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DESIGN OF THE CAM PROFILE FOR A ROLLER FINGER FOLLOWER VALVE TRAIN

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Abstract: *This paper presents a method for designing a cam profile for an oscillating roller follower valve train. The software applications used in this study are Virtual Lab LMS and AutoCad. The first software was used for creating the cam profile, and the second software for the kinematic analysis of the new designed cam profile. Results show that the designed cam profile generates an almost identical valve lift as the one used as input data.*

Key words: *Cam profile, Virtual Lab, AutoLlisp, kinematic simulation.*

1. Introduction

The valve train system is a very important subsystem of the internal combustion engine. It is responsible with the management of the gases flow which enters and leaves the cylinder.

The ecological and energetic performances are influenced negatively by the abnormal functioning of the valve train system, reason why it is necessary to assure its good functioning.

The cam is the component of the valve train which has the role to command the valve opening and closing at precise moments.

This paper presents a method for designing a cam profile for an oscillating roller follower valve train (Figure 1).

The cam is designed using the principle of kinematic inversion, starting from the valve lift curve. The cam profile was obtained by subtracting from a cylinder the successive positions of the finger follower roller operation done by using AutoCad software.

The kinematic simulations were performed using Virtual Lab software.

The input valve lift was compared with the one resulted from simulating the roller finger follower, with the new designed cam, and the errors between two lift curves were presented.

2. Description of the Analyzed Valve Train

The configuration of the valve train acting system consists of 4 valves per cylinder.

The movement is transmitted from the cam to the valve through a finger follower, which is a third order lever. The finger follower is mounted at one end onto the hydraulic lash adjuster (HLA), and is supported by the valve stem at the other end.

The hydraulic lash adjuster has the role in maintaining a zero valve clearance within the valve train mechanism.

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The valve spring is mounted between the cylinder head and the retainer. It has the role to overcome the inertial forces of the valve and the other parts of the mechanism and to maintain the valve on its seat, when the cam does not act upon the valve.

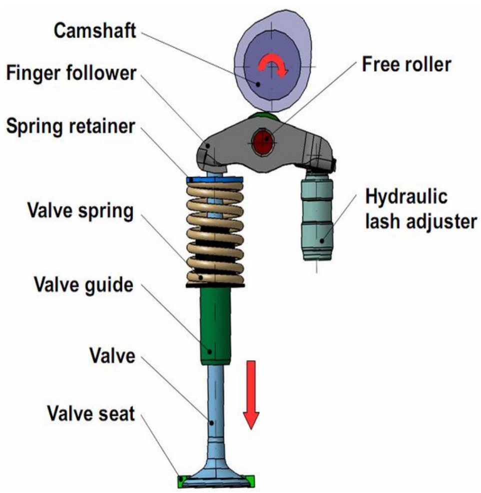

Fig. 1. *Description of the analysed valve train*

In order to simplify the virtual model, a single valve actuation system was submitted to analysis.

3. Design of the Cam Profile

When designed using the kinematic inversion principle, the cam profile is obtained by determining the successive positions of the roller, around the cam's base circle center.

The successive positions of the roller are determined by rotating the entire mechanism around the cam center, in opposite direction of cam rotation.

The coordinates of the rollers center were calculated starting from the valve lift curve (Figure 2).

First step was to determine the angle made by the oscillating finger follower due to the valve movement.

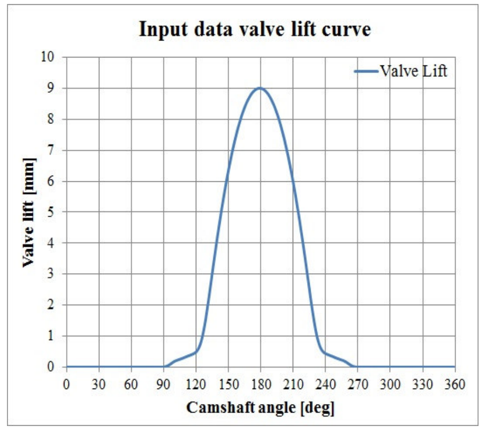

Fig. 2. *The input data valve curve lift*

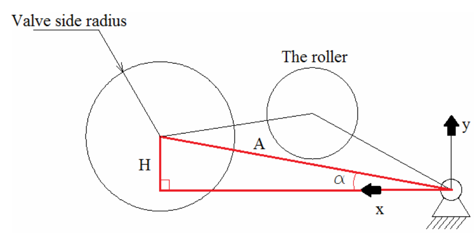

Fig. 3. *The method for determining the angular displacement of the finger follower*

