Thermally coupled structural analysis of a connecting rod obtained by powder metallurgy

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Abstract: The paper is structured in two parts, the first part is dedicated to modeling and numerical simulation in dynamic regime of the motor mechanism from a 4-stroke combustion engine and the second part, to finite element method analysis in thermally coupled structural behavior of sliding bearings. The bearings in the connecting rod structure are obtained by Powder Metallurgy. It is described the procedure for the experimental determination of the material properties of the parts made of metallic powders, which are required as input data for modeling in an integrated system of the sintering process coupled with the structural analysis of the engine assembly.

1. Introduction
This paper aims to analyze in dynamic regime a mechanism from a 4-stroke internal combustion engine. There are identified the laws of variation in time for the kinematic and dynamic parameters by virtual prototyping. The main purpose of this paper is to identify the answer of dynamic loads of the connecting rods' mechanism. The two sliding bearings composing the connecting rod subassembly are made of metallic powders obtained by pressing and sintering. To identify bearings behavior, the connecting rod subassembly is analyzed with the finite element method in thermally coupled regime. At the same time, the modeling and simulation with finite elements in thermal regime of the bearings behavior during the sintering process is pursued. The kinematic and dynamic analysis of the motor mechanism is studied in several works, respectively [1], [2].

There are several attempts for modeling with the finite element method of the sintering process of parts obtained through powder metallurgy.

Connecting rods made of sintered powders with a complex shape show problems related to non-uniform distribution of density. The optimal quality of the connecting rod is conditioned by the physical properties of the preform. The obtained results show that the stress flow increases with decreasing temperature and increasing strain rate. [3]

The invention presented by Lynn concerns an improved manufacturing method of a powder metal connecting rod with a stress riser crease formed in a side face by forging a sintered preform with a generally V-shaped notch in the side face. [5]

Many powder metallurgy processing techniques are available for manufacturing different components, ranging from pressing and sintering to hot isostatic pressing, powder forging, metal injection molding and rapid prototyping; these are discussed in various publications. [4]

2. Dynamic analysis of the mechanism of an internal combustion engine
2.1 Modeling with Finite Element Method
In order to analyze with finite elements in dynamic regime, the following steps are taken:

- The geometric model of the assembly crankshaft, connecting rod, piston is imported from Solid Works;
- There are defined the material properties for each component in the mechanical system;
- The kinematic joints between the mobile elements of the assembly are defined as 3D models with reference systems and contact surfaces;
- There are identified and defined the dynamic parameters for the two types of contacts, respectively:
  - The contact between elements without relative movement;
  - The link between elements with relative motion;
- We choose the type of finite element and mesh each component in the model;
- There are defined the pressure distribution laws on the four pistons (figure 2);
- There are defined the parameters for dynamic analysis (direct method, integration step, control algorithm, etc.);
- There are defined the local reference systems for monitoring the movement of the mechanical system in dynamic regime;
- There are identified the time-varying laws for dynamic system parameters or component elements, including strains, stresses or displacements resulting from the combination of rigid solid movement and the one of deformable solids. [8]

2.2 Input data for dynamic modeling of the mechanism:
The law of pressure variation on the piston, experimentally determined:
\[ p = -4.930 + 3203.386t - 1.631 \cdot 10^7 t^2 + 4.110 \cdot 10^9 t^3 - 4.504 \cdot 10^{11} t^4 + 2.229 \cdot 10^{13} t^5 - 4.102 \cdot 10^{14} t^6 \] (1)
- the law of variation of the crankshaft rotation angle.

Figure 1. Distribution of the resultant deformations on the assembly
3. Thermally coupled structural analysis of the connecting rod - bearing assembly.

3.1. Technology for obtaining bearings using metallic powders

**Bearings obtained from sintered metallic powders**

The connecting rod subassembly in the motor mechanism structure consists of two plain bearings made of pressed and sintered metallic powders.

Sintering was carried out at 1150°C, the samples being maintained at this temperature for 60 minutes. Heating was done slowly (60 min. at 350 degrees, 20 min. at 650 degrees) to maintain the temperature for the homogenization of heat in the mass of the pieces, as it is shown in the cyclogram from figure 6.

3.2. Characterization of the obtained specimens

After pressing and sintering, the densities of the specimens, their porosities and their contractions were determined.

![Figure 3. Density variation of unreinforced parts before and after sintering](image1)

![Figure 4. Density variation of reinforced parts before and after sintering](image2)
The curve of the density variation dependent on compaction pressure, before and after sintering for the unreinforced specimens (N) can be seen in Figure 3 and in Figure 4 for the reinforced ones (R).

