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Research Paper

Application of Model and Algorithms of the Circular Stretching Profile and Disc Modular Cutter

[1]Ezekiel Oluwadamilare Akintona, [2]Nwufo Maduka Augustine,
[3]Soyoye Victoria Olajumoke

[1]Department of Industrial and Production Engineering, Nnamdi Azikiwe University, Awka, Anambra state Nigeria.
[2]Department of Mechanical Engineering Technology, Federal Polytechnic Oko, Anambra State, Nigeria.
[3]Department of Aquaculture and Fisheries Management, Federal University of Agriculture. Abeokuta.

ABSTRACT
The problems of machine tool on the methods and means of parameterization for the main components of metal-cutting machine. The models and algorithm of parametric modeling for the contour of machine tool milling operational type by the criteria of maximum rigidity and minimum reduced load on the front spindle support are developed. Cutting kinematics includes the rotation of the cutter (main movement) and the movement of the feed of the work-piece, fixed in the spindle of the dividing head, along the machined cavity of the teeth. After processing one cavity, the work-piece is rotated one tooth and the next cavity is cut, etc. When cutting helical teeth, the work-piece is additionally given a circular transmission by turning the spindle with a dividing head, providing a total screw feed.The procedure for generating the transverse layout of the main drive in the multivariate design mode has been implemented.
KEYWORDS:*Machine tool, Metal cutting machine, Models and algorithms, Optimization andDisk modular gear milling cutter*

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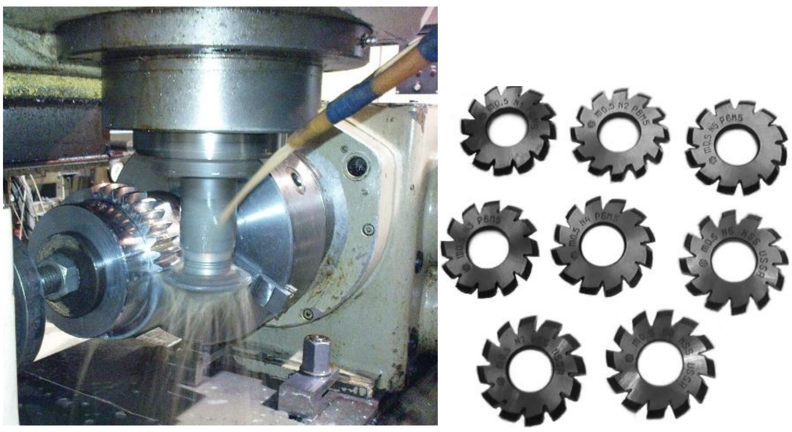
I. INTRODUCTION

There is a wide variety of gears and gearing mechanisms currently used in the automobile and machine-building industries. They are different by geometric parameters (number of teeth, flank line, tooth alignment and profile), gear quality (tooth profile, flank line and pitch accuracy, surface roughness) and material properties (hardness, weight, corrosion resistance) **[1][2][3].** For efficient single piece and small hatch production of different gears, flexible manufacturing technologies which can be implemented by using conventional cutting tools and machining centers are expected. One of such technologies is gear cutting with profile-independent tools such as disk milling cutters (see figure 1).



The loose connection between the cutting tool and tooth profile as well as provides possibilities to increase productivity and to reduce manufacturing costs**[3][4][5][6].** That is why machining process becomes more important. Methods for gear machining by disk milling cutters were developed and successfully implemented on the conventional machining centers**[3][4][5][6][7][8][9][10].**These methods are differ in strategies for material removal, tool movement and tool engagement as well as classified according to them **[11].** The koganov's method has already been studied theoretically and experimentally in mathematical simulation of the form-shaping kinematics (movement of the cutting tool relative to the work-piece) was developed for process simulation **12].** Then trajectories, velocities and accelerations of the machine tool component and material rates when gear cutting were calculated by using this mathematical simulation. **[13][14][15].**

II. PROCEDURE FOR CALCULATION AND PROFILING OF DISC GEAR MILLS

2.1. Initial data Dimensions of the cogwheel to be machined:
1. Normal module – m= 3.75
2. The number of teeth of the wheel - z_0=*53*
3. The angle of the profile of the original contour (angle of engagement) - $\alpha = 20°$α.
4. Coefficient of displacement of the original contour -ξ $= 0.72$ξ.
5. The ratio of the height of the tooth head -. $ha^* = 0.8$
6. Radial clearance - c, $\alpha = 20° \rightarrow c = 0.25$m, and at $\alpha = 15° \rightarrow c = 0.16$m
7. Mandatory thickening of the tooth to ensure a guaranteed lateral clearance in the transmission - ΔS, determined depending on the size of the module from the table.1 according to the corresponding amount of tooth thickening of the tool bar.

