Stress Analysis and Safety Factor of Shaft on Pepper Peeler Machine to Reduce Environmental Pollution

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Abstract. Manually, pepper peeling uses water flowing in the river for 8-14 days that cause the river to become polluted by pepper peel and cause a bad smell. A pepper peeling machine is a tool to peeling pepper that has a system using two dishes consisting of a fixed top dish and a rotating bottom dish. A shaft is used to rotate the bottom dish with 14.58 rpm rotation, and it requires 1 kW electric motor with 1400 rpm rotation that is transmitted by reducer ratio of 23.3:1 and a bevel gear ratio of 1.6:1. The shaft must be analyzed to determine its ability where the material is carbon steel material that has yield strength 350 MPa and is supported by two angular contact bearings which function as pin constraints and frictionless constraints. The shaft was analyzed using stress analysis with static analysis method using Autodesk Inventor Version 2019 software. Based on the analysis results, a minimum von mises stress of the shaft is 0.00 MPa and a maximum of 826.57 MPa on the diameter of 25 mm, minimum safety factors of 0.42 on the diameter of 25 mm and a maximum of 15. In Von-Mises stress and safety factor, the diameter of a shaft is not strong enough to withstand the load. To be able to meet the determined yield strength with a minimum safety factor of 1, the minimum diameter needed is 34.05 mm with a safety factor of 1.1. Using this machine, pepper peeling that done in the river can reduce river pollution.

1. Introduction
Manually, pepper peeling by immersing pepper into the flowing river water. A process of peeling pepper is needed time for 8-14 days [1] that causes microorganism contamination, which can eventually lead to river water pollution. Besides, the immersion method has several disadvantages, including the efficiency of time, the amount of labor and the quality of pepper produced [2], and the aspects of cleanliness and quality consistency have not been addressed [3]. To improve quality as well as reduce pollution, there has been a lot of carried out both pepper processing technology and supporting processes. One of the technologies of pepper processing is making pepper peels by avoiding soaking in the river.

Various machines for peeling pepper have been made. Suhendra, et al., 2010 [1] designed a vertical type cylindrical pepper peeler machine with 1.4 HP electric motor with a capacity of 10.3 kg/hour. Djajasukmana, 2010 [2] designed a pepper peeling machine with a rotating dish type of 300 rpm with a capacity of 60-70 kg/hour. Rosa, et al., 2018 [3] designed a pepper peeler machine with a crusher system using a 1 HP power, a rotation of 15 rpm and a capacity of 1 kg/hour as shown in Figure 1.

One part of the pepper peeler machine using a crusher system is bevel gear as a transmission element that is supported by shafts. A bevel gear is used in the machine because its gear element is efficiently transferred power and motion at an intersection of multiple axes [4]. One of the shafts used is a rotating
shaft which has a function to rotate the rotating dish. The geometry and dimensions of the rotating shaft are as shown in Figure 1(b), and the material of the rotating shaft is carbon steel material that material specifications are as in Table 1. Shaft analysis is using one of static analysis [5] to determine stresses in structures or components caused by the load.

![Figure 1](image.png)

**Figure 1.** (a) Pepper peeling machine [3]; (b) Rotating shaft

| Properties                     | Notations | Values       |
|--------------------------------|-----------|--------------|
| Mass Density                   | P         | 7.85 g/cm³  |
| Yield Strength                 | Sy        | 350 MPa     |
| Ultimate Tensile Strength     | Su        | 420 MPa     |
| Young's Modulus                | E         | 200 GPa     |
| Poisson's Ratio                | µ         | 0.29 ul     |
| Shear Modulus                  | G         | 77.5194 GPa |

2. Methodology

2.1. Parameters considered

2.1.1. Torsion.

The torque parameters are loaded on the rotary shaft, as shown in Table 2.

| Parameters                              | Notations | Values       |
|-----------------------------------------|-----------|--------------|
| Power of motor electricity              | P         | 0.735 kW     |
| Rotation of electricity motor           | N₁        | 1400 rpm     |
| Torsion of electricity motor            | T₁        | 5013.75 Nmm  |
| Reducer’s ratio                         | i₁        | 60           |
| Torsion of reducer                      | T₂        | 300825 Nmm   |
| Rotating of reducer                     | N₂        | 23.33 rpm    |
| Bevel gear’s ratio                      | i₂        | 1.6          |
| Torsion of bevel gear                   | T₃        | 481320.00 Nmm|
2.1.2. Force.
Forces are acting on a bevel gear as shown in Figure 2 and the parameters of bevel gear as Table 3.

![Forces acting on bevel gear](image)

**Figure 2.** Forces acting on bevel gear [6]

| Parameters                        | Notations | Values            |
|-----------------------------------|-----------|-------------------|
| Modul                             | M         | 4 mm              |
| Pressure angle                    | $\phi$    | 20°               |
| The pitch diameter of the pinion  | $D_p$     | 40 mm             |
| Number of pinion teeth            | $T_p$     | 10                |
| The pitch angle for the pinion    | $\theta_{p1}$ | 32.01°           |
| Tangential force on pinion tooth  | $W_T$     | 15041.25 N        |
| Axial force on pinion tooth       | $W_{RH}$  | 4642.42 N         |
| Radial force on pinion tooth      | $W_{RV}$  | 2901.51 N         |
| The pitch diameter of the gear    | $D_G$     | 40 mm             |
| Number of gear teeth              | $T_G$     | 16                |
| The pitch angle for the gear      | $\theta_{p2}$ | 57.99°           |
| Tangential force on pinion tooth  | $W_{TG}$  | 15041.25 N        |
| Axial force on pinion tooth       | $W_{RHG}$ | 2901.51 N         |
| Radial force on pinion tooth      | $W_{RVG}$ | 4642.42 N         |

2.1.3. Pressure.
The pressure released from the load received by the dish issued from the weight of the pepper, which will be peeled is 2.4525 N.

