Structure modeling and analysis for improving the strength of horizontal pump system

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Abstract. Generally, pumps are used as equipment to move liquids from one place to another, such as in power plants, petroleum companies, etc. One of the kinds of the pump is the Horizontal Pumping System which consists of a motor, trust room, cradle, pump, and base. This study is motivated by the problem appearing of load increase at the suction and discharge nozzle so that it exceeds the allowable load. That load surges cause the pump structure to receive large vibrations, which results in damage to some Horizontal Pump System structures. Therefore, structural analysis on the Horizontal Pumping System to determine the displacement and durability of each cradle are necessary. The purpose of this study is to determine the strength of the pump structure and design additional tools to strengthen the pump structure. In this study, SOLIDWORKS is used for 3D modeling of the Horizontal Pump System structure. Meanwhile, the strength analysis of the structure is conducted using ANSYS Static Structural. Based on the analysis results, there is a quite large displacement in the pump section associated with the suction nozzle. On the other hand, the cradle resistance is still in the elastic deformation area with a maximum value of 24881.97 psi ($\sigma_y = 3.01 \times 10^4$ psi). Therefore, development is needed by adding a cradle in the pump section associated with a suction nozzle. By adding this cradle there is a reduction in displacement experienced by the pump. Pump displacement changes to 0.036 - 0.097 inches in x-axis, 0.009 - 0.021 inches in y-axis, and 0.001 - 0.005 inches in z-axis.

1. Introduction

A pump is a machine that is widely used in industry, especially in the petroleum industry. The pump functions to move the fluid from one place to another through the piping medium by adding energy to the fluid being moved and takes place continuously. Based on its working principle, pumps can be grouped into two, namely positive working pumps (positive displacement pumps) and dynamic working pumps (non positive displacement pumps) [1]. One type of dynamic pump is the Horizontal Pumping System. Horizontal Pumping System, which consists of a motor, trust chamber, cradle, pump, and base. The motor functions to provide power to the shaft to drive the pump. The trust chamber serves to hold the shaft in the axial direction to prevent damage to several parts that are connected. Cradle and base serve as support and restraints for pump movement.

In this study, the suction and discharge nozzles experience an increase in load so that the structure of the pump experiences stress and displacement, which causes the Horizontal Pumping System structure to experience damage in several parts. In the European Patent Application (EPA) publication, the Horizontal Pumping System was created to solve the pump problem which was found to be a failure in removing viscous sand service oil [2]. Failure to move the oil is caused by the thickness and density of oil that is greater than air. During the fluid transfer process, there will be a large vibration, so the firm structure must also have large rigidity. The current horizontal pumping system structural design still needs proper...
development to produce a pump with the appropriate structure. Therefore, it is very important to analyze and develop the stiffness of the pump reporting the Horizontal Pumping System structure.

Displacement and stress in the Horizontal Pumping System can be estimated by performing statistical analysis. For this purpose, the ANSYS software is applied for modeling and analysis of the FEM Horizontal Pumping System. The analysis process is carried out under the existing geometry, boundary conditions, and load conditions. According to Merad Boudia et al [3], the connection in a structure is very influential in maintaining the rating of the load received. In the Horizontal Pumping System, the joints used are bolts and nuts. Bolts and nuts are designed to work together when the internally threaded fastener (nut) is screwed to the externally threaded fastener (bolt). So that the bolts are forced to accept the tension and the bolt and nut heads are maintained in the joint to maintain the connection with a certain tension. This maintained stress is called bolt tension [4]. Therefore, bolt tightening is also taken into account in the analysis process.