Table 1
Thickening of the tooth of the tool rack and tolerances for the thickness of the tool tooth, mm

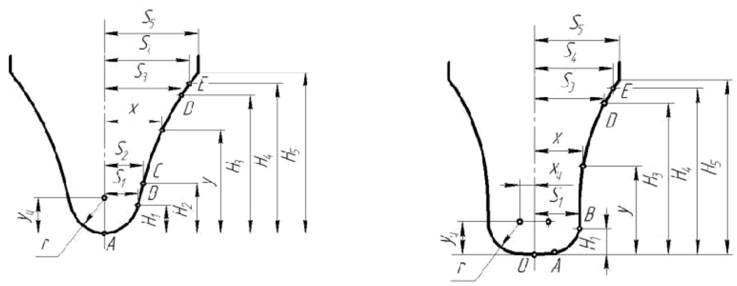
Module	Tooth thickening	Tolerance for classes		Module	Tooth thickening	Tolerance for classes	
		A	B			A	B
1,25 – 2,0	0,145	0,03	0,04	6,5 – 8,0	0,26	0,04	0,05
2,25 – 2,5	0,160	0,03	0,04	9,0 – 10	0,28	0,04	0,05
2,75 – 3,0	0,175	0,04	0,05	11,0 – 12	0,31	0,05	0,06
3,25 – 4,0	0,200	0,04	0,05	13 – 16	0,35	0,05	0,06
4,25 – 5,0	0,200	0,04	0,05	18 – 20	0,35	0,05	0,06
5,5 – 6	0,230	0,04	0,05				

8. Pitch circle diameter: $D_d = m * z = 3.75 * 53 = 198.75$ mm
9. Diameter of the base circle: $D_b = D_d * \cos\alpha = 0{,}9396 * 198.75 = 186.76$ mm
10. Diameter of the circumference of the protrusions: $D_a = D_d + 2m * h_a *= 198.75 + 2 * 3.75 * 1 = 206.25$mm, where ha1 is the height of the tooth head.
11. The diameter of the circumference of the depressions: $D_f = D_d + 2m * h_a^* = 198.75 - 2.5\text{m} = 189.375$mm, where h_f is the height of the tooth stem.
12. Thickness of teeth along the pitch circle arc $S = 0.5\pi * m - \Delta S = 0.5 * 3.14 * 3.75 - 0.230 = 5.6875$mm, taking into account thinning (GOST 1643-81):.
13. The degree of accuracy of the cut wheels - in accordance with GOST 1643-81.

2.2. Determination of the profile dimensions of disk modular cutters [16] p. 152, **[17]** p. 508, **[18]** p. 389, **[19]** p. 304.

Disk cutters for cutting uncorrected gear wheels are made in the form of sets of 8, 15 or 26 cutters (Table 2). Each cutter in the set is used to cut wheels with a specific number of teeth. A set of 8 cutters is used for cutting gears with a module of up to 8 mm. For a module over 8 mm, a set of 15 cutters should be used, and for more precise work - a set of 26 cutters. The dimensions of the coordinates of the cutters' profiles are normalized and are given in (table. 3) values of x and y coordinates for any point of the cutter profile, measured from the bottom of the tooth cavity (Figure. 2).

Type 1 Type II



A – Type I; B – Type II

Figure 2. Construction of the profile for the disk modular gear milling cutters:

Profile type I Institute VNII proposed a special table of *x(S)* and *y(H)* coordinate values for any point of the cutter profile measured from the bottom of the tooth root, coordinates x_z – centers of curvature in the tooth root, values of radii *r*, and also points *B, C, D, E* profiles (Figure 2). The coordinates S3, H_3 – set the position of the involute point *D*, lying on the addendum circle; *S4, H4* – set the position of the involute last point and the transition to the dimensions of the cutter width *B*. The calculation of the coordinates for the cutter profile points (Figure 2) is performed either in a tabular manner, or using the calculation form presented in (Table 1.1)**.** The capabilities of modern integrated CAD systems predetermine the expediency of transferring information from a tabulated form into analytical. Expressions (calculation form), which ensures higher accuracy of calculations with a significant reduction in the time required for this.

Table 2

Complete set of Disk Gear Cutter

№ cutters	Number of cutters in set			№ cutters	Number of cutters in set		
	26	15	8		26	15	8
	Cutting number of wheel teeth				Cutting number of wheel teeth		
1	12	12	12–13	5	26–27	26–29	26–34
1½	13	13	–	5¼	28–29	–	–
2	14	14	14–16	5½	30–31	30–34	–
2¼	15	–	–	5¾	32–34	–	–
2½	16	15–16	–	6	35–37	35–41	35–54
3	17	17–18	17–20	6¼	38–41	–	–
3¼	18	–	–	6½	42–46	42–54	–
3½	19	19–20	–	6¾	47–54	–	–
3¾	20	–	–	7	55–65	55–79	55–134
4	21	21–22	21–25	7¼	66–79	–	–
4¼	22	–	–	7½	80–102	80–134	–
4½	23	23–25	–	7¾	103–134	–	–
4¾	24–25	–	–	8	135	135	135

