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Donghong Hu (1055908606@qq.com)
Hubei University
Kai Wang
Hubei University
Ling Zhang
Hubei University
Pingjiang Wang
Huazhong University of Science and Technology
Guang Chen
Hubei University

Research Article

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Posted Date: April 1st, 2021

DOI: https://doi.org/10.21203/rs.3.rs-295769/v1

Research on Tool Presetting and Tool Deviation in CNC Lead Screw Grinding Process

Hu Donghong*[1], Wang Kai[1], Zhang ling[1], Wang Pingjiang[2], Chen Guang**[1]

1. School of Computer Science and Information Engineering, Hubei University, Wuhan, China, 430062

2. Numerical Control Center, Huazhong University of Science and Technology, Wuhan, China, 430074

Abstract: In the process of tool presetting for an CNC lead screw grinding, when A-axis rotating and Z-axis shifting synchronously according to the screw pitch length, *L,* of the lead screw workpiece, the handwheel corresponding to X-axis and Z-axis, respectively, is operated to align the grinding wheel with the middle of the screw groove. Then, the coordinates of Z-axis, A-axis and X-axis of the current position are recorded, and the coordinates of the grinding start position and grinding end position of the lead screw workpiece are calculated accordingly.

However, due to the mutual following error of Z-axis and A-axis in the synchronous movement process, tool deviation typically occurs when the grinding wheel moves from the grinding start position to the grinding end position to grind the lead screw workpiece. More specifically, the grinding wheel slightly deviates from the middle of the screw groove to the left or right of the screw groove.

To offset this deviation, the root cause for creating the deviation is analyzed, and a method to correct the tool deviation is proposed: First, the CNC system sends out grinding instructions, according to the requirements of grinding process, to make the A-axis and the Z-axis move synchronously. In the meantime, the CNC system measures and records the current coordinates of A-axis and Z-axis, and calculates the tool deviation caused by the mutual following error between Z-axis and A-axis. As a result the grinding start position and the grinding end position are adjusted in light of the value of tool deviation in the subsequent grinding process, so as to address the tool deviation issue.

Key Words: tool deviation; lead screw; lead screw grinding; tool presetting; CNC lead screw grinding

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***Biography:** Hu Donghong, male, Associate Professor, Ph.D., research areas: numerical control technology. E-mail:1055908606@qq.com, hudonghong@hubu.edu.cn

****Corresponding author:** Chen Guang, male, lecturer, M.S, research areas: numerical control technology.E-mail:80825798@qq.com;

***Corresponding author:** Hu Donghong, E-mail: 1055908606@qq.com, hudonghong@hubu.edu.cn;

1. Introduction

In aviation machinery, CNC machine tools, precision instruments and other precision mechanical equipment, lead screw is a key component to determine the accuracy of linear displacement. It transmits motion (precise positioning) and power, and is widely used in these machinery.

CNC lead screw grinding and tool presetting in grinding have been widely studied. The main effort of the study is focused on tool positioning [1,2], error compensation[3, 4, 5] and system intelligence[6]. Out of the studies, many methods and technologies including expert system [7], fuzzy logic[8], neural network[9, 10], advanced control theory, and operational research and information theory have been applied in CNC lead screw grinding.

The synchronous mutual following error between the moving axes in CNC machining process, and the tool deviation in CNC lead screw grinding are common problems due to the difference between the mechanical and electrical characteristics of each moving axis in the machine tools. This difference, makes the actual motion trail of the tool (grinding wheel) deviate from the instruction trail.

This problem also exists in the CNC lead screw grinding. Although the grinding wheel can be initially positioned in the middle of the screw groove by tool presetting, it slightly deviates from the middle of the screw groove, to the left or right of the screw groove, in the subsequent grinding processes.

In this work, a method to solve the problem of tool deviation in CNC lead screw grinding is proposed. First, according to the grinding process requirements, grinding instructions are sent out by the CNC system to make A-axis and Z-axis move synchronously according to the screw pitch length of the lead screw workpiece. Simultaneously, the coordinates of the current A-axis and Z-axis are measured and recorded by the CNC system, and the value of tool deviation caused by the mutual following error of Z-axis and A-axis is calculated. Consequently, the grinding start position and the grinding end position are adjusted accordingly in light of the value of tool deviation in the subsequent actual grinding process so as to address the tool deviation issues associated with CNC lead screw grinding process.

In Section 2, the procedural steps of CNC lead screw grinding, including tool presetting and grinding process are introduced. Additionally, the causes of tool deviation are analyzed. In Section 3, the method to correct the tool deviation problem in CNC lead screw grinding is described in detail. In Section 4, application examples are provided and conclusions are summarized.

2. Tool Deviation Analysis

In this section, the tool presetting process and grinding process in CNC lead screw grinding are introduced, and the reasons of tool deviation are explained.

2.1 Main Moving Parts in CNC Lead Screw Grinding

As shown in Fig. 1, the main moving parts in CNC lead screw grinding include four servo axes X, Z, A and Y. The grinding wheel can move along the X-axis direction to approach or leave the lead screw workpiece. The wheel dresser can move along the Y-axis, approaching or leaving the grinding wheel, and rotate half a circle around the dresser's rotation axis to dress the grinding wheel. The lead screw workpiece can move along the Z-axis and rotate around the A-axis.

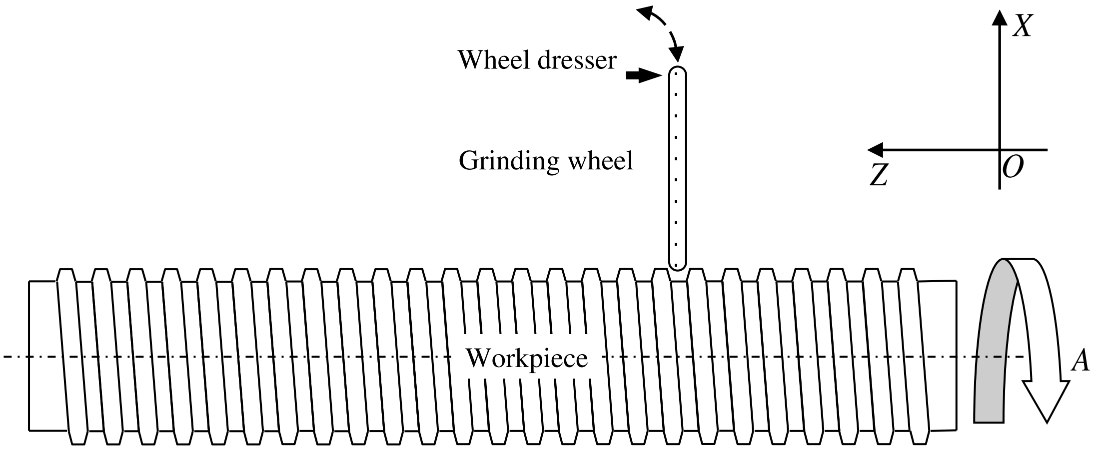

Figure 1. The lead screw workpiece, grinding wheel, wheel dresser and coordinate system in the CNC lead screw grinding.

The positive direction of rotation axis, A-axis, is shown in Figure 1. The direction of the grinding wheel that is away from the lead screw workpiece is defined as the positive direction of X-axis. The direction that the grinding wheel moves to the left in relation to the lead screw workpiece is designated as the positive direction of Z-axis.

2.2 Tool Presetting and Grinding Process

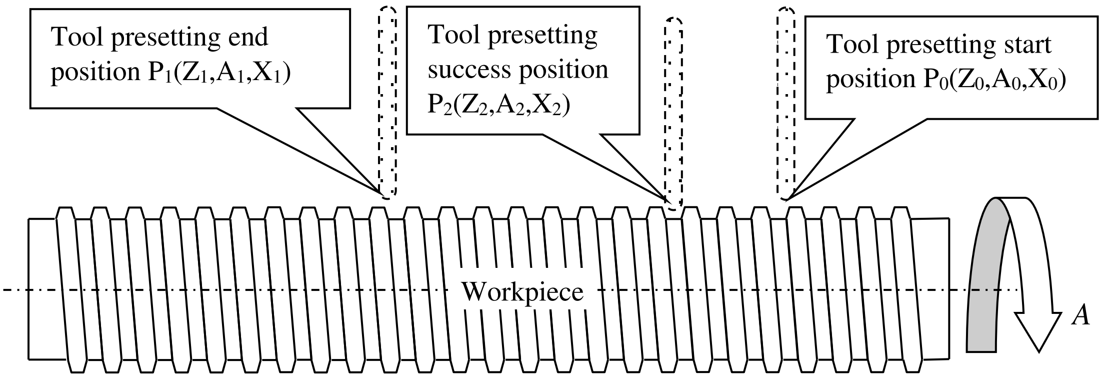

Figure 2. A schematic illustrating CNC lead screw tool presetting process.

