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ADJUSTEMNT ASPECTS OF GEAR HOBBING MACHINES IN DIAGONAL MILLING

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Abstract: *The processing of the gear tooth flanks represents one of the most complex ways of surface generation. As regards the application of diagonal milling method, the necessary motions for generation, kinematic generator chain structure, association mode and adjusting functions are presented. On their basis and using a calculation program the pears of change gears necessary for adjusting the threading kinematic chain are determined. For the rapidity and precision of the calculation, in the papers the concept of virtual machine tool is described and used. Some results of the method application are presented and discussed.*

Key words: *flank kinematic generation, adjusting function, adjusting calculation, virtual tooth processing machine, tooth direction deviation*.

1. INTRODUCTION

The establishing of the technological method of gear tooth processing by cutting is determined by the destination of gearing, production type, form and sizes of gears and teeth, costs, etc. The spur gears have important role and are used on large scale in industrial application such as machines and equipments, drive gears, speed reducers, etc. Among the productive processing methods there is the hobbing cutter milling. Even if this technological method is intensely used, there are many aspects that required and still require improvements for enabling the increase of gear performances, more efficient use of the machine tool and tools. The application of diagonal milling method ensures a uniform distribution of the tool wear on its length and an increase of process productivity [1, 4]. In industrial applications, the methods of calculation of the work and adjustment parameters of the technological system have some limitations mostly in establishing the dimension of processing errors and framing them in the prescribed precision step. For emphasizing al these aspects, in the paper the concept of virtual machine tool [7] is described and used, being particularized to a gear hobbing machine.

2. GENERATION KINEMATICS AND ADJUSTING FUNCTION OF KINEMATIC CHAINS

The advantages of the diagonal milling method are: the increase of productivity and processing precision, rational use of machine and hobbing cutter, decrease of processing cost. This is less spread in practice due to difficulties that appear in calculation of the change wheels and in the adjustment of machine. The kinematics of generation of the flanks of spur gear tooth flanks through this method enables the correlation of the revolution and prismatic motion of the hobbing cutter *S* (Fig. 1) with the revolution motion of the workpiece *P*.

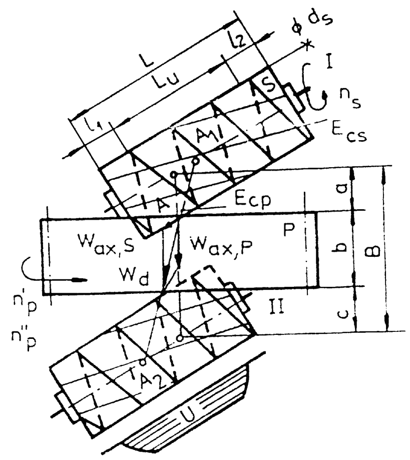

Fig. 1. Parameters of the diagonal milling.

The feed motion of the cutting tool having the speed w_d results from composing two feed motions having the speeds $w_{ax\,HC}$ and $w_{ax\,WP}$. The two speeds have the ratio

$$w_{ax\,HC} / w_{ax\,WP} = L_u / B = i_{CM}\,, \qquad (1)$$

limited to certain values. The parameters L_u, a, and c, are determined by known simple calculations [1, 2, 4]. The vectors of the speeds $w_{c\,HC}$, $w_{c\,WP}$, and w_d are indicated in Fig. 2. In the case of generation of helical gears having a certain angle β, the kinematic generation of the helical directrice (flank line) imposes the following condition

$$v_{TF} / v_{AF} = \tan\beta. \qquad (2)$$

Taking in consideration the motions necessary to generation and indicated in figure, it results that the generating element obtained through the tool feed motions moves along a workpiece cylindrical helix (E_{cp}) with the speed:

