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DEVELOPMENT OF PARAMETRIC G-CODE MACRO FOR GEAR POSITIONING RELATIVE TO A MILLED REFERENCE SURFACE

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Abstract

The orientation of gear teeth relative to a machined reference surface is an important requirement in the manufacturing of mechanical components, particularly in applications where the angular position of the gear must correspond to a functional surface. This paper presents the development of a parametric G-code macro for the automatic positioning of hobbed gear teeth relative to a milled reference surface. The proposed macro enables the angular orientation of the gear to be calculated from user-defined input parameters without requiring manual recalculation or modification of the NC program. The developed solution simplifies CNC programming and minimizes the possibility of positioning errors. The proposed method contributes to increased efficiency, repeatability, and reliability in CNC gear manufacturing.

Keywords: Gear hobbing; Parametric G-code; CNC programming; Gear positioning

1. Introduction

Loss of angular relationship between a reference surface and gear teeth during gear hobbing.

Gear hobbing is widely used for the production of external gears due to its high productivity and flexibility. In serial production, progressive axial shifting of the hob can be applied to distribute tool wear over a larger portion of the cutting edges and thereby improve tool utilization. However, axial displacement of the helical hob also changes the phase of its cutting profile relative to the workpiece. Consequently, progressive hob shifting may cause a change in the angular position of the generated gear teeth relative to a predefined reference surface of the machined component. This effect becomes particularly important when the angular relationship between a selected gear tooth and a functional reference surface represents a specified design requirement.

The investigated problem was identified during industrial production, where a deviation in the angular position of the first gear tooth relative to a machined reference surface resulted in a quality nonconformity. Although the manufactured gear met the basic geometrical requirements, the required angular relationship was not maintained after progressive hob shifting. Therefore, an automatic method for compensating the angular deviation caused by progressive hob shifting is

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required. The objective of the research is to determine the relationship between the axial displacement of the hob and the resulting angular displacement of the generated gear teeth and to implement the corresponding workpiece C-axis correction directly in the CNC program. The proposed approach is intended to maintain the required angular relationship between the selected gear tooth and the reference surface throughout serial production.

2. Literature review – critical overview

Gear hobbing technology and accuracy requirements

Gear hobbing is one of the most widely applied technologies for manufacturing external cylindrical gears due to its high productivity, flexibility, and ability to produce different gear geometries [1]. The process is based on synchronized rotational motion between the hob and the workpiece, whereby the hob acts as a worm-like generating tool and progressively generates the involute tooth profile [2]. The resulting gear quality is influenced by tool geometry, cutting parameters, machine accuracy, workpiece clamping, and synchronization between the hob and workpiece spindle [3]. Precise synchronization between the cutting tool and the workpiece spindle is also a fundamental requirement in modern gear machining processes implemented on multifunctional CNC lathes [4]. In multi-axis machining, the orientation of the cutting tool relative to the workpiece can also affect the resulting surface quality [5]. Previous research has therefore focused primarily on improving manufacturing accuracy through the selection and optimization of machining conditions and machining strategies [6]. Gear accuracy is commonly evaluated using standardized parameters such as profile, helix and pitch deviations, radial runout, and tooth thickness variation [7]. In particular, some components require a defined angular relationship between the gear teeth and a functional reference feature [8] [9]. Failure to maintain this relationship can affect subsequent assembly and the functional behaviour of the component even when conventional gear accuracy requirements are satisfied [10] [11]. Existing research has predominantly addressed tooth geometry, machining errors, cutting conditions, and process optimization, while comparatively less attention has been devoted to maintaining the angular orientation of the generated teeth relative to functional reference surfaces [12] [13].

Tool wear mechanism and hob compensation methods

During gear hobbing, the cutting edges are subjected to mechanical and thermal loads that progressively cause tool wear and may affect cutting performance and dimensional stability [14]. To improve tool utilization, controlled displacement of the hob can be applied during serial production. By progressively shifting the hob relative to the workpiece, different regions of the cutting edges are engaged, distributing wear over a larger usable tool length and extending effective tool life [15] [16]. In CNC-controlled manufacturing, this displacement can be implemented through programmed tool-coordinate corrections based on predefined increments or the number of manufactured components [17]. Gerth et al. [18] investigated the reproduction of gear hobbing tool wear mechanisms using a single-insert milling test, providing an experimental approach for analysing wear behaviour under simulated cutting conditions. Appropriate tool geometry, cutting conditions, and wear-management strategies can improve tool utilization while maintaining machining performance during extended production [19]. However, existing compensation approaches primarily address tool life, cutting performance, and conventional gear accuracy [16]. The influence of progressive hob displacement on the angular position of a specific gear tooth relative to a functional reference surface remains insufficiently addressed.

