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Force-controlled form honing using a piezo-hydraulic form honing system

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ABSTRACT

Form honing of cylinder bores represents a manufacturing approach to compensate mechanically or thermally induced distortions in combustion engines, aiming at reducing internal friction. This article describes a new concept of a form honing tool, based on a piezo-hydraulic force transmission for the actuation of the honing stone. Conception, constructive design, prototypical implementation, and experimental evaluation of the new form honing concept is presented. This new concept leads to a significantly increased process-performance and provides the possibility for in-process recording of the honing normal force, which represents the basis for a new force-controlled form honing process.

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1. Introduction

Frictional losses within combustion engines basically have their origin in the piston system (pistons, piston rings, cylinder bore). They can account for up to 15% of the total fuel consumption in the New European Driving Cycle (NEDC) [1]. Especially the deviation of the macroscopic cylinder shape in the particular operating point of the combustion engine from the cylindric ideal geometry represents a significant influence factor on friction. The deviations [1,2,3] are due to mechanically and thermally induced distortions during assembly and operation.

In industrial production a so-called torque plate is screwed to the cylinder crankcase prior to the honing process for compensation of the mechanically induced distortions, which are caused by the assembly of the cylinder head [2,3].

Honing of an inverse distortion geometry by (free) form honing is another approach for compensating influences of mechanically and thermally induced distortions. Superpositioning the occurring distortions, the inverse distortion geometry leads to an ideal cylindrical bore shape in engine operation.

Up to date systems for form honing utilize piezo actuators for location-dependent infeed of single honing stones because of the very good travel dynamics.

The actuators are either directly integrated into the honing tool [3] or arranged outside and equipped with a mechanical transmission of the travel motion [2].

However, the dynamic of the travel motion is limited by the spring-based retraction motion and friction during the mechanical travel transmission, which leads to deviations of the predefined target geometry in form of harmonics (Fig. 1). Additionally, the support bars for absorbing the reaction forces and guiding the tool in the bore that are required for form honing lead to an inhomogeneous surface topography (Fig. 1) by its friction on the workpiece surface and can therefore add to deviations of the target shape [2]. The currently known form honing systems compensate these form deviations by an iterative running-in process.

Controlling the infeed force by indirect measuring of the drive torque of the infeed device is common practise for improving the process stability during conventional honing. Approaches for contact pressure controlled processes for form honing are not known so far.

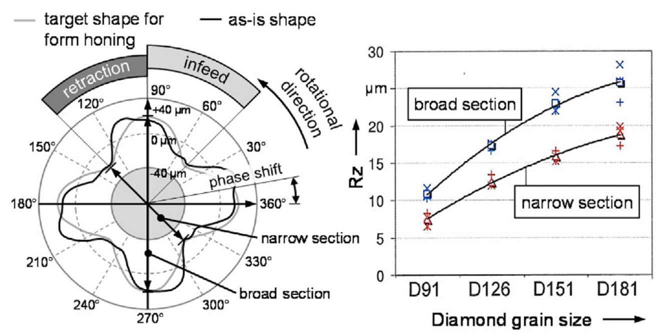

Fig. 1. Influence of the motion dynamic on the created shape and of the support bars on the workpiece surface according to Ref. [2].

2. Piezo-hydraulic travel systems

Piezo actuators can only create relatively low travels of about 0.1% of their length. Consequently, mechanical and hydraulic systems for travel extension for diverse applications were developed. Especially hydraulic transmitters, as a combination of piston, membrane, or corrugated tube for the input and output

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side including a hydraulic fluid [4,5,6] have proved successful for high dynamic applications such as valve actuation.

Hydraulic transmission systems bear some potential for an application in form honing. Besides a mere extension of the generated travel, an active retraction motion by direct coupling of a prestressed piezo actuator with the input side gives reason to expect positive influence on the achievable travel dynamic. Additionally, the output force can be implied by measuring the hydraulic pressure in the fluid associated with the known output surface. As a result, the hydraulic system pressure can be converted to the honing stone contact pressure and thus be used for controlling the process.

3. Development of a piezo-hydraulic form honing system

3.1. Design

A piezo-hydraulic form honing system was developed at the Institute of Machine Tools and Production Technology of the Technische Universität Braunschweig. Power transmission and data transfer, travel creation, and travel transmission are realized as single modules [7]. The system includes a slip ring transmitter, an infeed head with coaxial mounted and axial shiftable piezo actuators as a package, and a form honing tool as hydraulic travel extension system with corrugated tubes for input and output (Fig. 2). Wear of the honing stones can be compensated by axial shift of the complete actuator package and the honing stones can be put on the bore wall with a defined base contact pressure. The base contact pressure is superimposed by the piezo actuator infeed during the honing process. The form honing tool is equipped with a central double cone similar to a conventional honing tool. In this case it is only used for positioning the support bars.

