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Procedia Engineering 150 (2016) 312 – 317

Procedia Engineering

www.elsevier.com/locate/procedia

International Conference on Industrial Engineering, ICIE 2016

Dynamics Simulation Model for the Internal Combustion Engine Valve Gear

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Abstract

The paper sets forth the refined estimation technique of internal combustion engine valve train stress loading on example of VAZ engine, obtained by means of developed simulation model of valve train dynamics research. The experimental research of valve spring coil oscillations by high-speed motion-picture technique is being considered as well.

Peer-review under responsibility of the organizing committee of ICIE 2016

Keywords: valve spring coil oscillations; stress loading simulation model; valve train; internal combustion engine; experimental research; high-speed motion-picture technique.

1. Introduction

In modern engines the presence of elastic deformable links in valve train contributes to its oscillatory processes. Variable nature of loading, compression, tension, bending and torsion stresses that take place in the system, reduce reliability of the components. Valve train dynamics depends significantly on stiffness and damping properties of valve train elements and contact points of these elements. This effect is most tangible in valve spring being the element with the lowest stiffness and having the lowest natural frequency (as compared to other valve train parts).

At resonance (with respect to camshaft operating speeds) engine operating modes stress surges in valve spring occur which affect not only the loading of the spring itself, but can also be the cause of other poor performance of the valve train itself. Thereby, development of general-purpose simulation model for valve train dynamics research

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Peer-review under responsibility of the organizing committee of ICIE 2016
doi:10.1016/j.proeng.2016.07.017

adjusted for valve spring coil oscillations, that will allow us to describe all the processes existent inside valve train in a most accurate way and estimate its loading seems to be urgent.

2. Simulation model

The proposed valve train dynamics simulation method is based on generalized dynamic model («Dynamics», ***D***) that was developed on «Automobile and Tractor Engines» Department of VSTU. Determination of forces in valve train, displacement values of its parts is based on representation of the latter in the form of discrete masses connected with inertialess elastic elements and then the numerical integration of differential equations describing displacement of each mass.

In base model each valve spring is described by 6-mass discrete model (one spring mass is fixed and the other is attached to valve mass) (Fig.1). The developed simulation model provides for possibility to vary presentation of valve springs [1-8]. In addition to multi-mass approach presentation of equivalent flexible rods model – concentrated masses with distributed parameters (so called «surge-mode approach model») – able to perform longitudinal oscillations is realized as well (Fig. 2). The admissibility of such a representation follows from a more precise determination theory of springs parameters, where coil spring is considered as a thin curved space bar. This approach takes advantage of the fact that the stress wave propagation through valve spring elastic media can be described in terms of normal modes that are decisive in valve train loading estimation. To model these oscillations by longitudinal vibrations of the rod the equality of spring mass and stiffness values corresponding to those of the rod should be maintained. This scheme application, apart from valve displacement specification, allows to estimate valve springs loadings themselves in a more accurate way [3].

Valve springs vibrations and their influence on valve train dynamics calculating program was implemented as a separate calculating module (***SPR***) that works jointly with base dynamics simulation model. Valve spring forces affecting on valve were determined during valve spring coils oscillation numerical integration [3, 5] with corresponding initial and boundary conditions within ***SPR*** module. Valve spring coils oscillation equation has the form of wave equation with initial friction damping term.

$$\frac{\partial^2 U(\xi;\phi)}{\partial \phi^2} + \frac{2\mu}{\omega}\frac{\partial U(\xi;\phi)}{\partial \phi} = \left(\frac{a}{\omega}\right)^2 \frac{\partial^2 U(\xi;\phi)}{\partial \xi^2} \tag{1}$$

where U – longitudinal displacement of elastic rod's cross section equivalent to that of the real valve spring, mm; μ – viscous friction damping coefficient (takes the value of 20…30 if not using external friction damper); ξ – effective length (ratio of distance from valve spring active length start point to the coil section under consideration to total valve spring length); φ – camshaft angle, rad; ω – camshaft operating speed, rad/s; a – stress wave propagation speed, s^{-1}.

It's easy to use zero initial conditions when valve is closed and sits on valve seat; valve spring cross section displacements are also equivalent to zero. Boundary conditions are as follows: valve spring fastened end displacement is equivalent to zero and displacement of its moving end is determined by valve motion.

Developed valve train dynamic simulation technique is based on method of successive approximations that allows us to research valve spring dynamics at steady-state engine operating mode. Calculation of the first iteration began from static equilibrium state of valve spring coils. Camshaft angle origin corresponded to valve lift start time point provided valve train expansion gap is completely eliminated. The original variable $U(\xi;\varphi)$ – valve spring coil cross sections displacements – was determined by numerical integration of strain values $\eta(\xi;\phi)$ along effective length ξ of the valve spring.

$$U(\xi;\phi) = \left(\frac{\omega}{a}\right)\int_0^{\xi_i} \eta(\xi;\phi_j)\,d\xi \tag{2}$$