

Conference Article

## CAD/CAM/CAI Application for High-Precision Machining of Internal Combustion Engine Pistons

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### Abstract

CAD/CAM/CAI application solutions for internal combustion engine pistons machining was analyzed. Low-volume technology of internal combustion engine pistons production was proposed. Fixture for CNC turning center was designed.

*Keywords:* CAD/CAM/CAI, piston, Internal Combustion Engine

### 1. Introduction

Manufacturing of gas turbine engine parts with the required surface quality and tolerances is a complex task which requires the appropriate parameters of machining and using a suitable cutting tool according to previously conducted research [1-3].

The piston is one of the most loaded parts in modern engines. Increases in the maximum engine speed in modern engines requires the reduction of the piston weight. Piston weight reduction leads to a decrease in lateral inertia forces and mechanical losses with increase of its capacity and maximum permissible engine speed. A piston weight decrease should be accomplished for the same part shape and without losing simplicity.

The surface of the guide piston (skirt) should have a contact area with the surface of the cylinder and the necessary tolerance between these surfaces during operation. A 3-D model of the piston is shown on Fig. 1.

Detailed features of the part can be seen in Fig. 1. The internal surface of the piston has a complex shape. The head strengthening ribs are located on the bottom of the piston. Grooves for the sealing rings are placed on the outside of the piston. In the pin hole for the compression ring groove, the window and pockets are located on the outer surface.

A complicated arrangement of external and internal surfaces of the pistons of internal combustion engines allows for the low and non-uniform stiffness in the longitudinal and cross sections of the piston. This design requires a careful preparation of machining operations requiring high standards of design accuracy. A hole for the pin, the lower part (skirt) and grooves for compression and oil rings are the most crucial parts of the piston.

For a tight tolerance and no interference of the outer and inner surfaces, with precision shapes and sizes, they require

a grade 6-8 for a height of surface roughness up to Ra 0,32 microns. To reduce the sliding friction on the outer surface of the piston skirt a microprofile is specified as a broken line with a pitch of 0.34 millimeters and an angle of bend of 10°.

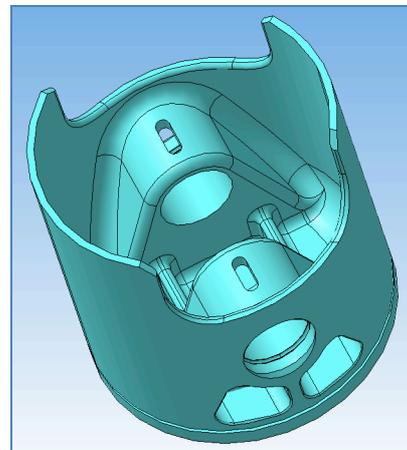


Fig. 1. The 3D model of ICE pistons

When machining the piston these specifications are provided by superposition of technological base and the design basis – the axis of the piston. Axis as technological base can be realized by including the inner conical surface of the piston, which should be located near the open end of the skirt. This conical surface formed in a single operation is maintained throughout the process and is used for machining the most accurate external surfaces of the piston. The principle of constancy of bases is realized, both at a piston fabrication stage, and at accuracy monitoring of the relative positioning stage (coaxiality of a head and a skirt, perpendicularity of an end face of a head and end faces of flutes under piston rings to an axis of the piston and others) and accuracies of a form of surfaces (profiles transversal and longitudinal head and skirt section). Locating of the piston in

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angular position around its axis is carried out on an opening under a pin.

The technology for low volume production employs specialized metal-cutting machines with CNC. The conic base on the inner part of a skirt is obtained with billet stamping. Processing of pin holes in this case is carried out on the machine milling group using a CAI software.

## 2. Computer model

In this work the specialized software product for monitoring and measurement of details on machines uses the contact measuring clearance gages of Delcam PowerINSPECT shown in Fig. 2.

For the building model in the software the control and measuring device and the probe type should be chosen in accordance to actually used in the machine. Measurements taken in one instance are shown in Fig. 3.

In PowerINSPECT there are two ways of setting a base. The first way - is called PSP ((plane - straight line - point). It is enough to define and measure three elements of the part under investigation to define its position. However there are cases when the part does not have such a geometry, for example this piston. In this case a different way of getting a base with an optimum combination is used. Thus the program attempts to combine the measured points and points on model so that the distance between each of them was the least.

The construction of an adjusted 3D-part model using CAD-systems in accordance with the actual state of a workpiece is produced according to the results of measurement. The NC-file for machining of pin holes is constructed with CAM-system on the base of the adjusted model with the new coordinate system.

