INCREASING THE PRECISION OF THE SMALL PINION GEAR MACHINING

УВЕЛИЧЕНИЕ ТОЧНОСТЬ ОБРАБОТКЕ МАЛЫХ ЗУБЧАТНЫХ КОЛЕСАН

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Abstract : *The paper proposes machining and control methods for the small sized gear pinions. One may face real problems during the finish grinding of the evolventic profile of the gear pinion. The purpose of this paper is to present methods that increase the machining precision of this gears. For the precision grind of the small sized gear pinions it was conceived a device composed of two half-drums with steel strips that is mounted on the grinders type MAAG. The development is done on the base circle, and for grinding one may use grinding discs shaped as discs. The method proposed can grind gear pinions that have very small diameters (theoretically, the value of the diameter can start from zero), because this does not depend on the diameter of the driving shaft of the device in straight reciprocating motion. A method based on the utilization of the manufacturing plant microscope is proposed for the control of the involute-tooth gear. The are presented the main measured value of the evolvent that can be tested, as well as the formula of calculus in this scope.*
KEYWORD : GEAR PINION, DEVELOPMENT, PRECISION, TESTING, MACHINING

1. Introduction

The specific characteristic of the gear pinion is the profile of the pinion. His shape is that of an evolvent. This profile line has several advantages. The mating profile is an evolvent too. The variation of the distance between the axes modifies very little the conditions of the mesh. One could use the movement of the profile of the tooth in order to modify the number of teeth or to increase the thickness of the root of the tooth. The tools and machine-tools used for generating are relatively simple.
The profile of the pinion plays an important role in assuring the precision of the gear pinion. Every deviation of the profile of the pinion from this theoretical line leads to errors in the normal functioning of the gear pinion: not uniform mesh, reduced power, quick wear and tear, noise, etc.
The small pinion gear, with modulus around 0.05 mm and diameters around 1 mm, present difficulties when machining and controlling the evolventic profile. The technical solutions for solving these problems are the following.

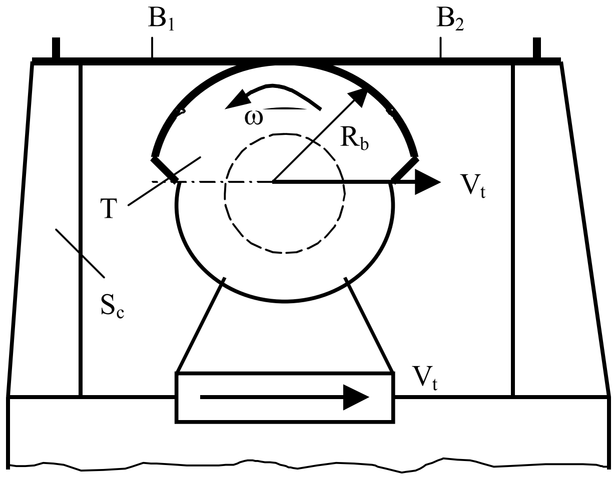

Fig 1. The principle of drum rolling and steel strip

2 . Device for precision grinding of the evolventic profile of the pinion gear of small dimensions

2.1. *Grinding by drum rolling and steel strip*

There are several ways of grinding the tooth-gear. The simplest and most productive is the 0^0 grinding process [2] fig. 1. One thereby uses two plane and parallel grinding discs. The pinion gear that one wants to grind lies on the same driving shaft as the drum T. The steel strip B1 and B2 have each one end bound to the drum and the other to the bearing frame S_c. The transversal translation of the drum with the speed v_t determines it to turn by the angular speed ω. Thus, the drum has a rolling motion on the line of the steel strip. The radius of rolling is the radius of the base circle and equals the radius of the drum.
The pinion gear with a diameter under 28 mm can not be grinded in this way. Their limit is imposed by the resistance conditions, which means the minimum diameter of the drum, as well of that of the driving shaft on which the drum is fixed. This driving shaft assures the straight reciprocating motion of the cross slide on with the device is assembled up.

