Maintenance Analysis of Boiler Feed Water Pump using Quantitative Methods

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Abstract: The boiler feedwater pump is a multistage pump driven by a boiler feed pump steam turbine on a steam power p plant. A boiler feedwater pump has many failures, the example high temperature and vibration in bearing and mechanical seal, leak in valve and line connection, etc. The failure in every component in the boiler feedwater pump could be reduced by maintenance analysis. There are many methods for maintenance analysis, one of that is quantitative analysis methods. Maintenance analysis with quantitative methods uses downtime data on the BFP component as reference data. The downtime data is simulated using Weibull 6 ++ software to get the right distribution to determine the value of Reliability (R (t)), MTTF (Mean Time To Failure), and failure rate. The result of maintenance analysis using quantitative methods is the reliability of the Boiler Feed Water Pump components decreases over time, the result of the Mean Time To Failure calculation is the value on the BFP component obtained the lowest MTTF value is the solenoid valve with the MTTF value 408.62 and the highest MTTF value on the accumulator and regulator with MTTF value 57428.358. The maintenance recommendation on BFP components are the components that have CFR failure rate characteristics the maintenance recommendations are corrective maintenance, and the maintenance recommendation for components that have failure rate IFR and DFR are preventive maintenance.

1 INTRODUCTION

The development of coal production in 2009-2018 increased significantly with the production of 557 million tons in 2018. One of the factors which cause the low realization of coal consumption is the operation of the steam power plant in a 35,000 MW program is not according to the plan and declining of the industry activities. In 2018, power plant production reached 283,8 TWh which was derived from 56.4% coal, 20.2% gas, 6.3% fuel, and 17.1% NRE (New Renewable Energy) (Secretariat General National Energy Council, 2019).

Steam Power Plant is a thermal power plant where water is converted into steam high temperature to rotate the steam turbine at a required rpm to generate electricity. The Steam power plant has many critical components there are boiler, low and high-pressure turbine, condenser, feed water pump, etc (Ahmed and Billah, 2012). Feedwater Pump or boiler feed water pump (BFP) is the main pump of a steam power plant, and it is the critical component of a steam power plant.

The Boiler feedwater pump (BFP) is a pump driven by a steam turbine boiler feed pump, the steam of the turbine boiler feed pump is from the extraction main steam turbin (PLTU 1 Jawa Tengah). The function of this pump is to supply feed water to boilers from the deaerator to the steam drum bypassing the high-pressure heater (HPH). This is the main pump in steam power plant so When this pump is tripped, the steam power plant can not produce electricity because this pump cannot be operated it can affect the performance of the other components. The failures on the boiler feedwater pump can be resolved by maintenance.

Maintenance is a routine activity to keep a particular machine at its normal condition so, it can deliver the expected performance without causing any looses and failure (Tadi and Ouali, 2011). Maintenance has 3 types there are preventive maintenance, corrective maintenance, and predictive maintenance. The maintenance analysis method to determine the reliability of the BFP component could use quantitative methods (Dhilon, 2006).

Maintenance analysis with quantitative methods uses downtime data on the BFP component as reference data for quantitative analysis. The downtime

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data is simulated using Weibull 6 ++ software to get the right distribution to determine the value of Reliability (R (t)), MTTF (Mean Time To Failure), and failure rate. the types of distributions used in reliability calculations are lognormal distribution, normal distribution, Weibull distribution, and exponential distribution

The previous study entitled “A study of the quantitative methods that support RCM operation” this research discusses investigates the quantitative methods to support the Reliability Centered Maintenance (RCM) operation. The result of this research is the quantitative method especially probability theory is commonly used to the RCM method to identify the maintenance analysis. the probability theory in quantitative methods can determine the distribution used to calculate reliability and the Mean Time to Failure in the RCM method (Mendes and Ribeiro, 2015).