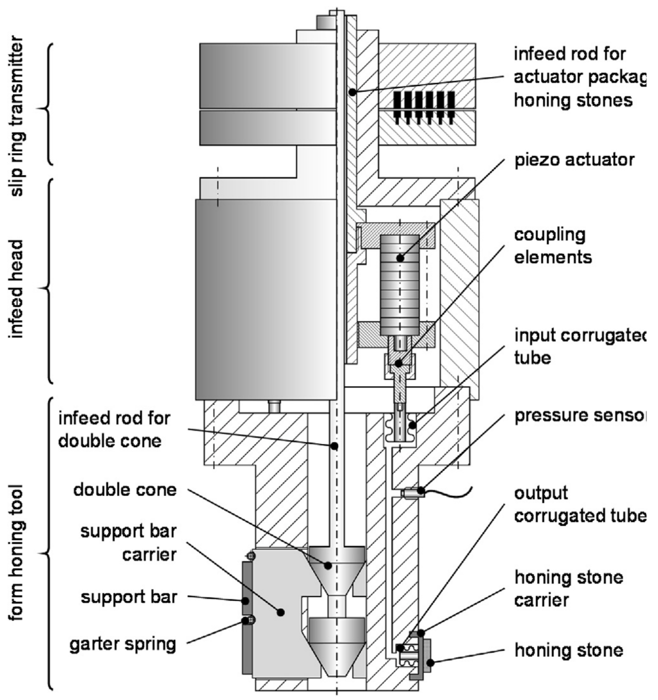

Fig. 2. Layout of the piezo–hydraulic form honing system.

3.2. Determination of system compressibility on the basis of a model test rig

The force at the output side of the hydraulic transmission significantly depends on the compressibility of the whole system K* (pressure depending change in volume) and therefore on the compressibilities of the system elements:

$$K* = KF + Kin + Kout + Kother \; in \; mm3 \; MPa - 1 \qquad (1)$$

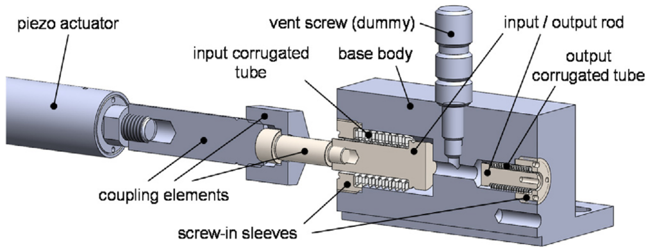

Fig. 3. Test rig for determining the compressibilities of the system elements.

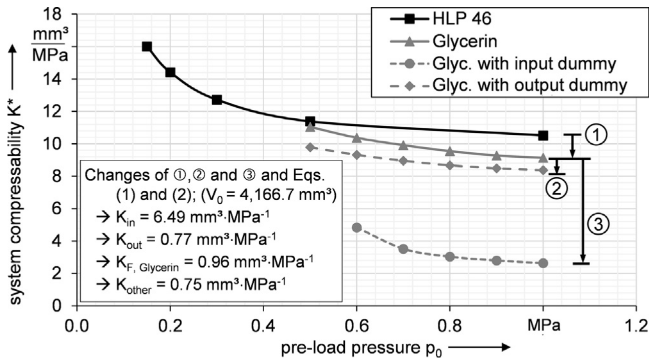

Fig. 4. Results of the compressibility in the test rig.

Where K_F is the compressibility of the fluid volume, K_{in}, K_{out} and K_{other} are the compressibilities by elastic deformation of the input and output corrugated tube and any other system elements involved. The compressibility of the fluid volume is defined by the compression module k_f of the fluid and initial volume V_0:

$$KF = V0 \cdot kf - 1 \; in \; mm3 \; MPa - 1 \qquad (2)$$

To determine the single compressibilities a test rig consisting of a simple base body, standard corrugated tubes for the input and output side, an absolute pressure sensor, and a ventilation screw for filling the system under medium vacuum (0.01 mbar) was built (Fig. 3). In order to achieve sufficient tightness of the system and to guarantee changeability of the corrugated tubes at the same time, they are laser-welded to an input rod respectively output rod and a screw-in sleeve which is assembled to the base body using liquid thread seal.

The system compressibility is determinable with the output side blocked mechanically by displaced volume on the input side (determinable by measuring the input travel by strain gauge on the piezo actuator and the hydraulically effective surface area of the input corrugated tube) in correlation with the resulting change of the system pressure.

The fluid was varied and each corrugated tube exchanged by an incompressible solid steel dummy while maintaining the fluid volume for experimental determining the compressibilities of the system elements. The individual compressibility can be calculated by Eqs. (1) and (2) from the resulting change of the system compressibility. The fluids standard hydraulic oil HLP46 and pure glycerin were used.

The results revealed that the system compressibility approaches a constant value with increasing preload pressure p_0, which is referable to the pressure dependent compression module of the fluids (Fig. 4, compare Ref. [6]). Additionally, it becomes clear that the compressibility in the model test rig is substantially determined by the input corrugated tube.

3.3. Built-up of the form honing tool

The form honing tool was designed for up to four independently controllable form honing stones (Fig. 5).

Based on the test rig results a special corrugated tube was developed in cooperation with the manufacturer, by which the compressibility of a glycerin-filled form honing tool could be

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