2.2. *The way it works*

In order to grind the very small diameter pinion gear too, the author proposes the use of the device presented in figure 2. The characteristic of this device is its structure: two semi drums of different radius R and r. The steel strips b_1 and b_2 have each the ends fixed on the two semi drums. The steel strips pass over the rollers of position adjustment R_l, which allow their horizontal position in accordance with the radius of the drums by a vertical movement.
In order to allow the turning, the common centre of the two semi drums translates with the horizontal celerity v_t, by the cross-slide of the machine tool. The motion is a straight reciprocating one. Each steel strip winds out from one semi drum and winds up to another semi drum, imposing to the two semi drums a turning movement with the angular speed ω. The pinion gear, being on the same driving shaft as the two semi drums, has the same movement.
When translating to the right the steel strip b_1 winds up on the semi drum de radius r and winds out the semi drum of radius R. The result is a trigonometric turning movement with the angular speed ω. Simultaneously, the steel strip b_2 winds up the semi drum of radius R and winds out the semi drum of radius r. When translating to the left, the sense of movement is inverted.

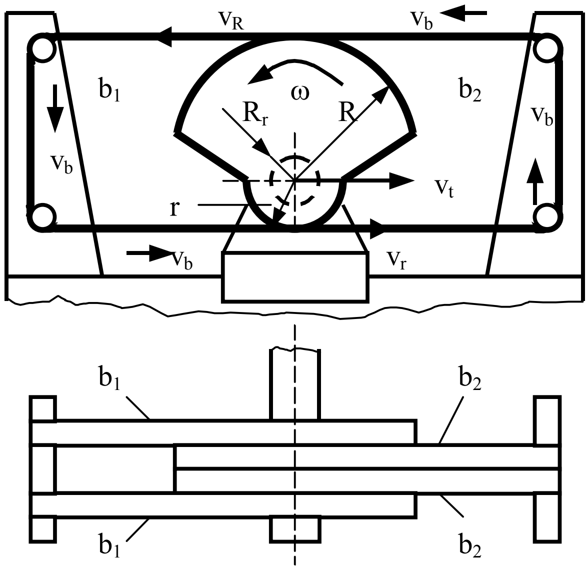

Fig 2. The schema of the principle of the device

2.3. Determining the radius of rolling of grinding

The system of reference being the mobile common centre of the two semi drums, there are two tangential speed:

- he speed of winding up of the steel strip on the semi drum r:

$$V_r = \omega \cdot r \qquad (1)$$

- the speed of winding out of the steel strip on the semi drum R:

$$V_R = \omega \cdot R \qquad (2)$$

because the two different tangential speeds are different, the steel strip B1 moves in respect with the bearing frame S_c (the fix reference system) with the speed V_b:

$$V_b = V_r + V_t = \omega \cdot r + V_t \qquad (3)$$

$$V_b = V_R - V_t = \omega \cdot R - V_t \qquad (4)$$

Equalizing the two relations :

$$\omega \cdot r + V_t = \omega \cdot R - V_t \qquad (5)$$

results the rolling angular speed :

$$\omega = \frac{2 \cdot V_t}{R - r} \qquad (6)$$

The piece to be grinded is fixed on the same driving shaft with the two semi drums. It would have a straight reciprocating motion with the speed V_t and a turning movement with the angular speed ω. The complete motion is a rolling one on a circle of radius R_r:

$$R_r = \frac{V_t}{\omega} = \frac{R - r}{2} \qquad (7)$$

When using this grinding process of the tooth gear, the rolling is on the base circle of radius R_b. Thus, the base radius of the pinion gear to be grinded equals the half of the difference of the radius of the two semi drums. It may be very small and theoretically it may be even zero. The two semi drums are realized with the necessary dimensions imposed by the technological conditions of manufacture, assemblage, and by the resistance conditions imposed to the drifting shaft on which all is assembled.

2.4. The advantages of this device

- it uses the 0^0 grinding process, the most precise and productive process.
- the drum and steel strip rolling mechanism assures the elimination of slacks, being at the same time simple to build.
- the base radius of the pinion gear to be grinded may be as small as one wants, even very close to zero, because it equals the half of the difference of the radius of the two semi drums.
- the radius of the semi drums may be as large as one wants, thus ensuring the rigidity needed by the drifting shaft on witch the device is assembled.

3. The control of the evolventic profile of the small dimension pinion gear

3.1. Definition of the from error of the evolventic profile

The precision of the pinion gear is determined by a number of parameters. Specialized apparatus control them. There are difficult problems when referring to controlling the errors of the evolventic profile of the small dimensions pinion gear. The form error of the evolventic profile means the distance measured on the normal to the direction between two theoretical evolvent profiles of the tooth of the gear that outlines the real profile. It must be situated within two theoretical evolventic profiles having the same base circle.

Thus, the author proposes two different control methods of the error of the evolventic profile for the small dimension pinion gear, using the manufacturing plant microscope.

