Dynamic Analysis of Valve Train Mechanism Using Finite Element Method

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Abstract:

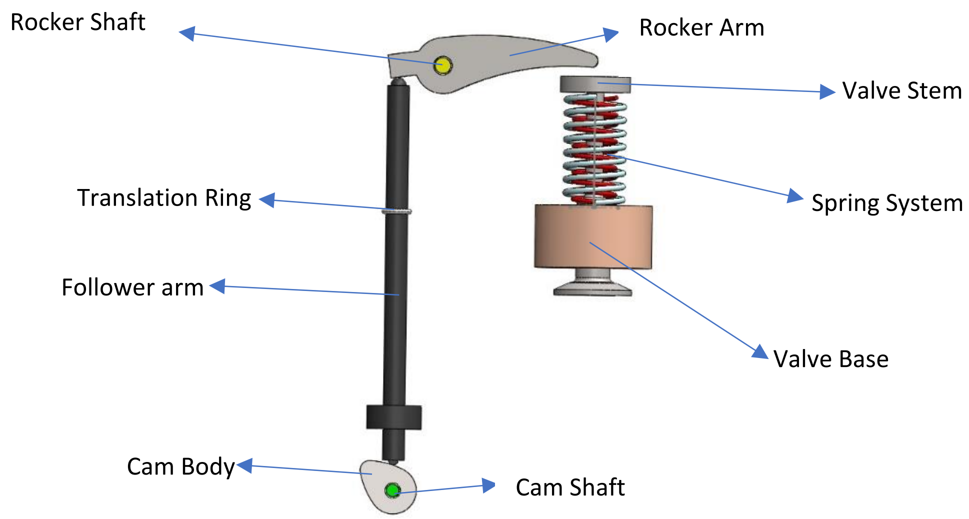
Valve systems play a very important role both in the entry of charge into the internal combustion engine cylinder as well as exhaust of combustion products. Valve train mechanisms play a vital role in the opening and closing of the valves with specific control mechanisms to ensure proper fuel efficiency and low level wearing of the system itself. The present study focuses on the design considerations of the various parts of a working valve train mechanism, developing them and their proper assembly. Further in this study, the assembled valve train was studied for temporal contact forces at several points, harmonic analysis for vibrational modes and a concise look at the failure analysis of spring and valve body.

Keywords: Internal Combustion Engine Valves, Valve Train, Assembly, Failure, Contact Force

1. **Introduction**:

Internal combustion engine valves are precision engine components. They open and close as and when needed. The fresh charge (air - fuel mixture in Spark Ignition Engines and air alone in Compression Ignition Engines) is sent in through the inlet valve into the cylinder and the exhaust gases are released through the exhaust valve. They are also used to seal the working space inside the cylinder against the manifolds.

These mechanisms are generally temporally controlled through the valve train mechanism which runs on a cam follower mechanism. On a general basis the cam on the valve train runs at 50% of the angular speed of the main cam shaft of the engine.



The cam body follows rotational body design which has a positive radius of curvature at all points of the cam to ensure constant link to the follower. The cam is in constant contact with the follower through a tappet mechanism. The other end of the follower is attached to a rocker arm. The rocker arm is specifically designed to provide periodic impact on the valve stem to move it downward allowing the entry or exhaust operation. The valve is attached to a base which restricts its motion in one direction. The valve stem is attached to the base through a spring system which offers resistance to the impact offered by the rocker arm.

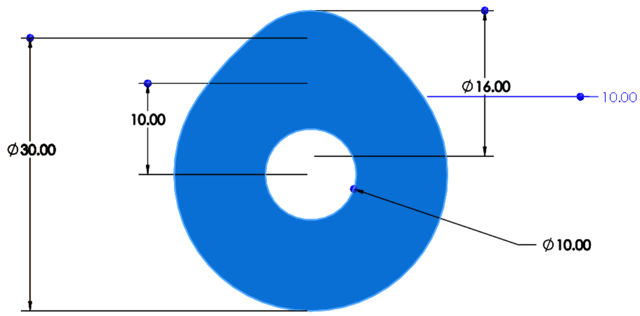
The valve body is subjected to heavy forces like the spring force and the combustion pressure inside the cylinder.It may reach as high as 15MPa. Such high pressures can cause extensive wear and may lead to failure. The presence of excessively high temperatures further enhances the situation. Since the exhaust valves operate at high temperatures, they are exposed to thermal load and chemical corrosion. The intake valves, which are not subjected to such extreme thermal loading, are cooled by incoming gases, thermal transmission at the seat, and by other means. This makes it necessary to study the stress characteristics, failure, and life of the individual components of the train mechanism.