CNC lead screw grinding mainly consists of tool presetting and workpiece grinding. The tool presetting process is schematically shown in Figure 2 with specific steps as follows:

- Step 1: the CNC system makes the grinding wheel move to the tool presetting start position $P_0(Z_0, A_0, X_0)$.
- Step 2: The CNC system makes the grinding wheel move along the Z-axis from the tool presetting start position $P_0(Z_0, A_0)$ to the tool presetting end position $P_1(Z_1, A_1)$ at a synthetic speed v_P. The coordinates of Z-axis and A-axis of $P_0(Z_0, A_0)$ and $P_1(Z_1, A_1)$ are in accordance with the relationship of screw pitch length L. For every 360 degree rotation of the A-axis, the Z-axis moves one screw pitch length L of the lead screw workpiece. The correlation between the A-axis rotation and the Z-axis movement can be described in following equation:

$$\frac{Z_1 - Z_0}{L} = \frac{A_1 - A_0}{360} \tag{1}$$

- Step 3: during the movement of the grinding wheel in step 2, manually operate the X-axis handwheel and the Z-axis handwheel so that the grinding wheel is located in the middle of the screw groove, gently touches both sides of the screw groove, and produces sparks of equal size on the left and right sides of the grinding wheel;
- Step 4, manually press the "tool presetting success" button so that the coordinates of the A-axis, A_2, the Z-axis, Z_2, and the X-axis, X_2 , of the current position $P_2(Z_2, A_2, X_2)$ are recorded automatically by the CNC system;

- Step 5: The grinding wheel retreats to a safe position along the X-axis after the tool presetting is successful. Thus, the process for the tool presetting process is finished.

If the "tool presetting success button" is not pressed while the grinding wheel has already moved to the tool presetting end position $P_1(Z_1, A_1)$, the CNC system would then signal the failure of the tool presetting. As a result,, the grinding wheel would retreat to the safe position, followed by the CNC system signaling "tool presetting failed". The tool presetting process is over.

If the tool presetting is successful, the CNC system will determine the X-coordinate position $Xa \approx X_2$ for the subsequent grinding automatically based on the coordinates of tool presetting success position, $P_2(Z_2, A_2, X_2)$. The coordinates of grinding start position $P_3(Z_3, A_3)$ and the grinding end position $P_4(Z_4, A_4)$ will be calculated accordingly using the following equations:

$$A_3 = A_2 + 360 \times \frac{Z_3 - Z_2}{L} \tag{2}$$

$$A_4 = A_2 + 360 \times \frac{Z_4 - Z_2}{L} \tag{3}$$

The subsequent grinding process is illustrated in Fig.3. The CNC system makes the grinding wheel move from the grinding start position $P_3(Z_3, A_3, X_a)$ to the grinding end position $P_4(Z_4, A_4, X_a)$ at a synthetic speed, v_G, to grind the screw groove of the lead screw workpiece. As the movement of the grinding wheel has to satisfy both equations (2) and (3), the grinding wheel should always be in the middle of the screw groove during grinding, and produce the sparks of equal sizes on the left and right sides of the grinding wheel.

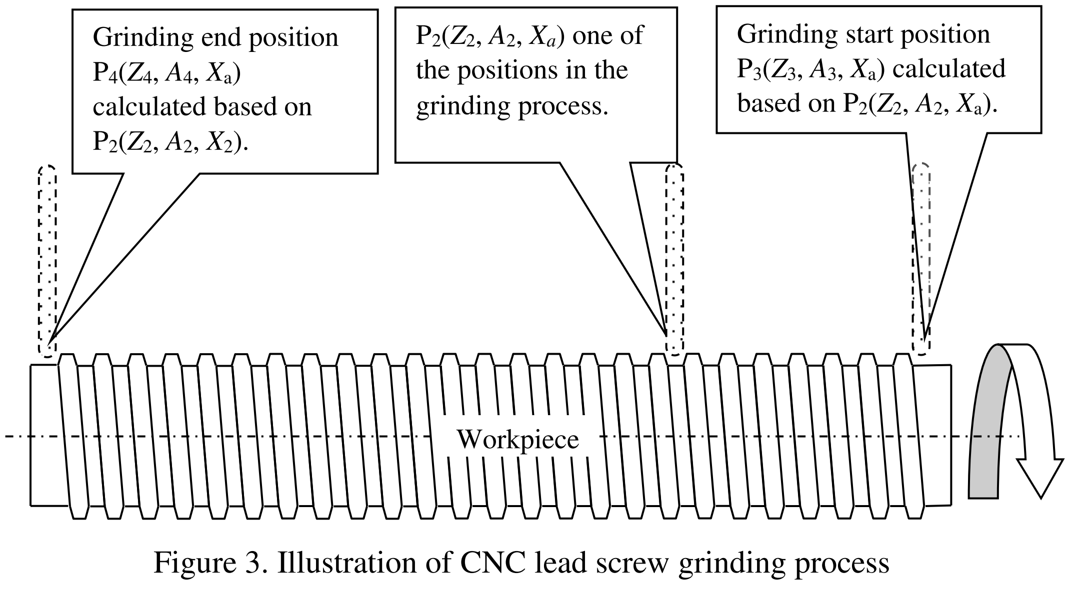

Figure 3. Illustration of CNC lead screw grinding process

2.3 Cause of Tool Deviation

According to the above analysis, the grinding wheel should be located at the middle of the screw groove of the lead screw workpiece in the subsequent grinding process after successful tool presetting. The spark size on the left and right sides of the grinding wheel should be identical. However, in practical grinding process, the grinding wheel is not in the middle of the screw groove. Instead, the grinding wheel deviates slightly to the left or right, resulting in unequal spark size on both sides of the grinding wheel.

As depicted in Fig. 4, during the grinding process from the grinding start position $P_3(Z_3, A_3, X_a)$ to the grinding end position $P_4(Z_4, A_4, X_a)$, the grinding wheel is not in the middle of the screw groove, but slightly deviates to the right, resulting in the spark on the right side of the grinding wheel larger than that on the left side.

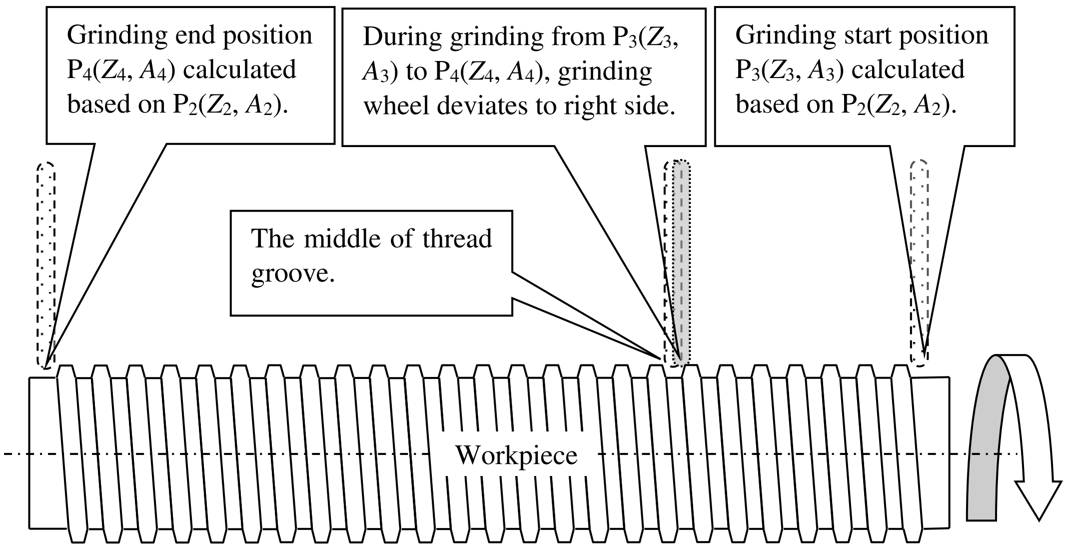

Figure 4. Illustration of tool deviation during CNC lead screw grinding ($X=X_a$).

In practical grinding process, it is difficult for Z-axis and A-axis to keep absolutely synchronous motion due to the differences in their servo and motor characteristics, and variance in acceleration and deceleration control characteristics in the interpolation algorithm. In general, the load of A-axis is lighter than that of Z-axis. Therefore, the acceleration and deceleration performance of A-axis is better than that of Z-axis. At the beginning of the grinding movement, the A-axis reaches the steady speed faster than the Z-axis. When grinding process reaches the grinding end position, the A-axis stops moving earlier than the Z-axis.

