Structural analysis on mild-steel and aluminium brake disk for application on belt conveyor

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Abstract. A disk brake system has three essential functions, namely, reducing the moving conveyor speed, preserving its steady downhill speed and stopping the conveyor fully during normal or emergency operation. There has been a persistent demand in recent years for light weight disks with highly efficient energy-absorbing structures and materials in the overall conveyor system. This aspiration has led to experimental work in attempt to use various materials for engineering designs. In this article, a rotating annular disc subjected to in-plane frictional loads is analytically modelled on the brake system. In order to obtain modal properties of breaking for inputs into the finite element model, the experimental modal test of disc brake device free under free boundary conditions is performed. The goal of this research is to recognize various properties that may in future enable us to optimize working parameters and increase braking system efficiency. The findings will enable us to achieve the optimal functionality of this structure to improve the operational disc life or performance. The aim of this document is to examine stress concentration, structural deformation and brake disk contact pressure during a single braking stop event using ANSYS 19.2 academic finite element software. This research therefore provides an important guide to the design and engineering of the brake disk and the brake pad. Structural and stress analysis are therefore preferred to pick the lightweight material for improved performance. Consequently, the lightweight material may be recommended to reduce the conveyor working load and preserve operational energy consumption, provided that light weight will satisfy working duty requirements. Comparing the results achieved with those of the technical literature, the simulation is satisfactory.

1. Introduction

A brake is a tool used by machines to avoid movement by supplying a moving part with artificial friction resistance. The brake disk absorbs the angular momentum and dissipates the heat energy [1]. The rotational movement of disks and the conveyor brake pulley on which it is placed will retard the frictional forces of the sliding interfaces between pads and disc [2]. The unequal temperature distribution on the frictional pad surface creates a so-called thermal distortion identified by the vibration effect and variance in disk thicknesses. It results in mechanical stress due to the friction forces generated by centrifugal forces and compression forces exerted by pushing the pad onto the disk surface and the braking effect induced by rubbing the brake pad on the disc [3]. The incoherent heat dissipation inside the brake disk could cause the disk to deform. Even worse, the deformation of the disk could also lead to a loss of traction and eventually a brake fade. In addition, high brake disc temperatures could cause the brake disk material to crack due to high thermal stress [4]. It was
concluded that the von-Mises maximum stress area coincides with the region of actual splits in the case of the variable pressure allocation on a frictional plate. The aim of these researches is to realize the optimal function of the given construction, in order to increase the lifetime or the performance. Most brake researches examine the thermal and tribological behaviour, where the behaviours of the different friction materials were checked at high temperature [5]. Analysis of structures are conducted in this paper for the finite element (FE) model of a disk brake assembly development, using the ANSYS 19.2 FE program, to obtain heat transfer distribution and structural deformation on brake disk. A nonlinear finite element approach will be used to simulate the stress attain under natural frequency, the von-misses stress and transient-structural performances on two different steel material with conclusion of which material give better results under dynamic braking torque and similar disc external geometry [6].

2. Mild-steel and Aluminium material properties for the disk brake
Disc brake material selection involves formulating equations that would simplify operational parameters like, surface topography, contact geometry, applied loads, slide speed and coefficient of friction. Material parameters such as hardness, ductility, fracture toughness, strength, work hardenability, elastic moduli and thermal properties need to be considered [7]. Furthermore, the operational parameter such as ambient temperature, number of start-stops and rigidity of supporting structure must also be taken care of. Mild steel with mainly pearl-like material is the common material used for conveyor brake discs. The advantages of using mild steel as a disk are high wear-ability and simplified manufacturing process. High thermal conductivity and heat capacity, resistance to brake fade and lowers cost [8]. For this study the following alloy steel with properties as indicated in Table1 will be investigated.

| Properties                          | Aluminum | Mild-Steel |
|-------------------------------------|----------|------------|
| Density (Kg/m³)                     | 2770     | 8200       |
| Coefficient of Thermal Expansion (1/C) | 0.000023 | 0.000012   |
| Thermal Conductivity (w/m. K)       | 23       | 38         |
| Young’s Modulus (MPa)               | 69000    | 210000     |
| Poisson’s Ratio                     | 0.33     | 0.30       |
| Shear Modulus (MPa)                 | 26669.2  | 81000      |
| Specific Heat (J/Kg/C)              | 875      | 470        |
| Compression Yield Strength (MPa)    | 280      | 250        |
| Mass of disk (Kg)                   | 96.1883  | 308.453    |
| Specific Heat (J/Kg/C)              | 875      | 470        |
| Disk Heat Generated (KJ)            | 5937,720 | 3189,404   |
| Brake surface area (m²)             | 0.300415 | 0.300415   |
| Duration of braking (sec)           | 30       | 30         |
| Disk Heat Flux (W/m³)               | 658.8353 | 353.888    |

