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Cylinder segment mount modification to reduce cylinder segment downtime problems on curing machines

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Abstract: In tire manufacturing companies in Indonesia, there is a tire production process consisting of material, building, curing, and final inspection. The curing process is the process of changing green tires into tires which takes place in a mold segment at temperature and pressure according to predetermined specifications. On the BOM 63.5 curing press machine there is a segmented cylinder that functions to press the mold segment. The problem that often occurs in curing machines is that the segment cylinder breaks. This causes quite high machine downtime. The number of cylinder segment bolt holes influences the strength of the bolt connection. Therefore, it is necessary to modify the cylinder segment bolt-hole holder so that the bolt can support the cylinder load. The results of this modification can reduce curing machine downtime problems and can increase company productivity. Based on the results of this research, it can be concluded that 6 bolts are safer than 4 bolts. The downtime problem of the cylinder segment after modification decreased by 94%. The previous one was 15181.18 minutes to 1038.11 minutes

Keywords: Curing machine; cylinder mount; bolt hole; downtime

1. INTRODUCTION

The tire production process in Indonesian tire manufacturing businesses consists of material, building, curing, and final inspection [1]. The process of turning green tires into tires is called curing, and it happens in a mold under preset pressure and temperature parameters [2][3]. This company's curing machine is a BOM (Bag O Matic) type, meaning that it is a curing machine that is powered by a motor and has a pinion gear as its driving mechanism when it opens and closes [4]. Segment cylinders, sometimes known as hydraulic cylinders, are found in curing machines [5]. A hydraulic cylinder is an apparatus that transfers and regulates pressure and movement using fluid [6]. This cylinder serves as a push for the mold segment when it is in the cure position or during the green tire cooking process, as well as a segment mold driver when it is open or closed.

A detailed examination of machine performance is required to identify the problem's core cause and suggest ways to improve production activities [7][8]. There will inevitably be machine downtime in every process due to issues, but downtime can be reduced by examining issues as they arise [9][10]. Figure 1 displays the production time losses resulting from machine damage over three month based on the conducted research. Field observation data and corporate data were used for the study.

Based on observations made between December 2023 and February 2024, it is possible to conclude that a fractured segment cylinder represents the greatest issue. According to this observation, the cylinder segment's breaking issue was caused by the fact that it still had four bolt holes in it. For large-size tire standards, there is a curing machine called the BOM 63.5. To prevent the cylinder segment from breaking as a result of high cylinder pressure, six bolt holes are made in the cylinder segment holder.

The ability of a bolted connection to sustain the tensile load of a cylindrical section is significantly influenced by differences in the bolt holes [11]. Distinctive features of every arrangement impact joint deformation, strength, and load distribution [12]. To ascertain the safety factor of bolted connections, this study must compute the tensile and shear stresses of the bolts.

