

**FEA BASED NUMERICAL MODELLING OF CONTINUOUS VARIABLE VALVE LIFT MECHANISM FOR SINGLE CYLINDER SI ENGINE**

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**DOI: 10.5281/zenodo.1034493****KEYWORDS:** VVA-Variable Valve Actuation, CVVL- Continuous Variable Valve Lift, FEA, ANSYS.**ABSTRACT**

Recently Variable Valve Actuation (VVA) systems are being extensively used in internal combustion engine. In such mechanism, cams and valves are connected via intermediate lever, which allows different maximum valve lifts and duration using same cam profile. Recently, novel valve actuation mechanism like Continuous Variable Valve Lift (CVVL) is being explored to regulate engine output without conventional throttle valve and this reduces the pumping losses especially at part load in SI engines. CVVL mechanism with three elements consists of eccentric shaft, Intermediate lever and Rocker arm, which in turn control the degree of valve lift. It ensures a continuous valve lift between two extreme heights.

This paper presents the development and evaluation of a Numerical model of novel CVVL mechanism on FEA platform using ANSYS 14.5, for small capacity single cylinder motorcycle engine. From the design point of view, on the strength basis all the critical components of CVVL mechanism with respective selected material were analyzed using developed numerical model in ANSYS 14.5 and compared with analytical results. Numerical results were found to be in good agreement with analytical one for the given set of conditions.

**INTRODUCTION**

The design of an IC engine is a complex compromise between performance, fuel economy and emissions. These factors are interrelated and cannot be simultaneously optimized. Once the physical parameters such as displacement, cam profile and compression ratio are determined, a conventional engine has nearly fixed performance, fuel economy and emissions properties. By making an engine more efficient, one or more of these factors could be increased without significantly compromising the others [1-3].

Conventional IC engines have mechanically-actuated valve motions, fixed with respect to the crankshaft position for all engine operating conditions. These valve motions (such as valve lift profile, event timing, and opening duration) are determined during the engine design stage by fixing the cam profile and its position. As such, the valve motions contain a number of engineering trade-offs involving engine performance, exhaust emissions, and fuel consumption over a full range of engine operating conditions. Until now, these technical compromises have been generally accepted within the industry because the performance, environmental, and efficiency requirements for IC engines can be and have been satisfied. However, increasing demands for improved fuel economy and stringent government regulations on exhaust emissions begin to motivate many researchers and engineers to explore alternative means in which the valve motions are no longer fixed to the crankshaft position. In this new approach, referred to as Variable Valve Actuation (VVA) engine technology, additional degrees of freedom allow the Valve events to be selectively optimized and controlled to provide a unique valve motion for each region of engine operating conditions to present the optimal engine performance, emissions, and fuel economy benefits at each particular operating region.

Variable valve actuation technology allows better engine performance by reducing fuel consumption and therefore low emissions, higher efficiency, highly precise responsiveness of the powertrain. The key parameter for SI engine combustion, and therefore efficiency, emissions and fuel consumption is the quantity and characteristics of the fresh air charge in the cylinders. In conventional SI engines, the throttle-based air control wastes about 10% of the input energy in pumping the air. Novel Continuously Variable valve lift mechanism is responsible for the best fuel economy, improvement in volumetric efficiency and increase peak torque and power [1-5].



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Thus in present work it is proposed to develop and evaluate a Numerical model on FEA platform using ANSYS of Continuous Variable Valve Lift mechanism for throttle free load control of Spark Ignition (SI) motorcycle engine.

## CONTINUOUS VARIABLE VALVE LIFT (CVVL) MECHANISM

Continuous variable valve actuation mechanism allows the valve lift to continuously change according to various engine operating conditions. Even though this type of system is typically more complex, costly, and difficult to implement in powertrain, it generally carries greater potential benefits in terms of fuel economy, exhaust emission, and engine performance [1-5].

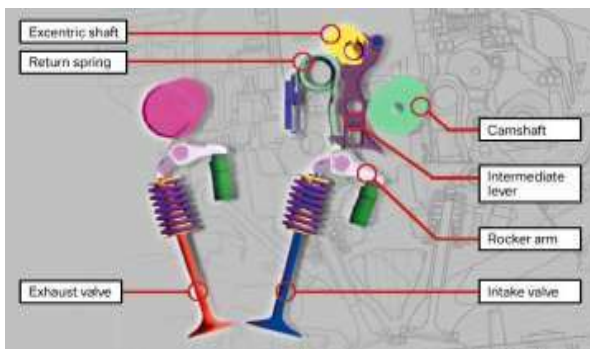


Figure 1. Description of CVVL Mechanism [2]

