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Preventive Maintenance with Block Replacement on the Thermo Circulating Dryer machine to Minimize Downtime

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ABSTRACT: This research was conducted in the raw material testing laboratory of PT. ABC is a textile company. This study aims to minimize downtime on the thermo-circulation dryer. This tool serves to dry samples of raw materials or fabrics that are tested in the PT. ABC. The method used is preventive maintenance with block replacement. The results of the calculation of the Thermo Circulation Dryer Inspection Schedule obtained comparative results, namely, In the initial condition the inspection frequency is 1 time per year with a downtime value of 0.391 days. Meanwhile, the result of the proposal is that 1.29 times a year inspection is carried out with an expectation of 0.303 days of downtime or 2.11 hours less. The results of the proposed preventive maintenance schedule for the Circulating Thermo Dryer are 1.29 times per 365 days or the equivalent of 2 times for one year.

KEYWORDS: Block Replacement, Minimize Downtime**,** Preventive Maintenance.

INTRODUCTION

PT. ABC is a textile company that has a laboratory to check raw materials and products such as fabrics, yarns and nonwovens. This laboratory is tasked with maintaining the quality of the production process and production results. The testing parameters in the laboratory are adjusted to the characteristics of the raw materials for fabrics, yarns and nonwovens. The role of this laboratory is very vital, therefore if there is damage to one of the tools, the testing process stops and the impact of the production process will also stop. The number of tools in the laboratory of PT. ABC is as many as 20 tools. Based on the damage data in 2020, there is one device with the highest number of damage, namely the Circulation Thermo Dryer with 19 times of damage and 76.35 hours of downtime. This tool serves to dry samples of raw materials or fabrics that are tested in the laboratory. The data regarding the damage is presented in table 1 below.

Table 1. Damage Data for Circulation Thermo Dryer

No.	Component Damage	Related Subsystem	*Downtime* (Hour)
1.	Bearing 6201-2Z/C3	Motor Fan	4,18
2.	Temperature Control	Digital Control	2,38
3.	Bearing 6201-2Z/C3	Motor Fan	4,77
4.	Bearing 6201-2Z/C3	Motor Fan	4,87
5.	Heater	Heater	5,70
6.	MCB 6A	Machine	2,28
7.	Bearing 6201-2Z/C3	Motor Fan	4,45
8.	Contactor	Machine	0,62
9.	Trafo	Trafo	6,10
10.	Bearing 6201-2Z/C3	Motor Fan	3,20
11.	Contactor	Machine	5,90
12.	Bearing 6201-2Z/C3	Motor Fan	3,43
13.	Contactor	Machine	0,35
14.	Temperature Control	Digital Control	4,38
15.	Power Suplay	Power Suplay	5,90

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16.	Sensor	Digital Control	2,93
17.	Bearing 6201-2Z/C3	Motor Fan	6,47
18.	Temperature Control	Digital Control	0,27
19.	Bearing 6201-2Z/C3	Motor Fan	8,17
Total Downtime			76,35

Maintenance management applied by PT. ABC is currently corrective maintenance. This method of treatment causes many disadvantages. According to Wang et al [1] corrective maintenance policies result in uncontrolled equipment damage due to the absence of scheduled maintenance. According to Otieno [2], the main weakness of corrective maintenance is that there is downtime and unscheduled machine maintenance and unplanned maintenance will lead to waste. Saharuddin et al [3] stated that the weakness of corrective maintenance is a waste of time and money. This laboratory is an interconnected system, if one of the equipment is damaged then the laboratory cannot operate and is detrimental to the company.

Maintenance management that can reduce the amount of downtime is preventive maintenance. According to Jokinen et al [4] preventive maintenance has the potential to solve the most critical corrective weaknesses and its efficient implementation. According to Cruzan [5] preventive maintenance is a scheduled program of routine inspections or replacement of worn or damaged parts to maintain the function and efficiency of the tool. According to Murar et al [6] the implementation of preventive maintenance can be a cost reduction, by avoiding equipment malfunctions or total damage. According to Prozzi & Banerjee [7] the implementation of preventive maintenance requires less cost than corrective maintenance. Therefore, based on the references to several studies above, this research will design a preventive maintenance system to minimize downtime on the thermo-circulation dryer.