3. Brake Disc Structural Analysis
There are types of mechanical and structural stresses associated with the impact of the disk brake. The strength of the traction is due to the centrifugal effect and torque times caused by a constant rotation of the disc, the pressure force caused by the breakage pad pressing perpendicularly on the disk surface and, finally, the breaking force because of the friction action of the brake pad against the disk surface, that results in the force of the traction [2, 9]. In intense braking such as emergency stops or repeated high-speed braking, adequate heat dissipation is critical to ensuring effective continued braking. The cooling method in the heat transfer is divided into three types: forced radiation, convection and conduction of the brake surface from the exposed position [10]. Two possible outcomes lie in these big temperature excursions, i.e. heat shocks that cause surface cracks or high deformation levels of the brake disks [11].
The most common application of finite element analysis is structural analysis. Modal analysis are performed to optimize the natural frequency of the break disks, in order to compare the rotor design, in particular, that show the lesser deformation and the much more vulnerable frequencies [12]. In effort to reducing costs and avoid risk in operation, of complex mechanical structures, modal analysis can successfully be used to validate construction design and structural integrity. Finite element analysis can provide important information on system vibrational properties, such as a dynamic component combination, pre-stress caused by the load used and friction properties [13]. In this case, a structural analysis is used to analyze deformation steel performance and stresses on the disk of the material chosen. Solid-works performed this analysis disk simulation, subsequently using ANSYS 19.2 software to evaluate the stress distribution under natural frequency, stress variance and deformation across the brake profile. Many assumptions were also made to simplify the analysis as follows:

- The kinetic energy on the disk braking surface is converted into thermal or heat flow
- For this study, only the conduction and convection mechanism was involved in the heat transfer. This study will ignore heat transfer radiation as it is now less than 10%
- The material on the disk is considered standard and isotropic
- The field is symmetrical in all axes
- Inertia and physical forces are negligible during the study
- The disk remains stress-free before braking action take place
- In this experiment, the ambient temperature and initial temperature are set at 22 °C
- All potential other disk brake loads are disregarded

Modal characteristics of the brakes can be formulated as follows [10]:

$$ M\ddot{x} + C\dot{x} + Kx = f $$

Where, M is the mass matrix, C is the damping matrix, K is the stiffness matrix, F is load vector and f and x are the function of time.

The approach of finite element is the methodology of numerical analysis for approximate solutions to a wide range of engineering challenges. It is widely regarded in almost every industry due to its versatility and flexibility as an analytical tool. The finite element method (FE) is a system of parts approach wherein the structure or entity is divided into finite-dimensional components called finite elements. Thus the body or structure of these objects attached to a finite number of joints called nodal points or nodes is known as assemblies of these elements [8]. The finite element method has become a powerful tool for computational approaches to a wide range of engineering issues. It has been conceived concurrently with the growing use of electronic computers of high speed and with a rising focus on digital analysis techniques. Thermal FE analysis is a scalar field problem contrary to the previous structural analysis. In elements and cross element boundaries, the tempering area of the FE model is continuous [14]. The process for static analysis is as follows step by step [8]:

- Step 1: - Develop the disk profile in Solidworks
- Step 2: - Meshing of the disk into elements nodes in ANSYS
- Step 3: - Description of domain structure
- Step 4: - Choice of the right form of model interpolation
- Step 5: - Derivation of stiffness dimension matrices and charge vectors characteristic matrices
- Step 6: - Assemblage of element equations to obtain the equilibrium equations
- Step 7: - Simulation processing and producing results

For this investigation, the limits of the ANSYS Workbench Multiphysics are defined by selecting the first simulation mode of all permanent or transitory modules and specifying the physical property
of the materials. These criteria are the first specifications for our simulation. After setting these parameters, a boundary with each surface is added.

4. Case Study
Sidewinder engineering software has been used as a design tool for a 2.1637 Kilometer overland conveyor with the results as indicated on table 2. The designed disk brakes have a diameter of 135mm and 465mm bore with a thickness of 30mm as shown by Figure 1. The braking time suitable to stop the conveyor will be 30 sec under normal operation. The conveyor encounters different working conditions at different frequencies during operation. Basic operating conditions, includes continuous running, loading and unloading. The Conveyor Profile of a fully loaded with material Lift -11.7 m is shown in Figure 2. The results of the conveyor inputs and output design data are provided in Table 2.