The previous study entitles “Availability Analysis of Heat Recovery Steam Generators Used in Thermal Power Plants” discusses the method for reliability and availability evaluation in HRSG, especially two HRSG in 500 MW combines-cycle power plant. The first stepis knowing the generator functional tree and FMEA analysis, the second step involves reliability and availability based on the time to failure data after thatit could be obtained the availability value for each HRSG components. After that, the maintenance analysis will be improved through the use of reliability centered maintenance (RCM) concepts (Carazas and Salazar, 2011).

1.1 Maintenance on Boiler Feed Pump Turbine

A. Boiler Feed Water Pump

The boiler feed Water Pump (BFP) is one of the critical rotating machinery on steam power plants (Yoshikawa, 2016). The Boiler feedwater pump is the application of large-sized centrifugal pumps in the steam power plant. TheBoiler feedwater pump serves to control and supply water from the water tank (feed water tank) to the boiler with certain pressure specifications.

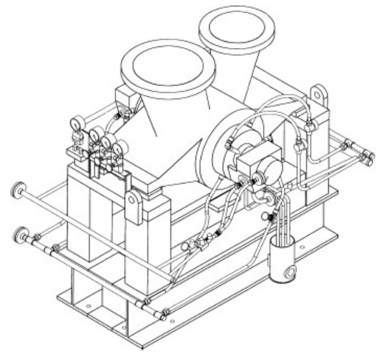

Figure 1: Boiler Feedwater Pump.

The boiler feedwater pump is driven by a small turbine, turbine boiler feed pump driven by steam from extraction in the main turbine. The workings of the boiler feedwater pump (BFP) are a shaft from the turbine boiler feed pump coupled with the boiler feed pump turbine shaft so the pump can be driven. When the BFP’s shaft rotated, the impeller attached to the shaft also rotated, and then the water can enter through the suction pump.

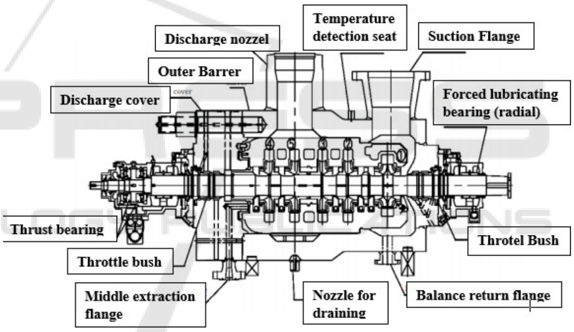

Figure 2: Components of the boiler feedwater pump.

The components of the boiler feed pump water pump are coupling, bearing, turning gear, mechanicalseal, selenoid valve, sensor LCV, control valve, transmitter, regulator, etc (Dhilon, 2006). These components mutually affect the performance of this boiler feed water pump, when one of the components has a failurethen the performance of the BFP will decrease or thisBFP will be trip.

B. Maintenance

The definition of maintenance is the technical and managerial action taken during component or asset usage period to maintain and restore the function (Shin and Jun, 20015). Maintenance has a function or influence on components, i.e (Patton and Joseph, 1995) :

1. Every component has a useful life and in the future could have many failures.

2. To find out precisely the equipment will behas a failure
3. To increase the lifetime of an operating unit.

Maintenance applications can be divided intoseveral types, among others :

a. Corrective Maintenance
   Corrective maintenance is maintenance activities are carried out on machines that fail and cannot function properly (Dhilon, 2006). The characteristic of corrective maintenance is replacing parts that are failing and the failure will affect the performance of other components or units.

b. Preventive Maintenance
   Preventive maintenance is maintenance that is scheduled and periodically (Dhilon, 2006). Preventive maintenance aims to expedite the production process and reduce the possibility of failures that will occur in the operating unit. Preventive maintenance can also determine the maintenance schedule so it can maintain the performance of equipment and prevent equipment from failing(MathWorks,2019).

