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ScienceDirect

Procedia Technology 22 (2016) 13 – 19

Procedia Technology

9th International Conference Interdisciplinarity in Engineering, INTER-ENG 2015, 8-9 October 2015, Tirgu-Mures, Romania

A New Method of Diminishing Errors of Form Generated by the Imprecision of CNC Machines

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Abstract

During the processing of the helical surfaces on CNC machines, independent of the number of axes of the machine, there will certainly appear geometric deviations from the theoretical profile. Errors of form, which appear in this situation, can be detected through successive measurements. In order to diminish them, it is possible to use a method of compensation the deviations previously measured, which consists in adapting the CNC code used to obtain the helical profiles to the conditions required by the imprecision generated by the geometry of the machine.

Peer-review under responsibility of the “Petru Maior” University of Tirgu Mures, Faculty of Engineering

Keywords: machine; helical profile; theoretical profile; compensation of the form deviations; geometry of the machine.

1. Introduction

During the processing of the helical surfaces on CNC machines, independent of the number of axes of the machine, there will certainly appear geometric deviations from the theoretical profile. Very few research attempts have been done to estimate the significance of energy required for the machining process [1]. Today, many CNC machines with different controllers and multiple capabilities are employed in a range of industries to meet customer demands [2].

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Peer-review under responsibility of the “Petru Maior” University of Tirgu Mures, Faculty of Engineering
doi:10.1016/j.protcy.2016.01.003

Errors of form, which appear in this situation, can be detected through successive measurements. In order to diminish them, it is possible to use a method of compensation the deviations previously measured, which consists in adapting the CNC code used to obtain the helical profiles to the conditions required by the imprecision generated by the geometry of the machine.

The subject of this research is finding a method of diminishing errors of form which appear on the surfaces generated by the CNC machines. The bases of the research are the results of the measurements regarding deviations of form and geometric deviations of pieces with helical surfaces. If measurements are performed on a helical piece, the conclusion will be that there are always deviations of the profile which is produced, as compare to the theoretical profile. Therefore it appears the necessity of detecting the influence which the wear of the tool and the errors in positioning generated by the geometry of the machine exerts on the form deviations of the processed piece. An efficient CAD/CAM method for obtaining the compensation of the form deviations, without modifying the geometry of the machine, may be a solution to solve the problem related to the deviations of the forms regarding helical pieces, without significant complementary expenses.

Nomenclature

α	angle defining the control point
t	index for theoretical profile
m	index for the profile obtained after the milling operation without compensation
c	index for the profile obtained after compensation
ΔB	angular deviation obtained after the milling operation following the theoretical profile
ΔBc	angular deviation obtained after compensation
Bc	compensated value for B axis
D%	diminishing of form errors expressed in percentages

2. Methodology

The present research is based on the measurements made on some pieces with helical profile, produced on a 5 axes CNC machine. Measurements were also made on the cutting tool, before and after the processing of the pieces. The wear of the tools proved to be minimal comparing the deviations observed after measurements. After processing the surface of the tool, the wear of the cutting tool has proved to be insignificant. The check has been done on the SECA-CC/EC tools adjustment machine. On the first stage of the experiment the cam has been processed on MAZAK QSM 350M taking into consideration the geometry of the equipment and its good stiffness.

Fig.1. Processing the profile of the piece on a lathe with C axis type MAZAK QSM 350M

After the processing of the profile some deviations appeared, as compared to the ideal profile, therefore we decided to use a 5 axes machine, type ZAYER KP 6000 AR which allowed to compensate the errors appeared in the processing. The structure and the geometry of the machine ZAYER KP 6000 AR ensures the necessary stiffness in order to obtain the ideal profile, because it allows to generate a helical profile through interpolation on 360°. Therefore, we concluded that it is necessary to generate a CNC code able to compensate the deviations resulted from the positioning errors of the machine. We must take into account the fact that these deviations grow directly proportional to the number of axes simultaneously controlled. At the same time, will be taken into account the fact that the unavoidable wear of any machine reflects directly upon the generated profile. After completing the measurements, the result was a number of data containing angle deviations for successive positions of the produced piece. Based on these data, we are able to generate a CNC code which compensates the deviations from the ideal profile. The angle deviations of the B and C axes of a 5 axes CNC machine were taken into account.

