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THE CONTROL OPERATIONS OF GEARS' PRECISION

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Abstract: *This paper presents the state of art in the field of gear measuring, focusing on the latest developments regarding the principles, procedures and equipments. These control operations, which are: the control of the pitch, the profile control, the control of the tooth direction, the contact pattern control, verify the geometrical parameters of the gears.*

Key words: *gear, precision, teeth flanks curvature, scanning surface.*

1. Introduction

Gear drives are the most used mechanisms building different machines and instruments. Nowadays there are just a few machines, which didn't use gears. In the last 60-70 years of machinery evolution can be simply characterized through the reducing of belt transmission, and the development of electrical and hydraulical transmissions. Using the gears, make the transmition of the rotary motion between two shafts.

The manufacturing of gear drives needs a complex technology, where certain conditions regarding the specific attributes of each gear must be fulfilled. These are as follows:

- Teeth surfaces form;
- Gear dimensions;
- Surface roughness;
- Geometrical parameters of the relative position.

The verification of fulfilling the conditions mentioned above, are made by control operations. These operations are used for gears, to have the final aim, the stabilization of the precision. Determining the differences, compared to the theoretical values, it can be eliminated with the optimal settings of the manufacturing procedure.

The objective of this paper is to synthesize these control operations, as a state of art in the field of gear measuring. These are presented in section three. Once with determining the precision of one gear, can regulate the manufacturing parameters for the following manufacturing procedures. Adjusting the machine tool, the gears can be manufactured more precisely, so can be eliminated the deviations between the theoretical and experimental values.

2. Classification of the Gears

The gears' axes can be situated in three different ways in space. Accordingly, gears can be classified in three groups (Table 1). Each type of gear is manufactured and controlled used specific technologies characterizing the group.

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The classification of the gears Table 1

Axes angle (Σ)	**Center distance, (*a*)**	**Axes position**	**Denomination**
∑ = 0	*a* > 0	Parallel	Spur gear
∑ < 0	*a* < 0	Oblique	Helical gear Hyperbolical gear Worm gear Hypoid gear Spyroid gear
∑ > 0	*a* = 0	Intersecting	Bevel gear

3. The Control Operations

The gears present many type of errors, which source is in most situations the manufacturing process. In order to obtain the proposed precision, these errors must be as much as possible reduced, eliminated, which involves precision engineering, and manufacturing [4].

3.1. The Control of the Pitch

The pitch control consists in measuring the following geometrical elements: the base pitch, the division, the caliper setting:

The base pitch control - consists in determining the length of arch on the base circle between two consequent flanks. The difference between the nominal and the effective base pitch value is influenced by the flank form, the error of the base circle and the non-uniformity of the base pitch. There are many kind of measuring tools, which have the same construction: they have a fix and a mobile detector and a mechanical watch-type output device, which shows the value.

The division control - the correct value of the division assures the quiet functioning of the gear. For measuring, it is used optical or mechanical tools.

The caliper setting - represents the distance between the intersection points of two opposite flanks, situated on different teeth, with the base circle's tangent line. This line is the common normal line of the opposite flanks mentioned above. That is the peculiar geometry that allows any position of the normal line without influencing the result of measuring. As follows, the control can be effected with a simple instrument, endowed with flat touches. For the angular teething the caliper setting can be determined in normal section; for the interior teething the touchers are spherical.

In [5], is presented the single pitch deviation measurement using a coordinate measuring machine without rotary table. The features of this method include:

- applying the multiple-measurement technique to eliminate systematic errors attributed to coordinate measuring machines;
- the estimation of the calibration uncertainty;
- optimizing the uncertainty evaluation by considering thecalibration symmetry.

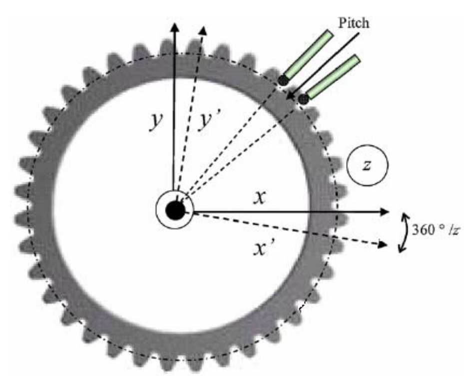

Fig. 1. *Measurement of gear pitch* [5]

Figure 1 shows a schematic overview of the multiple-measurement of gear pitch. The gear is fixed on the coordinate measuring machine (CMM), while one pitch is measured. Then, the gear is rotated around its axe while the coordinate system is also rotated. Each pitch is measured through the periodic rotation mentioned above who's value is typically $360^o/z$, where z is the number of teeth.