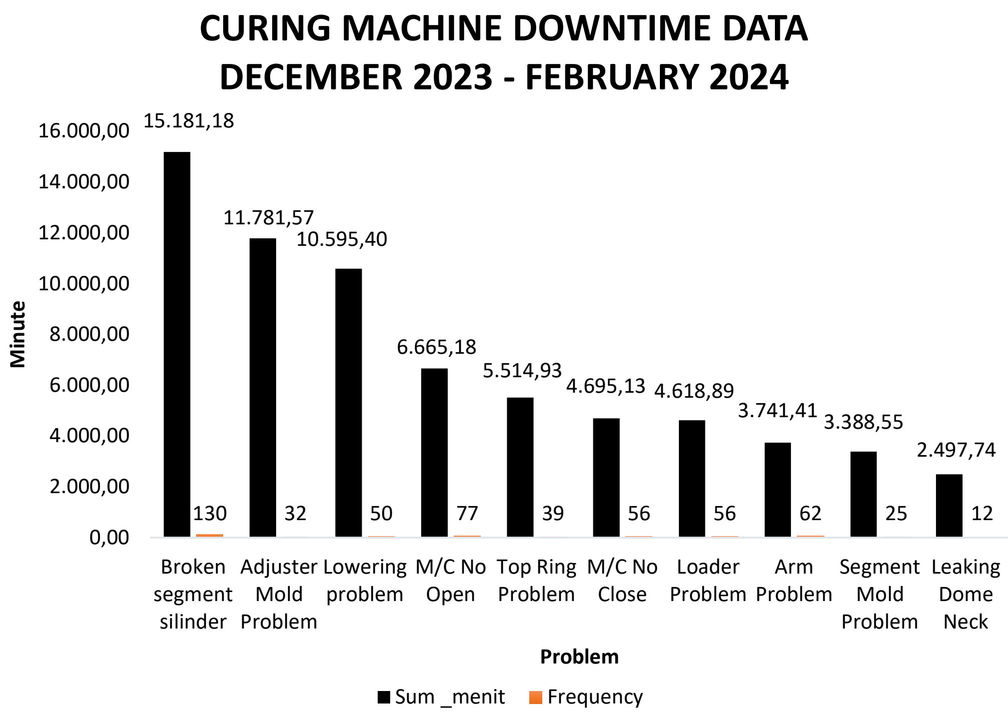

Figure 1. Curing machine graph.

However, the goal of this research is to minimize downtime of the curing machine caused by recurrent issues rather than analyzing the calculation of updated components. Here, before any modifications are made, bolted connections will be analyzed using Solidworks and FEA simulation [13]. Finite Element Analysis, or FEA for short, is the process of addressing a problem by meshing or breaking the analyzed object up into finite small components [14]. After that, these tiny components are examined, and the findings are used to determine the answer for the overall component [15].

It is therefore required to adjust the cylinder segment bolt-hole holder in light of the research and analysis conducted on the issues that arise. It is anticipated that this adjustment will be able to lessen engine downtime brought on by broken segment cylinder issues.

2. METHOD

Before making any changes, a plan needs to be created. The one before it didn't have a stand, and the one following it does. For this research to be conducted, a few steps in the research process need to be completed. Figure 2 depicts these procedures.

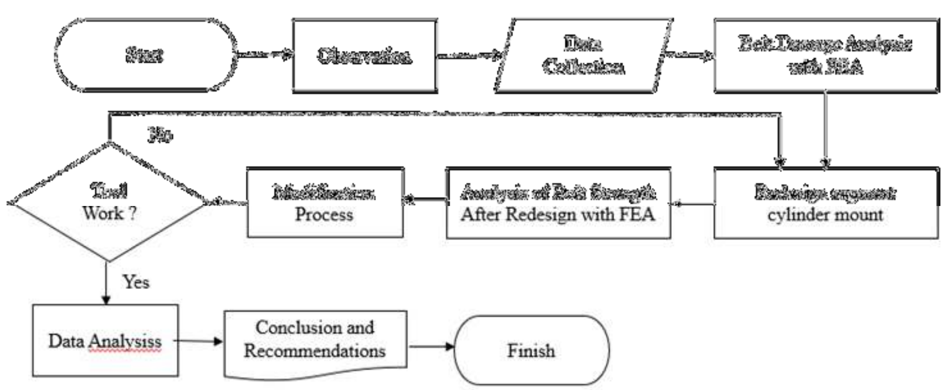

Figure 2. Flow chart modifications.

Flow chart explanation

The following is an explanation of the flow diagram regarding the stages in Figure 2. 1) Observations, namely those from direct field research and book reviews, are conducted in the first phase. Field studies, which involve making firsthand observations of the equipment under investigation, and literature studies, which involve looking up references to earlier publications. 2) Data collecting, specifically looking for company data on machine outages to use as a foundation for data comparisons following modifications. 3) Using the FEA approach to analyze bolt damage, in which the bolt is loaded virtually using the Solidwork program. 4) Redesign the segment cylinder seat by changing the bolt hole from hole 4 to hole 6 on the segment cylinder seat. 5) Using the Solidwork tool, a bolt strength simulation is performed following design before change. After the simulation of the building, the process of intensive modification is carried out by the previous redesign results. 6) Data analysis is completed following revisions by keeping an eye on field conditions and obtaining data from the business. 7) The data before and after the alteration procedure are compared to enable the formulation of conclusions and recommendations.

