of Circuit Breaker

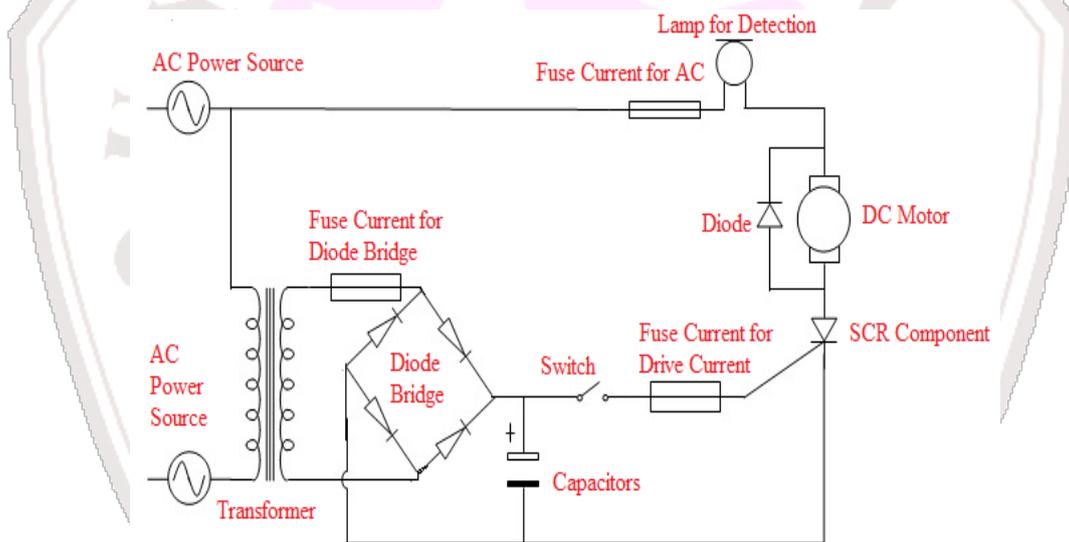


Figure 6: Installation Recommended Circuit Diagram

Revised RPN

In this section, the result of Revised Risk Priority Number (RPN) can be seen. Level criteria score from result of Revised RPNs can be seen at Table 8. These revised RPN results are got from prediction after recommendation action from brainstorming implemented. This result of revised RPN can be changed depends on the customers. There are so many customers that have a periodical

maintenance schedule but they are still having curative / corrective maintenance issue.

The reason is because the customers were not responsive. While in periodical maintenance process, most of customers are ignore the small irregularities that can cause the big issue. The responsive action is necessary even though recommendation actions are being taken. The red box with black

colour number means the level number before revised that must be prioritized.

The blue box means the level number after got revised. The yellow box means the RPN result before get revised. The green box means the RPN result after got revised. The deep red box with white colour number means the RPN result before get revised that must be prioritized.

$$\%Reduction\ in\ RPN = \frac{224 - 54}{224} \times 100 = 75.89\%$$

Reduction in the highest score on result of revised RPN is 75.89%. Reduction on the rubber piston component on result of revised RPN is 65.71%. Reduction on valve component on result of revised RPN is 87.5%. In this result of revised RPN, the purpose of FMEA is accomplished. That is to decrease the most prioritized component RPN more than 50%.

Table 8. Revised RPN

Component	Failure Mode	Effect	Severity	Occurrence	Detection	RPN
Rolling Type Bearing	Overspeed / Exceeding the speed limit	Overheat	8	3	1	24
			6	1	1	6
Rolling Type Bearing	Run out of Lubricant	Overheat, Damaged	7	2	1	14
			5	1	1	5
Sleeve Type Main Bearing	Run out of Lubricant	High Pressure	7	4	1	28
			5	1	1	5
Rubber Piston	Damaged on the rubber parts	Pressure loss	7	5	3	105
			4	3	3	36
Rubber Piston	Failure on Strainer	Pressure loss	7	5	3	105
			4	3	3	36
Rod	Gland Packing have Burned/Dried	Leakage	4	6	1	24
			4	3	1	12
Valve	Stoppage By foreign material	Pressure loss	5	2	3	30
			3	1	2	6
Valve	Seal became Brittle	Damaged	6	3	3	64
			4	1	2	8
SCR (DC Motor)	Failure on Input Power	Damaged on Coil	8	4	7	224
			6	3	3	54
Bearing (DC Motor)	Run out of Lubricant	Damaged	7	1	1	7
			5	1	1	5
Gasket (DC Motor)	Damaged	Oil Leakage	4	1	1	4
			4	1	1	4

Where:

Severity	Rank	Occurrence	Rank	Detection	Rank
Hazardous	10	Very High	10	Almost impossible	10
Serious	9		9	Very limited	9
Extreme	8	High	8	Limited	8
Major	7		7	Very low	7
Significant	6	Moderate	6	Low	6
Moderate	5		5	Moderate	5
Low	4		4	Moderately high	4
Minor	3	Low	3	High	3
Very Minor	2		2	Very high	2
Not Affect	1	Very Low	1	Almost Certain	1

Conclusion

The highest number in severity criteria is on Rolling type Bearing and SCR component. The highest number in occurrence criteria is on rubber piston and rod component. The highest number in detection criteria is on SCR component. The highest number in RPN is on Silicon Controller-Rectifier (SCR) on DC motor component, and Rubber piston on Pump Component. Because of this, the highest number in RPN becomes the most prioritized component for recommendation action that must be taken.

For Bearing Components, its recommendations are lubricant selection and Re-lubrication. For reciprocating duplex pump case, Oil lubricant is the most preferred because it is suitable for medium-high speed or operating condition. Non-detergent oil SAE 30 to 50 is used for bearing lubrication.

For Valve Components, its recommendations are to change curative maintenance method into predictive, periodic or preventive maintenance method and to choose valve type correctly. Depend on customers pump, for plate type, it is the best when the pressure pump is 5,000 PSI, and for wing type is 10,000 PSI. For Rubber Piston Components, its recommendations are installing strainer (if the pump does not have it) and foot-valve (non-return type) on the pump, changes curative/corrective maintenance method become periodical and preventive maintenance method, and choose strainer correctly.

For Rod (Gland Packing parts) Components, its recommendations are lubrication of packing selection, learn and know how to proper packing installation, and packing selection. For Silicon-Controlled Rectifier Component, its recommendation is to reduce ripple wave at converted DC waveform into pure DC waveform, prevent drive current shorting, installing fuse current / Circuit

breaker, and release residual voltage on DC motor.

The most prioritized component that has the highest number in RPN, has become reduced from 224 score to become 54 for SCR component, and from 105 to become 36 for Rubber Piston component. The responsive action is necessary even though recommendation actions are being taken. Reduction in the highest score on prediction result of revised RPN is 75.89%.

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