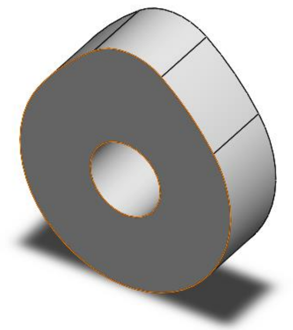
2. Part Modelling

1. Cam Body

It has been mentioned several times that the aim of the mechanism is to provide an instantaneous impact load on the valve stem. This is achieved by a close to cylindrical body for the cam. This is ideally made of high carbon steel or simply dry steel.

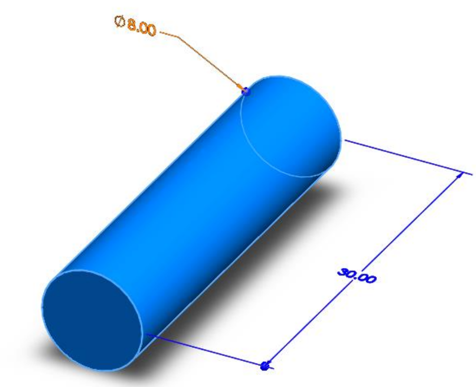
The CAM has the following dimensions as mentioned in the figure below.





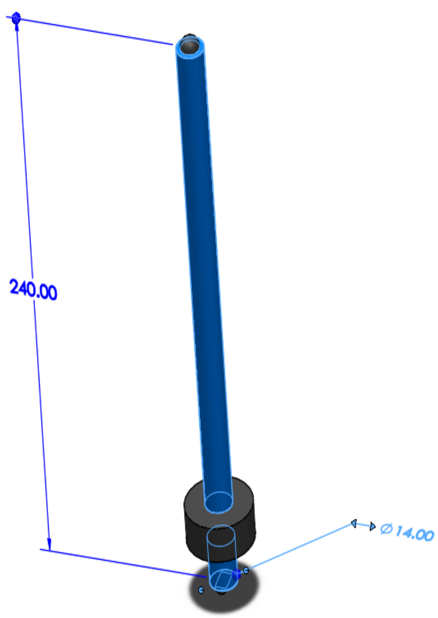
2. Cam Shaft

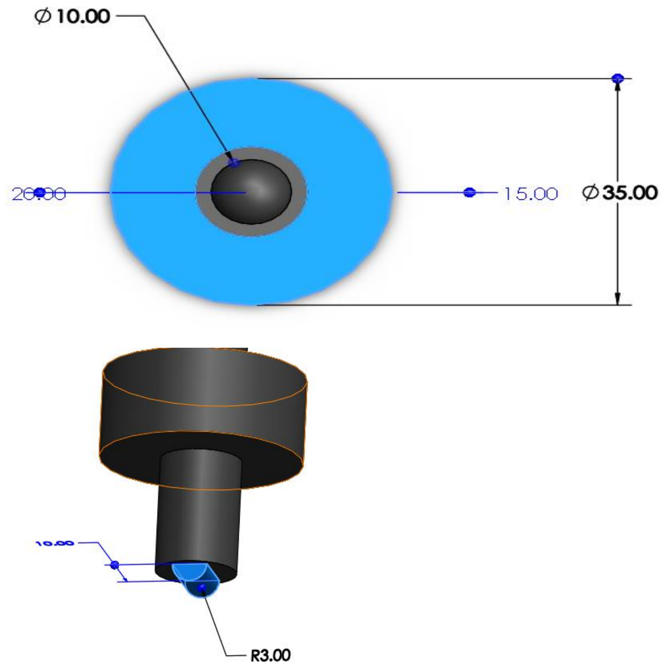
The cam shaft is a nearly cylindrical rod with the dimensions as in the figure. It is made to fit in the circular opening of the cam with a small clearance. This is made from carbon steel but can also be made of cast iron.



