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APPLICATION OF MODERN MATERIALS FOR CYCLO GEAR ELEMENTS AS A WAY OF OPTIMISATION OF THE PARAMETERES OF STRENGHT

The article presents the advantages of using gear cycloid. They indicated modern methods of their use. The principles of action Cyclo gear having two planetary gears with epicycloid outline. It presents modern materials that can be used in the gear-type cyclo. Carried out simulations using Inventor Professional is aimed to show dynamic analysis takes into account the use of different materials used in the transmission gear input shaft.

INTRODUCTION

Modern understanding to economics and ecological terrorism requires economic and efficient approaches for product life-cycle attributes of almost all man-made products. Since the drives are expected to build a compact, economical operation and reliability. In the domain of mechanical power transmission design, speed reducers are commonly used for mechanical power transmission.

Cyclo gear trains can deliver efficient means of mechanical power transmission under dynamic loading conditions, where the dynamic conditions are characterized by shock and time-dependent loading. Cycloidal gearing are known for their outstanding reliability and long trouble-free maintain. This is due to the complete absence of sliding friction as well as high material specifications, component quality controls and careful assembly procedures.

So cycloidal drives are used among others: intelligent machines, machine tools, textile machines and glass, woodworking machines, robots, medical technology, transport systems, nuclear systems, electrical navy ships, electric planes for the army, handling robots, positioners cooperating with robots, CNC machines, turret trays tools and rotary tables.

There are many advantages, which is supported by the use of cycloid gear trains. For example:

- very small angular clearance (about 1 arcmin),
- compact design (20% smaller overall dimensions to the same reduction ratio and power transmitted than in traditional gears),
- high gear ratio,
- low noise,
- high shock loading capacity (up to 500%),
- high mechanical efficiency at the level of 86-93%,
- small moment of inertia,
- large reduction ratio (as from 6:1 to 119:1 in one stage, up to 7,569:1 in two stages and up to almost 1,000,000:1 in three stages),
- prominent heat dissipation ,
- overall economy- minimal maintenance, high reliability, long life.

Currently gearing gears are widely used and commercially available from different manufacturers, differing from each other inter alia: parameters, components and parts [4].

1. THE CONSTRUCTION AND OPERATION OF CYCLO GEAR BOX WITH TWO CYCLOIDAL GEARS

Cycloid gear box also called Cyclo gear is a mechanism used to reduce the speed of the drive shaft by a certain factor. These transmissions have the opportunity to achieve a high degree of reduction while maintaining a relatively small size.

Planetary gears gearing, characterized by large ratios, compact design with high efficiency and stability during operation. The compact design is their undoubted and anytime especially in applications requiring high speed ratios. Typical planetary gear with a relatively large reduction require up to 3 degrees ratio, which considerably increases the size and weight of the regulator. Transmission cycloid, always has only 2 degrees of leverage, because of its size and weight are much smaller than the corresponding planetary gears. Cycloidal gearing can be significantly overloaded and react quickly to changes in load. They are silent, ensure high uniformity of movement and have fewer parts compared to conventional gear of the same ratio. Small clearances allow additionally for highly precise movement (backlash <1 min. angle). Cycloidal gearing is characterized by: high torque, high resistance to dynamic loads (up to 5 times the rated torque), high stiffness, low inertia. Fig. 1 shows a typical cyclo gear box.

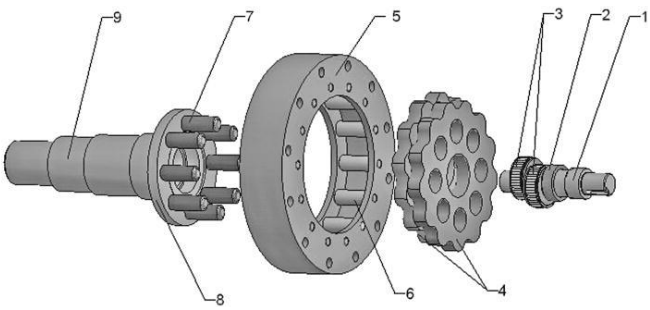

Fig. 1. *Typical circulating cycloid gear [1].*

The feature that distinguishes cyclo gear from other transmissions are two planetary gears with cycloidal teeth outline 4. planet gears are offset by an angle of 180°. Each planetary gear has external teeth in the form of equidistant epicycloid shortened. These wheels are mounted eccentrically on the shaft 3 active 1 and cooperate with the rollers 6 arranged in a circle center 5, acting at the same time the role of the body. Planet gears 4 with rollers 6 and the sun gear 5 form a recycle mechanism. For transferring the rotary movement from the shaft 1 to the active output shaft 9 is peripheral mechanism consisting of the pins 7 mounted with the sleeves in the holes of both planetary wheel cycloid 4. To fully convey the movement from the active to passive pins are mounted in holes in addition shield passive roller 8. therefore, it can be seen that the circulating gear gearing synthesis mechanisms are circulating and peripheral.

