



Component Design and Strength Analysis of Coffin Lowering Machine for COVID-19 Corpse: A Problem-Based Learning

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ABSTRACTS

The increasing number of deaths due to COVID-19 followed by an excessive number of burials had risen the emergence of a safety plan, supporting the burial process to minimize the dangerous impact on the human. The conventional way of burying the corpse with infectious disease in Indonesia utilizes ropes to lower the coffin and involves four to eight people. However, this is not practical because it is energy-wasting and crowding. This paper aims to propose a design of a safe, practical, and robust coffin lowering machine. The proposed design is available for all ages with a weight of up to 200 kg. The design has a 2000 x 600 x 750 mm dimension, in which the width can be extended from 600 to 1000 mm. The straps for lowering the coffin are mounted on the left and right-side shafts. Each of the components is connected with a pin joint. Then, the components are analyzed by calculating the static and fatigue strength to obtain the safety factor and to determine the service life. As a result, the proposed design demonstrates the safety factors for static and fatigue condition that are higher than one, indicating it can be considered for fabrication. In addition, the presented work can be referred as a problem-based learning case study in Machine Element Course.

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1. INTRODUCTION

In the middle of April 2021, the number of deaths due to COVID-19 in Indonesia had been recorded and reached 43.424 people. COVID-19 pandemic has continued to increase, adding to the long list of people who have been infected and died. The front-line contributors to this pandemic are healthcare workers. Many researchers have reported the ways how to against COVID-19 pandemic (Machmud and Minghat, 2020; Putra and Abidin, 2020; Anggraeni, 2020; Razon, 2020; Hamidah et al., 2020; Hashim et al., 2020; Dirgantari et al., 2020; Mulyanti et al., 2020; Sangsawang, 2020; Nasution and Nandiyanto)

The value of deaths had risen by about 2.7 % since the first Covid-19 cases announced in March 2020. The significant rise of death results in the rise of burials as well. The civil report about the registered burial in Jakarta, Indonesia, recorded excess mortality during the first ten months of the COVID-19 pandemic. The recorded funerals in Jakarta from January to October 2020 was 42,460, while the average sum for the same month in 2015 until 2019 was 26,342 burials (Elyazar et al., 2020). The data indicates that the number of burials in the first ten months of COVID-19 increased about 61 %.

The increasing number of burials made the burial workers overwhelmed because they needed to bury many corpses in a day. In the COVID-19 case or emergency conditions, the burial of the corpses was carried out by considering minimizing the dangerous impact on the human. The general principle for managing the human remains with COVID-19 includes conducting a preliminary evaluation and risk assessment, using PPE or Personal Protective Equipment, limiting the number of staff exposure to COVID-19, and undertaking a special procedures to manage the large numbers of dead body (Finegan et al., 2020).

Currently, the burial process refers to COVID-19 protocol still use a manual procedure using ropes to minimize contact with the coffin. The burial worker will handle each end of the ropes. Usually, there will be four to eight people involved during this process. However, this method is not practical because it is energy-wasting and crowding. The problems that appeared during the burial process, especially for the corpse infected by the virus, had risen the emergence of a safety plan which can help the workers to bury the corpse with a minimum number of people and safe distribution of the corpse into the grave.

In this work, a design of coffin lowering machine is proposed to overcome the difficulty in handling the COVID-19 corpse by the burial workers. The design is focused on minimizing the number of people involved in the burial process, as well as to provide a practical and economical solution. The maximum load that can be created by the machine is a 200 kg coffin. The procedure in lowering coffin into the grave using the machine will be discussed. The drawing is created by using computer-aided drawing software, and failure analysis of the machine frame under static and fatigue loading is evaluated by theoretical approach.

The proposed machine is expected to contribute positively in stopping the pandemic of COVID-19. In addition, the whole process presented in this work can be used as a case study for problem-based learning in mechanical engineering major.

2. METHODS

2.1. DESIGN CONCEPT

Several of the design ideas were proposed. At first, the main goal of the design was to create a coffin lowering machine that was also functioning as an ambulance stretcher. Moreover, the previous design also put the telescopic shaft and U-shape beam for the width and length to be the primary specification. The telescopic shaft was used to lower the coffin,

while the telescopic U-shape beam was used as the joint attachment of the stretcher's foot and wheels. However, this idea was difficult to realize.