## 3. Machining sequence

The process is followed by turning. To ensure the specified accuracy of turning at the beginning there is stripping, which determines the uniformity of skirts and head thickness. The next operation is forming of all surfaces of the piston. The machining sequence of the piston is shown in Fig. 4.

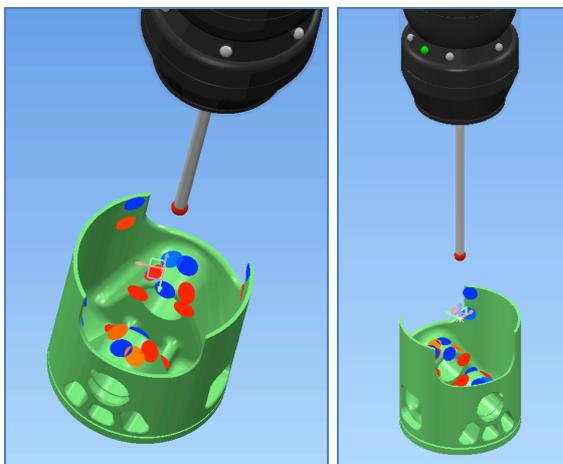


Fig. 2. Measurement of surfaces in the CAI-system

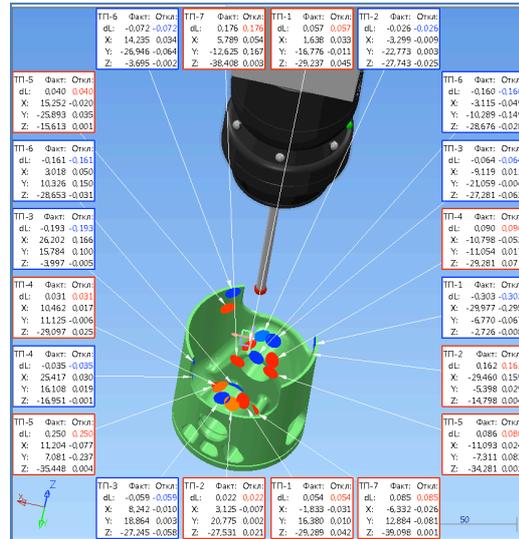


Fig.3 Measurements.

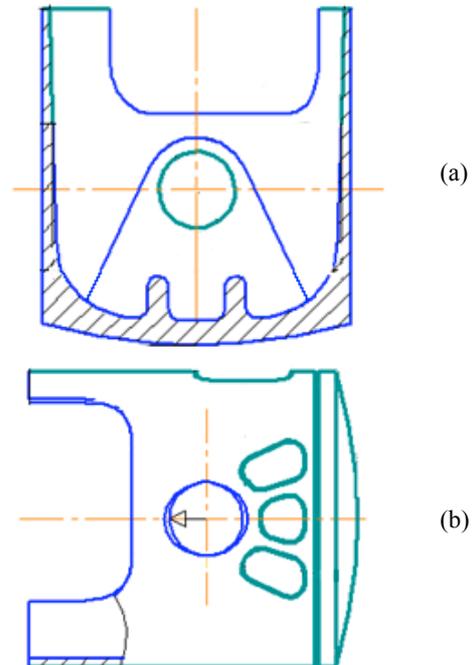


Fig.4- Sequence of machining of the piston  
 a) milling machine, b) turning machine

Most important operation is a formation of an oval and barrel shape which is carried out at the end of technological process. Ways of producing an oval and barrel shape are shown in table 1.

Table 1. Producing an oval and barrel shape of piston

Machining type	Turning	Milling	Turning with deformation of workpiece
Machines	lathe	Turning center	Lathe
Tools	Turning tool	Spherical milling cutter	Turning tool
Method	Fast electric drive of feed of cutting tool	Powered turret head	Specialized gripping accommodation
Productivity	high	low	high

