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PLASTIC CYCLOIDAL GEARS
APPLIED IN HYDRAULIC MACHINES

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Summary. The paper presents plastic cycloidal gears using the method of injection moulding. The design requirements for plastic gears were presented. The results of research of pump with plastic cycloidal gears were presented.

Key words: plastic cycloidal gears, injection mould, hydraulic machine

INTRODUCTION

Cycloidal gears are well known as elements of the mechanical transmission units (mechanical gears). It is not, though, the only application of the elements. For example, gears of different profiles and gear systems make the basic elements of the fluid power gear machines [Stryczek 2002]. As it is shown in Fig. 1, they are used in the machines:

– of the 1st generation, featuring external involute gear;
– of the 2nd generation, featuring internal involute gear;
– of the 3rd generation, featuring internal cycloidal gear.

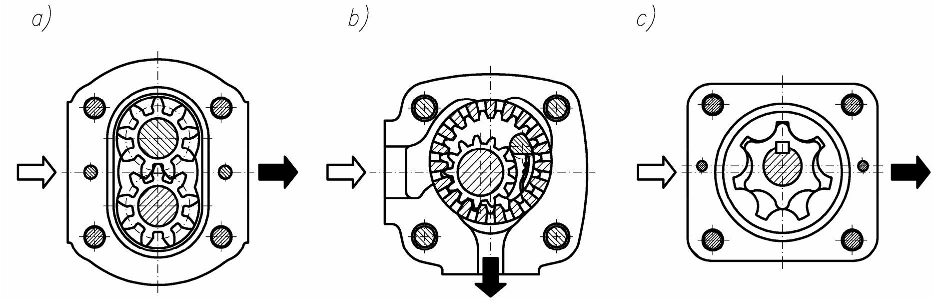

Fig. 1. Hydraulic gear machines: a) featuring external involute gear, b) featuring internal involute gear, c) featuring internal cycloidal gear

Elements which deserve special attention are the internal cycloidal gears applied in such fluid power machines as gerotor pumps, gerotor and orbital motors, control units, or torque amplifiers. Using the cycloidal gears makes it possible to manufacture machines that present very compact design, light weight and small dimensions, high inlet flow rate, low pulsation of the inlet flow rate, as well as a low level of noise. However, in order to achieve these advantages it is necessary to very precisely produce a set of internal cycloidal gears. So far, they have been made of steel by means of a rather complex and expensive technology. As it was given in [Lempart and Stryczek 1992, Stryczek 1994], the technology consists in milling and grinding of the external tooth gear and in pull broaching and grinding of the internal tooth gear. For that, very complex and expensive machines and tools are used. Having considered all the facts, it has been agreed that the following research would be worthwhile taking up:

– investigating the possibility of manufacturing plastic cycloidal gears using the method of injection moulding,

– verifying the operation of the plastic gears in the hydraulic machine, and determining reachable technical parameters at which the gears and the machine can operate.

DESIGN REQUIREMENTS FOR PLASTIC GEARS

As a result of the analysis of the structure and operation of a few typical hydraulic machines [Stryczek 2003, 2005] featuring cycloidal tooth system, design requirements for plastic cycloidal gears have been formulated. Fig. 2 shows a typical inner cycloidal gear system with the more important dimensions marked as well as the deviation of the profile and position.