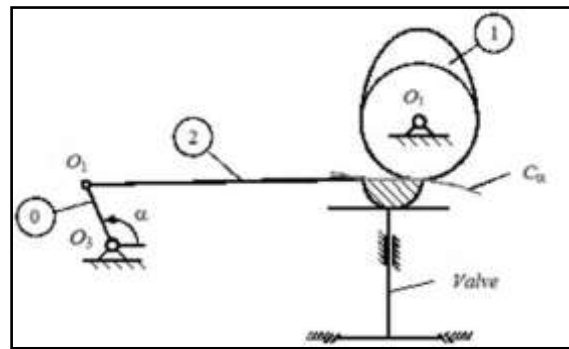
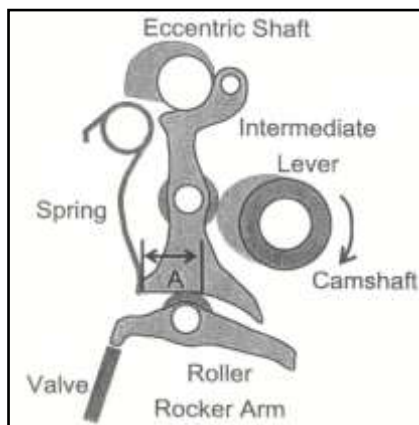


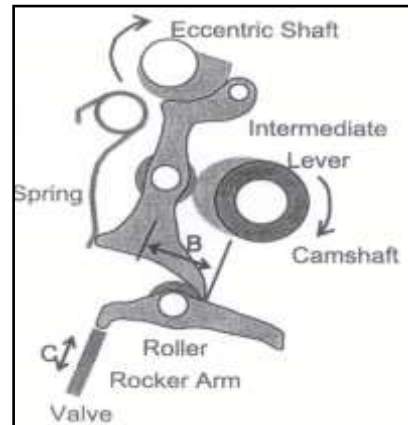
Figure 2. Line diagram of CVVL Mechanism

The CVVL mechanism mainly consists of the following components: electric motor, eccentric shaft, intermediate lever, roller rocker arm, and cam/ camshaft. The motor turns the eccentric shaft which moves the intermediate lever back and forth. The intermediate lever has a roller in the middle which is in direct contact with the cam. The upper end of the lever is in contact with the eccentric shaft while its lower end is in contact with the roller rocker arm, which eventually activates the valve motion, as shown in Figure1 and 2 [2]. In the case of no or low lift, the motor turns the eccentric shaft so that the contact surface between the intermediate lever and the roller rocker arm remains almost flat. In this case, the roller rocker arm moves only along the flat surface so that the rotation of cam shaft produces no or very small valve lift as intended.

In the case of high lift, however, the motor turns the eccentric shaft so that the contact surface between the intermediate lever and the roller rocker arm becomes more round. The roller rocker arm then moves along the rounded surface so that the rotation of camshaft now results in a high lift of the intake valve. Based on this operating principle, the system can generate the intake valve lift profile [3].



(a) No or Low Lift



(b) High Lift

Figure 3 Operating Principle of CVVL Mechanism [3]

**ANALYTICAL DESIGN****Material Selection [6]**

For the design purpose, suitable material is selected based on selection criteria requisite for the critical components of CVVL mechanism. Properties of selected materials are taken into consideration for the calculation of permissible stresses.

*Table 1 Material selection*

Sr. No	Name of component	Selection criteria	Material selected	Mechanical properties
1	Rocker Arm and Intermediate lever	1. Corrosion resistance 2. Wear resistance	Alloy steel 35Ni1Cr60	1. Yield stress ( $S_{yt}$ ) =680N/mm <sup>2</sup> 2. Ultimate stress ( $S_{ut}$ ) =520 N/mm <sup>2</sup>
2	Torsion Spring	1. Moderate elevated temperatures 2. Shock resistance	Patented and cold-drawn steel wires (Grade 4)	1. Minimum tensile strength =1610N/mm <sup>2</sup> 2. Modulus of rigidity =81370N/mm <sup>2</sup>

