4.10 INVOLUTE INTERPOLATION (G02.2, G03.2)

Involute curve machining can be performed by using involute interpolation. Involute interpolation ensures continuous pulse distribution even in high–speed operation in small blocks, thus enabling smooth and high–speed machining. Furthermore, machining tapes can be created easily and efficiently, reducing the required length of tape.

Format

Involute interpolation on the X–Y plane

G17 G02.2 X__Y__I__J__R__F__ ;
G17 G03.2 X__Y__I__J__R__F__ ;

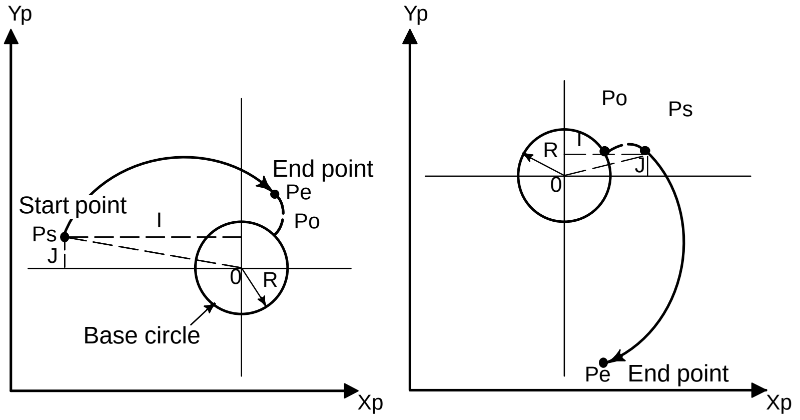
Involute interpolation on the Z–X plane

G18 G02.2 Z__X__K__I__R__F__ ;
G18 G03.2 Z__X__K__I__R__F__ ;

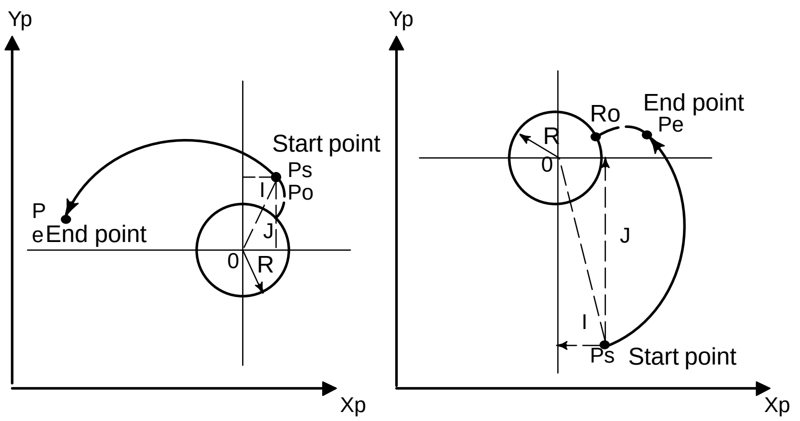
Involute interpolation on the Y–Z plane

G19 G02.2 Y__Z__J__K__R__F__ ;
G19 G03.2 Y__Z__J__K__R__F__ ;

Where,
G02.2 : Involute interpolation (clockwise)
G03.2 : Involute interpolation (counterclockwise)
G17/G18/G19 : X –Y / Z–X / Y–Z plane selection
X, Y, Z : Involute curve end coordinate
I, J, K : Center of the base circle for an involute curve viewed from the start point
R : Base circle radius
F : Cutting feedrate



Clockwise involute interpolation (G02.2)



Counterclockwise involute interpolation (G03.2)

Explanations

• Involute curve

An involute curve on the X–Y plane is defined as follows ;

$X(\theta)=R\,[\cos\theta+(\theta-\theta_0)\sin\theta]+X_0$

$Y(\theta)=R\,[\sin\theta-(\theta-\theta_0)\cos\theta]+Y_0$

where,

X_0 , Y_0 : Coordinates of the center of a base circle

R : Base circle radius

θ_0: Angle of the start point of an involute curve

θ : Angle of the point where a tangent from the current position to the base circle contacts the base circle

