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EVALUATE ERROR IN TRANSMISSION RATION OF ENVELOPE CHAIN AND INDEXING CHAIN IN SPIRAL-BEVEL-GEAR MANUFACTURING MACHINE GLEASON ZFTKK250X5

ĐÁNH GIÁ SAI SỐ TỶ SỐ TRUYỀN CỦA XÍCH BAO HÌNH VÀ XÍCH PHÂN ĐỘ CỦA MÁY GIA CÔNG BÁNH RĂNG CÔN RĂNG CONG GLEASON ZFTKK250X5

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ABSTRACT

The paper presents the method which evaluates the gear ratio error of envelope chain and indexing chain spiral-bevel-gear generator ZFTKK250X5 in the Gleason system. The elements in power transmission chains are gear transmitters, which are subject to kinetic errors, pitch errors, cumulative pitch errors, etc... Therefore, the errors of these chains will be the sum of the errors of the elements in the chains during machining, so when we process the Gleason gear system, its quality is directly affected by these errors. To evaluate these above errors, it is necessary to determine how many degrees of the gear pairs in the chains during the geometry and the gradation process, thereby calculating the errors of each pair of gears in the chain and the gear ratio of the elements. Finally, multiplying them together gives us the gear ratios of the chain when it comes to the errors. From there, the authors get the gear ratio error of the chains.

Keywords: *Envelope chain, indexing chain, transmission ratio, pitch error.*

TÓM TẮT

Bài báo trình bày về xây dựng phương pháp đánh giá sai số tỷ số truyền của xích bao hình và xích phân độ của máy gia công bánh răng côn răng cong Gleason ZFTKK250X5. Các phần tử trong các chuỗi xích là các cặp bánh răng ăn khớp với nhau, các cặp bánh răng mắc phải những sai số động học, sai số bước răng, sai số tích lũy bước răng,… vì vậy sai số của những chuỗi xích này sẽ là tổ hợp các sai số của các phần tử ăn khớp trong quá trình gia công, nên khi gia công bánh răng Gleason chất lượng của nó bị ảnh hưởng trực tiếp từ các sai số này. Để đánh giá được sai số trên cần xác định xem các cặp bánh răng ăn khớp trong quá trình bao hình và phân độ quay được một góc bao nhiêu độ, từ đó tính được các sai số của từng cặp bánh răng trong các xích, tính các tỷ số truyền của các phần tử, nhân chúng lại với nhau ta được tỷ số truyền của xích khi kể đến các sai số. Từ đó ta thu được sai số tỷ số truyền giữa các xích.

Từ khóa: *Xích bao hình, xích phân độ, tỷ số truyền động, sai số bước.*

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1. INTRODUCTION

Spiral bevel gears have advantages of large coincidence degree, smooth transmission and high strength. Moreover, they are widely applied in fields of ships, aerospace, and defense technology, etc. Therefore, forming the tooth surface of the Spiral bevel gears is of great interest to many scientists and has solved many basic problems to be applied in production. Scientists have come up with a variety of research and problem-solving solutions such as the gear surface theory, the solutions to improve the working quality of Spiral bevel gear [2, 3].

In Viet Nam, there are not many companies producing this type of gear, so the machinery and equipment for processing this type of gear are not many. Therefore, the study of this type of machine is necessary, especially the final machine for this type of gear. For this study, the author studied the ZFTKK250X5 machine manufactured by Modul [1]. In machining ZFTKK250X5, there are two important power transmission chains: envelope chain and indexing chain. These two chains are crucial to the quality of the Spiral bevel gear of the Gleason system. Therefore, it is necessary to evaluate the transmission errors of these two chains, because when knowing how much the error is and depending on what factors, it is possible to find a method to minimize the error.

Gear ratio error of envelope chain and indexing chain spiral-bevel-gear generator ZFTKK250X5 in the Gleason system directly affects the working quality of this gear pair, specifically the two biggest factors affecting the Gleason gear system pair was:

i) When there is a gear ratio error of envelope chain, the gear ratio of the generating crown gear and the generated gear (gear workpiece) is no longer in the correct gear ratio, causing the tooth height profile and the spiral direction profile of the tooth is no longer correct, thus causing tooth profile error and affecting the bearing pattern of Gleason's gears.

ii) When there is a gear ratio error of an indexing chain that makes indexing inaccurate when machining a tooth, this makes the gear workpiece carry tooth pitch error.

Therefore, the determination of these errors is necessary to determine how much these errors are theoretical, then find a way to minimize these errors.