Influence of hob position correction on gear tooth orientation

Hob displacement during tool compensation changes the geometrical relationship between the cutting tool and the workpiece [20]. In CNC gear hobbing, the hob position can be modified through controlled machine-axis movements [9]. Such displacement changes the spatial relationship between the tool and workpiece and may therefore require an additional compensation movement to preserve the required generating relationship [19]. An uncompensated change in hob position can consequently influence the angular relationship between the generated teeth and the workpiece coordinate system [21]. This deviation may not be identified by conventional gear accuracy parameters [7]. A gear may satisfy profile, pitch, and dimensional requirements while the angular orientation of a selected tooth relative to a reference feature differs from the required position [22]. Angular deviations can be compensated by modifying the angular position of the workpiece spindle [23] [24]. However, despite previous research on hob shifting, synchronization, machining accuracy, and CNC compensation [25], automatic correction of the angular position of a defined gear tooth relative to a reference feature during progressive hob displacement remains insufficiently addressed.

CNC parametric programming and compensation approaches

Modern CNC systems enable process automation through parametric programming and user-defined macros [25]. These approaches allow mathematical calculations, conditional operations, and automatic modification of machining parameters directly within the CNC program [26]. Fanuc Macro B provides variables, mathematical functions, and logical commands for creating flexible machining and compensation routines [25]. Previous applications have demonstrated the potential of macro programming to automate repetitive manufacturing operations, reduce operator dependency, and improve process reliability [27] [28]. Existing CNC compensation approaches, however, primarily focus on dimensional accuracy, tool wear, and machine positioning errors [25]. The integration of a mathematical relationship between hob displacement and workpiece angular correction with CNC macro programming therefore

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provides a potential approach for automatically maintaining the required angular relationship between the generated gear teeth and a reference surface [25].

Research gap and motivation

Previous studies have extensively addressed gear hobbing, tool wear, and hob shifting strategies [16]. Research has primarily focused on process optimization, tool life, and conventional gear accuracy [10]. However, the preservation of the angular relationship between generated gear teeth and a functional reference surface during progressive hob shifting remains insufficiently addressed. This research therefore proposes a parametric CNC compensation method that automatically determines the required workpiece angular correction from the actual hob displacement. The method is designed for implementation directly in the CNC control using Fanuc Macro B and aims to maintain the prescribed angular relationship between a selected gear tooth and the machined reference surface throughout serial production.

3. Proposed methodology and CNC compensation solutions

The investigated component was manufactured on a CNC turning centre equipped with a driven tool system and a Fanuc CNC control. The external gear teeth were produced directly on the turning centre using the gear hobbing process. The investigated gear has 17 teeth and a normal module of 1.5 mm, corresponding to a reference diameter of 25.5 mm. In addition to the external gear teeth, the component contains a machined reference flat whose angular position relative to the generated teeth represents an important functional requirement of the component. The required relationship between the selected gear tooth and the machined reference surface is illustrated in Fig. 1.

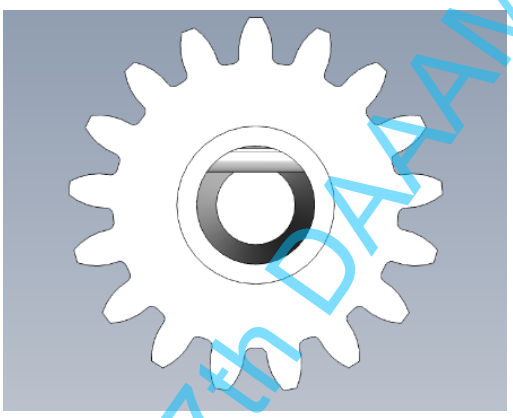

Fig. 1. Required angular position of the gear tooth relative to the machined reference surface

Fig. 2 shows the gearbox assembly in which the investigated gears are installed. The corresponding components contain externally visible machined reference flats whose orientation is functionally related to the angular position of the gears inside the gearbox. Consequently, a change in the angular position of the generated gear teeth relative to the reference surface can lead to an incorrect orientation of the functional feature in the final assembly, even when the conventional geometrical parameters of the gear teeth remain within the specified tolerance limits.

