Redesign of the coal gate on a 20 ton/hour chain grate boiler at pt sopanusa

Suhariyanto [1*], Liza Rusdiyana [2], Dika Andini Suryandari [3], Dimitra Meidina Kusnadi [4], Hafizh Naufal Atho'ulloh[5]

[1] Departement of Industrial Mechanical Engineering, Sepuluh Nopember Institute of Technology. E-mail: Suhariyanto@its.ac.id

[2] Departement of Industrial Mechanical Engineering, Sepuluh Nopember Institute of Technology. E-mail: liza@its.ac.id

[3] Departement of Industrial Mechanical Engineering, Sepuluh Nopember Institute of Technology. E-mail: dikaandinis@its.ac.id

[4] Departement of Industrial Mechanical Engineering, Sepuluh Nopember Institute of Technology. E-mail: dimitra@its.ac.id

[5] Departement of Industrial Mechanical Engineering, Sepuluh Nopember Institute of Technology. E-mail: naufalathoulloh45@gmail.com

Email of corresponding: liza@its.ac.id

Present Address:
AA-BB Building, Campus of ITS, Jl. Raya ITS, Keputih, Kec. Sukolilo, Surabaya, Jawa Timur 60111

Received: 5 November 2025 Revised: 28 November 2025 Accepted: 6 December 2025

Abstract— A chain grate boiler is a type of boiler with a moving grate system to transport solid fuel through the furnace. The coal gate regulates the distribution flow of coal from the hopper to the furnace. In the 20 tons/hour capacity chain grate boiler at PT Sopanusa, the existing coal gate experienced mechanical failure due to damage to components in the roller chain, shaft, and bearings, so that it could not operate as a coal distribution regulator. To overcome this problem, it is necessary to redesign the coal gate on the 20 tons/hour capacity boiler chain grate hopper at PT Sopanusa. The main components, such as the chain, sprocket, worm gear, shaft, bearing, and pin on the coal gate, need to be redesigned to avoid mechanical failure of the coal gate. After redesigning the main components of the coal gate, a coal gate design that is compatible with the boiler chain grate construction will be obtained. The results of the coal gate redesign are as follows: a lifting chain with Chain Grade 80 type, 4 mm diameter, and a sprocket diameter of 320.92 mm; a worm gear with a ratio of 30:1 using hardened steel for the worm and phosphor bronze for the gear; a shaft with S45C material, 60 mm diameter; bearings using single row deep groove ball bearings, unit number ASB Bearing UCP 212; and pins made of SAE 1045 material with dimensions of 60x20x12 mm to support the manual coal gate mechanism on the 20 tons/hour capacity boiler chain grate at PT Sopanusa.

Keywords— Coal Gate, Machine Elements, Lifting, Mechanism.

1. Introduction

A boiler is a piece of equipment or machine in the form of a closed vessel made of steel and used to produce steam. Steam is obtained by heating a vessel containing water using the results of burning fuel such as coal [1]. Based on the combustion method, there are several types of boilers that are commonly used, one of which is the Chain Grate Boiler, which is a type of boiler with a grate system that moves continuously to transport solid fuel through the furnace [2]. This combustion system allows for even distribution of solid fuel and good control over the combustion rate. Therefore, a device that can move linearly is needed to open or close the distribution flow path for feeding solid fuel evenly, located just before the furnace. This device is a coal gate, which is used to regulate the even distribution of coal feed from the hopper to the furnace [3]. The coal gate mechanism on the chain grate boiler can be raised or lowered manually by the operator using a mechanical steering wheel outside the boiler [4].

The existing coal gate on the 20 tons/hour capacity boiler chain grate at PT Sopanusa experienced a mechanical failure, whereby the existing coal gate could not be raised or lowered to regulate the even distribution of coal feed from the hopper to the furnace. The mechanical failure of the existing coal gate was caused by stiffness in the roller chain components, deflection in the shaft, and damage to the bearings [5]. The stiffness of the roller chain is caused by the roller chain not being suitable for direct lifting operations. The damage to the shaft and bearings is caused by the operating temperature inside the hopper, which reaches 300°C [6]. This indicates that the existing coal gate at PT Sopanusa requires efforts to overcome these problems.