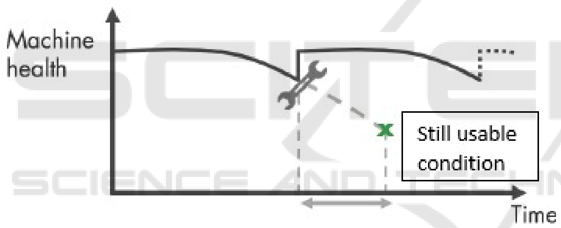

Figure 3: Preventive Maintenance.

c. Predictive Maintenance
   Predictive maintenance is a method that can predict the lifetime of a component, based on inspection or diagnosis so that the component's lifetime can be known (Dhilon, 2006). Knowing the predicted failure time will help to find the optimum time to schedule maintenance for the equipment.

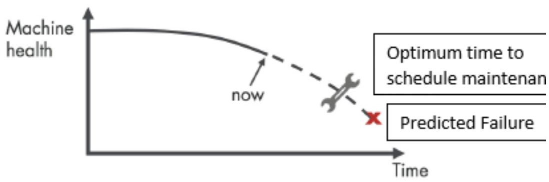

Figure 4: Predictive Maintenance.

C. *Quantitative Analysis Method*

The quantitative analysis method is a numerical method that can be used to determine the level of reliability of equipment by using mathematical calculations based on the distribution formula (Ebelling,1997).

1. Normal Distribution
   A normal distribution is used to model the phenomenon of wear and tear of the equipment or operating unit. The parameter used is μ (middle value) σ (standard deviation).

The reliability function is:

- Failure Distribution Function:

$$f(t) = \frac{1}{\sigma\sqrt{2\pi}} e^{[\frac{1}{2}(\frac{t-\mu}{2})^2]} \quad (1)$$

- Reliability Function:

$$R(t) = 1 - \phi\left(\frac{t-\mu}{\sigma}\right) \quad (2)$$

- Failure Rate Function :

$$\lambda(t) = \frac{f(t)}{R(t)} \quad (3)$$

- Mean Time to Failure :

$$MTTF = \mu \quad (4)$$

t : Failure Time
μ : Mean
ϕ: Normal Distribution Table
σ : Standard Deviation

2. Lognormal Distribution
   The lognormal distribution uses two parameters, namely (μ) (shape parameter) and (σ) (location parameter) which is the middle value of a failure distribution. The reliability function is:

- Failure Distribution Function :

$$f(t) = \frac{1}{\sigma\sqrt{2\pi}} e^{[-\frac{1}{2}(\frac{\ln t-\mu}{\sigma})^2]} \quad (5)$$

- Reliability Function :

$$R(t) = 1 - \phi\ (\frac{\ln t-\mu}{\sigma}) \quad (6)$$

- Failure Rate Function :

$$\lambda(t) = \frac{f(t)}{R(t)} \quad (7)$$

- Mean Time to Failure:

$$MTTF = e^{(\mu+\frac{\sigma^2)}{2}} \quad (8)$$

t : Failure Time
μ : Mean
σ : standard Deviation
Φ : normal distribution table

3. Exponential Distribution
   An exponential distribution is used to calculate reliability which has a constant failure rate. The

parameter used in the exponential distribution is λ which indicates the average failure on the component. The reliability function is0:

- Failure Distribution Function :

$$f(t) = \lambda e^{-\lambda t} \quad (9)$$

- Reliability Function:

$$R(t) = e^{-\lambda t} \quad (10)$$

- Failure Rate Function:

$$\lambda(t) = \lambda \quad (11)$$

- Mean Time to Failure:

$$MTTF = \frac{1}{\lambda} \quad (12)$$

t : Failure time
λ: lambda

4. Weibull Distribution
Weibull distribution is the most widely used distribution, this distribution is used for increasing failure rates and decreasing failure rates. In this Weibull distribution, there are 2 types, Weibull 2 parameter distribution, and Weibull 3 parameter distribution. The reliability Weibull 2 parameter distribution function is:

- Failure Distribution Function:

$$f(t) = \frac{\beta}{\theta}(\frac{t}{\theta})^{\beta-1} e^{-(\frac{t}{\theta})^{\beta}} \quad (13)$$

