Steady State Thermal Effect on Static Characteristic of Copper Roller Shaft

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Abstract. The static analysis of a copper roller shaft is performed. The copper roller shaft consists of bushing, pen roll and roller. All of those components consist of different materials. Thermal steady state and statical analysis is performed in order to investigate the thermal effect of high temperature copper slab on the roller shaft. The copper slab temperature is 1200 °C. Based on this work obtained that the maximum total deformation is 0.0050523 m, maximum equivalent stress is 41600 MPa, maximum life cycle is $10^{11}$, total heat flux maximum is 879910 W/m² and the maximum damage occur in the pen roll component.

Keywords: Static, shaft, pen roll, steady-state

1. Introduction

Copper is one of promising material that is produce and process in Indonesia, one of the biggest companies that work on this business is PT. Smelting which located in Gresik, East Java, Indonesia. In the process of transporting the high temperature copper, PT. Smelting use a machine that consist of 3 rollers, 3 pair of pen roll, bushing and frame. In this work the analysis is focus on 1 roller, 1 pair of pen roll and bushing. Temperature of the copper that is transported is 1200 °C in the form of slab metal and the mass is 400 kg. Due to the high temperature and impact force from the slab copper that work on the roller, failure occur. The failure always occurs in the pen roll component of the roller shaft. The failure occurs due to deflection and plastic deformation of the pen roll. The production process in PT. Smelting must stop due to this problem. So, it is important to understand the static characteristic of the copper roller shaft in order to improve life cycle of the components.

Many studies have been carried out in order to understand the problem of static characteristic due to steady state thermal effect on materials. Minghwa et al worked on the finite element method analysis and design of sprocket that connect to shaft in sintering machine. Finite element method gives the stress distribution and contact stress surface of the whole structure, perform the stress magnitude distribution and optimize the part structure. Zyl et al conclude from their work that the shaft on the conveyor pulley shaft failed due to fatigue and improper reconditioning of the shaft during overhaul. Finite element method employed in this work. Reddy et al worked on the fatigue analysis of chain sprocket using finite element method. In this work forces applied on the 3D model and evaluated, so that principal stress was generated. The principal stress use to calculated life cycle of the model by employed The Goodman theory. Those above studies have done so many finite element method analyses in static structural, especially in the shaft component.

In this paper, the static structural characteristic and failure will be analysis due to the steady state thermal effect from the high temperature copper slab. Finite element method is employed in order to compute the maximum stress equivalent (Von-mises), life cycle, damage, safety factor, heat flux distribution and the maximum total deformation on the copper roller shaft.
2. Methods
The components analysed in this paper are roller, pen roll and bushing of a copper roller shaft. In the actual case failure occurred on the pen roll component, either pen roll number 1 or number 2, since there are two components of pen rolls. In this work, author would like to study the static characteristics of those components due to steady state thermal effect. It describes in the previous chapter that there is such a high temperature copper load in the roller shaft itself. Detail information regarding the component’s material describe in the Table 1, as we can see from that table there are two different materials used. The roller and bushing materials are structural steel, the pen roll’s material is AISI 4140. From the data it is obvious that the pen roll’s material has higher yield tensile strength, but lower thermal conductivity than the other material. It is important to study their statical behaviour to obtain better understanding of the phenomenon, so that better design can be achieved in the future.

| Component | Material | Yield Tensile Strength (MPa) | Thermal Conductivity (W/mK) |
|-----------|----------|-------------------------------|-----------------------------|
| Roller    | Structural Steel | 250                           | 60.5                        |
| Bushing   | Structural Steel | 250                           | 60.5                        |
| Pen roll  | AISI 4140            | 415                           | 45                          |

In this work the analysis has been done using Ansys, by employed Finite Element Method (FEM). First of all, the 3D geometry model of the copper roller shaft is created using Autodesk Inventor.
Then, steady state thermal analysis carried out using Ansys. In this analysis the maximum temperature applied is 1200 °C, it is according to the real temperature of copper slab load that is imposed in the roller shaft. The ambient temperature is set to be 22 °C and the convection coefficient is 1.24 W/m² °C. At 1000 °C the convection coefficient increased to 12.4 W/m² °C. The third step of the analysis is static load modelling in the roller shaft’s components. The detail load is shown in the Figure 3. After that, the final static analysis is carried out in order to obtain some characteristics, such as total deformation, equivalent stress (Von- mises), life cycle, safety factor and damage of the roller shaft.

3. Results and Discussion

![Figure 3. Load on the roller shaft 3D model](image)

![Figure 4. Temperature distribution on the roller shaft components](image)
There are 8 different results in this work, which are temperature distribution, directional heat flux, total heat flux, equivalent stress, total deformation, life cycle, safety factor and damage distribution on the roller shaft components. The temperature distribution is displayed on the Figure 4. It is shown that the maximum temperature is 1200 °C and located throughout the roller. As for the bushing and pen roll, the temperature is reducing from the roller direction to the fixed pen roll position. So that the fixed point of the pen roll temperature is the lowest among other part of the roller shaft components. It is shown that the highest temperature portion of the pen roll located in adjacent with the bushing and pen roll.

Figure 5. Equivalent stress distribution on the roller shaft component

Figure 6. Total deformation distribution on the roller shaft components

Figure 7. Damage distribution on the roller shaft components
roller. Since the pen roll dimension is smaller than the other part, it is highly likely that the failure will be occurred there.

As for the distribution of directional heat flux and total heat flux are not describe in the figure. The W/m² and the lowest value is -408000 W/m². The total heat flux maximum is distributive value of directional heat flux in X axis mostly dominated by 43161 W/m², with the highest value is 4049090 W/m².

Due to the effect of steady state thermal condition on the roller shaft, the static characteristics analysis carried out. The first characteristic is equivalent stress (Von-mises) on the roller shaft that is describe in the Figure 5. Based on the analysis, it is obtained that the maximum equivalent stress throughout the roller shaft is 41600 MPa and the minimum one is 73.271 MPa. Overall, the minimum value of the equivalent stress is distributed evenly throughout the roller, except in the middle of pen roll. In this part the equivalent stress is higher, between 4687.3 MPa and 9301.3 MPa.

In the Figure 6, it describes the distribution of the total deformation that possible to be occurred in the roller shaft. The maximum total deformation is 0.0050523 m, located in the right side of the roller, exactly between roller, bushing and pen roll. The minimum value of total deformation is 0 that is located on both fixed points. The damage distribution is shown in the Figure 7, it describes that the maximum damage occurs on both side of the pen roll and the safest part from damage is the roller part. Based on the static analysis, the maximum life is $10^{11}$ cycles, and the minimum safety factor is 0.02.

From all the previous description of the steady state thermal and static analysis on the roller shaft, it is understandable that the failure occurs on the pen roll, especially which located in the right side of the roller shaft. In this part, the maximum deformation and damage happen to be largest with equivalent stress higher than adjacent part.

4. Conclusion
In this work, static analysis due to steady state thermal effect performed. Based on the thermal steady state analysis, the maximum temperature distributed is 1200 °C and the maximum convection is 12.4 W/m² °C. From the static analysis due to the steady state thermal effect, obtained the maximum equivalent stress is 41600 MPa, maximum total deformation is 0.0050523 m, the maximum life is $10^{11}$ cycles, and the minimum safety factor is 0.02. Based on these results, the failure of the roller shaft occurs in the pen roll, this is what exactly happen in the actual condition. So, this analysis can be describing the real condition accurately.

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