METHODS

According to Ke & Yao [8] this preventive maintenance model is carried out at a fixed interval to obtain the best level of reliability. According to Pardiyono and Indrayani [9] preventive maintenance is maintenance and care activities carried out to prevent unexpected damage and find damaged equipment conditions when used. According to Siagian et al in Pardiyono and Hartanto [10], reliability is the probability of a tool's ability to achieve a goal within a certain period and environmental conditions. The concept of reliability is described as a Bathtub Curve which describes the life cycle of an item/component.

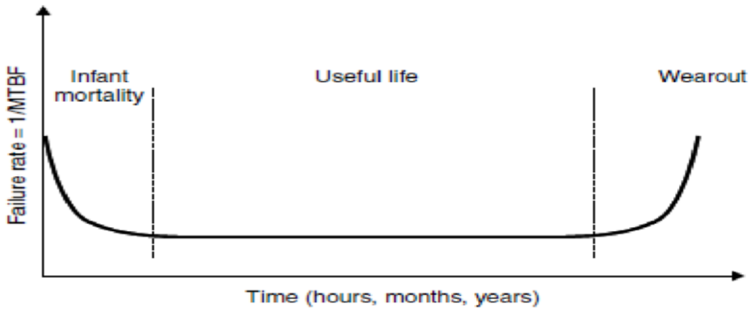

Figure 1. Bathtub Curve

The reliability function relates to the standard operating time of the machine. Statistically the reliability function or R(t) is defined as follows where x is the life of the component.

$$R(t) = P\ (x > t) \qquad (1)$$

If f(x) is a probability density function and F(x) dx represents the probability of a component failing at the interval (x, x + x), and the sum of the probability of the reliability function and the cumulative distribution function is equal to one, then the following equation is obtained:

$$F(x) = P(X < t) \qquad (2)$$

So that the probability of being able to operate at a predetermined specification or its reliability function can be expressed mathematically as follows::

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$$R(t) = 1\text{-}F(x<t) \quad (3)$$

$$R(t) = \int_{\infty}^{\infty} f(x)dx \quad (4)$$

$$R(t) = \int_{\infty}^{\infty} f(t)dt - \int_{\infty}^{\infty} f(t)dt \quad (5)$$

$$R(t) = 1 - F(t) \quad (6)$$

The rate of damage to the machine or component at time t is the probability that the machine or component will fail at the next interval. Meanwhile, when t the machine or component is in good condition (Tambe, et al [11]). Mathematically the rate of damage function can be described as below:

$$r(t) = \lim_{\Delta t \to 0} \frac{R(t) - R(t+\Delta t)}{\Delta t R(t)} = \frac{1}{R(t)}(-(\frac{d}{d(t)})R(t) \quad (7)$$

$$r(t) = \frac{f(t)}{r(t)} = \frac{f(t)}{1-F(t)} \quad (8)$$

If r(t) increases with time, then the function of the rate of damage increases (increasing failure route) and vice versa, if r(t) decreases with time, it is called the decreasing failure rate. Kapur & Pecht [12] state that in implementing the maintenance policy there are several distributions of damage that can be used, namely Weibull distribution, Lognormal distribution, Exponential distribution, and normal distribution. According to Muhammad in Pardiyono and Fadillah [13], in identifying the distribution can be done with the Index of Fit (r) and the Goodness of Fit Test. Index of Fit consists of Probability Plot and Least-Square Curve Fitting. Probability Plot is used for small or incomplete samples, Least-Square Curve Fitting method is better than Probability Plot. Calculations on the Least-Square Curve Fitting Method are:

$$F(t_i) = \frac{l - 0{,}3}{n + 0{,}4} \quad (9)$$

Information :
i = t-th time data
n = r = number of damage data

$$Index\ of\ fit\ (r) = \frac{n\sum_{i=1}^{n} x_i y_i - (\sum_{i=1}^{n} x_i)\ (\sum_{i=1}^{n} y_i)}{\sqrt{[n\sum_{i=1}^{n} x_i^2 - (\sum_{i=1}^{n} x_i)^2]\ [n\sum_{i=1}^{n} y_i^2 - (\sum_{i=1}^{n} y_i)^2]}} \quad (10)$$

According to Zhang & Xie [14] Goodness of Fit Test is carried out by comparing two opposite hypotheses, namely:

H0: Damage or repair data is close to a certain distribution.

H1 Damage or repair data does not approach a certain distribution.