As shown in Figure 3, the angular displacement of the finger follower was calculated using the following formula:

$$\alpha = \mathrm{Arcsin}\left(\frac{H}{A}\right), \tag{1}$$

where: H - sum between the initial displacement of the finger follower along y axis, and the valve lift value, corresponding to the camshaft angular position [mm]; A - length of the arm between two centers, respectively the center of rotation of the finger follower and the one of the contact circle, from the valve side [mm]; α - angular displacement of the finger follower [deg].

The second step in the design of the cam profile was the calculation of the coordinates of the successive positions of the roller.

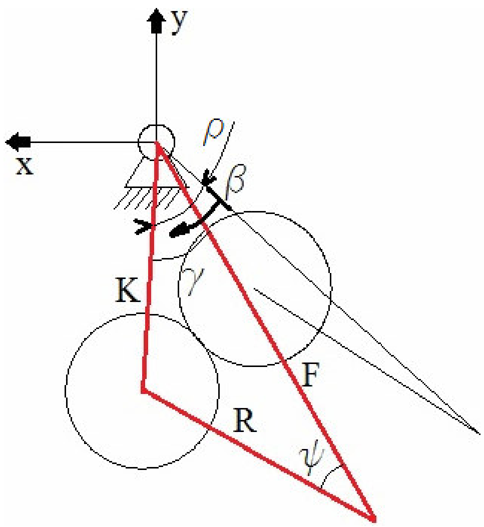

Fig. 4. *Description of the K, R, F, ρ, β, ψ, γ parameters*

In order to determine the coordinates of the roller center, first, the angle γ was first calculated, using the "Law of cosines" (Figure 4).

Knowing the values of R, F, and ψ parameters, the value of arm K and the angle γ were calculated, with the following formulas:

$$K = \sqrt{F^2 + R^2 - 2 \cdot F \cdot R \cdot \cos\psi}\,, \tag{2}$$

$$\gamma = \mathrm{Arc}\cos\left(\frac{K^2 + F^2 - R^2}{2 \cdot K \cdot F}\right), \tag{3}$$

where: R - length of the oscillating arm [mm]; F - the distance between the cam center and center of oscillation, of the finger follower [mm]; K - imaginary distance between the roller center and the cam center [mm]; ψ - sum between the initial angle, made by the arms R and F, and angle α, calculated with equation (1), [deg]; γ - the angle resulted due to the angular displacement of the arm R, [deg]; β - the angle that rotates the mechanism around the cam's center, and which has an increment of 1 degree, [deg]; ρ - the rotation angle of the arm which links the center of the cam with the center of the roller. This angle is obtained by summing the values of the β and γ angles.

The polar coordinates of the roller are defined by the following parameters: K and angle ρ.

The Cartesian coordinates needed for the construction of the cam profile were obtained by converting the Polar coordinates, calculated above:

$$x = K \cdot \cos(\rho),$$
$$y = K \cdot \sin(\rho). \tag{4}$$

Once the Cartesian coordinates of the roller, that envelope the cam profile, are known, the profile of the cam is built by subtracting from a cylinder a multitude of cylinders that represent the successive positions of the roller, as shown in (Figure 5).

