

An Approach to Analyze Valve Train Dynamics of an IC Engine using Software Tool ‘Tycon’

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Abstract - A study of dynamics of valve train is carried out using the software tool TYCON. Each and every component of valve train of a commercial vehicle engine is analyzed separately starting from cam to valve. A model is developed in ‘Tycon’ with all the required components to study the dynamics. The input including stresses and stiffness values of all the components are obtained from finite element analysis. Analytical approach is used in addition to software analysis to study the dynamics parameters of valve train. A mathematical model has been used to analyze the parameters such as acceleration, velocity and forces of the components of valve train. This study would be helpful to select the components with required stiffness values for effective working of the valve train. Stiffness values and other material constants of components in valve train are responsible for minimizing the jerk and bounce resulting in for smooth operation of the valve.

Keywords – Valve train, Tycon, dynamics, spring

I. INTRODUCTION

It is essential to study the valve train dynamics of an IC engine to understand its effects as the valve is operated in conjunction with various components of the valve train. The knowledge of valve train dynamics would be helpful to analyze the impact forces coming on each of the components and this impact forces can be minimized in order to have smooth functioning of valves. An IC engine with 6 cylinders inline which develops a power of 180 bhp is used to study the valve train dynamics. Valve train comprises of many components starting from cam to valve with various intermediate components in between. Dynamic parameters of all the components are studied using the software tool Tycon with required input values given. Tycon is a software tool developed by AVL, an Austrian based company which is used the current work to develop a model integrating all the required components of valve train. The stiffness values and other constants of valve train components are considered as input values. Working parameters like engine like speed, pressure inside the engine cylinder with reference to angle of rotation of the crank are also important factors to study the dynamics of valve train.

II. VALVE TRAIN MODEL IN TYCON

A. Valve train components in Tycon –

All the valve train components are divided into three types of elements in tycon as follows .

Specific elements: They are specialized for standard timing drive applications. Primarily, these elements contain mass and connection (stiffness, damping) information.

Generic elements: There are two kinds of generic elements: rigid bodies and connections. Rigid body elements contain information about the mass properties and some optional geometrical data. The connecting elements describe the forces acting between the rigid body elements. Predecessor/follower information is not required when using the generic elements. These elements are described in a general way; thus, they can also be used for more general applications and for more detailed modeling of timing drive systems.

Macro elements: These predefined elements consist of a large number of generic elements. They enable easier and more detailed modeling of belt and chain drives. It is possible to prepare models containing exclusively generic elements or containing generic elements and specific elements. In the latter case, the user should consider that only some of the specific elements can be connected to parts modeled with generic elements. Because the generic elements are more general, the user must put much more thought into modeling and the results. Generally, the use of generic elements will make it more difficult to prepare a model. Additionally, calculation time will increase. The added advantage of using generic elements is that the models can be adjusted to calculate very specific effects.

B. Model developed in Tycon – A model has been developed in Tycon with the components of the valve train as shown in Figure 1.

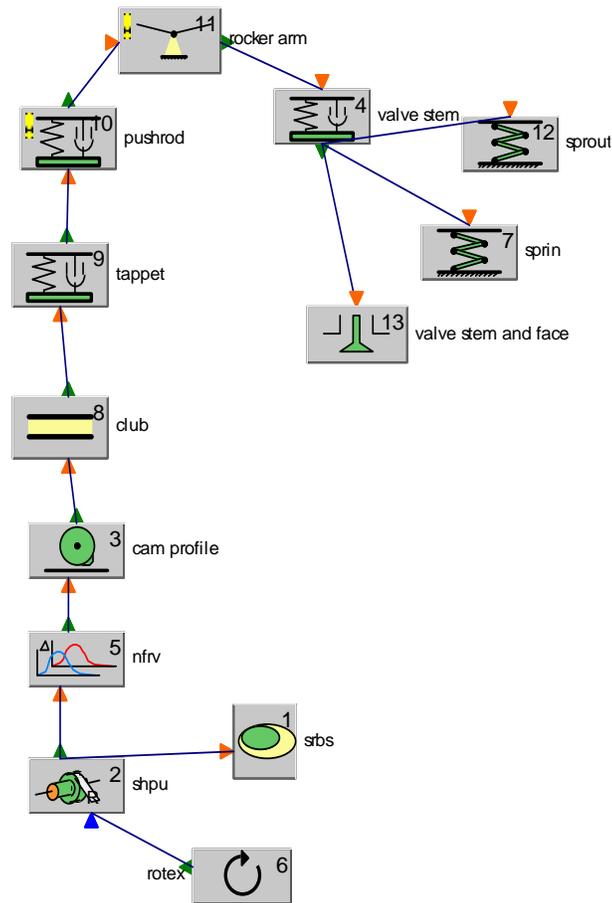


Figure 1. Valve train model in Tycon with all the components [2]