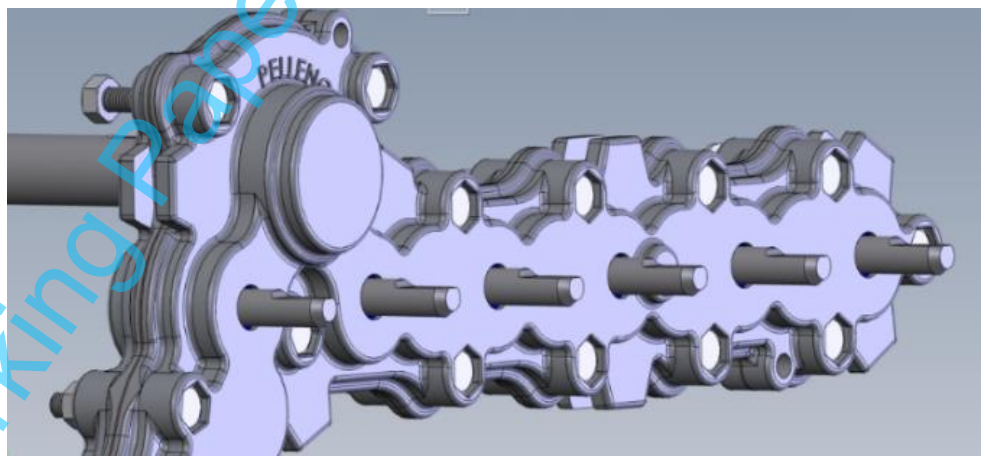

Fig. 2. Gearbox assembly showing the functional orientation of the shafts with machined reference flats

The external gear teeth are manufactured directly on the CNC turning centre using a driven hobbing tool. The actual arrangement of the hob and the workpiece during the investigated manufacturing process is shown in Fig. 3. A single-

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start hob with a module of 1.5 mm, an outside diameter of approximately 55 mm, and a pressure angle of 20° is used. The hob is positioned relative to the workpiece according to the kinematic requirements of the generating process.

Fig. 3. Arrangement of the hob and workpiece during the investigated gear hobbing process

In the original manufacturing process, the progressive compensation is applied only to the linear Y-axis position of the hob. The corresponding angular position of the workpiece spindle is not automatically corrected according to the actual Y-axis compensation value. Consequently, the relative position between the hob and the workpiece changes progressively during serial production. However, the axial displacement of the hob changes the region of the cutting edges engaged in the machining process, thereby distributing tool wear along the usable length of the hob. Due to the helical geometry of the hob, an axial displacement also changes the phase of its cutting profile relative to the workpiece. Consequently, progressive shifting of the hob may result in a change of the angular position of the generated gear teeth relative to the machined reference surface. Based on this relationship, an appropriate correction of the workpiece angular position can subsequently be calculated and implemented in the CNC program.