As shown in Fig. 5, in the process of tool presetting, the CNC system sends instructions to make the Z-axis and A-axis move from the tool presetting start position $P_0(Z_0, A_0)$ to the tool presetting end position $P_1(Z_1, A_1)$ at the specified synthetic speed

v_P, according to the screw pitch length L of the lead screw workpiece. Because the load of A-axis is smaller than that of Z-axis, A-axis will reach the specified speed earlier than Z-axis at the beginning of tool presetting. This acceleration is reflected on the solid trail (actual trail) from P_0 to P_0' (Fig. 5). Similarly, when approaching the tool presetting end position P_1, A-axis will reduce the motion speed to zero earlier than Z-axis at the end of tool presetting, as shown on the solid trail (actual trail) from P_1' to P_1 in Fig. 5 .

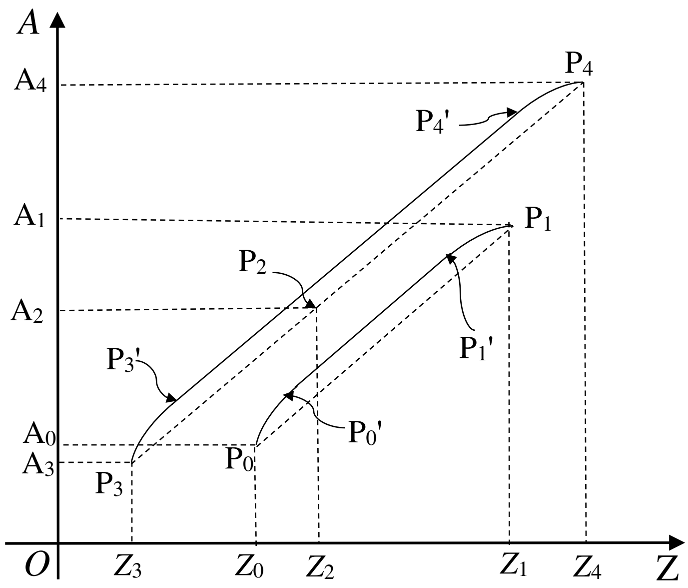

Figure 5. Tool presetting trail and grinding trail.
(P_3 and P_4 are calculated by P_2, so P_2 must be on the dotted line P_3P_4)

Therefore, if the operator does not intervene the movement of the grinding wheel by operating the Z-axis handwheel, the grinding wheel will move from point P_0 to point P_1 along the dotted line according to the instructions of the CNC system. However, in practical process, the Z-axis and A-axis would not move along the dotted trail (instruction trail) from P_0 to P_1 as shown in Fig.5. Instead, they move along the solid trail (actual trail) from P_0, P_0', P_1' to P_1.

If the operator operates the Z-axis handwheel, the grinding wheel will not follow the solid line trail of $P_0P_0'P_1'P_1$ shown in Figure 5. In the process of tool presetting, the operator will operate the Z-axis handwheel and the X-axis handwheel to make the grinding wheel in the middle of the screw groove of the lead screw workpiece. If the spark size on the left and right sides of the grinding wheel looks equal, the “tool presetting success button” would be pressed and the coordinates of the current grinding wheel position $P_2(Z_2, A_2, X_2)$ would be recorded automatically by the CNC system. Here X_2 is used to determine the X-axis coordinate X_a in subsequent grinding. In general, X_a is approximately equal to X_2, or $X_a \approx X_2$.

According to the coordinates $P_2(Z_2, A_2)$ of tool presetting success position and equations (2) and (3), the coordinates of the grinding start position $P_3(Z_3, A_3)$ and the grinding end position $P_4(Z_4, A_4)$ are automatically calculated by the CNC system. Consequently, the CNC system would send instructions to make the Z-axis and A-axis move along the dotted line trail (instruction trail, straight-line trail) from the grinding start position $P_3(Z_3, A_3)$ to the grinding end position $P_4(Z_4, A_4)$ at the specified synthetic speed v_G to grind the screw groove of the lead screw workpiece.

For the same reason, in the actual grinding process, the Z-axis and A-axis would not move along the dotted line trail (instruction trail) from P_3 to P_4, but along the solid trail (actual trail) from P_3, P_3', P_4' to P_4 as shown in Fig.5.

Because the motion instructions from $P_0(Z_0, A_0)$ to $P_1(Z_1, A_1)$ and the motion instructions from $P_3(Z_3, A_3)$ to P_4 (Z_4, A_4) are based on the same screw pitch length L of the same lead screw workpiece, therefore, the dotted line trail (instruction trail) of P_0P_1 should be parallel to that of P_3P_4.

After the synthetic speed of the Z-axis and A-axis reaches a stable value, the straight linear part of the actual trail such as $P_0'P_1'$ and $P_3'P_4'$ satisfies the relation of the screw pitch length L of the lead screw workpiece. Therefore, $P_0'P_1'$ and $P_3'P_4'$ are parallel to each other.

In Fig.5, if the synthetic velocity v_P of the tool presetting process is equal to the synthetic velocity v_G of the grinding process, it can be concluded that the actual trails (solid trails) corresponding to P_0P_0' and P_3P_3' have translational symmetry. Both trails are indicative of the processes for a grinding machine that is accelerated from static status to the same synthetic speed under the same mechanical, electrical and load conditions, and based on the same CNC system instructions.

Similarly, if the synthetic velocity v_P of the tool presetting process is equal to the synthetic velocity v_G of the grinding process, it indicates that the actual trails (solid trails) of $P_1'P_1$ and P_3P_3' have translational symmetry. Both trails are indicative of the processes for a grinding machine that is decelerated from the same synthetic speed to static status under the same mechanical, electrical and load conditions, and based on the same CNC system instructions.

Therefore, if the synthetic velocity v_P of tool presetting process is equal to the synthetic velocity v_G of grinding process, it can be concluded that the dotted line P_0P_1, the solid line $P_0'P_1'$, the dotted line P_3P_4 and the solid line $P_3'P_4'$ are parallel to each other. Further, it can be deduced that the distance between the solid line $P_0'P_1'$ and the dotted line P_0P_1 is equal to the distance between the solid line $P_3'P_4'$ and the dotted line P_3P_4. Regardless, the curve contour of the solid trail of P_0P_1 and P_3P_4 is independent of the X-axis coordinate.

In generally, as long as the following conditions are met:

1. The synchronous movement of of Z-axis and A-axis follows to the screw pitch length L of the lead screw workpiece;
2. The Z-axis and A-axis move at the specified synthetic speed v_G;
3. The grinding wheel moves to the left from the start position to the end position along the Z-axis;
4. As the grinding wheel is at the start position and the end position, the Z-axis and A-axis are both in static status.

Then, the distance between the dotted line of the instruction trail and the solid straight line segment of the actual trail is definite. This distance varies with L and v_G only.

Based on the actual motion trail (solid trail) in Fig. 5, it can also be concluded that as A-axis rotates to angle of A_2, Z-axis has not yet reached the Z_2 coordinate due to the lighter load of A-axis. In the actual grinding process, it can be observed that the grinding wheel slightly deviates to the right side of the screw groove, resulting in larger spark on the right side of the grinding wheel than that on the left side, as shown in Fig. 4.

3. Methods to Solve the Problem of Tool Deviation

According to the analysis in Section 2, the key to address the problem of tool deviation in lead screw grinding is to eliminate the distance between the instruction trail (dotted line P_3P_4) and the actual trail (solid line $P_3'P_4'$), as indicated in Figure 5.