3.2. The Profile Control

Gears are usually constructed by an arc of involute. This curve has its incontestable advantages in comparison with other profiles.

The profile error is generated by different factors like the cutting tool profile error, the kinematics of the cutting machine and the technological settings. This error can be determined using different measuring tools, like microscopes, models and involution meters.

The microscopes are used for gears with low module ($m \leq 1$ mm). This method consists on achieving coordinates of a set of points on the profile and to compare these with the theoretical involute profile. The points can be determined in rectangular or in polar coordinate system.

The model based control method can be performed using the following variants:

- using master gears having large dimension and lower precision (class 8);
- using optical projectors for gears having smaller dimension and higher precision.

Involution meters are special devices, which are able to register the profile error, the base circle radius and the flank line deviation error. These devices can be used for the straight or helical, internal or external teethed gears of any precision. There exist two types of involution meters depending on the way of the base circle is materialized: involution meters with discs and universal involution meters.

Involution meters with individual discs: are relative simple, and are applied in serial or mass production.

Involution meters realize the involute curve in the variants below:

- using a sliding ruler. These equipments are made by Goulder-Mikron, David Brown, Klingelnberg, Höfler [5];
- using a fixed ruler, devices manufactured by David Brown type no. 18T and Maag type no. PH60 [4];
- with fixed discs: the cutting tool machines don't use these.

The exploitation of the universal involution meters is relative simple but they present a very complicated structure and are also expensive. These features determine their usage only in laboratory conditions.

The procedure used to realize the theoretical involute classifies these devices as follows:

- with discs: constructed by the firm VEG "Karl Zeiss" Jena and Maag, types SP60, SP100, Pn100 and BV-5032, in [4];
- with master gear: constructed by firm like KEU-S and Fellows Gear;
- with sinus-ruler.

3.3. The Control of Tooth Direction

The tooth flank of the spur gears with angular teeth is a helical involute by which the generator is an involute and the directory line the helix line of the pitch cylinder.

The control can be performed in the following two ways: directly, if the effective dip angle is measured, or indirectly, where different geometrical elements are determined through measuring and followed by computing the effective dip angle.

The direct method uses special devices, determining the dip angle on the division circle or on a circle nearby these. Some firms manufacture them, where the most important are: David Brown, Maag, Höfler, Klingelnberg. The measuring devices can be used to measure some other parameters, like the profile, the pitch, the tooth's grossness etc.

The elements of the David Brown measuring device are represented in Figure 2: the controlled wheel 1, the rolling disc 2, the ruler 3, driver plate 4, and the tuocher 5. The device performs two movements: one vertical (*V*) and one horizontal (*H*), which a made by the driver plate. The combination of these two motions realizes the theoretical helix line that will be compared with the real flank line.

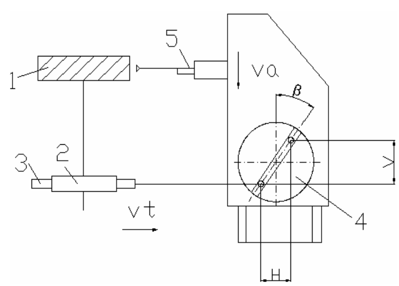

Fig. 2. *The David Brown measuring device* [4]

There exist other devices too, mentioning the Maag, Höfler, Klingelnberg products based on the same principle.

The indirect method is used to determine the tooth's direction error for the large wheels, where the axial pitch can be measured. Using this, the dip angle can be calculated.

3.4. The Contact Pattern Control

The contact pattern size, form and position informs on the wheel's behavior during the gearing.

The contact pattern is determined using two driven wheels, which center distance is set on the nominal gear center distance value. One of the wheel's flanks is spoiled with control paint (a mixture made by technical vaseline technical oil, and a usually blue pigment), that forms a thick (about 0.01 mm) film on the flank surface. Applying on one of wheels a continuously breaking moment and rolling the other in both senses, the contact pattern will be printed on the flanks. These print patterns are copied on a filter paper and their area is measured. The contact pattern dimensions are two types, which are determined in percent [4].

The area and the position of the contact pattern is the same important by bevel gears too. The dimension and the position of the contact pattern informs on the functional behavior of the gear drive. The control of the contact pattern is realized similarly to those applied by the spur gears.