Referring to the problems that occurred with the existing coal gate, this research will redesign the coal gate on the boiler chain gate to avoid mechanical failure of the coal gate. This design begins with the replacement of the roller chain component with a chain hoist to open and close the coal gate, and the shaft and bearing components are placed outside the hopper, which has a working temperature of 60C lower than inside the hopper [7]. Since the chain used is a chain hoist, the sprocket component also needs to be redesigned. Overall, this research involved the design of each component of the coal gate, namely the chain hoist as the lifting mechanism for the leaf door on the coal gate with two chain slings, the sprocket as the mount for the lifting chain, the shaft as the power transmission connected to two sprockets, the worm gear as the transmission that transfers rotational power from the manual mechanism to the shaft, pins as connectors and power transmissions between the shaft and the sprocket and gear, and bearings as shaft supports, with two bearings [8]. With this planning, it is hoped that the type of material and dimensions of each component and the design of the coal gate can be obtained in accordance with the operating conditions of the 20 tons/hour capacity boiler chain grate to solve the problems that occur in the existing coal gate.

2. Previous Researches

2.1 Boiler Chain Grate

A Boiler Chain Grate is a type of boiler that uses a moving grate system for the combustion of fuel, typically coal. In this system, bulk fuel material is poured into a hopper and then placed on a grate that moves continuously from the front to the back of the boiler [9], [10].

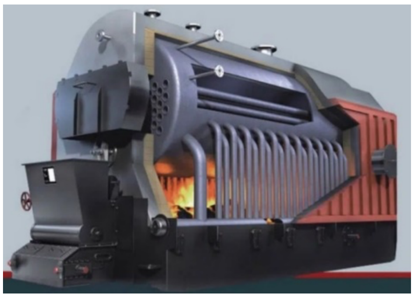

Figure 1 Boiler Chain Grate

2.2 Goal Gate

The coal gate is a component that functions to control and ensure the even distribution of coal on the grate towards the combustion chamber in the chain grate boiler. Even distribution of coal affects combustion efficiency and emissions [11]. The coal gate mechanism is a gate or door that can be raised or lowered linearly automatically using an actuator or manually by an operator [12]. In the manual coal gate mechanism, the coal gate can be raised or lowered with mechanical control such as a lever or wheel outside the boiler manually by the operator [13].

Figure 2 Goal Gate

2.2 Chain Hoist

A chain hoist is a mechanical device designed to lift and lower heavy loads using chains. This mechanism involves chains wrapped around a drum or wheel, with the load connected to the end of the chain. The main dimensions of a chain hoist consist of the chain bar diameter, inside length, and outside width [14].

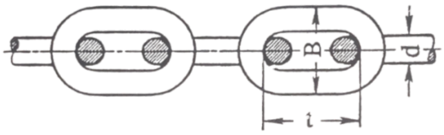

Figure 3 Lifting Chain

2.3. Shaft

2.3.1. Torque Shaft Design

$$M_t = 9{,}74 \times 10^5 \frac{P_d}{n} \text{ [15]}$$

Where:

M_t = Design Torque, (kgf.mm)

M_p = Design Power, (kW)

n = Rotations per minute, (rpm)

2.3.2. Stress and Safety Requirements for Solid Shafts

$$\tau_{max} = \sqrt{\left(\frac{16 \cdot M_b}{\pi \cdot ds^3}\right)^2 + \left(\frac{16 \cdot M_t}{\pi \cdot ds^3}\right)^2} \leq \frac{\sigma_{yp}}{sf}$$

Where:

ds : Shaft Diameter, (mm)

M_b : Bending Moment on the Shaft, (kgf.mm)

M_t : Torque on the Shaft, (kgf.mm)

σ_{yp} : Tensile Yield Strength, (kgf/mm^2)

sf : Safety factor

2.4. Peg

2.4.1. Pivot length due to shear stress

$$L = \frac{2. M_t. sf}{W. d. k_s. s_{yp}}$$

Where:

L : Bolt length, (mm)

M_t : Torsional moment, (kgf.mm)
sf : Safety factor
W : Bolt width, (mm)
d : Shaft Diameter, (mm)
k_s : Conversion factor from shear stress to tensile stress, (0.7)
σ_{yp} : Tensile Yield Strength, (kgf/mm^2)

2.4.2. Pitch length due to compressive stress

$$L = \frac{4. M_t. sf}{H. d. k_c. s_{yp}}$$

Where:
L : Bolt length, (mm)
M_t : Torque moment, (kgf.mm)
sf : Safety factor
H : Width of the dowel, (mm)
d : Shaft diameter, (mm)
k_c : Conversion factor from compressive stress to tensile stress tension, (1,2)
σ_{yp} : Tensile Yield Strength, (kgf/mm^2)

2.5Worm Gear

A worm gear is a transmission element that can transmit power and rotation to intersecting shafts [16]. A worm gear has a gear that is cut at an angle like a helical gear and is paired with a threaded rod called a worm [17], [18], [19].

