Numerical simulations of honing process of thin-wall cylinder liners, with constant and with variable thickness of wall of honed parts

M.Sc. Sender P.G.
Faculty of Mechanical Engineering – Gdansk University of Technology, Poland
piotr.sender@wp.pl

Abstract: Numerical simulations of honing process of thin-wall cylinder liners, with constant and with variable thickness of the wall of honed workpieces can improve and can help to conduct the experimental research of honing process and can improve the honing process. A very valuable research assumption, before performing the numerical analysis of computer simulation of honing process, is the measurement of the real geometry of the honing head using a CNC coordinate measuring machine and measuring of the honed workpiece's temperature occurring in the honed workpiece during honing process with a thermal infrared camera. Thick-walled workpieces do not create machining and technological performance problems. In a predictable way, it’s possible to plan the machining time remaining to receive the desired diameter of the hole being honed. Deformations of a thin-walled workpiece with varying wall thickness occurring during honing, which were measured after machining, showed that there is no linear correlation of holes deformation received for a different cross-section thicknesses of wall of honed cylinder liners for various oilstone pressure and due to the workpiece temperature increase.

Keywords: HONING, CYLINDER LINER, FEA SIMULATION OF HONING PROCESS

1. Introduction

1.1 Short literature review

Many attempts have been made by researchers to develop numerical simulation methods for manufacturing processes ... [6].

In order to reduce the time and costs of surface finish development, simulation programs have become a powerful tool and are being increasingly used in the automotive industry [3]. Numerous publications address the determination of the real shape and shape deviations of liner bores using various methods of simulation and measurements [2]. The model and simulation method can be used to predict the evolution of bore diameters during finish honing [5]. In the modern conditions, a computer simulation of processes is more frequently used as it accelerates design and allows avoiding some errors [7].

1.2 Serial manufacturing process of honing of cylinder liners – material removal rate (measured during real production of cylinder liners)

Several hundred of the cylinder liners of internal combustion engines (Fig. 1) underwent a honing process. The honed workpieces was mounted in such a way that round plates were placed on both faces and screwed together, so that the workpiece was stiffened (Fig. 3). Honed cylinder liners were attached to the honing machine by catching on the discs, so that the chain clamp did not cause deformation of the honed workpiece (Fig. 3).

Fig. 1 Drawing of honed cylinder liner with shown 4 measured sections

Fig. 2 Cylinder liners, with their treatment (No.19, No.20, etc.) and cross-section numbers used for making a manufacturing and process quality report (after honing process) [1]

Fig. 3 Cylinder liners mounted on a Sunnen’s CNC HTH 4000-S horizontal honing machine

Comparing Fig. 4 - Fig. 7, it can be seen that each workpiece’s cross-section (showed on Fig. 1 and Fig. 2) is characterized by a slightly different MRR behavior, which means that during honing, when honing several different sections of different thicknesses, different hole diameters are obtained (in different sections).
As a result of the honing on a Sunnen’s CNC HTH 4000-S horizontal honing machine, of cylinder liners with 4 variable cross-wall thickness, the received information is that only on the thickest section No. 4 there is a predictable MRR behavior in honing duration time $T$.

**Fig. 4** The material removal rate in section 1, in 4 stages honing

**Fig. 5** The material removal rate in section 2, in 4 stages honing

**Fig. 6** The material removal rate in section 3, in 4 stages honing

**Fig. 7** The material removal rate in section 4, in 4 stages honing

1.3 Serial manufacturing process of honing of cylinder liners – workpiece temperature increase during honing (measured during real production of cylinder liners)

Fig. 8 and Fig. 9 show the thermogram obtained with the thermographic camera. Fig. 8 shows the thermogram of the cylinder before machining. Fig. 9 shows the thermogram of the cylinder after the honing process. The measured temperature increase in honing process was even $\Delta T = 40^\circ$C.

Despite the use of a stiffening sleeve, due to the occurring temperature increase, the measured dimension of the diameter of the smoothed hole immediately after the treatment was different by a few hundredths of a mm after cooling the cylinder stored in the Quality Control Chamber.

Thermal distortions (measured diameter in different places of the honed workpieces) showed that is no linear correlation about thermal distortions in the same workpiece, but on different sections (in different cross-wall thickness).

