Motion and Stress Analysis of Cam System for Marine Diesel Engine 93 KW

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Abstract—**The developments of maritime sector in Indonesia shows increasing demand for ships. Especially ships with size of 30 GT has problem with low availability of the ship engine, which most of the ships still use non marine diesel engine as its main propulsion. The problem gives interest to make a step to improve by design marine diesel engine using reverse engineering method. Cam system of marine diesel engine design was needed to be calculate to select the material and the motion. The design of cam system needs study about the stress analysis in cam system to make sure the distribution of force and moment. The result of stress analysis was used to select material of components in cam system. The motion analysis result was used to be input data of stress analysis. The condition to obtain the stress of components was on maximum condition, its contain pressure, torque, rotation, and force. All component that calculated are camshaft, lifter (flat-tappet), push rod, rocker arm, spring, and valve. Each component was given two different materials and material selection was based on safety factor of each component. Material for camshaft and lifter were malleable cast iron, for push rod and rocker arm were mild steel, for spring was ASTM A231, for intake valve was steel JIS SUH3, and for exhaust valve was steel JIS SUH35. The result of motion analysis were angular velocity of camshaft with value was 2400 deg/sec, friction force between camshaft and lifter with maximum value was 125.393 N, and contact force between camshaft and lifter with maximum value was 845.307 N, and linear velocity of intake valve with maximum value was 696.573 mm/s, and linear velocity of exhaust valve was 463.734 mm/s.**

Keyword—**Marine Diesel Engine, Stress Analysis, Motion Analysis, Motion Study, Cam System, Material.**

I. INTRODUCTION

THE design of marine diesel engine for fishing vessels with capacity around 30 GT were begin to exist. The design data for other system was needed to complete the information, so that marine diesel engine could be made.[5] The engine was designed for 93 KW and cam system was the main role of the engineand it was needed to be filled with valid information. The design of camshaft affect the displacement of air that flow into combustion chamber. There were some motion forces that work into the material of cam system. In this case, the type of cam system was side operating camshaft with tappet (flat) and rocker arm. Using simulation and design of cam system to collect data and used for calculation. The calculation includes motion and stress distribution analysis. It is used to select the suitable material so that the motion and stress can be distributed correctly.Based on the description, brought out several formulation of the problem. Analyze the distribution stress of components cam system was one of the problem. The second was selecting material for components cam system. The third was analyze the motion of cam system to be the input data for stress analysis. The components includedcamshaft, lifter, pushrod, rocker arm, valves, and spring.

II. LITERATURE REVIEW

A. *Camshaft*

Camshaft is frequently called brain of the engine. This was because of its job to open and closed valves at just the right time during engine running, so that the maximum power and efficient cleanout of exhaust could be obtained.[3] The valve train system with type of overhead valve usually used for old engine. The camshaft rotates was driven by the crankshaft, usually through a set of gears or a chain or belt. The camshaft always rotates at half of crank rotation, taking two full rotations of the crankshaft to complete one rotation of the cam, to complete a four-stroke cycle.[1] The camshaft operates the lifters (cam followers) that in turn operate the rest of valve train. On overhead valve engines the lifters distribute force to pushrods theninto rocker arms thenpushthe valves.

The lift produced by the cam in cam-actuated valve drives, which are still primarily in use, is transmitted to the valve:

- by a tappet, push rod and rocker arm in under head camshafts,
- by a rocker arm or cam follower or by a bucket tappet in overhead camshafts and the valve is lifted against the valve spring’s force.[4]

Vibrations of camshafts with flat-faced follower differ from ores with roller follower because of the friction between cam and follower. Vibrations on the camshaft affect the follower motion and contact force.[6]

B. *Valve Train Systems*

Modern valve train systems can be broadly divided into overhead camshaft (ohc) and overhead valve (ohv) types. The ohv was gradually being replaced as the most common by the single ohc layout. The inherent high inertial forces of the ohv had thus lead to the greater use of ohc designs.[2]

The differences of design camshaft between OHV and OHC was the production of material parts. OHV camshaft need push rod and rocker arm to run the valve train, which the camshaft did not make direct contact to the valves. Furthermore, the rocker arm that contact into valves, so material of it needs to be hardening to protect high temperature especially in exhaust part. In other types, OHC was used with different structure design production. Camshaft for OHC was making direct contact with valve, and the conduction heat from exhaust gas will go through camshaft. Therefore, the camshaft in exhaust cam has different strength hardening with intake cam.