- Reliability Function:

$$R(t) = e^{-(\frac{t}{\theta})^{\beta}} \quad (14)$$

- Failure Rate Function:

$$\lambda(t) = \frac{\beta}{\theta}(\frac{t}{\theta})^{\beta-1} \quad (15)$$

β : beta
t : failure time
θ : teta

In addition to calculating reliability, the quantitative analysis also analyzes the availability, availability is the probability that a component carries out its function within a certain period of time when used during operating conditions (Dhilon, 2006).

$$A(i) = \frac{MTBF}{MTTF+MTTR} \quad (16)$$

MTBF : Mean time between failure
MTTF : Mean time to failure
MTTR : Mean time to repair

The availability value can change with time, it can be written in the equation (Dhilon, 2006).

$$A(t) = 1 - [\left(\frac{\lambda}{\lambda+\mu}\right) - (\frac{\mu}{\mu+\lambda})e^{[-(\lambda+\mu)t]}] \quad (17)$$

2 RESEARCH METHOD

The objective of this study is to determine the reliability, Mean Time to Failure, type of maintenance, and preventive maintenance scheduling on a boiler feedwater pump by using quantitative methods. the steps carried out in this study can be explained by this flowcharts.

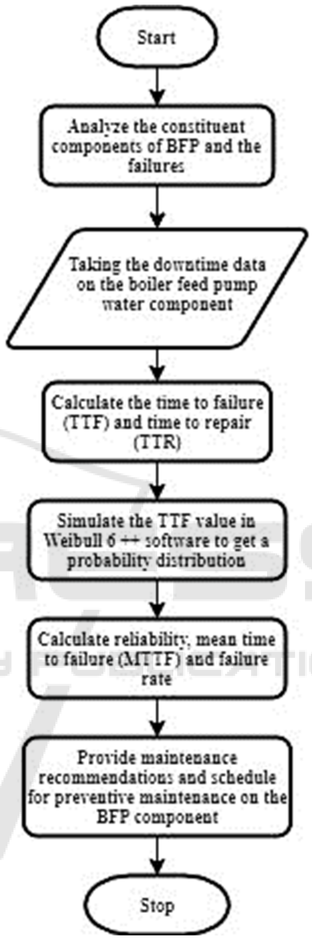

Figure 5: Flowchart Research.

This research to know the probability distribution and the parameter by using ReliaSoft Weibull 6++ software. ReliaSoft Weibull6++ software is a data analysis tool that performs utilizing lifetime distribution, warranty, and degradation data analysis geared toward reliability engineering.

The data input ReliaSoft Weibull 6++ software is the time to failure (TTF) and time to repair (TTR) data obtained form the industry. TTF and TTR data are obtained from the length of time to repair and vulnerable time between one failure and subsequent failure.

2.1 Procedure

There are several processes in simulating this Weibull 6 ++ software, i.e. Calculate the value of the TTF and TTR from the downtime data on the BFP components.

Table 1: Transmitter downtime data.

Actual Start	Actual Finish	TTF	TTR
3/9/12 9.00 AM	3/9/12 3.00 PM	0	6
5/16/12 10.26 AM	5/21/12 1.22 PM	1627	123
10/9/12 4.42 PM	10/9/12 5.42 PM	3365	1
4/8/16 7.24 AM	4/8/16 7.24 PM	4358	0
4/8/16 9.00 AM	4/8/16 5.00 PM	4347	8
12/20/16 9.00 AM	12/20/16 3.00 PM	6120	6
4/5/18 8.00 AM	4/5/18 1.00 PM	11313	5

Simulate the TTF data or TTR data on ReliaSoft Weibull 6++ software, after simulating the Weibull 6++ software, then we will find out the exact distribution used in the calculation of reliability in accordance with the TTF data owned. in addition to the known types of probability distributions that are also known parameter values according to the type of distribution,

Transmitter	Weibull 2 parameter	beta (β) = 1,5789 Eta (θ) = 7108,98

2.2 Maintenance Recommendation

Maintenance recommendations for each BFP component can be determined based on the type of failure rate for each component. every component hasa maintenance technique to reduce the chance of failure.

