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# A Flexible Electronic Helical Guide Controller

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**Abstract**

In this paper, an Electronic Helical Guide Controller (EHGC) is proposed, for helical gear shaping processes. In most traditional gear shaper machines, the cutter's reciprocating movement is driven by a crank-connecting rod mechanism. Therefore, this study adopts this kind of gear shaper as the machine platform to establish an accurate mathematical model. The control algorithm is embedded in the interpolation module of the CNC system using electronic gearbox techniques to realize special multi-axis linkage control requirements. The crankshaft's angular position is measured and the rotational speed is calculated in each control cycle. The actual position and velocity of the cutter along the Z-axis can be calculated using the geometric relations of the crank-connecting mechanism, and motion in the other axes can be controlled by the electronic gearbox. A special G code with parameters (G83) is also designed and the EHGC control through NC programming is realized in an improvised gear shaping CNC machine. The proposed EHGC is low cost and easy to implement in practice since it does not need a linear grating ruler and a probe on the Z-axis. Furthermore, EHGC allows the flexibility to change a part's helix angle to compensate for distortions caused by heat treatment. Simulations and experiments are performed to verify the effectiveness of the proposed EHGC.


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*Keywords:* Gear shaping; Electronic gearbox (EGB); Generating process; Tracking error

## 1. Introduction

Gear shaping is a versatile and accurate means of manufacturing helical gears, herringbone gears, internal gears, spur gears and face gears [1-3]. Previous generations of CNC controlled gear shaping machines were not truly flexible, because their guides for helical gears had remained mechanical[4]. There were some inherent weaknesses in adopting mechanical helical guides, since use of mechanical helical guides imposed a limitation of using only one lead in a given setup and was restricted to a given minimum lead angle. To address these problems a totally new shaping head was developed by the Gleason Company featuring a backlash-free direct driven helical guide for the cutter spindle. The shaping head is controlled by the software which is developed based on the Siemens 840D CNC. With the appropriate software, additional generating cutter rotational motion required for helical gears can be superimposed electronically on the cutter spindle rotation. These functions are embodied in the "Electronic Helical Guide". All gear cutting, tooling and process data are entered via the dialog program. The CNC controller calculates all the necessary machine data/settings. However this kind gear shaping machine is very expensive, such as the GP200ES.

In view of the above analysis, the paper mainly focuses on an Electronic Helical Guide Controller (EHGC) design, performance evaluation and experimental study. The EHGC designed in this work is different from Gleason's in the aspect that it does not need extra data dispersed through preprocessing, as the control process is based on an accurate mathematical model. In addition, a special G codes with parameters (G83) is designed and the EHGC control through NC programming is realized in a laboratory-scale gear shaping CNC. The control law is embedded in the interpolation module of the CNC system in the form of an electronic gearbox[5,6] to satisfy special multi-axis linkage


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control requirements. Furthermore, EHGC offers the flexibility to change a part's helix angle to compensate for heat treatment induced distortion. Typical "winding or unwinding" of the helix, resulting in helix angle slope errors can easily be addressed with simple changes in the part program by creating a compensating helix angle value.

The subsequent sections of this paper are arranged as follows: In Section 2, the theory model of EHGC is first introduced, the hardware platform of the laboratory-scale gear shaping CNC is given, and the implementation principle of EHGC is also introduced. Section 3 illustrates the tracking performance using the proposed EHGC through simulations. Experiments were then conducted based on a homemade four-axis CNC, and the results are analyzed in Section 4. Finally, our conclusions are given in Section 5.

## 2. Electronic helical guide controller design

In typical gear shaping processes, the cutter motion includes two stages [7, 8]: the cutting (down) stroke, where the work gear is generated and the return (back) stroke without material removal. The kinematics of gear shaping is depicted in Fig.1. When machining helical gears[9-11], the cutter (C2-axis) and workpiece (C1-axis) are rotating in parallel axes, in harmony with each set of the teeth. Meanwhile the cutter dose a reciprocating motion along the Z-axis to engage the workpiece. The constraint for the cutter rotational axis, workpiece rotational axis and reciprocating motion axis (Z-axis) is that the cutter rotational axis must move an additional round ( $\Delta C_2$ ), while the cutter moves a helical lead along the Z-axis, as shown in Fig.2. During the reciprocating motion of the cutter, the back-stroke features a lift-off maneuver from the workpiece to prevent damage of the face. The radial feed is along X-axis.

The relationship of C1-axis and C2-axis can be expressed as

$$n_{C2} = -\frac{Z_{C1}}{Z_{C2}} n_{C1} + \frac{\sin\beta}{\pi m_n Z_{C2}} v_Z \qquad (1)$$

In Eq. (1), $n_{C2}$ is the cutter-axis speed, $n_{C1}$ is the workpiece-axis speed, $v_Z$ is the feed rate on Z-axis caused by the reciprocating motion of the cutter, $Z_{C1}$ is the number of gear teeth, $Z_{C2}$ is the number of gear shaper cutter teeth, $m_n$ is the gear normal module, and $\beta$ is the gear helix angle.

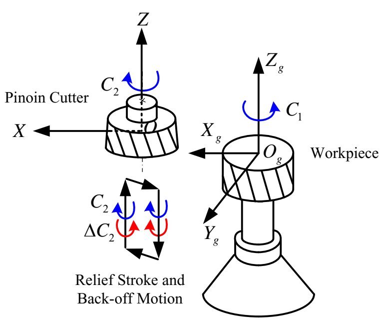


Fig. 1. The kinematics of gear shaping.

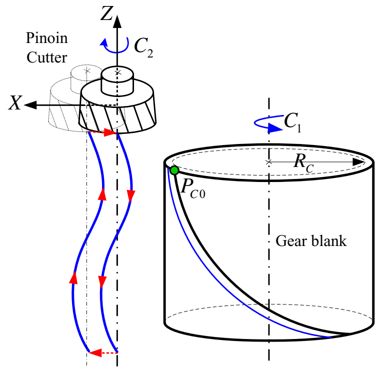


Fig. 2 The principle of EHGC.

The cutter reciprocating motion is driven by the crack-connecting rod mechanism in most gear shaper machines, as shown in Fig.3. The feed rate $v_Z$ is caused by the rotational movement of crank drive. So we can calculate the cutter moving speed through converting the rotation position and the speed of A-axis to the moving position and the speed of Z-axis.

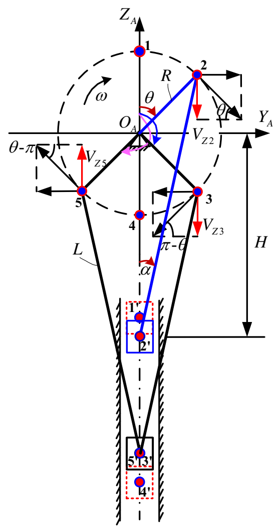


Fig. 3. The crack-connecting rod mechanism of gear shaper machine.

In Fig.3, Dot 1, 2, 3, 4 and 5 are the different positions of crack in a turning circle, while Dot 1', 2', 3', 4' and 5' are the corresponding positions of connecting rod on the Z-axis. The crank radius is R, the length of the connecting rod is L, $n_A$ is the rotational speed of crank (A-axis). $\theta$ is the angle of the crank turns from the starting point (Dot 1). Through the geometric relationships we have:

$$H = L\cos\alpha - R\cos\theta = R(\frac{L}{R}\cos\alpha - \cos\theta) \qquad (2)$$

$$L\sin\alpha = R\sin\theta \quad . \qquad (3)$$

Then we have