Numerical simulation and investigation of induction system for hardening of internal combustion engine camshaft

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Abstract. This paper describes the numerical simulation and investigation of the electrothermal processes in the induction system for hardening of cams and journals of camshaft. Hardening of the camshaft elements is carried out by one simple inductor of round shape due to shift of the camshaft axis inside it. During the process of the hardening of the cams, the camshaft is stationary, during the process of the hardening of the journals it rotates. The results of the investigations are presented in the form of the temperature distribution in the cam and the journal. The optimum parameters of the induction system are also given, at which the best temperature distribution in the elements of the camshaft is achieved.

1. The camshaft hardening problem
A camshaft, which consists from cams and journals, is very important detail of any internal combustion engine. The camshaft is used to operate engine valves, which give fuel mix or let out the fulfilled. The number of camshaft cams is equivalent to number of engine valves. As a result there is an individual cam for each valve, which opens it, when runs on a pusher lever of valve. When the cam "runs" from the lever, the valve closes because of force of returnable spring.

The journals of a camshaft rotate in bearings, and are exposed to destruction as well as cams, that's why a surface of these camshaft parts should have a high hardness. This property can be achieved by the way of induction surface hardening, which consists in preheating the workpiece to a temperature above the Curie point and its following cooling to temperatures of martensitic transformations. Induction surface hardening has a number of advantages over other methods of hardening workpieces with complex geometry [1].

The main problem of induction hardening of camshafts is uneven distribution of hardness on a surface of its elements and defect of cams after cooling.

The existing standard hardening methods have their disadvantages. The most broadcast method for hardening camshafts is when the shaft is inside the inductor, their axes coincide, and the shaft rotates. All shaft elements are hardened with one inductor. With this heating method surface of cam unevenly heats up in zones of a nape and a nose, and journal surface badly gets warm because of a big gap between a workpiece and inductor. As a result we get the low depth of the hardened layer, big thermal losses and low efficiency of process.

2. Numerical simulation of induction system for hardening a camshaft
Within the framework of this work, a solution to the problem of hardening cams and bearing journals of camshaft is presented using numerical simulation in ANSYS® Software.
This solution consists in:
- development of a 3D electrothermal model of the inductor-workpiece system;
- determination of the optimal position of the shaft axis about the inductor axis when various shaft elements hardened;
- optimization of the inductor geometry.

The developed induction system provides an uniform distribution of the hardened layer depth and hardness on the surface of the cams and the bearing journals of the camshaft.

Heating during hardening of the cams and bearing journals is carried out using one simple inductor by shifting the shaft axis inside the inductor. When the cams are heating, the shaft is stationary; when the bearing journals are heating, the shaft rotates.

The use of numerical simulation to solve a similar problem is shown on the example of a camshaft with three pairs of cams, which are located at an angle of 120 degrees relative to each other.

Figure 1 shows the parameters of 1/3 part of the camshaft, because the shaft consists of three symmetrical parts that differ only in the angle of the cams rotation.

![Figure 1](image1.png)

**Figure 1.** The parameters of 1/3 part of the camshaft

The position of the cams pairs relative to each other and the geometric parameters of the cam are shown in Figures 2 and 3, respectively.

![Figure 2](image2.png)

**Figure 2.** The position of the cams pairs relative to each other
2.1. Numerical simulation of induction heating of the camshaft cam
Using the approaches described in the literature [2, 3], a 3D model of the cam-inductor system was created in the ANSYS® Software, and then a numerical model of this system was developed on its basis. The cam is located inside the inductor, the inductor protrudes 6.5 mm from both sides of the cam along the Z axis. The 3D model of the cam-inductor system is shown in Figure 4.

Figure 4. The 3D model of the cam-inductor system
A single-turn round inductor has the following initial parameters:
• copper tube of rectangular profile 35×10 mm with a wall thickness of 2 mm;
• inner radius of the inductor – 85 mm.
Figure 5 shows a numerical model of an induction system.
Electrothermal calculations were carried out for several options for the location of the cam inside the inductor at a frequency of 2.4 kHz and an initial inductor current of 13 kA. In the course of research, the cam was displaced along the X and Y axes inside the inductor and changed the angle of rotation about the Z axis. Also, such system parameters as the height of the inductor and the current in the inductor was changing.

Based on the results obtained, presented in the form of the temperature distribution in the cam, it was found that the optimal heating of the cam occurs with the following parameters of the induction system:

- the shaft axis is displaced relative to the inductor axis by 2 mm in negative directions along the X and Y axes;
- the cam is rotated 90 degrees relative to the inductor current leads;
- inductor height – 33 mm;
- current in the inductor – 11.6 kA;
- heating time – 5 sec.

The results of numerical simulation of induction surface heating process of the cam at the optimal parameters of the induction system are shown in Figure 6 as a temperature distribution.

The temperature difference between the regions of the back and the nose of the cam is about 40 degrees, and the overheating of the nose corners is insignificant, which together is the best result among all the calculations performed.
2.2. Numerical simulation of induction heating of the camshaft bearing journal

Further, a numerical simulation and investigation of induction heating process of the bearing journal of this camshaft in a copper inductor was carried out, the optimal geometry of which was calculated earlier. The purpose of these investigations was to determine the optimal parameters of the induction system at which the bearing journal is uniformly heated to a temperature of 850-880 °C up to 2 mm in depth.

The inner diameter of the bearing journal is 19 mm, the outer diameter – 34 mm, and the height – 30 mm. A single-turn inductor of a round shape is made of a rectangular profile of 33×10 mm with a wall thickness of 2 mm, the outer diameter of the inductor is 85 mm.

The bearing journal is located inside the inductor, the inductor protrudes 1.5 mm from both sides of the bearing journal along the Z axis. Figures 7 and 8 show a 3D model and a numerical model of the bearing journal-inductor induction system.

**Figure 7.** The 3D model of the bearing journal-inductor system

**Figure 8.** The numerical model of the bearing journal-inductor system

Electrothermal calculations were carried out for several options for the location of the bearing journal inside the inductor. During the research, the bearing journal was displacing relative to the X and Y axes inside the inductor, while the effect of the shaft rotation about the Z axis was simulated.
According to the research results obtained in the form of the temperature distribution in the bearing journal, it was found that the camshaft bearing journal heats up evenly to a depth of 2 mm to a temperature of 850–880 °C at the following parameters of the induction system:
- displacement of the shaft axis inside the inductor by 2 mm to the current leads;
- current strength – 11.2 kA;
- current frequency – 2.4 kHz;
- heating time – 9 sec.

This heating mode provides a uniform depth of the hardened layer and a uniform distribution of hardness on the surface of the bearing journal due to its rotation and shift of the shaft axis inside the inductor.

The results of numerical simulation of the induction surface heating process of the camshaft bearing journal at the optimal parameters of the induction system are presented in Figure 9 in the form of a temperature distribution.

![Figure 9. Optimum temperature distribution in the bearing journal](image)

3. Conclusions and outlooks
Numerical simulation significantly reduces the time for developing real induction installations, as well as for investigations and debugging of the induction heating and hardening processes of workpieces with complex geometry.

The obtained results of numerical simulation of induction heating of camshaft elements can be used as a basis for investigations and developing of induction installations for hardening camshafts of various configurations.

References
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