Profile type II is designed for milling cutters No. 6-8 (z> 34; rb<rf) and consists of an involute BDE and a straight line segment OA conjugated along a circular arc AB. Given in (table. 3 and 4) values are given for module m = 100 mm. For other modulus values, the table values must be divided by 100 and multiplied by the calculated modulus. The obtained values of the coordinates of the cutter profile are entered into the table and used for graphical construction of the profile of the disk modular cutter performed on the drawing (Figure. 6).

2.1.2. Determination of the profile coordinates of the corrected ($\xi \neq 0$) disc cutters with a high degree of accuracy.

To cut corrected teeth of wheels, as well as uncorrected teeth of an increased degree of accuracy and wheels with a modified tooth profile, disc cutters are used, the exact profile of which is determined by special calculations. (Figure. 2)

Table 3
Coordinates (mm) of points x and y of the involute part of the profile of disk cutters for m = 100 mm

	Milling cutter 1		Milling cutter 2		Milling cutter 3		Milling cutter 4		Milling cutter 5		Milling cutter6		Milling cutter 7		Milling cutter 8	
	y	*x*	*y*	*x*	*y*	*x*	*y*	*x*	*y*	*x*	*y*	*x*	*y*	*x*	*y*	*x*
	91,100	66,590	83,122	64,495	71,342	61,856	62,149	59,358	53,794	56,785	46,851	53,861	38,732	50,165	30,461	45,955
	94,990	67,732	89,717	66,142	82,375	63,994	68,163	60,426	63,609	58,706	54,082	55,542	39,523	50,387	39,820	49,014
	104,638	71,239	99,453	69,258	92,181	66,809	78,043	62,682	73,503	61,148	63,999	58,121	49,470	53,155	49,793	52,332
	114,186	75,471	109,108	73,077	101,932	70,210	87,885	65,495	83,375	63,998	73,907	60,960	59,415	56,114	59,766	55,746
	119,866	78,321	118,689	77,456	111,632	74,107	97,691	68,763	93,221	67,198	83,799	64,060	69,350	59,206	69,739	59,170
	129,256	83,513	120,256	78,392	121,280	78,445	107,461	72,443	103,044	70,721	93,679	67,402	79,280	62,472	79,705	62,672
	138,546	89,227	128,196	82,341	130,874	83,191	117,197	76,473	112,844	74,557	103,543	70,970	89,202	65,860	89,671	66,217
	147,730	95,433	137,626	87,682	140,413	88,318	122,052	78,521	122,618	78,646	113,394	74,752	99,117	69,392	99,637	69,08
	156,803	102,103	146,976	93,459	149,894	93,805	126,897	80,852	132,367	83,016	123,228	78,732	109,024	73,066	109,603	73,465
	165,758	109,219	156,242	99,648	159,312	99,641	136,559	85,545	142,087	87,641	133,046	82,915	118,927	76,832	–	–
	174,588	116,772	165,417	106,241	168,666	105,810	146,179	90,552	151,780	92,517	142,846	87,296	123,875	78,798	124,534	79,029
	183,288	124,729	174,498	113,206	177,951	112,302	155,753	95,848	161,440	97,620	152,627	91,856	128,815	80,782	129,514	80,918
	191,845	133,108	183,481	120,542	187,165	119,111	165,292	101,436	171,069	102,958	162,392	96,610	138,698	84,827	139,472	84,745
	200,258	141,872	192,358	128,240	196,302	126,225	174,780	107,284	180,667	108,486	172,134	101,515	148,571	89,005	149,417	88,583
	208,515	151,021	201,123	136,297	205,358	133,643	184,218	113,404	190,223	114,307	181,858	106,618	158,438	93,295	159,369	92,500
	216,609	160,554	209,772	144,694	214,425	141,348	193,604	119,787	199,747	120,308	191,558	111,875	168,292	97,708	169,314	96,455
	224,533	170,449	211,491	146,395	223,311	149,344	202,937	126,425	*209,230*	126,516	201,238	117,307	178,135	102,242	179,258	100,455
	232,278	180,714	218,299	153,432	232,013	157,633	212,213	133,312	218,673	132,941	210,891	122,909	187,973	106,877	189,203	104,535
	239,835	191,336	226,696	162,500	240,712	166,196	216,771	136,851	228,076	139,565	220,521	128,673	197,794	111,636	199,140	108,627
	247,198	202,313	231,671	168,098	249,312	175,030	226,015	144,103	237,434	146,391	230,125	134,576	207,604	116,536	209,070	112,764
	–	–	238,228	175,736	257,900	184,142	235,137	151,603	246,747	153,412	239,710	140,577	217,405	121,467	219,001	116,974
	–	–	248,685	188,595	–	–	244,132	159,336	–	–	249,255	146,877	222,298	123,984	223,966	119,115
	–	–	–	–	–	–	253,178	167,301	–	–	268,776	153,257	232,083	129,130	238,852	125,554
	–	–	–	–	–	–	–	–	–	–	–	–	246,728	137,031	253,734	132,075
	–	–	–	–	–	–	–	–	–	–	–	–	271,080	150,726	278,514	143,217