$$\bar{v}_D^* = \bar{v}_{TF} + \bar{w}_d + \bar{w}_{axS}^*\,. \qquad (3)$$

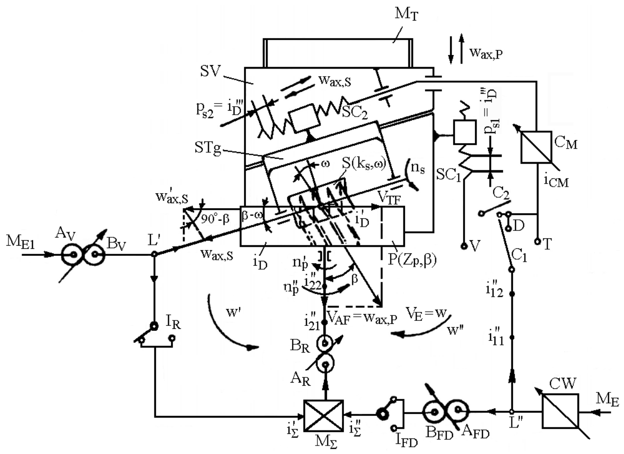

Fig. 2. Kinematic chains in diagonal milling.

Its tangential components satisfy the relation:

$$\overline{v_{TFd}} = \overline{w'_{axS}} + \overline{v_{TF}} \,. \tag{4}$$

The total tangential component results from composing:

$$\overline{v_{TRFd}} = \overline{v_{TR}} + \overline{v_{TF}} + \overline{w'_{axS}} \,, \tag{5}$$

considering also the rolling tangential speed v_{TR}.

From the analysis of relation (5), it results that the generation of the helical teeth through diagonal milling method needs the mixed association [1, 6] of three closed kinematic chains (Fig. 2), namely rolling, threading, and diagonal milling (form maintaining the closing condition of the rolling kinematic chain). The association of the threading and diagonal milling kinematic chains according to relation (5) is of parallel-series type, without differential. The kinematic chain obtained in this way it is in his turn associated in parallel-series mode with the rolling kinematic chain by using a differential mechanism M_{Σ}.

Writing the transfer equation of the rolling kinematic chain, its adjusting function becomes:

$$\frac{A_R}{B_R} = \frac{1}{i_W{}'} \cdot \frac{1}{i_{11}{}' \cdot i_{12}{}' \cdot i_{\Sigma}{}' \cdot i_{21}{}' \cdot i_{22}{}'} \cdot \frac{i_{D,S}}{i_{D,P}} = K_R \frac{k_S}{z_P} \,, \tag{6}$$

in which $i_{DS} = (\pi \cdot m_n \cdot k_S) / \cos\beta$, $i_{DP} = (\pi \cdot m_n \cdot z_P) / \cos\beta$, K_R – constant of rolling chain, and i'_w - transfer ratio of the fictive mechanism [1, 4]. The adjusting function of the threading and diagonal milling kinematic chain considered as a closed kinematic chain has the form:

$$\frac{A_{Fd}}{B_{Fd}} = \frac{1}{i''_w} \cdot \frac{i_{Dv}}{i_{DP}} \cdot \frac{B_R}{A_R} \cdot \frac{i''_{11} \cdot i''_{12}}{i_{21} \cdot i_{22} \cdot i''_{\Sigma}} =$$
$$= K_{Fd} \, (\sin\beta \pm i_{CM} \cos\omega) \cdot \frac{1}{k_s \cdot m_n} \,, \tag{7}$$

where: K_{Fd} is the kinematic chain constant (for machine FD 320 A it has the value 6), signs (±) corresponds to the case in which the helix direction is right and left respectively, $\frac{w_{ax\,S}}{w_{ax\,P}} = i_{CM}$, ($i_{CM}$ has the values ¼, ½, 1), ω - the inclination angle of groove helix E_{cs} (Fig. 1) for chip evacuation, and $i_{Dv} = p_{sc\,v}$.