Block Replacement Models

Components of the machine are often damaged suddenly and when the damage occurs must be replaced immediately. The damage is unexpected and cannot be precisely identified, so it is reasonable to assume that the cost of replacing damaged components is more expensive than preventive maintenance. According to Pardiyono & Suryani [15] the purpose of Block Replacement is to determine the optimal time interval between preventive replacements to minimize the expectation of the total replacement cost per unit time.

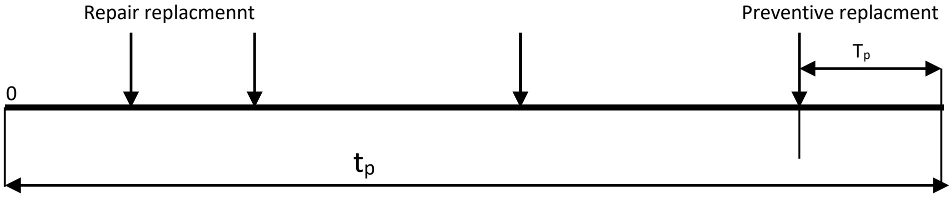

Figure 2. Block Replacement Policy

Expected total cost in interval $(0,t_p)$ = D_p – $D_r.H(t_p$. Where $H(t_p)$ is the expected amount of damage in the interval $(0,t_p)$, so

$$D(tp)\,\frac{\text{Dp+Cf H(tp}}{t_P} \quad (11)$$

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RESULT AND DISCUSSION

Determination of Critical Components

Determination of critical components based on the highest frequency of damage from the system on laboratory equipment, namely the Circulation Thermo Dryer. From the identification of Maintenance Significant Item (MSI) it is known that the Fan Motor subsystem is the subsystem with the highest frequency. Based on data on damage to the Circulation Thermo Dryer, there are components that are very influential with damage to the equipment in the Fan Motor subsystem, namely the Bearing 6201-2Z/C3 component. The function of Bearing 6201-2Z/C3 on the fan motor is as a bearing for the motor shaft (axle) on the stator fan. If this bearing is damaged then the fan motor cannot work optimally. This will result in downtime for the tool.

The following is an example of calculating the value of the Weibull distribution for *i=1*

a. a. Sort the data from smallest to largest.
   ti = sequence of damage intervals from smallest to largest
b. Determining the value Z_i
   $Z_i = ln\left[- ln\left(1 - \frac{i - 0,5}{n + 0,25}\right)\right]$ $Z_i = -2,484$
c. Calculate value M_i
   $M_i = Z_{i+1} - Z_i$
   $M_i = (-1,293) – (-2,484)$, $M_i = 1,191$
d. Calculate value $X_{i+1} – X_i = (lnt_{i+1} - lnt_i)$
   = 5,964-5,802 = 0,161
e. Calculate value sig (α = 5%)
f. Calculate value $(X_{i+1} – X_i)/ M_i = (lnt_{i+1} - lnt_i) / M_i$
   = 0,161 / 1,191 = 0,136
g. Calculate value M
   $M = \frac{k_1 \sum_{i=k_1+1}^{r-i}[(lnt_{i+1} – lnt_i)/M_i]}{k_2 \sum_{i=1}^{k_1}[(lnt_{i+1} – lnt_i)/M_i]}$
   with : $K_1 = n/2$, $K_2 = (n-1)/2$
   $K_1 = 6/2 = 3$, $K_2 = (6-1)/2 = 2,5 = 2$
   $M = \frac{3 \times 0,728}{2 \times 0,837} = 1,30$
h. Determine the decision criteria kriteria
   If $M < F_{table}, v_{1,\ V2}$ then H_0 is accepted and if $M > F_{table}$ then H_0 rejected.
   With = $V_1 = 2 \times 2 = 4$
   $V_2 = 2 \times 3 = 6$
   $F_{table} = 4,53$
   $M < F_{table,4,6} = 1,30 < 4,53$

Based on the calculations, $M < F_{table}$ then H_0 accepted. So the pattern of damage time data has a two-parameter Weibull distribution. The complete calculation of the Weibull distribution value for i= 2…n is presented in table 2 below.

