IMPACT: International Journal of Research in Engineering & Technology (IMPACT: IJRET)
ISSN(E): 2321-8843; ISSN(P): 2347-4599
Vol. 2, Issue 7, Jul 2014, 69-76

THE MODERNIZATION OF GEAR MICROPUMP CASING WITH THE USE OF FINITE ELEMENT METHOD

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ABSTRACT

This paper presents the results of modernization of gear micropump casing in order to achieve minimization of overall dimensions and mass of the construction. Three different cases of the pump casing size were analyzed during numerical simulations with the use of finite element method (FEM). The dimensions of the first of the casings were identical to prototype unit, the second model was characterized by 15% reduction in size and the third casing was reduced by 25%. During the analysis, stress and displacement distribution in pump casings were observed. In the first modernized casing (85%), maximal stress value was equal to 104MPa, and the maximal value of displacement 0.012mm. In the second modification of pump casing (75%), the highest stress values achieved 134MPa, and maximal displacement 0.017mm. Strength and stiffness criteria in both modernized pump bodies were achieved.

KEYWORDS: Gear Micropump, Pump Casing, Finite Element Method

INTRODUCTION

Hydrostatic drive is the most convenient type of drive used to control and regulation of working speed of machines and systems. In recent years, a dynamic progress in the field of microelectronics and micromechanics has created new opportunities for the development of fluid power microsystems and microhydraulics. In hydraulic microsystems, the working medium is a fluid and elements generating flow and pressure of a fluid have dimensions from a few hundred nanometers to several centimeters. The flow in microhydraulics may be small (2 - 50 cm^3/s) or very small (< 2 cm^3/s) [1]. Miniaturization of hydraulic elements allows to replace the classical hydraulics with microhydraulics, where due to size or weight the former cannot be applied [2].

A fluid flow energy generator is a major component of each hydraulic system. The most common in industry are external gear pumps, which share is estimated at over 50%. The main advantages of these pumps include simple and compact design, reliability, high resistance to working medium impurities and high efficiency [3]. Currently, the development of gear pump constructions is mainly focused on improving the operational performance enabling higher power transfer with minimum losses and low noise and vibration levels. The description of gear pump design meeting this criteria is given in the literature [4-6].

The development of modern gear units is associated with several main factors: increase of operating pressure [6], improvement of total efficiency [4], reduction of pulsation [7], minimization of weight and noise [8-10], and reduction of dynamic loads [11-13]. Introducing changes in gear pump design in order to improve its parameters is possible with the use of various computer aided design software (CAD) [14], finite element analysis (FEM) [15] and computational fluid dynamics (CFD) methods [16-18]. Although, CFD method is relatively often used to calculate flow in gear pumps, FEM is rather rarely used to investigate stress distribution in pump elements. Therefore, in this study, FEM analysis of gear pump casing is performed. Analyzed in this paper pump design belongs to a group of microhydraulic elements, since it is characterized by a small flow, up to 25cm^3/s.

During the previous research, a novel gear micropump was designed and manufactured. The aim of this study is to determine whether the casing of the micropump may be minimized with respect to maximum stress and displacement rates. The modernization of the pump casing is provided by means of numerical analysis with the use of finite element method (FEM). The influence of the change of overall dimensions of pump casing on the stress and displacement distribution in the pump body is analyzed.

GEOMETRIC MODEL

The prototype gear micropump consists of three main parts: flange, pump casing and back cover, which are bolted together. In the pump housing, pumping unit is placed - drive and idler gear. The gears are supported by the sliding bearings. Two bearing bushes are positioned between gears and the casing. In the casing, suction and pressure ports are placed, for connection to the drive system. In the flange and back cover, compensation and anti-extrusion seals are placed preventing the leakage. The exploded view of micropump design is shown in Figure 1.

