TECHNOLOGICAL ASPECTS OF KINEMATIC PLANETARY PRECESSIONAL TRANSMISSIONS WITH PLASTIC WHEELS

Bostan I., Academic, Dulgheru V., Dr.Sc., Prof., Bodnariuc I., PhD, Assoc.Prof.
Technical University of Moldova

1. MATERIALS USED TO MANUFACTURE GEAR WHEELS FOR KINEMATICAL GEARINGS

The materials used to manufacture gear wheels are very different. In machine building, gear wheels are made of carbon steel and alloy steel, cast iron; in equipment manufacturing, gear wheels are made of bronze, titanium, aluminium alloys, metal powders, in addition to steel. Plastics are used most often in small power kinematical transmissions. There are also examples of the use of plastics in medium load transmissions. In the production of unique plastic wheels, they are 50% more expensive than steel ones. Use of plastic wheels is more rational and efficient in terms of production in large series by replacing non-ferrous metals and cast (pressed) ferrous metals with plastic wheels in heavy tonnage production [1].

In selecting the material for gear wheels it should be considered the following: destination of transmission, duration of operation and working conditions, type and character of lubrication, technology requirements, existing equipment, and cost of material.

Plastics.

As a result of extensive study of plastics, a range of types of materials suitable for making kinematical gear wheels was established (Table 1. [1, 2, 3]).

2. MECHANICAL PROPERTIES OF PLASTICS

Plastics and polymer composites presents itself a class of polymer based materials, which differ from traditional building materials with low density, elasticity, high strength per unit mass, high corrosion resistance in various environments, favourable and easy machinability. In addition to these basic properties, plastics are characterized by relatively low module of elasticity, creep and relaxation, low diathermancy, high coefficient of thermal expansion, as well as strongly emphasized deformation properties and resistance to temperature [1].

As construction materials the following items are used: universal plastics, which are produced in large quantities (hundreds of thousands of tons per year) and has low cost, and special plastics, produced in small quantities (up to several tens of thousands of tons) and costs more than the universal ones.

To assess the effectiveness of polymeric materials used in required construction is reasonably to be considered two types of plastics – thermoplastic materials and thermosetting plastic materials, which differ not only by their behavior on repeated heating of the material, but also by various indices of strength and deformation.

The specific property of crystalline structure of thermoplastic polymers is their high failure, until appearance of completely non-crystalline sectors (amorphous). Among thermoplastic polymers there are amorphous or hard crystallizing polymers (Polysulphones, polycarbonate, phenol ether resin, polyacrylate, fenilon - crystallization degree 10 to 25%), which are by themselves rigid elastic materials – polymer glass with the limiting maximum operating temperature, appropriate to temperature Tc. Also, there are crystalline polymers with average crystalline degree (polyamides 50-75%) and high crystalline degree (polyacetal, polyethylene - 75-96%), with the limiting maximum operating temperature which can range from T_c of the amorphous phase to the melting temperature T_{top}.

Gauze structure of high density thermosetting plastic materials provides higher hardness indexes, modulus of elasticity, heat resistance and high fatigue resistance, compared to thermoplastic materials; they are characterized by low thermal expansion coefficient, allowing a high degree of filling up from 80 to 85% (by mass). Phenol formaldehyde and epoxide resins are used as binders for thermosetting plastic materials applied to manufacture gear wheels [1, 2, 3].

Table 1. Materials recommended for making kinematical gear wheels

	Name and conventional marking of material	**Density, Kg/m^3**	**Production mark**
1	2	3	4
1	High density polyethylene	960	PE – Schkopau, Baylon, Alkathene, Moplen, Lupolen, Vestolen, Hostalen LD, Naten
2	Low density polyethylene	920	Liten, Vestolen, Hostalen
3	High molecular polyethylene	916	Hostalen GUR, Lupolen
4	Polypropylene	905...910	Hostalen PP, Moplen, Mosten, Noblen, Novolen, Vestolen P, Napryl, Daplen
5	Polyamide 6 and its composite materials	1120...1150	Degamid, Durethan, Ultramid B, Miramid, Akulon, Grilon, Grodnamid, Etamid, Capron
6	Polyamide 66)	1120...1150	Ultramid A, Maranyl A, Zytel E, Leona, Sylamid, Spalamid
7	Polyamide 11	1020...1040	Rilsan B
8	Polyamide 12	1010...1020	Rilsan A, Grilamid, Vestamid
9	Polyamide 610	1070...1090	Ultramid S
10	Polyamide 6 with glass filling (PA 6 + 30% glass filling)	1350	Renyl, Zytel, Orgamide
11	Polyamide 66 with glass filling (PA 66 + 30% glass filling)	1350	Durethan, Aculon R, Catalin, Verton RF
12	Polycarbonate and its composite materials	1070...1230	Makrolon, Orgalan, Lexan, Merlon
13	Polyoxymethylenes and its composite materials	1340...1430	Delrin, Celcon, Hostaform, Duracon
14	Polyoxymethylenes with glass filling (POM + 30% glass filling	1700	Kematal, Tenac, Ultraform
15	Polybutylene terephthalate	1300	Pocan, Deroton, Ultradur, Dynalit
16	Polybutylene terephthalate with glass filling (PBT + 30% glass filling)	1550	Pibiter, Orgater, celanex, Snialen
17	Polyethylene terephthalate	1370	Arnite, Crastin, Tenite, Vestodur, Rynite, Hostadur, Pocan, Ultradur, Lavsan
18	Polyethylene terephthalate with glass filling (PETF + 30% glass filling)	1650	Rhodester
19	Phenol ether resin	1060	Noril
20	Polysulphones	1240...1250	Bakelite P, Udel, Polisulfon
21	Polyethersulfone	1370	Poliathersulfon, Victrex
22	Polyphenilsulphide	1340	Ryton
23	Polyimide	1430	Kapton, Vespel, Kinel
24	*Polyether ether ketone*	1320	Victrex
25	Thermoplastic polyurethane	1250	Desmopan, Elastollen, Vulkollan, Resistifol