Research by Seong Hyeon Lee et al in 2020 [5], conducted a pump strength analysis using structural analysis. Based on the results of the structural analysis, the number of displacement, and stress on the pump parts, Seong Hyeon Lee suggested developing a pump part that experienced a large displacement and stress exceeding the yield strength of the pump. If the damage is found in one of the pump holders (cradle and base) Horizontal Pumping System, it will cause damage to other pump parts so that a shutdown can occur. Structure analysis itself is a study that studies deformed behavior against a given force or load. Several branch of the implementation of structural analysis such as analysis of building bridges, machines, tools, etc. [6]. The structural analysis combines the discipline between the fields of mechanics, materials engineering, and engineering mathematics to calculate internal strength, stress, structural deformation, bearing reactions, and stability.

The purpose of this study is to analyze the structural strength and structure development of the Horizontal Pumping System. The SOLIDWORKS application is used to draw 3D models and ANSYS Static Structural as computation in analyzing the Horizontal Pumping System structure. The results of the research are to find out how much is the displacement and the stress on the pump. If a large displacement and/or the stress exceeds the yield strength of the material occurs, then it is necessary to develop the Horizontal Pumping System structure.

2. Materials and methods

2.1. Geometry and Materials

The geometry and material of the Horizontal Pumping System are obtained based on the results of measurements. Horizontal Pumping System geometry includes the motor, trust chamber, cradle, pump, and base. The Horizontal Pumping System geometry is modeled using SOLIDWORKS, the modeling results can be seen in figure 1. The materials used are shown in table 1.

![Assembly Horizontal Pumping System](image)

**Figure 1. Assembly Horizontal Pumping System**

| Material | Part                      |
|----------|---------------------------|
| GS A525  | Cradle and Base           |
| SS 304   | Suction Nozzle, Discharge Nozzle, and pump |
In this study, the cradle is divided into 5 parts, namely cradle A, cradle B, cradle C, cradle D, and cradle V. The position of each cradle can be seen in figure 2.

![Figure 2](image)

**Figure 2.** Position 1) Cradle A, 2) Cradle B, 3) Cradle C, 4) Cradle D, and 5) Cradle V on a Horizontal Pumping System

2.2. **Numeric Equations**

The structural analysis method uses equilibrium, stress, strain equation, and Young's modulus. The final step is to express the relationship between the external forces acting on the discrete point and the inner forces. In general, this requires that the equations of force and moment of equilibrium be satisfied along the three independent axes shown, as shown by Equations 1 and 2.

\[
\sum F_x = 0 ; \sum F_y = 0 ; \sum F_z = 0
\]

\[
\sum M_x = 0 ; \sum M_y = 0 ; \sum M_z = 0
\]

For loads that are still in the elastic region, the relation between stress and strain is stated by Hooke's law as formulated in Equation 3 below:

\[
\sigma = \varepsilon E
\]

Where $E$ indicates the modulus of elasticity while $\varepsilon$ is the strain which is defined as the ratio of the increase in length due to the force applied to the initial length of the object before the force is applied, namely:

\[
\varepsilon = \Delta L / L
\]

The degree of structural change or strain depends on the amount of stress that is applied [7].

2.3. **Analysis Procedure**

The analysis was performed using ANSYS Static Structural software. In this study, a structural analysis was carried out and the results showed how much displacement and stress on the pump was. Load and moment data on the suction and discharge nozzles are entered as input parameters of the Horizontal Pumping System boundary conditions. Load and moment data can be seen in table 2.

| Nozzle | $F_x$ (lb) | $F_y$ (lb) | $F_z$ (lb) | $M_x$ (ft.lb) | $M_y$ (ft.lb) | $M_z$ (ft.lb) |
|--------|------------|------------|------------|---------------|---------------|---------------|
| Suction| -2406      | 344        | -1069      | 2178,3        | -803,6        | -6197,6       |
| Discharge| 2775    | 2775        | 0          | -507,5        | 507,5         | 0             |
The bolt pretensioning is entered as the input parameter to maintain the pump position. The Bolt Pretensioning is assumed to be 75% of the ideal, following Table 3 is how big the bolt pretensioning is used in the Horizontal Pumping System.

| Bolt Pretensioning on a Horizontal Pumping System [8] |
|------------------------------------------------------|
| Diameter (in) | Torsion (ft.lbs) | Tensioning (lbf) | Pretensioning (lbf) |
| ------------- | ----------------- | ----------------- |-------------------- |
| ¾            | 129              | 955.5            | 716,625            |
| ½            | 45               | 500              | 375                |

Besides, Fix Support is assumed to be at the base of the pump as load support and a barrier to the pump movement so that it does not experience a displacement.