2. METHODS OF EVALUATING THE GEAR RATIO ERROR

To evaluate the the gear ratio error, the authors followed these steps:

Step 1: Draw the kinematic schematic of the machine

Sample directly taken from the gear forming chain and intermittent chain on ZFTKK250x5. Since the documents came with the machine do not include schematic so the authors take samples directly from the machine. After disassembling, measuring, the authors archived the kinematic schematic of the machine as Figure 1.

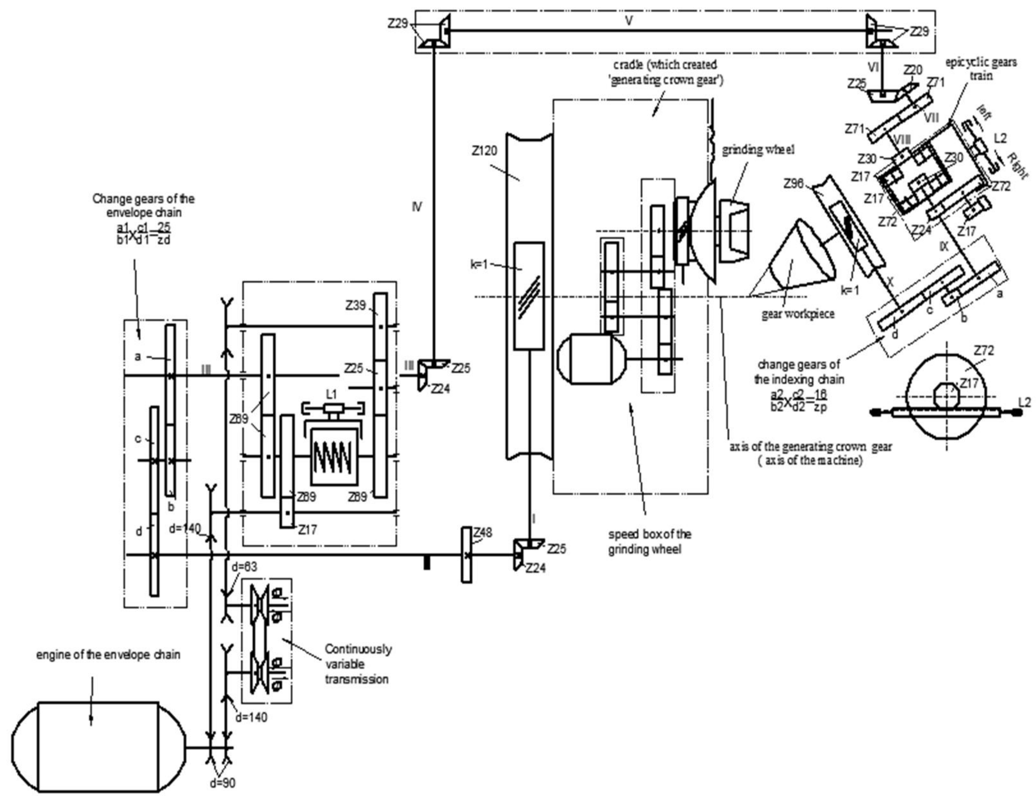

Figure 1. Kinematic Schematic of ZFTKK250X5 [1]

Step 2: Write the equations of the chains in the machine

i) Equation for the indexing chains

Intermittent mechanism: After the hydraulic clutch L2 cut the transmission of the envelope chain by pushing the planetary gears away from the envelope chain, at the same time closed the pin for gear Z72 and Z17 to fit. The hydraulic clutch L2 has the rack to perform the intermittent mechanism. The chain is intermitted as followed:

1 cycle of hydraulic clutch L2 rack L2 → pass through the gear pairs Z17 and Z72 make the gears to rotate 720° (2 cycle) pass through the gears pairs $\frac{72}{24}$ (IX) → pass through the gear pairs replacing the intermittent drive $\frac{a_2}{b_2}x\frac{c_2}{d_2}$ (X) pass through the worm drive $\frac{1}{96} \rightarrow \frac{360^\circ}{z_p}$ cycle through the workpiece.