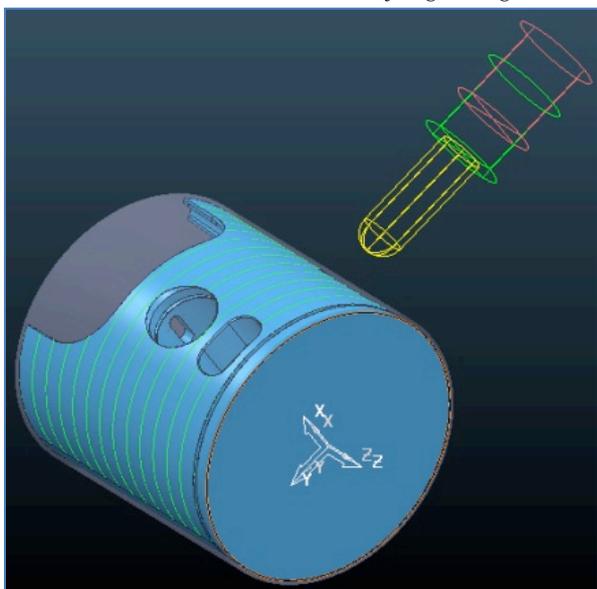


Fig. 5 - Producing an oval and barrel shape piston by milling

The multi-purpose turning center is used to produce the necessary geometry. The turning purpose with high-speed feeding means the reciprocal movement of the tool in the radial direction synchronously with spindle rotation. The “trace and trace” shaping method is used in this scheme. It is necessary to install the rapid drive of cutting tool movement on the machine for the implementation of this scheme. The main requirement for this drive is providing synchronization with the main movement drive by given frequency and amplitude.

The shaping of an oval and barrel shape of the piston during milling is carried out by the “contact and trace” method. For machining of piston elements like cooling pockets, and for pin holes, the machine must be equipped with a turret drive and it should have the ability to use the rotation of the main spindle as the feed motion. For this scheme any additional equipment for the machine is not required. Thus it has low cost, but there is a significant drawback. To ensure the required quality of the machined surface cutting line width should be about 0.05 mm, and it means that the machining time will be much greater than in case of turning schemes.

Turning with preliminary elastic deformation is widely used in manufacturing of pistons of four-stroke engines where only the skirt has an oval shape. Piston head also has an oval cross-section, which greatly complicates the task of designing a device. It should provide an uneven clip with taking into account the stiffness of individual elements of the piston to obtain the desired geometric characteristics after unloading.

Thus, using of the milling scheme for producing an oval and barrel shape parts is optimal for the case of small-scale production. At large-scale production it is recommended to use turning schemes, which provide necessary geometrical characteristics of the piston with high efficiency. The machining scheme for producing an oval and barrel shape is shown on Fig. 5.

For producing a barrel shape of the piston the spherical mill is used which has to be located perpendicular to an workpiece rotation axis.

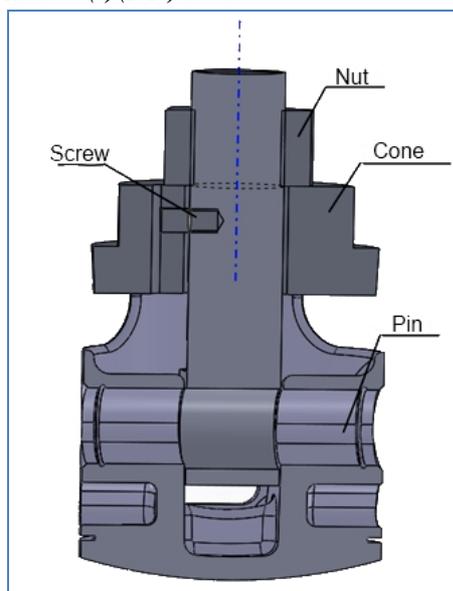


Fig. 6. The fixture tool scheme for locating and fixing the piston on the machine

Reliable locating and fixing of the piston on the machine is required during its milling and turning. In this regard, it was decided to use a design of fixture tool (Fig. 6) as a prototype [4-5] of an workpiece clamping device for a multi-purpose lathe machining center.

The locating of the workpiece on the fixture tool is carried out by two conic surfaces. One of them is located on a piston skirt, another – on the piston head. Axial clamping is performed by using a cross pin through the central hole of the piston. The pin is attached to the central shaft device. Its movement along own axis provides reliable fixing of the workpiece. In this scheme of the device the pin is also the basis of the angular position of the workpiece. This design enables the handling of all external surfaces of the piston in a single setup. High requirements for surface roughness determine the using of a lubricant and coolant fluids. The effect of the external conditions and lubricant and coolant fluids on tool-workpiece contact is described in [6].

The necessary geometry of the piston can also be produced by high-speed feeding of a turning tool in the radial direction. A special device for non-circular turning is established on the lathe in these cases. The spindle is rotating and turning tool is moving back and forward in the radial direction simultaneously. This allows non-circular turning at low speed of the spindle.

#### 4. Conclusions

Thus, CAD / CAM / CAI systems allow a technological engineering of small-scale pilot production of engine pistons. CAD-system let us to adjust the initial 3-D model in accordance to the technological requirements. CAD-system makes it possible to design a fixture device for an workpiece. A NC file for precision machining is constructed by CAM-system. CAI-system makes it possible to determine the actual location of the workpiece on the machine. Using CAD / CAM / CAI systems let us to avoid major errors at the stage of technological engineering and to reduce the cost of pilot production.

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