Table 2: Maintenance Recommendation.

Failure Rate Characteristic	Maintenance Recommendation
DFR (Decreasing Failure Rate)	Preventive maintenance
CFR (Constant Failure Rate)	Corrective maintenance
IFR (Increasing Failure Rate)	Preventive maintenance

3 RESULT AND ANALYSIS

Maintenance analysis with quantitative methods to determine the reliability value of a component through calculations using a probability distribution. the results of the reliability calculation and the meantime to failure on the BFP components

Table 3: Quantitative Analysis Result.

Components	Type of Distribution	The time is taken whenR (t) = 80%	MTTF
TurningGear	Exponential	740 jam	3333,33
Bearing	Lognormal	340 jam	2946,6
MechanicalSeal	Weibull 2 parameter	30 jam	2121,71
Solenoid Valve	Weibull 2 parameter	167 jam	408,62
Sensor	Exponential	90 jam	1666,67
LCV	Weibull 2 parameter	370 jam	2398,76
Control Valve	Weibull 2 parameter	26000 jam	40445,168
Relief Valve	Exponential	1100 jam	5000
Frame Pumpand turbine	Lognormal	1200 jam	8509,22
Transmitter	Weibull 2 parameter	2700 jam	6382,11
Accumulator	Exponential	12800 jam	57428,358
Regulator	Exponential	12800 jam	57428,358
Indicator Gauge (pressure and Temperature)	Weibull 2 parameter	945 jam	3137,15
Line dan Valve	Exponential	6450 jam	28964,518

The results of quantitative analysis that has been done by calculating the reliability and MTTF on eachBFP component. Form fig 6 can be seen that the value of reliability decreases with time due to lifetime and components that have decreased component function over time. In the calculation of the Mean Time to Failure value in the BFP component, the higher the MTTF value indicates that the component rarely have fails and the lower MTTF value indicates that the component often has failed. this is because when the MTTF value decreases the distance between failures is very close so it can be concluded that the component most often has a failure.

From table 3 it can be concluded that the component has most frequently failed is the solenoid valve with an MTTF value of 408.62. Failure that often happened in the solenoid valve is the solenoid coil broken because of the poor quality of electronic components so that failure often occurs. The highest MTTF value is the accumulator and regulator with an MTTF value of 57428,358, this indicates that the accumulator and regulator are the most often components have failure and the time interval between failures is quite long. the highest the MTTF value, it shows that the components more

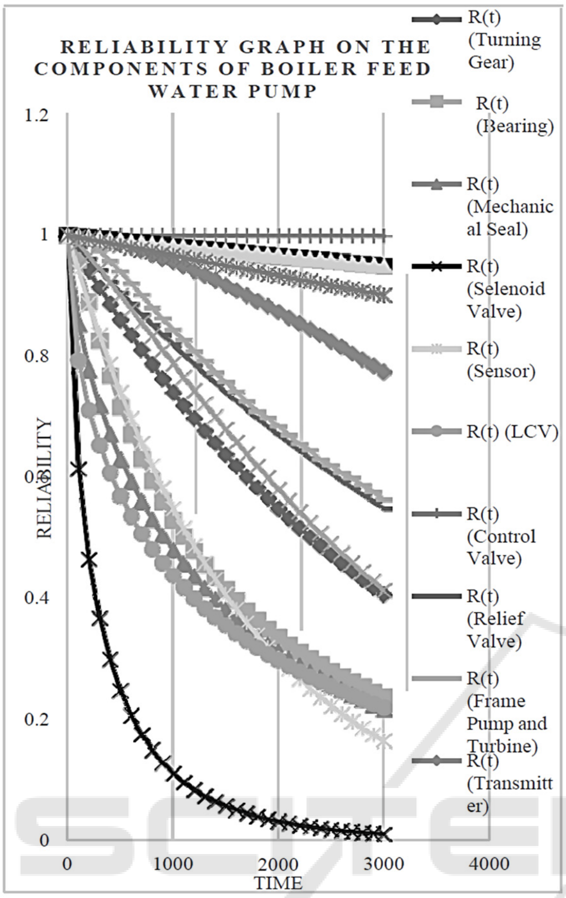

Figure 6: Reliability Graphic on BFP component.

often have a failure, and the smallest MTTF value indicates the componentis most often has a failure.

