The Effect of Various Two-wheeler Camshaft Materials on Dynamic Response Using Finite Element Analysis

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Abstract

A camshaft from a 4-stroke engine operating at idle with an average speed of 650 rpm was studied. The study was carried out using the finite element method and the Ansys software. The study was carried out to determine the dynamic response (reaction force, stress distribution, and deformation) of a camshaft circuit operating under torsional pressure at 650 rpm for 1 s. Analysis studies were carried out by varying the camshaft materials such as structural steel, aluminum alloy, and stainless steel. The results of this numeric study show that the structural steel camshaft has the greatest total deformation when compared to the other two materials. Stainless steel has the highest equivalent stress value, followed by structural steel, and aluminum alloy has the lowest. These findings also suggest that aluminum alloy has a better structural response than other materials. This is due to the aluminum alloy having the lowest stress of 239.87 MPa. This is supported by the relatively high safety factor value of 2.165, which is higher than the other two materials.

Keywords: camshaft, finite element method, dynamic response

Abstrak

Suatu studi telah dilakukan pada sebuah camshaft dari mesin 4-langkah yang beroperasi pada kondisi idle dengan kecepatan rata-rata sebesar 650 rpm. Studi dilakukan dengan menggunakan metode elemen hingga menggunakan bantuan software Ansys. Studi dilakukan untuk mengetahui respon dinamis (gaya reaksi, distribusi tegangan, dan deformasi) dari rangkaian camshaft yang bekerja di bawah tekanan torsional pada kondisi operasi 650 rpm selama 1 s. Studi analisis dilakukan dengan memvariasikan material camshaft seperti structural steel, alumunium alloy, dan stainless steel. Hasil studi nemuerik ini menunjukkan bahwa pada camshaft yang terbuat dari material structural steel memiliki total deformation terbesar dibandingkan dengan dua material lainnya. Adapun nilai equivalent stress terbesar terjadi pada material stainless steel diikuti oleh structural steel dan paling kecil pada alluminium alloy. Hasil ini juga menunjukkan bahwa material alumunium alloy memiliki respon struktur yang lebih baik daripada material lainnya. Hal ini dikarenakan aluminium alloy mengalami tegangan paling rendah sebesar 239,87 MPa. Hal ini didukung pula oleh nilai factor keamanannya yang cukup besar sebesar 2,165, lebih besar dibandingkan 2 material lainnya.

Kata kunci: *camshaft, metode elemen hingga, respon dinamik*

1. Introduction

The camshaft is a critical component in an engine that acts as a driving mechanism. This device regulates air intake while also removing residual combustion gases. This is accomplished by opening and closing the inlet and exhaust valves in the combustion chamber [1]. As the camshaft rotates, the two valves alternately open and close. Another important function is to control the duration of the two valves opening. The camshaft has a nose or cam that will wear and tear as a result of friction with the push rod holder. Even though they have been lubricated, these two parts will experience wear and tear as well as relatively large loads over time [2]. On the other hand, several engine components, such as the rocker arm and cylinder volume, influence the shape of the camshaft as well as the amount of power obtained and the engine speed at which maximum power is obtained [3].

Since cast iron has good physical and mechanical properties, it is primarily used to produce camshafts. In terms of reconditioning, the camshaft has brittle (prone to cracking) material properties. According to the Vickers hardness test results, the reconditioned camshaft had a higher hardness value than the standard camshaft [4]. This has a long-term negative impact because it can affect the camshaft. To improve the performance of the reconditioned camshaft, a heat treatment process is employed to improve the ductility properties of the material. This can help to prolong the lifespan of the camshaft. This is due to the improved surface can withstand the loads and forces applied to the camshaft [5].

In order to perform its function of closing and opening the valve, the intake and exhaust lobes work independently. Because the separation distance between the two lobes is measured in degrees, it is known as the lobe separation angle or LSA. Lobe separation is the distance between the peaks of the intake and exhaust lobes. The lobe separation is approximately half the crankshaft rotation between the exhaust peak and the intake peak. The overlap that occurs can be increased by shrinking the LSA, or it can be reduced by enlarging the LSA [6]. A well-designed desired overlapping will result in maximum torque at a given engine speed. Based on the foregoing, it is clear that a dependable and strong camshaft design is required.