A rotating shaft rotates the bearings 2 mounted eccentrically on the input shaft 1 by forcing the rolling planet gear along the circumference of the stationary sun gear with rollers. While the planet gears roll to one side inside the circle of the central rollers simultaneously rotate in an opposite direction about its axis. This rotation is caused to engage the next tooth recycle the gear 4 with rollers 6 sun gear 5. The rotary motion of the planet gear about its axis is transmitted to the output shaft by a sleeve disposed in the planet gear openings. The sleeves are mounted on the pins of the output shaft. Each planet gear has one less tooth than the number of rollers in the wheel center.

Analyzing the principle of the cyclo gear working, it is noted that this is a kind of running gear, in which all the elements of the combination of the contoured move with rolling. You can distinguish the following pairs of bearings: planet gears cooperating with rollers, forming a mesh Cyclo gear; the rolling bushing in the aperture and the planetary gear cylindrical roller bearings, mounted in the central opening of the planetary gear. It is therefore concluded that the planet gear cycloidal-profile is an essential part of all roller pairs, and the two mechanisms (peripheral and recycle) and the composite is subject to the arrangement of loads, resulting from transmission operation [1].

At each site responsible for the transfer of torque applied rolling elements. This results in a significant increase in the coefficient of mechanical efficiency and increase system reliability.

An additional profit resulting from the application of the tooth-profile cycloid is the effect of simultaneous engagement of many teeth. Unlike the involute gear trains, in cycloid gearboxes the simultaneous engagement is from 10 to 50% of the teeth. It depends on the size ratio (number of teeth) and the load. The minimum number of teeth meshes with the idling, the maximum shock load torque of 500% of the rated torque. Such a phenomenon results in even load distribution to a larger number of teeth around the periphery resulting in a very uniform and smooth torque transmission characteristics.

Durability of Cyclo gear is conditioned durability weakest kinematic pair in a transfer of power. This arrangement creates a series connection of three nodes bearings, namely: a central roller bearing, the rolling pin set peripheral mechanism and a special engagement of the cycloidal gear,, in order to obtain gear ratio i = 9-87. A kind of consumption for the durability of this type of gear is fatigue wear [2].

2. MODERN MATERIALS USED FOR THE GEAR COMPONENTS

Typically, the materials used on the planet gears are constantly for quenching and tempering: carbon, silicon, manganese, chromium-molybdenum, chrome-manganese-silicon, chromium-carbon (with the contents of approximately 1% C and 1.5% Cr), nickel-chromium, chrome-nickel-molybdenum. Shall also case-hardened steels: carbon, chromium, chromium-manganese, chrome-manganese-molybdenum, chrome-nickel.

For gears and shafts applied induction hardening to minimize the oxidation and decarburization of the surface and to increase the wear resistance, fatigue strength, surface hardening of steel and other alloys, while maintaining a soft core.

Induction hardening uses the phenomenon of heating electric current induced in the treated product by an alternating magnetic field. Modern devices allow cooling of the heated element directly in the heat so the liquid sprays lead with the driver or lead between the turns of the inductor.

Carburizing process is used for surface gears, because these are elements whose task is long-term work under large impact loads. This treatment is used to obtain a hard, wear-resistant surface layer while maintaining a soft, ductile core. With the carburizing and hardening, we can get on the surface hardness of the order of 60-65 HRC, the core hardness of approx. 15 HRC and the carburized layer thickness of 0.5-2 mm. Carburizing can be many kinds of steel. The combination of a hard wear-resistant surface of the malleable core may be controlled by the choice of alloying material and process parameters. The process of carburizing involves saturation of the carbon surface layers of parts made from low-alloy steels and low carbon on heating steel in a suitable medium the lubrication (gaseous or solid – so called carburization powders) to a temperature above A3, withstand product for a specified period at that temperature to obtain a desired thickness of the carburized layer and slow cooling. The main components of gaseous media include CO, saturated hydrocarbons C_nH_{2n+2} and unsaturated hydrocarbons C_nH_{2n}. As a permanent centers used powders containing a mixture of charcoal and means to accelerate carburizing (barium carbonate or sodium). After carburizing steel is hardened and annealing at low temperature.