3. RATIONALE OF PLASTIC MATERIALS SELECTION FOR MAKING GEAR WHEELS

Certain requirements, determined by operating conditions compared with thermal and mechanical properties of thermoplastic materials, have to be followed in selecting the material for gear wheels manufacture. Safe operating condition of the gear transmission is provided by the maximum coincidence of the operating requirements with the chosen material properties. But in majority of cases, practically all imposed conditions cannot be met.

Table 2. Qualitative comparison of polymer materials properties.

Properties	Poly-amided	Polyamide +% filling glass	Polyacetal	Polybutylene terephthalate	Polycarbo-nate
Rigidity	▲	●	■	■	■
Mechanical strength	■	●	■	■	■
Sliding friction wear	●	■	●	■	x
Stability of creep	■	●	●	■	■
Resistance to fatigue	■	●	●	■	▲
Temperature resistance	■	●	■	●	■
Resistance to chemicals	●	●	●	●	x
Dimensional stability	▲	■	■	■	●
Density	■	▲	▲	▲	■
Water absorption	x	x	●	●	●
Molder	■	■	■	■	▲
Properties at temperatures below 0°C	■	●	■	■	●
Stability to atmospheric influences	▲	■	▲	■	●

NOTE:● very good,▲ satisfactory, ■ good, x insatisfactory

Criteria for material selection

Necessary spectrum of tasks is the most important criterion in selecting material that determines the bearing capacity of gear wheel. High load capacity defines the selection of tough and rigid plastics. Tooth loading is determined by the frequency of rotation. The main criteria for choosing the material for such machine parts are the admissible temperature on long-term operation and thermal resistance. Higher noise and vibration levels are expected at light loads and high angular speeds. In this case it is necessary to use high damping materials. High shock elasticity materials are used in transmissions, characterized by shock load [1].

Tribological characteristics of the transmission are determined by the lubricant properties. When selecting the material the following factors are taken into account: influence of the environment (temperature, humidity, presence of chemicals and abrasives, etc.), mode of operation, load capacity of the transmission. Potential changes in the size of gear wheels, which influence the accuracy of transmission, are previously calculated in accordance with specified deviations of temperature and humidity of the environment. In addition we must take into account that there are active chemicals, under which thermoplastic materials usually resist in unstressed state, but under load they are sources of micro cracks, conditioned by the existence of high remanent stresses in the material. Qualitative comparison of some properties of polymeric materials is shown in Table 2 [1].

Operating criteria

Choosing the right material for gear wheels supposes knowledge of defects encountered in plastic gear wheels exploitation and reasons of their occurrence. Loss of functioning capacity of the thermoplastic polymer gears is more often subject to the following defects: broken tooth at the base, in the dangerous section zone; cracks on the working side of the tooth surface; tooth breaking in the gearing pole zone; remanent bending of tooth due to material plastic flow; appearance of pitting on lateral surfaces of teeth; wear as a result of seizure; wedging – common for kinematical pairs.

Most failures are caused by material properties and are subject to certain operating restrictions. At the polyamides gear wheels operation, a small remanent bending of the tooth occurs, which increases rapidly before the destruction of the gear crown. Tooth breaking at its basis is common for polyacetal gear wheels.