Table 4
Coefficients for determining the coordinates of point *B, C, D, and E* profile disk modular cutter for the module 100mm

№ of cutter	№ of teeth of the cut wheel	Coordinates of non-volatile points						Coordinates of Volatile point			
		Point B		*Point C*		*Center of circle*		*Point D*		*Point E*	
		H_1	S_1	H_2	S_2	$x_ц$	$y_ц$	H_3	S_3	H_4	S_4
1	12-13	58.393	63.724	91.100	66.590	0	63.968	208.515	151.021	210	158.61
2	14-16	56.993	62.197	83.122	64.435		62.434	211.491	146.075		160.59
3	17-20	55.982	60.630	71.342	61.856		60.822	214.466	141.075	220	150.87
4	21-25	51.294	58.013	62.149	59.358		58.458	216.814	136.967		151.23
5	26-34	48.162	55.938	53.794	56.785		56.565	218.673	132.941		144.42
6	35-54	42.551	52.916	46.851	53.861		54.178	220.521	128.873		137.38

7	55-134	38.290	50.015	38.732	50.165		51.850	222.298	123.984	230	130.40
8	135-Infinte	30.161	45.955	--	--	4.007	44.114	223.966	119.115		123.33

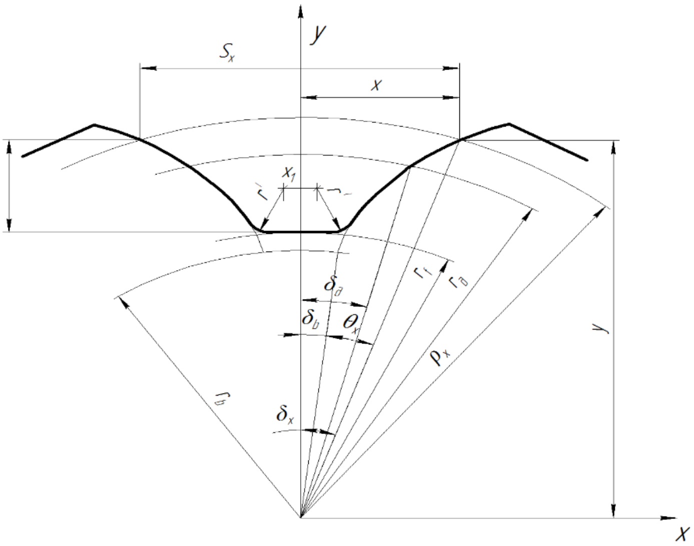


Figure 3 Main parameters of disk modular milling cutter profile

Table 5
Dependencies for calculating the profile of a disk modular cutter

№ of dependencies	Designation	Dependencies
1	δ_{∂}	$\delta_{\partial} = \frac{\pi}{2z} - \frac{2\xi * tg\,\alpha}{z} + \frac{\Delta S}{mz}$
2	δ_b	$\delta_b = \delta_{\partial} - inv\,\alpha$
3	α_x	$cos\alpha_x = \frac{r_b}{\rho_x}$
4	δ_x	$\delta_x = \delta_b + inv\,\alpha_x = \delta_b + \theta_x$
5	x	$x = \rho_x \sin \delta_x$
6	y	$y = \rho_x \cos \delta_x$
7	S	$S = 2x$
8	t	$t = y - r_f$
Designations: δ_d - half of the angular width of the depression along the pitch circle;δb - half of the angular width of the depression on the base circle; θx - current polar angle at arbitrary points on the radius vector ρx; αx - current angle of pressure (engagement);δx - half of the angular width on the circle of the radius vector ρx;x, y - coordinates of the profile point		

When calculating, it is necessary to show a number of values of ρ_x - the radius vector of the points of the involute profile of the gear wheel in the range from at z≤34 or $\rho_x = r_b$ at z> 34 and to $\rho_x = r_a$. To do this, the distance between adjacent points of the profile in height is set at the height of the tooth, taking into account that the total number of points under consideration is usually taken within the limits depending on the required accuracy of the profile. Then the smallest radius vector will be equal to: ρ_x min = $p_f + \Delta_p$. Subsequent values of ρ_x are calculated depending on the number of the point in question. Coordinate calculation data are summarized in a table (Table 6) and are used to construct a profile of a disk modular cutter, a template and a counter-template to check the manufacture of a cutter, as well as for profiling a relief cutter.