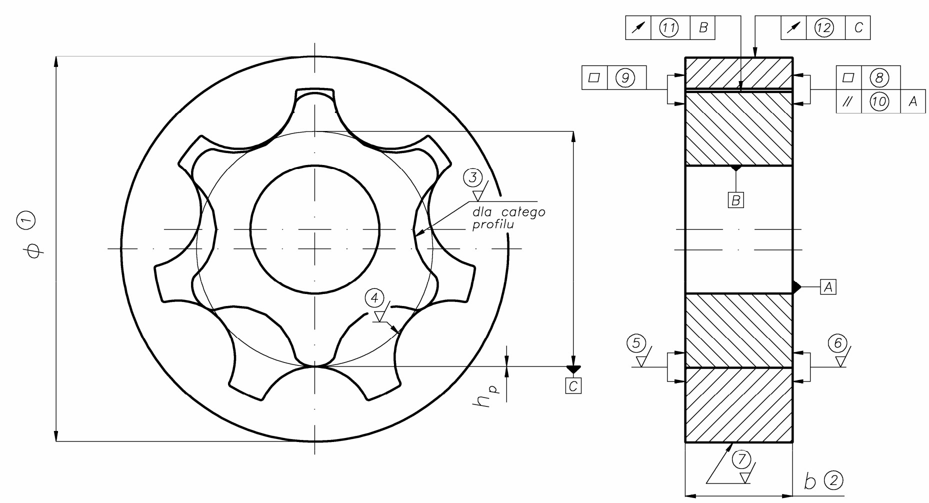

Fig. 2. Design requirements for plastic cycloidal gears

The outline of the gear teeth and the dimensions of the gears were determined using the equations given in [Stryczek 2002, 2003]. In Table 1 the required values of the dimensions as well as the deviation for the plastic gears have been presented.

Table 1. Required values of the more important dimensions and the profile and position deviation in the system of the cycloidal gears

Dimension	Dimension kind	Required value
1, 2 3, 4 5, 6, 7 8, 9 10 11, 12 hp	Outside diameter and the gear system width Surface finish of the gear teeth Side surfaces and outer surface of the inner tooth system gear Flatness of the gear side surfaces Parallelism of the gear side surfaces Gear surface run-out Radial clearance	$\phi^{-0.1}_{-0.2}$ $b^{-0.1}_{-0.2}$ Ra1.25÷Ra2.5 Ra1.25÷Ra2.5 0.05÷0.1 0.05÷0.1 0.05÷0.1 0.5

The values are bigger than in the case of steel gears, because it is necessary to consider the material shrinkage. After finishing the injection moulding process the outside surface of the gears should be smooth and clean. The edges of the gears should be clean and sharp. The inner structure of the material should be uniform, with no material defects or discontinuity. Considering these requirements and the necessity of forming the gears by means of injection moulding, it has been assumed that they will be made of polyoxymethylene.

DESIGNING THE INJECTION MOULD

Fundamental for shaping the plastic cycloidal gears is to design a proper injection mould. Proper design and manufacture guarantees meeting the requirements for the gears, and further on, their proper work in the hydraulic machine. Fig. 3 depicts a schematic diagram of the injection mould design.

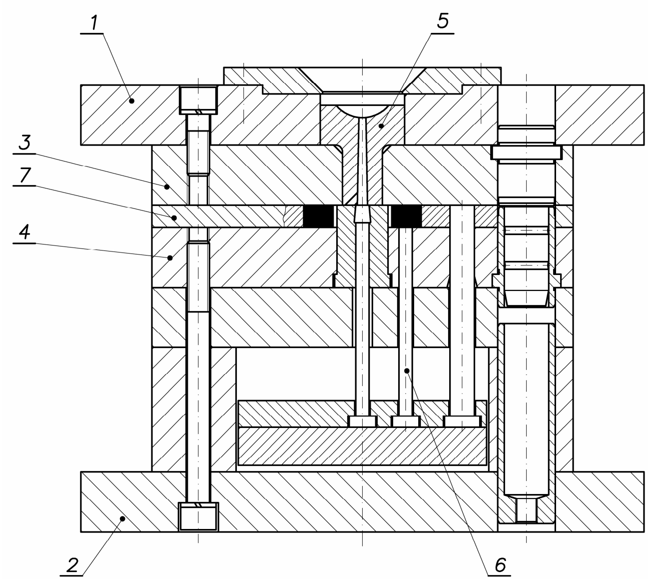

Fig. 3. Schematic diagram of the injection mould design: 1 – top mounting plate, 2 – bottom mounting plate, 3 – top moulding plate, 4 – bottom moulding plate, 5 – injection bush, 6 – set of knock–outs, 7 – core housing

A place for the mould cavity has been made in the core housing (7). In this place it is possible to locate the cavity for making the internal tooth system gear or the external tooth system gear. The shape of the cavities, which corresponds to the cycloidal profile of the tooth system, is made by means of the numerical control milling machine, and their surface is ground in order to provide good surface finish of the teeth. The cavity is placed between the top (3) and the bottom (4) moulding plate. The plates enable achieving the assumed finish, flatness, and parallelism of the side surface of the gears. The plastic is fed to the mould cavity by the injection bush (5). The view of the moulded piece is blackened in the diagram. To push the moulded piece out of the mould cavity a system of knock-outs (6) is used. The mould is fixed to the injection mould with the top mounting plate (1) and the bottom mounting plate (2).