Studying wear, subject to mutual sliding of the side surfaces of the teeth, two types of wear can be distinguished: wear due to relative slip that occurs in any transmission (including transmission with ideal geometry); wear caused by contact of the outer edge of the metal wheel gear tooth with the root of the distorted tooth of the plastic gear wheel beyond the theoretical line of gearing - contact on the edge. In the first case (typical of metal wheels) wear may be even or uneven depending on the working conditions of transmission. In the second case, a wear channel appears on the tooth root that can spread on the tooth to the gear pole. This type of wear does not destroy the tooth but creates places with high concentration of stresses. Indicated type of wear depends considerably on the load and is most common in polyamide PA12 gears wheels, and less – in polyamide PA6 and PA66 gear wheels.

Wear channels on the teeth of polyacetal gear wheels are smaller than on the polyamides gear wheels. Wear subject to seizure is typical for gearing operating without lubrication and lubricated with plastic material of the polymer - metal and polymer - polymer pairs. Wear occurs as a result of local heating at side friction of the teeth. Wear area is the region with the highest relative velocities of sliding on head and foot of plastic wheel tooth.

Figure 1 shows the schedule of energy consumption and material utilization coefficient for three types of processing: sintering, molding and cutting. Material utilization coefficient is about 0.95 of the initial material and energy costs are 35% of product cost at processing by sintering. Material utilization coefficient is 0.95 as of the initial material and energy costs are 30% of the product at molding processing. Material utilization coefficient is 0.5 of the semi product and energy costs up to 80% of the product at material machining. As shown in the diagram analysis most rational in terms of costs are sintering and casting methods. And cutting is used only in unique cases, when a few parts are needed and it is not rational to execute a mold.

4. CONSTRUCTION OF PLASTIC GEAR WHEELS

Construction of gear wheels must meet requirements concerning its destination, and satisfy operational capacity of the wheel in given circumstances. An important requirement is construction workability, which saves material, simplifies tools construction and molding equipment, decreases manufacturing cost. Strength, reliability and durability of transmission depends on the material used, the size of the gear, the execution accuracy and other factors. Obtaining a structure to meet all imposed requirements is possible only if all specific physico-mechanical and technological properties of polymeric materials are taken into account.

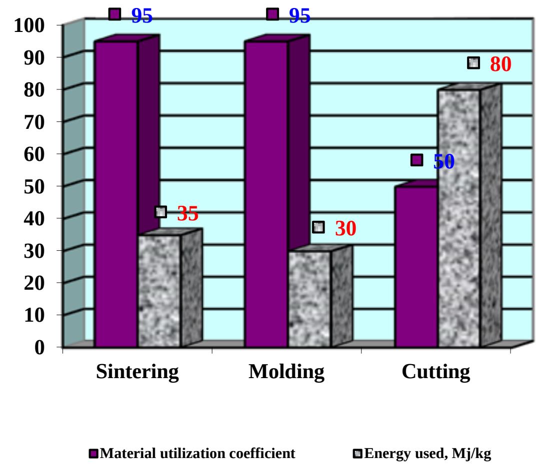

Figure 1. Comparative diagram „*cost-gear* wheel manufacture.

Based on the analysis of operating conditions, wheel construction, polymer material and basic parameters of the wheel are established. In addition, plastic properties must be respected such as high flexibility, mechanical strength, low diathermancy, temperature dependence of resistance and load speed, load relaxation.

Sections homogeneity and wall thickness uniformity of the gear must be respected so as the difference between maximum and minimum dimensions does not exceed 25 - 30%. Correlation of constructive parts' dimensions is indicated taking into account the possibility of wheel molding and use of rational schemes for casting systems with the distribution of splashing points. In addition, the principle of successive filling of mold with smelt polymer must be respected, beginning with sections of larger sizes.

When removing gear wheels with small thickness of the walls out the forms the risk of their bending arises. To remove it, the wheel disc is reinforced with stiffening ribs, which should have uniform thickness and technological inclinations. In addition it should be taken into account that per a small number of stiffening ribs polyhedral surfaces may occur on the gear crown, because radial contraction of wheels sectors, where stiffening ribs are located, differs from areas where the stiffening ribs are missing.

5. CHOICE OF METHOD AND DESIGN OF MANUFACTURING FORMS FOR GEAR WHEELS OF PRECESSIONAL GEARING BY CASTING

Based on the analysis of molding methods for plastic gear wheels according to certain selection criteria (simplicity and technological design, production volume, etc.) to manufacture the wheel, the method of casting under stress was chosen, which is one of the most widespread methods for manufacturing plastic products and composites based on them. Its advantages are: high productivity, possibility of process automation, safe consumption of material, comparatively high accuracy of obtained products, technological simplicity, and high quality of molded products [1].

Design of manufacturing molds for gear wheels of precessional gearing by casting under stress: Based on careful analysis of the construction of casting molds and according to the casting method selected construction and technical documentation was developed under which the mold was made. The process of tooth mold (core of mold) manufacture is protected by a patent [4]. The casting mold for plastic gearwheels of kinematical precessional transmission, shown in Fig. 2, is composed of three parts: one fixed, the intermediary and the mobile parts.