3. Cam Follower

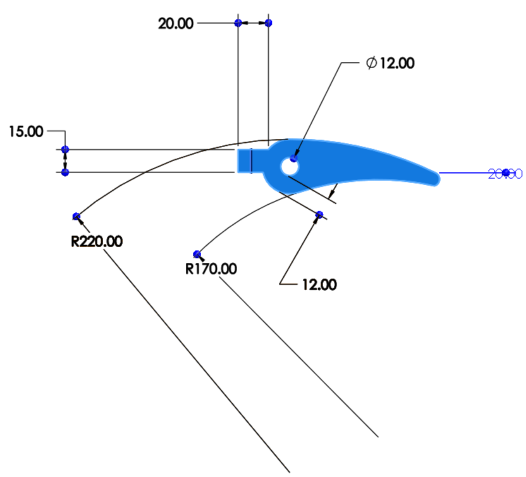
This part is close to a cylindrical rod with a semicylindrical tappet contact with the cam surface. An external weight ballast is added at the lower part of the follower to help add weight to the follower to keep it in continuous contact with the cam body. The upper edge of the cam follower holds a hemispherical protrusion in order to provide constant contact with the rocker arm while at the same time maintaining less stress as possible in the overall contact nut/weld.

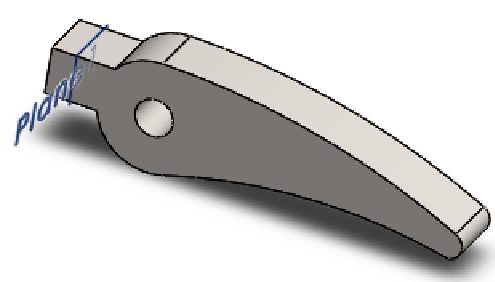




4. Rocker Arm

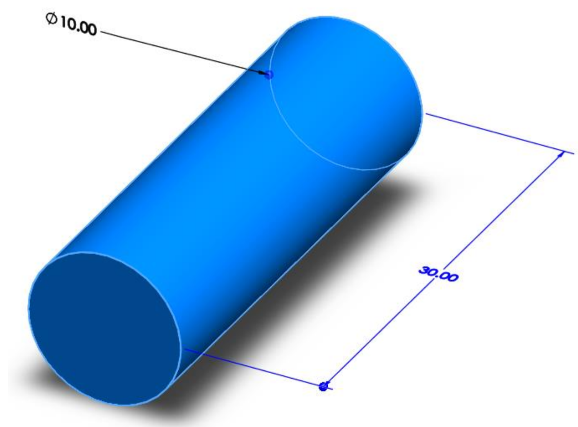
The rocker arm is specially designed to provide an impact contact on the valve stem. It has a special design which allows it to have a long body while maintaining a good strength to weight ratio. The hind end of the rocker arm is close connected to a follower while the front end is a curve which touches the valve step only when it is angularly turned.