2.1. Case study

In modern manufacturing systems, high-accuracy and high-speed CNC machining prompts researches in parametric interpolation technique [3]. There are many industry applications where the processing times are controllable [4]. In most applications, suppression of contour error is more critical than feed error, to minimize dimensional inaccuracies of the machined part [5]. The development of control systems requires a significant investment and the availability of powerful scientific and engineering capabilities, but even more important is to define the concept of development [6].

Our wish is to obtain a cam with a helical profile on an average radius of 108 mm with an axial growth $\Delta Z=25$ mm over 180 degrees. In order to obtain the control points, we divide the profile on every 10 degrees and we generate a CNC program for a 5 axes machine type ZAYER KP 6000 AR. The axis of rotation for this type of machine are around the axes Y and Z, therefore obtaining the programmable axes B and C. We begin taking into consideration the fact that the profile resulted after running the program based on mathematical calculation will have deviations from the theoretical profile. The cam which will be processed, will previously be fixed with the help of two dowels placed in angles of 120 degrees, which allows the centering of the cam on the machine table with minimal deviations. After running the program, the cam presents errors as compared to the theoretical profile. We may observe the fact that the rolling roll forms a footprint which is reduced as compared to the real length of the generating roll.

Fig. 2. The piece fixed into working position

The measurements for the cam are made by a measuring tool TESA MICRO-HITE 3D and the data obtained will be entered into an excel table, where we can perform mathematical calculations easily, and from this calculations we will obtain the necessary compensation values in order to get a CNC program for the corrected profile.

Fig. 3. Measurements performed on TESA MICRO-HITE 3D machine

The results of the measurements were generated as a database, which was used to generate the POSTPROCESSOR application for the diminishing of the form errors.

The deviating helical profile may be mirrored towards the ideal profile and, as a result, we may obtain the trajectory of the cutting tool. As a result of this method, we obtain a profile which approximates, with diminished essential errors, the theoretical profile.

With the use of the compensation values a CNC program will be written, called CNC compensatory program, which will roll on the profile of the cam fixed with the help of two dowels, in the position corresponding to the first program, the milling program without compensation.

After the milling process performed with the CNC compensatory program, new results will be obtained, data obtained will be entered into an excel table. After the data analysis we observe a clear diminishing of errors, the values obtained being much closer to the theoretical profile. We therefore may establish that the deviations are reduced in average with 62%.

The code of the CNC program for milling without compensation and the code for the CNC compensatory program are presented in Table1.

Table 1. The codes of the CNC programs

The code of the CNC program for milling without compensation	The code of the CNC compensatory program
G1 X115.223 Y-20.317 Z80.014 B90 C10	G1 X115.223 Y-20.317 Z80.014 B89.286 C10
N100 G1 X109.944 Y-40.016 Z81.403 B90 C20	N100 G1 X109.944 Y-40.016 Z81.403 B89.299 C20
N110 G1 X101.325 Y-58.500 Z82.792 B90 C30	N110 G1 X101.325 Y-58.500 Z82.792 B89.323 C30
N120 G1 X89.627 Y-75.206 Z84.181 B90 C40	N120 G1 X89.627 Y-75.206 Z84.181 B89.339 C40
N130 G1 X75.206 Y-89.627 Z85.569 B90 C50	N130 G1 X75.206 Y-89.627 Z85.569 B89.356 C50
N140 G1 X58.500 Y-101.325 Z86.958 B90 C60	N140 G1 X58.500 Y-101.325 Z86.958 B89.370 C60
N150 G1 X40.016 Y-109.944 Z88.347 B90 C70	N150 G1 X40.016 Y-109.944 Z88.347 B89.393 C70
N160 G1 X20.317 Y-115.223 Z89.736 B90 C80	N160 G1 X20.317 Y-115.223 Z89.736 B89.387 C80
N170 G1 X0.000 Y-117.000 Z91.125 B90 C90	N170 G1 X0.000 Y-117.000 Z91.125 B89.457 C90
N180 G1 X-20.317 Y-115.223 Z92.514 B90 C100	N180 G1 X-20.317 Y-115.223 Z92.514 B89.420 C100
N190 G1 X-40.016 Y-109.944 Z93.903 B90 C110	N190 G1 X-40.016 Y-109.944 Z93.903 B89.390 C110
N200 G1 X-58.500 Y-101.325 Z95.292 B90 C120	N200 G1 X-58.500 Y-101.325 Z95.292 B89.481 C120
N210 G1 X-75.206 Y-89.627 Z96.681 B90 C130	N210 G1 X-75.206 Y-89.627 Z96.681 B89.444 C130
N220 G1 X-89.627 Y-75.206 Z98.069 B90 C140	N220 G1 X-89.627 Y-75.206 Z98.069 B89.461 C140
N230 G1 X-101.325 Y-58.500 Z99.458 B90 C150	N230 G1 X-101.325 Y-58.500 Z99.458 B89.488 C150
N240 G1 X-109.944 Y-40.016 Z100.847 B90 C160	N240 G1 X-109.944 Y-40.016 Z100.847 B89.454 C160
N250 G1 X-115.223 Y-20.317 Z102.236 B90 C170	N250 G1 X-115.223 Y-20.317 Z102.236 B89.488 C170