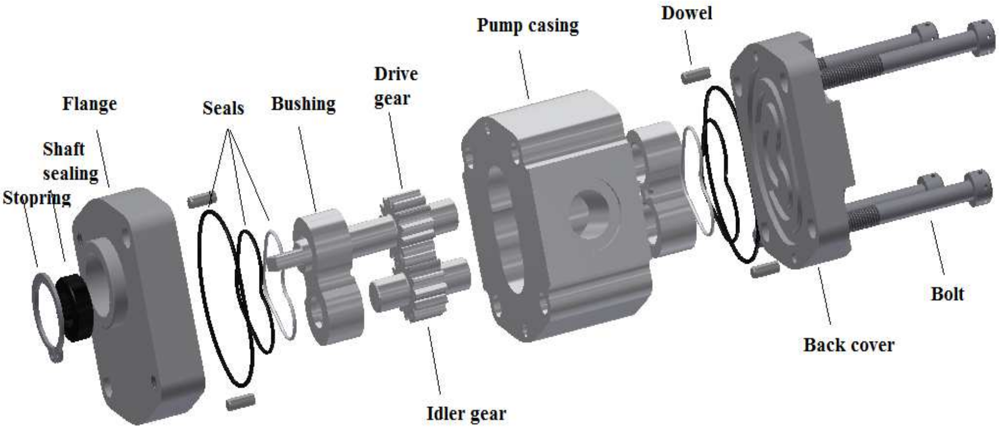

Figure 1: Elements of Gear Micropump

Three geometric models of gear micropump casings were prepared for numerical simulations. The first model of gear micropump casing was prepared on the basis of technical documentation of gear micropump prototype PZ0 manufactured during the implementation of developmental grant no. 03 0032 04/2008. All the dimensions were set identically. The second model overall dimensions were reduced by 15% in relation to the basic model (Figure 1), however pumping unit, bushings, suction and discharge port were not changed. The third model dimensions were reduced by 25% of the basic pump casing.

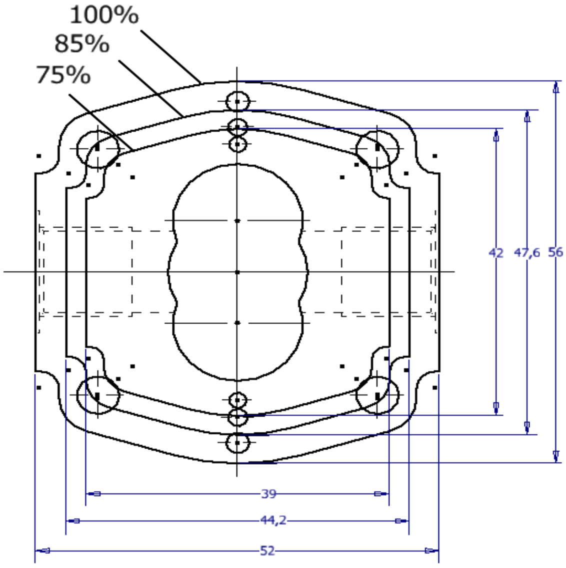

Figure 2: Comparison of Geometric Models: Basic Model (100% Size), First Modification (85% Size), Second Modification (75% Size)

The gear micropump is made of aluminium alloy PA6 (EN-AW-2017A). Mechanical and physical properties of the alloy, which were set in numerical calculations and used for further analysis of the results, are shown in Table 1.

Table 1: Properties of Aluminium Alloy PA6 (EN-AW-2017A)

Property [Unit]	Value
Tensile strength R_m [MPa]	390
Yield strength $R_{0.2}$ [MPa]	250
Density ρ [g/cm^3]	2.79
Tensile modulus E [MPa]	72500
Poisson's ratio ν [-]	0.33

MESH, LOADS AND BOUNDARY CONDITIONS

Each of the tree analyzed gear pump casing models were meshed and fixed in the same way. Therefore the further description refers to each case. The 3D geometric model of the micropump body was imported into Ansys Multiphysics environment and divided into tetrahedral finite elements of higher order (solid187). In each element ten nodes are included - at the vertices and at each edge of the tetrahedron. The element is adapted to model irregular meshes, especially for complex geometries from CAD/CAM systems. In each node of the element, three degrees of freedom are defined, representing the possible movement in three axes: x, y and z. Mesh elements ensure high accuracy of the calculations in case of complex model geometry [19].