THE CYCLOIDAL GEARS MANUFACTURE

The injection mould presented in Fig. 3 was manufactured and then used for making a series of polyoxymethylene gears. The view of the gear series is shown in Fig. 4. Test measurements have shown that the overall dimensions, such as the diameters and the width of the gears (Table 1, entry 1, 2), agree with the assumed values. Also the teeth profiles were made correctly. The surface finish of the gear teeth and of the side surface of the gears (Table 1, entry 3, 4, 5, 6, 7) remained one class lower than the previously assumed. The flatness of the surface and the parallelism (Table 1, entry 8, 9, 10) were not achieved. The side surface of the gears were slightly concave. Flatness of the driving gear was equal 0.08÷0.12, whereas for the driven gear, the flatness was much better and equaled 0.1÷0.2. It should be mentioned that such high values of the flatness were on the points of contact of the front surfaces with the knock-outs; in other places, the flatness was definitely lower and within the assumed limits (Table 1, entry 8, 9). The lack of flatness was probably a consequence of the thermal shrinkage of the material of which the gears were made. The outer surfaces of the teeth as well as the side surfaces of the gears were clean and smooth.

Fig. 4. View of the polyoxymethylene cycloidal gears

The gears were cut across and examined for their internal structure. It occurred that in the structure of the gears there were sporadic cavities of 2.5×1×1 mm. It could be a result of a non-uniform shrinkage as well as too low injection pressure at the moment of injection of the plastic to the mould.

The gears (manufactured separately) featuring the external and the internal tooth systems were arranged into systems (Fig. 4). After assembling, the teeth of the two gears contacted each other, which was a necessary condition to form the internal displacement chambers between the teeth of the gears, essential for the proper operation of the hydraulic machine (Fig.1, 2). The measured radial clearance was bigger than the previously assumed. It was equal to hp = 0.5÷0.7 mm.

Apparently, values of some dimensions as well as the deviation of the profile and of the position were bigger than the ones assumed at the stage of determining the design requirements. In spite of that fact, the precision of the gear manufacture was decided to be good enough to continue the research.

EXPERIMENTAL RESEARCH ON THE PLASTIC CYCLOIDAL GEARS

The cycloidal gears presented in Fig. 4 were used as a displacement unit in the hydraulic machine (depicted in Fig. 5).

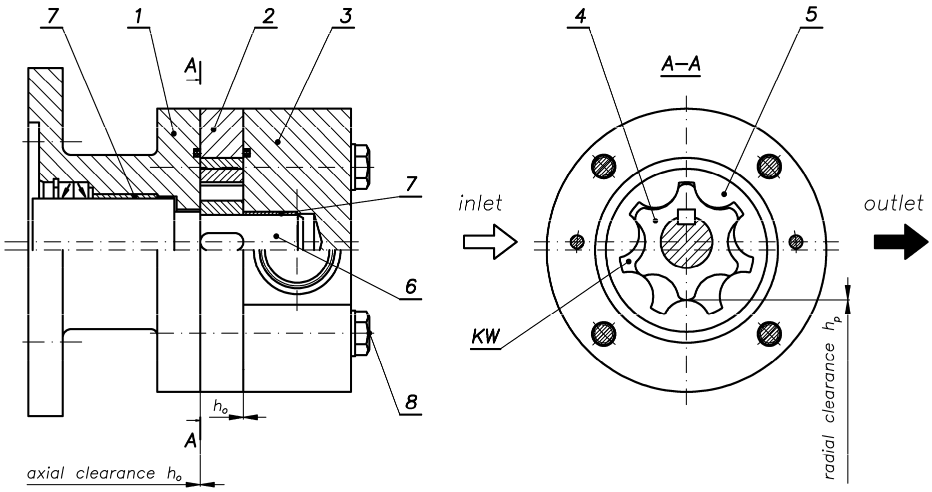

Fig. 5. Design and operation principle of the hydraulic machine featuring plastic cycloidal gears
1 – front body, 2 – middle-body, 3 – back body, 4 – driving gear, 5 – driven gear,
6 – drive shaft, 7 – slide bearing, 8 – screw