In the case in which for the mixed association [1, 6] of the three closed kinematic chains two summing (diferntial) [4] mechanisms M_{Σ} would be considered, the calculation difficulties for adjustment mechanism of each kinematic chain would be decreased. Such a kinematic structure was not required from many causes, among them being the kinematic precision reduction.

3. STAGES OF ADJUSTING CALCULATION

The adjusting calculation of the machine [1, 2, 5] is achieved on the basis of the parameters that define: workpiece gear (z, m, β, and direction of helix E_{cP}), tool (k_s, w, direction of helix $E_{cS'}$, L, d_s) and the cutting regime (cutting speed v_c, v_{as}, $w_{ax\,S}$, $w_{ax\,P}$, and directions of the feed speeds). The stages of calculation are as follows:

a. establishing the lengths: L_u, of entry a and exit c in/from contact with the tool/workpiece and the ratio $w_{ax\,S} / w_{ax\,P}$;

b. position of the tool axis in regard with the workpiece gear achieved by inclining the tangential saddle S_T of the machine depending on the values of the angles β and ω and directions of helices E_{cP} and $E_{cS'}$;

c. change wheels for adjustment of the main, rolling and diagonal milling kinematic chains. The necessary data of calculation for two machines for tooth processing of the family FD Cugir are supplied in [8]. For the main kinematic and rolling chains, the determination of the change wheels is simple by using diagrams and tables.

The change wheels A_{Fd} ... D_{Fd} for adjustment of diagonal milling kinematic chain are determined with relatively difficulty, having in view the algebraic sum of two trigonometric functions in the structure of the adjusting equation (7). The approximation accepted in calculation is expressed by a certain error of kinematic generation of the flank lines (helix E_{cP});

d. the deviation of the tooth direction $F_{\beta r}$ [8], its direction being determined with relation

$$F_{\beta r} = b\,(\tan\beta' - \tan\beta), \tag{8}$$

where β′ is the real value of the inclination angle. This angle is determined from relation (7) considering for A_{Fd} ... D_{Fd} the values established at point c. It is required that $F_{\beta r} < F_{\beta}$, the value of the tolerance F_{β} being indicated in standards (STAS).

4. DIAGONAL MILLING SIMULATED WITH THE VIRTUAL MACHINE

In industrial practice the calculation methods of the technological and adjustment parameters of the technological system have some limitations, especially in determining the magnitude of processing errors and bringing them in the prescribed precision stage. For this purpose the virtual machine was created. The concept of virtual machine tool applied in this paper is particularized to the gear hobbing machine.

According to the respective approach, the followings are defined analytically: the cutting edge form, positions and motions of machine elements, time progress of the generation motions. Generally, the generation motions are achieved along or about an axis for the couple shaft-bearing (*R*) or slide-guide (*T*). To each fixed or mobile element (tool, workpiece, slides) that takes part in the process of flank generation a coordinate system was attached.

Further, from generation the followings are defined:

– cutting tool, by expressing analytically of the cutting edges; in the analysed case – the hobbing cutter;

– generation trajectories, defined in coordinate systems, their number being given by the numbers of kinematic couple *R* and *T* of the gear hobbing machine structure on which the machining is done and by defining the motions that are achieved. In regard with the machine, the coordinate systems consists of two branches, namely of the tool and of the workpiece;

– workpiece (cylindrical wheel), by attaching to it topographic surfaces (plane, cylindrical, conical, spherical surfaces, etc.). With their aid the generated surface is determined (tooth flanks) [7].

The mathematical treatment of generation consists of going through for stages, starting from the generatrice curves, and up to the parametric expression of the generated surfaces.

For the analysed case, it is considered that the machine structure has three basic elements: bed as fixed element, cutting tool, and workpiece as mobile elements. To these elements a coordinate system is associated, notated: $O_fX_fY_fZ_f$, $O_sX_sY_sZ_s$ and $O_pX_pY_pZ_p$ (Fig. 3).

The coordinate systems connected to the tool and workpiece respectively are situated at the end of the kinematic chains that drive them.