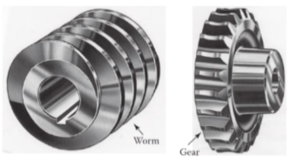

Figure 4 Worm Gear

2.5.1 Worm Dimensions

$$D_W = 3 \cdot p_c$$
$$L_W = \left(p_c(4{,}5 + 0{,}02 \cdot Z_W)\right) + 30\ mm$$

Where:
D_W : Worm pitch circle diameter, (mm)
p_c : Circular pitch, (mm)
L_W : Worm Face Length, (mm)
Z_W : Number of Worm Teeth

2.5.2 Gear Dimensions

$$D_G = m \cdot Z_G$$
$$b = 2{,}38\ p_c + 6{,}5\ mm$$

Where:
D_G : Gear pitch circle diameter, (mm)

Z_G : Number of Gear Teeth
b : Face width of the gear, (mm)

2.5.3 Worm Gear Efficiency

$$\eta = \frac{\tan\lambda(\cos\phi - \mu\tan\lambda)}{\cos\phi\tan\lambda + \mu}$$

Where:
η : Worm Gear Efficiency
λ : Lead Angle, (^{o})
ϕ : Normal Pressure Angle, (^{o})
μ : Coefficient of Friction

2.6 Bearing
2.6.1 Bearing Life Prediction

$$L_{10h} = \left(\frac{C}{P}\right)^b \times \frac{10^6}{60 \times n}$$

Where:
L_{10h} : Bearing Life, (Hours)
C : Dynamic Load Rotating, (N)
b : Bearing type constant (ball bearing (b=3), roller bearing (b=3.33))
P : Equivalent Bearing Load, (N)
n : Shaft Rotation, (rpm)

2.6.2 Equivalent Bearing Load

$$P = F_s(V \cdot X \cdot F_r + Y \cdot F_a)$$

Where:
P : Equivalent Bearing Load, (N)
F_s : Load Condition Constant
V : Rotating Factor (Inner Race Bearing Rotates (V = 1), Outer Race Bearing Rotates (V = 1,2))
X : Radial Factor / Radial Constant
F_r : Radial Load, (N)
Y : Thrust Factor / Axial Constant
F_a : Axial Load, (N)

3. METHOD

3.1. Research Flowchart

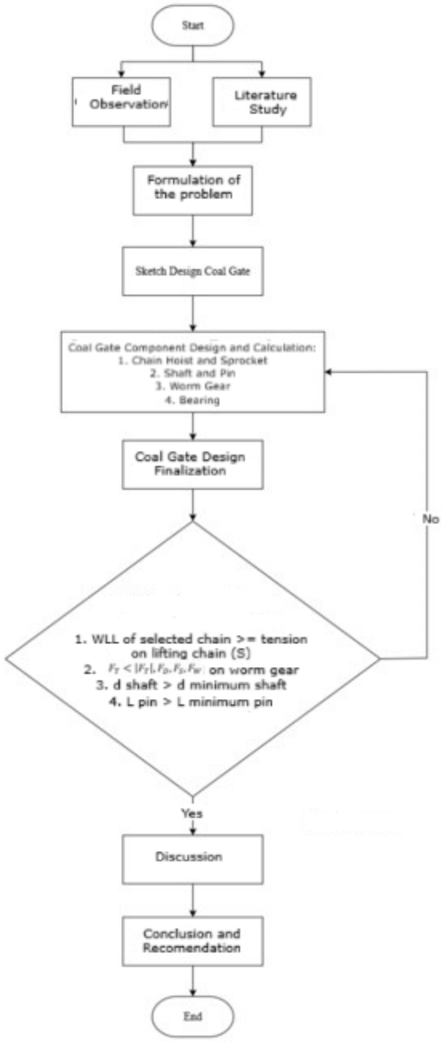

Figure 5 Research Flowchart

3.2 Existing Coal Gate

The existing coal gate has a design in which the shaft, sprocket, and bearing components are located inside the hopper, causing these three components to be exposed to extreme temperatures [20]. The chain component uses roller chain type [21].

