Process method for machining rotor shafts using ESPRIT and MAZAK E670H turning and milling combined machining

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Abstract: This article takes the rotor shaft of the GE1000T internal mixer as an example, dissecting the external structure, machining characteristics, dimensions, and geometric elements of the part, and carrying out the design of the overall process flow. It focuses on the design of the finishing process on the turning and milling compound equipment, comprehensively analyzing the semi-finishing turning reserved blank, positioning clamping, tool selection, machining parameters, tool path trajectory, the use of center frame and tip attachment, NC code, and other contents. The optimization design of each step in the turning and milling compound finishing process is carried out, especially focusing on the difficulties encountered during the machining process, such as the control of finishing turning dimensions and roughness, deep hole drilling methods, etc. At the same time, the exploration of the MAZAK E670H 6000U equipment and ESPRIT software, as well as the method of combining software and hardware, is conducted.

Key words: rotor shaft; turning and milling; MAZAK; ESPRIT; turning; deep hole drilling

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0 Preface

Currently, domestic turning and milling compound equipment, especially large-scale ones, has not yet become widespread in the rubber and plastic equipment field. Our company is the first to use turning and milling compound equipment in this field. The MAZAK E670H 6000U-6 m and 4000U-4 m, 7-axis 5-link turning and milling compound machine tools we use, integrate functions such as turning, milling, drilling, boring, and long boring bars, shortening the product manufacturing process chain and improving production efficiency; reducing the number of clamping operations and enhancing machining accuracy. At the same time, they have an online detection function that allows precise control of dimensions. They are mainly used for machining rotor shafts, rotor bodies, conical screws, and other disc-type and shaft-type components, as well as components with complex curved surfaces.

The rotor shaft is the core component of the internal mixer, being the largest and most precisely required shaft-type part in the mixer equipment. Currently, our company has developed the GE1000T meshing internal mixer, which is the largest model of internal mixer in China. Its rotor shaft is 4 meters long, with a diameter of 520 mm, and a gross weight of approximately 5 tons, making it a large-scale shaft-type part. In the past, the manufacturing of the rotor shaft involved multiple processes such as turning, grinding, scribing, and drilling, which were relatively scattered and required a long manufacturing process chain.

Large-scale turning and milling compound machining is rarely applied domestically, especially in the internal mixer

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industry, where there is no processing experience to draw upon. This article takes the rotor shaft of the GE1000T, the largest internal mixer in China, as an example to study the processing flow of the turning and milling finishing process. It explores and analyzes the turning and milling compound machining technology for processing large shafts by combining MAZAK and ESPRIT, hardware and software.

1 Machine tool structure

The equipment, MAZAK E670H-6000U, boasts 7 axes, including X, Y, Z, B, C, W, and V, and features a five-axis linkage function. Its dimensions are X1025 mm, Y670 mm, and Z6170 mm. It is equipped with a 24" hydraulic chuck, a center frame ranging from 350 to 700, a high-thrust center, capable of supporting up to 7 t of load, and a high-torque, high-performance spindle. The main spindle has a power of 45 kW, while the milling spindle boasts 37 kW.

Figure 1 MAZAK machine tool structure

Equipped with the LBB long boring bar system as shown in Figure 2, it utilizes a Sandvik shock-absorbing boring bar with a length of 1.8 m, an internal length of 0.5 m, and a boring length of 1.3 m.

2 Part structure

The GE1000T rotor shaft, as depicted in Figure 3, is constructed from 45 steel. It has a tempered hardness of HB220-260, measures 4,000 mm in length, and has a maximum diameter of 520 mm. The main constituent features of the part include radial elements such as an outer circle, square slot, relief groove, circular arc slot, trapezoidal external threads (left-hand and right-hand), metric external threads, a D10 oil filling hole, a D60 water outlet hole, and dual key slots. Axial features include a D15 oil filling hole, RC3/4 threads, deep holes of D95-1.5 m and D80-2.5 m, blind holes D110 on both ends, M48 lifting holes, and M10 threaded holes. The roughness is Ra1.6.

Figure 2 LBB long boring bar

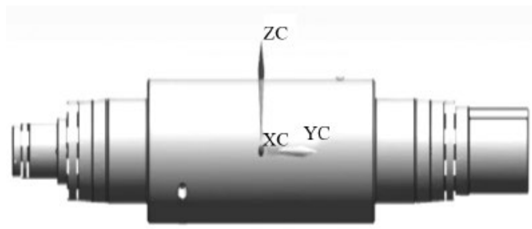

Figure 3 3D model of part structure

3 Processing difficulties

3.1 Dimensional control

The external cylindrical dimensional tolerance is 0.03, the geometric tolerance for coaxiality is 0.03, the roundness is 0.02, and the runout is 0.02. To effectively control various dimensions and geometric tolerances, it is necessary to eliminate all turning steps at the clamping end in one go.