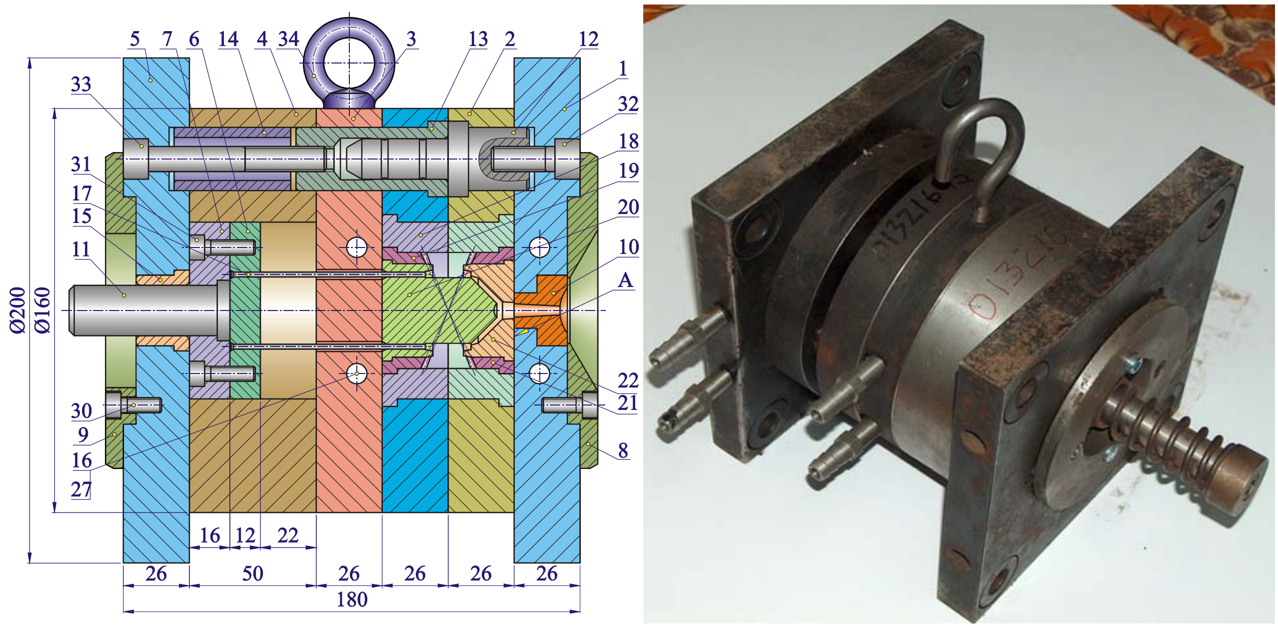

Figure 2. Mold of plastic gear wheels in the precessional gear.

In the developed technical documentation ("Sigma" factory, Chisinau) the metal mold of the wheel satellite was executed (Fig. 2) with a set of molds (Fig. 3), which allowed the casting of satellite wheels with various geometrical parameters, presented in Table 3. A set of satellite wheels with different geometrical parameters (Table 3) was produced from plastics using the mold). Samples of cast wheels are show in fig. 4.

Table 3. Geometrical parameters of the satellite wheels.

Parameters	Symbol	Satellite wheel					
Number of teeth	Z_2	30	31	30	31	30	31
	Z_3	20	20	22	22	25	25
Conical axoid angle, º	$\square_1$	22,5	22,5	22,5	22,5	22,5	22,5
	$\square_2$	0	0	22,5	22,5	22,5	22,5

Figure 3. Set of moulds from the hollow mould.

Figure 4. Satellite gear wheels cast from different plastic materials.

References

1. Starzhy'nskij V., Timofeev B., Shalobaev E., Kudinov A. *Plastmassovy'e zubchaty'e kolesa v mexanizmax i priborov. – Sankt-Peterburg – Gomel': IMMSNAN B,– 1998, 538 s.*

2. Mirzoev R. *Plastmassovy'e detali mashin i priborov. M.– Л. Izd. Mashinostroenie, 1985, 356 s.*

3. Zemlyakov I. *Prochnost' detalei iz plastmass, Mashinostroenie, 1972, 158 s.*

4. Bostan I., Dulgheru V., Ţopa M., Bodnariuc I., Dicusară I., Trifan N., Ciobanu R., Ciobanu O., Malcoci Iu. *Anthology of Inventions. Vol. 4: Kinematic Precessional Planetary Transmissions. Publ. House BonsOffices SRL, 2011. 553 p. – ISBN 978-9975-4100-9-0*

5. Bostan I., Dulgheru V., Dicusară I., Bodnariuc I. *Patent no. 3623 MD. Gear wheel-tool for mould processing and procedure for its processing. Publ. BOPI no. 6/2008.*

Rcommended for publication: 20.05.2015.