The calculation algorithm requires the use of two matrices: one that has the coordinate systems in their succession on the workpiece branch (between the bed and workpiece) and the second one that has the coordinate system on the tool branch (between the bed and tool).

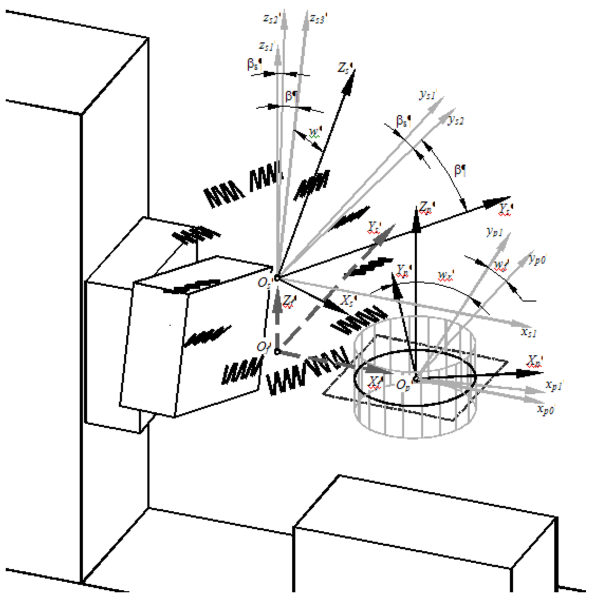

Fig. 3. Coordinate systems of machine and cutting edges of the hobbing cutter.

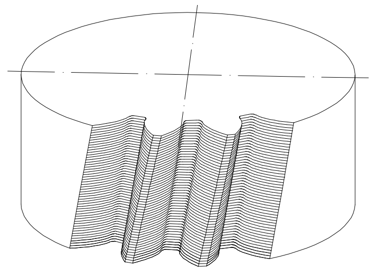

Fig. 4. Generated flanks.

The matrices contain the geometric parameters of the tool and workpiece, adjustment parameters, and also the parameters that define the generation motions in the case of processing spur or helical gears.

For exemplification of the results obtained by using the virtual machine, in Fig. 4 the flanks of two successive teeth that are generated on the workpiece are presented. The considered topographic planes are perpendicular to the workpiece axis and axially distanced with 0.5 mm.

The elaborated calculation method enables the numerical evaluation and the representation of some errors due to the adjustment of the gear hobbing machine, namely:

• errors of the tooth profile in frontal plane, if the inclination of the hobbing cutter has an angular error;

• tooth direction errors;

• errors of the tooth profile in frontal plane, if the hobbing cutter is eccentrically mounted on the tool holder shaft of the main spindle.

For exemplification, the case of processing on FD 320 A gear hobbing machine of a spur gear having m_n = 2.5 mm; b = 40 mm and β = 12 °, right helix and a hobbing cutter having k_s = 1 and ω = 1° 2′ is considered. The precision step of the gear is 6.

Applying the relation (7), it results:

$$\frac{A_{Fd}}{B_{Fd}} \cdot \frac{C_{Fd}}{D_{Fd}} = 1.6986467\,,$$

value that has to be approximated as close as possible by the change wheel ratios. The change wheel are chosen from the set on the machine (20, 21, 22, 23, 24, 26, 27, 28, 29, 30, 31, 33, 34, 35, 36, 39, 40, 42, 43, 45, 46, 48, 50, 52, 54, 55, 60, 62, 63, 64, 66, 68, 69, 70, 72, 75, 77, 80) [8]. They need to satisfy the mounting condition: $A_{Fd} + B_{Fd}$ = 60 ... 90 (90 ... 125), $C_{Fd} + D_{Fd}$ = 90 ... 122 (72 ... 125).