For the formation of properties of gears is used as a nitriding treatment of the final. Nitration are employed to produce an extremely hard and wear-resistant surface layer and to increase the corrosion resistance and fatigue strength. Frequently nitriding is subjected to structural steels, carbon and alloyed and utilities. The hardness of the nitrided steel can be up to 1200 HV. The thickness of the nitrided layer is typically approximately 0.2-0.3 mm. Nitriding involves diffusion of nitrogen saturated with the metal surface by annealing the material at a temperature range of 500-700˚C (for a time: 5-80 hours) under an atmosphere partially dissociated ammonia NH3.

The process of nitrocarburizing chosen to shape properties of elements such as gears and shafts and pins. Carbonitriding is used for forming a hard, wear-resistant and fatigue diffusion layer. Due to the lower temperature required for carbonitriding compared to the carburization can reduce the risk of significant distortion and cracks. Carbonitriding involves the simultaneous impregnation of the carbon surface layer carbon or nitrogen by annealing the material in gaseous or liquid centers (i. e. cyanation). The use of solids (powders) is limited due the high cost and low yield process. Distinguishes between high-temperature carbonitriding (800-900˚C), similar to the process of carburizing, carbonitriding and low temperature (500-600°C) compared to the nitriding process in order to obtain a hardness at 1000 to 1100 HV. The thickness of the layer after nitrocarburizing is approximately 0,05-0,8 mm. Process similar to the nitriding, carbonitriding processing is final. If a process similar to carburizing after nitrocarburizing used hardening and tempering at 150- 200˚C, depending on the actual conditions of operation of the component.

The carburizing and quenching process obtain high hardness on the surface of the tooth with the core. This is accomplished by use of a material with a carbon content below 0.23%, the carburization of the surface layer diffusion. After hardening you can get up to 60 HRC hardness. The thickness of the carburized layer depends on the size of the tooth (module). Nitrided layers are usually thin and characterized by fragility. Therefore, after nitriding does not apply finishing working - grinding.

Sulfidation is applied to the sleeve cylinder, ball bearings, shafts, gears in order to lower the coefficient of friction and erosion of the cooperating parts from seizing, as well as obtaining a surface resistant to corrosion, which easily reach and do not alter the properties at elevated temperatures. Sulfidation based on the enrichment of the surface layer of the product sulfur by annealing it in nitric sulfur liquid or gas medium, wherein the active agent is hydrogen sulfide. At a temperature of 200-900˚C hydrogen sulphide decomposes to the hydrogen and the sulfur, which reacts with iron. The thickness of the layer is 0.02-0.05 mm.

For elements such as rollers, gears, from which need to have high surface hardness at a relatively soft core, corrosive environments and elevated temperatures and working elements of the friction conditions apply alloying (melting), laser or electron. This is a saturation process in which there is a mixing element or elements of the alloy melted or not melted base material and partially diffusion. Alloying is carried out using a laser beam or an electron beam. Laser melting consists of remelted material of stop coated on the substrate material and simultaneously melted film of the substrate, and an intense convection and gravity stirring the melt, and rapid solidification of the resulting alloy, the structure, composition and characteristics are different material substrate and the stop material. Saturates the surface layer compounds which increase resistance to abrasion and chemical corrosion and temperature, e.g. steel- chromium or coal. Alloying is performed at power densities ($5\text{-}10 \cdot 10^6$ W/cm^2), with exposures of tens of thousandths of a second. With the increase of the power density is increased the density of remelting. At high power plasma can be formed, resulting in evaporation of the material [2].

3. NUMERICAL TESTING

Fatigue strength test of rolling couples of complex shape cooperating surfaces carried out numerically. The biggest problem was the programming of complex load contact. Therefore, to study the fatigue life of meshing cycloidal used, the prototype copy of the Cyclo gear. Dynamic tests were conducted at a given load and constant speed drive shaft.

In this newspaper authors focused only on single parts of cyclo gear train. They performed modal analysis with Autodesk Inventor Professional 2017.