In order to find out the amount of load that occurs on the camshaft, finite element analysis can be applied. This method can be used to analyze various structural loads and offers a theoretical cornerstone for design [7]. The high-speed rotation of this camshaft causes pressure and acoustic noise in the system. Moreover, the camshaft is indeed subject to fatigue loads as a result of cam plunger contact [8]. This precise value must be ascertained in order to avoid camshaft damage. The goal of this research is to model and analyze camshaft pressure. CATIA V5R21 software was used to model and analyze standard engine camshafts. The basic requirements of the equipment are used to create this model. That is done against the backdrop of all else that is proceeding, such as the forces that act on the cams through the valves when the engine is running at low engine speed. The approach becomes entirely CAE-based (computer aided design) at this point. The CAE-based approach deepens the research while shortening the time frame. A previous study was carried out to predict the structural behavior of various camshafts made of different materials using finite three-dimensional stresses of the components. Steel, titanium, aluminum, and magnesium are four types of materials considered. The maximum stress and displacement results are calculated and compared to all of the materials listed above. The conclusion was that an appropriate method for the camshaft should be found in order to reduce maximum displacement and weight. According to analysis, titanium is the best material for manufacturing camshafts [9].

The mesh characteristic is significant in FEA (finite element analysis) because it reflects the discretization virtual domains needed to transform a continuous body into such a finite number of nodes and elements. Since the meshing strategy has a direct impact on the accuracy of the calculated simulation, several parameters must be taken into account in order to generate a realistic model with accurate results while requiring minimal computational effort. Generation of the mesh requires making several decisions such as the shape of the elements and their dimensions. The mesh quality is then crucial in determining an optimal trade between solution precision and computational effort. In fact, a mesh that is excessively coarse will generate an imprecise solution, whereas a mesh that is too thick will produce a computationally inefficient solution [10].

As a result, a finer mesh is necessitated for improved numerical solution convergence, but this condition increases the computation complexity required for the simulation [11]. The determination of the mesh in this study is highly concerned to obtain results that are reasonably accurate.

According to previous research, the selection of the appropriate material for the camshaft has a significant impact on the camshaft durability because each material has a different response. As a result, more research into the camshaft and the various materials used is required. Following the completion of this research, it is hoped that the main outcomes of the study will provide an overview of phenomena that are very similar to practical results. Furthermore, it can show which individual components are very vulnerable so that they can be adjusted further, as well as assist in determining why the camshaft design is insufficiently optimal.

2. Materials and methods

The study was carried out with the assistance of the Ansys software. The analyzed camshaft is the same type of engine found in standard two-wheeler. The camshaft geometry is showed in Figure 1. Table 1 shows the engine specifications. The torque load is caused by the engine speed of 650 rpm when the engine is idle. Variations in camshaft material are observed in this study, which includes the use of a variety of materials, including structural steel, aluminum alloy, and stainless steel. Table 2 shows the material properties.

After deciding on the geometry and material, the next step is to apply the mesh to the geometry. The hexahedral method is used with a global size of 10 mm, but the tetrahedron method is used on the contact part with a size of 4 mm on the cam lobe and 2 mm on the tip of valve. Therefore, the camshaft and valve domain will then have 4114 elements and 12277 nodes in total. The global and contact mesh are showed in Figure 2.

After applying this mesh, the analysis settings and boundary conditions are defined. The valve is pulled onto the cam by a spring element. The revolute joint is attached to the shaft end and regulates the rotary movement of the valve in the z direction. The translation

joint restricts the valve lateral movement and only allows it to move axial direction in the x-axis. In one second, the revolute joint completes one full cycle. The rotational velocity is set to 650 rpm, and the time step is set to 1 s. Low engine speed was chosen as the starting point for understanding the conditions that can occur at high engine speeds.

Figure 1. Camshaft geometry

Table 1. Engine specification [12]

Engine specification	Data
Engine type	Single overhead camshaft
Engine cycle	4-stroke
Bore/stroke	50 x 49.5 mm
Displacement volume	97.1 cm^3
Compression ratio	9.0 : 1
Rated power	7.3 PS @ 8.000 rpm
Peak torque	0.74 kgf.m @ 6.000 rpm
Gear settings	N-1-2-3-4-N (rotary)

Table 2. Camshaft material characteristics

Materials	Characteristics	Value	Unit
Structural steel	Density	$7.85x10^{-6}$	kg/m^3
	Ultimate tensile strength	460.00	MPa
	Tensile yield strength	250	MPa
	Shear modulus	76.923	GPa
	Elastic modulus	200	GPa
	Poisson ratio	0.3	
Aluminum alloy	Density	$2.77x10^{-6}$	kg/m^3
	Ultimate tensile strength	310	MPa
	Tensile yield strength	280	MPa
	Shear modulus	26.692	GPa
	Elastic modulus	710	GPa
	Poisson ratio	0.33	
Stainless steel	Density	$7.75x10^{-6}$	kg/m^3
	Ultimate tensile strength	586	MPa
	Tensile yield strength	207	MPa
	Shear modulus	73664	GPa
	Elastic modulus	1.93	GPa
	Poisson ratio	0.31	