$X(\theta)$, $Y(\theta)$: Current position on the X–axis and Y–axis

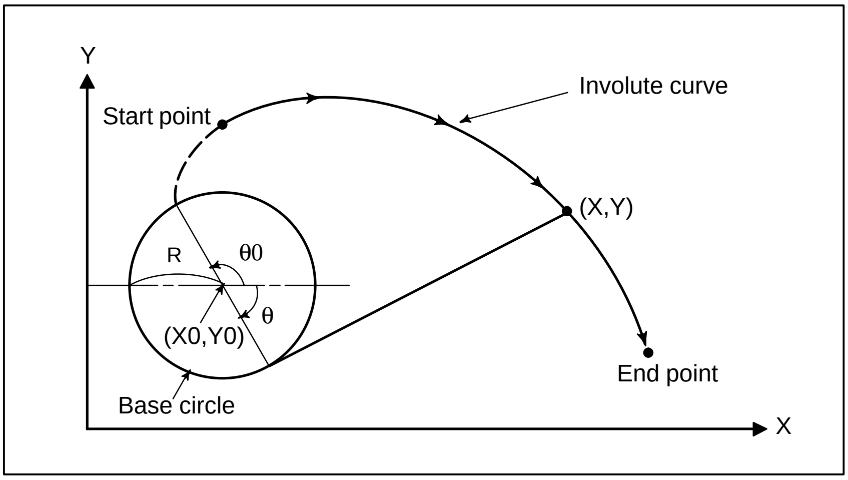


Fig. 4.10 (a) Involute Curve

Involute curves on the Z–X plane and Y–Z plane are defined in the same way as an involute curve on the X–Y plane.

• Start point and end point

The end point of an involute curve is specified using address X, Y, or Z. An absolute value or incremental value is used to specify an X, Y, or Z value. When using an incremental value, specify the coordinates of the end point viewed from the start point of the involute curve.
When no end point is specified, P/S alarm No. 241 is issued.
If the specified start point or end point lies within the base circle, P/S alarm No. 242 is issued. The same alarm is issued if cutter compensation C causes the offset vector to enter the base circle. Be particularly careful when applying an offset to the inside of an involute curve.

• Base circle specification

The center of a base circle is specified with I, J, and K, corresponding to X, Y, and Z. The value following I, J, or K is a vector component defined when the center of the base circle is viewed from the start point of the involute curve; this value must always be specified as an incremental value, regardless of the G90/G91 setting. Assign a sign to I, J, and K according to the direction.
If I, J, and K are all left unspecified, or I0J0K0 is specified, P/S alarm No. 241 or No. 242 is issued.
If R is not specified, or R < 0, P/S alarm No. 241 or No. 242 is issued.

- **Choosing from two types of involute curves**

When only a start point and I, J, and K data are given, two types of involute curves can be created. One type of involute curve extends towards the base circle, and the other extends away from the base circle. When the specified end point is closer to the center of the base circle than the start point, the involute curve extends toward the base circle. In the opposite case, the involute curve extends away from the base circle.

- **Feedrate**

The cutting feedrate specified in an F code is used as the feedrate for involute interpolation. The feedrate along the involute curve (feedrate along the tangent to the involute curve) is controlled to satisfy the specified feedrate.

- **Plane selection**

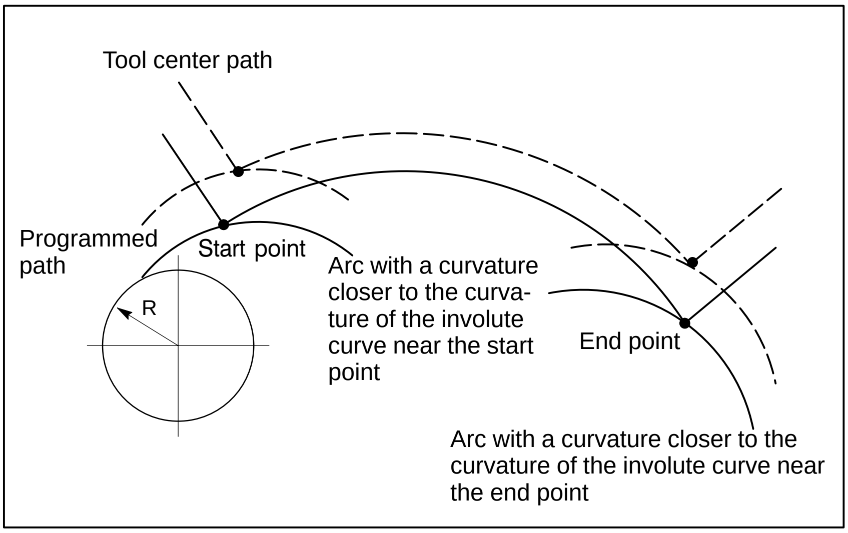
As with circular interpolation, the plane to which to apply involute interpolation can be selected using G17, G18, and G19.