Table 6

Calculation of the coordinates of the profile of the disk modular cutter

№ of Profile point	ρ_x,мм	$\cos\alpha_x$	$\alpha_x°$	inv_{α_x}	δ_x,рад	$\delta_x°$	*x*, мм	*y*, мм	*S₀*, мм	*t*, мм
*a*1	94,22	0,991084	7 51'36"	0,0008	0,0066	0,3814	0,627	94,233	1,254	0,043
*a*2	95,06	0,982326	10 4’48’’	0,0022	0,0081	0,4653	0,772	95,066	1,544	0,087
*a*3	95,91	0,973621	13 29’33’’	0,0041	0,0100	0,5734	0,959	95,908	1,918	0,130
*a*4	96.75	0,965167	15 31’40’’	0,0063	0,0122	0,7004	1,182	96,749	2,364	0,174
*a*5	97,60	0,956762	16 17’32’’	0,0088	0,0147	0,8436	1,437	97,590	2,874	0,218
*a*6	98,44	0,948598	18 51’43’’	0,0116	0,0174	1,0010	1,719	98,429	3,438	0,261
*a*7	99,28	0,940572	19 17’58’’	0,0145	0,0204	1,1710	2,029	99,267	4,058	0,305
*a*8	100,13	0,932587	21 37’15’’	0,0177	0,0236	1,3524	2,363	100,104	4,726	0,349
*a*9	100,97	0,924829	23 50’53’’	0,0211	0,0269	1,5444	2,721	100,939	5,442	0,392
Aa	101,81	0,917198	25 59’46’’	0,0303	0,0362	2,0759	3,735	103,057	7,47	0,436
Ark	95,63	0,976471	12 46’08’	0,0034	0,0093	0,5354	0,893	95,630	1,0708	0,479

The calculation of the values δд, δb, δx (in radians) is performed with accuracy of 0.000001, and in a degree measure with an accuracy of up to. The accuracy of counting the coordinates of the profile points x, y, S0, t is 0.001 mm. Conversion of angles from radian to degrees is carried out according to tables.**[18]** p. 596, adj. X or by multiplying by 57.29578 and further converting fractions of a degree into minutes and seconds. The coordinates of the points of non-involute profile elements are determined in accordance with GOST 10996-64 (Table 4) **[19]** Table. 121, p. 307. The values of the radius of curvature at the top of the cutter tooth (Figure. 3) are recommended to be selected according to (table. 7).

Table 7

The value of the radii and abscissas of the profile of shaped gear cutting mills,mm

z	12-13	14-16	17-20	21-25	26-34	35-54	55-134	Over 134
r'	0.52	0.49	0.46	0.43	0.40	0.36	0.32	0.25
x_1	0.2086	0.2150	0.2382	0.2640	0.2950	0,3200	0.3458	0.4000
Note: for a module other than m= 1 mm, the given data must be multiplied by the corresponding module								

III. CALCULATION OF DESIGN PARAMETERS OF DISC MODULAR MILL

3.1.The main parameters **-** outer D and inner diameters, width B, the number of teeth z0 of uncorrected cutters from the set (Figure. 4) are selected depending on the size of the module and the cutter number in accordance with the data established by GOST 10996-64 (table.8 **[17]** p. 510, table. 13.11; **[18]** p. 391, table. 157).

Table 8

Basic dimensions of modular disk cutters, mm

m	*D*	*d*	z_0	Width B for number cutters														
				1	1½	2	2½	3	3½	4	4½	5	5½	6	6½	7	7½	8
1,125	50	19	14	4,5	–	4,5	–	4	–	4	–	4	–	4	–	4	–	4
1,25	50	19	14	5	–	5	–	4,5	–	4,5	–	4,5	–	4,5	–	4	–	4
1,375	50	19	14	5,5	–	5,5	–	5	–	5	–	5	–	5	–	4,5	–	4,5
1,5	55	22	14	6	–	6	–	5,5	–	5,5	–	5	–	5	–	5	–	5
1,75	55	22	14	7	–	6,5	–	6,5	–	6,5	–	6	–	6	–	5,5	–	5,5
2	63	22	12	8	–	7,5	–	7,5	–	7	–	7	–	6,5	–	6,5	–	6
2,25	63	22	12	8,5	–	8,5	–	8	–	8	–	7,5	–	7,5	–	7	–	7
2,5	70	22	12	9,5	–	9,5	–	9	–	8,5	–	8,5	–	8	–	8	–	7,5
2,75	70	22	12	10,5	–	10	–	10	–	9,5	–	9	–	9	–	8,5	–	8
3	80	27	12	11,5	–	11	–	10,5	–	10,5	–	10	–	9,5	–	9,5	–	9
3,25	80	27	12	12	–	12	–	11,5	–	11	–	10,5	–	10,5	–	10	–	9,5
3,5	80	27	12	13	–	13	–	12,5	–	12	–	11,5	–	11	–	11	–	10,5
3,75	80	27	12	14	–	13,5	–	13	–	12,5	–	12	–	12	–	11,5	–	11
4	90	27	12	15	–	14,5	–	14	–	13,5	–	13	–	12,5	–	12	–	11,5
4,25	90	27	12	15,5	–	15	–	14,5	–	14	–	13,5	–	13	–	12,5	–	12
4,5	90	27	12	16,5	–	16	–	15,5	–	15	–	14,5	–	14	–	13,5	–	13
5	100	27	12	18	–	17,5	–	17	–	16,5	–	16	–	15,5	–	15	–	14,5
5,5	100	27	12	20	–	19	–	18,5	–	18	–	17,5	–	17	–	16	–	15,5
6	110	32	10	21,5	–	21	–	20	–	19,5	–	19	–	18	–	17,5	–	17