2.2. Modeling and Analysis
Modeling and analysis use Autodesk inventor 2019 software where applied loads and constraints are shown in Table 4. For modeling, loads, and constraints, as shown in figure 3(a) and mesh model, as shown in Figure 3(b).
Table 4. Applied loads and Constraints

| Parameters                          | Notations | Values         |
|------------------------------------|-----------|----------------|
| Torsion of bevel gear              | T<sub>3</sub> | 481320.00 Nmm  |
| Tangential force on pinion tooth   | W<sub>TG</sub> | 15041.25 N     |
| Axial force on pinion tooth        | W<sub>RHG</sub> | 2901.51 N      |
| Radial force on pinion tooth       | W<sub>RVG</sub> | 4642.42 N      |
| Pressure                           | P         | 2.4525 N       |
| Pin constraint                     | A         | -              |
| Frictionless constraint            | B         | -              |

In Figure 3 show that the location of the loads on a bevel gear contains three forces and one torsion where the structure of the shaft has two constraints, a fixed constraint, and a pin constraint. The meshing model is using a triangular mesh [7] with specifications from inventor software is average element size (fraction of model diameter) 0.1, minimum element size (fraction of average size) 0.2, grading factor 1.5, maximum turn angle 60°. There is no create curved mesh elements and use part based measure for assembly mesh. The convergence of the FEA analysis versus Von Mises stress is 50% based on the software.

3. Result and Discussion

3.1. Static analysis of existing rotating shaft

One of the significant aspects of the filed design is an analysis of structures [8]. Based on table 1, the material of the structure is ductile, and it can be solved by the Finite Element Method (FEM) and analyzed using Von Mises stress [9].

3.1.1. Von Mises Stress.

The stress that occurs on the rotating shaft will be compared to the allowable stress on the material based on yield strength. For ductile material, static stress analysis uses the Von Mises stress method [6],[10]. From the simulation results, the graph, as shown in Figure 4 states that the maximum stress occurs at 826.57 N/mm² in a diameter of 25 mm. Based on Table 2, the stress that occurs in a diameter of 25 mm, is greater than the yield strength of material where it is 350 N/mm² where the value of Von Mises stress must be less than the maximum allowable stress [11].
3.1.2. Safety factor
The safety factor that occurs in the rotating shaft must be more than one so that the design is safe [12]. Different safety factor levels are set depending on failure criticize and other parameters [13]. Safety factor minimum on a rotating shaft is 0.42 mm on the diameter of 25, and the maximum safety factor is 15 mm. From the results of the analysis of safety factors, a diameter of 25 mm is not safe to accept the loads.

Figure 4. (a) Von mises stress; (b) Safety factor

3.2. Parametric optimization of dimension
The requirement diameter that suitable to the load that occurs is necessary to do the optimum dimensions on diameter 25 to find the best configuration [14] using Autodesk Inventor 2019 software. From the software results, the graph of diameter versus von mises stresses as shown in Figure 5(a) and the diameter versus safety factor as shown in Figure 5 (b).

Figure 5. (a) Diameter versus von mises stress; (b) Diameter versus safety factor

Based on Figure 5(a), the diameter of 25 mm has a maximum strength of 826.573 N/mm² and the diameter of 35 mm has a minimum strength of 300.238 N/mm². The strength of the material on the diameter of 35 mm is still below the yield strength of the material, but it is not the optimum diameter of the shaft.
So based on Figure 5(b), the diameter of 25 mm has a minimum safety factor of 0.423, and the diameter 35 mm has a maximum safety factor of 1.166. The safety factor on the diameter of 35 mm is still above the requirement of the safety factor, but it is not the optimum diameter of the shaft.

To get the optimum of the shaft diameter and fulfill requirement Von Mises stress, and safety factor, from the diameter versus Von Mises stress graph, using the interpolation method [15], the minimum diameter that fulfills the yield strength is 34.05 mm with a safety factor of 1.1.

4. Conclusion
From the analysis using Autodesk Inventor 2019 software, it was found that a diameter of 25 mm with carbon steel material with a yield strength of 350 MPa was not able to withstand the von-mises stress of 826.6 MPa and a safety factor of 0.42. By using Autodesk Inventor Parametric Optimization, a minimum diameter of 34.05 mm is obtained with a von mises stress of 350 MPa and a safety factor of 1.1.

Acknowledgments
We gratefully acknowledge the support from USAID through the SHERA program - Centre for Development of Sustainable Region (CDSR) and the University of Bangka Belitung as an affiliate. In the year 2017-2021 CDSR is led by Center for Energy Studies – UGM.

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