2.4. Meshing

Meshing is a method for dividing an object to be simulated into small elements. One of the most important things in a mesh is the size of the mesh elements applied to the model. The smaller the mesh size, the more accurate the results will be, but it requires more computing power and time than the larger mesh sizes. Therefore, it is necessary to determine the correct size of the mesh elements.

The mesh generation is carried out using ANSYS Static Structural as shown in figure 3. The mesh generation uses fine meshing to obtain mesh convergence. Triangular meshing is considered because it matches the geometry and material characteristics of the pump. So the Horizontal Pumping System is distributed to 275,033 elements which contain 528,450 nodes. The average skewness of the mesh has a value of 0.34926.

![Figure 3. Geometry meshing](image)

2.5. Validation

In this study as validation, the results of research by Seong Hyeon Lee et al, conducted in 2020 [5] were used. One of the methods used in this research is static load analysis, which investigates the stress intensity of the primary heat transport system (PHTS) pump using ANSYS structural analysis. The results of Seong Hyeon Lee's research were in the form of displacement and stress on the primary heat transport system (PHTS) pump parts and looking for the parts that experienced the greatest stress. The results of the validation using the program can be seen in table 4.

| Table 4. Displacement and Stress Validation |
|--------------------------------------------|
| Analysis | Lee et. al. | Present | Error |
| Displacement (mm) | Max 0.201x10^-3 | 0.213x10^-3 | 6% |
| Min 0 | 0 | 0 | 0% |
| Stress (Pa) | Max 0.943x10^-4 | 0.952x10^-4 | 1% |
| Min 31. x10^6 | 31.7x10^6 | 1% |
Figure 4. Analysis Results Displacement (i) Present and (ii) Lee et al.

From table 4, it appears that the differences that occur in the displacement and stress analysis between the results obtained in this study and Lee et al. are small enough so that the results of the analysis in this study can be accepted. Furthermore, based on figure 4, it can be seen how much displacement is in each part of the pump.

3. Results and discussion

3.1. Displacement in the Horizontal Pumping System Structure

In this research, the forces and moments come from the increase in fluid load in the suction nozzle and discharge nozzle in the Horizontal Pumping System. The results of the structural analysis show the magnitude of the displacement based on equilibrium equation, stress, strain, and Young's modulus. The results of the analysis of the Horizontal Pumping System structure can be seen in figure 5.

Figure 5. Displacement on the z-axis.

The increase in the load of the Horizontal Pumping System causes stress-strain on the pump. So that there is displacement in several pump parts. Based on Figure 5, it is found that the largest displacement occurs in the Horizontal Pumping System located on the side of the pump which is connected to the suction nozzle. These results are the same as the research conducted by Pramod H Kadam et al. [9]. The largest displacement occurs at the suction nozzle. Very large displacement occurs because the load increase exceeds the allowable load on the Horizontal Pumping System structure. The amount of displacement at each nozzle can be seen in table 5.

| Table 5. Displacement on the Suction Nozzle and Discharge Nozzle |
|---------------------------------|---------|---------|---------|
| Nozzle             | Displacement (in) |
|                   | X       | Y       | Z       |
| Suction           | 0.084 - 0.115 | 0.116 - 0.226 | 0.007 - 0.011 |
| Discharge         | (-0.006) - (-0.009) | - | 0.003 - 0.007 |
Based on the results of the structural analysis regarding displacement, it was found that the suction nozzle had a very large displacement, so it was necessary to make improvements to the side of the pump that was close to the suction nozzle.

