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Strength Analysis Plastic Deformed Centrifugal Pumps

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ABSTRACT

The G-3503 centrifugal pump functions to flow Diethanolamine fluid with a viscosity of 380 Cp which functions to reduce H2S and CO2 levels in natural gas. When operating, the pump shaft experiences a torque load which causes the shaft to be twisted by 80. From the exact and finite element analysis results, the shear stress that occurs on the shaft is greater than the shear stress of the shaft material. Thus, the shaft is deformed plastically. The shear stress that occurs is 164 MPa.

I. Introduction

Industrial development takes place very rapidly as advances in science and technology have resulted in innovations that aim to facilitate human work, and can increase the quality and quantity of production. Especially for the construction and industrial parts, there is a device called a pump.

The pump has the main component, namely the shaft, the shaft is a mechanical device component that transmits rotating motion and power, the role of the shaft is very important to continue the rotation of the motor or drive to the impeller [1,2].

Now many engineering sciences have been developed in the field of finite element science which unites mathematics, engineering and computers to produce software such as Autodesk Autocad, Autodesk Inventor, Ansys, Abaqus and others. From this software, the shape can be designed so that it fits the dimensions and load given. Because the shaft must be designed taking into account in detail in terms of function, material, shape and safety factors [3].

The fluid that flows in the pipe is Diethanolamine (DEA, viscosity 380 cP) which is one of the solvents used in the system unit which functions to reduce the H2S and CO2 content from natural gas. This solvent uses an absorption working principle which will attract the CO2 and H2S content in natural gas [4].

Due to the pressure of the flowed fluid, this affects the power of the pump in transmitting. The pump component that plays an important role in this transmission process is the pump shaft. Increasingly, if the fluid pressure exceeds the allowable stress of the pump shaft, the pump will experience plastic deformation. This will interfere with the performance of the pump in transmitting fluid. In the end, due to decreased pump efficiency, productivity will not reach the expected target.

From the phenomenon that appears based on the simulation of finite element method software, incorrectly designed shafts will experience plastic deformation and are dangerous when used [5]. The stress concentration indicates the criteria for which the shaft is safe or not to use. Because the greater the stress concentration that occurs, the greater the possibility of fracture [6].

Stress analysis is very important and valuable for safety, durability and pump performance; therefore, the author is motivated to conduct research on the stress analysis that acts on the centrifugal pump shaft. which works on the centrifugal pump shaft in order to avoid plastic deformation.

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This research will study the shear stress on the centrifugal pump shaft with SUS 304 material which has undergone plastic deformation of 80, this case happened to the G-3503 pump at PT Arun. To analyze the stress distribution acting on the shaft with the finite element method.

II. Method

The material used in this study was SUS 304 / ASTM A240 [8]. This material is assumed to be an isotropic material which has mechanical properties as shown in Table 1 and dimension of specimen as shown at Figure 1.

Table 1. Mechanical Properties of SUS 304 / ASTM A240.

No	Description	Values
1	Density, ρ	8000 kg/m3
2	Modulus of Elasticity, E	193 - 200 GPa
3	Modulus of shear, G	83 GPa
3	Maximum of strength, σu	505 MPa
4	Yield strength, σy	215 MPa
5	Poisson Ratio, ν	0.29
6	Shear stress, τ	42 MPa

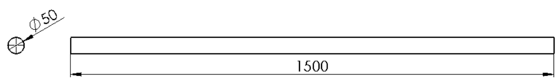

Figure 1. Analyzed pump shaft (unit: mm).

On this axis, several analyzes are carried out, namely:

1. The shaft provides torsional stress (torque), periodically starting from a torque of 500 Nm, 1000 Nm, 1500 Nm, 2000 Nm, 2500 Nm, 3000 Nm, 3500 Nm, 4000 Nm, 4015 Nm, 4050 Nm. After that, the torsion angle that occurs at each stress is analyzed.
2. The shaft is given a torsion angle of 80 then analyzed the amount of torsional stress that occurs on the shaft, the position (position) of the maximum stress.
3. Shaft is analyzed manually (empirically), how much is the maximum stress that occurs, when given a torsion angle of 80.