Table 2. Testing the Weibull Distribution of Bearing Components 6201-2Z/C3

i	(ti)	Xi = Ln(ti)	Zi	Mi	X(i+1) - Xi	(Xi+1 - Xi)/Mi	(Xi+1 - Xi)/Mi
1	331	5,802	-2,484	1,191	0,161	0,136	
2	389	5,964	-1,293	0,621	0,231	0,372	
3	490	6,194	-0,672	0,474	0,156	0,330	
4	573	6,351	-0,197	0,439	0,200		0,456
5	700	6,551	0,241	0,510	0,139		0,272
6	804	6,690	0,752				
Total						0,837	0,728

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Estimation of Damage Parameter Distribution of Bearing 6201-2Z/C3

To estimate the distribution of damage parameters to the Bearing 6201-2Z/C3 component, it can be seen in table 3. below.

Table 3. Estimated Distribution of Damage Parameters of Bearing 6201-2Z/C3

i	(ti)	F(ti)	1-F(ti)	Xi	Yi	Xi.Xi	Xi.Yi
1	331	0,109	0,891	-2,156	5,802	4,647	-12,507
2	389	0,266	0,734	-1,175	5,964	1,381	-7,009
3	490	0,422	0,578	-0,602	6,194	0,362	-3,726
4	573	0,578	0,422	-0,147	6,351	0,022	-0,935
5	700	0,734	0,266	0,282	6,551	0,079	1,847
6	804	0,891	0,109	0,794	6,690	0,631	5,314
Total				-3,003	37,552	7,122	-17,017

The following will explain an example of calculating the parameter estimation of the Weibull distribution at i = 1, which can be seen below

$$\mathrm{F(ti)} = \frac{(i-0{,}3)}{(n+0{,}4)} = \frac{(1-0{,}3)}{(6+0{,}4)} = 0{,}109$$

$$\mathrm{X(i)} = \ln\frac{\ln(\ln(1))}{1-F(ti)} = \frac{\ln(\ln(1))}{1-0{,}109} = -2{,}156$$

Yi = ln(ti) = ln(331) = 5,802

$$b = \frac{\mathrm{N}\sum_{i=1}^{r} X_iY_i - \sum_{i=1}^{r} X_i \sum_{i=1}^{r} Y_i}{\mathrm{N}\sum_{i=1}^{r} X_i^2 - (\sum_{i=1}^{r} X_i)^2} = \frac{(6)(\text{-}17{,}017)\text{-}(\text{-}3{,}003)(37{,}552)}{(6)(7{,}122)-(-3{,}003)^2} = 0{,}317$$

$$a = \frac{\sum_{i=1}^{r} Y_i}{N} - b\frac{\sum_{i=1}^{r} X_i}{N} = \frac{37{,}552}{6} - (0{,}646)\frac{(\text{-}3{,}003)}{6} = 6{,}417$$

After obtaining the constant values of a and b, then the calculation of the value of β as a shape parameter and the value of θ as a scale parameter is carried out.

$\beta = \frac{1}{b} = \frac{1}{0{,}317} = 3{,}155$ and value $\theta = exp\ (\alpha) = e^{6{,}417} = 612{,}16$

Calculation of Mean Time To Failure Value

Mean Time To Failure (MTTF) is the average time interval for damage that occurs when the tool or component has been repaired until the tool or component is damaged again (Asha & Unnikrishnan[16]). Therefore, the MTTF value can be used as an estimate of the life of the component. The calculation for the MTTF value of the Bearing 6201-2Z/C3 component is as follows:

$$MTTF = \theta\,\Gamma\left(1+\frac{1}{\beta}\right) = 612{,}16\,\Gamma\left(1+\frac{1}{3{,}155}\right) = 612{,}16\,\Gamma\,(1{,}32) = 547{,}66 \text{ days} = 547 \text{ days}$$

Based on the results of the calculations above, to find out the value of Gamma (Γ), and it can be seen that the estimated life span of the Bearing 6201-2Z/C3 component according to the MTTF value with a two-parameter Weibull distribution is 547 days.

Calculation of Reliability Function and Damage Rate Function of Bearing 6201-2Z/C3

The reliability function shows the ability of a component or equipment to operate continuously without any damage (O'Connor & Kleyner [17]). While the damage rate function is the rate of damage that occurs within a certain time interval. In the Weibull distribution the reliability function and the damage rate function is formulated as follows::

a. Reliability function

R(t) = $e^{-\left(\frac{t}{\theta}\right)^{\beta}}$ when θ>0,β>0, and t≥0

So the reliability function for Bearing components 6201-2Z/C3 is R(t) = $e^{-(t/612,16)3,155}$

b. Damage rate function

h(t) $= \frac{\beta}{\theta}\left(\frac{t}{\theta}\right)^{\beta-1}$ when θ>0, β>0, and t≥0