![Figure 1. Brake disc assembly drawing](image1)

![Figure 2. Overland conveyor profile](image2)
Table 2. Conveyor design calculation input data

| Properties Description | Value |
|------------------------|-------|
| **Power Breakdown**    |       |
| Total installed power (kW) | 1200  |
| Max demand power (kW) | 1243  |
| **Conveyor Profile Summary** |       |
| Length (m)            | 2163.7|
| Height (m)            | -11.7 |
| Minimum Elevation (m) | -42.4 |
| Maximum Elevation (m) | 7.4   |
| **Material Properties** |       |
| Type                  | COAL  |
| Through-put Tonnage (t/h) | 4800  |
| Density (kg/m³)       | 1050  |
| Coal Lump size (mm)   | 300   |

In the multi-physical module ANSYS Workbench, the boundary conditions are added, the first simulation mode is chosen (permanent or interim) and the physical properties of the materials are described. Once these parameters have been fixed, a boundary condition associated with each surface is introduced [9].

Table 3. Brake disc total deformation natural frequency modal analysis

| Modal Analysis – Simulation Results |
|------------------------------------|
| **Modal Analysis**                 | Aluminum Alloy Steel | Mild-Steel |
| **Total Deformation**              | 176.2                | 169.29     |
| **Type**: Total Deformation        |                      |            |
| **Frequency**: 261.17 Hz           |                      |            |
| **Units**: mm                      |                      |            |
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Table 4. Brake disc natural frequency range

| Natural frequency results | Aluminum | Mild-Steel |
|---------------------------|----------|------------|
| Mode 1 - Minimum          | 176.2    | 169.29     |
| Mode 16 - Maximum         | 262.17   | 256.59     |

Brake disc structural vibration and noise caused by the conveyor brakes are one of the toughest problems from the beginning, in particular because the root causes are often challenging to solve. Due
to different parameters such as pressure, speed, temperature, nature of vibrations cannot be repeated. It provides hard conditions for the phenomenon to be tested [13]. This section of the investigation analyzed the deformation characteristic performance for different material based on natural frequency ranging from 132Hz to 262Hz. The results are favorable for mild steel with a total deformation 4.75 mm, however aluminum results are adverse with total deformation of 8.195mm. The results for natural frequency deformation characteristics can be used as input for material selection data during design phase, coupled with other selection criteria. Throughout braking, low-frequency energy in the vibrated mechanism propagates and resonates throughout the structure with other conveyors parts, while high-frequency vibration produces unwanted noises that may lead to new challenges [13].

Table 5. Brake disc static structural analysis – total deformation based

| Material      | Total Deformation (mm) |
|---------------|-------------------------|
| Aluminum      | 8.195                   |
| Mild Steel    | 4.75                    |

Table 6. Brake disc static structural analysis – equivalent stress based

| Material      | Equivalent Stress (von-Mises Stress) (MPa) |
|---------------|------------------------------------------|
| Aluminum      | 5.73669                                 |
| Mild Steel    | 4.36159                                 |

The brake material should be of sufficient ductility to withstand stresses and avoid extreme deformation. Using the material selection process, aluminium and mild steel are researched based on their properties to decide which material is suitable for the disc brake. The dissipation or absorption of heat is dependent not only on the outside of the device, but on internal heat e.g. in the process of adiabatic deformation or latent transformational heat. Correspondingly, the distribution of plastic
strain in the part also depends both on its constitutive characteristics and on how form deformations compensate for stress production due to phase transformations [3]. The structural deformation for two materials were obtained and compared and shown in Table 5 under static structural analysis. Mild steel shows little deformation on the outer diameter with a value of 5.985mm whereas aluminium results value are 14.326mm maximum deformation on outer radius of the disc. On the reference disc in Table 5 on the cross sections, the results characterize the plastic deformation and the surface damage on the most external surface of the disk.

Stress Von Mises is used to estimate the material performance in complex loads of uniaxial stress analyzes. Von Mises stress fulfills the property of equal power distortion in two stress states with equal energy distortion. The disk brakes are subject to three kinds of mechanical stress: - the centrifugal traction effect stress, stress due to the strength of compression exerted perpendicular to the brake disc and the stress due to the brake pad rubbing onto the disk surface moving in the other direction of the disk [2, 9]. In this study, Table 6 presents the distribution of constraint equivalent von Mises stress for various moments of simulation with the scale varying from minimum on the inner radius and maximum on the outer radius of the disc. This is due to the induced torsion and shear modes occurring during braking. The high concentrated stress can cause cracks on the disc surfaces. The material chosen for equivalent stress simulation are Aluminum and Mild steel as they are two materials on either side of the spectrum from the previous simulation.

5. Conclusion
The structural analysis was done on the Disc Brake by comparing Mild steel and Aluminium. The analysis has proved that Mild Steel has better strength than Aluminium materials as it can withstand forced stresses thereby showing that the deformation occurring on the disc plate will be minimum. Comparing the different transient analysis results based on equivalent stress, total static deformation and deformation based on natural frequencies obtained shows that Mild steel disc performed better in that it has high strength and will deflect far less that Aluminium. The static structural results are favourable for Mild steel as opposed to Aluminium because Mild steel is more rigid. The future work includes verifying these structural analysis results via experimental work.

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