REKAYASA MESIN V12 N3
eISSN 2477-6041 artikel 10, pp. 605 – 612, 2021

THE RELIABILITY ASSESSMENT OF CRUCIAL COMPONENTS IN HYDRAULIC AXIAL PUMP BY TWO-PARAMETERS WEIBULL

I.M.W. Ekaputra
Tenaga Pengajar (Dosen)
Universitas Sanata Dharma
Jurusan Teknik Mesin
made@usd.ac.id

Gunawan Dwi Haryadi
Tenaga Pengajar (Dosen)
Universitas Diponegoro
Jurusan Teknik Mesin
gunawan_dh@ft.undip.ac.id

Rando Tungga Dewa
Tenaga Pengajar (Dosen)
Universitas Pertahanan Indonesia
Jurusan Teknik Mesin
rando.td@gmail.com

Petrus Kanisius Purwadi
Tenaga Pengajar (Dosen)
Universitas Sanata Dharma
Jurusan Teknik Mesin
pkpurwadi1966@gmail.com

The proper maintenance of the hydraulic axial pump was discussed to maximize its performance and minimize downtime. In this study, reliability assessment by a two-parameter Weibull was applied as a reference for the periodic maintenance of the components in the hydraulic axial pump with a capacity of 2000 litres per second. The two-parameter Weibull consisted of shape parameter β and scale parameter θ. An assessment was conducted to determine the critical parts and determine the failure rate of the formed data patterns. The three critical components of mechanical seal, bearing, shaft were investigated from each of six hydraulic axial pumps. By applying the two-parameter Weibull, the mean time to failure value of mechanical seal, bearing, and the shaft is obtained as 182.91 hours, 381.08 hours, 755.67 hours, respectively. Furthermore, the reliability values of those components were 52%, 52%, and 53%, respectively. By following these results, periodic maintenance could be then conducted regularly.

Keywords: *Hydraulic Axial Pump, Mean Time to Failure, Reliability Assessment, Two-Parameter Weibull*

1. INTRODUCTION

Natural disasters are a phenomenon that can occur anywhere and anytime. Natural disasters pose a risk or danger to human life, both loss of property and loss of human life. One of the natural disasters that often occurs in Indonesia is a flood. Floods often occur in the city of Semarang. Geographically, the city of Semarang is located at the edge of the Java Sea in the north. The topographical condition of the area consists of hilly areas, lowlands and coastal areas. It shows the existence of various slopes and protrusions that make the city of Semarang potentially prone to the threat of natural disasters. One of the efforts to prevent and reduce flood disasters is by using pumps in flood-prone areas in Semarang.

A pump is a device used to move a liquid fluid from one place to another by increasing fluid pressure [1]. Since 2018 the city government of Semarang has used a pump with the hydraulic axial pump type produced by the nation's children. An axial hydraulic pump is a pump that works by sucking oil from the hydraulic tank and pushing it into the hydraulic system in the form of flow [1-3]. To maximize performance, a proper maintenance system is required to minimize downtime [4-6]. Weibull analysis is an appropriate method to determine which includes the critical and non-critical parts [6-10]. So far, the company does not have a role in a regular maintenance system, so the Hydraulic Axial Pump gets corrective maintenance without paying attention to the reliability factor of the pump components. The determination of the number of spare parts only uses estimates based on past demand. It is necessary to make preparations to monitor critical components so that immediate preventive maintenance is carried out and prepared components spare parts before they are damaged to reduce unit downtime. In this study, a probability assessment of the critical components in the hydraulic axial pump was conducted by applying the two-parameter Weibull.

2. RESEARCH METHOD

The hydraulic axial pump used in this study consists of five pumps with a capacity of 200 litres per second. This pump generates most of the pressure from the propeller and the lifting force of the blade against the fluid. This pump is widely used in drainage and irrigation systems. The single-stage vertical axial pump is more

Corresponding Author: made@usd.ac.id Received on: April 2021 Accepted on: August 2021
DOI: https://doi.org/10.21776/ub.jrm.2021.012.03.10

commonly used. However, sometimes the two-stage axial pump is more economical in the application. A horizontal axial pump is used for large fluid flow discharge with slight pressure in the flow.