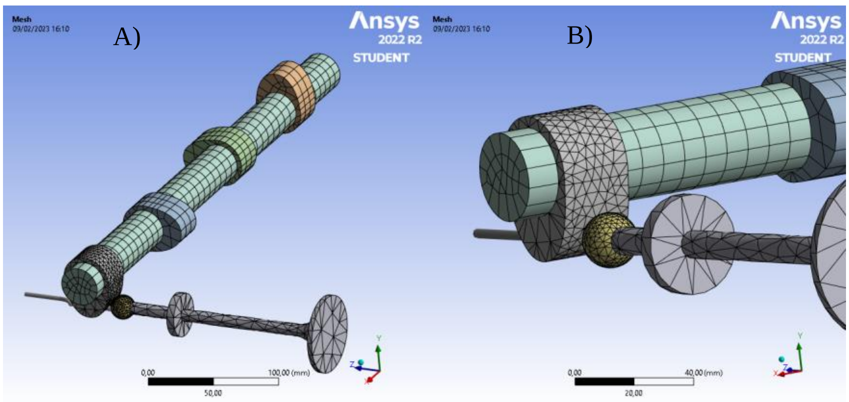

Figure 2. A) Global mesh and, B) contact mesh

3. Results and discussion

Total Deformation simulation results with ANSYS R22 2022 Workbench can be seen in Figure 3 for camshafts made from aluminum alloy, structural steel and stainless steel respectively. It is apparent that the maximum deformation value in each material is comparable. However, the lowest value obtained for aluminum alloy material was 61.602 mm, while the highest value obtained for structural steel material was 61.678 mm. Aluminum's deformation resistance is due to its superior physical and mechanical

properties. Since aluminum is both light and strong, it is widely used in applications ranging from household appliances to advanced technology, such as aircraft airframe. The high ductility of aluminum contributes to this advantage of good deformation. This advantage is demonstrated by aluminum when the tensile test results

in no necking [13]. Another benefit of aluminum against deformation is its low rigidity, that further makes it possible it to absorb energy in an elastic manner without permanent damage [14]. Aluminum achieves higher strength while retaining ductility through subsequent heat treatments.

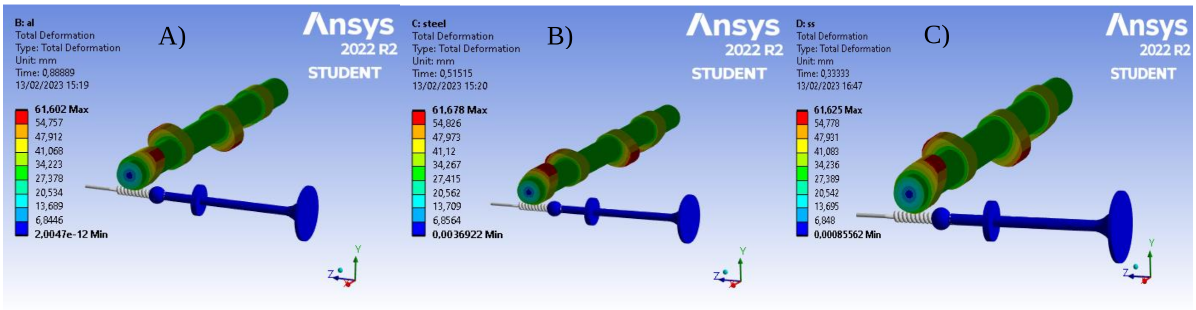

Figure 3. A) Total deformation of an aluminum alloy, B) structural steel (middle) and, C) stainless steel camshaft

The maximum stress value of each material is shown in Figure 4. The stainless-steel material has the highest equivalent stress value of 343.44 MPa and the aluminum alloy material has the lowest equivalent stress value of 239.87 MPa. Since stainless steel is composed of various compounds, the equivalent stress experienced by stainless steel is greater than that of the other two materials. The main component of stainless steel is chromium (Cr), which is intended to be corrosion resistant. As a result, it is insufficient to receive a high voltage [15]. Moreover, a study was conducted that examined the camshaft assembly made of aluminum metal matrix composite and discovered that the maximum deformation occurred at the center of camshaft. The findings also show that such von Mises stress distribution is consistent across the camshaft [16]. It should be noted, however, that this study only glanced at one type of material (aluminum metal matrix composite) and didn't contrast it to other materials like structural steel or stainless steel.