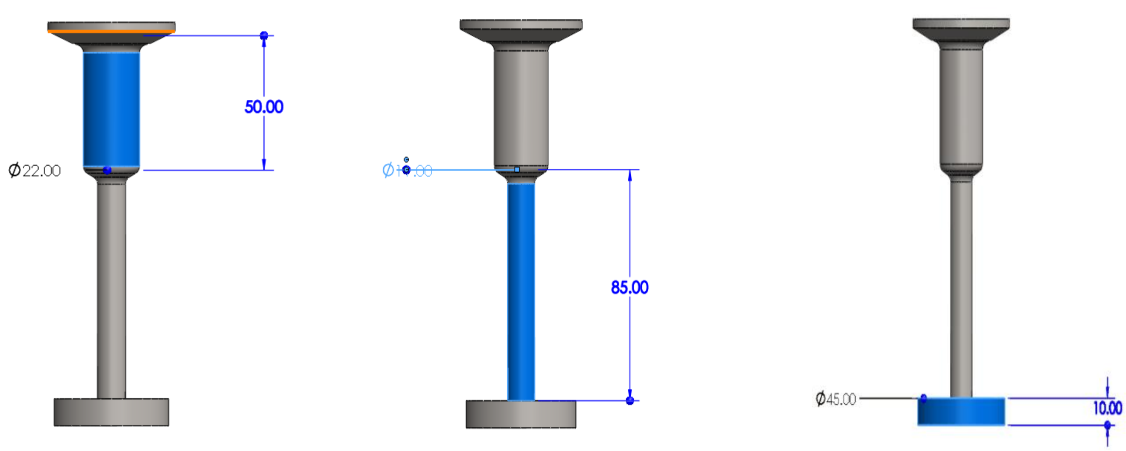
5. Rocker Shaft

The rocker shaft is a nearly cylindrical rod with the dimensions as in the figure. It is made to fit in the circular opening of the rocker with a small clearance. Special care is taken for the wear of this component as it acts as the connection point for the entire train mechanism This is made from carbon steel but can also be made of cast iron.



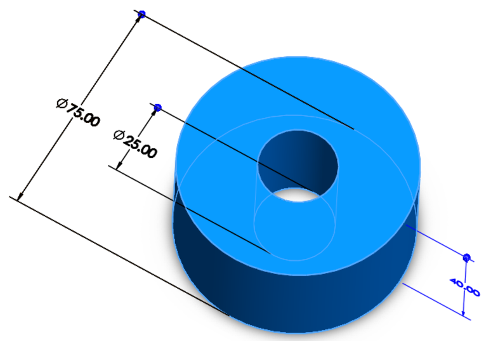
6. Valve Stem

This is the main operating component of the train mechanism which controls the inlet/ outlet operations. The component is designed in such a way that it can handle several stress cycles. The current design has been optimized to handle 1 million cycles of impact stresses as shown in the figure. The contact area with the rocker arm has an increased area to distribute the stresses on the surface.



7. Valve Base

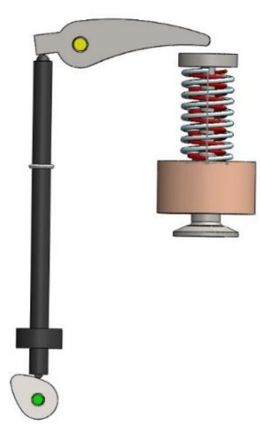
This is a restricting component which allows the movement of the valve stem in only one direction, i.e, the downward direction. This component is designed in such a way that wear of the component due to angular impacts by the valve stem do not directly effect the stem or the base. The base is made strong with a high strength to weight ratio in order to minimize waste material usage.



8. Valve Spring

This is a parallel spring combination of the springs with the following details. They cover length from the valve stem base to the valve base and act as a repelling force against the force provided by the rocker arm. This makes the valve stem come back to its original position after each impact attack maintaining the cycle of valve operations.

3. Assembly



The part assembly follows a simple system. (i)The cam runs in a revolute joint around the central shaft maintaining a small **5% clearance** in order to avoid friction and ensure wear avoidance. (ii)The cam is in constant contact with the follower through a linear format. It runs through a steel ring which ensures single directional motion. A **2 to 3 % clearance** is mentioned in the same manner. (iii)The upper end of the follower is in a mechanical contact with the rocker arm ensuring that constant contact is maintained between the two. (iv)The rocker arm is fitted over the rocker shaft in a revolute joint maintaining a **5% clearance**. (v)The knocking end of the rocker arm lies directly over the impact surface of the valve stem. A small **3% clearance** is maintained between the 2 to allow for impact knocking. (vi)A parallel spring system is fitted between the valve base and base of the valve stem. The Parallel arrangement ensures a higher stiffness constant thus allowing quicker return mechanism after return.

4. Analysis and Iterations

The components of the train mechanism were constructed, analyzed and reconstructed iteratively in order to bring about the optimized design for the mechanism. The entire system was analyzed to check the contact forces, impact forces, modal frequencies, and life against constant stress cycles.