Data collection was carried out by conducting direct interviews with workers and operating manuals regarding how the unit works on the hydraulic axial pump and details on the shape of the components and the number of uses of components in a period. Other data also includes a list of engine component damage, usage time. The results of the assessment can be used as input in predictive maintenance [4-5].

In component inventory control related to component age characteristics, the mean time to failure (MTTF) is estimated by the two-parameter Weibull. The reliability formula for the two-parameter Weibull is given as the following equation [11-12],

$$f(\mathrm{T}) = R(T) = \frac{\beta}{\theta}\left(\frac{\mathrm{T}}{\theta}\right)^{\beta-1} e^{-\left(\frac{\mathrm{T}}{\theta}\right)^{\beta}} \quad (1),$$

where T is time to failure, θ is the scale parameter, and β is the shape parameter. The shape parameter β is indicated the slope of the regressed line in the probability plot [11]. The shape parameter β is often used in determining the level of failure or damage and rate of damage. The failure rate value for the shape parameter β is listed in table 1.

Table 1. Values of β Parameters in the Weibull Distribution [11-12]

Value	Failure rate
$0 < \beta < 1$	Reduction of the rate of damage (DFR)
$\beta = 1$	Exponential Distribution
$1 < \beta < 2$	Increased rate of damage (IFR)
$\beta = 2$	Rayleigh distribution
$\beta > 2$	Increased rate of damage (IFR)
$3 \leq \beta$	The increase in the rate of damage (IFR), approaching the normal curve

The MTTF is the average time interval of damage from a damage distribution where the mean time is the expected value of identical units operating under normal conditions. For the two-parameter Weibull, the MTTF is expressed as the equation below [11].

$$MTTF = \theta \times \Gamma\left(\frac{1}{\beta} + 1\right) \quad (2),$$

where Γ $(1+1/\beta)$ is the loccation parameter γ function evaluated at the value of $(1+1/\beta)$.

3. RESULTS AND DISCUSSION

To identify the most critical components, the frequency of failure data is obtained and summarized as listed in table 2. The main components of a hydraulic axial pump consist of seal, bearing, shaft, impeller, and housing. Among the components from the six hydraulic pumps, the critical components are listed in table 3 based on the number of failure occurrence. The critical unit of the hydraulic axial unit pump component consists of seal, bearing, and shaft.

Table 2. Frequency failure of hydraulic axial pump components

Pump unit	Component	Freq. of failure
1	Seal	14
1	Bearing	8
1	Shaft	4
1	Impeller	2
1	Housing	2
2	Seal	9
2	Bearing	4
2	Shaft	3
2	Impeller	2
2	Housing	2
3	Seal	6
3	Bearing	3
3	Shaft	3
3	Impeller	2
3	Housing	2

Pump unit	Part	Freq. of failure
4	Seal	12
4	Bearing	5
4	Shaft	3
4	Impeller	2
4	Housing	2
5	Seal	11
5	Bearing	5
5	Shaft	2
5	Impeller	2
5	Housing	2
6	Seal	6
6	Bearing	3
6	Shaft	2
6	Impeller	2
6	Housing	2

Table 3. List of critical components

Pump unit	Component	Freq. of failure
1	Seal	14
1	Bearing	8
1	Shaft	4
2	Seal	9
2	Bearing	4
2	Shaft	3
3	Seal	6
3	Bearing	3
3	Shaft	3

Pump unit	Component	Freq. of failure
4	Seal	12
4	Bearing	5
4	Shaft	3
5	Seal	11
5	Bearing	5
5	Shaft	3
6	Seal	6
6	Bearing	3
6	Shaft	3

3.1 Determination of two-parameter Weibull

The step for determining the shape parameter β and scale parameter θ is initially conducted by ranking the times to failure in ascending order [11]. Further, the median rank is estimated by applying the equation below,

$$MR\% \sim \frac{i-0.3}{N+0.4} \times 100\% \qquad (3),$$

where *i* is the failure order number and *N* is the total sample size. By plotting the probability plot between the median rank at *the y*-axis and time to failure at *the x-axis*, the shape parameter β and scale parameter θ are obtained and summarized in table 4. The MTTF can be determined by applying the parameters in table 4 into equation 2. The MTTF values for each component are listed in table 5.