- **Cutter compensation C**

Cutter compensation C can be applied to involute curve machining. As with linear and circular interpolation, G40, G41, and G42 are used to specify cutter compensation.

G40 : Cutter compensation cancel
G41 : Cutter compensation left
G42 : Cutter compensation right

Cutter compensation for an involute curve is implemented as described below.
First, near the start point of an involute curve, an arc with a curvature close to the curvature of the involute curve is found. Next, an offset intersection between the arc and the linear line or arc in the previous block is found. Similarly, an offset intersection is found near the end point. Then, the involute curve passing through the two points is used as the tool center path.
In involute interpolation mode, cutter compensation cannot be started or cancelled.



- **Specifiable G codes**

The following G codes can be specified in involute interpolation mode:

G04 : Dwell
G10 : Data setting
G17 : X–Y plane selection
G18 : Z–X plane selection
G19 : Y–Z plane selection
G65 : Macro call
G66 : Macro modal call
G67 : Macro modal call cancel
G90 : Absolute command
G91 : Incremental command

- **Modes that allow involute interpolation specification**

Involute interpolation can be specified in the following G code modes:

G41 : Cutter compensation left
G42 : Cutter compensation right
G51 : Scaling
G51.1 : Programmable mirror image
G68 : Coordinate rotation

- **End point error**

As shown below the end point may not be located on an involute curve that passes through the start point.
When an involute curve that passes through the start point deviates from the involute curve that passes through the end point by more than the value set in parameter No. 5610, P/S alarm No. 243 is issued.
When there is an end point error, the feedrate is not guaranteed.

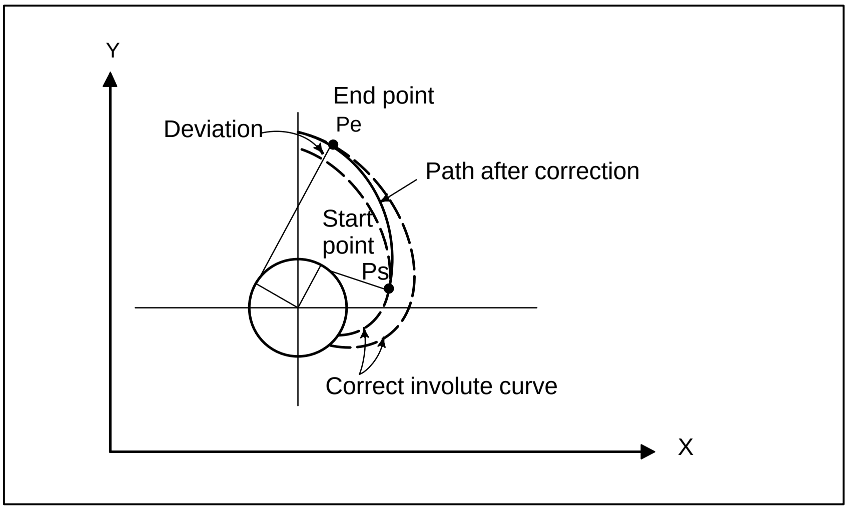


Fig. 4.10 (b) End Point Error in Counterclockwise Involute Interpolation (G03.2)

Limitations

- **Number of involute curve turns**

Both the start point and end point must be within 100 turns from the point where the involute curve starts. An involute curve can be specified to make one or more turns in a single block.
If the specified start point or end point is beyond 100 turns from the point where the involute curve starts, P/S alarm No. 242 is issued.