**Design of Components***Table 2 Input parameters for the analysis*

Sr. No.	Mechanical Properties	Permissible Value
1	Modulus of Elasticity	200 GPa
2	Poisson's ratio	0.3
3	Permissible Direct stress (for Rocker Arm and Intermediate lever)	260 N/mm <sup>2</sup>
4	Permissible Shear stress (for Rocker Arm and Intermediate lever)	130 N/mm <sup>2</sup>
5	Maximum force for Rocker Arm at Suction valve	479.136 N
6	Maximum force for Rocker Arm at Exhaust valve	904.96 N
7	Maximum force for Intermediate lever at Suction valve	479.136 N
8	Maximum force for Intermediate lever at Exhaust valve	904.96 N
9	Cam Force	916 N
10	Torsional Spring Force	606 N
11	Minimum tensile strength ( for Torsional spring)	1610 N/mm <sup>2</sup>
12	Modulus of rigidity	81370 N/mm <sup>2</sup>

The critical components of the mechanism namely, Rocker arm, Intermediate lever and Torsion spring was designed on the strength basis, under the wide open throttle (WOT) and maximum speed condition.

The rocker arm is used to actuate the inlet and exhaust valves motion as directed by the cam and follower. It made of rectangular cross section. In four stroke engines, the rocker arm for the exhaust valve is the most heavily loaded. Though the force required to operate the inlet valve is relatively small, yet it is usual practice to make the rocker arm for the inlet valve of the same dimensions as that of exhaust valve.



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The intermediate lever has a roller in the middle which is in direct contact with the cam. The upper end of the lever is in contact with the eccentric shaft while its lower end is in contact With the roller rocker arm, which eventually activates the valve motion.

A helical torsion spring is used to transmit the torque to a particular component of a mechanism. Table 2 gives the input parameters required for the analysis.

### Analytical design of components [7]

As mentioned above, apart from standard component (Poppet valve and helical spring) remaining components were designed analytically on strength basis with the help of input parameters as shown in table 2. The results obtained in terms of stresses (compressive and/or bending stresses) are as shown beneath in table 3.

*Table 3 Analytical results for suction and exhaust valve*

Sr. No.	Parameter	Permissible stresses	Analytical Results
1	Bending stresses at Rocker arm cross-section at suction valve	260 $N/mm^2$	23.95 $N/mm^2$
2	Bending stresses at Rocker arm cross-section at exhaust valve	260 $N/mm^2$	45.25 $N/mm^2$
3	Compressive stresses at Intermediate lever at suction valve	260 $N/mm^2$	9.98 $N/mm^2$
4	Compressive stresses at Intermediate lever at exhaust valve	260 $N/mm^2$	18.85 $N/mm^2$
5	Bending stresses at Intermediate lever at suction and exhaust valve	260 $N/mm^2$	18.83 $N/mm^2$
6	Bending stresses at Torsion spring	1610 $N/mm^2$	1025 $N/mm^2$

### NUMERICAL MODEL WITH ANSYS 14.5 SOFTWARE [8]

#### STATIC STRUCTURAL NON-LINEAR ANALYSIS IN ANSYS 14.5[8]

##### *Geometry Simplifications*

To reduce the complexity of the finite element modeling we have neglected minute details like small fillets, details of rollers etc.

##### *Meshing Strategy*

Rocker Arm is having regular shaped geometry so by slicing the geometry into small parts; rocker arm can be meshed easily with lower order tetrahedral elements. Intermediate Lever is bit complex to mesh with so after simplifying the geometry, they are meshed with lower order tetrahedral elements .Finalization of element size is done on the basis of stress convergence.

In real life, the stress distribution over any component is uniform, and doesn't always vary abruptly from one point to its subsequent point. In software, each node which is obtained by discretizing the model is having different stress value. The accuracy of this uniformity within the stress distribution depends upon the discretization quality and also the element size used to mesh the component.

The average element size is taken as 6 to mesh all the components. For finalization of the element size there is a method which has to be carried out to have converged stresses. In this method, we have to go through the trial and error methods of the stress plots for different element sizes. The variation between any two stress values of subsequent element size should be less than 10%-15%.



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We have to go with trial and error method to acquire such element sizes, so that the difference will be less than 10% between two consequent stress values.

After getting those two element sizes, the decision has to be taken according to the node count of the FEA model for respective mesh sizes that which mesh size should be taken for further analysis.

### **Loading and Boundary Conditions**

Boundary conditions for Rocker arm are provided by applying all degrees of freedom zero at fulcrum pin. For Intermediate lever which is dynamically constrained component and eccentric shaft being fixed, the degrees of freedom at upper end of the intermediate lever is zero. For the Torsional spring, at one end all degrees of freedom is zero whereas force is applied at another end.

After meshing, boundary conditions and loads are applied on the nodes and then solver is set to obtain the solution. Further in Postprocessor results are analyzed. Von-Mises Stress plots are taken for visualization and interpretation of results. Maximum stresses are visualized at the sharp corners and thin sections. The same procedure is followed for the structural analysis of other components like Intermediate lever and Torsion spring.