3.2. Stress on the Horizontal Pumping System Structure

Stress can be defined as the result of the ratio between the force/load received by an object to the area of the object being deformed. The results of the structural analysis show the amount of stress on the Horizontal Pumping System as shown in Figure 6.

![Figure 6. Stress on the Horizontal Pumping System.](image)

Based on the results of the structural analysis, it was found that the greatest stress was found on the middle side of the Horizontal Pumping System. Stress is caused by an increase in the load on the suction nozzle and discharge nozzle of the Horizontal Pumping System. The part of the pump that plays a very important role in maintaining the displacement due to an increase in load is the cradle. Research by M. Z. Norhirni et al in 2011 [10], conducted in an axial piston pump design, the swash plate plays an important role in controlling the displacement of the pump. Likewise, the cradle-mounted design. Therefore, it is necessary to see how much stress each cradle is experiencing.

![Figure 7. The stress of each Cradle on the Horizontal Pumping System.](image)

The stress of each cradle in the Horizontal Pumping System can be seen in Figure 7. The increase in load on the suction nozzle and discharge nozzle causes the cradle to stretch and tighten. The greatest stress is experienced at cradle V because cradle V is the center of support for all cradles, the amount of stress from each cradle can be seen in Figure 7. After knowing the amount of stress in each cradle, it is necessary to analyze the strength of the cradle by comparing stress received by the yield strength of the cradle material. The material used in the cradle is galvanized steel with a yield strength of 3.04 x10^5 Psi. Based on the type of material as described on the Azo Materials website [11], it can be concluded that the cradle is still in the elastic zone so it is still safe to use and does not require improvement.

3.3. Additional Cradle Creation

An additional cradle is made to maintain the position of the pump to prevent displacement. The additional cradle position will be placed in the part of the pump that is connected to the suction nozzle. The material used in this cradle is a solid rod fabricated in a circular shape with galvanized steel material as seen in Figure 8.
3.4. Displacement on the Horizontal Pumping System After Improvement

After the improvement of the Horizontal Pumping System by adding a cradle on the side of the pump associated with the suction nozzle, the results are shown in figure 9. The results of the comparison of changes in the amount of displacement can be seen in table 6. Displacement changes occur because of the center of displacement force that is held by the cradle, so that displacement on the pump can be minimized.

![Additional Cradle on the pump](image)

**Figure 8.** Additional Cradle on the pump.

**Table 6.** Comparison of Displacement After and Before Improvement

| Nozzle  | Displacement (in) |
|---------|-------------------|
|         | X                 | Y                 | Z                 |
| Suction | Before            | 0.084 - 0.115     | 0.116 - 0.226     | 0.007 - 0.011     |
|         | After             | 0.036 - 0.097     | 0.009 - 0.021     | 0.005 - 0.009     |
| Discharge| Before            | (-0.006) - (-0.009)| -                | 0.003 - 0.007     |
|         | After             | (-0.006) - (-0.009)| -                | 0.001 - 0.005     |

**Figure 9.** Z-axis Displacement After Improvement.

4. Conclusion

This study uses structural analysis to determine how much displacement in several parts of the pump and stress on the pump cradle. Based on the structural analysis, it is found that the largest displacement is located on the pump side associated with the suction nozzle, which is 0.084 - 0.115 on the x-axis, 0.116 - 0.226 on the y-axis, and 0.007 - 0.011 on the z-axis. So that improvement is needed by adding a cradle to the pump to hold the pump so that a large displacement does not occur. After the improvement, there was a significant change in the pump displacement to 0.036 - 0.097 on the x-axis, 0.009 - 0.021 on the y-axis, and 0.001 - 0.005 on the z-axis. So it can be concluded that the additional cradle can reduce the amount of displacement at the pump.

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