Analysis of the original Y-axis shifting strategy

In the original manufacturing process, the axial position of the hob was progressively modified in the Y-axis in order to distribute tool wear along the usable cutting length of the hob. The displacement was performed automatically after each manufactured component using variables implemented directly in the CNC program. The relevant part of the original program is shown in Fig. 4.

```
(***** STARTING POSITION – REFERENCE *****)
G97;
M764;
#522=0.02 (Y-AXIS MOVEMENT ON NEXT PIECE)
M8;
M69;
M5;
G330 ( V2 INTO REFERENCE)
G0G53X-110;
G0G28V0. (REFERENCE POINT Y-AXIS);
G0G53Z-350. (SAFETY POSITION IN Z AXIS);
G54G98;
G0T0505 (POSITION OF THE MOUNTED TOOL);
G0Y#520 (MOVEMENT IN Y AXIS);
G0Z-15.;
G54G98;
G81.4R26.L1.Q1.5P0. (START OF SYNCHRONIZATION OF HOBBING AND C-AXIS);
S506M13 (START OF THE RPM*VC=50/MIN);
G1X100.F1000 (THE X-AXIS APPROACH);
G1X45.F1000 (THE X-AXIS APPROACH * DIAMETER OF WORKPIECE);
G1X36.648F100. (THE HOBB APPROACH INTO CUT);
G1W-24.F25. (HOBBING REQUIRED DIAMETER);
G1U50.F1000. (TOOL EXIT FROM MATERIAL)
G0Z0;
(***** KS-OK*END OF HOBB MACHINING *****);
#520= [#520+#522](SHIFTING IN Y-AXIS);
M9;
G80.4. (ENDING THE SYNCHRONIZATION);
M5;
M46; (END OF C-AXIS);
G0G28Y0. (REFERENCE POINT OF Y-AXIS)
```

Fig. 4. Original CNC program used for progressive Y-axis shifting of the hob

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The Y-axis shifting strategy is based on two CNC variables. Variable *#520* represents the accumulated *Y-axis* displacement of the hob, while variable *#522* defines the displacement increment applied after each manufactured component. In the investigated process, the increment was defined as: *#522 = 0.02 mm*.

Before the gear hobbing operation, the actual value stored in variable #520 is used for positioning the hob in the Y-axis by the following command: *G0 Y#520*.

After completion of the gear hobbing operation, the accumulated displacement is increased according to: *#520=[#520+#522]*.

Therefore, assuming an initial value of *#520 = 0*, the first component is machined without an additional Y-axis displacement. After completion of the first component, the value of #520 is increased by *0.02* mm and this value is subsequently used for machining the next component. The sequence of Y-axis positions is consequently: *0, 0.02, 0.04, 0.06, 0.08, ...* mm.

To describe the shifting strategy independently of the component number, the accumulated hob displacement can be expressed as equation (1):

$$Y_{acc} = N\Delta Y \tag{1}$$

Where Y_{acc} is the accumulated axial displacement of the hob, N is the number of completed shifting steps, and ΔY is the displacement increment. For the investigated process $\Delta Y = 0.02$ mm. For example, after ten completed shifting steps, the accumulated displacement of the hob is: $Y_{acc} = 10 * 0.02 = 0.2$ mm.

The purpose of this strategy is to progressively change the active cutting region of the hob. As a result, successive components are not machined continuously using exactly the same axial region of the cutting edges. The available cutting length of the hob can therefore be utilized more effectively and the cutting load is distributed over a larger region of the tool. However, the original compensation strategy considers only the linear displacement of the hob in the *Y-axis*. No additional angular correction of the workpiece is calculated as a function of the accumulated *Y-axis* displacement. This becomes important because the hob is a helical generating tool. An axial displacement of the hob changes the phase position of its cutting profile relative to the workpiece. Consequently, the accumulated *Y-axis* displacement may also influence the angular position of the generated gear teeth relative to the machined reference surface.

The value stored in variable *#520* therefore represents not only the current axial position used for distributing hob wear but also a parameter that can be used to determine the required angular compensation. The relationship investigated in the subsequent analysis can be generally expressed as equation (2):

$$Y_{acc} \rightarrow \Delta\varphi h \rightarrow \Delta\varphi g \rightarrow \Delta C \tag{2}$$

Where $\Delta\varphi h$ represents the phase change of the hob caused by its axial displacement, $\Delta\varphi g$ is the resulting angular displacement of the generated gear teeth, and ΔC represents the required correction of the workpiece angular position. The mathematical relationship between the accumulated *Y-axis* displacement and the required angular correction is derived in the following section.

Mathematical determination of the required angular correction

The progressive axial displacement of the hob described in the previous section changes the position of the helical cutting profile relative to the workpiece. Therefore, in order to maintain the prescribed angular relationship between the generated gear teeth and the machined reference surface, the phase change introduced by the axial hob displacement must be determined and subsequently compensated by an appropriate angular correction of the workpiece.