The real deviation from the theoretical profile has been obtained with the calculation formula (1).

$$\Delta B = \arctan \frac{ZmR117 - Zm100}{117 - 100} \times \frac{180}{\Pi} \left[^\circ \right] \tag{1}$$

The compensated value for B axis, called Bc, will be obtained with the calculation formula (2).

$$Bc = 90^\circ - \Delta B \tag{2}$$

Table 2. Theoretical values measured on the control radius R117

α *(degree)*	XtR117 *(mm)*	YtR117 *(mm)*	Zt *(mm)*	ZmR117 *(mm)*	ZcR117 *(mm)*
10	115,223	-20,317	80,014	80,042	80,028
20	109,944	-40,016	81,403	81,434	81,420
30	101,325	-58,500	82,792	82,820	82,804
40	89,627	-75,206	84,181	84,210	84,195
50	75,206	-89,627	85,569	85,606	85,591
60	58,500	-101,325	86,958	86,995	86,979
70	40,016	-109,944	88,347	88,408	88,394
80	20,317	-115,223	89,736	89,797	89,782
90	0,000	-117,000	91,125	91,191	91,175
100	-20,317	-115,223	92,514	92,574	92,558
110	-40,016	-109,944	93,903	93,965	93,950
120	-58,500	-101,325	95,292	95,355	95,340
130	-75,206	-89,627	96,681	96,735	96,718
140	-89,627	-75,206	98,069	98,118	98,102
150	-101,325	-58,500	99,458	99,514	99,499
…	…	…	…	…	…
250	-40,016	109,944	88,347	88,393	88,379
260	-20,317	115,223	89,736	89,771	89,755
270	0,000	117,000	91,125	91,165	91,148
280	20,317	115,223	92,514	92,544	92,529
290	40,016	109,944	93,903	93,936	93,920
300	58,500	101,325	95,292	95,308	95,291
310	75,206	89,627	96,681	96,715	96,699
320	89,627	75,206	98,069	98,098	98,083
330	101,325	58,500	99,458	99,493	99,478
340	109,944	40,016	100,847	100,891	100,876
350	115,223	20,317	102,236	102,268	102,252

Table 3. Theoretical values measured on the control radius R100

α *(degree)*	XtR100 *(mm)*	YtR100 *(mm)*	Zt *(mm)*	ZmR100 *(mm)*	ZcR100 *(mm)*
10	98,481	-17,365	80,014	80,254	80,114
20	93,969	-34,202	81,403	81,642	81,509
30	86,603	-50,000	82,792	83,021	82,878
40	76,604	-64,279	84,181	84,406	84,256
50	64,279	-76,604	85,569	85,797	85,662
60	50,000	-86,603	86,958	87,182	87,039
70	34,202	-93,969	88,347	88,588	88,447
80	17,365	-98,481	89,736	89,979	89,830
90	0,000	-100,000	91,125	91,352	91,208
100	-17,365	-98,481	92,514	92,746	92,598
110	-34,202	-93,969	93,903	94,146	94,009
120	-50,000	-86,603	95,292	95,509	95,371
130	-64,279	-76,604	96,681	96,900	96,752
140	-76,604	-64,279	98,069	98,278	98,147
150	-86,603	-50,000	99,458	99,666	99,530
…	…	…	…	…	…
250	-34,202	93,969	88,347	88,649	88,506
260	-17,365	98,481	89,736	90,047	89,913
270	0,000	100,000	91,125	91,415	91,282
280	17,365	98,481	92,514	92,791	92,661
290	34,202	93,969	93,903	94,173	94,030
300	50,000	86,603	95,292	95,544	95,404
310	64,279	76,604	96,681	96,931	96,792
320	76,604	64,279	98,069	98,334	98,182
330	86,603	50,000	99,458	99,708	99,569
340	93,969	34,202	100,847	101,096	100,963
350	98,481	17,365	102,236	102,465	102,321