Discrete model of the pump body is shown in Figure 3 in the model the existence of two zones of pressure were assumed: the zone of linear pressure growth and zone of discharged pressure. Additionally, zone of bearings pressure on the pump body was modeled (Figure 3). The values of pressure increase angles were determined on the basis of the circumferential pressure measurements. The zone of pressure increase includes 73° in which pressure rises from 0MPa to 28MPa (red colored zone, Figure 3). The suction pressure is negligibly small compared with the discharged pressure, and therefore was not included in the model. The pump body was loaded symmetrically on the drive and idler gear side. In the model, reaction force on the bearings was taken into account (green colored zone, Figure 3). Fixing of the model were assumed accordingly to the literature [15], and therefore the model was fixed in four holes for screws connecting the pump elements. Al the translations in x, y, and z directions in the nodes of this elements were set to zero.

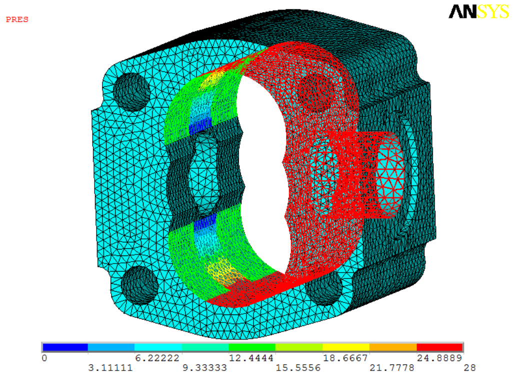

Figure 3: The Discrete Model and Load Schematic in the Gear Pump Body

RESULTS

In order to determine whether the modified gear micropump casings satisfy stiffness and strength criteria, the numerical analysis with the use of finite element method in Ansys software was performed. Strength calculations in the field of linear static analysis were carried out for free casing models. In the pump housings, distribution of reduced stress according to Huber-Mises hypothesis and distribution of displacement vector sum were observed.

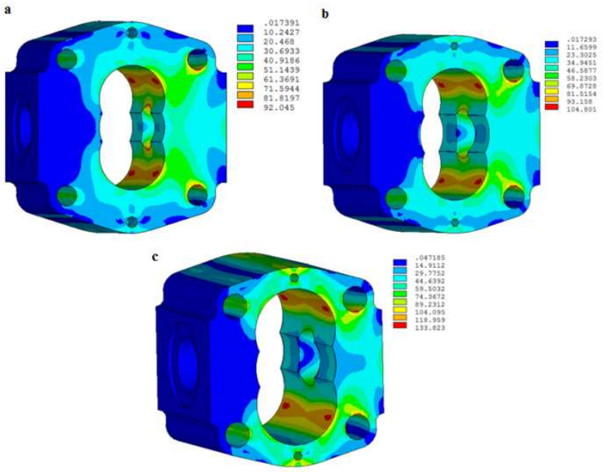

Figure 4: Results of Stress Distribution in Gear Micropump Casings: Basic Model (a), 15% Reduced Model (b), 25% Reduced Model (c)