The area and the position of the contact pattern are determined, when the gear is charged, because if not, elastic and thermic deformations on the teeth, shafts, and on other components couldn't be correct appreciate. In this case, the flanks of the crown wheel will be painted with an oil resistant paint like Salzburg vitriol. The contact eliminates the paint from the contact points. The uncontacted flank parts remain painted. It is proved that in case of a charge is applied it exists a tendency of location of the contact pattern on the adjacent exterior cone. If no load is used, the contact pattern is located on the interior bevel surface.

In [3], is demonstrated that at the bevel gears the contact pattern is an elliptical surface, and its aria can be calculated while the contact surface is smaller than the tooth's surface. The ellipse's extension depends on a pre-assigned elastic approach (Figures 3, 4).

In [6] is analyzed the instantaneous contact area under load. Using a computer aided method it is demonstrated the misalignments in spiral bevel gears worsen the conjugation of the contacting tooth surfaces, resulting high tooth contact pressure.

In [1], is proposed a method based on the geometric properties of the generated surfaces

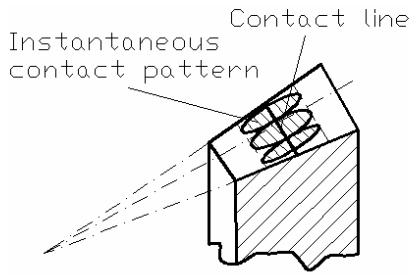

Fig. 3. *Instantaneous contact area* [3]

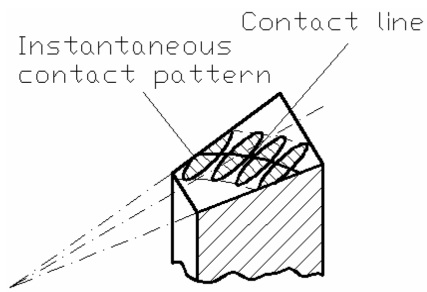

Fig. 4. *Instantaneous contact area, which is diagonal; this kind of contact is inadequate* [3]

of the gear and neglects the mechanical characteristics of the mating members. The instantaneous contact area is estimated employing a simple surface intersection procedure that simulates the marking compound removal during meshing, (Figures 5, 6).

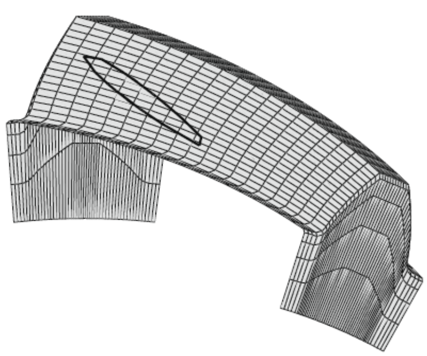

Fig. 5. *Instantaneous contact area on the pinion surface* [1]

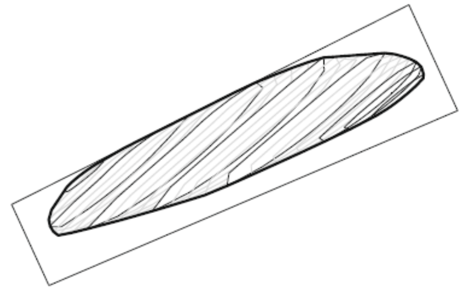

Fig. 6. *Contact pattern estimation. Thin lines: instantaneous contact area; think lines: estimated contact pattern* [1]

4. Conclusion

The main goal is the design of an instrument, which scans the gear's tooth flanks and compares them with the theoretical surfaces. The obtained surface presents the real geometrical parameters. The control operation presented in section three can be carried out with this one device.

The real flank can be investigated in two ways:

- using coordinate measuring machines (CMMs);
- scanning the surface using a system based on an optical sensor (laser) implemented on a coordinate measuring machine.

For the proposed measuring system it is used an existent construction [2], that is improved.

To reduce the volume of the system, and avoid direct contact the implementation of a laser sensor is suggested. The detector uses a vertical and a horizontal DOF. The bevel gear is mounted on a shift, which has a controlled intermittent rotary motion realized by a step motor.

This system is connected to a calculator using a data acquisition card, which processes the measured data. The whole gear is scanned. The achieved information contains the flank geometry, more precisely it's curvature. The theoretical data is loaded in order to compare it with the acquired data and to compute the errors, which are used to set the manufacturing machine correctly.

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