3.1 Calculation of Tool Deviation

In order to calculate the tool deviation of grinding wheel in grinding process, Fig.5 is intentionally reconfigured as Fig.6. During the movement of the grinding wheel from P_3 to P_4 at the synthetic speed v_G, the CNC system can record the current position coordinates $P_5(Z_5, A_5)$ at any time. If a horizontal line is made from point P_5 to intersect the dotted line P_3P_4, then an intersection point can be obtained and marked as $P_6(Z_6, A_6)$. Similarly, if a vertical line is drawn from point P_5 to intersect the dotted line P_3P_4, another intersection point will be gotten and marked as $P_7(Z_7, A_7)$. The relationship between the coordinates of points $P_5(Z_5, A_5)$ and $P_6(Z_6, A_6)$, $P_5(Z_5, A_5)$ and $P_7(Z_7, A_7)$ can be mathematically expressed as follows:

$$A_6 = A_5 \tag{4}$$

$$Z_7 = Z_5 \tag{5}$$

$$\Delta Z_{Lv} = Z_6 - Z_5 = Z_3 + L\frac{A_6 - A_3}{360} - Z_5 = Z_3 + L\frac{A_5 - A_3}{360} - Z_5 \tag{6}$$

$$\Delta A_{Lv} = A_7 - A_5 = A_3 + 360\frac{Z_7 - Z_3}{L} - A_5 = A_3 + 360\frac{Z_5 - Z_3}{L} - A_5 \tag{7}$$

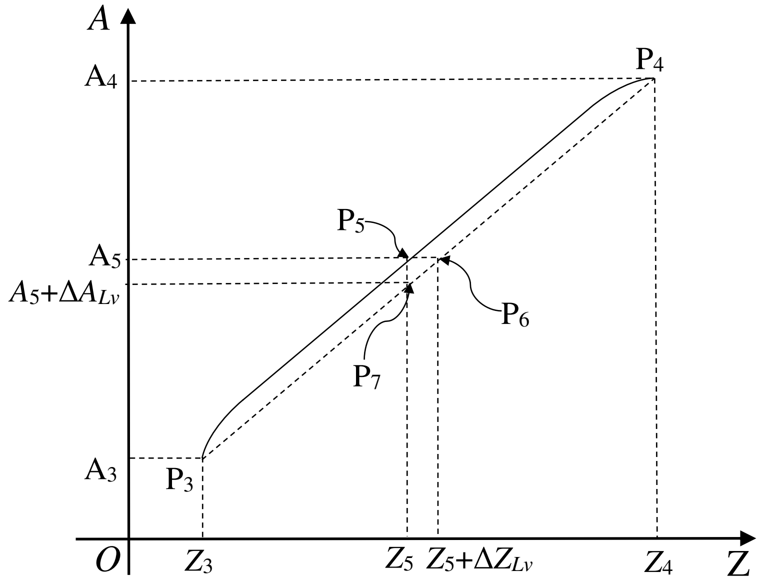

Figure 6. Tool deviation in the grinding process.

According to Fig. 6, it is not difficult to conclude that if points P_3 and P_4 are moved down vertically (along direction in parallel to A-axis) at a distance, ΔA_{Lv} , to reach new points P_8 and P_9 , and the grinding wheel moves along P_8P_9 at the synthetic speed v_G, then the actual grinding trail would be P_8P_9 solid line trail, as shown in Fig.7. If points P_3 and P_4 are moved horizontally (along direction in parallel to Z-axis) to right at a distance, ΔZ_{Lv} , reach another set of new points P_{10} and P_{11}, and the grinding wheel moves along $P_{10}P_{11}$ at synthetic speed V_G, the actual grinding trail would be $P_{10}P_{11}$ solid line trail, as illustrated in Fig. 8. The formulas for calculating the respective coordinates of points $P_8(Z_8, A_8)$, $P_9(Z_9, A_9)$, $P_{10}(Z_{10}, A_{10})$ and $P_{11}(Z_{11}, A_{11})$ from the given points $P_3(Z_3, A_3)$, and $P_4(Z_4, A_4)$ are as follows：

$$Z_8 = Z_3 \tag{8a}$$

$$A_8 = A_3 + \Delta A_{Lv} \tag{8b}$$

$$Z_9 = Z_4 \tag{8c}$$

$$A_9 = A_4 + \Delta A_{Lv} \tag{8d}$$

$$Z_{10} = Z_3 + \Delta Z_{Lv} \tag{9a}$$

$$A_{10} = A_3 \tag{9b}$$

$$Z_{11} = Z_4 + \Delta Z_{Lv} \tag{9c}$$

$$A_{11} = A_4 \tag{9d}$$

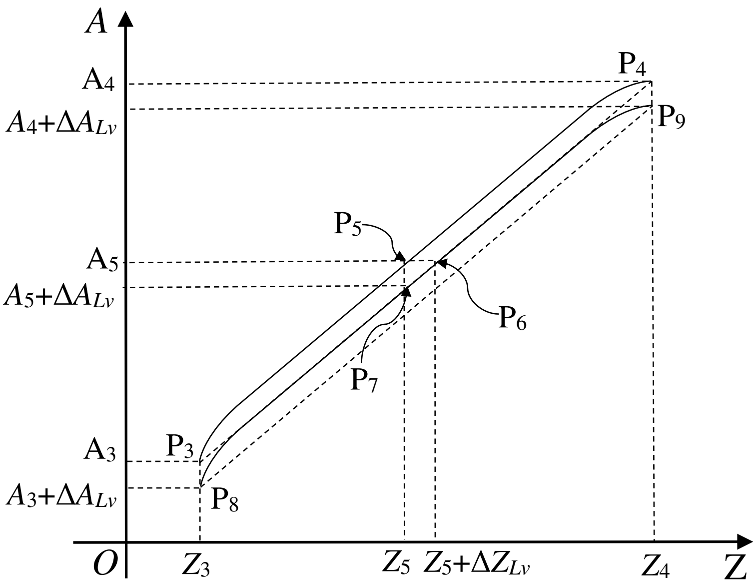

Figure 7. The grinding trail moves down vertically at a distance, ΔA_{Lv}, along the direction in parallel to A-axis.

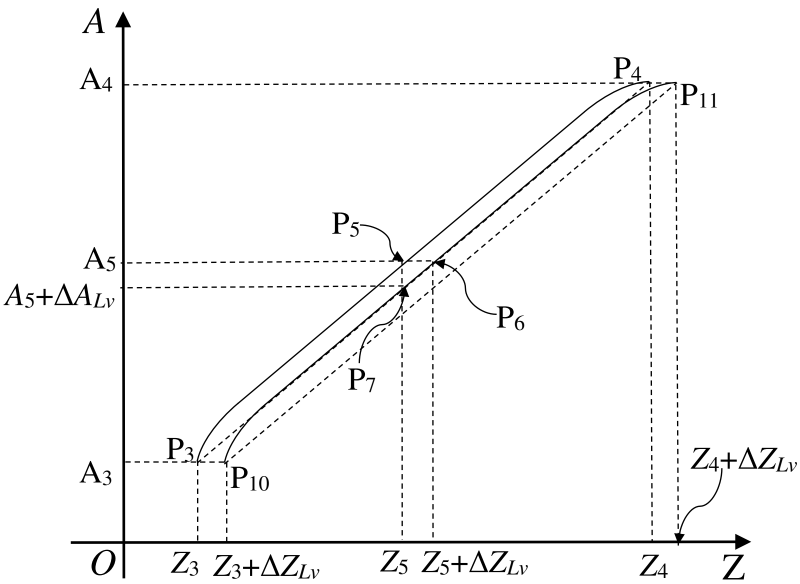

Figure 8. The grinding trail moves right horizontally at a distance ΔZ_{Lv} along the direction in parallel to Z-axis.

Obviously, the P_8P_9 and $P_{10}P_{11}$ of the actual trail (straight line part of the solid line trail) coincide with the P_3P_4 of the instruction trail (dotted line trail). It can be observed in Fig.5 that along the P_3P_4 dotted line trail, the grinding wheel will be strictly located in the middle of the screw groove of the lead screw workpiece, just like the grinding wheel passing through tool presetting success position P_2 during tool presetting(Fig. 2).

Generally speaking, according to Fig.5, different screw pitch length L and different synthetic speed v will inevitably result in different slope for the straight-line segment of the instruction trail. Similarly, different actual trail curve contour in acceleration stage and different actual trail curve contour in deceleration stage will also be produced. On the contrary, the same screw pitch length L and the same synthetic speed v will inevitably lead to identical slope for the straight-line segment of the instruction trail. In the same way, the same actual trail curve contour in the acceleration stage and the same actual trail curve contour in deceleration stage will be produced.

For a given screw pitch length, L, and grinding synthetic speed, v, the corresponding tool deviation ΔZ_{Lv} or ΔA_{Lv} is measured and calculated. The subscript Lv means that the tool deviation ΔZ_{Lv} and ΔA_{Lv} are related to the screw pitch length L and the synthetic velocity v. In practical grinding process, as shown in Fig. 7 or Fig. 8, the problem of tool deviation should be eliminated as long as the Z-axis or the A-axis coordinates of the grinding start position and the grinding end position are moved by ΔZ_{Lv} or ΔA_{Lv}.

3.2 Application Example

In this section, an application example is provided to illustrate the specific methods and steps about how to eliminate the tool deviation in the CNC lead screw grinding.

A lead screw workpiece, with a screw pitch length of 4mm, is to be ground at a synthetic speed of 3000mm/min according to the grinding process requirements.

