Failure Analysis with Material Variations in Rocker Arm using Finite Element Method

A Y Aswara¹ and Andoko²*

¹,²Mechanical Engineering Department, Engineering Faculty, Universitas Negeri Malang, 65145 Semarang, Malang, Indonesia

*Corresponding e-mail address: andoko.ft@um.ac.id

Abstract. Rocker arm is one of the important components in an internal combustion engine. The rocker arm is driven by a camshaft which functions to push and open the inlet and exhaust valves. This allows fuel and air to be drawn into the combustion chamber during suction steps and exhaust steps. During the working process the rocker arm receives a force from the valve due to the valve spring-back force, so that at one time the rocker arm has a failure of both fatigue and component cracks. In this article the material used is titanium alloy which is usually used for racing vehicles, the method used for testing is FEM. The maximum stress value in red is 227.74 MPa. The maximum deformation is 0.28267 mm, while the result of the crack test is the largest SIFS (K) value in the horizontal crack, which is -65.869 MPa.mm0.5. Maximal J-Integral is found on horizontal crack that is equal to 0.083512 mJ/mm². From the results above the rocker arm crack occurs due to design errors and material failure.

1. Introduction
An object that moves rotation occurs when the inertia which is affected by the mass and the distance of the rotary axis to its mass center. In engine components such as rocker arm there is an effect on the valve opening and closing performance because the rocker arm moves rotating on the rocker arm shaft periodically to suppress the valve. The spring on the valve will be pressed deeper at a faster rotation, so the valve gap opens longer. This is not desirable because the open lid angle and valve timing must be adjusted correctly to obtain good engine performance [1].

When the protruding part of the camshaft touch the outer side of the rocker arm, then it will press the valve stem down so that the valve opens [2], and when the camshaft surface which is not protruding touch the outer side of the rocker arm, the valve return spring pushes the rocker arm back to its original position so the valve closed. In the center of the rocker arm there is a rocker shaft that can make the rocker arm move up and down.

This up and down movement results in a reduction at the point where contact occurs between the valve end and the rocker arm tip [3]. Most Rocker arm uses materials that are lightweight but strong and have economic value because with rocker arm material that has excess mass will limit the ability of the engine to achieve the desired work efficiency. Material damage usually starts from defects on
the material surface due to the influence of environmental factors such as corrosion or wear due to interaction with other components [4]. The corrosion rate is dependent much on the solution concentration [5]. Most cars use rocker arms made from alumnium alloy material. Therefore the material mass becomes an important consideration [6].

1.1. Rocker Arm failure
Rocker arm failure usually occurs because of cracks in the hole or rocker arm neck, various factors of rocker arm failure [7]. Cracks that occur due to fatigue of the material mechanism, material hardness is the cause of the failure of rocker arm gradually decreasing its strength. Initiation and increasing cracks are caused by low fatigue strength microstructure as happened in the rocker arm hole [8].

![Figure 1. Cracks position on the rocker arm neck](image)

Based on research by Kullyappa et al [1]. The value of ultimate tensile strength (UTS) and the pressure received by the rocker arm is 164 MPa and 2.5%, this value is slightly lower than the die-cast AI alloy. In the stress measuring test conducted by Spiegelberg, the results of compressive stress showed the maximum value and decreased when the engine speed increased, the maximum stress value on the rocker arm neck was 21 MPa at idle speed. Therefore this rocker arm is considered safe in terms of fatigue fractures.

Based on the explanation above, in order that the mechanism contained in the rocker arm system has a long life, then effective and efficient design planning is needed, both in terms of loading analysis and selection of the component material. Along with the purpose of knowing the effects of damage caused by the dynamic load acting on the rocker arm component, a rocker arm simulation is needed to determine the stress distribution that occurs.

2. Method
In this analysis, the Finite Element Method (FEM) is used to estimate the stress in the rocker arm. To design a rocker arm at an economical and limited cost, numerical simulation is the best way. Finite element analysis provides a way to carry out easy and efficient research on various parameters used with design conditions and manufacturing conditions that are easily evaluated [9]–[12]. ANSYS 18.1 is software used to model simulation with finite element method [13].

2.1. Construction model
Rocker arm in this paper is designed by using Autodesk Inventor Professional 2012 Software with dimensions that follow as a rocker arm on a 4 cylinder engine. Rocker arm generally uses allumunium alloy material for mass vehicles because the actual rocker arm is used at high speed and heavy loads [5]. Rocker arm has several types of materials usually used for vehicles that are common in the market, namely made of Allumunium Alloy. Where the material properties are explained in the table,

| Material Property | Value | Unit |
|-------------------|-------|------|

Table 1. Allumunium alloy material properties.
Density 2.77E-005 Kg/m³
Young’s Modulus 73000 MPa
Poisson’s Ratio 0.33

2.2 Simulation
Then the rocker arm design results are simulated on the material strength by using ANSYS Workbench Software version 15. The rocker arm simulation process provides various loading conditions, including the force of 5000 N, and using a meshing size of 2 mm. From the results of simulation analysis performed, it obtained stress and deformation on the rocker arm due to loading for maximum conditions. The results of the analysis is the basis for analyzing crack on the rocker arm neck, as the rocker arm has cracked.

