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Peculiarities of stress calculation of basic parts of valve timing gear of modern locomotive electric power installations

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Abstract
The article highlights one of the promising directions for improving the fuel economy and reliability of modern locomotive power plants, which is to improve the design of the valve mechanisms. The expediency of increasing the amount of "time-section" through the use of highly efficient drive cams of drive gear of intake and exhaust valves is grounded. There highlighted features of stress calculations of the basic details of gas distribution mechanism of modern locomotive power plants. The necessity of calculations taking into account dynamic development in the valve drive gear is specified.
Keywords: LOCOMOTIVE, LOCOMOTIVE POWER PLANT, GAS DISTRIBUTION MECHANISM, DYNAMICS, REAL LAWS OF MOTION, STRENGTH

Introduction. Railroad transportation takes leading position in satisfaction of wants in production sphere and among population in transportation it is the important factor for securing of social and economic development of Ukraine, strengthening of its external economic relations. Its stable and effective performance is the necessary condition for defense potential, national security and country entirety. Existing control structure of railroad transportation, condition of production and technical facilities of railroad and technology level of transport management do not correspond in many parameters to increasing demands of society and European standards of freight service quality, prevent increase of effectiveness of branch functioning and are in need of reform.

Problem statement and its relevancy. Resolution of the Cabinet of Ministers of Ukraine dated December 16, 2009 No 1390 (as revised by the Cabinet of Ministers of Ukraine dated October 26, 2011 No 1106) there was approved state target program of reforming of railroad transportation for 2010-2019 within the limits of which one of the priority development fields for railroads is the increase of fuel efficiency and reliability of locomotive electric power installations (LEPI) [1, 2], which is currently important for further economically efficient functioning of Ukrainian railroads. Together with this the researches focused on the securing of high level of technical-economic values of Diesel engines of LEPI hold a specific place.

Analysis of the latest researches and publications showed that together with process improvement in the superchargers, aggregates of fuel supply, carburetion and burning, heat transmission, there also current the developments concerning refinement of gas-exchange processes in the cylinders, which greatly depend on the characteristics of functioning of camshaft mechanism of gas distribution (CMGD). Herein area for improvement of technical-economic values of LEPI by means of their modernization on the base of design development of CMGD by means of usage of control shafts with fundamentally new camming contours of suction and eduction valves drivegear, which provide (as compared with serial) significant increase of “hour-cross section” (HCS) of the valves when meeting all the requirements (gas distribution, strength, manufacturing method, effectiveness) and satisfying dynamics, which is characterized by continuity in the joints of kinematic chaine of valve driver, is considered to be perspective [3]. In its turn drive to increase of the value “hour-cross section” by means of application of high-efficiency cams is connected with significant increase of dynamic loads, which determine the necessity of stress calculations of main pieces of camshaft mechanism of gas distribution at all the stages of design works concerning creation of new electric power installations or updating of already existing ones.

The aim of the article is lighting of peculiarities of stress calculations of main parts of valve gear drive of modern locomotive electric power installations of diesel Ukrainian Railroad Park.

Exposition of base material. The usage for determination of acting in the gear loads of theoretical laws of valve movement, which are fully correspond to the profiles of camshaft lobe [4, 5] is general feature of stress calculations under traditional methods.

Meanwhile the results of fulfilled researches [6] speak for significant difference of theoretical laws from real ones (the ones, which take place at the working electric power installation), which is conditioned by the influence of dynamic processes, which is integrally determined by the peculiarities of kinematic, inertia, elastically dissipative parameters of members of gas distribution mechanism. This conditions the necessity of development of new approaches to stress calculation of main pieces of CMGD, corresponding specified methodologies, which should consider the display of gear drive dynamics – base on the usage of real laws of valve motion, obtained experimentally for existing electric power installations or with the help of mathematic modeling for the ones, which are being created.

Corresponding development works for stress calculations of the most important pieces of CMGD: valve springs, ram for stiffness, kinematic pair profile of cam-roller of lifter for contact strength are as follows.

The value of contact voltage in kinematic pair cam-roller of lifter of valve operating mechanism is determined under Hertzian formula [7]:

$$\sigma_H = \sqrt{0{,}175 \cdot \frac{k \cdot F_\Sigma \cdot E}{l_k \cos\beta}\left(\frac{1}{\rho} + \frac{1}{R}\right)}$$

where k - lever ratio (for example for gas distribution mechanism of LEPI D80 $k = 1$);

F_Σ - joint force, which squeezes the ram (its calculation is given below);

E – multiple elasticity modulus of roller and cam materials. For the steel $E = 2{,}15 \cdot 10^5\, MPa$ [8].

l_k – contact line length (for example, for gas distribution mechanism of LEPI D80 $l_k = 0.027\ m$);

β - current contact angle;

ρ – roller radius (for example, for gas distribution mechanism of LEPI D80 $\rho = 0.028\ m$);

R - reference radius of cam profile.