After that, the finalized design was invented. This design put the telescopic shaft for the length into the secondary specification and emphasized its functionalities in lowering the coffin, the number of operators, and the strength. This design consists of telescopic width, allowing the operator to adjust the width for storing purpose. The rotating shaft for the length is used to attach the straps to lower the coffin. A human-power gearbox is provided with the aim to rotate the shaft. During the lowering process, the gravity effect will be utilized, and the brakes and crank handle are used to control the rotation of the shaft. Moreover, the design has the foot and the wheels with brakes, which will ease the movement of the machine from one place to another.

2.2. MATERIAL SELECTION

The material selected for developing the machine is steel because it can provide high strength, long-lasting, good machinability, and durability (Sushil et al., 2017). Moreover, it is affordable and recyclable (Zulaikah et al., 2020). The specific material used is AISI 1020 – Cold Drawn. Applying cold drawing on material can improve the mechanical strength, machinability, surface finish, and dimensional accuracy (Armah, 2018). The mechanical properties of these materials are recorded in **Table 1**.

AISI 1020 is low carbon steel which commonly used in industry. This material will be processed further to produce the machine components for lowering machine. Some of the part in the lowering machine requires machining process especially for making hole for pin joint attachment and keyset installation. Due to the small size of the hole, micro-milling can be proposed for fabrication purpose. Micro-milling is one of the mechanical machining process which known for its flexibilities and abilities to manufacture 2D, 2 ½ D, and 3 D features available for wide range of materials (Saptaji et al., 2021).

2.3. DESIGN OF COMPONENTS

The proposed design for the coffin lowering machine is shown in **Figure 1**. The structural components used in this machine consist of hollow shafts which dimension is shown in **Table 2**. Components 1 and 2 are the rotating shaft which connected to the gear through a keyset. The width of component 2 can be extended by using a telescopic shaft — component 3. The remaining part, 4 and 5, is used as the base structure and foot. These components are joined by a pin joint.

The gearbox consists of 2 bevel gear and two spur gears, which varies in dimensions. The gearboxes installed in this machine are 3 — one of the gearboxes functions as the driver and the other function as transmission. The driver gearbox is shown in **Figure 2**. It has a gear reduction unit that can reduce the amount of load to the operator's hand. According to **Figure 2**, gear reduction unit uses spur gear denotes as number 1 and 2 and bevel gear labels as number 3 and 4. The dimension of the gears is shown in

Table 3 and **4**. Meanwhile, the other two gearboxes serve as transmission only consist of 2 bevel gears.

Table 1. Mechanical Properties of AISI 1020

Properties	Value
Tensile Strength	470 MPa
Yield Strength	390 MPa
Elongation at break	15%
Reduction in area	40%
Brinell Hardness	131

Table 2. Dimension of hollow shaft

Component Number	Outer Diameter (mm)	Inner Diameter (mm)
1	50	25
2	50	25
3	30	15
4	40	20
5	40	20