Table 4. The shape and scale paramter for each component

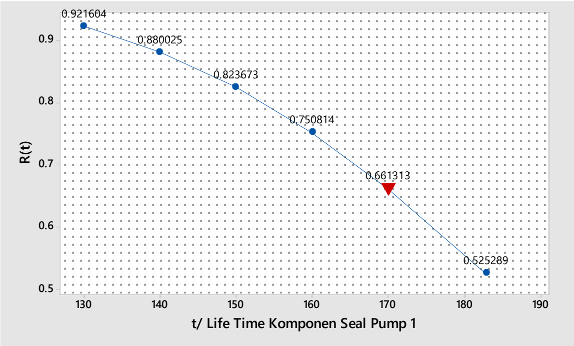
Pump unit	**Component**	β	θ	**Pump unit**	**Component**	β	θ
1	Seal	6.047	196.73	4	Seal	6.637	207.84
1	Bearing	6.383	408.43	4	Bearing	13.853	482.69
1	Shaft	14.878	780.06	4	Shaft	46.626	711.76
2	Seal	5.074	191.97	5	Seal	18.675	224.13
2	Bearing	4.698	391.98	5	Bearing	18.893	443.99
2	Shaft	59.695	484.01	5	Shaft	11.097	1193.23
3	Seal	35.968	158.71	6	Seal	29.880	162.46
3	Bearing	45.780	315.95	6	Bearing	42.583	323.23
3	Shaft	53.872	425.27	6	Shaft	47.877	484.82

Table 5. MTTF assessment

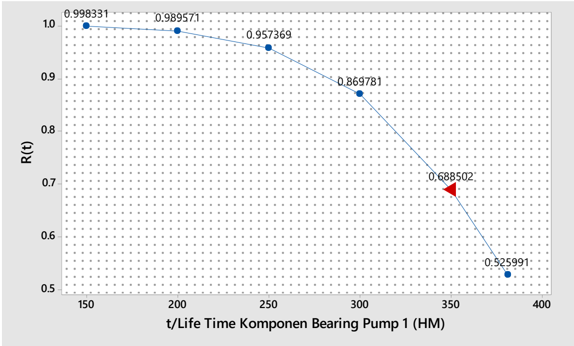
Component	θ	β	MTTF (jam)
Seal Pump 1	196.73	6.047	182.91
Bearing Pump 1	408.43	6.383	381.08
Shaft Pump 1	780.06	14.878	755.67
Seal Pump 2	191.97	5.074	176.78
Bearing Pump 2	391.98	4.698	358.89
Shaft Pump 2	484.01	59.695	481.26
Seal Pump 3	158.71	35.968	156.93
Bearing Pump 3	315.95	45.780	312.42
Shaft Pump 3	425.27	53.872	422.85
Seal Pump 4	207.84	6.637	193.92
Bearing Pump 4	482.69	13.853	465.38
Shaft Pump 4	711.76	46.626	703.82
Seal Pump 5	224.13	18.675	218.19
Bearing Pump 5	443.99	18.893	432.23
Shaft Pump 5	1193.23	11.097	1140.08
Seal Pump 6	162.46	29.880	159.788
Bearing Pump 6	323.23	42.583	319.62
Shaft Pump 6	484.82	47.877	479.41