So the damage rate function for the Bearing component 6201-2Z/C3 as follows.

h(t) $= \frac{3{,}155}{612{,}16}\left(\frac{t}{612{,}16}\right)^{3{,}155-1}$ when θ>0, β>0, and t≥0

Determination of the Optimal Replacement Interval for Bearing 6201-2Z/C3

The data on the replacement time of the Bearing 6201-2Z/C3 component which became the object of the study were obtained through direct interviews with maintenance technicians, namely the time data for preventive replacement (Tp) and time data for repair replacement (Tf). The replacement time data are as follows:

Table 4. Elements of the process of replacing Bearing 6201-2Z/C3

Component Name	Type of Maintenance	Maintenance activity elements	ime (Minute)	Total Time (Hour)
Bearing 6203ZZC3	Repair (Tf)	Reporting Damage	15	4,08
		Preparing Equipment	10	
		Disassembling the Dryer Tool 41-54	85	
		Fan Motor Inspection	15	
		Locating the broken Bearing 6201-2Z/C3	25	
		Preparing replacement Bearing 6201-2Z/C3	10	
		Disassembling Installing Bearings 6201-2Z/C3	30	
		Installing the Dryer 41-54	25	
		Machine Set Up	30	
		Total	245	
	Preventive (Tp)	Disassembling the Dryer Tool 41-54	85	2,83
		Disassembling Installing Bearings 6201-2Z/C3	30	
		Installing the Dryer 41-54/72-042-A	25	
		Machine Set Up	30	
		Total	170	

Replacement Schedule with Block Replacement Model

In determining the optimal preventive replacement interval using the Block Replacement model with the criteria of minimizing downtime. The total downtime per unit time for preventive maintenance at time tp or D(tp) is:

$$D(tp) = \frac{\text{Downtime Due to Damage} + \text{Downtime Due to Preventive Replacement}}{\text{cycle length}}$$

Downtime due to damage is the amount of damage in the interval (0, tp) times the time required to replace the damage, so the equation is H(tp) x Tf. Time required to perform preventive replacement = Tp

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$$D(t_p) = \frac{H(t_p)T_f + T_p}{t_p + T_p}$$

with :
Tp : Time required to perform preventive replacement
Tf : The time it takes to replace the damage
tp : preventive maintenance time interval
D(tp): Downtime per unit time
H(tp) : The amount of damage in the interval (0,tp) following the formula H(tp) = (t/θ)β

The results of calculations using the above formula for the Bearing component 66201-2Z/C3 can be seen as follows:

Table 5. Determination of the Replacement Interval for Bearing 6201-2Z/C3

No	tp	θ	β	H(tp)	Tp	Tf	D(tp)
1	401	612,16	3,155	0,263246	2,83	4,08	0,009668
2	402	612,16	3,155	0,265323	2,83	4,08	0,009665
…	…	…	…	…	…	…	…
23	423	612,16	3,155	0,311562	2,83	4,08	0,009631
24	424	612,16	3,155	0,313892	2,83	4,08	0,009631
25	425	612,16	3,155	0,316234	2,83	4,08	0,009631
26	426	612,16	3,155	0,318587	2,83	4,08	0,009630
27	427	612,16	3,155	0,320953	2,83	4,08	0,009631
28	428	612,16	3,155	0,32333	2,83	4,08	0,009631
29	429	612,16	3,155	0,32572	2,83	4,08	0,009631
30	430	612,16	3,155	0,328121	2,83	4,08	0,009631