On the crack test which was carried out in the rocker arm with aluminum alloy material, it obtained the highest stress and deformation results compared to the material of cast iron and titanium alloy material. The crack location is in the Y coordinate = 0.5 mm, the crack dimension is: 8 mm (major radius), 2 mm (minor radius), and 2 mm (large contour radius) with a meshing size of 2 mm. Then given a force of 5000 N.

### Figure 2. Loading on the rocker arm

### Figure 3. Horizontal and vertical crack test loading

3. Result and discussion
Figure 4. results of the load equivalent (von-mises) stress on the rocker arm with allumunium alloy material

Figure 5. results of the analysis of the maximum principal stress loading on the rocker arm with allumunium alloy material

Figure 6. analysis results of maximum shear stress loading on rocker arm

Figure 7. total deformation of the rocker arm allumunium alloy loading
3.1 Stress and deformation
The maximum stress simulation results on the rocker arm with aluminium alloy material shown in Figure 3 shows the highest maximum equivalent stress value of 227.74 MPa, whereas the lowest stress value has a stress value of 0.0079002 MPa. While Figure 4 shows the highest maximum principal stress simulation results of 260.95 MPa, whereas the lowest principal stress value is -31.798 MPa. Figure 5 shows the results of the highest simulation of maximum shear stress of 118.95 MPa, whereas the lowest value is 0.0044327 MPa. Finally from Figure 6 shows the results of the total deformation loading simulation in the rocker arm with aluminium alloy material, it was obtained that the highest total deformation value is 0.28267 mm.

3.2 Crack test
The results of simulation analysis of crack test with crack, Table 2.

| Value                      | Horizontal | Vertical |
|----------------------------|------------|----------|
|                            | Max        | Min      | Max      | Min    |
| SIFS (K1) (MPa.mm^0.5)     | -65.869    | -81.249  | -6.0309  | -30.907|
| J-Integral (mJ/mm^2)       | 0.083512   | 0.061908 | 0.012549 | 0.00046558 |

From the results of the Horizontal crack test simulation analysis above, the SIFS (K1) and J-Integral values are obtained. The J-Integral value is the strain energy release rate of a crack body per unit increasing the crack length that occurs in the body. From the maximum J-Integral of 0.083512 mJ/mm2. Furthermore the minimum J-Integral value is 0.061908 mJ/mm2. In addition, the SIFS value (K1) is also used to determine the stress intensity factor (K) of a material with a certain geometric shape under elastic loading conditions. The maximum value of SIFS (K1) is -65,869 MPa.mm0.5. While the minimum SIFS (K1) value is -81,249 MPa.mm0.5.

While the results of the analysis of vertical crack test simulation obtained the J-Integral value of the J-Integral maximum value of 0.012549 mJ/mm2. Furthermore, the value of the minimum J-Integral is 0.00046558 mJ/mm2. Besides that the SIFS value (K1) is also used to determine the stress intensity factor (K) of a material with a certain geometric shape under elastic loading conditions. The maximum value of SIFS (K1) is 6.0309 MPa.mm0.5. While the minimum SIFS (K1) value is -30.907 MPa.mm0.5. When the small cracks simultaneously spread except the main cracks, the existing elastic energy for the growth from the main cracks certainly would be reduced, particularly in view of the creation of the larger crack surface; thus reducing the general level of crack growth. In some cases, it locally can cause a sudden crack. In addition, the orientation of the ferrite laths in matrix can influence the crack path [14].

4. Conclusions
Based on the simulation results, the results of stress and deformation simulation analysis in the rocker arm with aluminium alloy material above, it was obtained a maximum stress value in red color of 227.74 MPa. The maximum deformation is 0.28267 mm, while the results of the crack test obtained the greatest stress intensity factor (K) in the horizontal crack that is equal to the obtained main reason for failure can result from two problems, namely -65,869 MPa.mm 0.5J-Integral is the strain energy release rate of a crack body per unit increasing the crack length that occurs in the maximal body found in the horizontal crack that is equal to 0.083512 mJ/mm2. From the results above the rocker arm crack occurs due to design errors and material failure.

References
[1] Kullayappa D R, Krishna M N A, Chakravarthy M A, and Chandra R R 2017 IJESC. 9
[2] Husain S M and Sheikh S 2013 *IJEMERR*. 7
[3] Chung C S and Kim H K 2010 *Materials & Design*. 31
[4] Puspitasari P, Andoko A, Suryanto H, Risdanareni P, and Yudha S 2017 *MATEC Web Conf*. 101
[5] Gapsari F, Andoko, and Wijaya H 2018 *Metalurgija*. 57
[6] Pysz S and Żuczek R 2012 *Teka. Commission Of Motorization And Energetics In Agriculture*. 12
[7] Chaitanya D G and Sreenivasulu R *Akgec International Journal Of Technology*. 7
[8] Yu Z W and Xu X L 2006 *Elsevier*. 13
[9] Andoko and Saputro N E 2018 *MATEC Web of Conferences*. 204
[10] Andoko and Puspitasari P 2016 *IMEEEC*
[11] Andoko and Saputro N E 2018 *MATEC Web of Conferences*. 204
[12] Andoko and Puspitasari P 2016 *IMEEEC*
[13] Permanasari A A, Puspitasari P, Choiron M A, Andoko, and Affandi M T 2018 *MATEC Web of Conferences*. 204
[14] Andoko A and Puspitasari P 2017 *MATEC Web of Conferences*. 97