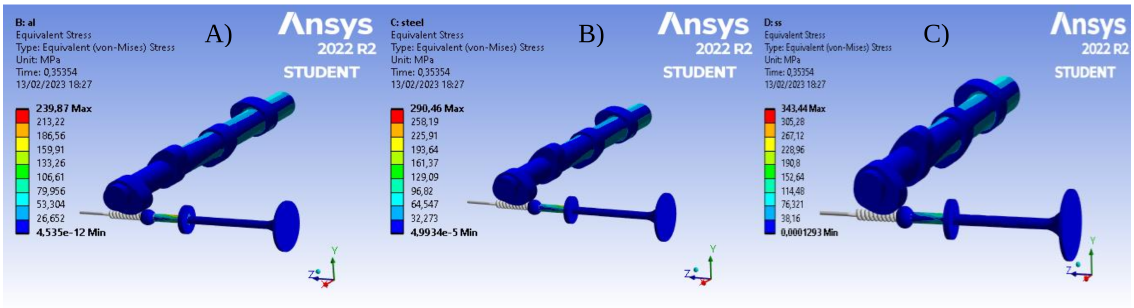

Figure 4. A) Equivalent stress on an aluminum alloy camshaft, B) structural steel and, C) stainless-steel camshaft

The maximum stress versus time for each material can be graphed from the results of the camshaft simulation using Ansys R2 Workbench, as shown in Figures 5, 6, and 7. Figures 5–7 show that aluminum has the lowest maximum stress of 239.87 MPa of the three materials. Maximum stress occurs when the valve tip comes into contact with the cam lobe or cam nose. This is because the cam lobe protrudes the most, resulting in the greatest pressure load when compared to the cam heel. Rotating the cam reduces the stress until it reaches a minimum on the cam heel. The nature of aluminum, which is light but strong, is strongly suspected of being the source of the small maximum stress experienced [17]. Moreover, other aluminum's advantages for camshafts include its wear-resistant properties, high durability and strength, and low cost. Aluminum is also lighter than iron, which benefits engine blocks. Furthermore, a plastic camshaft module has been developed that is said to absorb noise-producing vibrations better than aluminum while requiring less energy to manufacture. All-aluminum engines also dissipate heat more quickly than other materials, allowing for higher compression ratios with less risk of detonation [18].

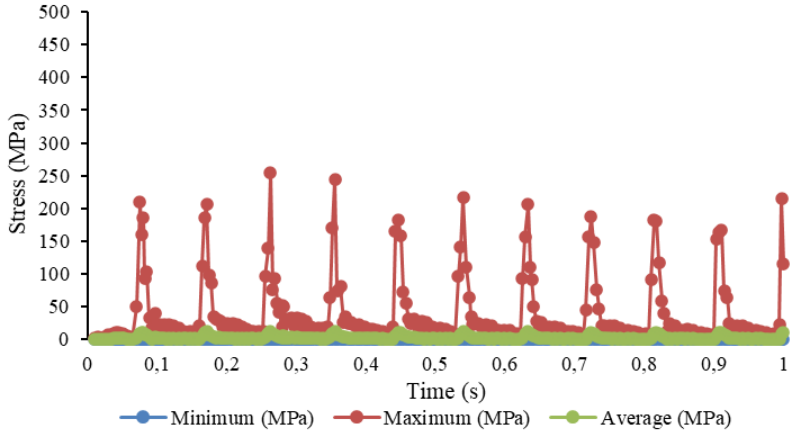

Figure 5. Maximum stress and time graph for an aluminum alloy camshaft

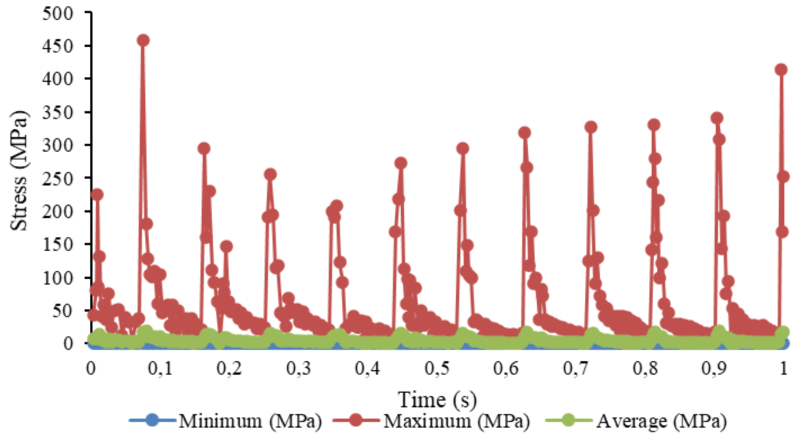

Figure 6. Maximum stress and number of spokes graph for wheels with an additional 3 mm flange thickness