3.2 Reliability assessment for the critical components

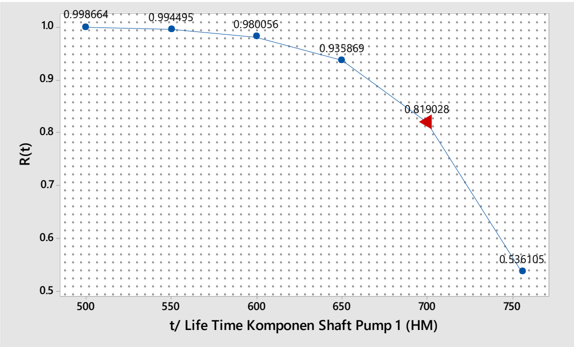
The reliability $R(T)$ of the critical components can be predicted by applying the two-parameter Weibull into equation 1. The graph of $R(T)$ vs lifetime prediction for each component is shown in figure 2 (a)-(r).


R(t)
t/ Life Time Komponen Seal Pump 1
0.921604
0.880025
0.823673
0.750814
0.661313
0.525289

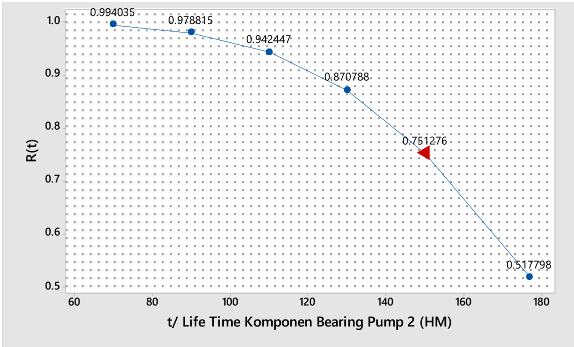
(a)


R(t)
t/Life Time Komponen Bearing Pump 1 (HM)
0.998331
0.989571
0.957369
0.869781
0.688502
0.525991

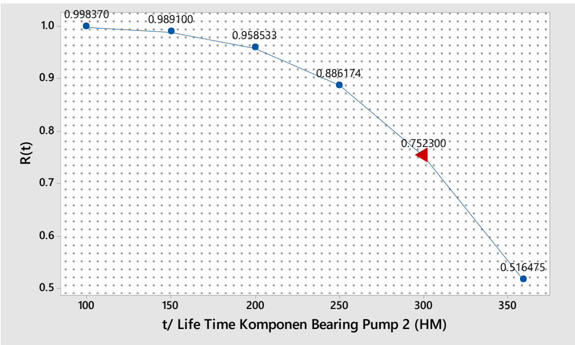
(b)


R(t)
t/ Life Time Komponen Shaft Pump 1 (HM)
0.998664
0.994495
0.980056
0.935869
0.819028
0.536105

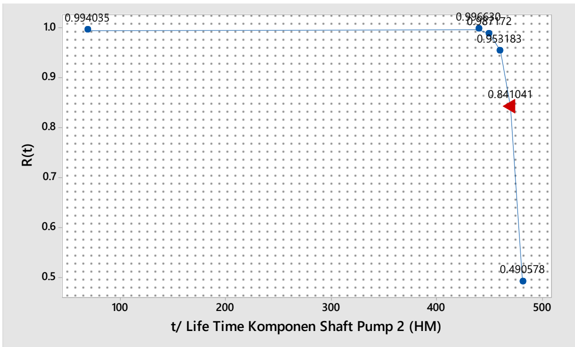
(c)


R(t)
t/ Life Time Komponen Bearing Pump 2 (HM)
0.994035
0.978815
0.942447
0.870788
0.751276
0.517798

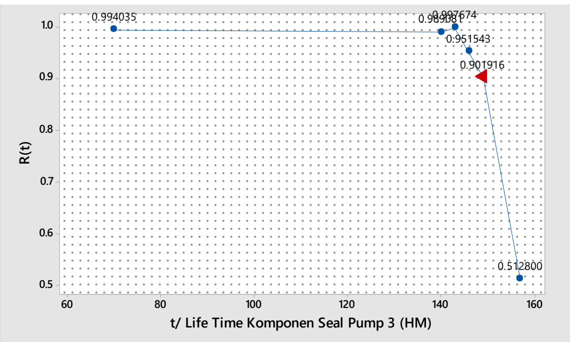
(d)