**Fig. 8** Thermogram of cylinder liner (treatment No. 42) before honing process

**Fig. 9** Thermogram of cylinder liner (treatment No. 42) after honing process (red color show an increase $+\Delta T$ °C of workpiece temperature)

The reason to make the FEA numerical simulation of the honing process of combustion’s cylinder liners was to recognize the differences of honing of parts with variable and with the same cross-section’s thickness of honed workpiece’s walls.
2 Numerical simulations of honing process

2.1 Preparing of 3D model of honing head used in FEA softwares

Numerical simulations of the honing process FEA (Finite Element Analysis) of thin-wall cylinder liners, with constant and with variable thickness of the wall of honed workpieces can improve and can help to conduct the experimental research of honing process and can to improve the honing process. A very valuable research assumption, before performing the numerical analysis of computer simulation of honing process, is the measurement of the real geometry of the honing head using a CNC coordinate measuring machine, and measuring of the honed workpiece’s temperature occurring in the honed workpiece during honing process using a thermal infrared camera. Fig. 10 and Fig. 11 shows the measuring stand - the CNC coordinate measuring machine Zeiss Contura. Deformation of a thin-walled workpieces with variable wall thickness causes the most difficulties in the honing process, due to the variable MRR value (efficiency of honing process) in cross-sections of various thicknesses [1, 4].

Fig. 10 Zeiss Contura with measuring swivel head RDS

Fig. 11 Measurement of the axial pressure shaft of the honing head on a CNC coordinate measuring machine Zeiss Contura

All parts of the honing head were measured and then the received dimension of each of the parts was used for making the 3D solids of honing head, needs for conducting a numerical simulation of the honing process.

Fig. 12 shows the 3D model of the honing head, created in the CAD system in 1:1 scale, according to measurements made on the CNC coordinate measuring machine.

Fig. 12 3D model of honing head made by the author of the article

Fig. 13 Honing head’s and cylinder liner’s 3D model, made by the author of the article

2.2 Distortion of thin-walled workpieces with constant cross-section thickness of the wall of honed parts

Fig. 14 shows the 3D model of the honing head and cylinder liner with the measuring grid, which has been subjected to numerical FEA simulations.

Fig. 14 3D model of the honing head and cylinder with computing FEA measuring grid
In practice, when performing for several years dozens of cylinders of internal combustion engines, it was noticed that it is not possible to honing the holes in one stage, due to thermal deformations. It was noticed too that honing of holes of workpieces with thick wall thickness runs smoothly.

Fig. 16 presents an example of a computer simulation, of the cylinder with a constant cross-section wall thickness, of deformation value depending on the value of the honing working pressure of oilstones to the machined surface of the honed hole. For the 0.5 MPa pressure (axial direction, Fig. 15a) a deformation value in the X direction (radial vertical direction) of 0.027 mm was obtained.

The effect of the simulation of the honing process of the workpieces with cylindrical holes (with a constant cross-section thickness of honed workpiece walls) for three values of the honing pressure: 0.5, 1.0 and 1.5 MPa as shown in Fig. 17, the impact of the oilstone pressure on the deformation of the honed cylinder’s diameter dimension is a linear function.

\[ Y = -0.0047 + 0.056x \]  

where:
- \( k \) - heat transfer coefficient [W/mK]; 
- \( L \) - workpiece’s honed hole length [m]; 
- \( T_1 \) - internal temperature [°C]; 
- \( T_2 \) - external temperature [°C]; 
- \( T_0 \) - ambient temperature [°C]; 
- \( r_1 \) - internal radius of the honed hole [m]; 
- \( r_2 \) - external radius of the honed workpiece [m]; 
- \( g \) - cross-section of honed workpiece from Fig. 1.

Simulation of honing process of workpieces with the same cross-sectional thickness showed a linear correlation coefficient \( r \) value of \( r = 0.97 \), which means that honed parts with the same thickness have the possibility of machining in the predicted manner, i.e. conducting honing with predictable treatment time \( T \) remaining until the expected dimension of the diameter of the hole to be honed.

2.2 Simulation of thermal deformations of the honed workpiece in the honing process

On Fig. 18 shown received temperature of the honed workpiece’s received during real honing of the engine’s cylinder liners. Fig. 18a and Fig. 19 shows photographs of a honed workpiece, made with a thermal infrared camera. Fig. 18b schematically presents the heat flow through the cylindrical baffle.