Figure 4 depicts contour plots of stress distribution in three models of gear micropump casings. The first model (Figure 4a) refers to basic (100%) overall dimensions of the pump prototype. The maximum value of stress in this case equals 92MPa and occurs inside pump casing at discharge side, where discharge pressure on circumference of gears achieves maximal value. High values of stress may be seen around holes for screws at discharge side of the casing and may occur as a consequence of model fixing. At suction side of the pump, the stress values are close to zero. In remaining part of the casings, stress values vary in a range from 10 to 40MPa. Safety factor calculated in reference to tensile strength of 390MPa (Table 1) equals 4.2. The second model (Figure 4b) refers to the pump casing reduced by 15% relative to the base model. Stress values in this case are relatively higher, which results from the fact that smaller amount of material carries the same load as the previous casing. Maximal stress value also occurs at discharge side of the pump on circumference of gears and equals 104MPa. Safety factor in this case equals 3.7. In the third model, which refers to the reduction of basic dimensions to 75% of the prototype unit, the maximal stress value is almost equal to 134MPa (red zones in Figure 4c). At the side of discharge port, the stress values also achieved high levels in range from 15 to 60MPa. Safety factor for this casing is equal to 2.9.

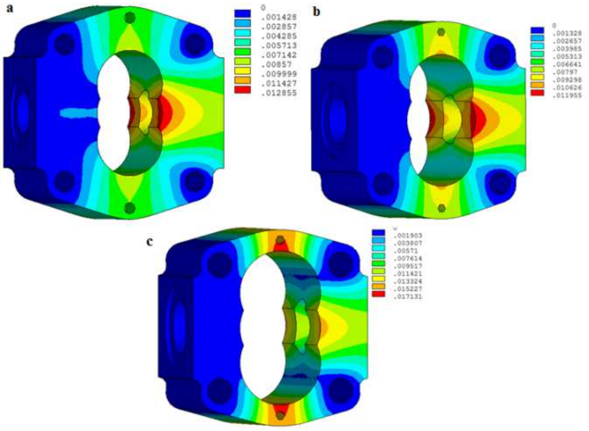

Figure 5: Results of Displacement Distribution in Gear Micropump Casings: Basic Model (a), 15% Reduced Model (b), 25% Reduced Model (c)

In Figure 5, displacement distribution in three analyzed casings of gear micropump are shown. In the first casing (Figure 5a) maximal value of displacement is equal about 0.013mm and occurs at discharge side of the pump. In the second casing (Figure 5b), reduced by 15% relative to the base model, the maximal value of displacement equals 0.012mm. High values of displacement also occurred near holes for dowels, therefore the size of holes in the modified casings were reduced from 3mm to 2mm. The third casing, reduced by 25% relative to the base casing is shown in Figure 5c. The maximal value of displacement equals 0.017mm and occurs near dowels holes. The maximum displacement value should not have a negative impact on the leak tightness of the pump during its work. Significant values of displacement in the pump body occurred on the areas in which the pressure at the circumference of the gears is no longer incremented. Thus, a slight increase in the gap between the tip of the tooth and the body of the pump will not affect its volumetric efficiency. The radial clearance in gear pumps is often referred to as circumferential backlash and ranges from 0.01 to 0.03mm.

CONCLUSIONS

In this paper the use of numerical calculations on the basis of finite element method in order to modernize gear micropump casing was shown. On the basis of obtained results, it was observed that the 15% reduction of the casing dimensions as well as 25% reduction is possible and will not negatively affect the strength of the pump construction. In the first modernized casing (85%), maximal stress value was equal 104MPa, and the maximal value of displacement 0.012mm. The safety factor equals 3.7. In the second modification of pump casing (75%), the highest stress values achieved 134MPa, and maximal displacement 0.017mm. The safety factor in this case is also high and equals 2.9. The results of the simulations indicate that the micropump casing dimensions may be reduced, as the stiffness and strength criteria were achieved in modernized casings.

The analyzes were performed in static conditions, therefore pressure pulsations occurring during pump operation were not included, which also has an impact on the effort of casing material. Therefore, high values of safety factors were assumed for all the cases. In further research, modification of other gear micropump elements, flange and back cover, should be considered. The size of gears und bushings was assumed the same for all the three casings, in order to maintain desired efficiency of gear micropump. FEM computer analyze is a great tool for selecting the best model before manufacturing and allows to freely experiment with the ideas. The numerical model will be subjected to verification and validation by experimental measuring the stress values in the micropump casing.

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