

Evaluation of a 4-stroke 4-cylinder Diesel Engine Valve-train for Replacement of a Solid Camshaft with a Hollow Camshaft

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ABSTRACT

The use of hydroforming technique is commonly used for the manufacturing of BIW, chassis and suspension components. For low weight and cost effective solutions it is also finding application in powertrain components mainly in the engine camshafts.

Weight of the valvetrain parts plays a vital role for enhancing the engine response and performance. Hollow camshafts are produced by assembling aggregate parts, i.e., cam lobes, journals, sprockets etc. on a tubular shaft. Compared to conventional solid cast or forge camshafts, hollow camshafts provide opportunities for weight reduction exceeding 60%, design flexibility to improve performance of engine and valve train because of reduced rotational inertia.

In order to obtain the above benefits the valve train of an existing 4-cylinder 4-stroke diesel engine is modified by replacing the solid forged camshaft with a hollow camshaft. The main consideration in carrying out the change is that the valve train performance should be enhanced. For this, the basic requirement of the camshaft torsional and bending rigidity should be same as that of the solid camshaft.

Physical validation of such a system on an engine dynamometer would involve investment in tooling for the camshaft and the lobes, journals and sprocket. This is also a time taking process, as the development would require tuning at various levels.

In order to reduce the development time and cost, a numerical model of the valve train is developed. The valve train is then analyzed and the performance is

compared with the solid camshaft. Once the valve train parameters are optimized, the hollow camshaft is evaluated for durability.

INTRODUCTION

The customer expectations from powertrain performance in terms of power and fuel economy are increasing.

Both of the above parameters are highly influenced by the valve train performance. Optimized engine breathing capacity helps in improving the fuel consumption. The need for increased power and efficiency often leads to higher engine operating speeds. The maximum sustainable speed for an engine is usually determined by the dynamic behavior of the valve train system. The valve train in an internal combustion engine is responsible for controlling the air/fuel mixture into the cylinder during intake and to allow the exhaust gases to exit after combustion. The function of the valvetrain mechanism is to use the intake and exhaust valves to control in a timely way the entry of charge and the exit of the exhaust gas in each individual cylinder following each cycle of engine operation. For improvement in efficiency, the valve must respond quickly to the valvetrain inputs.

The dynamic elasticity characteristics in a valve train system is one of the major factor limiting engine breathing capacity, consistency and long term valve train durability. The performance of the engine valvetrain system is closely interrelated with its mass and stiffness. Lightweight components of the valve train provide low inertia force, which influences the deflection of the valvetrain at high-speed operation.

The overall valvetrain stiffness affects the performance of the engine, and it is mainly governed by the pushrod, camshaft, rocker arm and valve stiffness. High valvetrain stiffness results in improved valvetrain system natural frequency that allows a more aggressive camshaft profile design and a high-performance engine.

EXISTING ENGINE VALVE TRAIN

The valvetrain for this 4-cylinder 4-stroke engine is of pushrod type. The existing camshaft complete solid shaft and is made by casting with lamellar graphite cast iron material. The solid camshaft has all the lobes and bearings integral and is made of same material. It is heat treated at the cam lobe and bearing positions. The precise cam profile is achieved by grinding the cam lobes.

The schematic of pushrod type valvetrain is shown in figure 1.

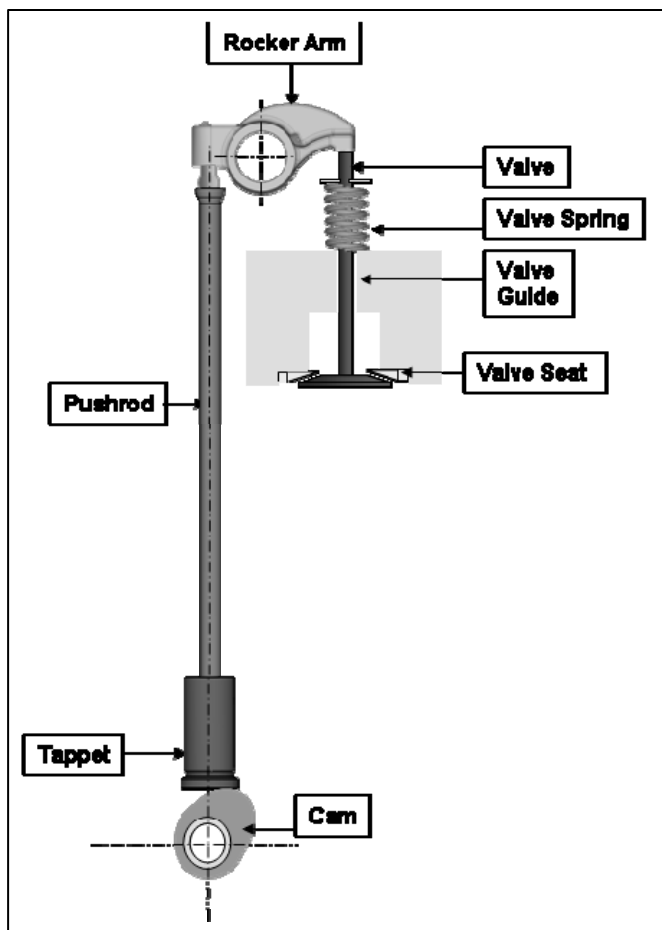


Figure 1: Schematic of Pushrod type valvetrain system.