Stream of heat \( \dot{Q} \) flowing from the inside of the cylinder to the outside (from Fig. 18b) is represented by the formula (1):

\[ \dot{Q} = \frac{T_2}{r_2} \ln \left( \frac{r_2}{r_1} \right) \]  

where:
- \( k \) - heat transfer coefficient [W/mK]; 
- \( L \) - workpiece’s honed hole length [m]; 
- \( T_1 \) - internal temperature [°C]; 
- \( T_2 \) - external temperature [°C]; 
- \( T_0 \) - ambient temperature [°C]; 
- \( r_1 \) - internal radius of the honed hole [m]; 
- \( r_2 \) - external radius of the honed workpiece [m]; 
- \( g \) - cross-section of honed workpiece from Fig. 1.
The next stage was to import of data (received in the real honing process) to Solidworks Simulation 2016 and to Autodesk Simulation 2014 FEA softwares and to conducting the numerical simulations of the honing process.

Fig. 19, Fig. 20 and Fig. 21 shows an image recorded during computer simulations, illustrating stresses created during the honing process, that have different values in different cross-sections.

Fig. 22 FEA computer simulation image: von Misses stresses in a honed thin-walled cylinder liner with variable wall’s cross-section thickness

Fig. 23 shows a cylinder of an internal combustion engine with marked sampling measuring points (where simulation results were collected). The FEA numerical simulations showed that anywhere in the honed cylinder liner, loaded with a temperature of $T = 40^\circ$C on each oilstones, there is a different temperature on the outside surface in different sections.

At a difference of 22°C between the temperature of the oilstone and the cylinder (Fig. 22), 6 microns of thermal deformation occur. The flow of heat from the oilstone at 40°C to the workpiece with ambient temperature $T_0 = 20^\circ$C (measurement of heat flux at many points) shown on Fig.23.

Fig. 23, Fig. 24 and Fig. 25 shows a different temperature field on the honed cylinder liner received in FEA thermal simulation analysis.
Fig. 24 Window view of heat flux temperature measurement, from Autodesk Simulation 2014 FEA software

Fig. 24 and Fig. 25 shows the image recorded during computer simulations from FEA software, showing the flow of temperature, which have varied behavior in different workpiece’s cross-sections.

Fig. 25 Window view of flow of temperature measurement, from Autodesk Simulation 2014 FEA software

This different temperature flow behavior in a different cross-sections causes a differential thermal stresses and distortions of honed holes’s diameter.

Fig. 26 Window view from Solidworks Simulation 2016 - the measurement of stresses in various cross-sections of a thin-walled sleeve with a variable wall thickness

Fig. 26 shows an image recorded during FEA computer simulations, illustrating stresses that have different values in different cross-sections, of the honed engine’s cylinder liner.

Fig. 27 shows the cylindricity deviations obtained during the serial manufacturing honing process of a thin-walled cylinder liners for the section with the largest thickness, due to the occurring pressure of the oilstone to the surface of the borehole being honed. There is no linear correlation for a thin-walled workpieces with varying wall thickness between individual wall thicknesses in each section of honed workpiece, and the measured strain. This means that due to the stresses behavior occurring in honing process (influencing on MRR value), the honing process creates technological problems.

Fig. 27 The lack of linear correlation between the effect of cross-section of wall thickness on the cylindricity deviation of the hole being honed relative to machining efficiency on each cross-wall thickness
Fig. 28 shows the cylindricity deviations obtained during the serial honing manufacturing process of a thin-walled engine’s cylinder liners due to the temperature increase of honed workpieces during machining. There is no linear correlation for thin-walled parts with variable cross-wall thickness, between the temperature increment in the machining system and the measured cylindrical deviation of the honed hole. This means that due to the temperature behavior, machining of workpieces with variable cross-wall thickness creates operational problems, due to the inability to easily set the time remaining to finish of machining, in order to remove the material to obtain the required diameter of the honed hole.

Computer simulations illustrate the different values of strains recorded during the honing of a thin-walled workpieces with variable wall thickness in different sections of honed part. The heat flow observed during computer simulations shows that more heat is present in a thicker cross-section. The more heat - the greater its thermal deformation. The obtained results also change the different stress values for cross-sections on the different cross-section of wall thicknesses.

There is no linear correlation for a thin-walled workpieces with varying wall thickness between individual wall thicknesses in each sections of the honed workpiece, and the measured strain. This means that due to stresses behavior occurring in the honing process, the machining creates technological problems.

Thermal and stress distortions make it impossible to perform the treatment (honing of cylinder liners) in one step, due to the lack of linear correlation of machining efficiency for each cross-section of the honed workpiece, that’s why the honing process of a thin-wall cylinder liners with a variable cross-section thickness should be carried out in several stages.

### References