According to the operator's typical practice for tool presetting, the synthetic speed v_P for tool presetting is 2000 mm/min. The Z coordinate of grinding start position P_3 is 700 mm. The Z coordinate of grinding end position P_4 is 1400 mm. The Z coordinate of tool presetting start position P_0 is 900 mm. The Z coordinate of tool presetting end position P_1 is 1100 mm. Based on the aforesaid conditions, the implementation steps are as follows:

Step 1: make sure that the grinding wheel is far away from the workpiece in the X-axis direction. The CNC system sends out instructions to make the grinding wheel move from the tool presetting start position P_0 (900, A_0) to the tool presetting end position P_1(1100, A_0+360×200/4) at the given synthetic speed of 2000 mm/min;

Step 2: before moving to Step 2, the operator operates the X-axis handwheel and the Z-axis handwheel to align the grinding wheel with the middle of the screw groove, and ensure that the size of sparks on both sides of the grinding wheel is identical. Subsequently, the "tool presetting success button" is pressed by the operator. The coordinates of the current position $P_2(Z_2, A_2, X_2)$ are recorded by the CNC system automatically. Further, the coordinates of grinding start position and the coordinates of grinding end position are automatically calculated by the CNC system according to formula (2) and (3), respectively. The detailed procedures are as follows:

$$Z_3 = 700 \tag{10a}$$

$$A_3 = A_2 + 360\frac{Z_3 - Z_2}{L} \tag{10b}$$

$$Z_4 = 1400 \tag{11a}$$

$$A_4 = A_2 + 360\frac{Z_4 - Z_2}{L} \tag{12b}$$

Step 3: make sure that the grinding wheel is far away from the workpiece in the X-axis direction. The CNC system sends out the instructions to make the grinding wheel move from the grinding start position $P_3(Z_3, A_3)$ to the grinding end position $P_4(Z_4, A_4)$ at the given synthetic speed of 3000 mm/min;

Step 4: as the grinding wheel moves to the position with Z-coordinate between 710 mm and 1390 mm (as long as the grinding wheel reaches the steady synthetic speed of 3000 mm/min), the CNC system will collect the coordinates of the Z-axis and A-axis of the current position $P_5(Z_5, A_5)$ automatically, and calculate the tool deviation ΔZ_{Lv} or ΔA_{Lv} according to formulas (6) and (7);

$$\Delta Z_{Lv} = Z_3 + L\frac{A_5 - A_3}{360} - Z_5 \tag{13}$$

$$\Delta A_{Lv} = A_3 + 360\frac{Z_5 - Z_3}{L} - A_5 \tag{14}$$

Step 5: the CNC system automatically sends out instructions to make Z-axis and A-axis move from the grinding start position $P_{10}(Z_3+\Delta Z_{Lv}, A_3, X_c)$ to the grinding end position $P_{11}(Z_4+\Delta Z_{Lv}, A_4, X_c)$ at the given synthetic speed of 3000 mm/min to grind the lead screw workpiece. In another way, the Z-axis and A-axis are moved from the grinding start position $P_8(Z_3, A_3+\Delta A_{Lv}, X_c)$ to the grinding end position $P_9(Z_4, A_4+\Delta A_{Lv}, X_c)$ at the synthetic speed of 3000mm/min to grind the lead screw workpiece. The value of X_c is determined by slightly approaching or moving away from the workpiece along the X axis based on the value of X_2 according to the grinding process requirements.

As discussed in Section 2, the tool deviation ΔZ_{Lv} and ΔA_{Lv} are only correlated to the screw pitch length L of the lead screw workpiece and the synthetic speed v_P during grinding. If it is needed to grind the workpiece multiple times at different synthetic speeds v_1, v_2 and v_3, the corresponding tool deviation $\Delta Z_{Lv1}(\Delta A_{Lv1})$, $\Delta Z_{Lv2}(\Delta A_{Lv2})$ and $\Delta Z_{Lv3}(\Delta A_{Lv3})$ can be obtained as long as the step 3 and step 4 are repeated several times at different synthetic speeds v_1, v_2 and v_3.

In step 5, when the workpiece is ground at different synthetic speeds v_1, v_2 and v_3, $\Delta Z_{Lv1}(\Delta A_{Lv1})$, $\Delta Z_{Lv2}(\Delta A_{Lv2})$ and $\Delta Z_{Lv3}(\Delta A_{Lv3})$, calculated according to formula (8) and (9), can be applied to adjust the grinding starting point P_3 to P_{10} or P_8, and the grinding end point position P_4 to P_{11} or P_9, respectively.

4. Conclusion

Seven CNC lead screw grinding systems, developed on Huazhong 21 CNC system platform, have been successfully installed in a manufacturing company in Shanghai, P.R. China.

In the first few weeks, when the lead screw workpiece with a screw pitch length of 4 mm was ground at a relatively low Z-axis and A-axis synthetic speed, the tool deviation was insignificant. However, as the lead screw workpiece with a screw pitch length of 6 mm was ground , tool deviation is observed.

By using the method proposed in this work and additional running test, it was found that there is 0.03~0.04mm tool deviation in grinding the lead screw workpiece with a screw pitch length of 4 mm, and 0.05~0.07mm tool deviation in grinding the lead screw workpiece with a screw pitch length of 6mm, respectively. As discussed in section 2, the actual tool deviation is also related to the synthetic speed in the grinding process. Tool deviation corresponding to a few representative synthetic speed is listed in Table 1.

Table 1. Tool deviation under different grinding processes

Pitch(mm)	Z-A Synthetic speed(mm/min)	Tool deviation ΔZ_{Lv}(mm)	Tool deviation ΔA_{Lv}(degree)
4.00	6000	0.040	-3.6
4.00	5000	0.032	-2.88
6.00	6000	0.072	-4.32
6.00	5000	0.051	-3.06

As shown in Table 1, at a screw pitch length of 4mm and a grinding synthetic speed of 6000mm/min, the resulted tool deviation ΔZ_{Lv} is 0.04mm (corresponding ΔA_{Lv} is -3.6 degrees); at the screw pitch length of 4mm and the grinding synthetic speed of 5000mm/min, the tool deviation ΔZ_{Lv} is 0.032mm (corresponding ΔA_{Lv} is -2.88 degrees); at the screw pitch length of 6mm and the grinding synthetic speed of 6000mm/min, the tool deviation ΔZ_{Lv} is 0.072mm (corresponding ΔA_{Lv} is -4.32 degrees); at the screw pitch length of 6 mm and the synthetic grinding speed of 5000mm/min, the tool deviation ΔZ_{Lv} is 0.051 mm (corresponding ΔA_{Lv} is - 3.06 degrees).

After the method of tool deviation automatic extraction and compensation proposed in this paper was implemented, the grinding wheel has always been reliably aligned with the middle of the screw groove in grinding process with no tool deviation observed, regardless of different screw pitch length and grinding synthetic speed.

Declarations

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We hereby declare several points as listed below:

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--We declare that all the authors have made contribution on this manuscript and their names have been listed by order of importance and contribution.

(5) Funding-Funding

--No funding was received to assist with the preparation of this manuscript.

(6) Competing Interests

--We have no relevant financial or non-financial interests to disclose.

(7) Availability of data and materials

--We understand the data policy of the International Journal of Advanced Manufacturing Technology. We agree that all the data or software in our manuscript can be transparent for public when it is published. We agree to follow the Springer Nature Research Data Policies.