Where a_2, b_2; c_2, d_2 are the gears pairs replacing the indexing chain corresponding to the number of tooth in the manufactured gear zp. $\frac{a_2}{b_2}x\frac{c_2}{d_2}=\frac{16}{z_p}$

Equation for the indexing chains:

1 cycle of hydraulic clutch L2 rack L2 (corresponding to 2 cycle of the gear pair Z17 and Z72) x

$$\frac{72}{24}x\frac{a_2}{b_2}x\frac{c_2}{d_2}x\frac{1}{96}=\frac{360^\circ}{z_p}$$

ii) Equation for the envelope chains

1 cycle of shaking stand → pass through the worm drive $\frac{120}{1}$ (I) → pass through the bevel gears pair $\frac{25}{24}$ (II) → pass through the gears replacing gear forming drive $\frac{d_1}{c_1}x\frac{b_1}{a_1}$ (III) → pass through the bevel gears pair $\frac{24}{25}$ (IV) → pass through the bevel gears pair $\frac{29}{29}$ (V) → pass through the bevel gears pair $\frac{29}{29}$ (VI) → pass through the bevel gears pair $\frac{25}{20}$ (VII) → pass through the bevel gears pair $\frac{71}{71}$ (VIII) pass through the planetary gear pairs $\frac{30}{17}x\frac{17}{72}x\frac{72}{17}x\frac{17}{30}$ (IX) → pass through the gear pairs replacing the intermittent drive $\frac{a_2}{b_2}x\frac{c_2}{d_2}$ (X) → pass through the worm drive $\frac{1}{96} \rightarrow \frac{z_d}{z_p}$ cycle through the workpiece.

Equation for the envelope chain:

(1 cycle of shaking stand) x

$$\frac{120}{1}x\frac{25}{24}x\frac{d_1}{c_1}x\frac{b_1}{a_1}x\frac{24}{25}x\frac{29}{29}x\frac{25}{20}x\frac{71}{71}x\frac{30}{17}x\frac{17}{72}x\frac{72}{17}x\frac{17}{30}x\frac{a_2}{b_2}x\frac{c_2}{d_2}x\frac{1}{96}=\frac{z_d}{z_p}$$

(cycle of the workpiece)

More specific dimensions are in the below table:

Table 1. Specification of the gears in the chains

No	Specification	m	Z	β	α
1	Worm wheel z120	5.6	120	4.4°	20°
2	Worm screw k = 1 (shaft I)	5.6	1	4.4°	20°
3	Straight bevel gears Z25 (Shaft I)	2.5	25	0°	20°
4	Straight bevel gears Z24 (Shaft I)	2.5	24	0°	20°
5	Change gears of the envelope chain a_1; b_1; c_1; d_1	2		0°	0°
6	Straight bevel gears Z24 (Shaft III)	2.5	24	0°	20°
7	Straight bevel gears Z25 (Shaft IV)	2.5	25	0°	20°
8	Straight bevel gears Z29 (Shaft IV)	2.5	29	0°	20°
9	Straight bevel gears Z29 (Shaft V)	2.5	29	0°	20°
10	Straight bevel gears Z29 (Shaft V)	2.5	29	0°	20°
11	Straight bevel gears Z29 (Shaft VI)	2.5	29	0°	20°
12	Straight bevel gears Z25 (Shaft VI)	2.5	25	0°	20°
13	Straight bevel gears Z24 (ShaftVII)	2.5	20	0°	20°
14	Spur gear Z71 (Shaft VII)	2	71	0°	20°
15	Spur gear Z71 (Shaft VIII)	2	71	0°	20°
16	Spur gear Z30 (Shaft VIII)	2	30	0°	20°
17	Spur gear Z17	2	17	0°	20°
18	Spur gear Z72	2	72	0°	20°
19	Spur gear Z30 (Shaft IX)	2	30	0°	20°
20	Change gears of the indexing chain a_2; b_2; c_2; d_2	2		0°	20°
21	Worm screw k = 1 (Shaft X)	3.15	1	4.57°	20°
22	Worm wheel z96	3.15	96	4.57°	20°
23	Spur gear Z17 (indexing chain) in clutch L2	3	17	0°	20°
24	Rack in clutch L2	3	-	0°	20°
25	Spur gear Z72 (indexing chain)	3	72	0°	20°
26	Spur gear Z72 (indexing chain)	3	24	0°	20°

Where m: Module; z: Number of teeth; β: Spiral angle; α: Profile angle.

Step 3: Determine the errors in rotation of the components in the kinematic chain

There are a lot of errors in gears [4, 5], however the ones that affects the number of cycles of the gear transmission are: kinematic error of gears f_i, cumulative gear pitch error F_{pr},... In the scope of this study, the article only considers the kinematic errors f_i' and cumulative gear pitch error F_{pr}.