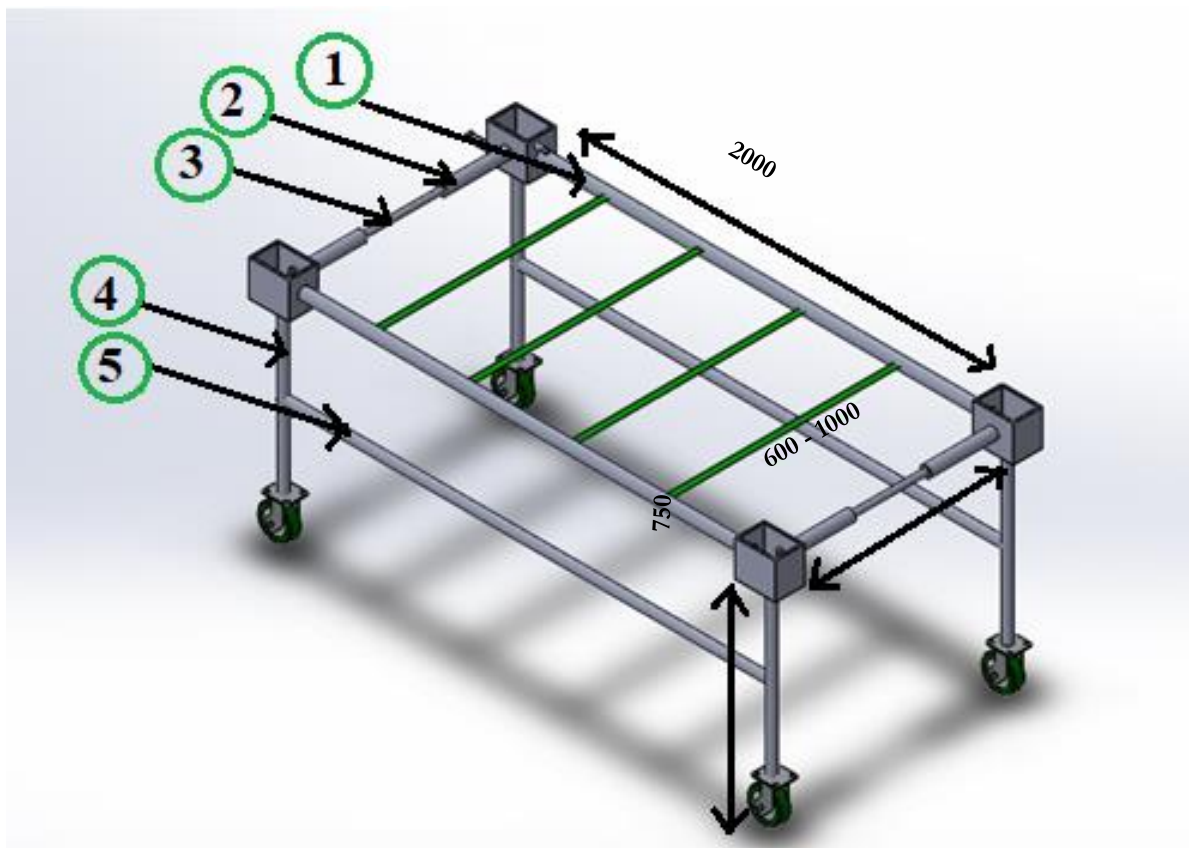


Figure 1. Coffin lowering machine (dimension in mm)

Table 3. Specification and dimension of spur gears

Specification and Dimension	Gear 1	Gear 2
Pressure angle	20°	20°
Module	1	2
Number of teeth	18	60
Shape	S1	S1
Bore diameter	8 mm	25 mm
Hub diameter	15 mm	55 mm
Pitch diameter	18 mm	120 mm
Outside diameter	20 mm	124 mm
Face width	10 mm	20 mm
Hub width	5 mm	19 mm
Total length	15 mm	30 mm
Allowable bending strength	12.1 Nm	4.57 Nm

Table 4. Specification and dimension of bevel gears

Specification and Dimension	Gear 3	Gear 4
Pressure angle	20°	20°
Helix angle	35°	35°
Module	4	3
Number of teeth	20	30
Shape	BK	B4
Bore diameter	30 mm	30 mm
Hub diameter	70 mm	60 mm
Pitch diameter	90 mm	90 mm
Outside diameter	87.34 mm	92.21 mm
Mounting distance	85 mm	60 mm
Total length	45.53 mm	40.34 mm
Crown to the back length	27.45 mm	31.66 mm
Hub width	21.67 mm	21 mm
Length of bore	42 mm	36 mm
Face width	23 mm	17 mm
Holding surface diameter	48.07 mm	57.14 mm
Allowable bending strength	193 Nm	4.57 Nm