- **Unspecifiable functions**

In involute interpolation mode, chamfer corner R (with an arbitrary angle), helical cutting, or axis–by–axis scaling functions cannot be specified.

- **Modes that do not allow involute interpolation specification**

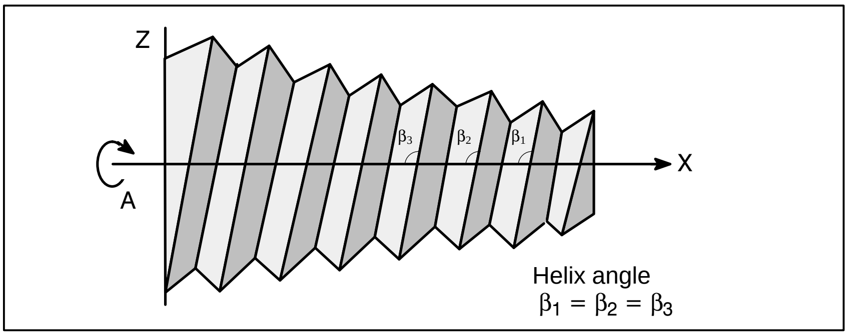
Involute interpolation cannot be used in the following modes:
G41.1 (G151) : Normal direction control left side on
G42.1 (G152) : Normal direction control right side on
G07.1 (G107) : Cylindrical interpolation
G12.1 : Polar coordinate interpolation mode
G16 : Polar coordinates command
G72.1 : Drawing copy

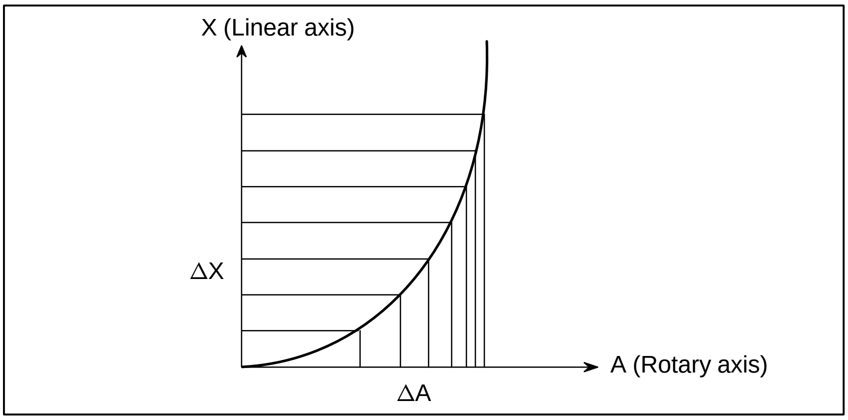
- **Cutting accuracy**

The curvature of an involute curve varies rather sharply near the base circle. In such locations, a larger load is applied to the cutter when the programmed feedrate is used for cutting; in this case, the surface produced may be somewhat uneven

4.11 EXPONENTIAL INTERPOLATION (G02.3, G03.3)

Exponential interpolation exponentially changes the rotation of a workpiece with respect to movement on the rotary axis. Furthermore, exponential interpolation performs linear interpolation with respect to another axis. This enables tapered groove machining with a constant helix angle (constant helix taper machining). This function is best suited for grooving and grinding tools such as end mills.





Format

positive rotation (ω=0)

G02. 3 X__ Y__ Z__ I__ J__ K__ R__ F__ Q__ ;

Negative rotation (ω=1)

G03. 3 X__ Y__ Z__ I__ J__ K__ R__ F__ Q__ ;

X__; Specifies an end point with an absolute or incremental value.
Y__; Specifies an end point with an absolute or incremental value.
Z__; Specifies an end point with an absolute or incremental value.
I__ ; Specifies angl I (from ±1to ±89 deg in units of 0.001deg).
J__ ; Specifies angle J (from ±1 to ±89 degin units of 0.001deg).
K__; Specifies the amount to divide the linear axis for exponential interpolation (span value). Specify a positive value.
When no value is specified, the value specified in parameter (No. 5643) is used.
R__; Specifies constant R for exponential interpolation.
F__; Specifies the initial feedrate.
Specified in the same way as an ordinary F code. Specify a composite feedrate including a feedrate on the rotary axis.
Q__ ; Specifies the feedrate at the end point.
The same unit used for F is used. The CNC internally performs interpolation between the initial feedrate (F) and final feedrate (Q), depending on the travel distance on the linear axis.