Form the distribution parameter it can calculate the failure rate on every component of BFP. There are three kinds of failure, increasing failure rate, decreasing failure rate, and constant failure.

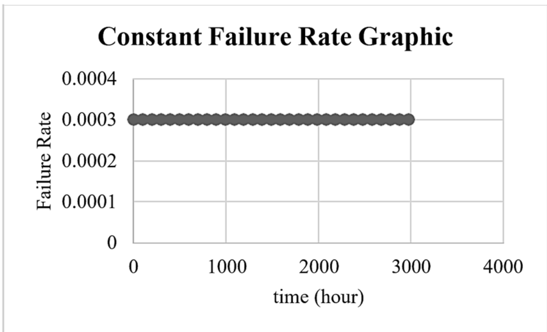

Figure 7: Constant failure rate graphic.

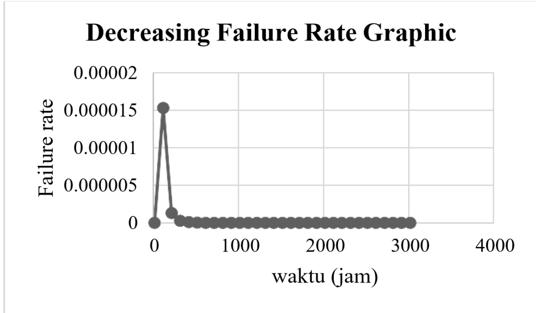

Figure 8: Decreasing Failure Rate.

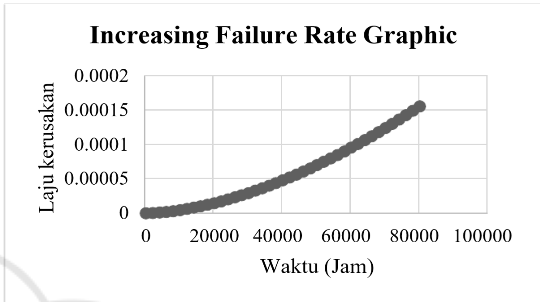

Figure 9: Increasing Failure Rate.

The constant failure rate graph above shows the components are in a constant condition. the failure rate characteristic with the constant graph above is Constant Failure Rate (CFR), it means that this equipment is in the useful life phase or the equipment is in a condition where there is not increasing or decreasing in failure and the failure that occurs on this CFR phase is mostly caused by human error. The graph with the CFR (Constant Failure Rate) characteristic is also caused by the lambda parameter value (λ) on the exponential distribution (Dhilon, 2006).

The second failure rate graph above shows that there is a decreasing in the failure rate over time, the failure rate characteristic with the decreasing graph is the Decreasing Failure Rate (DFR), it means that this equipment is in the burn-in phase and the failure in the components that have DFR graph is caused due to defects in the production of manufacturing (Ebelling,1997). The graph with the DFR (Decreasing Failure Rate) characteristic is also by the results of the 2-parameter Weibull distribution where the value of the shape parameter (β) is less than 0 (Dhilon, 2006).

The third failure rate graph above shows that there is an increase in the failure rate over time, the characteristics of the failure rate with the graph increase as above are Increasing Failure Rate (IFR), it means that this equipment is in the wear-out phase or long use and the failure caused is due to fatigue, corrosion, aging and many more (Ebelling,1997). To reduce these failures, preventive maintenance is required to reduce the failure rate. The graph with the IFR (Increasing Failure Rate) characteristic is also caused by the results of the 2 parameters Weibull distribution with the value of the shape parameter (β) is more than 2 (Dhilon, 2006).