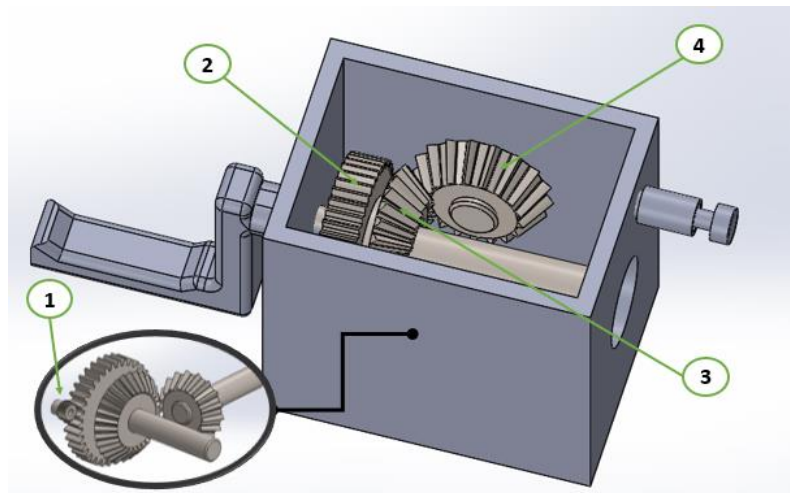


Figure 2. The driver gear box

2.4. DESIGN INSTALLATION

In practice, the machine will be installed outside of the grave as shown in **Figure 3**. The straps will be placed on the shaft in component 1 shown in **Figure 1** and the coffin will be put on the top of the straps. Once the coffin is safely placed, the gear's braker on the driver gear provided in **Figure 2** will be pulled off and the gear will automatically rotate the shaft until the coffin arrive at the bottom. Once the coffin already gets into the grave, the strap will be taken off from the shaft and it will be buried along with the coffin. After taking off the strap, the machine is removed, and the coffin is buried.

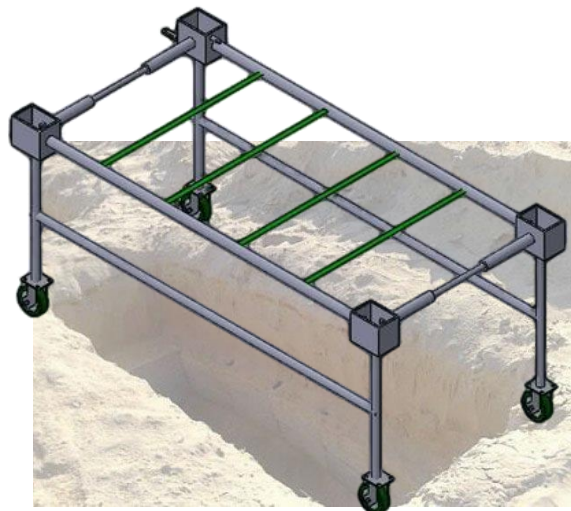


Figure 3 The installation of coffin lowering machine

2.5. ANALYSIS PROCEDURE

In analyzing the strength of the structure in static and dynamic condition; a step-by-step calculation is carried out. The assumption is taken before the analysis. For the static analysis, a torsional load is assumed to be cantered in four separate locations, which evenly distributed. The torsional load is translated into the axial load to the base structure or the lower device's foot. Applying the equation of equilibrium into the structure will result in every joint's reaction forces, especially in component 1, 4, and 5. For further analysis on the statics condition, some of the equations below are used.

$$I = \frac{\pi}{64} (D_o^4 - D_i^4) \quad (1)$$

$$J = \frac{\pi}{32} (D_o^4 - D_i^4) \quad (2)$$

$$\sigma = \frac{Mc}{I} \quad (3)$$

$$\tau = \frac{Tc}{J} \quad (4)$$

$$\sigma_{1,2} = \frac{\sigma_x + \sigma_y}{2} \pm \sqrt{\left(\frac{\sigma_x - \sigma_y}{2}\right)^2 + (\tau_{xy})^2} \quad (5)$$

$$n = \frac{S_y}{\sigma_1 - \sigma_2} \quad (6)$$

Where,

D_o	: outer diameter of circle (m)
D_i	: inner diameter of circle (m)
I	: second moment of inertia (m ⁴)
J	: polar moment of inertia (m ⁴)
M	: bending moment (Nm)
c	: maximum distance from neutral axis (m)
σ	: normal stress (Pa)
T	: torsion (Nm)
τ	: shear stress (Pa)
$\sigma_{1,2}$: principal stress (Pa)
S_y	: yield strength (m)
n	: safety factor

The analysis of dynamic condition also requires an assumption. For dynamic analysis, loading and unloading condition are used for the assumption. The loading condition is when the coffin is placed on the straps mounted on the left and right sides of the structure. Meanwhile, the unloading condition is when there is no load applied to the structure. Therefore, the applied load during dynamic analysis is repeated with a maximum load equals to 200 kg (2000 N) and a minimum load equals to 0 kg. Some of the formulas used during dynamic (fatigue) analysis are stated below.