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Various components in the model developed starts from driving shaft to inlet valve with cam profile, push rod tappet and rocker arm being important component. The stiffness values and other constants of the components of the valve train in the developed model are the requisites for simulating the dynamic aspects. The cam data should be as accurate as possible (the more significant digits the better) because the derivatives and several other characteristic values are determined numerically. For more accuracy the cam data values are considered up to eight decimals as input values.

C. Cam shaft model in Tycon - Tycon considers the cam shaft model as shown in figure 2. An equivalent mass for the camshaft must be found. The two main parameters which must be kept in the calculation model are the camshaft stiffness and the natural frequency of the cam shaft. To obtain the second target an equivalent mass must be calculated. This can be done using the following two formulas:

The natural frequency of simple single mass oscillator:

$$\omega = \sqrt{\frac{c}{m_{eq}}}$$

$\omega =$ natural frequency

$c =$ stiffness of camshaft in tycon model

$m_{eq} =$ equivalent mass of camshaft.

The bending natural frequency of the beam with small additional masses assuming that additional masses do not influence the bending deflection.

$$\omega = \pi^2 \sqrt{\frac{E.I}{l^3 \left[m_s + 2 \sum m_i \sin^2 \left(\frac{\pi \cdot a_i}{l} \right) \right]}}$$

with

$\omega =$ natural frequency

$E =$ youngs modulus

$I =$ second degree moment of area of shaft

$m_s =$ mass of shaft without cams

$m_i =$ additional mass due to cam

$a_{i,1}$ are shown in figure

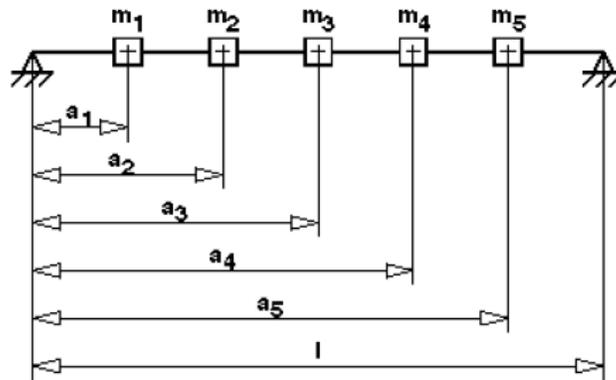


Figure 2. Camshaft considered as a beam

III. Simulation and Results

All the required values are calculated and fed as input for the TYCON model to arrive at the analysis of various components. The results obtained including various parameters displacement, velocity, acceleration and forces on various components in the valve train. As it is very essential to understand mainly the acceleration and force distribution of the components during the process, concentration is made of force and acceleration which are also shown in the figures below. Though analysis of all the elements is done, here analysis of cam and spring which operates the valve are discussed.

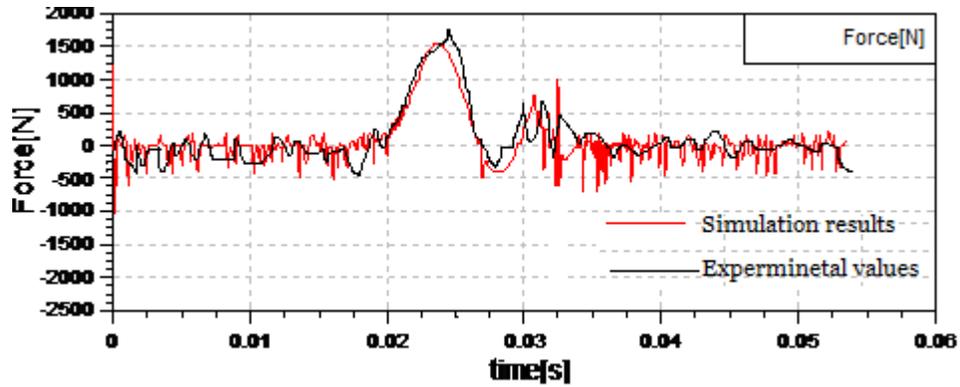


Fig 3. Cam Force

Figure 3. shows that the force on the cam reaches a maximum value of 1500 N and can be understood that the change in acceleration values would bring out change in the force distribution. The acceleration distribution can be minimized changing the stiffness parameters of the component in order to minimize the bounce of the follower which is in contact with the cam.