3. RESULTS AND DISCUSSION

Calculation of modified component weight

This section's goal is to ascertain each modified component's weight value. Using Solidworks 2021 software, we apply changed components based on material type to determine the volume of each component in the calculation. This guarantees a more accurate weight value based on field circumstances. The cylinder segment weighs the following:

a. Determine the weight of the segment cylinder

The segment cylinder design seen with Solidwork software has a mass of 281120.09 grams and a volume of 35760360.39 mm^3. So how much force is needed to lift a maximum load of 281,120 Kg on this segment cylinder using equation (1).

$$W = m \; x \; g \tag{1}$$
$$W = 281{,}12 \text{ kg } \; x \; 9{,}8 \; m/s^2$$
$$W = 2754{,}976 \; N$$

Where :
W = Load (N)
m = Mass (Kg)
g = Gravitational Acceleration (m/s^2)

b. Determine the weight of the cylinder segment mount.

For the design of the cylindrical segment holder, stainless steel is used with a density of 0,01 gram/mm^3 and volume of 12352034,04 mm^3. Thus, to calculate the mass of the cylindrical segment holder using the equation (2).

$$m = \rho \; x \; v \tag{2}$$
$$m = \; 0{,}01 \; gram/mm^3 x \; 12352034{,}04 \;\; mm^3$$
$$m = 123520{,}34 \; gram$$

Where :
m = Mass (gram)
ρ = Density (gr/mm^3)
v = Volume (mm^3)

Calculate the weight using the equation (3).

$$W = m \; x \; g \tag{3}$$
$$W = 123{,}52 \; kg \; x \; 9{,}8 \; m/s^2$$
$$W = 1210{,}496 \; N$$

c. Determine the fluid volume

Figure 3 is a sketch of a double-acting cylinder segment. For the cylinder segment here, a pressure of 18 bar is used.

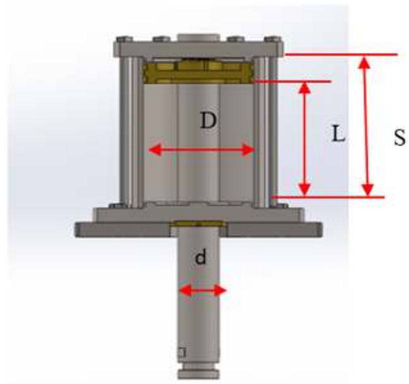

Figure 3. Segment cylinder dimensions sketch.

Where :

D	= Head Piston Diameter	= 305 mm
d	= Rod Diameter	= 100 mm
S	= Stroke Length	= 520 mm
L	= Cylinder chamber length	= 412,5 mm
P	= Pressure Hidrolik	= 18 bar

There are two parts to the cylinder segment volume: the normal cylinder volume and the compressed cylinder volume. Determine the area of the cylinder axle and piston to get the cylinder volume initially. Apply equality (4) to the piston area.

$$A_1 = \frac{\pi}{4}\ x\ D^2 \quad (4)$$

$$A_1 = \frac{\pi}{4}\ x\ (305\ mm)^2$$

$$A_1 = 73024{,}625\ mm^2$$

For the cross-sectional area of the cylinder axle, use the equation (5).

$$A_2 = \frac{\pi}{4}\ x\ d^2 \quad (5)$$

$$A_2 = \frac{\pi}{4}\ x\ (100\ mm)^2$$

$$A_2 = 7850\ mm^2$$

After that, count the cylinders in a compressed state. The cylinder is in a compressed state, namely the position where the axle moves out and the fluid fills the volume of the cylinder segment piston liner.

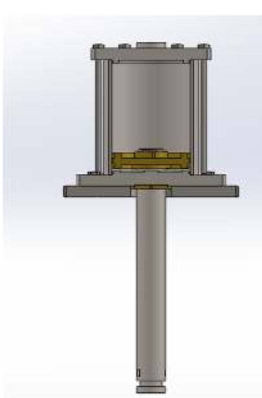

Figure 4. The cylinder is in a compressed condition.