$$\sigma_a = \left| \frac{\sigma_{max} - \sigma_{min}}{2} \right| \quad (7)$$

$$\sigma_m = \frac{\sigma_{max} + \sigma_{min}}{2} \quad (8)$$

$$\sigma'_a = (\sigma_x^2 - \sigma_x\sigma_y + \sigma_y^2 + 3\tau_{xy}^2)^{1/2} \quad (9)$$

$$S_e = k_a k_b k_c k_d k_e k_f S'_e \quad (10)$$

$$n_f = \frac{1}{\frac{\sigma_a}{S_e} + \frac{\sigma_m}{S_{ut}}} \quad (11)$$

Where,

σ_a	: amplitude component (Pa)
σ_m	: midrange component (Pa)
σ_{max}	: maximum stress (Pa)
σ_{min}	: minimum stress (Pa)
σ'_a	: von Misses stress (Pa)
S_e	: endurance limit modifying factors (Pa)
S'_e	: endurance limit (Pa)
k_a	: surface condition modification factor
k_b	: size modification factor
k_c	: load modification factor
k_d	: temperature modification factor
k_e	: reliability factor
k_f	: miscellaneous-effect modification factor
S_{ut}	: ultimate strength (Pa)

Some of the equations are employed for life prediction analysis purpose. The equations used for it are listed below.

$$\sigma_{rev} = \frac{\sigma_a}{1 - \frac{\sigma_m}{S_{ut}}} \quad (12)$$

Where,

σ_{rev}	: completely reversed stress (Pa)
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3. RESULTS AND DISCUSSION

3.1. STATIC ANALYSIS

In this stage, the statics analysis was conducted to analyze the strength of the structure. For this condition, 200 kg of loads or equivalent to 2000 N of forces were distributed in four different locations in the structure. This assumption is addressed for a 70 kg of adult male body (Uçisik & Rushbrook, 1998). Besides, the assumption also considers the data from Health and Safety Laboratory Report, average weight of coffin and heavier body could reach 157 kg.

With the assumed load, a free body diagram was generated as shown in **Figure 5**. And **Figure 5**. The free body diagram is useful to help determine equation of equilibrium to solve the unknown forces at each component (Wang, 2017). By equating the equation to zero, unknown forces at each point were obtained and summarized in **Table 5**.

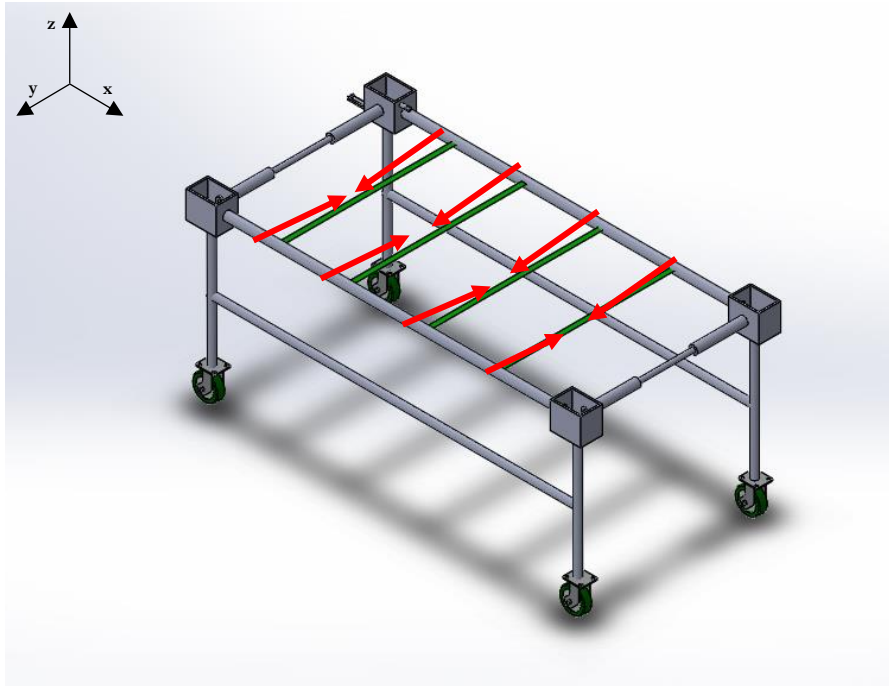


Figure 4. Free body diagram of the structure with the 200 kg of load (Isometric View)