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Figures

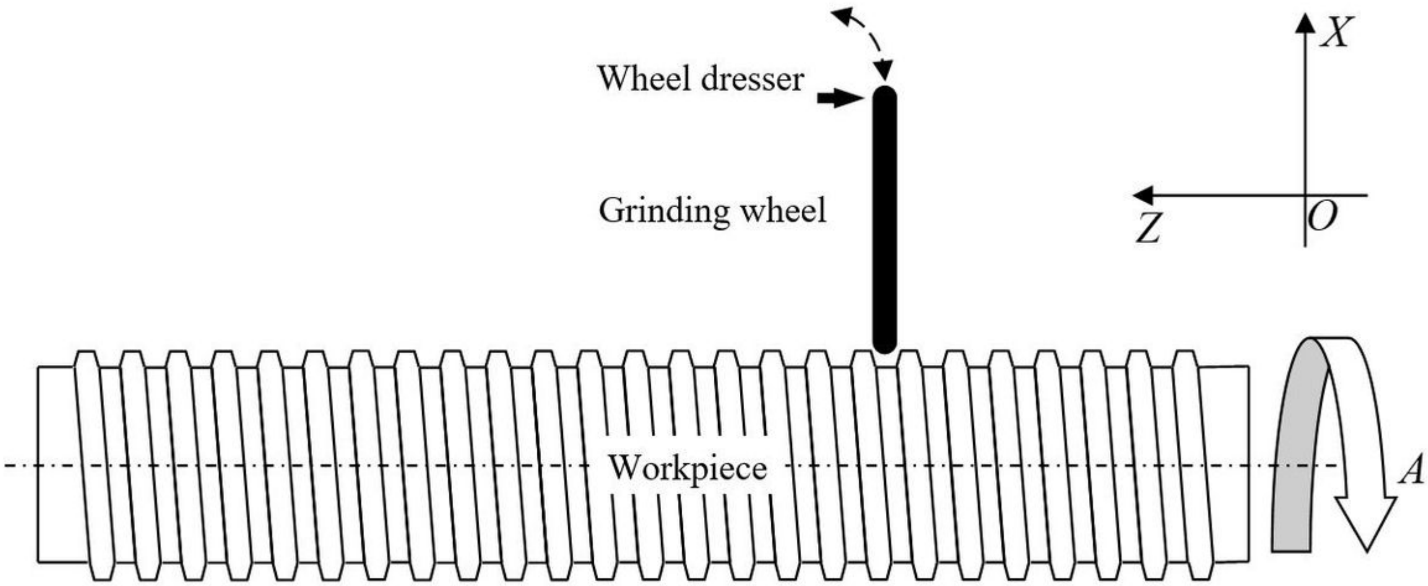

Figure 1

The lead screw workpiece, grinding wheel, wheel dresser and coordinate system in the CNC lead screw grinding.

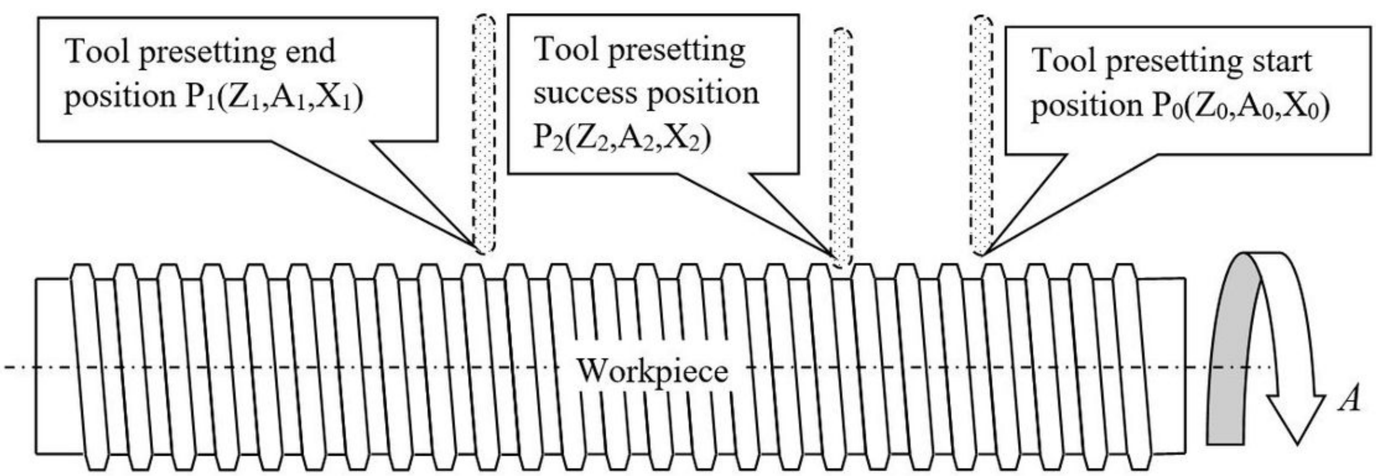

Figure 2

A schematic illustrating CNC lead screw tool presetting process.