Thus to determine the rotation error of the gear in the chain, one needs to:

i) Look up the errors of the gears in [4, 5]

ii) If the gears finished a whole number of cycle (1 cycle, 2 cycle,...) then the erros will be calculated by f_i', if not the errors would consist of the cumulative gear pitch error F_{pr} plus the kinematic error of gears f_i'.

3. DETERMINE THE TRANSMISSION ERRORS OF THE CHAINS

Consider the spiral bevel gear pairs that need to be manufactured have the specifications:

Table 2. Specifications of the helical bevel gear pairs need to be manufactured [1, 2, 3]

No	Specification	Symbol	Pinion	Gear
1	Spiral angle	BET	35	35
2	Number of teeth	Z	15	30
3	Average module	m_n	3.5	3.5
4	Hand of Spiral	Right = 1; left = 0	1	0

- Number of teeth of generating crown is $z_d=\sqrt{z_1^2+z_2^2}=\sqrt{15^2+30^2}=33.54101966$

- Gear replacing the indexing chain when machining pinion z1:

$$\frac{a_2}{b_2}x\frac{c_2}{d_2}=\frac{16}{z_1}=\frac{16}{15}=\frac{48}{45}x\frac{60}{60}$$

- Gear replacing the indexing chain when machining gear z2:

$$\frac{a_2}{b_2}x\frac{c_2}{d_2}=\frac{16}{z_2}=\frac{16}{30}=\frac{40}{60}x\frac{48}{60}$$

- Gear replacing the envelope chain when machining pinion and gear:

$$\frac{a_1}{b_1}x\frac{c_1}{d_1}=\frac{25}{z_d}=\frac{25}{33.54101966}$$

$$=0.745356\approx\frac{40}{64}x\frac{62}{52}=0.745193$$

Transmission errors of the envelope chain when calculating the alternative gear $\Delta i=0.00016$

Through the sampling, all the spur gears in the kinematic chain of the machine have the module of m = 2 and the precision degree of 6, the straight bevel gear m = 2.5, precision degree 7, the worm wheel on the shaking stand z = 120 and precision degree 7, the worm wheel on the workpiece shaft has the precision degree of 6.

3.1. Transmission errors of the indexing chain

Calculating the transmission errors of the manufactured gear z1 based on the replacing gears $\frac{a_2}{b_2}x\frac{c_2}{d_2}=\frac{48}{45}x\frac{60}{60}$ was shown in table 3, 4.

Table 3. Calculating the transmission errors of the indexing chain in gear z1

No	Specs	n	z_k	F_{pr}	f_i	f_p	F	Δφ	n_{max}	n_{min}
1	L2		0	80	20	4.706	20	0.067		
2	z = 17	2	0	25	18	1.471	18	0.061	720.13	719.87
3	z = 72	2	0	45	20	0.313	20	0.016	720.14	719.86
4	z = 24	6	0	25	18	0.521	18	0.043	2160.04	2159.96
5	$a_2 = 48$	6	0	32	18	0.333	18	0.021	2160.06	2159.94
6	$b_2 = 45$	6.4	4.5	32	18	0.356	19.6	0.025	2304.02	2303.98
7	$c_2 = 60$	6.4	4.5	45	18	0.375	19.69	0.019	2304.04	2303.96
8	$d_2 = 60$	6.4	4.5	45	18	0.375	19.69	0.019	2304.02	2303.98
9	k = 1	6.4	0.4	63	12	1.313	12.53	0.005	2304.02	2303.98
10	z = 96	0.06	6.4	63	20	1.313	28.4	0.011	24.01	23.99

Table 4. Results of the transmission errors in the indexing chain z1

Specs	Z72/Z24	a2/b2	c2/d2	1/Z96	i^{z1}_i
Largest transmission ratio	3.0006	1.0667	1.00003	0.01042	0.0334
Smallest transmission ratio	2.9993	1.0666	0.99997	0.01041	0.0333
Theoretical Transmission ratio	3.0000	1.0666	1.00000	0.01042	0.0333
Error in largest transmission ratio					2.564E-05
Error in smallest transmission ratio					-2.56E-05
Error in transmission ratio					5.126E-05
Error in angle when machining gear z1					0.0369052
Error in normal surface when machining gear z1 (μm)					20.640953

f_p: Cumulative gear pitch error for one tooth: $f_p = \frac{F_{pr}}{z}$

n: Rotation cycle (cycle)

zk: Number of odd teeth: $z_k = [n - int(n)].z$

F: Sum of errors: if $z_k = 0$ then $F = f_i$ else $F = f_i + z_k.f_p$

D: Pitch diameter

Δφ = 2F/D: Error of rotation angle

n_{max} : Maximum Rotation angle: $n_{max} = n.360 + Δφ$

n_{min} : Minimum Rotation angle: $n_{min} = n.360 - Δφ$

i^{z1}_i: Transmission errors in the indexing chain z1

Transmission error in percent

$$\Delta i^{z1}_{pd}(\%) = \frac{5.126x10^{-5}}{0.03333333}x100\% = 0.154\%$$

Error in normal surface when machining gear z1:

$F_p = 20.64\mu m$

Calculating the transmission error when machining gear z2 based on the replacing gears $\frac{a_2}{b_2}x\frac{c_2}{d_2} = \frac{40}{60}x\frac{48}{60}$ was shown in the table 5, 6.

Table 5. Calculating the transmission errors of the indexing chain in gear z2

No	Specs	n	z_k	F_{pr}	f_i	f_p	F	Δφ	n_{max}	n_{min}
1	L2		0	80	20	4.706	20.00	0.0674		
2	z=17	2	0	25	18	1.471	18.00	0.0607	720.13	719.87
3	z=72	2	0	45	20	0.313	20.00	0.0159	720.14	719.86
4	z=24	6	0	25	18	0.521	18.00	0.0430	2160.04	2159.96
5	a2=40	6	0	32	18	0.333	18.00	0.0258	2160.07	2159.93
6	b2=60	4	0	32	18	0.356	18.00	0.0172	1440.02	1439.98
7	c2=48	4	0	45	18	0.375	18.00	0.0215	1440.04	1439.96
8	d2=60	3.2	12	45	18	0.375	22.50	0.0215	1152.02	1151.98
9	k=1	3.2	0.2	36	12	1.125	12.23	0.0049	1152.03	1151.97
10	z=96	0.033	3.2	63	20	1.313	24.20	0.0096	12.01	11.99

Table 6. Results of the transmission errors in the indexing chain z2

Specs	Z72/Z24	a2/b2	c2/d2	1/Z96	i^{z2}_i
Largest transmission ratio	3.0007	0.6667	0.8000	0.0104	0.0167
Smallest transmission ratio	2.9993	0.6666	0.8000	0.0104	0.0166
Theoretical Transmission ratio	3.0000	0.6667	0.8000	0.0104	0.0167
Error in largest transmission ratio					1.89E-05
Error in smallest transmission ratio					-1.89E-05
Error in transmission ratio					3.78E-05
Error in angle when machining gear z2					0.027226
Error in normal surface when machining gear z2 (μm)					30.45528

$i^{z2}i$: Transmission errors in the indexing chain z2

Transmission error in percent

$$\Delta i^{z2}_{pd}(\%) = \frac{3.78x10^{-5}}{0.0167}x100\% = 0.23\%$$

Error in normal surface when machining gear z2:

$F_p = 30.46\mu m$

3.2. Transmission error of the envelope chain

Angle of shaking stand, we can caculate in the material… With the machine ZFTKK250X5 and ZFTKKR250X5 to ensure the width of the tooth B, the angle of shaking stand has to be choosen as $\varphi_d = 55°$.

- Look up the table and do the similar calculation like the indexing chain, the transmission errors of the envelope chain based on the replacing gears $\frac{a_1}{b_1}x\frac{c_1}{d_1} = \frac{25}{z_d} = \frac{25}{33.54101966} = 0.745356 \approx \frac{40}{64}x\frac{62}{52} = 0.745193$.

When machining the bevel gear z1 with the replacing gear $\frac{a_2}{b_2}x\frac{c_2}{d_2} = \frac{48}{45}x\frac{60}{60}$

Table 7. Calculating the transmission error of the envelope chain when machining gear z1

No	Specs	F	Δφ	n_{max}	n_{min}
1	z120	82.78	0.01	55.01	54.99
2	k = 1	15.78	0.00	6600.00	6600.00
3	z25	70.00	0.13	6600.13	6599.87
4	z24	40.25	0.08	6875.08	6874.92
5	$d_1 = 52$	26.75	0.03	6875.11	6874.89
6	$c_1 = 62$	19.53	0.02	5766.15	5766.11
7	$b_1 = 64$	19.53	0.02	5766.16	5766.09