Explanations

- **Exponential relational expressions**

Exponential relational expressions for a linear axis and rotary axis are defined as follows:

$$X(\theta)=R \times (e^{\frac{\theta}{k}}-1) \times \frac{1}{\tan(I)} \quad \cdots\cdots\cdots \text{ Movement on the linear axis (1)}$$

$$A(\theta)=(-1)^{\omega} \times 360 \times \frac{\theta}{2\pi} \quad \cdots\cdots\cdots \text{ Movement on the linear axis (2)}$$

Where,

$$K = \frac{\tan(J)}{\tan(I)}$$

ω=0/1 .... Rotation direction

R, I, and J are constants, and θ represents an angle (radian)

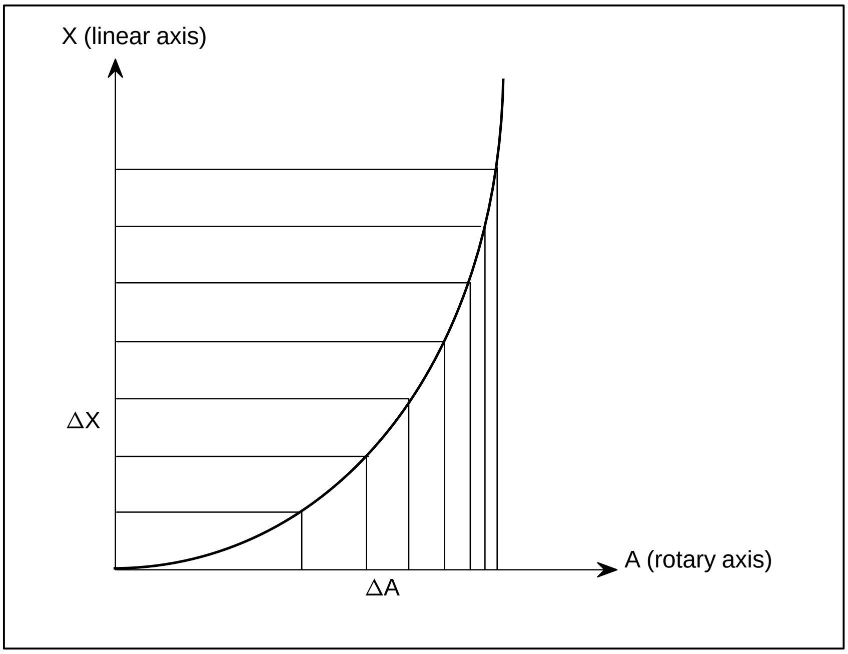
The following is obtained from Expression (1)

$$\theta(X)=K \times \ln(\frac{X \times \tan(I)}{R}+1)$$

When there is movement from X_1 to X_2 on the linear axis, the amount of movement on the rotary axis is determined by :

$$\Delta\theta= K \times \{ \ln(\frac{X_2 \times \tan(I)}{R}+1) - \ln(\frac{X_1 \times \tan(I)}{R}+1)\}$$

Specify Expressions (1) and (2) in the format described earlier.