Each BFP components have their failure rate graph, the failure rate graph can also determine the appropriate maintenance recommendations for each component. The following table shows the characteristics of the failure rate and maintenance recommendations for each component of the boiler feedwater pump.

Table 4: Failure Rate Characteristics andMaintenance Recommendation.

No	Equipment	Failure Rate Characteristics	Maintenance Recommendation
1	Turning Gear	CFR (ConstantFailure Rate)	Corrective maintenance
2	Bearing	DFR (DecreasingFailure Rate)	Preventive maintenance
3	Solenoid Valve	DFR (DecreasingFailure Rate)	Preventive maintenance
4	MechanicalSeal	DFR Decreasing Failure Rate	Preventive maintenance
5	LCV	DFR Decreasing Failure Rate	Preventive maintenance
6	Sensor	CFR (ConstantFailure Rate)	Corrective maintenance
7	Control Valve	IFR (IncreasingFailure Rate)	Preventive maintenance
8	Relief Valve	CFR (ConstantFailure Rate)	Corrective maintenance
9	Frame Pumpdan turbine	DFR Decreasing Failure Rate	Preventive maintenance
10	Transmitter	IFR (IncreasingFailure Rate)	Preventive maintenance
11	Accumulator	CFR (ConstantFailure Rate)	Corrective maintenance
12	Regulator	CFR (ConstantFailure Rate)	Corrective maintenance
13	Indicator Gauge (pressure and Temperature)	IFR (IncreasingFailure Rate)	Preventive maintenance
14	Line danValve	CFR (ConstantFailure Rate)	Corrective maintenance

The components that have a CFR (Constant Failure Rate) failure rate indicates that maintenance recommendation is corrective maintenance, this is because when the component is in the CFR phase it indicates that the component is in the useful life phase or the component is in a condition to operating properly according to its function, and for components with CFR failure rates that occur due to human errors. To reduce this failure in the components that are in the CFR phase, corrective maintenance can be carried out by replacing damaged or decreased performance components with new components so that they can run properly.

Components that have the characteristics of the IFR lure rate (Increasing Failure Rate) and DFR creasing Failure Rate) recommended maintenance preventive maintenance because the components at have IFR failure rate characteristics are in wear- ut condition. Failures that often occur in components with IFR failure rates are fatigue, corrosion, aging (lifetime), etc. So to avoid this failure, it is necessary to periodically check the conditions so the performance of the BFPT components is well maintained and components have a DFR (Decreasing Failure Rate) failure rate are also recommended for preventive maintenance because the components at the DFR failure rate are in burn-condition or the component has just been operated and has failed. Failures that occur are due to manufacturing defects that reduce the performance of the components when used, so preventive maintenance is needed so that the defect does not cause excessive failure to a component, and the performance of the boiler feedwater pump is well maintained.

4 CONCLUSION

The emphasis of this research is the use of quantitative analysis methods to determine the maintenance of the Boiler Feed Water Pump. From the results are, it can be concluded that the Boiler Feed Water Pump is a critical component that often has fails. The results of the analysis using quantitative methods are calculating reliability, MTTF, and failure rate using probability distribution that the reliability of the Boiler Feed Water Pump components decreases over time, the decrease in reliability is due to age or lifetime, thus affecting the BFP's components performance. The result of the Mean Time To Failure calculation is the value on the BFP component obtained the lowest MTTF value is the solenoid valve and the highest MTTF value on the accumulator and regulator. This MTTF value shows how often the BFP component has failed, the smaller the MTTF value indicates that the component often has failed and the highest the MTTF value means that the component rarely has failed. Determination of maintenance recommendations for BFP components based on the failure rate characteristics of each component, components that have CFR failure rate characteristics, maintenance recommendations are corrective maintenance, and the maintenance recommendation for components that have failure rate IFR and DFR are preventive maintenance.

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