III. METHODOLOGY

Arranged to resolve the problem would be used by the simulation method. The method resolving problemwere divided in several stages:

A. *Identification Components*

Figure 1 – Figure 6 shows the components geometry of cam system, which was conducted for motion and stress analysis.

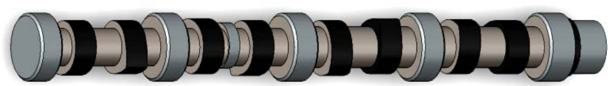

Figure 1. Camshaft

Figure 2. Pushrod

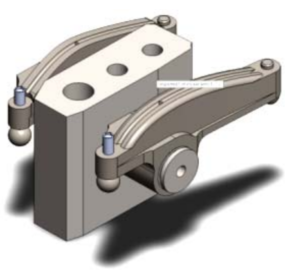

Figure 3. Rocker Arm

Figure 4. Lifter

Figure 5.Spring

Figure 6a). Intake Valve; Figure 6b). Exhaust Valve

B. *Input Data Analysis*

Stress analysis input data was taken from motion analysis result and simulation engine performance software for the pressure, contact force, and friction force. It shows at table 1. Motion analysis input data was taken from simulation engine performance software for the pressure and rotation of the engine. Condition of analysis was used for the highest pressure, torque, force, and rotation. Its all to select the material that suitable to hold in highest stress condition.

Camshaft and lifter used gray cast iron and malleable cast iron. Pushrod and rocker arm used mild steel and chromoly tubing. Spring used wire steel ASTM A231 and ASTM A401. Intake valve used steel JIS SUH3 and JIS SUH11. Exhaust valve used steel JIS SUH35 and SUH37.

Motion analysis was analyze first to get contact force and friction force to be the input data for stress analysis. Motion analysis condition was in 2200 rpm to seek the higher value of the result. It seen in Figure 7 that shows the cylinder pressure.

Stress analysis was started with meshing all component, then input the data that already calculated and processed. Each component was analyzed to hold maximum stress condition.

Table 1 Input Data of Stress Analysis

Torque in camshaft	953.186	Nm
Rotation in camshaft	800	Rpm
Spring constant (K)	61.65	N/mm
Intake friction	125.393	N
Outtake friction	106.217	N
Intake normal force	845.307	N
Outtake normal force	717.088	N
Intake rocker arm ratio	31.33 : 48.14	
Outtake rocker arm ratio	31.33 : 54.65	
Additional friction *)	2.15	N
Pressure valve	17.442	MPa