3.2. First control method

The errors are referenced to a reference system having the centre in the centre of the locating surface of the pinion gear. The piece is laid on the table of the microscope. Then:

♦ The coordinates of three points of the reference surface of the pinion gear are measured: the bore of the gear, the exterior circle or another surface machined for this purpose.

♦ The coodinates (ξ_0, η_0) of the centre O of the pinion gear is measured in reference to the coordinates of the three points. The calculus uses the well known analytical relations.

♦ The coodinates (ξ_I, η_i) of a certain number of points M along the real profile are measured.

♦ The profile error is calculated using the relations 8, 9 and 10 [1], as in figure 3. The segment PM means the error.

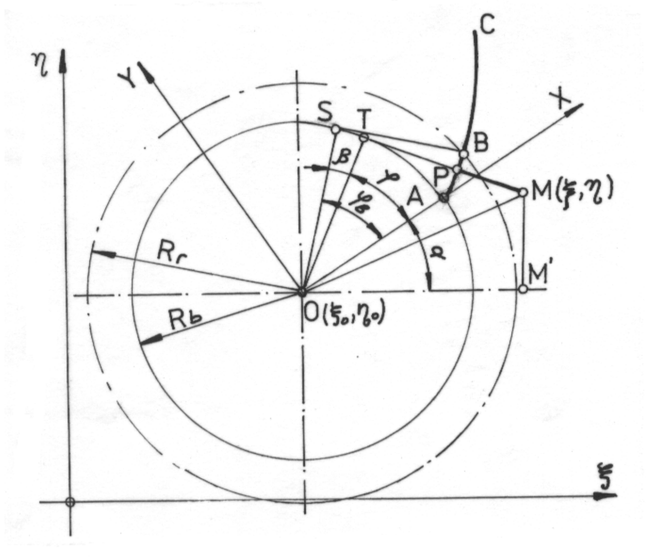

Fig.3, The measurement scheme according to the first control method

- P is a point on the theoretical profile.
- M is the correspondent point of P on the real profile.

$$E_{fpi} = R_b \cdot \left(\lambda_i - arctg\lambda_i - arctg\frac{\eta - \eta_0}{\xi - \xi_o} + \alpha \right) \qquad (8)$$

For the right profile: $\lambda > 0$.

For the left profile: λ < 0.

$$\lambda_i = \sqrt{\left(\frac{\xi_i - \xi_0}{R_b}\right)^2 + \left(\frac{\eta_i - \eta_0}{R_b}\right)^2 - 1} \qquad (9)$$

$$\alpha = \frac{1}{n} \cdot \sum_{i=1}^{n} \left(arctg \frac{\eta_i - \eta_0}{\xi_i - \xi_0} + arctg\lambda_i - \lambda_i \right) \qquad (10)$$

R_b - the base radius of the pinion gear
λ_I, α - angles, as in figure 3.
N - the number of points to be measured on the tooth flank

3.3. The second control method

This method consists in referencing the errors to a reference system having the centre in the centre of the circle passing through the middle of the height of the teeth. This method is more precise and it adapts the idea of the apparatus ES-430 MAAG [3]. The pinion gear is laid on the table of the microscope by using a special device. The device has two guide pins b_1 and b_2, and their position can be determined according to the measurement system of the microscope. The following steps must be followed:

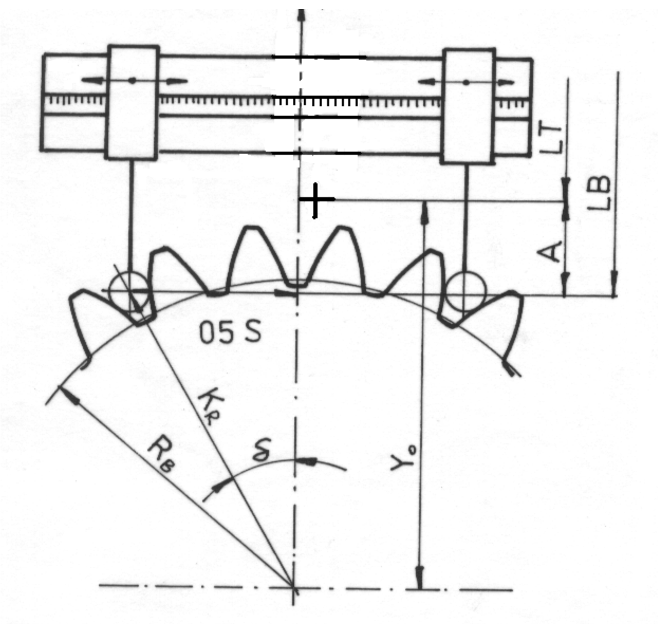

Fig. 4, The positioning scheme of the gear pinion

- ♦ The pinion gear is laid on the table of the microscope
- ♦ The stadia line is positioned in N points of the tooth profile, like in figure 5, where:

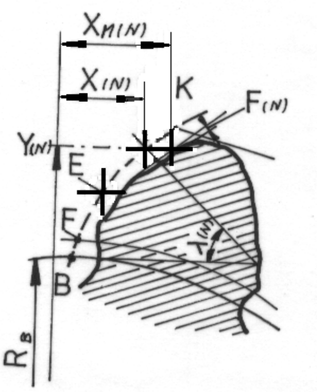

Fig. 5, The scheme for the determination of the profile error

- – F- the point at the base of the tooth, the first point of the tooth profile;
- – K- the point of the top of the tooth, the last point of the tooth profile;
- ♦ For each movement Y_N the movement X_{Nm} on OX is measured.
- ♦ After touching the point K the stadia point is moved to the other tooth flank and the same steps are followed.
- ♦ The profile error is determined using the relation 11, comparing the theoretical values X_N with the measured values X_{Nm}

$$F_N = \left(X_N - X_{Nm}\right) \cdot \cos \lambda_N \qquad (11)$$

When determining the theoretical values X_N and λ_N the following steps are to be followed:

- The distance Y_0 from the centre of the circle that passes through the middle of the height of the teeth (the reference circle) to the line that joins the centres of the guide pins B_1 and B_2 is measured -as in fig. 4, as in relation 12:

$$Y_0 = K_R \cdot \cos \delta = \frac{0{,}5 \cdot S}{\sin \delta} \cdot \cos \delta = 0{,}5 \cdot ctg \frac{\pi \cdot k_z}{z} \qquad (12)$$

- The ordinates Y_K and Y_F of the points F and K are measured.
- The stadia line is moved on the Y direction, until a distance Y_E to the centre of the reference circle is obtained. Y_E is obtained by the relation 13:

$$Y_E = \frac{Y_K - Y_F}{2} + Y_F \qquad (13)$$

- The distance L_E between two close flanks is measured, in the points E of ordinates Y_E, as in fig. 6.

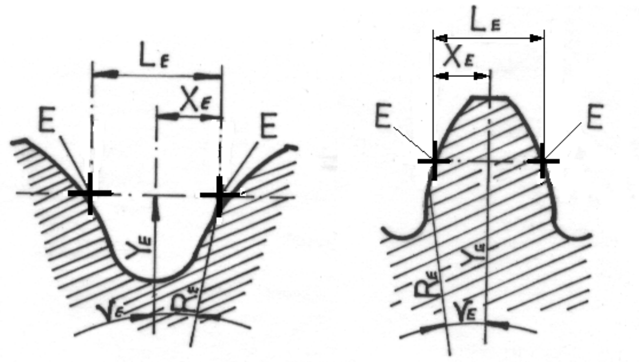

Fig. 6, The scheme for measuring the distance L_E

- The radius R_E of the circle on which are situated the points E is calculated through the relation 14:

$$R_E = \sqrt{Y_E^2 + X_E^2} = \sqrt{Y_E + \left(0{,}5 \cdot X_E\right)^2} \qquad (14)$$

- The angle φ that determines the position of the first point of the evolventic profile (B) is calculated through the relations 15, 16, 17, 18 (fig.7):

$$\gamma_E = \arccos \frac{Y_E}{R_E} \qquad (15)$$

$$\alpha_E = \arccos \frac{R_B}{R_E} \qquad (16)$$

$$\varphi_E = \frac{1}{R_B} \sqrt{R_E^2 - R_B^2} \qquad (17)$$

$$\varphi = \gamma_E + \alpha_E - \psi_E \qquad (18)$$

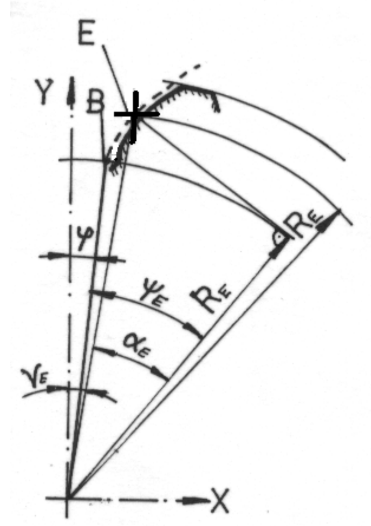

Fig. 7, The scheme for calculating the angle φ

- The angles ψ_F and ψ_K, as in fig. 8, using the approximate relations 19 and 20:

$$\psi_F \cong \frac{1}{R_B}\sqrt{Y_F^2 - R_B^2} \quad (19)$$

$$\psi_K \cong \frac{1}{R_B}\sqrt{Y_K^2 - R_B^2} \quad (20)$$

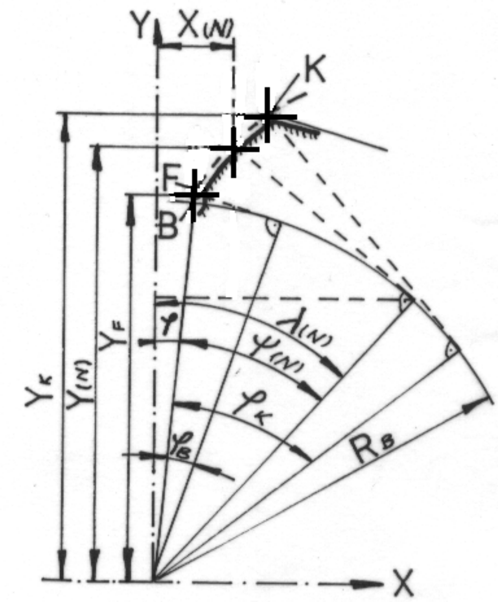

Fig.8, The scheme for calculating the coordinates of the points on the evolvent

- The angle ψ_N is calculated for every point N on the evolvent , as in figure 8, using the relation 21:

$$\psi_N = \psi_F + N \cdot \frac{\psi_K - \psi_F}{n} \quad (21)$$

n- the number of points on the evolvent on which measures are made.

- The angle λ_N, as in figure 8, with the relation 22 is calculated:

$$\lambda_N = \varphi + \psi_N \quad (22)$$

- The coordinates of the theoretical evolvent points are calculated as in figure 8. For every point N of the evolvent the relations 23 and 24 are used:

$$X_N = R_B \cdot \left(\sin\lambda_N - \psi_N \cdot \cos\lambda_N\right) \quad (23)$$

$$Y_N = R_B \cdot \left(\cos\lambda_N + \psi_N \cdot \sin\lambda_N\right) \quad (24)$$

4. Results and discussion

The precision grinding of the small diameter pinion gear and very small modulus raise a series of difficult problems. The machining principle and the control methods proposed by the author resolve these problems.
The devices conceived in order to apply this method is based on the idea of grinding two plane and parallel grinding disks, by turning on the base circle (the 0^0 grinding principle). It may be used on the machines that grind pinion gears that use this principle. By using the mechanism of turning (development) with steel strips, one eliminates the slacks, increases the machining precision and the productivity. By using the two semi drums, the principle proposed allows the machining of pinion gears having a very small diameter, and even zero. At the same time the diameter of the driving shaft may be as large as the resistance conditions demand.
For each value of the base diameter of the gear to be grinded, one must use the pair of semi drums that have the half of the difference of their diameters equal to this value. In order to use the same semi drums for different values of the base diameter, one may introduce supplementary steel strips, gauged under the fixed steel strips b_1 and b_2.
The methods proposed for measuring the tooth profile allow its precise determination without any special devices and apparatus. Because the pinion gear has a very small diameter, a universal apparatus is used, that is the manufacturing plant microscope. The coordinates of the theoretical profile that is the reference to the determination of the errors may be referenced to a system of coordinates having the centre in the centre of the reference surface of the pinion gear or in the centre of the circle that passes through the middle of the height of the teeth. The measured values may be separately processed, by using a special computer program or may represent the automatic acquisition and processing of the microscope, if it allows this.

5. Conclusion

The device proposed by the authors is original. His characteristic is that it is formed by two semi drums that circulate on steel strips that are fixed. This method allows the grinding of very small dimensions pinion gears, that the classical machine tools are not able to grind.
Using the manufacturing plant microscope allows a precise control of the surface to be grinded at the small dimensions pinion gear. The methods proposed by the authors mean an adaptation of the methods used for the control of the evoleventic profile in the conditions imposed by the use of the manufacturing plant microscope.

6. Literature

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