3.2 Roughness control

The roughness of the entire shaft is Ra1.6, ensuring uniformity, stability, and consistency of the roughness.

3.3 Tool selection

The part that mates with the rotor body has a length of 2,000 mm and a diameter of 520 mm. Since it is a mating dimension, it needs to be turned in one operation. According to the high-speed turning requirements of VC250, it takes 1.5 to 2 hours, and the wear must be controlled between 0.01 and 0.02, placing extremely high demands on the cutting tool.

3.4 Deep hole machining

D15, depth of 800 mm, 55-fold deep hole machining.

4 Process design

The process design is shown in Table 6.

The semi-finishing process of operation 6 is completed on a general-purpose lathe, mainly to remove the black oxide layer after tempering. The two end faces are machined to a size of 4000 mm, with accurate machining allowance reserved for finishing. The process holes for blocking plates on both ends and M48 lifting holes are machined.

Here we focus on explaining the advantages of process 6 on the general-purpose lathe. Although turning and milling possess relatively strong processing capabilities, in practical applications, it is still necessary to comprehensively consider the requirements of the product to avoid excessive concentration of processes.

(1) Machine tool

Taking a medium-sized rotor shaft as an example, with a length of 3.5 meters and a diameter of 350, after tempering, the middle section of the shaft may exhibit bending, with the maximum bending reaching 3~5 mm. The turning and milling process utilizes a 24" hydraulic three-jaw chuck, which cannot be adjusted. On the other hand, the 4-jaw chuck used on the general-purpose lathe is easier to adjust.

(2) Production cost

Performing semi-finishing machining on the general-purpose machine to remove the black layer after tempering is more beneficial for machining on the turn-milling compound machine, reducing machine and tool wear; some non-critical dimensions can be machined here to reduce operations on the turn-milling compound machine and avoid excessive concentration of work steps.

(3) Drilling deep holes after semi-finishing is better than drilling deep holes after finishing, as it avoids scratching the surface of the part during the transfer process.

(4) Process 9 can be processed on a floor boring machine, but the efficiency will be lower. This is a matter of capacity balancing.

Table 1 Process Design

Process	Process Content	Process Resources
1	forging	open die forging
2	normalizing	trolley furnace, 380 degrees
3	rough turning	Ordinary car
4	quenching and tempering	pit furnace, 840 degrees, HB220~250.
5	ultrasonic flaw detection	ultrasonic flaw detector
6	semi-finishing lathe	ordinary car
7	deep hole drilling	drilling machine
8	finish turning	turn-milling
9	drilling	floor boring

5 Semi-finished rough castings after fine machining

The blank after semi-finishing turning is shown in Figure 4, with the flat end face dimensions in place. The two ends of the blank are provided with blocking plate holes and M48 lifting holes. Since we use Sandvik CNMG120408-PR 4425, which is a 12HP high-pressure internal cooling tool, a single-sided cutting depth of 3 mm is required to ensure good chip breaking capability. Therefore, in process 6, a single-sided allowance of 3 mm is ensured, mainly considering the tool used to ensure good chip breaking.

Figure 4 Semi-finished product after semi-finishing turning

6 Positioning and installation

A brief introduction is given to the components required for positioning and installation, such as the chuck, center frame, and center point, as shown in Figure 5.

6.1 Soft gripper

Soft jaws can maximize the repeatability of workpiece positioning accuracy, ensuring that the centerline of the machined workpiece can fully coincide with the centerline of the spindle. Most importantly, the software can achieve maximum fit with the surface of the workpiece, which not only ensures the transmission of greater torque but also avoids damage to the workpiece during clamping. Soft jaws are used for axle parts with high machining requirements, while hard jaws are used for rotor body parts in milling.

6.2 Setting parameters

Taking a 5-ton part as an example, it involves a clamping force of 3 MPa from the 24 hydraulic chuck, a clamping force of 2 MPa from the center frame, and a thrust force of 5 MPa from the center. The maximum thrust force of this machine is 7 MPa, and when processing a part weighing approximately 7 tons, it corresponds to approximately 1 MPa=1 ton.

6.3 Installation of blocking plate

Install the process blind plate on the right end of the rotor

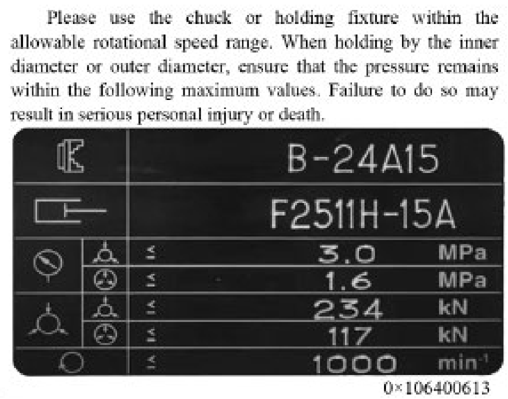

Figure 5 Setup diagram

shaft as required.