More than one approximation ratios are determined. Form them the following ratios are kept:

$$1.6988417 = \frac{33}{37} \cdot \frac{40}{21};\, 1.69811321 = \frac{45}{53} \cdot \frac{60}{30};$$

$$1.69863014 = \frac{80}{40} \cdot \frac{62}{73},$$

in which not all the numbers are in the change wheel set. The calculation is continued for finding other ratios. Thus, it is calculated $1.6923076 = \frac{24}{26} \cdot \frac{55}{30}$, whose numbers are in the set, but do not satisfy the mounting conditions. The calculation is continued up to the next ratio: $1.69899425 = \frac{43}{29} \cdot \frac{55}{48}$. For accepting in this calculation a certain approximation, it is accepted a generation error of the flanks.

On the basis of relation (7), the effective value of the inclination angle $\beta_r = 12°0'30''$ and the tooth direction error according to relation (8) are determined.

This error is compared to the tolerance of the tooth direction that has the value F_β = 11.32 μm resulted from calculation according to STAS 6273-81. Because $F_{\beta r} < F_\beta$, the change wheels A_F = 43, B_F = 29, C_F = 55, D_F = 48 can be used for adjusting the diagonal milling kinematic chain.

5. CHANGE WHEEL DETERMINATION USING CALCULATION ALGORITHM

The calculation of the change wheels A_{Fd} ... D_{Fd} in a classical way, taking in consideration the given conditions for a certain case, leads to a relatively large time consumption and possible errors that could be determined in generated flank testing. A calculation program was achieved, which on the basis of the input data (m_n, β, ω, k, K_{Fd}) calculates the change wheel in certain conditions (set of wheels, mounting conditions, required precision for angle β). In Tables 1 and 2, a part of the output data obtained by program running is presented.

Even partial, the results could be used in the adjustment practice of the machine FD-320 A. These could be anytime completed and the program used for every machine of the family FD Cugir.

Tabelul 1

Change wheels for diagonal milling of spur gears

$k_s = 1$; $i_{CM} = 1$					
m, mm	**ω, degrees**	**Change wheels**			
		A_{Fd}	**B_{Fd}**	**C_{Fd}**	**D_{Fd}**
1	1° 15′	43	23	77	24
1.25	1° 35′	43	23	77	30
1.5	1° 25′	68	27	50	42
2	2° ′	52	66	70	23
2.5	2° 15′	39	22	62	55
3	2° 25′	68	39	55	52
3.25	2° 40′	29	66	75	22
4	2° 55′	48	70	66	34
4.5	3° 20′	40	69	62	33
6	3° 35′	50	54	68	21

Tabelul 2

Change wheels for diagonal milling of helical gears

$k_s = 1$; $i_{CM} = 1$								
β degrees	**Change wheels**							
	E_{cp} - right direction				**E_{cp} - left direction**			
	A_{Fd}	**B_{Fd}**	**C_{Fd}**	**D_{Fd}**	**A_{Fd}**	**B_{Fd}**	**C_{Fd}**	**D_{Fd}**
1	62	23	52	43	29	34	77	24
1.25	48	31	63	29	43	28	72	42
1.5	60	33	60	31	36	31	64	30
2	39	29	70	26	55	35	68	45
2.5	54	31	62	29	48	26	64	52
3	68	28	63	40	27	33	69	26
3.25	52	34	77	30	60	39	70	52
4	69	27	50	31	36	55	63	22
4.5	40	23	75	29	35	62	69	26
6	43	28	70	21	33	46	66	54

6. CONCLUSIONS

The precision of the gear processing is determined by many factors, among them the adjustment calculation and the adjustment itself being of major importance. The change wheels are determined on the basis of the adjusting functions that contain geometric parameters of the tool and workpiece, parameters of kinematic generation and of reciprocal position. The two calculation programs elaborated and applied ensure the rapidity and increase of the calculation precision of the change wheels and the decrease of the machining errors.

Using the virtual gear hobbing machine, the simulation the tooth flank generation and 3D representation of profile form and flank lines is achieved.

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