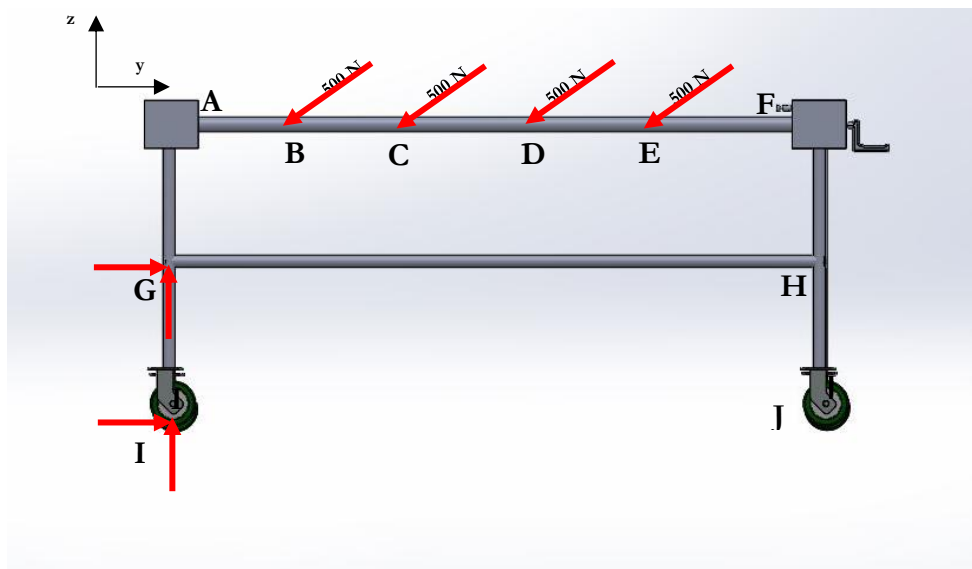


Figure 5. Free body diagram of the structure with applied load and reaction forces (side view)

Table 5. Reaction forces in each component

Components	Point	Resultant Forces (N)
1	A	1000
	B	500
	C	500
	D	500
	E	500
	F	1000
4	G equivalent to H	500 N
	I equivalent to J	500 N

After finding the reaction forces in every point, the shear forces and bending moment diagram were made. Based on the shear forces and bending moment diagram, the maximum shear force and bending moment were found for each of the component. Thus maximum value moment helps to find the critical point along the shaft for the maximum stress (Wang, 2017). The value of the maximum shear and bending moment can be seen in **Table 6**.

Based on the known bending value, the critical location which existed in the structure was at the outer surface of the structure. This location was getting worse if the torsional force was applied. Then, the known value of bending moment and torsional force were combined to find the normal stress and shear stress value by using formula (3) and (4). The calculated normal and shear stress were used to calculate the principal stress using (5).

$$\sigma_z = \frac{Mc}{I} = \frac{32M}{\pi(D^3 - d^3)} = \frac{32(600.1008249)}{\pi(0.05^3 - 0.025^3)} = 55.89 \text{ Mpa}$$

$$\tau_{yz} = \frac{Tr}{J} = \frac{16T}{\pi(D^3 - d^3)} = \frac{16(50)}{\pi(0.05^3 - 0.025^3)} = 2.33 \text{ MPa}$$

$$\sigma_{1,2} = \frac{\sigma_x + \sigma_y}{2} \pm \sqrt{\left(\frac{\sigma_x - \sigma_y}{2}\right)^2 + (\tau_{yz})^2} = \frac{55.89}{2} \pm \sqrt{\left(\frac{55.89}{2}\right)^2 + 2.33^2}$$

$$\sigma_1 = 55.987 \text{ Mpa}$$

$$\sigma_2 = -0.097 \text{ Mpa}$$

Table 6. Maximum bending moment and shear force value for each component

Components	Bending (N.m)	Shear Force (N)
1	600	1000
4	562	1000
5	1050	500

The value of principle stress was useful for calculating the safety factor of each component using Maximum Shear Stress theory in (6). **Table 7** shows the factor of safety for component 1, 4, and 5 under statics condition. According to the result, the critical component of the structure is component 5 with safety factor 2.04. Since all the components have number of safety factor greater than 1, it appears that the lowering machine is in the safety zone. When the number of safety factor is too small, the possibility of failure is large (Armah, 2018). However, large number of safety factor does not indicate the design is good as well. If the safety factor is too large, uneconomical and unfunctional design is resulted (Armah, 2018).

3.2. DYNAMIC ANALYSIS

For the dynamic analysis or fatigue analysis, the machine was assumed in unloading and loading conditions. The load applied during unloading was 0 kg, while the load applied during loading was 200 kg. Therefore, the maximum force and minimum force for the dynamic condition were 0 N and 2000 N. For analysis, another variable, namely as endurance limit, was needed. There were three elements need to be analyzed, which were components 1, 4, and 5.