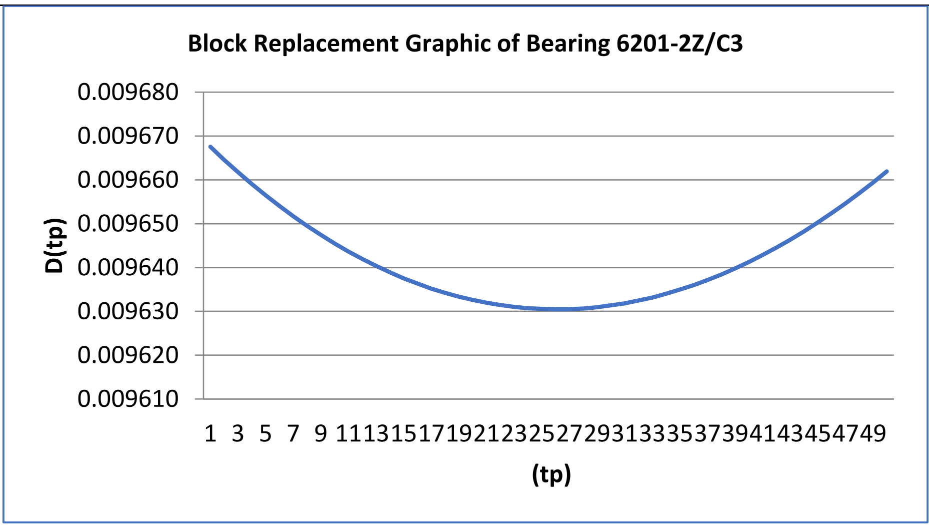

Figure 3. Graphic *Block Replacment* Component Bearing 6201-2Z/C3

The following will explain an example of calculating the replacement interval for Bearing 6201-2Z/C3 components which can be seen below, with a tp value of 426, a Tf value equal to 4.08 and a Tp value of 2.83.
$H(tp) = (t/\theta)^{\beta} = (426/612,16)^{3,155} = 0,318587$

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$$D(426) = \frac{H(tp).Tf + Tp}{tp + Tp} = \frac{(0{,}318587 * 4{,}08) + 2{,}83)}{426 + 2{,}83} = 0{,}00963\ day$$

Weibull Distribution Testing of Circulating Thermo Dryers. The following is an example of calculating the value of the Weibull distribution for i=1

a. Sort the data from smallest to largest.
   ti = sequence of damage intervals from smallest to largest
c. Determining the value of Zi

$$Zi = \ln[-\ln(1 - \frac{i - 0{,}5}{n + 0{,}25} = \ln[-\ln\frac{(1 - 0{,}5)}{18 + 0{,}25} = -3{,}583$$

a. calculate value M_i
   $M_i = Z_{i+1} - Z_i = (-2{,}456) - (-3{,}583) = 1{,}127$
b. calculate value $X_{i+1} - X_i$
   $X_{i+1} - X_i = (\ln t_{i+1} - \ln t_i)$
   $= 3{,}850 - 3{,}664 = 0{,}187$
c. calculate value sig ($\alpha = 5\%$)
d. calculate value $(X_{i+1} - X_i)/ M_i$
   $(X_{i+1} - X_i)/ M_i = (\ln t_{i+1} - \ln t_i) / M_i$
   $= 0{,}187 / 1{,}127 = 0{,}166$
e. calculate value M

with : $K_1 = n/2$, $K_2 = (n-1)/2$

$K_1 = 18/2 = 9$, $K_2 = (18-1)/2 = 8{,}5 = 8$

$$M = \frac{k_1 \sum_{i=k_1+1}^{r-i} [(\ln t_{i+1} - \ln t_i)/M_i]}{k_2 \sum_{i=1}^{k_1} [(\ln t_{i+1} - \ln t_i)/M_i]} = \frac{9*4{,}334}{8*4{,}119} = 1{,}18$$

f. determine decision criteria

If $M < F_{table}, v_{1,V2}$ then H_0 accepted and if $M > F_{table}$ then H_0 rejected.

With = $V_1 = 2 \times 8 = 16$

$V_2 = 2 \times 9 = 18$

$F_{table} = 2{,}25$

$M < F_{table}, 16{,}18 = 1{,}18 < 2{,}25$

Based on the calculations, M < Ftable then H0 is accepted. So the pattern of damage time data has a two-parameter Weibull distribution.

Table 6. Testing Data for Damage Distribution of Thermo Circulation Dryers.

i	(ti)	Xi = Ln(ti)	Zi	Mi	X(i+1) - Xi	(Xi+1 - Xi)/Mi	(Xi+1 - Xi)/Mi
1	39	3,664	-3,583	1,127	0,187	0,166	
2	47	3,850	-2,456	0,541	0,227	0,420	
3	59	4,078	-1,915	0,368	0,507	1,378	
4	98	4,585	-1,547	0,285	0,275	0,964	
5	129	4,860	-1,262	0,236	0,177	0,749	
6	154	5,037	-1,025	0,205	0,026	0,125	
7	158	5,063	-0,820	0,184	0,031	0,169	
8	163	5,094	-0,636	0,169	0,012	0,072	
9	165	5,106	-0,467	0,159	0,012	0,076	