Figure 4 shows the acceleration distribution with time during operation, this acceleration is very important parameter as this would highly change with change in stiffness values. The change in spring stiffness values significantly bring out the change in acceleration and thus changes the force distribution.

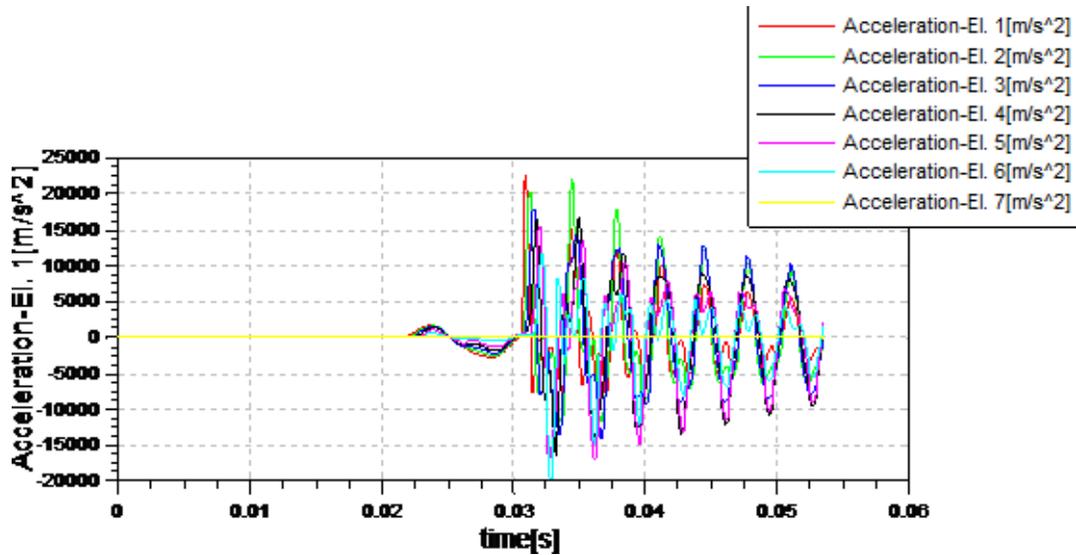


Fig 4. Acceleration distribution of spring which operates valve

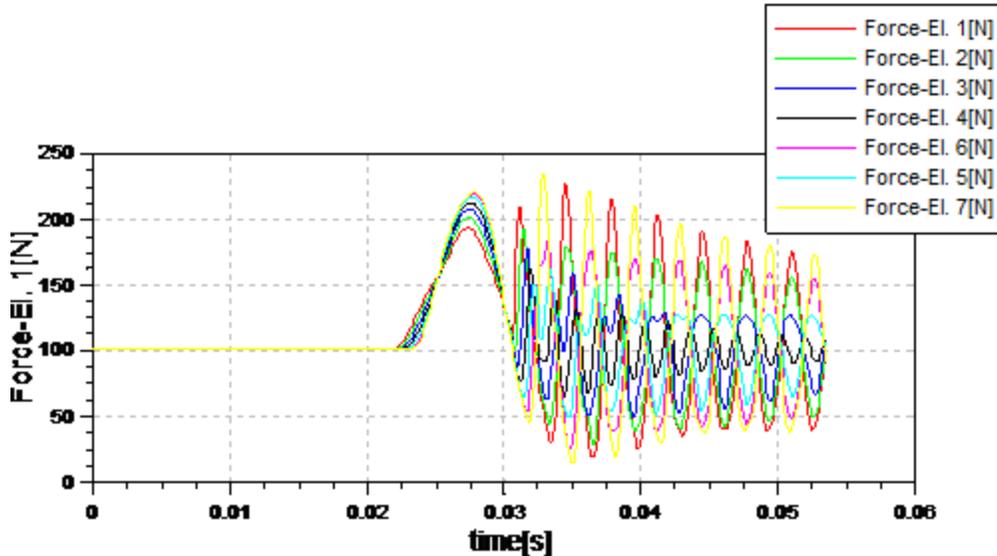


Figure 5. Force distribution on spring

The force distribution on the spring shown in Figure 5 is the most important consideration because the valve is operated by this spring for proper closure. This force is responsible for the operation of the valve as the spring applies and relieve the force on it. The stiffness constants of the material of spring has to be chosen with great care which helps in correct and smooth operation of the valve.