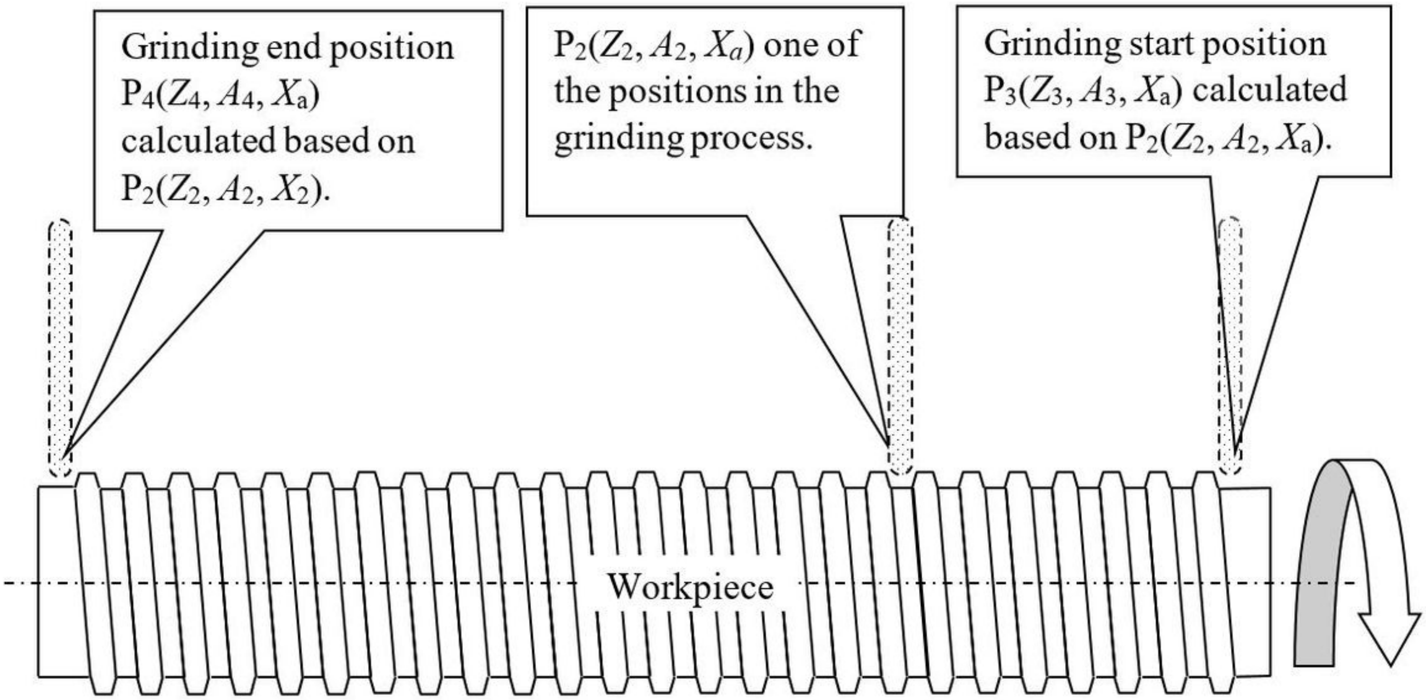

Figure 3

Illustration of CNC lead screw grinding process

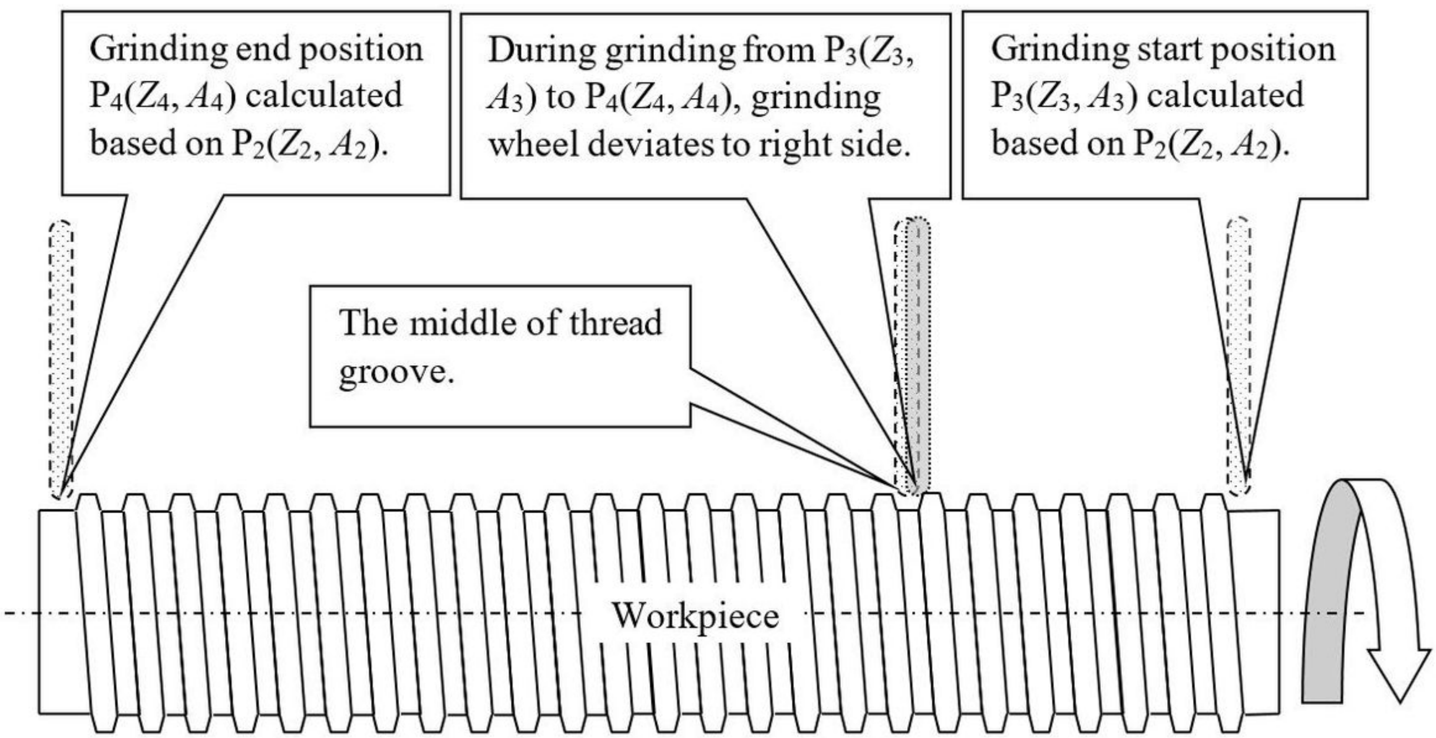

Figure 4

Illustration of tool deviation during CNC lead screw grinding (X=Xa).

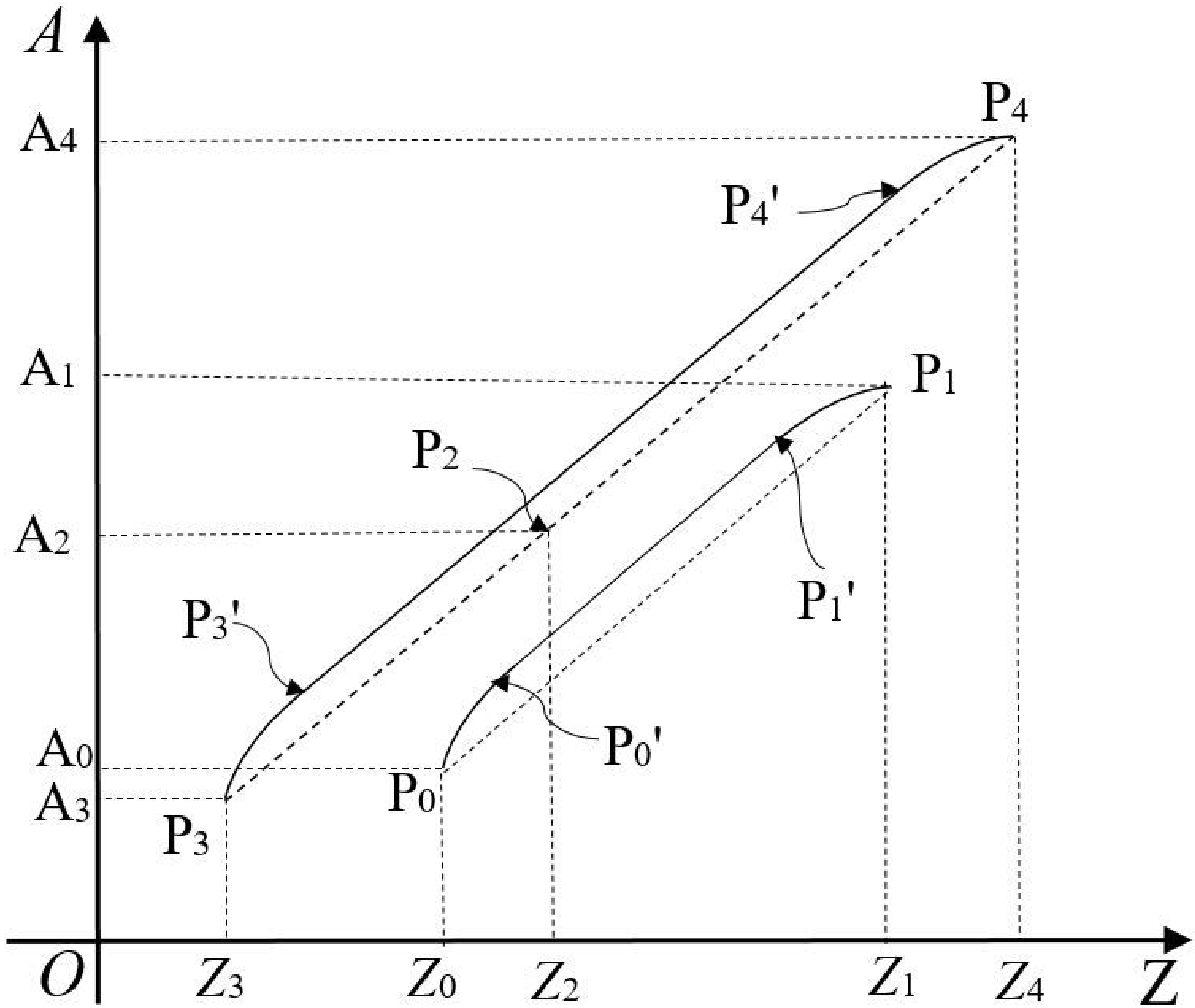

Figure 5

Tool presetting trail and grinding trail.

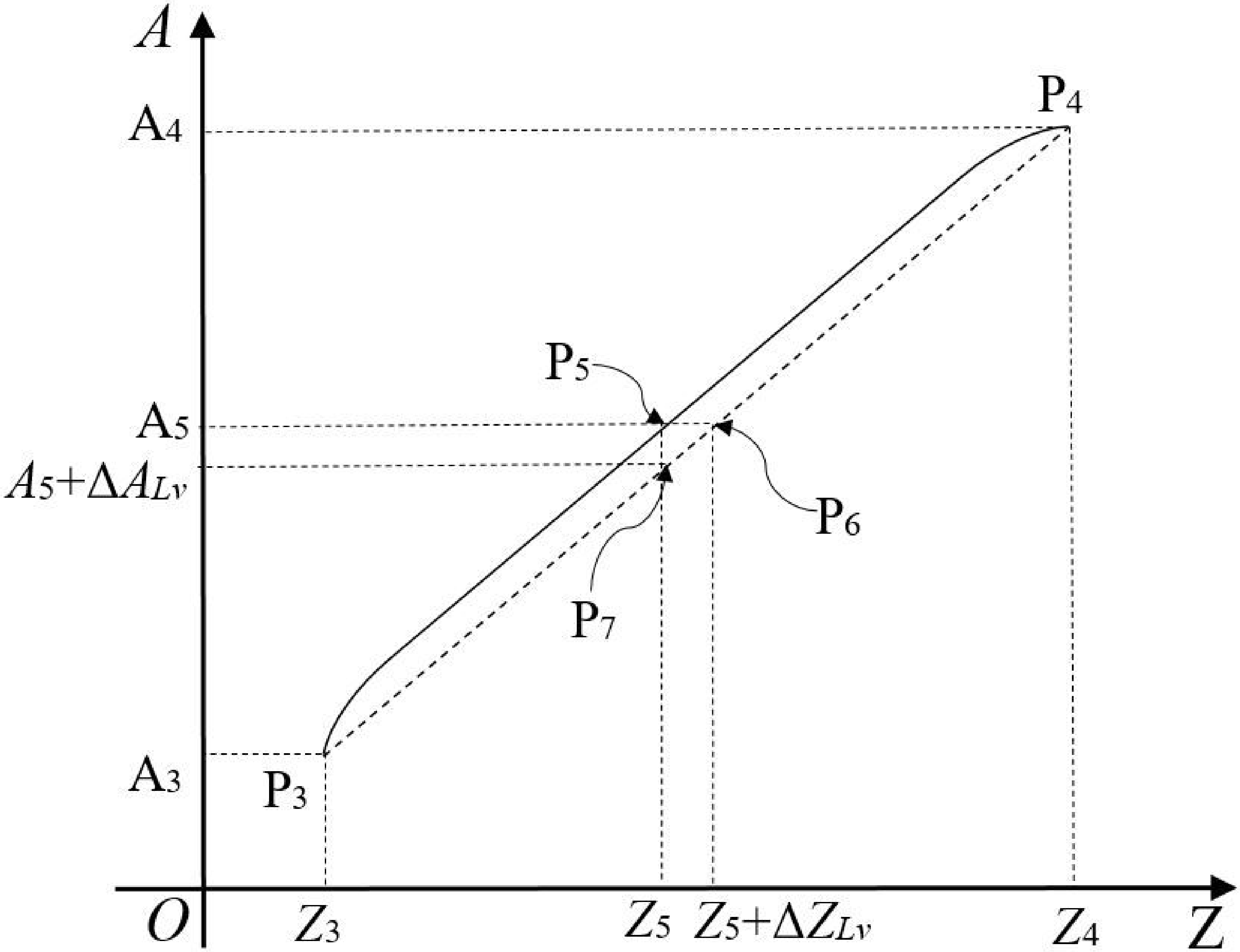

Figure 6

Tool deviation in the grinding process.