### **Design of component**

#### **1) Rocker Arm**

Simplified geometry Model and meshed component

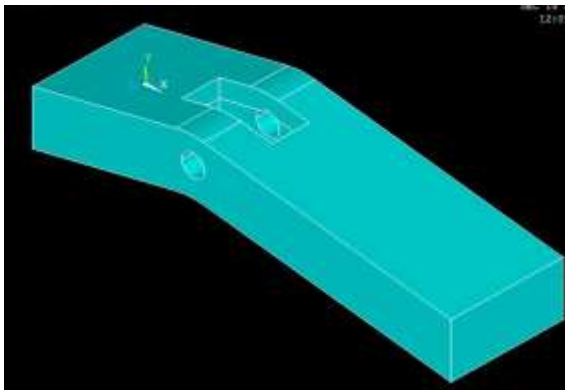


Figure 4 Baseline model

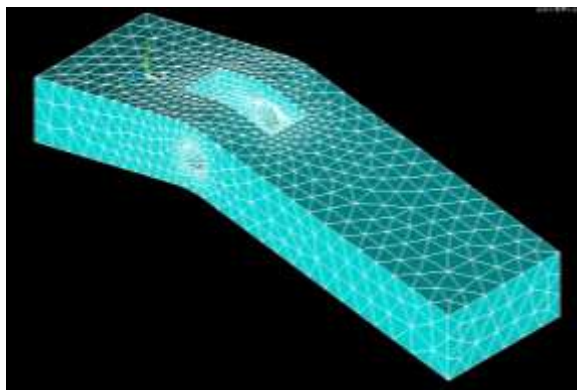
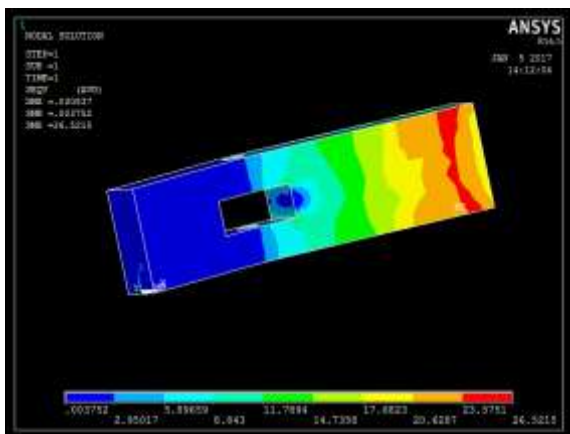
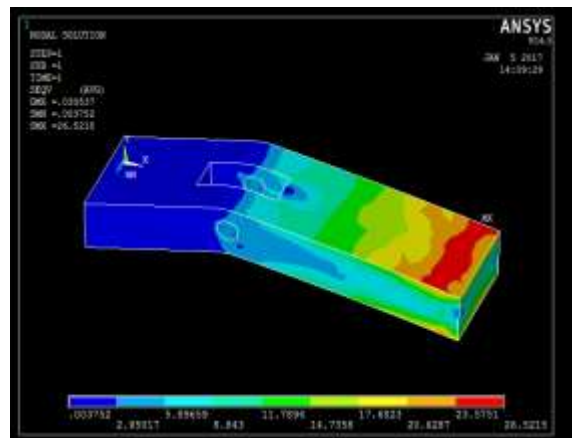


Figure 5 Meshed FEA model

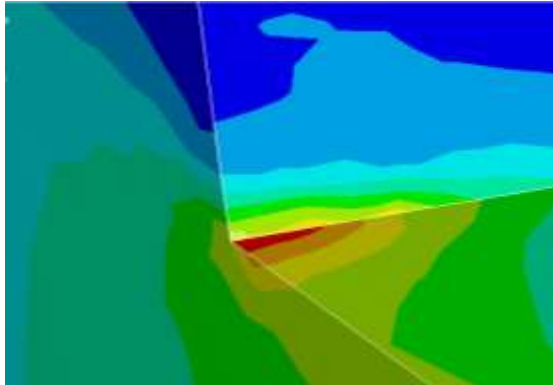
### **Stresses at suction valve**



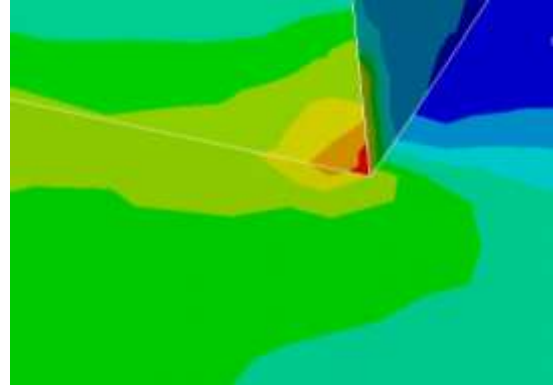
(a)