Figure 4 shows that the cylinder is in a compressed state, namely the cylinder axle moves out of the cylinder liner and presses the mold segment, this position is held when the machine is open. Calculate the compressive volume using the equation (6).

$$V_{tekan} = A_1 \; x \; L_1 \tag{6}$$
$$V_{tekan} = 73024{,}625 \; mm^2 x \; 412{,}5 \; mm$$
$$V_{tekan} = 30122657{,}8125 \; mm^3$$

To calculate the cylinder compression volume into mass, use equation (7). This cylinder uses water fluid with a water density of 1 kg/m^3.

$$m = \rho \; x \; v \tag{7}$$
$$m = 1 \; kg/m^3 \; x \; 0{,}0301 \; m^3$$
$$m = 0{,}0301 \; kg$$

Calculate the cylinder compression volume to weight using the equation (8).

$$W = m \; x \; g \tag{8}$$
$$W = 0{,}0301 \; kg \; x \; 9{,}8 \; m/s^2$$
$$W = 0{,}294 \; N$$

When the cylinder is in its normal condition, the axle position moves inward and fluid fills the volume of the cylinder rod liner.

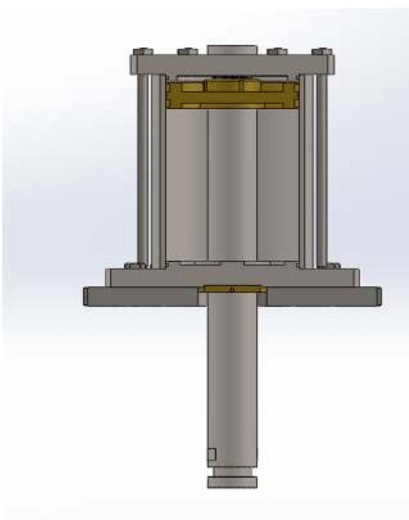

Figure 5. The cylinder is in normal condition.

Figure 5 shows the cylinder in normal condition when the engine is closed. To calculate the volume of a normal cylinder using the equation (9).

$$V_{normal} = (A_1 \; x \; L) - (A_2 x \; L) \tag{9}$$
$$V_{normal} = 73024{,}625 \; mm^2 \; x \; 408{,}5 \; mm - (\; 7850 \; mm^2 x \; 408{,}5 \; mm)$$
$$V_{normal} = 26623834{,}3125 \; mm^3$$

Calculate the normal cylinder volume into mass using the equation (10). This cylinder uses water fluid with a water density of 1 kg/m^3.

$$m = \rho \; x \; v \tag{10}$$
$$m = 1 \; kg/m^3 \; x \; 0{,}0266 \; m^3$$
$$m = 0{,}0266 \; kg$$

Calculate the normal cylinder volume to weight using the equation (11).

$$W = m \; x \; g \tag{11}$$

$W = 0{,}0266\ kg\ x\ 9{,}8\ m/s^2$
$W = 0{,}26\ N$

d. Determine the force on the cylinder

The force calculation analysis begins with calculating the cylinder force required to move the cylinder segment. The following is the force calculation using the equation (12).

$$P = \frac{F}{A} \quad (12)$$

Where :
P = Pressure Fluida (MPa)
F = Cylinder Segment Force (N)
A = Piston cross-sectional area (mm^2)

$$1{,}8\ MPa = \frac{F}{\frac{\pi}{4}(305\ mm)^2}$$

$$F = 131444{,}325\ N$$

e. Determine the total load of the segment cylinder when working

To calculate the total cylinder load when working, use the equation (13).

$$P = (W.Cyl\ segment) + (W.\text{Cyl segment when compress}) + F.Cylinder \quad (13)$$
$$P = 1210{,}496\ N + 0{,}294\ N + 131444{,}325\ N$$
$$P = 132655{,}115\ N$$

Analysis of fastening bolt connections in cylinder segments

Here we carry out an analysis of the number of bolts 4 and 6. After doing the calculations, a comparison is made between bolts 4 and bolts 6.

a. Cylinder segment bolt 6

The cylinder segment bolts use M24 x 3 bolts totaling (n) 6 bolts to fasten the cylinder segment to the cylinder segment holder. To calculate bolt shear stress using the equation (14).

$$P = \frac{\pi}{4}\ xD^2\ x\ \tau\ x\ n \quad (14)$$
$$132655{,}115\ N = \frac{\pi}{4}\ x(24mm)^2\ x\ \tau\ x\ 6$$
$$\tau = 48{,}896\ MPa$$