For a helical generating tool, an axial displacement can be related to the angular phase change of the hob through its lead. The lead L_h represents the axial distance corresponding to one complete revolution of a selected hob thread. For a hob with z_0 starts, the lead can be expressed from the axial pitch p_x as equation (3):

$$L_h = z_0 p_x \tag{3}$$

For the investigated single-start hob, $z_0 = 1$.

The axial displacement of the hob ΔY therefore corresponds to a change in its angular phase according to equation (4):

$$\Delta\varphi h = 360° \frac{\Delta Y}{Lh} \tag{4}$$

Equation (4) shows that even a relatively small axial displacement of the hob produces a change in the phase of its helical cutting profile at the tool-workpiece contact region. In the investigated manufacturing process, the hob is progressively shifted by $\Delta Y = 0.02$ mm after each manufactured component. Consequently, the accumulated axial displacement after N shifting steps is calculated according to equation (1). However, the phase change of the hob cannot be directly applied as the required *C-axis* correction. During gear hobbing, the hob and workpiece are kinematically

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coupled according to the number of hob starts z_0 and the number of teeth of the gear z. Their rotational relationship is expressed by equation (5):

$$\frac{\omega g}{\omega h} = \frac{z0}{z} \tag{5}$$

Where ω_g is the angular velocity of the workpiece and ω_h is the angular velocity of the hob. For the investigated gear, $z = 17$ and the hob is single-start, $z_0 = 1$. Therefore, one complete revolution of the hob corresponds to a workpiece rotation, as expressed by equation (6):

$$\frac{360°}{17} = 21.1765° \tag{6}$$

The required angular correction of the workpiece resulting from the phase change of the hob can consequently be expressed as equation (7):

$$\Delta C = \Delta\varphi h \frac{z0}{z}. \tag{7}$$

Substitution of equation (6) into equation (7) gives equation (8):

$$\Delta C = 360° \frac{\Delta Y}{Lh} \frac{z0}{z} \tag{8}$$

For the accumulated Y-axis displacement, the corresponding relationship is expressed by equation (9):

$$\Delta C_{acc} = 360° \frac{Yacc}{Lh} \frac{z0}{z} \tag{9}$$

This equation represents the basic mathematical relationship required for the proposed compensation strategy. It enables the accumulated Y-axis displacement stored in the CNC variable #520 to be converted into the corresponding angular correction of the workpiece.

Development and implementation of the automatic C-axis compensation

Based on the mathematical relationship derived in the previous section, an automatic compensation algorithm was developed for implementation directly in the Fanuc CNC program. The proposed method links the progressive axial displacement of the hob with the corresponding angular correction of the workpiece, while preserving the original Y-axis shifting strategy used for distributing hob wear.

The accumulated axial displacement of the hob is already stored in variable #520 of the original CNC program. Therefore, the accumulated axial displacement can be expressed by equation (10):

$$Y_{acc} = \#520 \tag{10}$$

The required accumulated angular correction can be expressed by equation (11):

$$\Delta C_{acc} = 360° \frac{Yacc}{Lh} \frac{z0}{z} \tag{11}$$

Where L_h is the hob lead, z_0 is the number of hob starts, and z is the number of teeth of the manufactured gear. For the investigated single-start hob ($z_0 = 1$) and the gear with z = 17, equation (11) becomes equation (12):

$$\Delta C_{acc} = \frac{360°}{17Lh} Y_{acc.} \tag{12}$$

For practical CNC implementation, a compensation coefficient K_C is introduced as defined by equation (13):

$$K_C = \frac{360°}{17Lh}. \tag{13}$$

For the investigated hob with module m = 1.5 mm, the hob lead is approximately $L_h = 4.714$ mm, resulting in equation (14):

$$K_C \approx 4.492°/mm. \tag{14}$$

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Consequently, the accumulated C-axis correction is calculated directly from the current value of #520, equation (15):

$$\Delta C_{acc} = 4.492\#520. \quad (15)$$

The compensation can therefore be implemented in Fanuc Macro B using two additional variables:

```
#523 = 4.492          (C-AXIS COMPENSATION COEFFICIENT)
#524 = [#520*#523] (C-AXIS CORRECTION)
```