R(t)
t/ Life Time Komponen Bearing Pump 2 (HM)
0.998370
0.989100
0.958533
0.886174
0.752300
0.516475

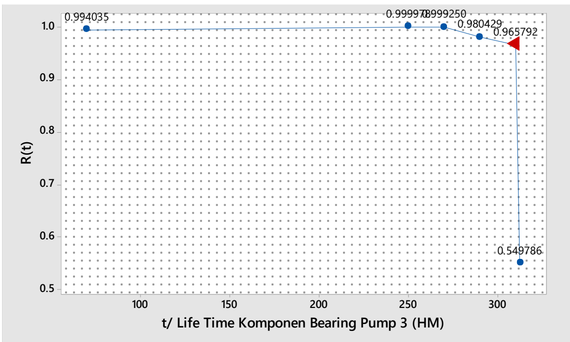
(e)


R(t)
t/ Life Time Komponen Shaft Pump 2 (HM)
0.994035
0.953183
0.841041
0.490578

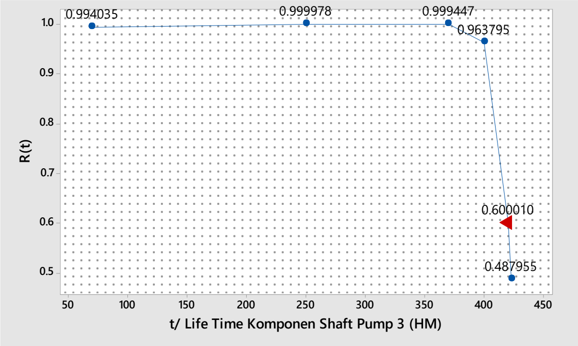
(f)


R(t)
t/ Life Time Komponen Seal Pump 3 (HM)
0.994035
0.997674
0.951543
0.901916
0.512800

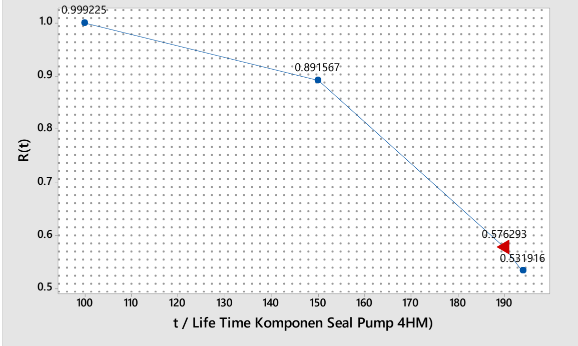
(g)


R(t)
t/ Life Time Komponen Bearing Pump 3 (HM)
0.994035
0.999250
0.980429
0.965792
0.549786

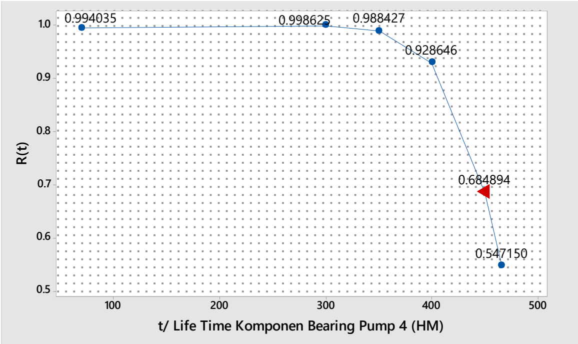
(h)


0.994035
0.999978
0.999447
0.963795
0.600010
0.487955
R(t)
1.0
0.9
0.8
0.7
0.6
0.5
50
100
150
200
250
300
350
400
450
t/ Life Time Komponen Shaft Pump 3 (HM)