6,5	110	32	10	23	–	22,5	–	21,5	–	21	–	20	–	19,5	–	19	–	18
7	110	32	10	24,5	–	24	–	23	–	22	–	21,5	–	21	–	20	–	19,5
8	125	32	10	28	–	27	–	26	–	25	–	24,5	–	24	–	23	–	22
9	125	32	10	31	31	30	30	29	29	28	28	27	27	27	26	26	25	24
10	140	40	10	34	34	33	33	32	32	31	31	30	30	29	29	28	28	27
11	140	40	10	37	37	36	36	35	34	34	33	33	32	32	31	31	30	29
12	160	40	10	41	40	39	39	38	37	37	36	36	35	35	34	34	33	32
14	160	40	10	47	46	46	45	44	43	43	42	41	41	40	39	39	38	37
16	180	50	10	53	52	52	51	50	49	48	48	47	46	45	45	44	43	42

3.2.When designing special gear cutters (corrected non-corrugated, increased accuracy and for modified wheels), their outer diameter is determined (as for shaped relief cutters) depending on the diameter of the bore and the height of the tooth H:

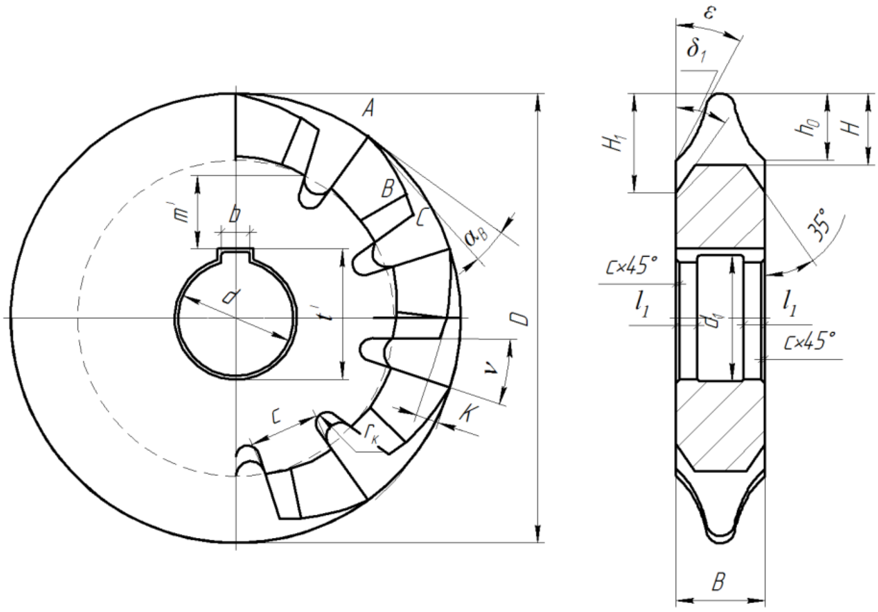


Figure.4. The main parameters of the disk modular cutter

The value (in mm) is taken from the normal range of sizes of the diameters of the holes of the plug-on cutting tool, GOST 9472-83: 16, 19, 22, 27, 32, 40, 50 with the tolerance field H7 or H6, depending on the height of the profile of the cutter tooth (table. 9).