*) weight material effect for friction

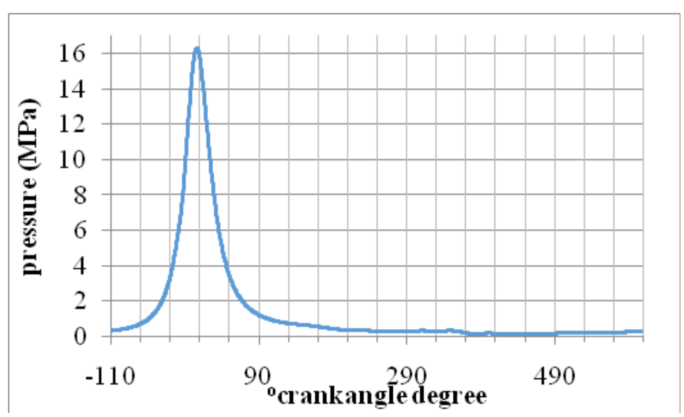

Figure 7. Pressure – Angle in 2200 rpm

IV. DISCUSSION AND RESULT

A. *Stress Analysis*

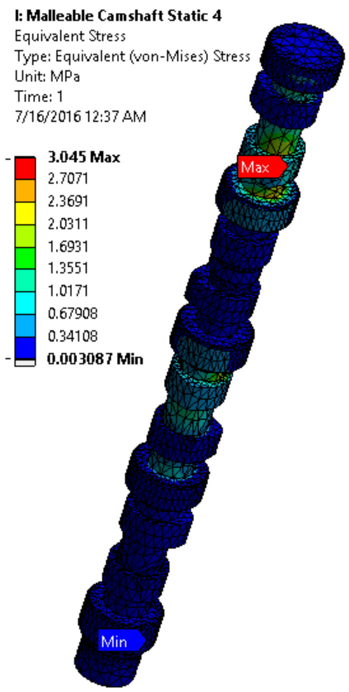

Figure 8. Malleable Cast Iron Equivalent (von-mises) Stressof Camshaft

Figure 8 shows result the simulation of camshaft static structural which was using malleable cast iron material. The result shows equivalent stress maximum value was 3.045 MPa and minimum value was 0.003087 MPa.The result of maximum stress position was in other side of camshaft gear, where torsion were ended in this side and all the seats of camshaft hold friction stress.

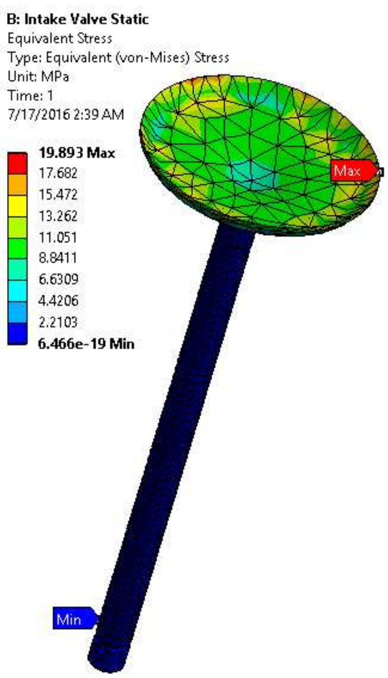

Figure 9. Steel JIS SUH3 Equivalent (von-mises) Stress of Intake Valve

Figure 9 shows results stress analysis of intake valve using steel JIS SUH3 material. The result shows equivalent stress maximum value was 19.893 MPa and minimum value was 6.466e-19 MPa. In figure can be seen the result of stress analysis maximum value point on side of area that be pressured.

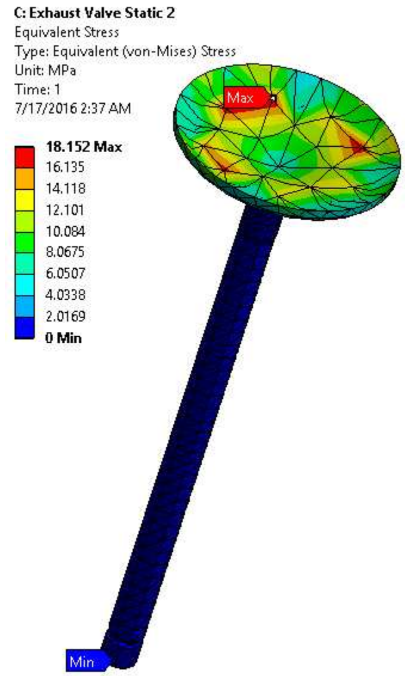

Figure 10. Steel JIS SUH35 Equivalent (von-mises) Stressof Exhaust Valve

Figure 10 shows results stress analysis of exhaust valve using steel JIS SUH35 material. The result shows equivalent stress maximum value was 18.152 MPa and minimum value was 0 MPa. In figure can be seen the result of stress analysis maximum value point on side of area that be pressured.