(b)



(c)



(d)

Figure 6 Von-Mises stress plot at suction valve of Rocker arm

Stresses at exhaust valve

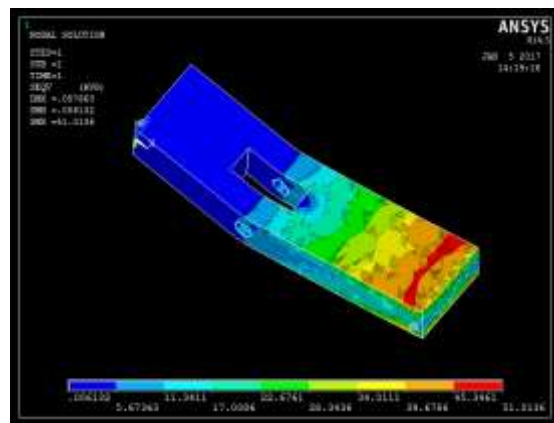
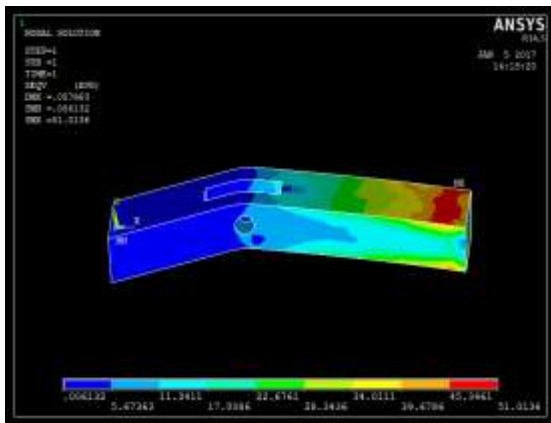


Figure 7 Von-Mises stress plot at exhaust valve of Rocker arm

Von Mises stresses of Rocker arm are 26.52N/mm<sup>2</sup> at suction valve and 51.01 N/mm<sup>2</sup> at exhaust valve. Maximum stresses occur at the end of rocker cross section and at the corners roller slot due to sharp corners.

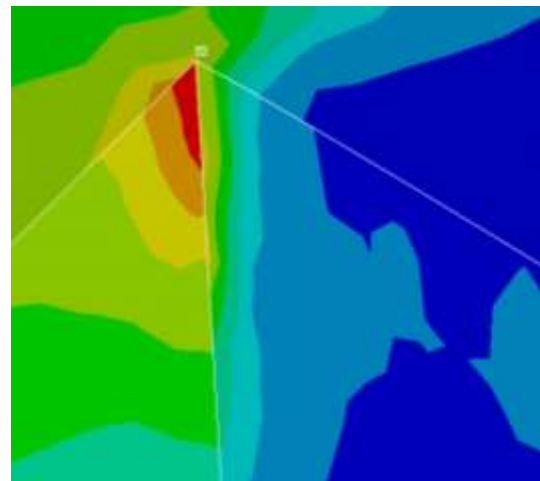
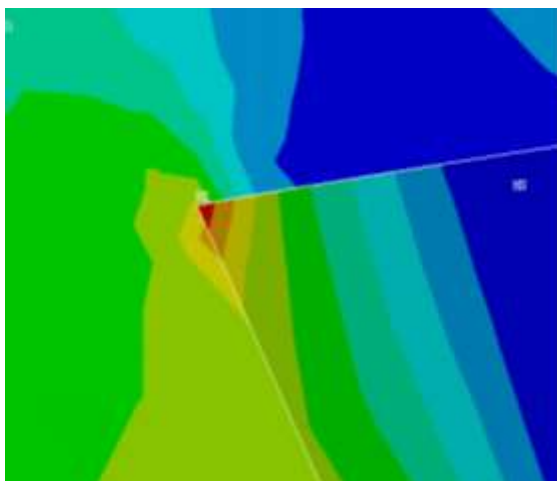