III. Results and Discussion

A. Shaft with Torsion Load

The shaft is given a torsional load gradually so that a torsion angle of 80 is achieved. The mesh on this axis can be seen in Figure 2.

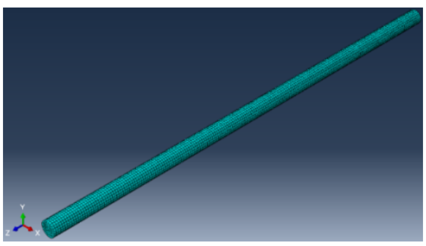

Figure 2. Meshing of the analyzed shaft

The maximum torsion angle that occurs will vary depending on the torque load applied to the shaft. Figure 3 shows the amount of torsion angle that occurs on the shaft due to the torque load applied.

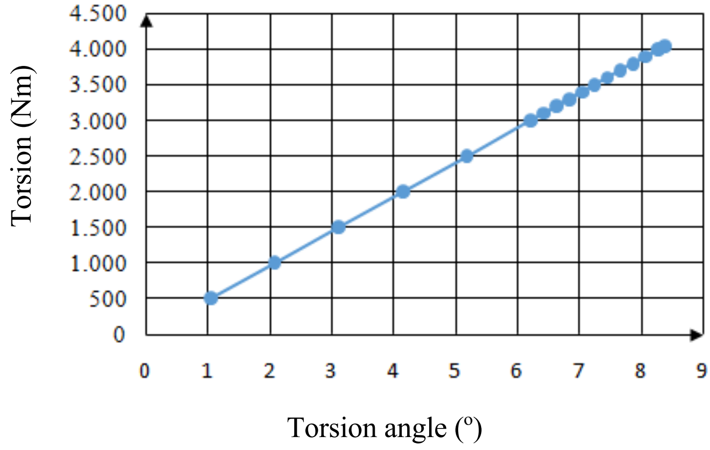

Figure 3. Torque Curve - Torque Angle on the shaft of the centrifugal pump.

B. Shaft with Torsion Angle

In this method, the shaft is given a torsion angle of 8°. When it reaches a torsion angle of 8°, the amount of stress obtained can be seen as in Figure 4.

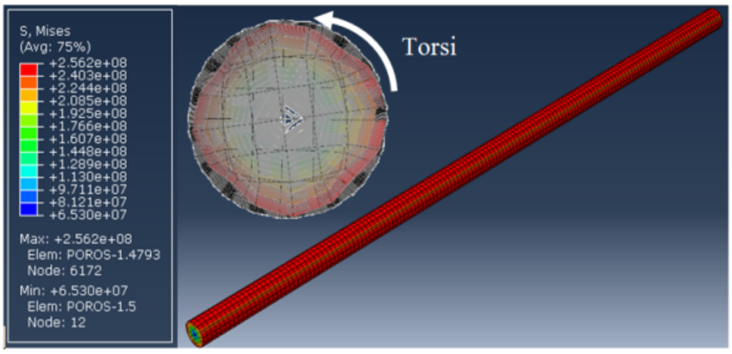

Figure 4. Stress when given a torsion angle of 8°.

The shear stress that occurs in the cross section of the pump shaft can be seen in Figure 5.

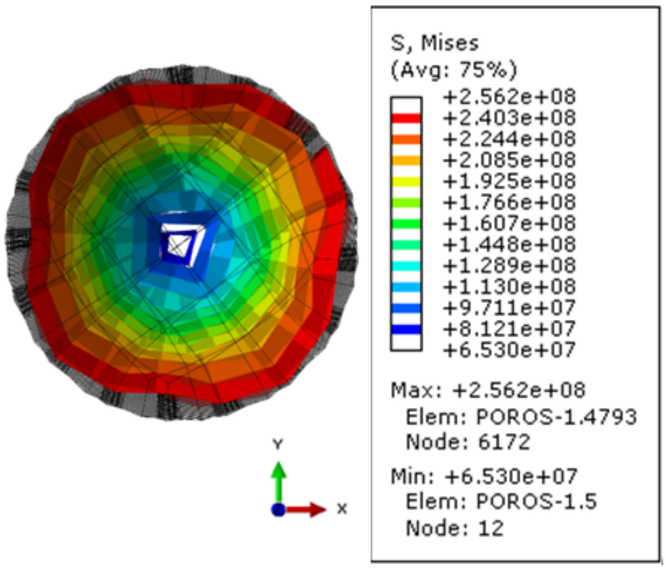

Figure 5. Change in stress when given a torsion angle of 8°.