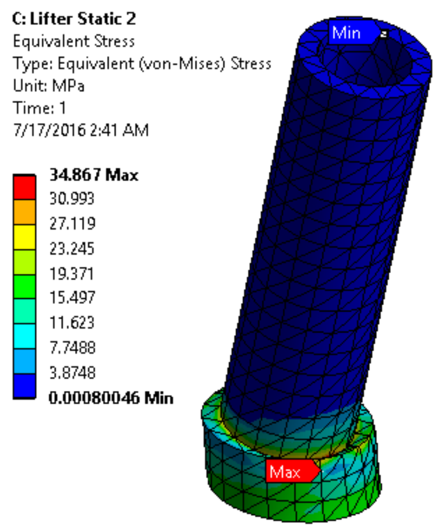

Figure 11. Mallable Cast Iron Equivalent (von-Mises) Stress of Lifter

Figure 11 shows result stress analysis lifter using mallable cast iron material with the maximum value was 34.867 MPa and minimum value was 0.00080046 MPa. In figure can be seen the position maximum value of stress was below side, because it holds the stress from friction force with camshaft and distribute force from camshaft to pushrod.

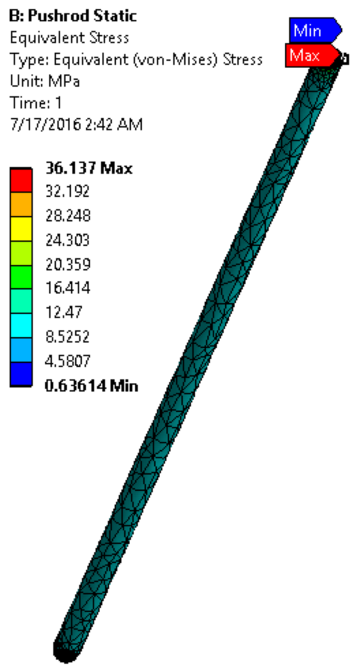

Figure 12. Mild Steel Equivalent (von-Mises) Stress of Pushrod

Figure 12 shows result stress analysis pushrod using mild steel material with the maximum value was 36.137 MPa and minimum value was 0.63614 MPa. In figure 4.17 can be seen the position of maximum value at the top side that connected with rocker rod. The other side also given stress that pressed by lifter.

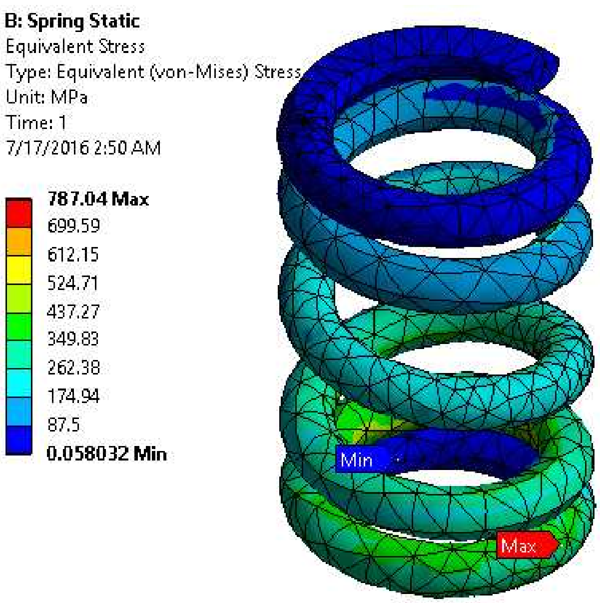

Figure 13. ASTM A231 Equivalent (von-Mises) Stress of Spring

Figure 14 shows result stress analysis spring valve using ASTM A231 wire material with the maximum value was 787.04 MPa and minimum value was 0.058032 MPa. The maximum stress value position was in bottom side area, because all the stress was distribute to bottom side.

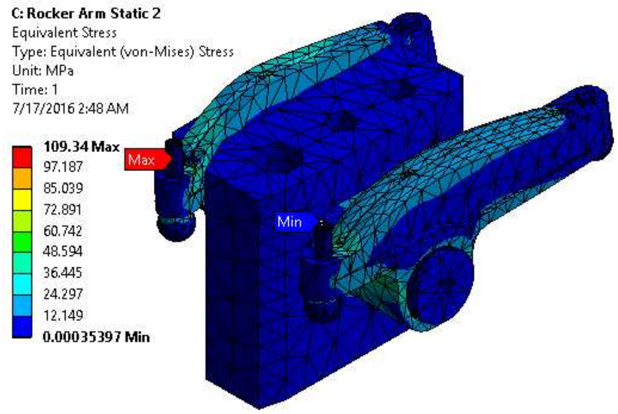

Figure 14. Mild Steel Equivalent (von-Mises) Stress of Rocker Arm

Figure 13 shows result stress analysis rocker arm using mild steel material with the maximum value was 109.34 MPa and minimum value was 0.00035397 MPa.In figure 13 can be seen the position of maximum stress value near the rocker rod placed. The position was on side of intake arm because the force from that side was bigger than the exhaust arm.