The material specifications used stipulate that the permissible shear stress (τ) is taken as 30% of the tensile elastic limit (σ el), but must not exceed 18% of the ultimate tensile stress (σ u). To calculate the permissible shear stress of bolts using the equation (15).

$$\tau_{permiss} = 0{,}18\ x\ \sigma_u \quad (15)$$
$$\tau_{permiss} = 0{,}18\ x\ 625\ MPa$$
$$\tau_{permiss} = 112{,}5\ MPa$$

$$\tau \leq \tau_{permiss}$$
$$48{,}896\ MPa \leq 112{,}5\ MPa$$

The shear stress on the six bolts is less than the permissible stress, indicating that the fastening bolts are safe to use. The cylinder is operational, so the steel material's safety factor is 8. It is required to use equation (16) to determine the allowed stress before calculating the bolt tensile stress.

$$FS = \frac{\sigma_{max}}{\sigma_{permiss}} \quad (16)$$
$$8 = \frac{625\ MPa}{\sigma_{permiss}}$$
$$\sigma_{permiss} = 78{,}125\ MPa$$

Calculate the tensile stress with equality (17).

$$W = \frac{\pi}{4}\, x D^2\, x\, \sigma_t\ \ x\, n \quad (17)$$
$$132655{,}115\, N = \frac{\pi}{4}\, x(24\, mm)^2\, x\, \sigma_t\ \ x\, 6$$
$$\sigma_t = 48{,}896\, MPa$$
$$\sigma \leq \sigma_{permiss}$$
$$48{,}896\, MPa \leq 78{,}125\, MPa$$

It can be concluded that bolt 6 has a shear stress that is smaller than the allowable stress so the fastening bolt is safe to use

b. Cylinder Segment Bolt 4

The cylinder segment bolts use M24 x 3 bolts totaling (n) 4 bolts to fasten the cylinder segment to the cylinder segment holder. To calculate bolt shear stress using the equation (18).

$$P = \frac{\pi}{4}\, x D^2\, x\, \tau\, x\, n \quad (18)$$
$$132655{,}115\, N = \frac{\pi}{4}\, x(24mm)^2\, x\, \tau\, x\, 4$$
$$\tau = 73{,}345\, MPa$$

According to the material requirements in use, the maximum allowable shear stress (τ) cannot be greater than 18% of the ultimate tensile stress (σ u) and is calculated as 30% of the tensile elastic limit (σ_el). To get the bolts' allowable shear stress, use equation (19).

$$\tau_{permiss} = 0{,}18\, x\, \sigma_u \quad (19)$$
$$\tau_{permiss} = 0{,}18\, x\, 625\, MPa$$
$$\tau_{permiss} = 112{,}5\, MPa$$

$$\tau \leq \tau_{permiss}$$
$$73{,}345\ \ MPa \leq 112{,}5\, MPa$$

We can conclude that the fastening bolts are safe to use because the shear stress on the four bolts is less than the permissible stress. The cylinder is operational, so the steel material's safety factor is 8. It is required to use equation (20) to determine the allowed stress before calculating the bolt tensile stress.

$$FS = \frac{\sigma_{max}}{\sigma_{permiss}} \quad (20)$$
$$8 = \frac{625\, MPa}{\sigma_{permiss}}$$
$$\sigma_{permiss} = 78{,}125\, MPa$$

To calculate the tensile stress with equality (21).

$$W = \frac{\pi}{4}\, x D^2\, x\, \sigma_t\ \ x\, n \quad (21)$$
$$132655{,}115\, N = \frac{\pi}{4}\, x(24\, mm)^2\, x\, \sigma_t\ \ x\, 4$$
$$\sigma_t = 48{,}896\, MPa$$

$$\sigma \leq \sigma_{permiss}$$
$$73{,}345\, MPa \leq 78{,}125\, MPa$$

It can be concluded that bolt 4 has a shear stress that is smaller than the allowable stress so the fastening bolt is safe to use

Simulation results

a. Cylinder bolt hole 6

Entering the cylinder segment load split by six will allow you to simulate the load using the solid work application. M24 x 3 bolts constructed of AISI 1045 steel with set geometry on the bolt threads have a load of 22,109.185 N apiece.