Figure 8 Stress concentration at roller slot corner



Intermediate Lever

- Simplified geometry Model and Meshed Component

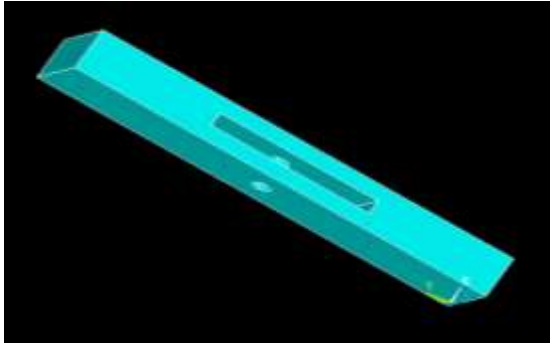


Figure 9 Baseline model

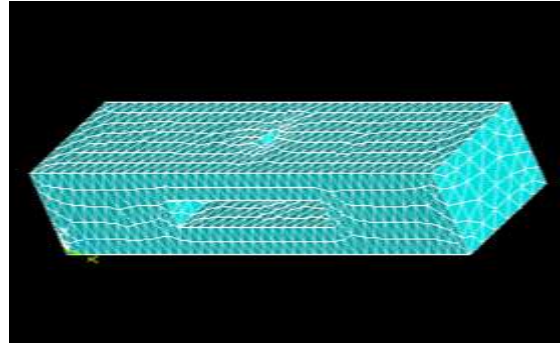


Figure 10 Meshed FEA model

Stresses at suction valve

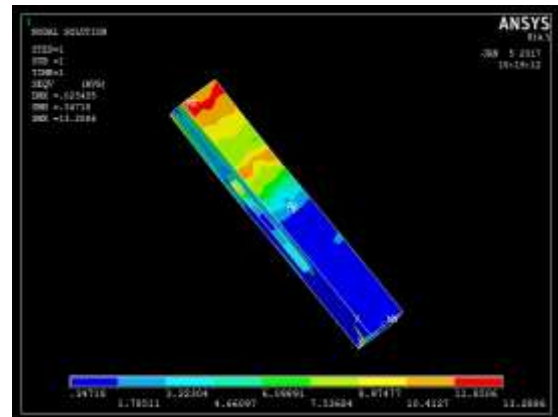
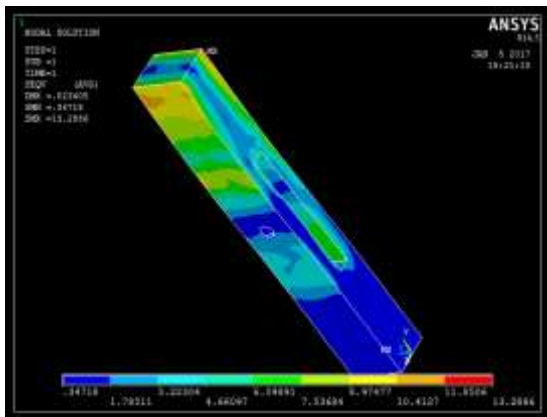


Figure 11 Von-Mises stress plot at suction valve of Intermediate lever

Stresses at exhaust valve

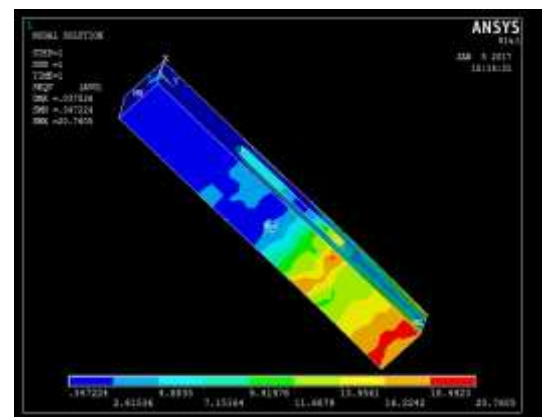
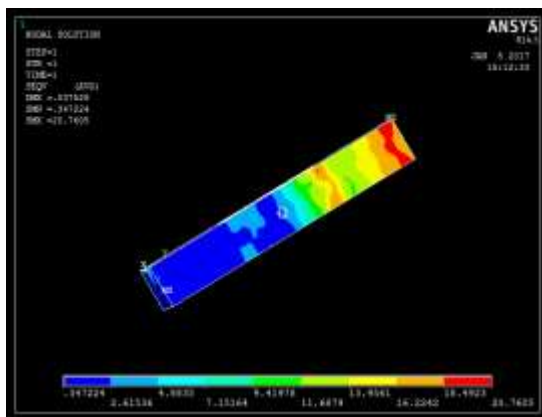


Figure 12 Von-Mises stress plot at exhaust valve of Intermediate lever



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Von Mises stresses of Intermediate lever are 13.28 N/mm<sup>2</sup> at suction valve and 20.76N/mm<sup>2</sup> at exhaust valve. Maximum stresses occur at the corners roller slot due to sharp corners which induces the stress concentration at corners and at the center of Intermediate lever due to thin section.