10	167	5,118	-0,308	0,153	0,030		0,193
11	172	5,147	-0,155	0,150	0,232		1,554
12	217	5,380	-0,005	0,149	0,005		0,031
13	218	5,384	0,144	0,153	0,145		0,947
14	252	5,529	0,297	0,162	0,076		0,472
15	272	5,606	0,459	0,179	0,105		0,585
16	302	5,710	0,638	0,214	0,092		0,428
17	331	5,802	0,852	0,309	0,039		0,125
18	344	5,841	1,161				
Total						4,119	4,334

Estimation of Distribution of Damage Parameters of Circulating Thermo Dryers. The following will explain an example of calculating the parameter estimation of the Weibull distribution at i = 1, which can be seen below.

$$\mathrm{F(ti)} = \frac{\mathrm{i} - 0{,}3}{n + 0{,}4} = \frac{(1 - 0{,}3)}{18 + 0{,}4} = 0{,}038$$

$$\mathrm{Xi} = \ln \frac{[\ln(1)]}{1 - F(ti)} = \frac{[\ln(1)]}{1 - 0{,}038} = -3{,}250$$

Yi = ln(ti) = ln(39) = 3,664

$$b = \frac{N\sum_{i=1}^{r} X_i Y_i - \sum_{i=1}^{r} X_i \sum_{i=1}^{r} Y_i}{N\sum_{i=1}^{r} X_i^2 - (\sum_{i=1}^{r} X_i)^2} = \frac{(18)\,(-36{,}820) - (-9{,}752)\,(90{,}854)}{(18)\,(28{,}332) - (-9{,}752)\;2} = 0{,}538$$

$$a = \frac{\sum_{i=1}^{r} Y_i}{N} - b\,\frac{\sum_{i=1}^{r} X_i}{N} = = \frac{90{,}854}{18} - (0{,}538\,\frac{-9{,}752}{18} = 5{,}339$$

After obtaining the constant values of a and b, then the calculation of the value of β as a shape parameter and the value of θ as a scale parameter.

$$\beta = \frac{1}{b} = \frac{1}{0{,}538} = 1{,}858$$

θ = *exp (α)*

= $e^{5,339}$ = 208,3

Table 7. Estimated Distribution of Damage Parameters of Circulation Thermo Dryers

i	(ti)	F(ti)	1-F(ti)	Xi	Yi	Xi.Xi	Xi.Yi
1	39	0,038	0,962	-3,250	3,664	10,561	-11,905
2	47	0,092	0,908	-2,334	3,850	5,446	-8,985
3	59	0,147	0,853	-1,841	4,078	3,389	-7,506
4	98	0,201	0,799	-1,494	4,585	2,232	-6,849
5	129	0,255	0,745	-1,221	4,860	1,491	-5,934
6	154	0,310	0,690	-0,992	5,037	0,985	-4,998
7	158	0,364	0,636	-0,792	5,063	0,628	-4,012
8	163	0,418	0,582	-0,612	5,094	0,375	-3,119
9	165	0,473	0,527	-0,446	5,106	0,199	-2,277
10	167	0,527	0,473	-0,289	5,118	0,084	-1,479
11	172	0,582	0,418	-0,138	5,147	0,019	-0,710

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i	(ti)	F(ti)	1-F(ti)	Xi	Yi	Xi.Xi	Xi.Yi
12	217	0,636	0,364	0,010	5,380	0,000	0,055
13	218	0,690	0,310	0,159	5,384	0,025	0,854
14	252	0,745	0,255	0,311	5,529	0,097	1,720
15	272	0,799	0,201	0,473	5,606	0,223	2,649
16	302	0,853	0,147	0,652	5,710	0,425	3,722
17	331	0,908	0,092	0,868	5,802	0,753	5,035
18	344	0,962	0,038	1,184	5,841	1,403	6,918
Total		-9,752	90,854		28,332	-36,820	

Calculation of the Reliability Function and the Damage Rate Function of the Circulation Thermo Dryer. In the Weibull distribution, the reliability function and the damage rate function are formulated as follows:

a. Reliability Function

$R(t) = e^{-\left(\frac{t}{\theta}\right)^{\beta}}$ with θ>0, β>0, and t≥0

So the reliability function for the Circulation Thermo Dryer is as follows.