The constructions of the cylinders that copy the successive positions of the roller were done by using an AutoLisp function presented below:

```
  (Defun C:cc ()
  (setq gros 10.0 R0 14.7 Rrola 9.5 )
(setq xCama 0 yCama 0)
(setq filename
(getfiled  "Selectati  fisier  cama"
"" "txt" 0))
(setq f (open filename "r"))
(setq lp nil)
(setq sir (read-line f))
(while sir
(setq l1
(read (strcat "(" sir ")")))
(setq lp (append lp (list l1)))
(setq    sir    (read-line    f)))
;;while(close f)
   ;;(foreach elem lp
(progn
(Command "Cylinder"
(list (car elem)
(cadr    elem))    Rrola    gros)))
;;foreach )
 ;;end
```

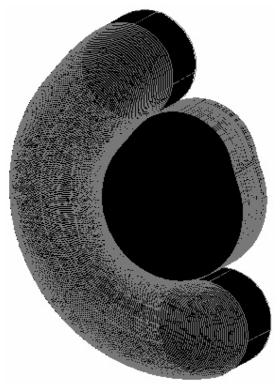

Fig. 5. *The cam profile*

In order to obtain the Cartesian coordinates of the cam profile, a second AutoLisp function was used.

Before using the second function, a face of the cam profile was dismounted in a series of polyline curves. Then the function extracted the *x, y* Cartesian coordinates of each individual polyline curve.

The function created for extracting the *x, y* Cartesian coordinates is presented below, [1]:

```
(setq filename
( getfiled "" "" "" 1))
(setq f
(open filename "w"))
(setq l (entget (entlast)))
(foreach x l
(if (= (car x) 10)
(print x f)))
```

The resulted coordinates were used for the construction of the spline curve needed for simulation of the mechanism, in Virtual Lab.

For obtaining a satisfactory cam profile it is necessary to have as input a valve lift curve with an angular step of 1 degree and a precision of a tenth of a micron so that the minimum precision is reached [2].

4. Description of the Kinematic Model Used in the Analysis

The model used in the analysis consists of 4 rigid bodies.

The cylinder head is a complex body formed by fixing together the following bodies: valve guide, hydraulic lash adjuster and camshaft bearings.

Between the valve and its guide a translation joint was placed. The finger follower is linked to the cylinder head through a spherical joint [3].

The contact between the cam and the finger follower, and the contact between the finger follower and the valve are modeled using curve to curve joints [3].

The driver used for controlling the revolute joint, also called Joint Driver, uses the angular speed as input for the model.

The kinematic diagram of the virtual model used in the analysis is presented in Figure 6.

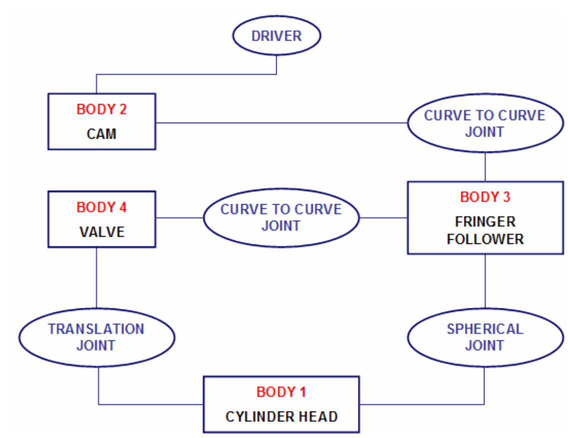

Fig. 6. *Diagram of the kinematic model used in the analysis*

5. Results

The data obtained from the simulations are presented below.

Figure 7 presents the error between the original valve lift and the one obtained from simulation. The maximum value of the error is 0.1 [mm], which is an acceptable value.

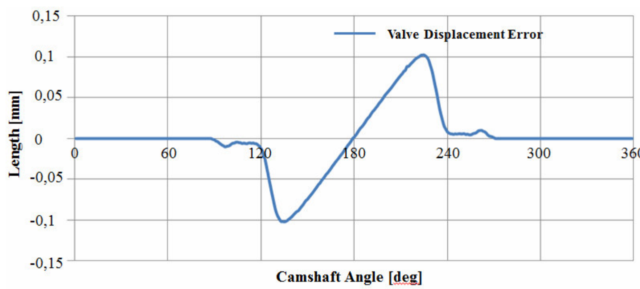

Fig. 7. *The error between the original valve lift and the one obtained from simulation*