Table 2 Comparison Static Structural Stress of Component

	Component	Mechanical Stress (MPa)	
	Material	Max	Min
1	Camshaft		
a	Gray Cast Iron	3.0463	0.00291
b	Malleable Cast Iron	3.045	0.00309
2	Intake Valve		
a	Steel JIS SUH11	19.056	6.98E-20
b	Steel JIS SUH3	19.893	6.47E-19
3	Exhaust Valve		
a	Steel JIS SUH35	18.152	0
b	Steel JIS SUH37	16.075	5.52E-20
4	Lifter		
a	Gray Cast Iron	35.321	7.585E-4
b	Malleable Cast Iron	34.867	8.005E-4
5	Pushrod		
a	Mild Steel	36.137	0.63614
b	Chromoly Tubing	36.140	0.76579
6	Rocker Arm		
a	Mild Steel	109.34	3.540E-4
b	Chromoly Tubing	112.16	3.662E-4
7	Spring Valve		
a	ASTM A231	787.04	0.05803
b	ASTM A401	772.97	0.05614

Table 2 shows the comparison value static structural stress of component. It’s all the result value of the stress analysis each material in each component. Table 3 shows the comparison value deformation each material in each component. Table 4 shows the comparison safety factor between components.

Table 3 Comparison Deformation Result of Components

	Component Material	Deformation (mm) Max	Min
1	Camshaft		
a	Gray Cast Iron	0.002516	0
b	Malleable Cast Iron	0.001088	0
2	Intake Valve		
a	Steel JIS SUH11	0.00050392	0
b	Steel JIS SUH3	0.00025571	0
3	Exhaust Valve		
a	Steel JIS SUH35	0.00053259	0
b	Steel JIS SUH37	0.00048913	0
4	Lifter		
a	Gray Cast Iron	0.0072587	0
b	Malleable Cast Iron	0.0031331	0
5	Pushrod		
a	Mild Steel	7.3777	7.15
b	Chromoly Tubing	8.1543	7.9026
6	Rocker Arm		
a	Mild Steel	0.039525	0
b	Chromoly Tubing	0.043155	0
7	Spring Valve		
a	ASTM A231	3.1469	0
b	ASTM A401	3.0288	0

Table 4 Comparison Safety Factor of Components

No	Component Material	Safety Factor
1	Camshaft	
a	Gray Cast Iron	187.82
b	Malleable Cast Iron	135.83
2	Intake Valve	
a	Steel JIS SUH11	48.91
b	Steel JIS SUH3	46.85
3	Exhaust Valve	
a	Steel JIS SUH35	48.59
b	Steel JIS SUH37	48.83
4	Lifter	
a	Gray Cast Iron	16.20
b	Malleable Cast Iron	11.86
5	Pushrod	
a	Mild Steel	12.18
b	Chromoly Tubing	15.50
6	Rocker Arm	
a	Mild Steel	4.02
b	Chromoly Tubing	4.99
7	Spring Valve	
a	ASTM A231	2.85
b	ASTM A401	2.68