ADVANTAGES OF HOLLOW CAMSHAFT

The functional advantages are as follows,

1. Weight reduction can exceed 60%

2. Less rotational inertia
3. Lower noise & vibration
4. Extra horsepower
5. Improved fuel economy
6. Lower cost
7. Net shape forming and assembly - reduce/ eliminate grinding & several related problems
8. The lobe profile can be more aggressive than grinding allows - optimize valve opening/closing
9. Reduce or eliminate need for heat-treating
10. Choice of roller or sliding follower
11. Improved engine dynamics and performance
12. Compromises with respect to material selection and design are reduced or eliminated
13. Suitable material properties for a sturdy assembly and to withstand high lobe contact stresses

Weight reduction of the camshaft can be achieved by largest inner diameter for the thinnest wall tube, but the stiffness, strength requirements and durability limits how far this design direction can go.

The disadvantages related to hollow camshaft are mainly with manufacturing and related to productivity because of the increased number of interfaces.

HOLLOW CAMSHAFT ASSEMBLY

Hydroforming process is used to produce hollow camshaft. In this process, individual cam-lobes & bearings are inserted onto hollow tube of ERW-2 steel material. This assembly then kept in die, which is having cavities as per final camshaft taking into consideration the different orientations of cam lobes. Then the die is closed & very high-pressure water of around 900-1500 bar is applied at both ends. Due to high pressure inside the tube, the tube expands which sequentially exerts pressure on the lobes, which has oblong hollow cavity.

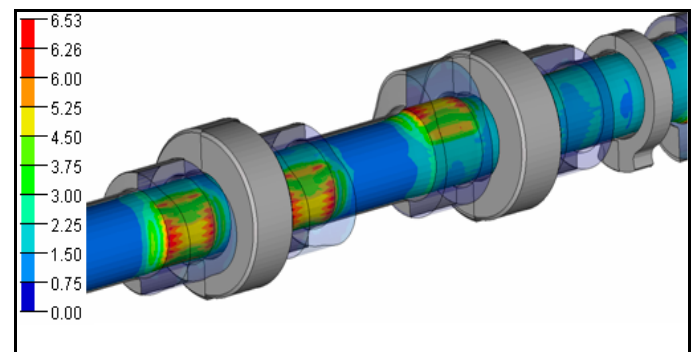
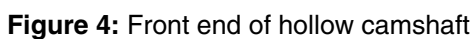


Figure 2: Forming Simulation showing thinning of the tube. Maximum 6% thinning has occurred.

This interface is capable of transmitting three times higher torque than the maximum operating torque on camshaft, which is found from valve train simulation. Later on, this assembly is taken out from die. Tube is trimmed off as per requirement. The grinding of lobes is done to achieve precise cam contour.

The hydro formed hollow camshaft is shown in figure 3. The front end of hydro formed hollow camshaft is shown in figure 4.



The multi-body dynamic (MBD) simulation has been carried out in commercially available software “AVL/excite timing drive” and a comparison has been

SINGLE VALVE TRAIN MODEL

The diagram illustrates the mechanical components and their interactions in a cam-follower system. The components are numbered 1 through 12, corresponding to the labels on the left and right sides of the diagram.

- Rotational Excitation (1):** The input motion, shown as a circular arrow.
- Shaft & Pulley Element (11):** The shaft and pulley assembly that receives rotational excitation.
- Camshaft Bearing (12):** The bearing that supports the camshaft.
- Connection of Cam with shaft (2):** The connection point between the camshaft and the pulley.
- Cam Contour (3):** The cam profile that converts rotational motion into linear motion.
- Cam Lubrication (4):** The lubrication system for the cam-follower contact.
- Lower Part of Pushrod & Tappet (5):** The lower part of the pushrod and tappet assembly.
- Upper Part of Pushrod (6):** The upper part of the pushrod.
- Valve Stem (8):** The valve stem that moves the valve.
- Valve Spring (9):** The spring that returns the valve to its closed position.
- Valve Face (10):** The face of the valve that seals against the seat.
- Rocker Arm (7):** The lever that converts the linear motion of the pushrod into the desired output motion.

Arrows indicate the direction of motion and force transmission between these components.

COMPLETE VALVE TRAIN MODEL

The complete valve train is modeled to study the dynamic behavior, which is combined effect of all the SVT models of different cams and complete camshaft