Variable #523 stores the compensation coefficient, while #524 contains the calculated angular correction corresponding to the current axial position of the hob. For the investigated machine configuration, the correction is applied in the positive C-axis direction. The corrected angular reference position is therefore expressed by equation (16):

$$C_{corr} = C_0 + \#524. \quad (16)$$

Where C_0 represents the original C-axis reference position. The calculated value stored in variable #524 must be subsequently transferred to the angular positioning of the workpiece before the gear hobbing cycle is initiated. Therefore, the original CNC program was extended by an additional calculation block that determines the C-axis correction directly from the actual accumulated hob displacement. The proposed Macro B implementation is expressed as follows:

```
#523 = 4.492          (C-AXIS COMPENSATION COEFFICIENT)
#524 = [#520*#523] (C-AXIS CORRECTION)
...
(C-AXIS REFERENCE POSITIONING)
...
(APPLY +#524 TO ORIGINAL C-AXIS REFERENCE)
...
(GEAR HOBBING CYCLE)
...
```

In this implementation, variable #523 contains the compensation coefficient in degrees per millimetre, while variable #524 represents the accumulated angular correction corresponding to the actual axial hob position stored in #520. In the proposed compensation strategy, the calculated correction is added to the original C-axis reference position before the hobbing cycle. Consequently, each change in the axial position of the hob is intended to be accompanied by a corresponding adjustment of the workpiece angular reference. The original Y-axis shifting strategy remains unchanged. After completion of the hobbing operation, the accumulated hob displacement is updated using the following command:

```
#520 = [#520+#522] (SHIFTING IN Y-AXIS)
#522 = 0.02           (Y-AXIS MOVEMENT ON NEXT PIECES)
```

Thus, the same variable #520 is used both for positioning the hob and for determining the corresponding C-axis correction. Each increment of 0.02 mm in the axial hob position produces an angular correction calculated using equation (17):

$$\Delta C = 4.492 * 0.02 = 0.08984°. \quad (17)$$

The operating principle of the modified compensation strategy can therefore be summarized as equation (18):

$$\#520 \rightarrow Y_{acc} \rightarrow \Delta C_{acc} \rightarrow C_{corr}\ . \quad (18)$$

The proposed modification creates a direct mathematical link between the existing tool-wear compensation and the angular positioning of the workpiece. Unlike the original program, in which only the axial position of the hob was progressively modified, the proposed algorithm simultaneously adjusts the angular reference of the workpiece without requiring manual intervention by the operator. The proposed implementation preserves the original purpose of the

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progressive hob shifting strategy while extending it with an automatic compensation of the angular position of the generated gear teeth. The proposed approach is therefore intended to maintain the prescribed angular relationship between the selected gear tooth and the machined reference surface throughout serial production.

4. Results and Discussion

The proposed compensation method was theoretically evaluated using the parameters of the investigated manufacturing process. As derived in the previous section, the compensation coefficient for the investigated combination of the single-start hob and the 17-tooth gear was determined using equation (19):

$$K_C = 4.492°/\text{mm}. \tag{19}$$

For the applied axial hob-shifting increment of 0.02 mm, the corresponding C-axis correction for each shifting step is calculated using equation (20):

$$\Delta C = K_C \Delta Y = 4.492 * 0.02 = 0.08984°. \tag{20}$$

Although the angular correction corresponding to a single shifting step is relatively small, the effect becomes significant as the axial displacement of the hob accumulates during serial production. Since both the Y-axis displacement and the calculated C-axis correction increase linearly, the accumulated correction can be expressed as equation (21):

$$\Delta C_{acc} = 4.492 Y_{acc}\ . \tag{21}$$

Table 1 presents selected values of the accumulated hob displacement and the corresponding calculated C-axis correction.

Shifting steps N	Y_{acc} [mm]	ΔC_{acc} [°]
0	0.00	0.000
1	0.02	0.090
5	0.10	0.449
10	0.20	0.898
25	0.50	2.246
50	1.00	4.492
100	2.00	8.984

Table 1. Calculated C-axis correction for the selected accumulated hob displacement

The results demonstrate that the angular deviation that would remain uncompensated in the original shifting strategy increases proportionally with the accumulated axial displacement of the hob. For example, after ten shifting steps, corresponding to an accumulated displacement of 0.20 mm, the required angular correction reaches approximately 0.898°. At an accumulated hob displacement of 1 mm, the required correction already reaches 4.492°. Therefore, even a relatively small shifting increment can result in a considerable cumulative change in the angular position of the generated teeth during extended serial production.