B. *Motion Analysis*

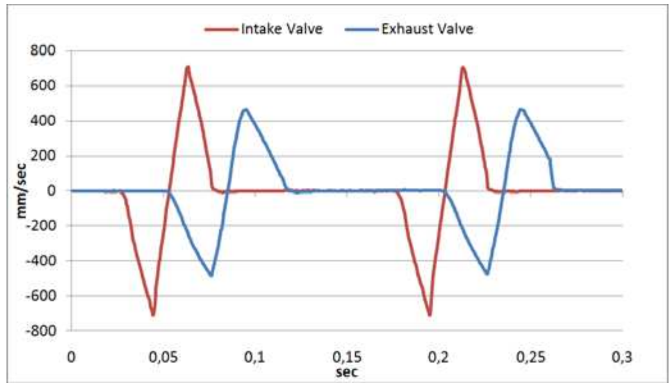

Figure 15. Chart Linear Velocity of Valves

Figure 15 shows chart the comparison between intake valve and exhaust valve linear velocity. Its gave information that intake valve lift array was higher than exhaust valve. Chart also shown that velocity of upward and downward was looking the same, it could give information that spring was given same velocity to close the valves.The maximum value of intake valve linear velocity was 696.573 mm/s and the minimum value was -695.883 mm/s.The maximum value of exhaust valve linear velocity was 463.734 mm/s and minimum value was -483.085 mm/s.

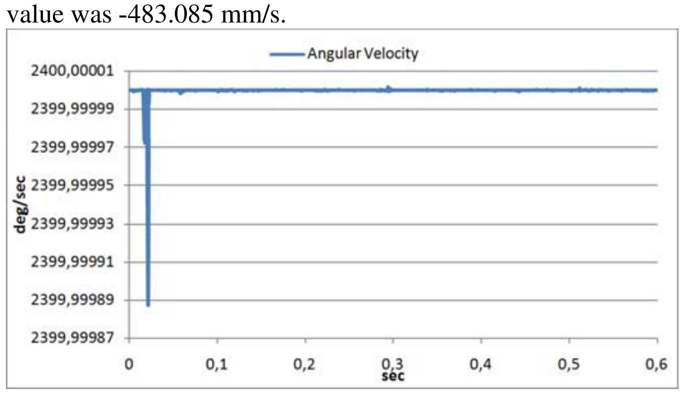

Figure 16. ChartAngular Velocity of Camshaft

Figure 16 shows chart the value of angular velocity in camshaft was around 2400 deg/sec. It was half value of angular velocity in the crankshaft. The condition of angular velocity was in 800 rpm.

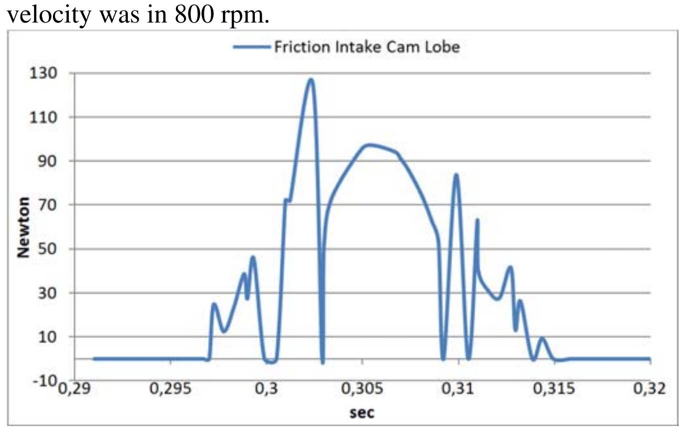

Figure 17. ChartFriction Intake Cam Lobe

Figure 17shows chartthe friction force intake of cam lobe area maximum value was 125,393N and this result become input data for stress analysis. The condition of friction force was in 2200 rpm.

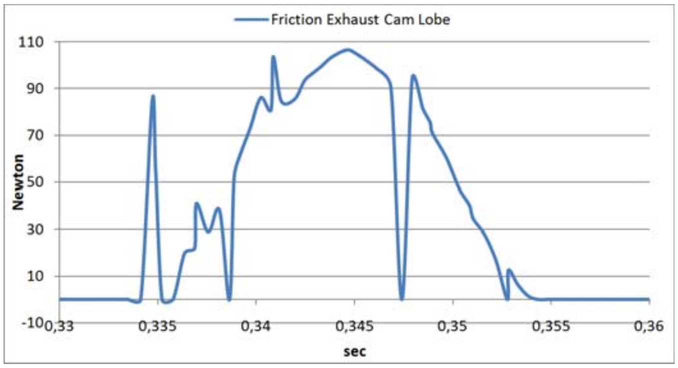

Figure 18. ChartFriction Exhaust Cam Lobe

Figure 18showschart the friction force intake of cam lobe area maximum value was 106,373N and this result become input data for stress analysis. The condition of friction force was in 2200 rpm.