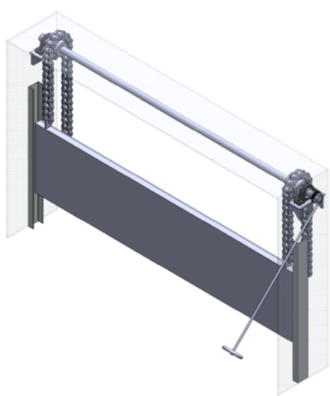

Figure 6 Existing Coal Gate Design

3.3 Coal Gate Design Sketch

The coal gate design sketch is a redesign of the existing coal gate design, in which the shaft, sprocket, and bearing components are designed to be located outside the hopper, and the chain type is replaced with a chain hoist [22], [23].

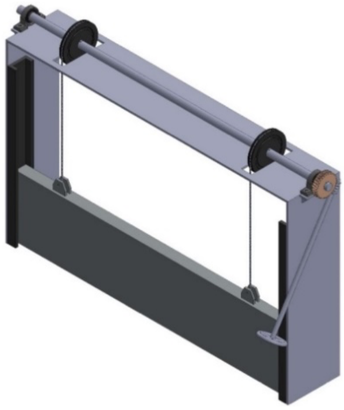

Figure 7 Coal Gate Design Sketch

4. RESULT AND DISCUSSION

This chapter discusses the coal gate design that will be developed to address the mechanical failure issues in the existing coal gate. The main objective of this chapter is to explain the design process and considerations taken in determining the specifications of the components in the coal gate by calculating and planning each component, namely the leaf door, chain hoist and sprocket, shaft, bearing, worm gear, and pin.

4.1 Leaf Door Weight Calculation Analysis

The leaf door on the coal gate consists of SS400 steel plate and castable. The leaf door is 2625 mm long, 100 mm wide, and 900 mm high.

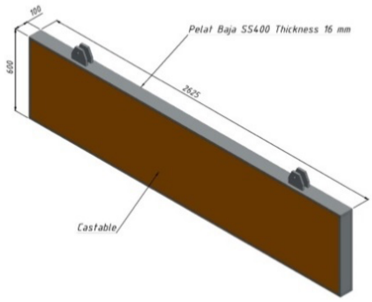

Figure 8 Leaf Door

4.1.1 Mass Calculation Analysis of SS400 Steel Plate

The mass calculation result for the SS400 steel plate on the leaf door with a plate thickness of 16 mm, consisting of three size variations, is 265.19 kg.

4.1.2 Castable Mass Calculation Analysis

The castable used is type TNC-12, which has a bulk density of 2.1 $^{tons/m^3}$. The mass of the castable on the leaf door is 259.81 kg.

4.1.3 Leaf Door Mass Calculation Analysis

The results of the mass and weight calculations for the leaf door, which consists of SS400 steel plate and castable, are 525 kg or 5150.25 N.

4.2 Chain Hoist and Sprocket Planning

4.2.1 Chain Hoist Design

The chain hoist is planned to have two links, so that the load borne by each chain link is 2575.125 N. Based on this, the selected lifting chain is Chain Grade 80 type AS2321 Short Link Chain Grade T 80 with a chain rod diameter of 4 mm, which has a Working Load Limit (WLL) of 500 kgf or 4905 N.

1 . Specifications for AS 2321 Short Link Chain Grade T 80

Nominal Size	Pitch	External Width	Working Load Limit	Weight
(mm)	(mm)	(mm)	(tonf)	(kg/m)
4	12.0	13.2	0.5	0.349

4.2.2 Sprocket Design

In accordance with the hoist chain design and the client's request to open the coal gate 500 mm, half a sprocket rotation is required. The sprocket design results in a pitch circle diameter of 320.92 mm with 42 sprocket teeth.

4.3 Force and Torque Analysis on the Coal Gate Lifting Mechanism

4.3.1 Lifting Force Analysis on the Chain

The chain lifting force to lift the leaf door on the coal gate when it first moves (F_C) is 2587.18 N with a speed of(v) 0.05 m/s and acceleration of(a) 0.025 m/s^{2}to lift the coal gate up to 500 mm.