Modal analysis with Autodesk Inventor Professional 2017, results for Input shaft:

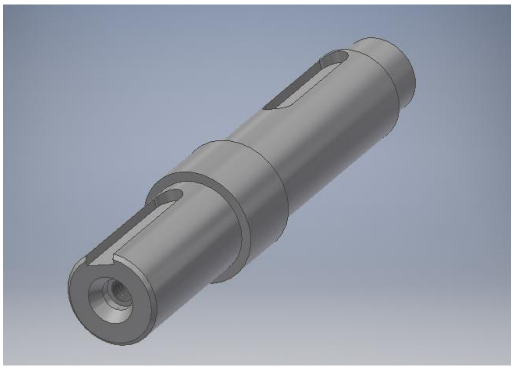

Fig. 2. *Input shaft*

Model information:

Table 1. *Input shaft properties*

Material	Steel
Density	7,85 g/cm^3
Mass	0,533228 kg
Surface area	139495,66 mm^2
Volume	67927,1 mm^3
The center of gravity	x= 67,7673 mm y = -0,139494 mm z = 0,000000000029039 mm
The type of researches	Modal analysis
Number of models	8
Frequency range	0-50
Type of load	Torque: 240000 Nmm

Tab. 2. *Material properties*

Name	steel high-strength, low-alloy steel
Yield strength	275,8 MPa
Tensile strength	448 MPa
Young's modulus	200 GPa
Poisson's ratio	0,287 ul
Modulus of elasticity	77,7001 GPa

Assumption: shaft moves in rigid bearings based on the flanges of the inner race of the roller. Frequency: 0-50 Hz. Torque: 24000 Nmm.

For high strength alloy steel, an analysis of the dynamic gear shaft cycloid. According to the calculations of the input shaft deformation will occur at a frequency F1= 2835,11 Hz, i.e. 170100 rev/min (Fig. 3).

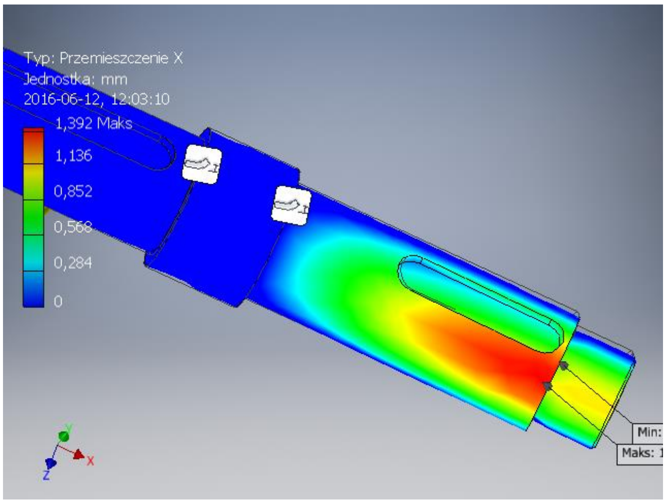

Fig.3. *Displacement in x-axis for shaft manufactured of high strength alloy steel*

The authors obtained other results of dynamic analysis assuming the same motion, and the use of other materials. The table below presents the results of these simulations.

Using austenitic stainless steel deformation will occur at a frequency F1=2742 Hz, i.e. 164520 rev/min (Fig. 4).

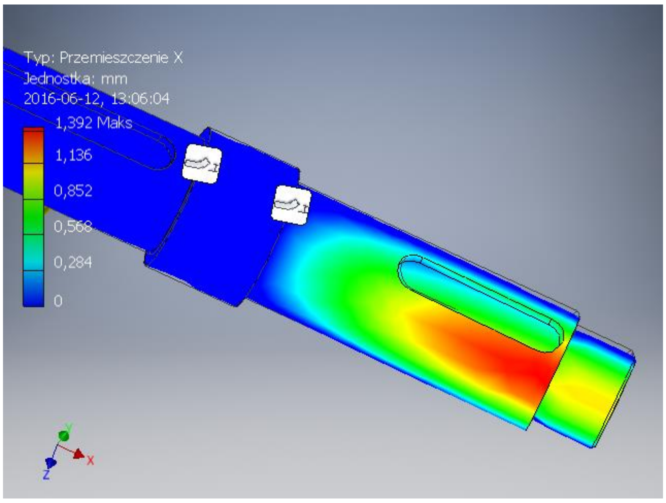

Fig. 4. *Displacement in x-axis for shaft manufactured of austenitic stainless steel.*

Using mild steel, welded deformation will occur at a frequency F1=2971 Hz, i.e. 178260 rev/min (Fig 5).