8	$a_1 = 40$	42.14	0.06	9225.87	9225.75
9	z24	44.03	0.08	9225.95	9225.66
10	z25	40.87	0.07	8856.85	8856.70
11	z29	42.93	0.07	8856.92	8856.63
12	z29	42.93	0.07	8856.84	8856.71
13	z29	42.93	0.07	8856.91	8856.64
14	z29	42.93	0.07	8856.84	8856.71
15	z25	40.87	0.07	8856.92	8856.63
16	z20	46.19	0.11	11071.07	11070.86
17	z71	84.59	0.07	11071.14	11070.79
18	z71	84.59	0.07	11071.04	11070.90
19	z30	30.13	0.06	11071.09	11070.84
20	$z = 17$	24.74	0.08	19537.09	19536.92
21	$z = 72$	21.43	0.02	4612.92	4612.89
22	$z = 17$	24.74	0.08	19537.09	19536.92
23	$z = 30$	18.07	0.03	11071.00	11070.93
24	$a_2 = 48$	18.04	0.66	11071.66	11070.27
25	$b_2 = 45$	18.85	0.79	11809.82	11808.25
26	$c_2 = 60$	18.89	0.59	11810.41	11807.65
27	$d_2 = 60$	18.89	0.59	11809.62	11808.44
28	$k = 1$	13.05	0.17	11809.79	11808.27
29	$z = 96$	63.05	0.03	123.04	122.99

Table 8. Results of the transmission error of the envelope chain when machining gear z1

Specs		**Z120/1**	**Z25/Z24**	**d1/c1**	**b1/a1**	**Z24/Z25**	**Z29/Z29**	**Z29/Z29**
Largest transmission ratio		120.02880	1.04170	0.83873	1.60002	0.96002	1.00002	1.00002
Smallest transmission ratio		119.97122	1.04163	0.83869	1.59998	0.95998	0.99998	0.99998
Theoretical transmission ratio		120.00000	1.04167	0.83871	1.60000	0.96000	1.00000	1.00000
Z25/Z20	Z71/Z71	Z30/Z17	Z17/Z72	Z72/Z17	Z17/Z30	a2/b2	c2/d2	Z1/Z96
1.25003	1.00002	1.76473	0.23611	4.23533	0.56667	1.06680	1.00017	0.01042
1.24997	0.99998	1.76468	0.23611	4.23526	0.56666	1.06653	0.99983	0.01041
1.25000	1.00000	1.76471	0.23611	4.23529	0.56667	1.06667	1.00000	0.01042

Specs	**envelope chain when machining gear z1**
Largest transmission ratio	2.23885194
Smallest transmission ratio	2.23426876
Theoretical transmission ratio	2.23655914
Error in largest transmission ratio	0.002292804
Error in smallest transmission ratio	-0.00229038
Error in transmission ratio	0.004583187
Error in transmission ratio in percentage	0.204921353

Error in transmission error of the envelope chain in percentage $\Delta i_{bh}^{z1}(\%) = 0.205\%$

- Similarly, the error in the transmission ratio of the envelope chain when machining z2 (with the replacing gear $\frac{a_2}{b_2} x \frac{c_2}{d_2} = \frac{40}{60} x \frac{48}{60}$) can be calculated as table 9.

Table 9. Results of the transmission error of the envelope chain when machining gear z2

Specs	**envelope chain when machining gear z2**
Largest transmission ratio	1.119138766
Smallest transmission ratio	1.117421019
Theoretical transmission ratio	1.11827957
Error in largest transmission ratio	0.000859197
Error in smallest transmission ratio	-0.00085855
Error in transmission ratio	0.001717748
Error in transmission ratio in percentage	0.153606273

Error in transmission error of the envelope chain in percentage $\Delta i_{bh}^{z2}(\%) = 0.154\%$

4. CONCLUSION

The results of the study show that: the transmission error of the envelope chain and indexing chain of the machine ZFTKK 250x5 of Modul appears when machining the Gleason spiral-bevel-gear. The results when calculating the kinematic chain when machining gear pairs z15/z30 yield:

Specs	$z1 = 15$	$z2 = 30$
Transmission error in the indexing chain (%)	0.154%	0.23%
Error in tooth pitch calculated at the normal surface due to error in intermittent transmission error	20.64μm	30.46μm
Transmission error in the envelope chain (%)	0.205%	0.154%

With this result, to increase the fitting quality of the gear, one need to shorten the kinematic chain of the envelope chain and the indexing chain.

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THÔNG TIN TÁC GIẢ

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