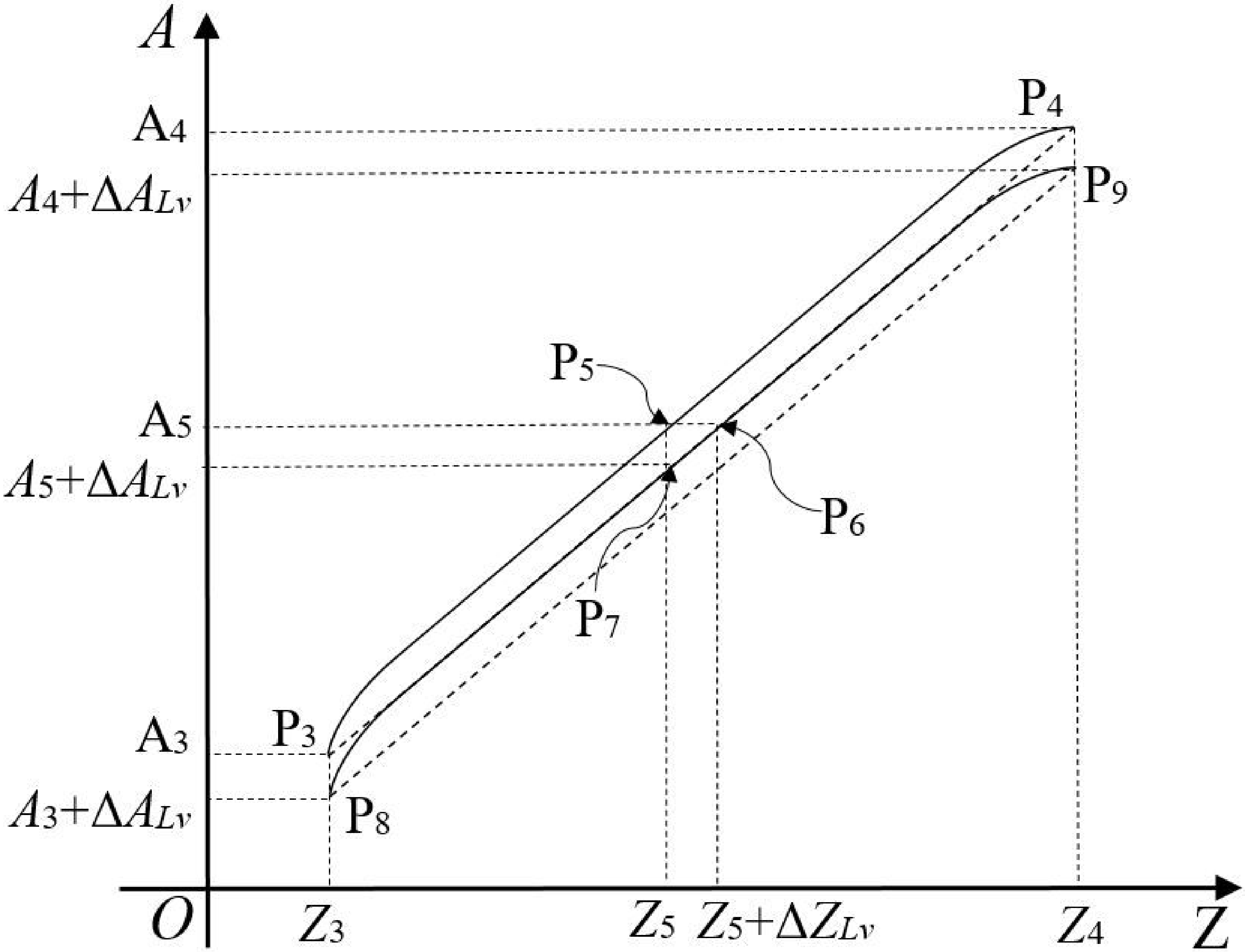

Figure 7

The grinding trail moves down vertically at a distance, ΔALv, along the direction in parallel to A-axis.

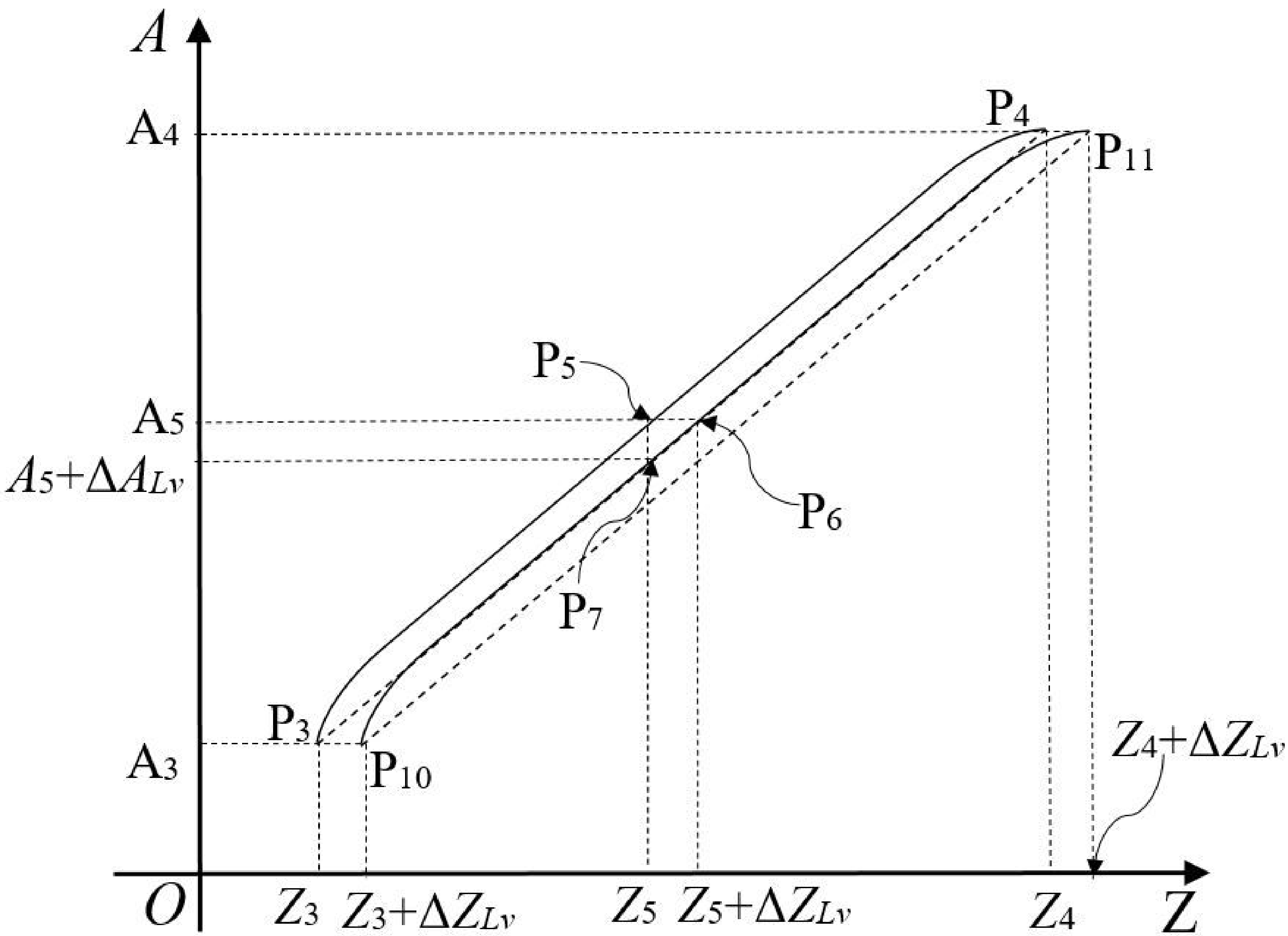

Figure 8

The grinding trail moves right horizontally at a distance ΔZLv along the direction in parallel to Z-axis.