### Torsion spring

- Simplified geometry Model and Meshed Component

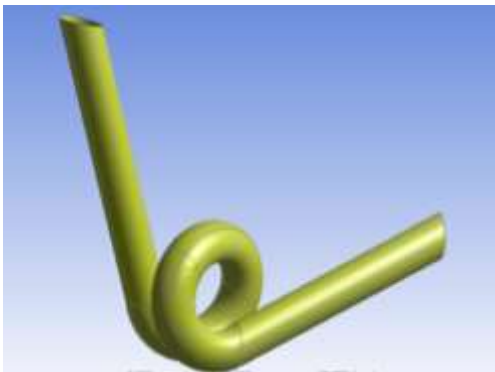


Figure 13 Baseline model

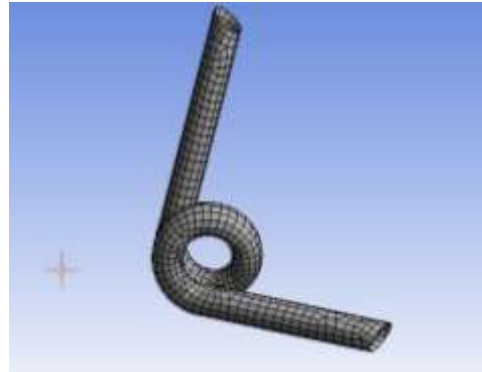


Figure 14 Meshed FEA model

### Stresses at torsion spring

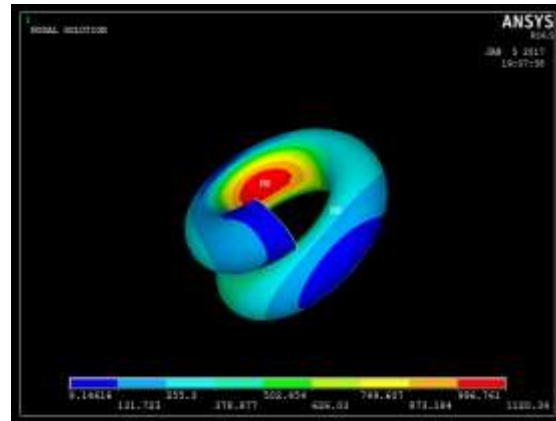
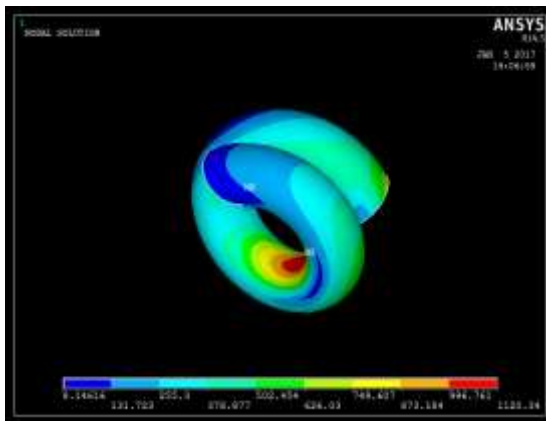


Figure 15 Von-Mises stress plot for Torsion spring

Stress of Torsion spring obtained is 1120 N/mm<sup>2</sup> which is within the permissible limit hence safe

## RESULTS AND DISCUSSION

### Comparison of FEA results with Analytical results

Table 4 Comparison of FEA Stress results with Analytical

Sr. No.	Parameter	FEA results	Analytical Results
1	Bending stresses at Rocker arm cross-section at suction valve	26.52 N/mm <sup>2</sup>	23.95N/mm <sup>2</sup>
2	Bending stresses at Rocker arm cross-section at exhaust valve	51.01 N/mm <sup>2</sup>	45.25 N/mm <sup>2</sup>





3	Compressive stresses at Intermediate lever at suction valve	13.28 $N/mm^2$	9.98 $N/mm^2$
4	Compressive stresses at Intermediate lever at exhaust valve	20.76 $N/mm^2$	18.85 $N/mm^2$
5	Bending stresses at Intermediate lever at suction and exhaust valve	24.94 $N/mm^2$	18.83 $N/mm^2$
6	Bending stresses at Torsion spring	1120.34 $N/mm^2$	1025 $N/mm^2$