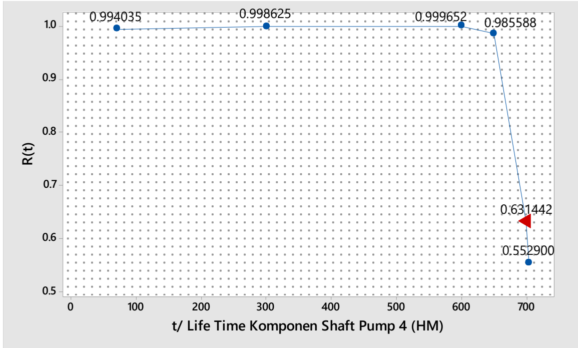
(i)


0.999225
0.891567
0.576293
0.531916
R(t)
1.0
0.9
0.8
0.7
0.6
0.5
100
110
120
130
140
150
160
170
180
190
t / Life Time Komponen Seal Pump 4HM)

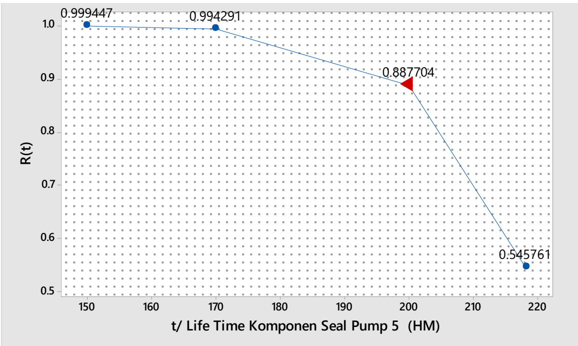
(j)


0.994035
0.998625
0.988427
0.928646
0.684894
0.547150
R(t)
1.0
0.9
0.8
0.7
0.6
0.5
100
200
300
400
500
t/ Life Time Komponen Bearing Pump 4 (HM)

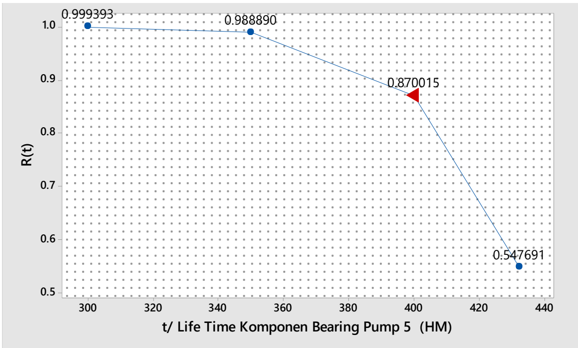
(k)


0.994035
0.998625
0.999652
0.985588
0.631442
0.552900
R(t)
1.0
0.9
0.8
0.7
0.6
0.5
0
100
200
300
400
500
600
700
t/ Life Time Komponen Shaft Pump 4 (HM)

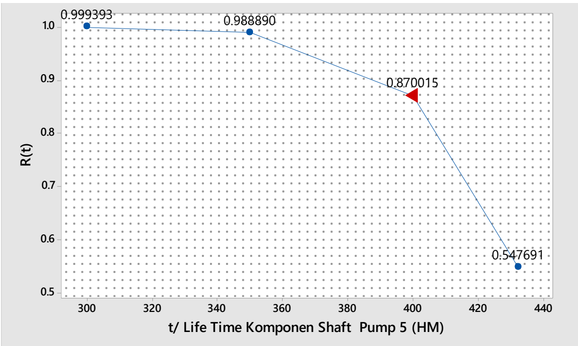
(l)


0.999447
0.994291
0.887704
0.545761
R(t)
1.0
0.9
0.8
0.7
0.6
0.5
150
160
170
180
190
200
210
220
t/ Life Time Komponen Seal Pump 5 (HM)

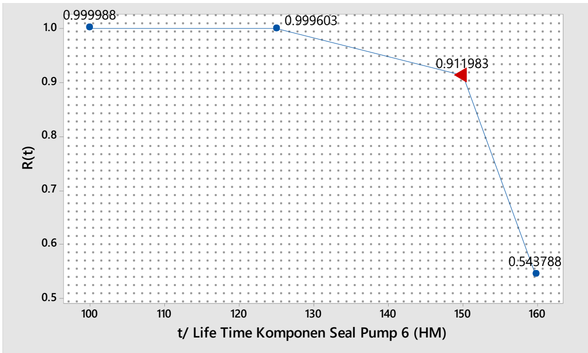
(m)