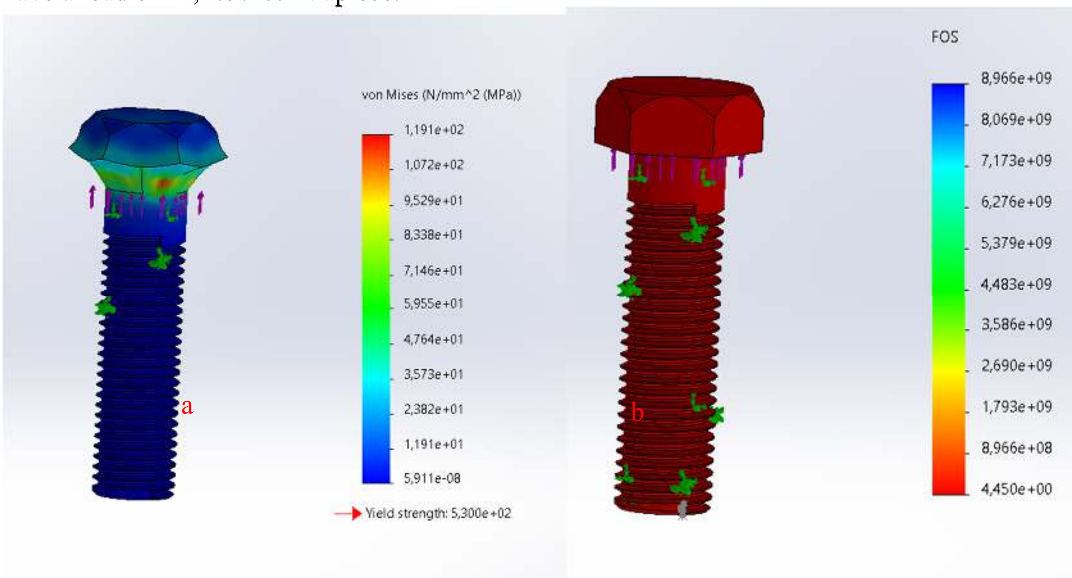

Figure 6. Bolt Loading Simulation Results 6. (a) Tensile stress, (b) Safety factor.

Figure 6 shows the simulation results for bolt 6, it is found that the M24 bolt experiences a maximum tensile stress of 1.191 MPa, and the factor of safety of the bolt is 8.966. This bolt is still categorized as safe because it is still below the yield strength.

b. Cylinder Bolt Hole 4

To simulate the load, use the solid work application by entering the cylinder segment load divided by 4. So the load for each bolt is 33163.77875. M24 x 3 bolts made of AISI 1045 material with fixed geometry on the bolt threads.

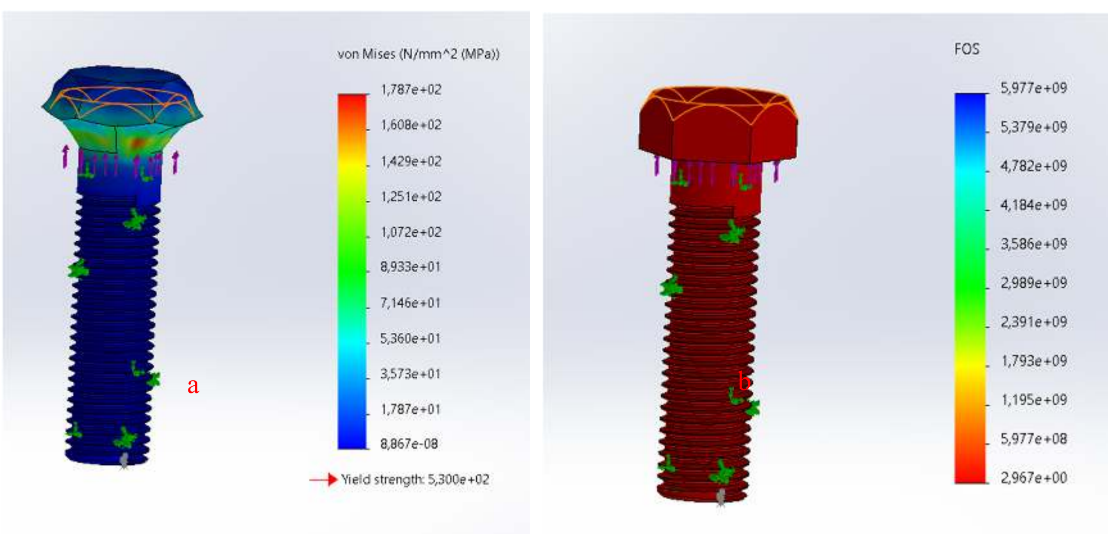

Figure 7. Bolt loading simulation results 4; (a) Tensile stress, (b)Safety factor.