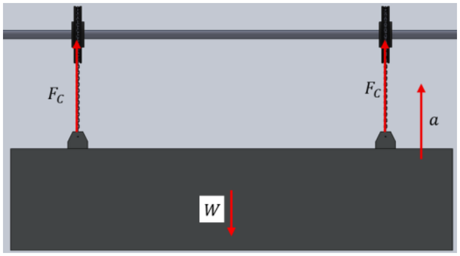

Figure 9 Leaf Door Lifting System Diagram When Initially Moving

4.3.2 Torque and Rotation Analysis on the Sprocket

With a lifting force (F_C) of 2587.18 N and a sprocket pitch circle diameter of 320.92 mm, the torque on the sprocket is 415.24 Nm and the sprocket rotation is 5.953 rpm.

4.4 Worm Gear Design

With the torque required to lift the leaf door being 415.24 Nm, a transmission system using a worm gear with a speed ratio of 30:1 is obtained, using a single threaded worm made of hardened steel with a worm pitch circle diameter D_W=D_W = 56.52 mm and a worm face length L_W=115.16 mm and a gear with 30 teeth made of phosphor bronze with a pitch circle diameter D_G =180 mm and a gear face width b=51.34 mm. With these design results, the worm gear efficiency η=47.66% is obtained, so that the worm gear has self-locking properties and is safe to use for lifting applications on coal gates.

4.5 Shaft Diameter Calculation

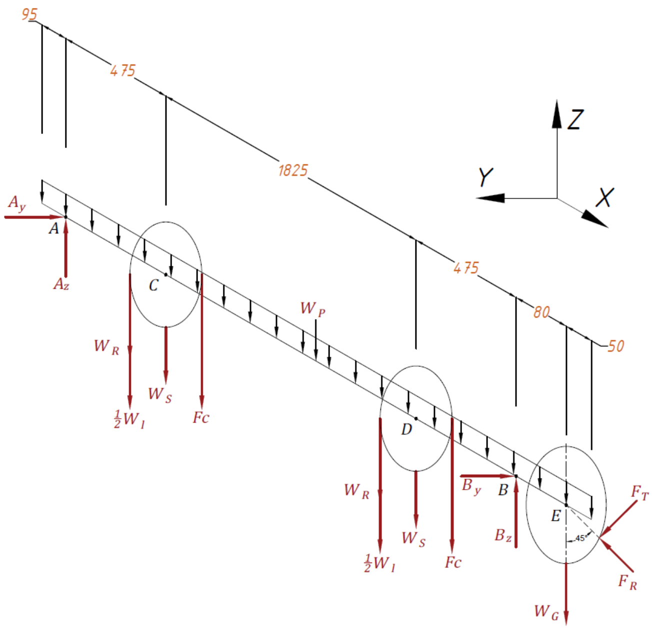

Figure 10 Free Body Diagram of the Shaft

Based on the shaft calculations, the maximum bending moment is 2,626.05 Nm or 267,691.13 kgf.mm, which is used to determine the minimum shaft diameter. The minimum allowable shaft diameter is 47.46 mm, so a shaft diameter of 60 mm is used to exceed the minimum diameter and match the bearings available on the market.

4.6 Bearing Design

From the bearing planning calculations, it was found that a single row deep groove ball bearing with the unit number ASB Bearing UCP 212 with a bore diameter of 60 mm, outside diameter of 110 mm, and width of 26 mm was used for two bearings with a predicted bearing life of approximately 149,163.4 working hours for bearing A and 32,253.5 working hours for bearing B.

4.7 Pinion Dimension Calculation

Based on a shaft diameter of 60 mm, a pin width (W) of 20 mm and a pin height (H) of 12 mm were selected. In accordance with the minimum pin length (L) calculation for shear stress and compressive stress, the minimum pin dimensions used are (L × W × H = 60 mm × 20 mm × 12 mm).

5. CONCLUSION

Based on the planning and calculations in this final project, the following conclusions were obtained:

1. The results of the planning and calculations for the coal gate machine element components in the 20 tons/hour capacity boiler chain grate at PT Sopanusa are as follows:
   a. The chain hoist was designed using Chain Grade 80 type AS2321 Short Link Chain Grade T 80 with a diameter of 4 mm and a lifting force of 2,587.18 N for a load of 2,575.125 N per chain link.
   b. The sprocket was obtained using cast iron material with a pitch circle diameter of 320.92 mm.
   c. The worm gear is designed to have a speed ratio of 30:1 using a single threaded worm made of hardened steel with a worm pitch circle diameter DW = 56.52 mm and a worm face length LW = 115.16 mm. The gear has 30 teeth made of phosphor bronze with a gear pitch circle diameter DG = 180 mm and a gear face width b = 51.34 mm. The efficiency of the worm gear is 47.66%, giving the worm gear self-locking properties.
   d. The shaft on the coal gate uses JIS S45C material with a shaft diameter of 60 mm and a pin using SAE 1045 material with dimensions L×W×H = 60×20×12 mm.
   e. The bearing on the shaft support uses a single row deep groove ball bearing, unit number ASB Bearing UCP 212, with a bore diameter of 60 mm, an outside diameter of 110 mm, and a width of 26 mm. There are two bearings with a service life of approximately 149,163.4 working hours for bearing A and 32,253.5 working hours for bearing B.
2. Based on the results of the planning and calculation of the coal gate components, a suitable coal gate design was obtained for the hopper on the 20 tons/hour capacity boiler chain grate at PT Sopanusa, with hopper dimensions of 2.7 meters long, 0.5 meters wide, and 1.7 meters high.