By overlaying the two diagrams, we can compare the two types of specimens (Figure 5).

From the diagram study (Figure 5), it is noticed that the unreinforced specimens are denser than the reinforced ones. This is due to the fact that the reinforcement prevents the free flow of iron powder particles; it is possible that in the area of the wire to have more porous areas.

After sintering, the density of the pieces increases and the dimensions decrease.

![Figure 5. Density variation of reinforced and unreinforced parts before and after sintering](image)

![Figure 6. Sintering cyclogram of the samples](image)

Analyzing contraction variation charts, it is noted that the highest contractions are for B (0.8% for both unreinforced and reinforced parts pressed with 200 MPa pressures). The contraction value increases with the decrease of compaction pressure for width B, both for reinforced and unreinforced parts. [7] The contraction in height has the same tendency to decrease as the compaction pressure increases for both types of specimens. The L-length contraction value increases with increasing compaction pressure for unreinforced parts and has a random distribution for the reinforced ones (increases for a pressure of 300 MPa versus 200 MPa, then decreases to 400 MPa). [6]

![Figure 7. Variation of tensile breaking strength depending on the compaction pressure of the standard parts](image)

It is determined by experimental testing of tensile strength for different compaction pressures. In order to analyze the dynamic behavior of the bearings in the structure of the connecting rod subassembly, the data obtained on the models are at a compaction pressure of 400 MPa.
From the obtained force-strain diagrams analysis, it was found that the tensile breaking strength is directly proportional to the density of the parts (implicitly with the compaction pressure). It is also clear that the tensile breaking strength is higher for the reinforced parts than for the unreinforced ones. Using the previous data, can plot the variation of the tensile strength resistance of the unreinforced calibrator parts and the reinforced ones according to the compacting pressure which can be seen in Figure 7.

3.3. Finite element analysis in structural thermally coupled regime

For the finite element analysis of a bearing, the following steps were taken:
- Developing the geometric model;
- Defining the type of finite elements and material properties;
- Model meshing;
- Specification of loads and contouring conditions;
- Thermally coupled structural analysis;
- Processing the results.

For identifying the critical values of thermal or structural parameters were selected the nodes from the interest areas, obtaining the diagrams of variation for thermal flux, the thermal gradient and respectively the equivalent stresses von Mises (Figure 11).

**Figure 8.** Distribution of the resultant gradient on the bearing

**Figure 9.** Distribution of the resultant thermal heat flux on the bearing

**Figure 10.** The equivalent strain von Mises thermally-structural coupled

**Figure 11.** The resulting von Mises stresses in distributed on the bearing generatrix.
4. Results and discussions
From analyzing this paper, there can be established the following aspects:

- The mathematical model for determining the angular velocity and the motor moment of the actuation mechanism has been realized;
- The dynamic model with finite elements of the entire engine assembly with the ANSYS program was built;
- There were identified the laws of variation in time for the connecting forces in the two sliding bearings in the connecting rod structure;
- It is described the procedure for the experimental determination of the mechanical characteristics of the two bushings obtained by powder metallurgy (PM);
- The material properties were established on unreinforced and reinforced specimens, before and after sintering, by comparison;
- There were realized samples for more compaction pressures, the dynamic study being carried out on the 400 MPa sample without reinforcement;

By laboratory tests were established the modulus of elasticity, the Poisson ratio and other characteristics necessary for the analysis with finite elements in thermally coupled thermal regime;

5. Conclusions
It was found that the stresses, deformations and displacements monitored by the finite element method are in normal values for the two bearings in the connecting rod structure;

The obtained results recommend the use of parts made by powder metallurgy in the construction of the internal combustion engine drive mechanisms, which have an optimal thermal and structural behavior.

Mainly the thermal transient analysis of the studied bearings highlights the following results:

- distribution of heat flux in the bearing body (figure 9);
- distribution of the thermal gradient (figure 8);
- distribution of friction forces on the bearing in cylindrical coordinates;
- the distribution of equivalent strain (figure 10) and equivalent stresses (figure 11) in a thermally - structural coupled span.

The above-mentioned laws are materialized in the form of diagrams. The elaborated models fit into an integrated system that allows the extension of the procedure for the study of different types of sliding bearings in the structure of which are used groups of materials with different properties, allowing a complete verification in terms of static and dynamic resistance calculation, as well as thermal transfer.

6. References
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