Table 9
Values of the diameters of the bore of the profile cutters, mm

Cutter tooth profile height h_0	3	3-6	6-10	10-25	25-37	Over 37
Bore diameter d	16 19	22	27	32	40	50

The height of the cutter tooth H when determining the diameter D is roughly assumed:

$$H = h_0 + (5 \dots 10)\text{мм} = 15{,}479$$

Where;- $h_0 = t_{max} + (1 \dots 5) = 5.479\text{мм}$; $t_{max} = t_{10} = 0.479$-the maximum height of the tooth profile of the cut wheel is selected from the calculated table of the values of the coordinates of the cutter profile (see Table 6).
3.3.The cutter width B is calculated to the nearest 0.1 mm using the formula:

$$B = (1 + 0.01b) * S_{0max} = 7.47 * (1 + 0.01 * 30) = 9.711,$$

Where$b$- is the coefficient determined from the graph (Figure 5);- the maximum width of the profile of the root of the tooth, selected from the calculated table of the values of the coordinates of the profile cutter width (in mm) is recommended to be taken from the following row: 10;12;14;15;16;17; 18;22;24;25;26;28;30;32;34;35;36;38;40 and further every 5 mm
3.4.The number of teeth can be roughly calculated for cutters with mm (GOST 13838-68) with a straight flute according to the formula:

$$z_0 = (1.8 \dots 2.2)\frac{D}{H} = \frac{80}{15.479} = 5.1$$

And for cutters with mm (GOST 10996-64) with a reinforced hub and with a milled chip groove providing the tooth with a stronger shape (Figure. 4):

$$z_0 = (2.2 \dots 2.8)\frac{D}{H} = \frac{74.158}{15.479} * 2.5 = 11.9771.$$

Here it is recommended to take smaller coefficients for small diameters, and larger ones for large diameters of cutters. The values of the quantities$D, d, H, B, z_0$are specified during further calculations of the parameters, graphical construction of the profile and design of the cutters, as well as in accordance with the data of the given standards.

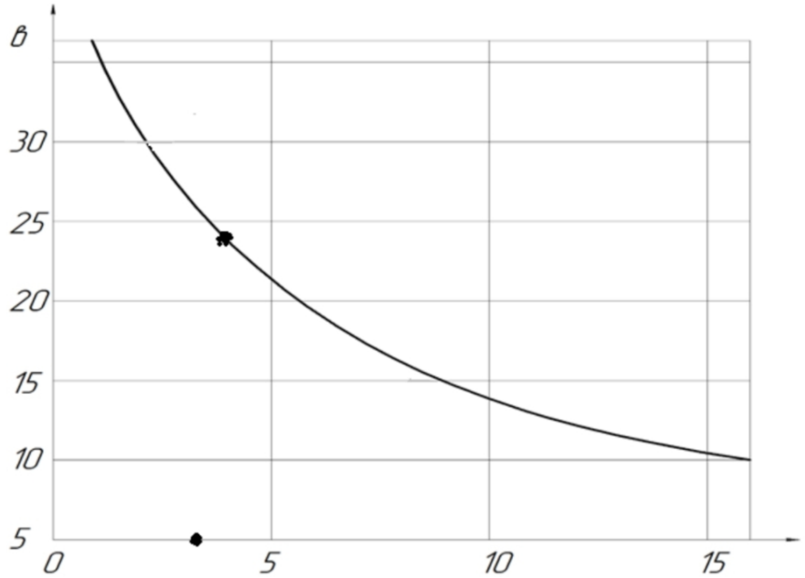


Figure.5. Graph for determining the cutter width ratio

$$K = \frac{\pi \cdot D}{z_0} tg\,\alpha_B\ ;\ tg\,\alpha_B = \frac{tg\,\alpha_б}{\sin\ \varepsilon},$$

Where α_B is the posterior angle at the apex of the tooth (i.e. on the outer diameter);- the D $\alpha_б$ posterior angle on the lateral sides of the tooth, taken roughly; $\alpha_б = 1,5^o \dots 3^o$; ε the angle of inclination of the tooth profile of the outer diameter of the cutter, is selected according to table.10 depending on the number of the cutter. It is allowed to use the calculated values, from (table.10). For precise finishing mills with a ground profile, the amount of relief of the ground part K is determined by the above formula,

$$K_1 = (1{,}2 \dots 1{,}4)K\ =1.2* 4.5 = 5.4 \approx 5.5.$$

And the amount of relief of the unpolished part of the tooth is determined by the formula: $K\ u\ K_1$values are rounded to the nearest 0.5 mm.

№ of cutters	1	1½	2	2½	3	3½	4	4½	5	5½	6	6½	7	7½	8
Profile inclination angles	5°	5°10´	5°20´	6°40´	8°10´	10°	9°40´	10°30´	11°30´	11°50´	14°	14°40´	16°40´	17°	18°
Angles used for the calculation	ε $\alpha_б$ α_B	5° 1°20´ 15°			8° 1°40´ 12°						14° 2°30´ 10°				

3.6. Tooth height H for cutters with straight flute is calculated with an accuracy of 0.1mm using the formula;

$$H = h + K + r_k, =10+4.5+1.36=15.86$$

Or with double profile relief:

$$H = h + \frac{K+K_1}{2} + r_k.=10+\frac{4.5+5.5}{2}+1.36=16.36$$

For cutters with a milled chip groove (figure 4), the value of H is determined from the expression:

$$H = h + r_k = 10+1.36=11.36,$$

Where H is the height of the working tooth profile approximately $h = r_a - r_f$, or more precisely from the calculated table of profile coordinate values.