The machine with the plastic gears was mounted in the test stand [Bednarczyk *et al.* 2006] and subjected to the test as a displacement pump. The pump driven by the electric motor with the velocity of n = 1370 rev/min was working properly. The plastic gears were rotating at a uniform rate, showing no stoppage or beating, realizing the pumping process. Fig. 6 depicts the volumetric efficiency characteristics.

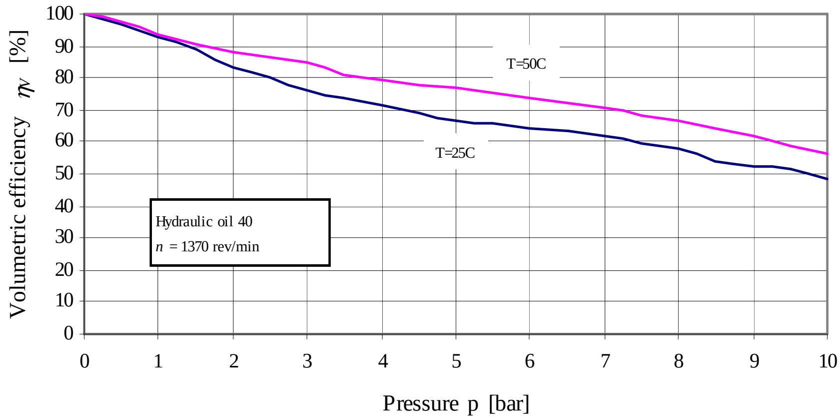

Fig. 6. Volumetric efficiency characteristics of the hydraulic machine featuring the plastic cycloidal gears working as a pump

It can be seen in the diagram that the pump was working at the temperature T = 25˚C, in the pressure range p = 0÷1 MPa, achieving efficiency ηv = 50%. Increasing the oil temperature to T = 50˚C resulted in an increase of the volumetric efficiency to ηv = 60%. That was caused by enlarging of the gears' dimensions in a higher temperature, which caused a reduction of clearances ho, hp and an increase of the internal tightness of the pump. Consequently, volumetric efficiency ηv increased. There was also a 100 hour durability test carried out, after which the gears showed no sign of wear. Additionally, the pump's operation at the foul oil was verified. The verification was being conducted while discharging the fouled oil tanks and rinsing the hydraulic systems. The pump was working properly and the gears did not seize. Most oil impurities were pumped over, and only a small part of them dye-penetrated the plastic gear surface. This does not eliminate the gears from operation.

CONCLUSION

It was stated that there is a possibility of making plastic cycloidal gears by means of the injection moulding method. Therefore, design requirements for the plastic gears were formulated, and a series of polyoxymethylene cycloidal gears was designed and manufactured using injection moulding. Precision of the gears' manufacture is not fully satisfactory, chiefly due to too big radial clearances hp in the system of the gears. In spite of that, the polyoxymethylene gears were working properly in the hydraulic machine, rotating at the uniform rate, with no stoppage or beating. On the basis of the experimental research it was stated that the machines featuring the plastic cycloidal gears can work as low pressure pumps, at pressure p = 1 MPa, and the volumetric efficiency ηv = 50%. They can be used for charging both pure and foul oil. Operating in the foul oil environment, the polyoxymethylene gears do not get seized.

There are possibilities of improvement both of the design of the plastic cycloidal gears and of the injection moulding method. Therefore, research on plastics other than polyoxymethylene, showing higher mechanical durability, better dimensional stability in changing thermal conditions is worthwhile carrying out. Improvements concerning the injection mould and the process of injection moulding in order to eliminate the shrinkage and to make more precise gears are also necessary.

Positive effects in this field of research will make it possible to achieve gears which could work in medium pressure hydraulic machines at higher efficiencies.

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