1. Analysis

As mentioned before the analysis has 3 parts, (i) visualization of contact forces and impact forces, (ii) modal frequencies and (iii) total life. Different simulation techniques and mesh formations have been used to study the mechanism in detail.

4.1.1. Contact and Impact Forces

The original analysis was done in SOLIDWORKS 2020 structural simulations. The entire assembly was studied temporally for the contact forces between cam-follower, valve-rocker and the translation of the valve stem.

The entire assemble was meshed finely at 1 mm with a finer mesh at paths of contact. The cam was then given a 1200 RPM rotation and the other contacts were made as explained before.

4.1.2. Results

The translational motion of the valve mechanism was studied with the possible vibrational presence due to impact.

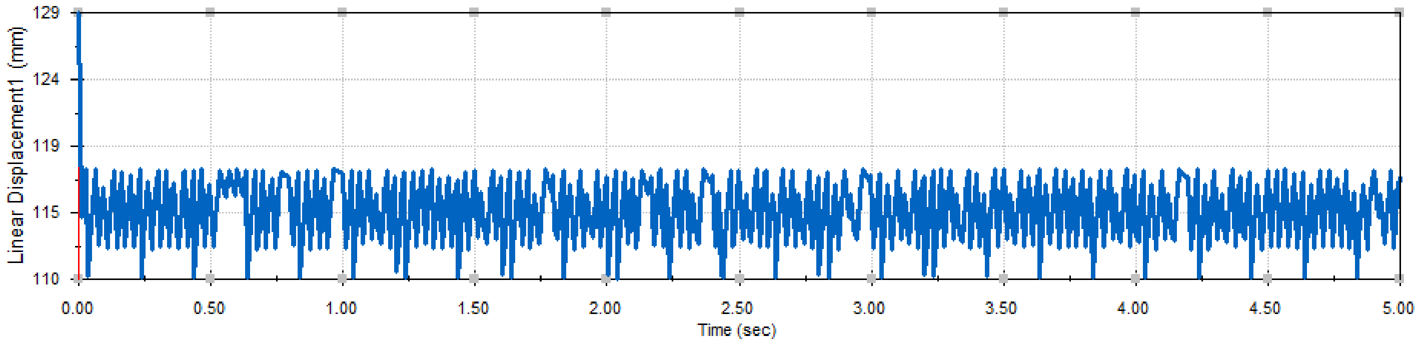
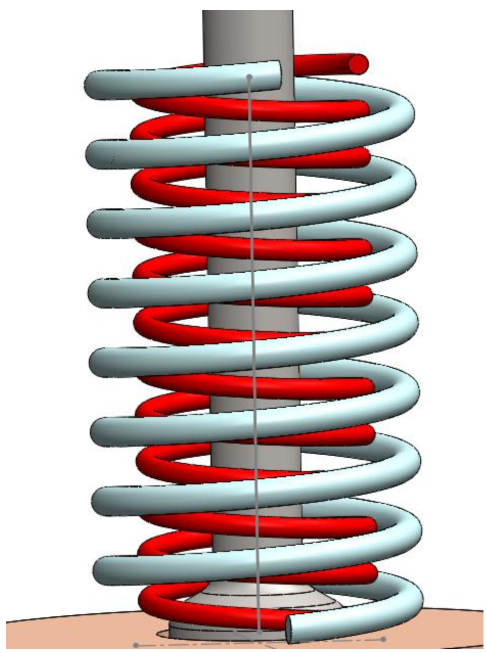


Chart 1: Linear Displacement of the Valve Head from the centre of the the cam shaft.

As can be seen from the Chart 1, the overall displacement due to the entire process are at the points of large upward movement of the graph and stand at 7mm.The minute oscillations on either side of major displacements indicate vibrational oscillations due to the spring and the material itself. Iterations on the spring stiffness and valve material were carried out to reduce these. To allow for a higher spring stiffness, two concentric springs were used to solve the problem.



The final springs hence follow the parallel concentric combination both of which are prestressed ensuring a total spring stifness of about 65 N/m. Both the springs have 12 turns with the outer spring having a 25 mm spring diameter and the inner one having a 17 mm diameter. The core diameter is at 5 mm for both the springs.