0.999393
0.988890
0.870015
0.547691
R(t)
1.0
0.9
0.8
0.7
0.6
0.5
300
320
340
360
380
400
420
440
t/ Life Time Komponen Bearing Pump 5 (HM)

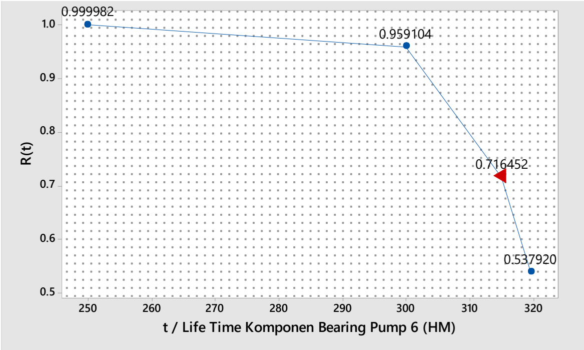
(n)


0.999393
0.988890
0.870015
0.547691
R(t)
1.0
0.9
0.8
0.7
0.6
0.5
300
320
340
360
380
400
420
440
t/ Life Time Komponen Shaft Pump 5 (HM)

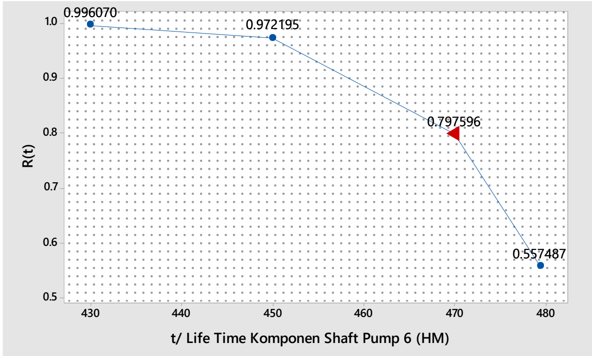
(o)


0.999988
0.999603
0.911983
0.543788
R(t)
1.0
0.9
0.8
0.7
0.6
0.5
100
110
120
130
140
150
160
t/ Life Time Komponen Seal Pump 6 (HM)

(p)



(q)



(r)

Figure 1. Reliability assessment; (a) Seal Pump 1, (b) Bearing Pump 1, (c) Shaft Pump 1, (d) Seal Pump 2, (e) Bearing Pump 2, (f) Shaft Pump 2, (g) Seal Pump 3, (h) Bearing Pump 3, (i) Shaft Pump 3, (j) Seal Pump 4, (k) Bearing Pump 4, (l) Shaft Pump 4, (m) Seal Pump 5, (n) Bearing Pump 5, (o) Shaft Pump 5, (p) Seal Pump 6, (q) Bearing Pump 6, (r) Shaft Pump 6

By considering the reliability assessment shown in figure 1, maintenance activities, especially for the critical components, can be carried out periodically or within a certain period. Determination of the period of periodic maintenance can be done based on time intervals (for example, doing maintenance every one month, every four months or every one year), and based on the working hours of the product machine as a schedule of activities, for example, once every hundred hours [13-15].

4. CONCLUSIONS

In this study, the seal, bearing, and shaft were identified as the critical component for all hydraulic axial pumps with a capacity of 200 litres per second. Two-parameter Weibull assessed the lifetime prediction for critical components of the hydraulic axial pump with great satisfaction. For further investigation, another method, such as the log-normal probability distribution method, can be applied for the comparison

5. REFERENCES

[1] SULARSO & TAHARA, H., Pompa dan kompresor, 7th ed., Jakarta, Pradnya Paramita, 2000.