2.2. Experimental results

After using the POSTPROCESSOR generated CNC code in order to compensate the deviations we ascertained that the produced piece had geometrical deviations reduced with 62% as compared to the use of the CNC code which contained the theoretical profile. The deviations caused by the cutting tool were negligible in this case.

Table 4. Experimental results obtained after the calculation with the calculation formulas (1) and (2)

α *(degree)*	ΔB	ΔBc	Bc	D%
10	0,714	0,289	89,286	59,54
20	0,701	0,301	89,299	57,01
30	0,677	0,248	89,323	63,35
40	0,661	0,206	89,339	68,83
50	0,644	0,241	89,356	62,58
60	0,630	0,202	89,370	67,92
70	0,607	0,181	89,393	70,23
80	0,613	0,160	89,387	73,85
90	0,543	0,112	89,457	79,37
100	0,580	0,134	89,420	76,92
110	0,610	0,196	89,390	67,86
120	0,519	0,105	89,481	79,68
130	0,556	0,113	89,444	79,61
140	0,539	0,152	89,461	71,85
150	0,512	0,105	89,488	79,45
160	0,546	0,106	89,454	80,55
170	0,512	0,053	89,488	89,72
190	0,890	0,445	89,110	50,01
200	0,866	0,411	89,134	52,53
210	0,923	0,518	89,077	43,87
220	0,849	0,393	89,151	53,74
230	0,853	0,412	89,147	51,72
240	0,822	0,422	89,178	48,63
250	0,863	0,431	89,137	50,06
260	0,930	0,532	89,070	42,76
270	0,843	0,451	89,157	46,48
280	0,832	0,443	89,168	46,84
290	0,799	0,371	89,201	53,52
300	0,795	0,378	89,205	52,48
310	0,728	0,313	89,272	56,94
320	0,795	0,333	89,205	58,19
330	0,725	0,308	89,275	57,56
340	0,691	0,292	89,309	57,70
350	0,664	0,231	89,336	65,24

Average values D% is 62.

According to the results of the research, we concluded that the method of diminishing the form deviations through generating a CNC code based on compensation of the form errors is efficient in the case of helical profiles.

3. Conclusions

According to our expectations we found that if we generate a helical profile with an approximate width of 21,5mm on a 5 axes machine we will obtain a profile which is very close to the theoretical profile.

The maximum deviation on the larger diameter, closer to the main axle, is of 0,067mm, while the deviation towards the interior diameter tends to 0,3mm, although the finishing of the profile has been made with a processing adjunction of about 1 mm.

After the measurements results and the precise repositioning of the piece, we ran a compensatory program where we used data about the deviations of the profile. As a result of the run of this CNC compensatory program we obtained a profile much closer to the theoretical one. On average, the deviations were reduced by 62%. It follows that: in order to get even closer to the theoretical profile, the compensatory values need to be a little higher than those resulted from our calculations, therefore, the compensatory values we used are overtaken. A 38% supplementary compensation should be necessary, which could consist in a subject for a new study.

According to the graphical representation of the three profiles we may observe as well small deviations in the direction of axis Z, which appear because of the imprecision of the positioning in this direction. Taking into consideration the geometrical construction of the machine we used for these processing, we may conclude that the maximum imprecision have been caused by the weakest element, in our case, the axis B.

Using a very precise repositioning and some compensations which result from very precise measurement, it is basically easy to obtain a diminishing of positioning errors by about 62%.

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