Contact force on the components was measured. Firstly, the contact force between the cam and follower are measured to look at the load mechanism on the components.

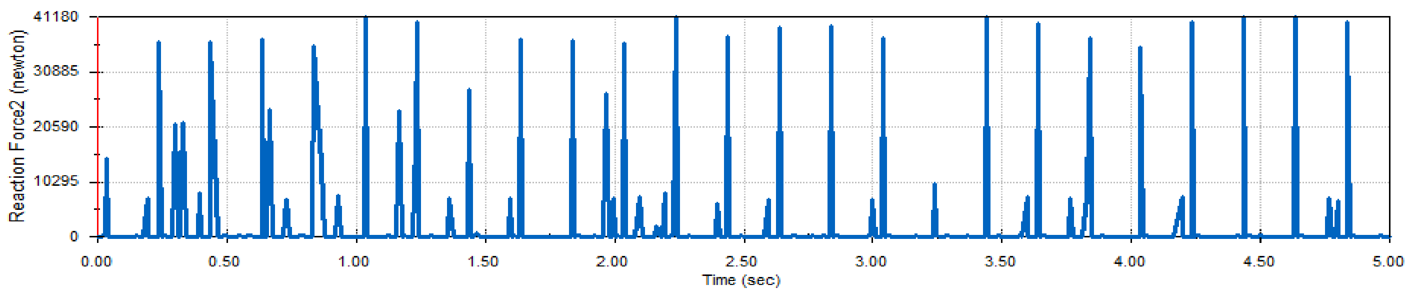


Chart 2: Reaction force at Ca- Follower Interface

Chart 2 represents the contact force experienced by the follower at the point of contact with the cam. As can be seen, the major jumps in the force represent the follower motion at the part with the least radius of curvature on the cam body. The secondary oscillations indicate the vibrational components and friction-based components. The aim of the cam design analysis was to reduce these components. The final design parameters have been mentioned earlier.

Finally, the impact analysis at the rocker-valve interface was measured.

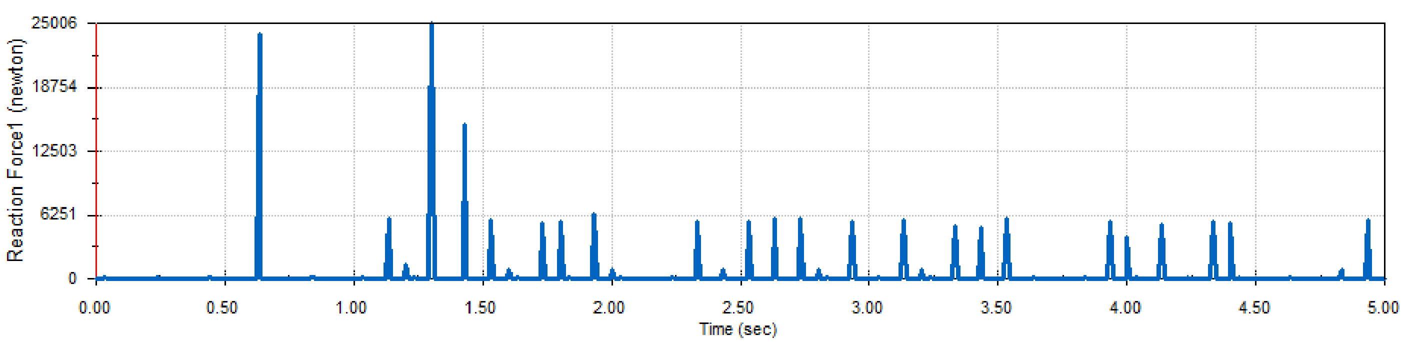


Chart 2: Reaction force at Valve Stem- Rocker Interface

In this case the major jump indicates the first impact of the of the rocker on the valve stem. The minor components on either side indicate the irregular impact between the components. The aim at these positions was to reduce these components and increase the main jump. This was done through a sharp rocker design and an increased impact surface area for distribution of the force.

5. References

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