Figure 6 shows the strain that occurs in the shaft cross section.

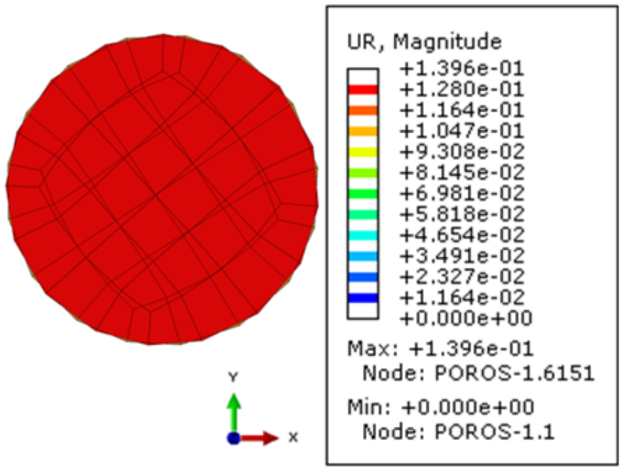

Figure 6. Strain when given a torsion angle of 8°.

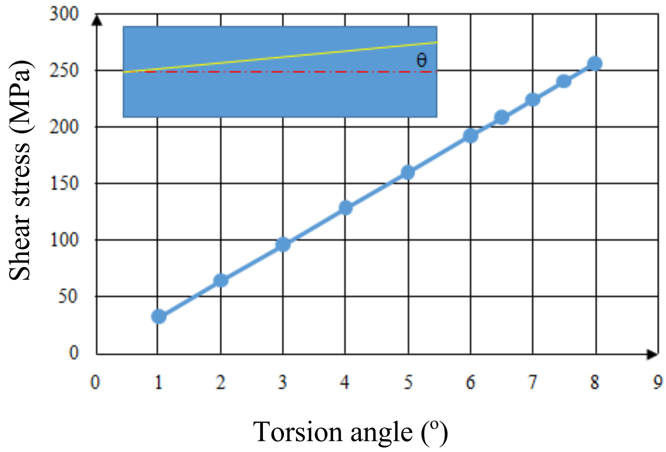

Figure 7. Curve relationship between
shear stress and torsional angle.

Figure 7 shows the relationship curve of shear stress to torsional angle that occurs when the torsion angle reaches about 80. The more torsional angle increases, the higher the shear stress that occurs. The maximum shear stress that occurs is around 256.2 MPa.

Figure 8 shows the analyzed nodal on the shaft and is the part where the maximum shear stress occurs.

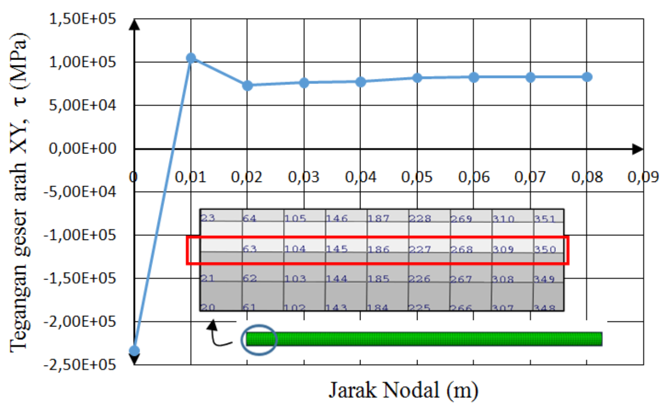

Figure 8. Stress Curve Slide XY axis along the shaft of the centrifugal pump.