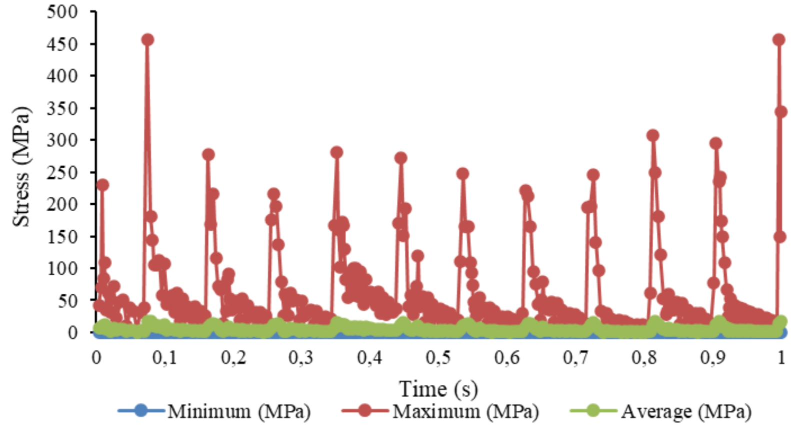

Figure 7. Maximum deformation and number of spokes graph for wheels without area thickness flange

The results of testing the safety factor value in each material are shown in Figure 8. The value of the safety factor in the aluminum alloy material is 2.165, indicating that the geometry is safe in receiving a torsional load of 650 rpm. The structural steel and stainless-steel materials, on the other hand, have a safety factor value less than one, indicating that the geometry is not viable in accepting a torsional load of 650 rpm. Structural steel materials typically have a safety factor of 4-6 for building work and 5-7 for bridges [19]. Meanwhile, the safety factor for stainless steel is relatively low, namely 1.8. m although for other uses such as for water pipes the safety factor is quite good [20].

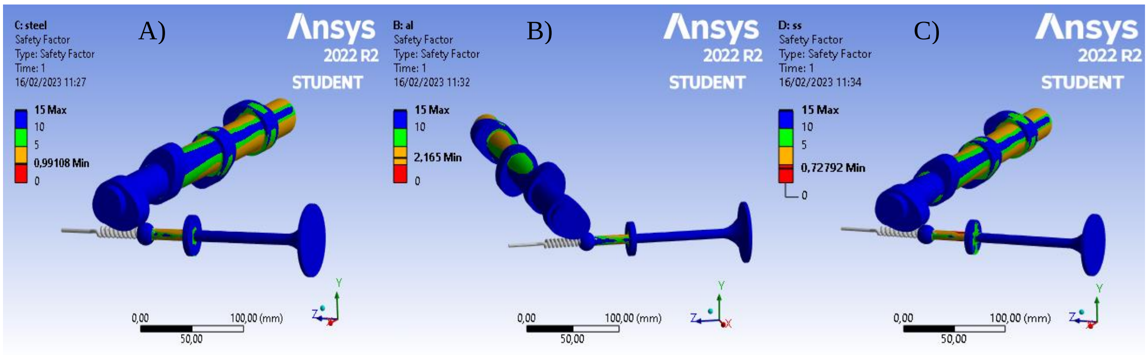

Figure 8. A) The safety factor values for structural steel, B) aluminium alloy and, C) stainless steel are shown

4. Summary

Based on the results and discussion, the following conclusions can be drawn: the study's numerical simulation (ANSYS software) results suggest that the aluminum alloy camshaft material is the best camshaft since it has the smallest maximum stress value and greatest deformation among other modified camshafts. When force is applied, the smallest maximum stress is 239.87 MPa and the smallest maximum deformation is 61.602 mm. Meanwhile, structural steel is not suitable as a material for the camshaft because of its high overall deformation. The numerical simulation results reveal that the camshaft made of aluminum alloy material is safe when subjected to a torsional force of 650 rpm because it has a safety factor value of 2.165. Whereas structural steel and stainless steel materials are improper since their safety factor values are 0.99108 for structural steel and 0.72792 for stainless steel.

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