Limitations

- **Cases where linear interpolation is performed**

Even when the G02.3 or G03.3 mode is set, linear interpolation is performed in the following cases:

- When the linear axis specified in parameter(No. 5641) is not specified, or the amount of movement on the linear axis is 0
- When the rotary axis specified in parameter (No. 5642) is specified
- When the amount for dividing the linear axis (span value) is 0

- **Tool length compensation / cutter compensation**

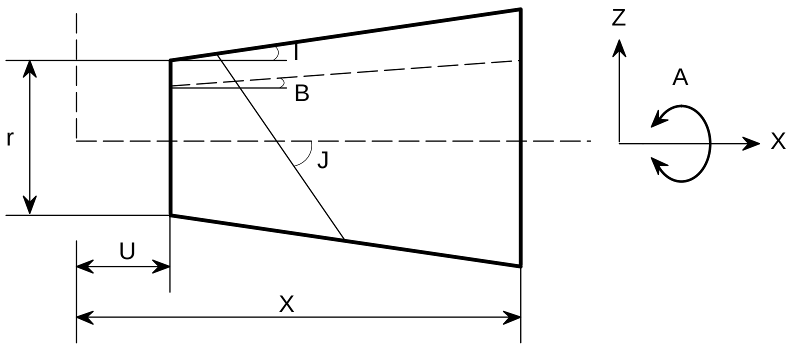
Neither tool length compensation nor cutter compensation can be used in the G02.3 and G03.3 modes.

CAUTION

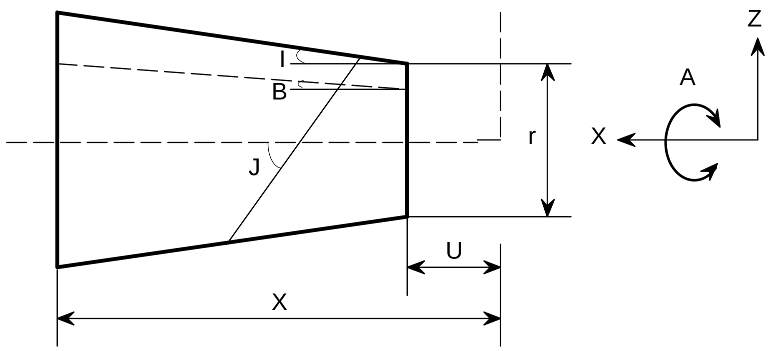
The amount for dividing the linear axis for exponential interpolation (span value) affects figure precision. However, if an excessively small value is set, the machine may stop during interpolation. Try to specify an optimal span value depending on the machine being used.

Examples

Constant helix machining for producing a tapered figure



Constant helix machining for producing a reverse tapered figure



Relational expressions

$$Z(\theta) = \left\{ \frac{r}{2} - U \times \tan(I) \right\} \times \left(e^{\frac{\theta}{k}} - 1\right) \times \frac{\tan(B)}{\tan(I)} + Z(0) \quad \cdots\cdots\cdots \quad (3)$$

$$X(\theta) = \left\{ \frac{r}{2} - U \times \tan(I) \right\} \times \left(e^{\frac{\theta}{k}} - 1\right) \times \frac{1}{\tan(I)} \quad \cdots\cdots\cdots \quad (4)$$

$$A(\theta) = (-1)^{\omega} \times 360 \times \frac{\theta}{2\pi}$$

where

$$K = \frac{\tan(J)}{\tan(I)}$$

X (θ), Z (θ), A (θ) : Absolute value on the X–axis, Z–axis, and A–axis from the origin
r : Left end diameter
U : Excess length
I : Taper angle
B : Groove bottom taper angle
J : Helix angle
X : Amount of movement on the linear axis
ω : Helix direction (0: Positive, 1: Negative)
θ : Workpiece rotation angle

From expressions (3) and (4), the following is obtained ;

$$Z(\theta) = \tan(B) \times X(\theta) + Z(0) \quad \cdots\cdots\cdots \quad (5)$$

The groove bottom taper angle (B) is determined from the end point position on the X–axis and Z–axis according to Expression 5. The amount of movement on the Z–axis is determined from a groove bottom taper angle (B) and X–axis position.

From Expressions (1) and (4), the following is determined:

$$R = r/2 - U \times \tan(I) \quad \cdots\cdots\cdots \quad (6)$$

Constant R is determined from the left end diameter (r) and excess length (U) according to Expression (6). Specify a taper angle (I) in address I, and specify a helix angle (J) in address J. Note, however, that a negative value must be specified as the taper angle (I) for constant helix machining in order to produce a reverse tapered figure. Select a helix direction with G02.3 or G03.3. The user can perform constant helix machining to produce a tapered figure or a reverse tapered figure.