IV. ANALYTICAL APPROACH FOR VALVE TRAIN DYNAMICS

The model includes two different descriptions of the valve spring, which can be schematized either by an ideal elastic reaction or by a multi-mass scheme, including the possibility of contact among adjacent masses. This approach led to the realization of a modular system, which through appropriate component selection allows the study of several valve train architectures; to pursue this objective the point of start was the most comprehensive, i.e. a model including valve follower, pushrod and rocker arm in addition to valve and valve spring.

A. Forces on spring-

The components in the valve train will undergo the acceleration. The exception to this is the spring, for which an allowance may be made by using 1/3 of its mass as an effective mass. The major components of valve train are shown in Figure 6.

Maximum force will then be:

$$F = \text{max. acceleration} * \text{masses of the tappet} + \text{retainer} + \text{collets} + \text{valve} + \frac{1}{3} \text{ of spring}$$

The analysis becomes more complex when the engine does not have an overhead cam shaft, or when there is an overhead cam shaft that operates the valves by rockers. When this is the case the inertia of the rocker needs to be considered and the 'lever effect' of the rocker needs to be considered – as the two side arms of the rocker are frequently unequal. As the displacement required by the valve is generally large compared to that achieved due to eccentricity of the cam. This is achieved by making the arm on the valve side longer than that of the arm on the cam side. This arms ratio is called as rocker ratio and is equal to 1.59 in this valve train. The acceleration of the valve without considering the damping and stiffness of the intermediate components is calculated.

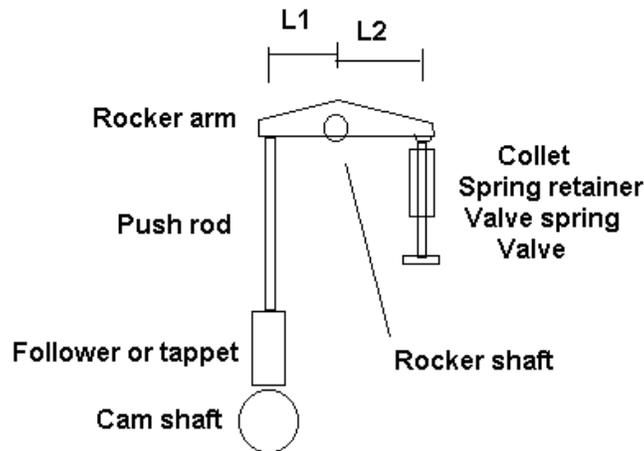


Figure 6. Arrangement of valve train in engine with the cam in the side of cylinder block

The following are the values and dimensions of the valve train:

Tappet -107 gms, Push rod-143.3 gms, Valve-138.5 gms, Retainer-39.4 gms, Spring (inner) -25.2 gms, Spring (outer) -64.1 gms, Arm1 (L1)-30 mm, Arm 2 (L2)-47.7 mm

The rocker now needs to be represented as an equivalent mass at the valve side. First the moment of inertia needs to be estimated. Depending upon the design of the rocker it may be possible to perform a 'compound pendulum' experiment to determine this. If this is not possible then an estimate of the radius of gyration of the rocker about the rocker shaft (K_p) can be made. The radius of gyration is the radius at which the mass would have to be concentrated to give the same moment of inertia. Figure 7 helps for further calculations.