.

REFERENCES

[1] Achmadi, A. (2016). Experimental Study of the Effect of Quenching Treatment with Variations in Salt Water Concentration Cooling on the Hardness and Tensile Strength of ST 37 Steel. SIMETRIS, 10(2).

[2] Aswan, D., & Ritonga, A. (2016). Design of a 20 KG Capacity Laboratory Scale Aluminum Melting Furnace. In Jurnal Inotera (Vol. 1, Issue 1).

[3] Daeng Polewangi, Y. (2019). Analysis of Boiler Maintenance Systems in the Palm Oil Industry. Industrial Engineering Journal, 8(2).

[4] Fruchtbaum, J. (1988). Bulk Materials Handling Handbook. Springer US.

[5] Irawan, D., & Nugraha Gusniar, I. (2021). Design of Crankshaft and Pin on STAR SPG 1600 Generator Set. In Indonesian Journal of Mechanical Engineering (Vol. 16, Issue 2).

[6] Japanese Industrial Standard. (2015). JIS G 3101 Rolled steels for general structure.

[7] Kitto, J. B., & Stultz, S. C. (2005). Steam, its generation and use. Babcock & Wilcox.

[8] Li, M. (2018). The Economical Operation of Coal Chain Grate Boiler. IOP Conference Series: Earth and Environmental Science, 170(4). https://doi.org/10.1088/1755-1315/170/4/042056

[9] Mishra, R. C., & Pathak, K. (2012). Industrial Safety and Maintenance Management. New Delhi: PHI Learning.

[10] Mott, R. L., Vavrek, E. M., & Wang, Jyhwen. (2018). Machine Elements in Mechanical Design (Sixth Edition). New York: Pearson Education, Inc.

[11] Muin, Syamsir A. (1995). Lifting Equipment. Jakarta: PT RajaGrafindo Persada.

[12] National Association of Chain Manufacturers. (2003). Welded Steel Chain Specifications by the National Association of Chain Manufacturers.

[13] Oberg, Erik, & McCauley, C. J. (2012). Machinery's Handbook (29th Edition). New York: Industrial Press.

[14] Pasla, R. (2004). Hoisting Crane for Thresher Feed in Palm Oil Mills Maximum Lifting Weight: 5 Tons Maximum Lifting Height: 10 M [Research]. Medan Area University.

[15] Pytel, A., & Kiusalaas, J. (2012). Mechanics of Materials (Second Edition). Cengage Learning.

[16] Rudenko, N. (1996). Material Handling Machines. Translated by Nazar Foead. Erlangga Publishers.

[17] Suhariyanto, Mashuri, Sampurno, B., Sanyoto, B. L., & Rusdiyana, L. (2022). Machine Elements 1. Surabaya: ITS Press.

[18] Suhariyanto, Mashuri, Sampurno, B., Sanyoto, B. L., & Rusdiyana, L. (2022). Machine Elements 2. Surabaya: ITS Press.

[19] Sularso, & Suga, K. (2004). Fundamentals of Machine Element Design and Selection. Jakarta: PT. Pradnya Paramita.

[20] Ugural, A. C. (2015). Mechanical Design of Machine Components (Second Edition). CRC Press.

[21] Uicker, J. J., Pennock, G. R., & Shigley, J. E. (2016). Theory of Machines and Mechanisms (Fifth Edition). New York: Oxford University Press.

[22] Wiranto, D. T. (2020). Design and Construction of a Rotary Sand Sieving Machine (Gears and Bearings) [Research Report]. Sebelas Maret University.

[23] Wiryosumarto, H., & Toshie Okumura (2000). Metal Welding Technology. Jakarta: Pradnya Paramita, 2000.