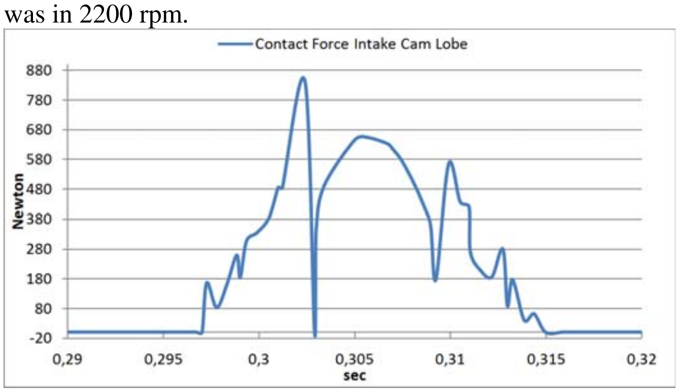

Figure 19. ChartContact Force Intake Cam Lobe

Figure 19 showschart the contact force intake cam lobe maximum value was 845.307 N and this result become input data for stress analysis. The condition of friction force was in 2200 rpm.

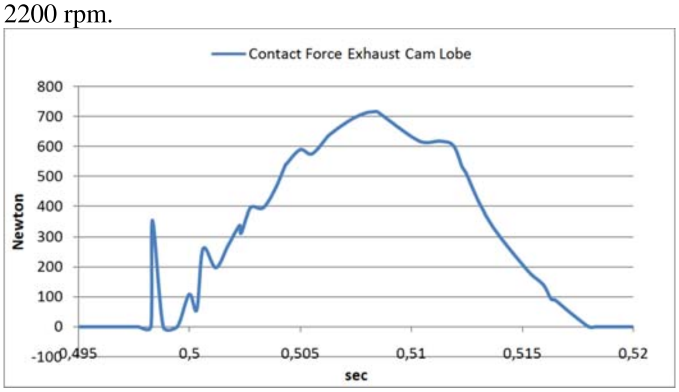

Figure 20. Chart Contact Force Exhaust Cam Lobe

Figure 20shows chartthe contact force exhaust cam lobe maximum value was 715.945 N and this result become input data for stress analysis. The condition of friction force was in 2200 rpm.

V. CONCLUSION

1. Distribution stress of components in cam system was based on moment, force, friction force, and pressure. Moment rotate the camshaft and inflict contact force with lifter. The force distributed by lifter into pushrod, and pushrod continue to distribute into rocker arm. Rocker arm had ratio length for each arm, where the intake arm was shorter than exhaust arm. The rocker arm was reducing force that comes from pushrod by the ratio. The force had to be bigger from spring requirement force to push the spring and valve. Spring would be return the valve into starting position.
2. Material selection each component was based by safety factor, if the safety factor was high enough it was allowed to select the lower value. The stress analysis result gave information data of stress each component and calculated data for safety factor.
   a. Camshaft : Malleable cast iron
   b. Lifter : Malleable cast iron
   c. Pushrod : Mild steel
   d. Rocker Arm : Mild steel
   e. Spring : ASTM A231
   f. Intake Valve : Steel JIS SUH3
   g. Exhaust Valve : Steel JIS SUH35
3. Motion analysis gave information about correlation between components. Linear velocity of valves gave information data which spring has given same velocity to return the valves into starting position and also lift array of valves. Friction force between camshaft and lifter was measured by the software and those result became input data for stress analysis as well as contact force. The maximum value of intake valve velocity was 696.573mm/s and exhaust valve velocity was 463.734 mm/s in 800 rpm condition. Friction force maximum value for intake area was 125,393 N and for exhaust area was 106,373 N in 2200 rpm condition. Contact force maximum value for intake area was 845.307 N and for exhaust area was 715.945 N in 2200 rpm condition.

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