Available hob-shifting range and compensation limits

In the investigated manufacturing setup, the progressive axial displacement of the hob is performed within the available Y-axis working range. The CNC turning centre provides a total Y-axis travel of 110 mm. Considering the hob diameter of 55 mm, an effective shifting interval of 55 mm was assumed for the theoretical analysis. By locating the reference position at the centre of this interval, the available shifting range is defined by equation (22):

$$Y_{shift} = -27.5 \text{ mm to } +27.5 \text{ mm}\ . \tag{22}$$

With the applied shifting increment of 0.02 mm, the number of available shifting steps from the reference position to either limit is calculated using equation (23):

$$N_{max} = \frac{27.5}{0.02} = 1375\ . \tag{23}$$

At the positive limit of the investigated shifting range, the corresponding accumulated C-axis correction is calculated by equation (24):

$$\Delta C_{max} = 4.492*27.5 = 123.53°. \tag{24}$$

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The calculated value demonstrates the importance of compensating the angular position of the workpiece throughout the complete hob-shifting range. After the available shifting range in one direction has been utilized, the shifting coordinate can be reset and production can continue using the opposite part of the available range. The compensation algorithm can consequently calculate the required angular correction from the actual value of the Y-axis displacement without changing the basic principle of the original tool-wear distribution strategy.

Evaluation of the proposed compensation strategy

The main difference between the original and proposed strategies is that the original CNC program modifies only the axial position of the hob, whereas the proposed method simultaneously modifies the angular reference of the workpiece. The same accumulated displacement variable used for hob shifting is therefore also used as the input for calculating the C-axis correction. In the proposed strategy, the corresponding positive C-axis correction is calculated automatically from the actual hob position, theoretically maintaining the prescribed angular relationship between the selected gear tooth and the machined reference surface. The compensation is derived directly from the Y-axis displacement already available in the CNC program. The proposed solution represents a relatively simple modification of the existing CNC program, but addresses a positioning error that is not reflected directly by conventional gear accuracy parameters.

The proposed compensation strategy will be experimentally verified under industrial machining conditions using a coordinate measuring machine (CMM) or an optical gear measuring machine (GMM). Gear components manufactured at the selected accumulated hob-shifting positions will be measured to determine the residual angular deviation between a selected gear tooth and the milled reference surface. The measured angular deviations will be evaluated to assess the influence of cutting forces, machine thermal drift, and positioning repeatability on the resulting angular accuracy. This experimental verification will enable the effectiveness and limitations of the proposed compensation algorithm to be evaluated under actual manufacturing conditions.

5. Conclusion

This study addressed the loss of the prescribed angular relationship between a selected gear tooth and a machined reference surface caused by progressive axial hob shifting during serial gear hobbing. Although hob shifting is an effective method for distributing tool wear along the usable cutting length, the axial displacement of the helical hob simultaneously changes the phase of its cutting profile relative to the workpiece. Consequently, the angular position of the generated gear teeth changes if no additional compensation is applied. A mathematical relationship between the accumulated axial displacement of the hob and the required angular correction of the workpiece was derived. For the investigated 17-tooth gear manufactured using a single-start hob with a module of 1.5 mm, the resulting compensation coefficient was determined as $K_C = 4.492°/mm$. With the applied hob-shifting increment of 0.02 mm, each shifting step corresponds to a C-axis correction of approximately 0.08984°. Based on this relationship, an automatic compensation strategy was developed for implementation using Fanuc Macro B. The existing accumulated Y-axis displacement stored in the CNC program is used directly to calculate the corresponding positive C-axis correction. The proposed method therefore preserves the original hob-shifting strategy while eliminating the need for manual recalculation of the workpiece angular reference during serial production. The main contribution of the proposed approach is the direct integration of hob wear distribution and workpiece angular positioning within the CNC program. The method provides a simple and repeatable means of maintaining the required angular relationship between the generated gear teeth and a functional reference surface. Future work will focus on experimental verification of the proposed compensation over the complete hob-shifting range and on evaluating the residual angular positioning error under industrial production conditions.

6. Acknowledgments

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