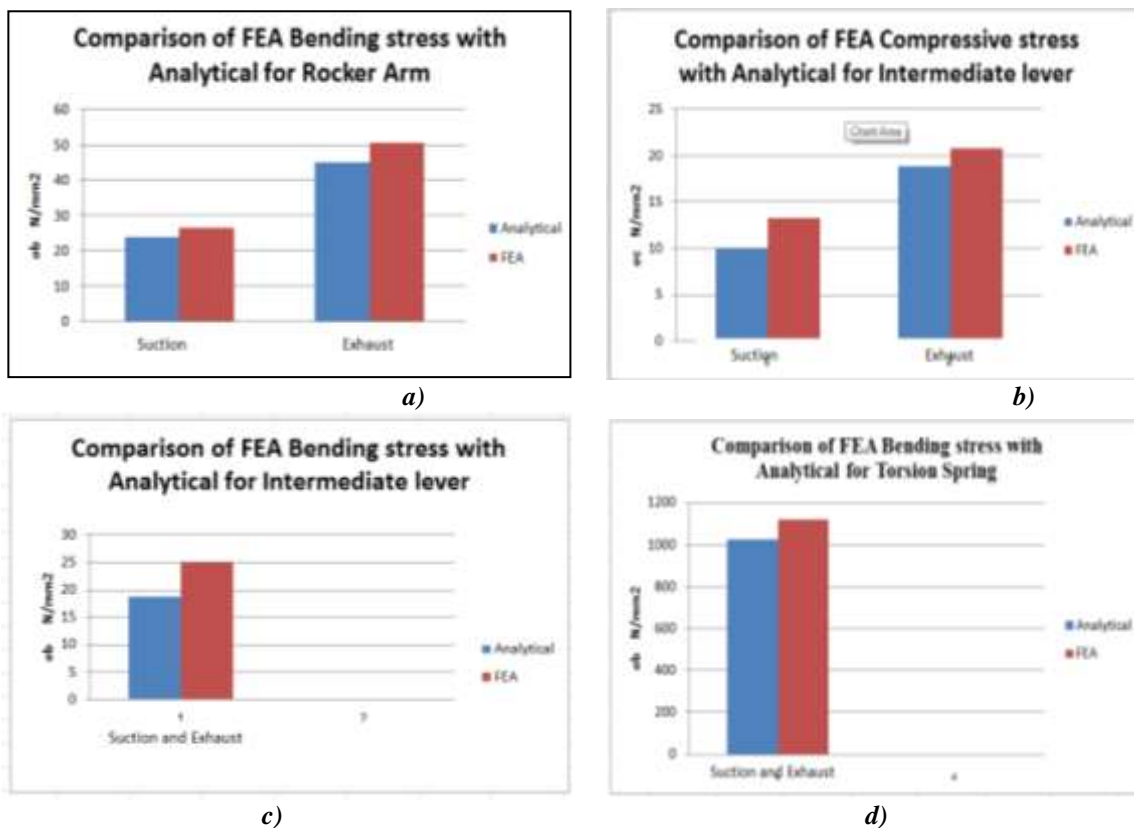


Figure 16 Comparison of FEA Stress results with Analytical of various components

Maximum stresses are in higher magnitude at Rocker arm, Intermediate lever and torsion spring in numerical analysis. A stress at exhaust valve is higher as compared to suction valve because of higher pressure, temperatures and forces.

## CONCLUSIONS

This paper presents design of critical components of the mechanism namely, Rocker arm, Intermediate lever and Torsion spring on the strength basis, for the wide open throttle condition by analytical method and validated the same with the numerical results in ANSYS 14.5.

Conclusions drawn are as follows:

1. From the design point of view, on the strength basis all the critical components of CVVL mechanism with respective selected material are found to be safe with analytical and numerical simulation with ANSYS 14.5.
2. Maximum stresses are in higher magnitude in numerical analysis. This may be due to simplification of geometry and certain assumptions.



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3. A stress at exhaust valve is higher in magnitude as compared to suction valve because of higher pressure, temperatures and forces.
4. Von Mises stresses of Intermediate lever are  $13.28 \text{ N/mm}^2$  at suction valve and  $20.76 \text{ N/mm}^2$  at exhaust valve.
5. Von Mises stresses of Rocker arm are  $26.52 \text{ N/mm}^2$  at suction valve and  $51.01 \text{ N/mm}^2$  at exhaust valve. Maximum stresses occur at the end of rocker cross section and at the corners roller slot due to sharp corners and at thin sections.
6. Numerical results were found to be in good agreement with analytical one for the given set of conditions.

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