[2] KAMIEL , B.P., PRASTOMO, N., RIYANTA, B., “Ekstraksi Parameter Statistik Domain Waktu dan Domain Frekuensi untuk Mendeteksi Kavitasi pada Pompa Sentrifugal Berbasis Principal Component Analysis (PCA)”, *Rekayasa Mesin*, v. 10, n. 2 pp. 165-176, 2019.

[3] WAN, L.R., LU, Y.J., ZENG, Q.L., GAO, K.D., JIANG, S.B., “The Research on Comprehensive Performance Evaluation of Axial Piston Pump Based on AHP”, *Mathematical Problems in Engineering*, v. 2018, 2018.

[4] HIDAYAT, R., ANSORI. N., IMRON, I., “Perencanaan Kegiatan Maintenance Dengan Metode Reability Centered Maintenance II”, *Makara, Teknologi*, v. 14, n. 1, pp. 7–14, 2010.

[5] SCHEFFER, C., & GIRDHAR, P., Machinery Vibration Analysis & Predictive Maintenance, 1st ed., Oxford, Newnes, 2004.

[6] EKAPUTRA, I.M.D., HARYADI, G.D., MARDIKUS, S., PUJA, I.G.K., DEWA, R.T., “Reliability Evaluation of Fatigue Crack Growth Rate of Heat-Treated TIG-Welded Al 6013-t4 by Two-Parameter Weibull”, *Key Engineering Materials*, v. 867, pp. 75-81, 2020.

[7] EKAPUTRA, I.M.D., HARYADI, G.D., MARDIKUS, S., DEWA, R.T., “Probabilistic Evaluation of Fatigue Crack Growth Rate for Longitudinal Tungsten Inert Gas Welded Al 6013-T4 Under Various PostWeld Heat Treatment Conditions”, In: *Proceedings of The 1st International Conference on Automotive, Manufacturing, and Mechanical Engineering (IC-AMME 2018)*, v.130, Denpasar, Nov. 2019.

[8] VOJDANI, A., FARRAHI, A., MEHMANPARAST, WANG, B., “Probabilistic assessment of creep-fatigue crack propagation in austenitic stainless steel cracked plates”, *Eng. Fract. Mech*, v. 200, pp. 50-63, 2018.

[9] LIAO, M., SHIMOKAWA, T., "A New Goodness-Of-Fit Test for Type-I Extreme-Value And 2-Parameter Weibull Distributions With Estimated Parameters", *Journal of Statistical Computation and Simulation*, v. 64, n. 1, pp. 23–48, 2007.

[10] KIM, W.G, PARK, J.Y., HONG, S.D., KIM, S.J., "Probabilistic assessment of creep crack growth rate for Gr. 91 steel", *Nucl. Eng. Des*, v. 241, pp. 3580–3586, 2011.

[11] O'CONNOR, P.D.T., KLYENER, A., *Practical Reliability Engineering*, 5th ed., United Kingdom, Jhon Wilye & Sons, 2012.

[12] EBELING, C.E., *An Introduction to Reliability and Maintainability Engineering*, 2nd ed., United Kingdom, McGraw-Hill, 2004.

[13] MEKONNEN, Y., ABURBU, H., SARWAT, A., "Life cycle prediction of Sealed Lead Acid batteries based on a Weibull model", *Journal of Energy Storage,* v. 18, pp. 467-475, 2018.

[14] MEDIANSYAH, HARYADI, G.D., ISMAIL, R., KIM, S.J., "Risk Analysis of Central Java Gas Transmission Pipeline by Risk-Based Inspection Method", In: *Proceedings of The The 4th International Conference on Advanced Materials Science and Technology*, v.202, Malang, Sept. 2017.

[15] SASIKIRONO, B., HARYADI, G.D., HUDA, A., KIM, S.J., "Risk Analysis using Corrosion Rate Parameter on Gas Transmission Pipeline", In: *Proceedings of The The 4th International Conference on Advanced Materials Science and Technology*, v.202, Malang, Sept. 2017.