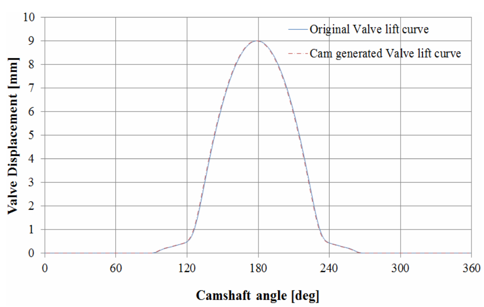

Fig. 8. *Comparison between Original valve lift curve and the one obtained from simulation*

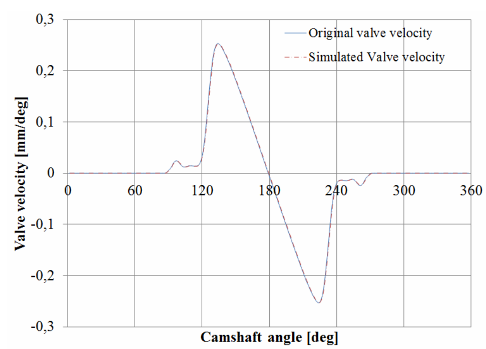

Fig. 9. *Comparison between Original valve velocity curve and the one obtained from simulation*

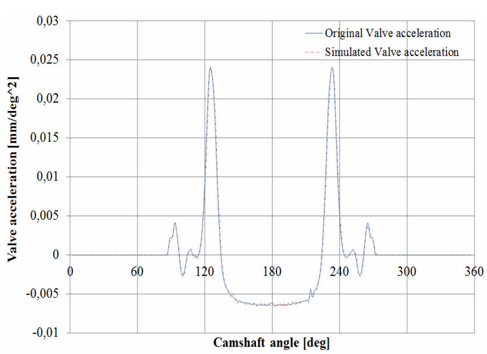

Fig. 10. *Comparison between Original valve acceleration curve and the one obtained from simulation*

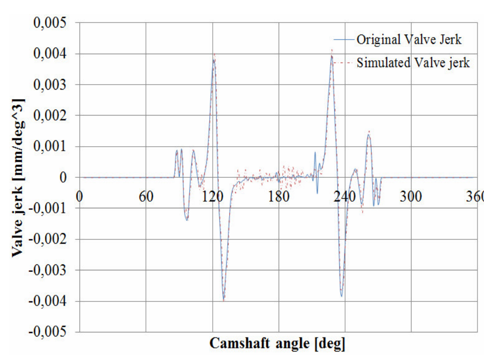

Fig. 11. *Comparison between Original valve jerk curve and the one obtained from simulation*

As shown in Figure 8 the compared valve lift curves are almost identical. The error between the two curves was presented in Figure 7.

Also, in the case of the valve velocity curves comparison (Figure 9), the error between the two curves is not noticeable.

In Figure 10, it can be seen that the simulated acceleration curve differs from the original curve on the cam base circle interval, taking into consideration an acceptable error.

In the case of jerks curves comparison (Figure 11), the difference between the two curves is also acceptable.

6. Conclusions

This paper presents a method for designing a cam profile for an oscillating roller follower valve train.

The cam is designed using the principle of kinematic inversion, starting from the valve lift curve.

After the angular displacement of the finger follower was calculated, respectively the Cartesian coordinates of rollers center, the cam profile of the cam was built.

The cam profile was constructed using 2 AutoLisp functions, one to generate a series of cylinders with the same coordinates as the roller positions around the cam and the other to extract the *x, y* Cartesian coordinates of the cam profile curve.

Using as input the Cartesian coordinates of the cam profile, the cam was built, in Virtual Lab environment.

After the kinematic simulation was done, using Virtual Lab software, the obtained results, respectively lift, velocity, acceleration and jerk curves were analyzed.

The valve lift and velocity curves resulted from simulation were almost the same as the one used as data input, respectively the error between the original valve lift and the one obtained from simulation was of maximum 0.1 [mm].

A visible difference between the original and simulated curves was observed only at acceleration and jerk curves.

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