The comparison between the torque and shear stress that occurs against the torsion angle can be seen in Figure 9.

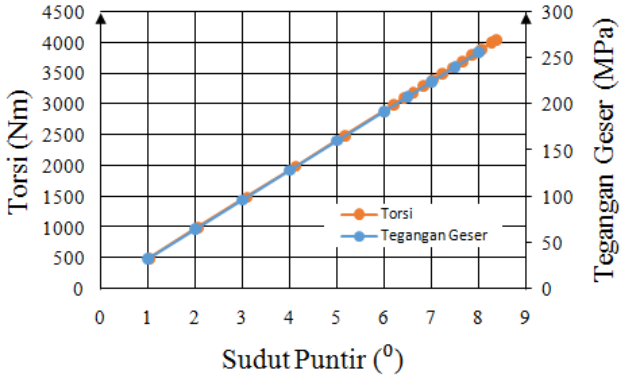

Figure 9. The curve of the relationship between the increase in torque and shear stress to the torsion angle.

From Figure 9, for the centrifugal pump shaft material of 215 MPa, the maximum torsion angle that can be accepted by the pump shaft is around 7.50 with a maximum torque of around 3600 Nm. When compared between the stress that occurs on the shaft with the yield stress of the material, it is found that $\sigma_{8}^{o} > \sigma_{y}$. So that the shaft has undergone plastic deformation.

C. Exact Analisys

In this method, the shaft is given a torsion angle of 80. L is the length of the shaft, which is 1.5 m. D is the shaft diameter, which is 0.05 m. When it reaches the torsion angle of 80, the amount of stress obtained is as follows:

$$\theta = \frac{L \cdot T}{I_p \cdot G}$$

$$\theta = \frac{L \cdot T}{\left(\frac{\pi \cdot D^4}{32}\right) \cdot G}$$

$$8^0 = \frac{8\pi}{180} = \frac{L \cdot T}{\left(\frac{\pi \cdot D^4}{32}\right) \cdot 83 \times 10^9}$$

$$\frac{\pi^2}{45 \cdot 16} \cdot 83 \times 10^9 = \frac{L \cdot T}{D^4}$$

$$963{,}657{,}207.5 = \frac{1.5 \cdot T}{0.05^4}$$

$$T = 4542\ Nm$$

Maximum shear load:

$$\tau_{poros} = \frac{T \cdot r}{I_p}$$

$$\tau_{poros} = \frac{T\left(\frac{D}{2}\right)}{\left(\frac{\pi(D^4)}{32}\right)}$$

$$\tau_{poros} = 164\ MPa$$

Base on Failure Theory as follows:

- Von Mises

$$\tau_{oct} = \frac{\sigma_y}{3}\sqrt{2} = \frac{215}{3}\sqrt{2} = 101{,}352\ MPa$$

- Tresca

$$\tau_{max} = \frac{\sigma_y}{2} = \frac{215}{2} = 107{,}5\ MPa$$

When compared between the maximum shear stress that occurs on the shaft with the failure theory according to Von Mises, it is found that $\tau_{oct} < \tau_{shaft}$. So that the shaft has failed because it has undergone plastic deformation. If compared between the maximum shear stress that occurs on the shaft with the failure theory according to Tresca, it is found that $\tau_{max} < \tau_{shaft}$. So that the shaft has failed because it has undergone plastic deformation.

Based on the results of the analysis using the Finite Element method which is then compared with the results of manual calculations, it is found that when the shaft twists by 80, the shaft with material SUS 304 has exceeded the elastic stress. Thus, the stress and strain that occurs when the torsion angle has reached 80 is the plastic stress and strain.

IV. Conclusion

From the results of the exact and finite element analysis, the following conclusions are obtained:

1. From both analysis results, exact and finite element, the shear stress that occurs on the shaft exceeds the shear stress of the shaft material. So that the shaft undergoes plastic deformation and is twisted.
2. Torque, shear stress and strain that occur on the shaft increase with increasing torsion angle experienced by the shaft.

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