$R(t) = e^{-(t/208,3)1,858}$

b. Damage Rate Function

$h(t) = \frac{\beta}{\theta}\left(\frac{t}{\theta}\right)^{\beta-1}$ with θ>0, β>0, and t≥0

o the damage rate function for the Circulation Thermo Dryer is as follows.

$$h(t) = \frac{1,858}{208,3}\left(\frac{t}{208,3}\right)^{1,858-1}$$

Calculation of Reliability Under Preventive Maintenance

When viewed on the graph of the reliability function, the result of R(t) = 0.99 with R(t) which is assumed to be a function of reliability without preventive maintenance is t=1 day. In carrying out preventive maintenance, if we want the Circulation Thermo Dryer to have reliability for a longer period of time than today, with a maintenance interval of R(t)=0.99 then by doing this calculation, we will get the frequency of maintenance that needs to be done (n). The value of is 1.858, the value is 208.3 and the plan T = 365 days (1 year). Finding the value of n is follows:

$$exp\left[-n\left(\frac{T}{\theta}\right)^{\beta}\right] = \left[-n\left(\frac{365}{208,3}\right)^{1,858}\right] = 0,99$$

$$n = \frac{(-\ln 0,99)}{(365/208,3)^{1,858}} = 1,29 \text{ time per } 365\ days$$

$$Rm(t) = exp\left[-n\left(\frac{T}{\theta}\right)^{\beta}\right] exp\left[-\left(\frac{t-nT}{\theta}\right)^{\beta}\right]$$

$$0,99 = exp\left[-(1,29)\left(\frac{365}{208,3}\right)^{1,858}\right] exp\left[-\left(\frac{t-(1,29)(365)}{208,3}\right)^{1,858}\right]$$

$$0,99 = 0,99\ exp\left[-\left(\frac{t-(1,29)(365))}{208,3}\right)^{1,858}\right]$$

$t = 208,3\,[-\ln(0,99/0,99)]^{1/1,858} + 470,85 = 470,85$ days

In the Circulating Thermo Dryer, it can be seen that with a planned maintenance interval (T) of 365 days, the optimal maintenance frequency (n) is 1.29 times/365 days, with a long time of reliability (t) of 470.85 days. it is proven that by doing n maintenance, it can increase the length of time of reliability.

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Downtime Expectation Calculation with Optimal Inspection Frequency

Performed calculations to determine the minimum expected total downtime..

n = 1,29 time / 365 days
= 0,0035
k = (breakdown frequency / total working days)
= 19 / 2880 = 0,0063
μ = (total breakdown time/breakdown frequency) / 24 hour
= (72,40 / 19) hour / 24 hour = 0,17 day
i = (waktu pemeriksaan / 24 hour)
= 1,5 hour / 24 hour = 0,0625 day

$$D(n) = \frac{k\,x\,\mu}{n} + n\,x\,i$$

$$D(n) = \frac{0{,}0063 * 0{,}17}{0{,}0035} + 0{,}0035 * 0{,}625 = 0{,}303\ day$$

On the Circulation Thermo Dryer, it can be seen that by checking (n) of 1.29 times/365 days, the expected downtime that occurs is 0.303 days.

Downtime Expectations From Current Examination Schedule

Similar to the previous calculation, in determining the expected level of downtime, in this sub-chapter it is also calculated using the same formula using the calculation of the optimal inspection frequency (minimization downtime). However, the value of n here is different because it follows the schedule of inspection activities carried out by the maintenance dept.

n = 1 time per 365 days
= 0,0027 time/day

$$D(n) = \frac{0{,}0063 * 0{,}17}{0{,}0027} + 0{,}0027 * 0{,}625 = 0{,}391\ day$$

From the results obtained, it is shown that with an inspection interval that is carried out once a year, the expected downtime is 0.391 days.

RESULT

The results of the calculation of the inspection schedule for the Circulation Thermo Dryer obtained comparison results, namely, in the initial condition the inspection frequency was 1 time per year with a downtime value of 0.391 days. Meanwhile, the result of the proposal is that 1.29 times a year be inspected with an expectation of 0.303 days of downtime or a decrease of 2.11 hours. This is in line with research conducted by Chen, et al [18], Zhang et al [19], and Biazzo & Filippini [20] that preventive maintenance can reduce downtime. The results of the proposed preventive maintenance schedule for the Circulating Thermo Dryer are 1.29 times per 365 days or the equivalent of 2 times for one year.

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