Herein the fulfillment of the following condition is observed $\sigma_{H\,max} \le [\sigma_H]$, where

$[\sigma_H]$ - allowable contact voltages $[\sigma_H] = 1500 MPa$.

During stress calculations of the ram – one of the main pieces of CMGD – the fulfillment of condition is controlled:

$k_{st} \geq 3$

where k_{st} - is ram stability factor. To define k_{st} one may use the following formula:

$$k_{st} = \frac{F_{cr}}{F_{\Sigma}},$$

where F_{cr} - critical load, during which there is possible the loss of ram stability.

In general case the critical load is determined under the formula

$$F_{cr} = \sigma_{cr} \cdot A,$$

where A – is ram cross section;

σ_{cr} - critical stress, which arises in the ram material and for gas distribution mechanism of LEPI D80, is determined under the formula of Tetmaera-Yasinskogo [7] , which is given below

$\sigma_{cr} = a - b\lambda$

where a, b - empirical coefficients, which are chosen depending on the material (for example for steel *20X: a = 310; b = 1.14*);

λ – ram elasticity, which is determined under the following formula

$$\lambda = \frac{\nu \cdot l}{i}$$

where ν – coefficient, which characterizes the conditions of ram fixing; for pin-edge fixing $\nu = 1$;

l – the length of ram (for the ram of camshaft mechanism of gas distribution of LEPI D80 it is *536* mm);

i - radius of inertia, which is determined under the formula

$$i = \sqrt{\frac{J}{F}}$$

where F – cross section of the ram;

J - moment of inertia, which is determined under the following formula

$$J = \frac{\pi(d^4 - d_0^4)}{64}$$

where d - outer diameter of the ram $d = 0.024\ m$;

d_0 - inner diameter of the ram $d_0 - 0.016\ m$.

To calculate F_{Σ} we may use the following formula

$F_{\Sigma} = F_i + F_{es} + F_g$

where F_i , F_{es}, F_g - inertial force, elastic strain of the spring and force of waste gases (is considered for eduction valves).

Upon the recommendations of literary sources [9] during design of valve springs it is recommended first of all to choose characteristics of spring force variations, which should not exceed maximum value of negative force of inertia in valve gear drive on $60 - 100\%$ to provide continuous work of valve operating mechanism. In such a way maximum force of the spring is chosen from the following correlation

$$F_{sp\,max} = k_{saf} F_{i\,max},$$

where $F_{i\,max}$ - maximum negative inertia force in valve gear drive; k_{saf} – factor of safety of valve spring according to inertia forces, which should be within the limits k_{saf} - 1.6….2 according to recommendations [9].

The figure 1-3 shows calculation results of valve springs, kinematic pair of profile cam-roller lifter on the contact strength, rams for stiffness considering theoretical and real laws of valve motion of gas distribution mechanism of locomotive electric power installations with average running Diesel engine D80.

Conclusions and perspective of further usage. Traditional approaches for determination of inertia forces, spring elastic strain force and forces of waste gases allowed to fulfill it with the help of application of theoretical laws of valve motion (corresponding movement and valve acceleration). However the given above statements condition practicability of stress calculations of basic pieces of CMGD considering the dynamics of their valve gear drive.