In general, the component's material was machined to create a keyset and hole for the joint. For component 1, a torsional load was applied on the rotating hollow shaft. Then, those conditions produced the endurance limit S_e equal to 118.217 Mpa by using formula (10). Since there was an attachment for the straps, a stress concentration was generated on component 1. The stress concentration on this component was assumed to be a circular hole and experienced torsion and bending.

$$S_e = k_a k_b k_c k_d k_e k_f S'_e$$

$$S_e = (0.97)(0.879)(0.59)(235) = 118.217 \text{ Mpa}$$

For components 4 and 5, the axial load was applied to the hollow shaft. The material was the same and machined. Therefore, the endurance limit for component 4 and 5 was 174.382 MPa. The safety factor for dynamic analysis for each component was calculated using modified Goodman criterion in (11). According to **Table 7**, finite life was predicted for components 4. Component 4 was the most critical component compared with 1 and 5 because there was torsional force. Torsional structure would experience fatigue damage because it could twisting and propagating crack (Yang et al., 2020). The following section will discuss the life of each component in detail.

Table 7. Safety factor of each component under statics loading

Components	Safety Factor
1	6.95
4	3.48
5	2.04

3.3. LIFE PREDICTION ANALYSIS

During the dynamic analysis, number of the safety factor for each component recorded in **Table 8**. The safety factor of each component based on dynamic loading was obtained. According to the result, two of the elements were predicted to have finite life. To conduct the life prediction analysis, a calculation on the endurance strength based on the Marine factor and the reversed stress were evaluated using (11) and (12). By calculation, the life prediction of each component on the structure are shown in **Table 9**.

$$\sigma_{rev} = \frac{\sigma_a}{1 - \frac{\sigma_m}{S_{ut}}} = \frac{160.894}{1 - \frac{160.894}{470}} = 244.642 \text{ Mpa}$$

3.4. GEAR ANALYSIS

During the lowering process, a gear reduction unit was used. The gear reduction unit is important to reduce the torque transmitted from the rotating shaft to the crank handle. Since four gears consisted of two bevel gear and two spur gears, the calculation should evaluate each gear. The summary of the torque for each gear is shown in **Table 10**.

Table 8. The safety factor of each component based on dynamic loading.

Components	Safety Factor
1	0.59
4	2.28
5	1.33

Table 9. The life prediction of each component under dynamic loading

Components	Endurance Strength (MPa)	Reversed Stress or Fatigue Strength (MPa)	Life Prediction
1	118.22	244.642	Finite life
4	174.38	63.45	Infinite life
5	174.38	119.8846	Finite life

Table 10. Torque transmission value for each gear

Gear number	Torque (Nm)
1	3.75 (CCW)
2	25 (CW)
3	25 (CW)
4	28.125 (CCW)

Based on the analysis, to make humans able to control the wheel's rotation, a hand crank used for lowering the coffin is installed. Then, there will be reaction torque between the outer part of the countershaft in gear one and the inner surface of the hand crank. The reaction

force is in the inner surface of the crank, which causes a movement toward the clockwise (CW) direction. Therefore, the power input for operating the machine will be clockwise.

According to the free body diagram of the shaft, the gearbox consisting of the driver will be located on the machine's left side. In the end, the torque needed to operate the machine is 3.75 N.m. The mechanism of this machine will utilize the gravity effect to lower the coffin.

4. CONCLUSION

A component design and strength analysis of the coffin lowering machine under static and dynamic loading is reported in this paper. The proposed machine is equipped with a hasp shaft to tie the straps to the shaft. The handle will be rotated on the driver gearbox and made the shaft also rotated. The calculation results obtained that the most critical part in static analysis is component 5, while in dynamic (fatigue) analysis is component 1. The safety factor obtained for component 5 under static loading condition is 2.04, and component 1 under dynamic loading is 0.59. This result indicates that all components are in safety condition under both static and fatigue condition, although an extra monitoring should be done to prevent component 1 from a sudden failure after a certain service life. Moreover, determination of the dimensions of the gearbox has been adjusted so that it can be rotated by human hand. This machine is expected to become a reference for an innovative design to help the handling of COVID-19 victims. In addition, the whole process presented in the paper can be used a case study for Machine Element Course of mechanical engineering major.

5. AUTHORS' NOTE

The authors declare that there is no conflict of interest regarding the publication of this article. The authors confirmed that the paper was free of plagiarism.

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