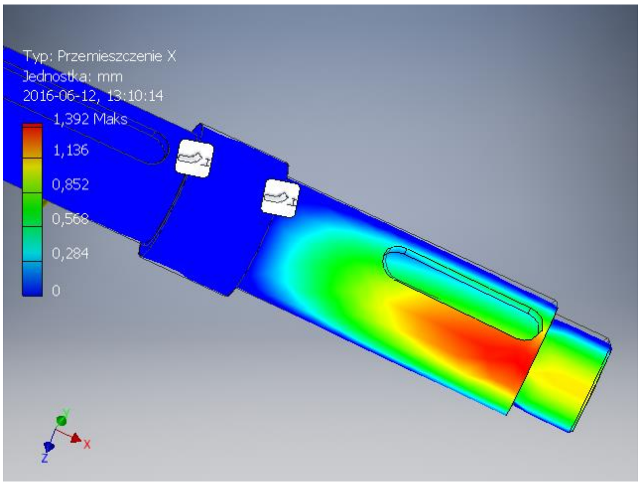

Fig. 5. *Displacement in x-axis for shaft manufactured of mild steel welded.*

Using 440C stainless steel, welded deformation will occur at a frequency F1=2888 Hz, i.e. 173280 rev/min (Fig. 6).

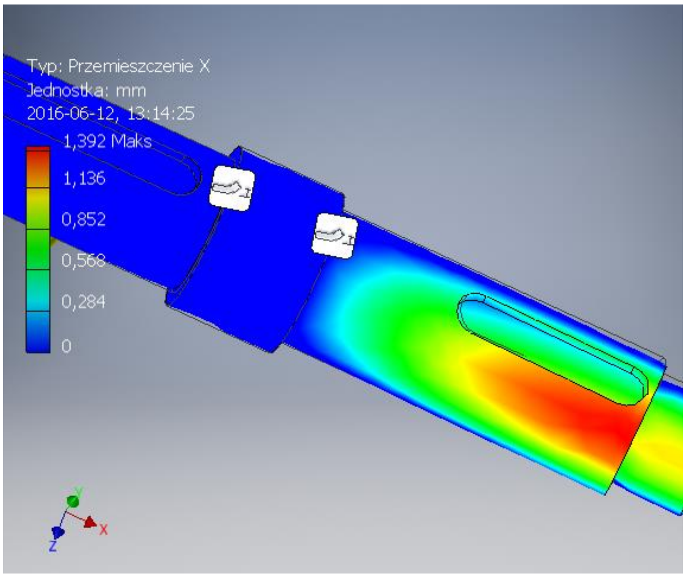

Fig. 6. *Displacement in x-axis for shaft manufactured of 440C stainless steel welded.*

SUMMARY

Inventor Professional allows the analysis of the dynamic without the need for an experimental method as in the case of the selection of materials and the need to implement the method is very labor-intensive and costly. This is connected primarily with the need to produce many items, covered or made of different materials and the need to install them in varying combinations. Dynamic Simulation allows the use of the best possible combination of materials used for elements of the gear unit, which enable as broad as possible reliable operation. The article shows a fragment of a simulation based on the choice of materials used in the transmission input shaft, using the same parameters and boundary conditions for each of the above cases. The results of the analysis made it possible to verify that the materials used for the shaft material is the most durable and allows for the longest possible operating process. In this case, it was a mild steel welded.

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Zastosowanie nowoczesnych materiałów na element przekładni cykloidalnej jako sposób optymalizacji jej parametrów wytrzymałościowych

W artykule przedstawiono zalety stosowania przekładni cykloidalnych. Wskazano nowoczesne metody ich zastosowania. Omówiono zasady działania przekładni cykloidalnej posiadającej dwa koła obiegowe o zarysie epicykloidy. Przedstawiono nowoczesne materiały, które można zastosować w przekładniach typu cyclo. Przeprowadzano symulacje z użyciem programu Inventor Professional mającą na celu pokazanie analizy dynamicznej uwzględniającej wykorzystanie różnych materiałów, stosowanych na wale wejściowym przekładni.

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