$h = t_{\max}$; r_K - the radius of curvature for the flute, usually taken equal to 1…..5mm, depending on the diameter of the cutters or calculated by the formula:

$$r_k \cong \frac{(D-2h-2K)}{2} * \sin\frac{\varphi}{2} = \frac{80-20-8}{2} * \sin\frac{6}{2} = 1.36.$$

The value of angle ψ depends on the amount of idle movement of the relief cam. With a cam idle stroke of 60° (basic design case)

$$\psi = \frac{360^o}{6 \cdot z_0} = \varphi = \frac{360°}{6*z_0} = \frac{360°}{6*12} = 5$$

With 90°, cam idle, used for cutters with large chip flutes, the angle is defined as:

$$\psi = \frac{360^o}{4 \cdot z_0} = \varphi = \frac{360°}{4*z_0} = \frac{360°}{4*12} = 7.5$$

The largest chip groove (figure 4) is determined by the formula:

$$H_1 \geq H + K = h + K + r_k = 10+4.5+1.36=15.86.$$

The angle of milling grooves δ_1 (figure 4) is usually chosen equal to the angle of inclination of the tooth profile in this area or is taken constructively $\delta_1 \geq \varepsilon$

3.7 The value of the angle of the profile of the chip grooves is roughly determined from equation

$$v = \frac{360°}{(4 \ldots 8) \cdot z_0} + (16^o \ldots 22^o) = \frac{360°}{4*12} = 29.5$$

And is equal to 18 °, 22 °, 25 °, and 30 °.

3.8. The width of the cutter tooth C at its base (Figure. 4) is determined from the expression: $C \geq 0{,}75\,H$ If this condition is not met, the outer diameter D is increased or the number of teeth is reduced. z_0 .

3.9 The length of the ground part of the back surface of the AB cutter tooth (Figure. 4) with double relief must be at least $2/3$ the length of the AC tooth and is determined by the formula:

$$AB = \left(\frac{1}{3} \ldots \frac{1}{2}\right) * \frac{\pi * D}{z_0} = \frac{3.14 * 80}{6 * 10} = 1.39$$

3.10**.** The dimensions of the elements of the bore of the cutter are taken according to GOST 4020-82 or GOST 9472-84 **[17]** p. 170 table. 6.1,**[18]** p. 579 Appendix III.For the accepted diameter d_0H7 or d_0H6 of the hole or (see paragraph 3.2) determine the dimensions of the longitudinal keyway - width $bC11$ and height $t'H12$. At the base of the groove perform rounding with a radius r, which can be replaced with a chamfer. $r_{\min} \times 45°$. On both sides of the bore, bevels are made with a width of $C = 1{,}5 \ldots 2{,}0$ mm at an angle of 45 °. For cutters with a width of more than 15..20 mm, a recess with a diameter of $d_1 = d_0 + 1$ mm and a length $l \cong (0{,}2 \ldots 0{,}6)B$ is made in the hole (Figure. 4) in order to reduce the contact surface of the mandrel with the cutter hole. In this case, the length of precisely worked out grooves should be:

$$l_1 \geq \left(\frac{1}{3} \ldots \frac{1}{4}\right) B = 2.4.$$

3.11. The thickness of the cutter body in the most dangerous section above the keyway must be at least.0.35d

3.12. The rake angle of disk modular cutters is adopted $\gamma_B = 0° \ldots 10°$ depending on the properties of the material being processed and the type of cutter.Rough cutters (for preliminary cutting of a tooth) are designed with a rake angle $\gamma_B = 8°...10°$ in order to improve cutting conditions. The resulting inaccuracies in the profile are compensated for by the finishing allowance.Finishing cutters (for finishing a tooth cavity) are made with precise (usually ground) profiles and rake angles $\gamma_B = 0$ Otherwise, the profile of the cutter is subject to correction.

3.13. Disk modular gear cutters (both solid and prefabricated) are made of high-speed steels of normal performance P6M5, P12; P9 in accordance with GOST 19265-73 with the hardness of the working part HRC 63 ... 66.

IV. CONCLUSION

During the work we faced the question of how to develop the optimal version of the cutting tool for a given work piece. We adhered to the recommendations that during cutting, the specified accuracy of the part should be ensured, the tool should be securely fastened to the machine and its geometry should provide cutting conditions that best suit the given production conditions. The initial data for the design were working drawings of the part with the required dimension and deviations applied to them, the parameters of the machine on which the work piece is fastened and processed.

Conflict of Interest

On behalf of all authors, the corresponding author states that there is no conflict of interest.

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