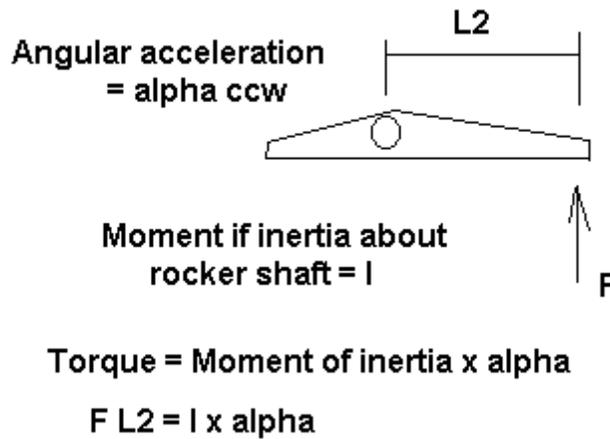


Figure 7. Rocker arm dimensions

$$F_{valveside} = m_{total\ equi\ on\ valveside} * a_{valveside} \quad \text{where } a \text{ is acceleration}$$

Moment of inertia is given by

$$= m * K_p^2$$

$$= 0.2125 * 0.024^2$$

$$= 0.0001224 \text{ Kg}m^2$$

*Torque developed = moment of inertia * α (where α = angular acceleration)*

$$FL_2 = I * \alpha$$

α can be written as (a / L_2)

$$\therefore FL_2 = I * \frac{a}{L_2}$$

$$\text{so } F = I * \frac{a}{(L_2)^2}$$

\therefore the equivalent mass of the rocker on the valveside is

$$= \frac{I}{(L_2)^2} \text{Kg.}$$

The mass of the components on the cam side (*tappet+pushrod*) be m_{camside} and let the force required to give this mass an ' a_{camside} ' be F_{camside} .

$$F_{\text{camside}} = m_{\text{camside}} * a_{\text{camside}}$$

both sides of the rocker arm have the same acceleration (alpha)

$$\text{alpha}(\alpha) = \frac{a_{\text{camside}}}{L_1} = \frac{a_{\text{valveside}}}{L_2}$$

The force on the valve side to accelerate the camside at ' a_{camside} ' is given by

$$F_{\text{valveside}} * L_2 = m_{\text{camside}} * a_{\text{valveside}} * \frac{L_1}{L_2}$$

$$F_{\text{valveside}} = m_{\text{camside}} * a_{\text{valveside}} * \left[\frac{L_1}{L_2} \right]^2$$

$$\text{so the equivalent mass of camside on valveside} = m_{\text{camside}} \left[\frac{L_1}{L_2} \right]^2$$

$$\therefore \text{equivalent mass at valveside} = \text{mass of valve + retainer + collet} + \frac{1}{3} \text{ of spring} + \frac{I_{\text{rocker}}}{(L_2)^2}$$

$$+ (m_{\text{tappet}} + m_{\text{pushrod}}) \left[\frac{L_1}{L_2} \right]^2$$

putting in values :

$$m_{\text{equi.valveside}} = 0.2107 + \frac{0.0001224}{(0.0477)^2} + 0.2503 \left[\frac{1}{1.59} \right]^2$$

$$= 0.363 \text{Kg.}$$

the max acceleration required by the valve when being driven by spring is $1600 \text{m} / \text{s}^2$.

$$\therefore \text{the spring force needed is } 1600 * 0.363 = 580.8 \text{N}$$

V. DISCUSSIONS

From the dynamics analysis carried out in Tycon, it is evident that the stiffness values and other constants of various components in the valve train are responsible for distribution of dynamic parameters such as acceleration and force. This dynamics values effect the bounce and jerk of the components during opening and closing of the valve during operation. Further, it is clearly understood from the analysis that the acceleration values of the components, especially spring which operates the valve is a major factor for smooth functioning and movement of the valve reducing the bounce which results in effective operation. The acceleration of the cam profile is following a pattern which can be understood and predictable that the acceleration distribution is due to rotation of cam shaft during the operation. The maximum acceleration is around 1200m/sec^2 and at a certain point it is having a peak value due to the jerk arise during combustion stroke. This jerk can be minimized by taking necessary care, however

in the present work, it has been ignored as our concentration is to study the dynamic parameters due to motion. The force on the spring has maximum value of 200 N and there are two springs in the engine valve train considered for this work. Two springs having equal stiffness are used to operate valve and thus it can be understood that the force applied is double the value observed in the results. It is also seen that the analytical approach which has considered only mass and acceleration is helpful in evaluating the acceleration and force of the components. The length of the rocker arm, masses of components and moment of inertia will effect the dynamics which would be chosen based on the knowledge accordingly to minimize the forces. Considering stiffness and damping factors, a lumped mathematical can be developed to study further and validate the results of Tycon for more accuracy. However this work helps us to analyze the dynamics of valve train using Tycon as well as analytical approach.

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