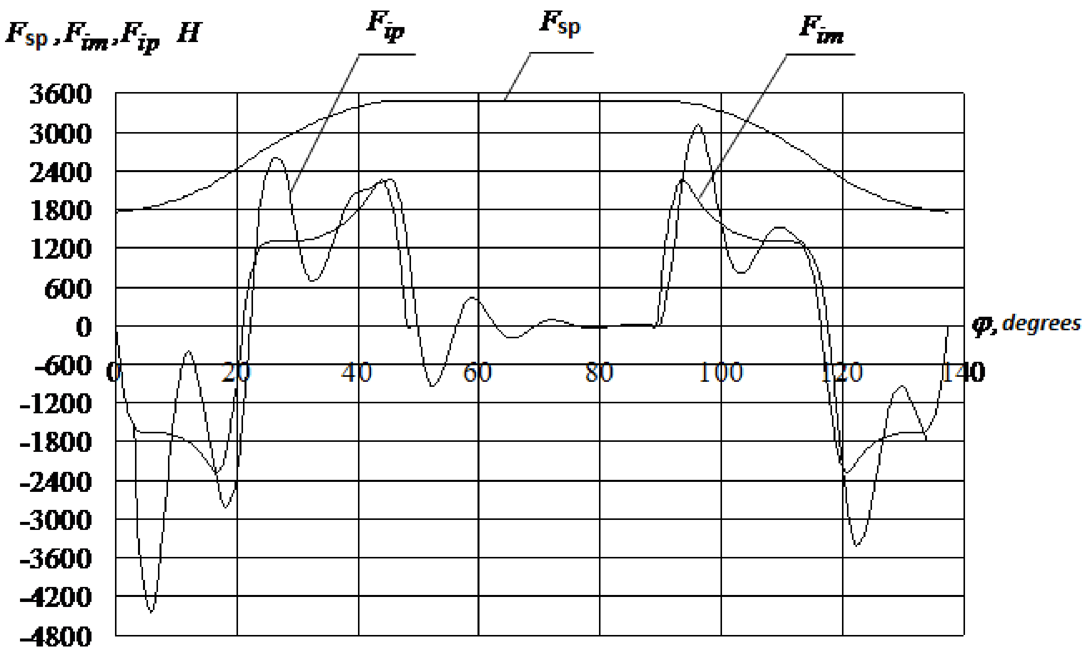

Figure 1. Calculation results of valve springs

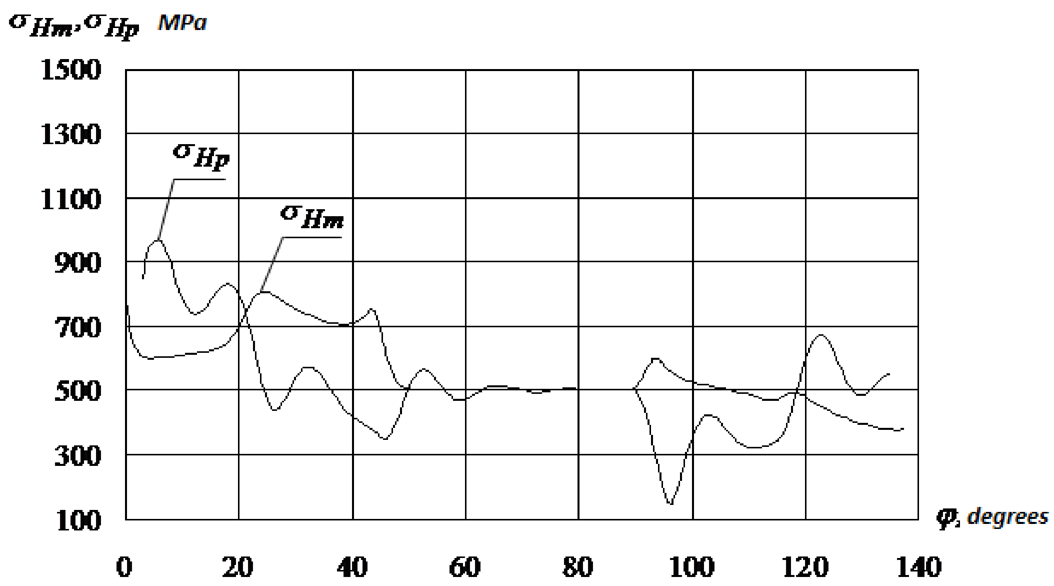

Figure 2. Calculation results of valve springs

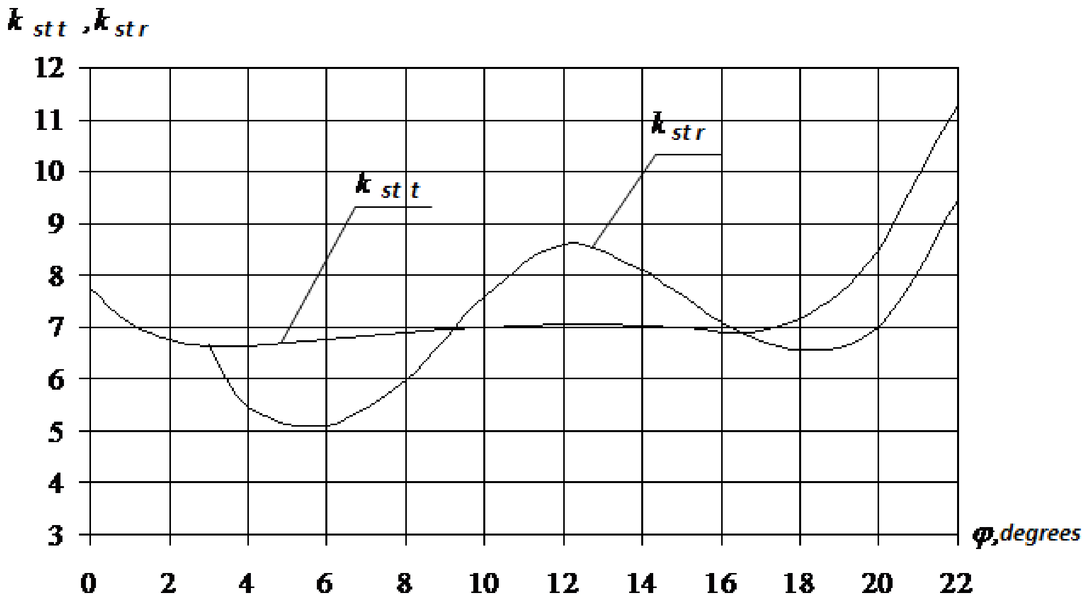

Figure 3. Calculation results of valve springs

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