Figure 7 shows the simulation results for bolt 6, it is found that the M24 bolt experiences a maximum tensile stress of 1.787 MPa, and the factor of safety of the bolt is 5.977. This bolt is still categorized as safe because it is still below the yield strength, but bolt 6 is safer than bolt 4 because the safety factor value is higher.

After summarizing the results of the analysis and simulation, data is obtained to show whether the modification is successful or not. The following is a comparison of the use of bolt hole 4 and bolt hole 6 based on the results of calculations and loading simulations.

Table 1. Summary of comparison of analysis results for bolt 4 and bolt 6.

		Bolt 4	**Bolt 6**
Analysis Result	Actual Tensile Stress	73,345 MPa	48,896 MPa
	Permissible Shear Stress	78,125 MPa	78,125 MPa
	Actual Shear Stress	73,345 MPa	48,896 MPa
	Permissible Shear Stress	112,5 MPa	112,5 MPa
Simulation Results	Tegangan Tarik	1,787 MPa	1,191 MPa
	The factor of Safety	5,977	8,966

Table 1 shows a comparison of the results for bolt 4 and bolt 6, by comparing the shear stress of the bolt and the tensile stress of the bolt. Where it can be concluded that bolt 6 is safer than bolt 4, because bolt 6 tensile stress and clearance are smaller than bolt 4.

Condition after modification

In this section, there are changes after the modifications made as in Figure 5 and Figure 6. Figure 8 shows that before modification, the cylinder segment hole uses 4 bolts.

Figure 8. Bolt holes.

Figure 9 shows after modification by adding a cylinder segment holder. This cylinder segment holder has 6 holes to prevent bolts from breaking.

Figure 9. Bolt holes 6.

Welding is used to attach the cylinder holder to the curing machine's top body. Six segment cylinder bolts are then used to install and secure the segment cylinder. To ensure uniform tightening of the bolts, the impact is used to tighten them. The findings of comparing the data before and after the modification were then ascertained by monitoring for three months following the modification.

Modification achievement results

The results of the modification of the cylinder segment holder show the data before and after the modification shown in Figure 10.

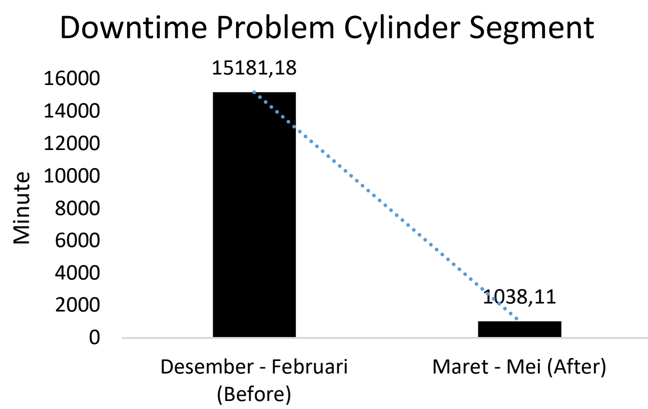

Figure 10. Downtime before and after modification graph.

There was a notable 94% decrease in downtime, as seen in Figure 10. Our goal in implementing it was to decrease the amount of downtime for the cylinder section RTC G2 from 15181.18 minutes to 1038.11 minutes.

4. CONCLUSION

Our research's findings led us to the conclusion that inserting bolt 6 is safer than bolt 4, as the two bolts' tensile and shear stresses may be fairly closely compared. After the change, the cylinder segment's downtime issues from March 2024 to May 2024 dropped by 94% as compared to the downtime from December 2023 to February 2024 before the change, which was 15181.18 minutes to 1038.11 minutes. This adjustment was effective since it reduced the cylinder segment's downtime issue.

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