6.4 Part hoisting

Lift the parts according to the requirements, and pay attention to safety as they are relatively heavy.

6.5 Record top position

Use M841 to record the top zero position. After the workpiece is installed and the top is properly positioned, use M842 to record this position.

7 Cutting tools

Only a brief explanation will be provided for precision turning tools, trapezoidal thread turning tools, and gun drills. Multiple manufacturers of precision turning tools have been tested (see Table 2), and comprehensive factors such as turning quality and stability, chip breaking ability, and cost should be considered. This article only uses Sandvik 4415 carbide and Kyocera PV720 ceramic, and the tests were conducted only under specific conditions for reference purposes only.

7.1 Fine turning tool

Processing parameters: The test conditions are uniformly set at vc=200 and 250, fn=0.12 mm/r, and ap=0.3 mm. The linear speed for Sandvik should be 250 m/min, and it should be maintained at least above 200 m/min. For Kyocera, both 200 and 250 m/min are acceptable.

(1) Tool geometric angle: For C-type 80-degree tools, only 04 round corner options are available. 08 will produce chatter marks. Both Sandvik CNMG120404-WF4415 and CNMG120404-WP PV720 are suitable. However, for long-term cutting, Sandvik can meet the lifespan requirements. Overall, D-type 55-degree tools are also an option, offering lighter and faster turning.

(2) Tool fillet: R0.4 or R0.8. If using a C80 degree tool, R0.4 is more suitable, as R0.8 is prone to generating chatter marks. Sandvik's CNMG120404-WF 4415 material has a longer processing lifespan; when machining the mating end, continuous turning for 1.5 to 2 hours results in stable dimensions. For the D series with a 55 degree angle, the 04 fillet can be used, such as Sandvik's DNMX150604-WF 4415.

(3) Chip breaking capability: Under high-pressure M103 conditions, Kyocera's WP groove type exhibits strong chip breaking capability, producing flaky and very short iron chips.

(4) Processing Lifespan: Sandvik 4415 material boasts a longer processing lifespan, capable of turning 4~5 meters. Sandvik is the top choice for turning carbon steel.

Table 2 Roughing and finishing tools

Rough turning		
knife handle	C8-391.02-63080B	Sandvik
tool holder	C6-PCLNL-45065-12HP	Sandvik
blade	CNMG120408-PR 4425	Sandvik
finish turning		
knife handle	C8-391.02-63080B	Sandvik
tool holder	C6-PCLNL-45065-12HP	Sandvik
blade	CNMG120404-WF 4415	Sandvik
blade	CNMG120404-WP PV720	Kyocera
knife handle	C8-391.02-63080B	Sandvik
tool holder	C6-PDJNL-45065-15HP	Sandvik
blade	DNMX150604-WF 4415	Sandvik

Table 3 Gun drill and trapezoidal thread

Gun drill		
knife handle	CA80-XP16-80.0R	ISCAR
tool holder	GD-DH 15.00-800-23	ISCAR
blade	TOGT 070304-DT IC908	ISCAR
guide strip	GPS-05-18-060-DC IC908	ISCAR
trapezoidal thread		
knife handle	CA80-SEL-55080-22T	Sentai Yingge
blade	4EL 6.0 TR VTX	VARQUS

7.2 Gun drill

It is recommended to use indexable gun drills as shown in Table 3, which are suitable for high-feed machining with a higher feed rate than brazed gun drills. The indexable insert system significantly reduces tool management costs, eliminating the need for re-sharpening the drill bit. The use of indexable gun drills facilitates the use and operation for workers.

(1) Trapezoidal thread: Using the VARGUS VRX series, higher linear speeds can be achieved, enhancing machining efficiency. When turning P6 threads, employing radial cutting can produce threads of superior quality.

Table 4 lists the tool types required for each step, the custom names of the tools, and brief information about the processing content of each tool. Due to the vast amount of brand information, specific brands are not mentioned.

Table 4 Tool for working steps

Number	Type	Name	Remarks
T1	External cylindrical turning tool	CNMG120408	rough turning
T2	External cylindrical turning tool	DNMX150604	finish turning
T3	External circular groove cutter	6R0.2	Outer circular groove of the car
T4	External cylindrical slot cutter	R2.5	Outer circular groove of the car
T5	Thread turning tool	Trapezoidal thread P6	thread turning
T6	drilling	D60U drill	Drill a water hole
T7	drilling	D15 alloy drill bit	Pre-drilling
T8	drilling	D15 gun drill	Gun drill
T9	drilling	D24.5U drill	Drill the bottom hole
T10	End mill	D10 alloy	Pre-drilling and spot-facing
T11	drilling	D10 gun drill	Gun drill
T12	Thread cutter	Rc3/4	tapping
T13	Thread turning tool	M3	thread turning
T14	drilling	Step drill bit	drilling
T15	drilling	D8.5 alloy drill bit	drilling
T16	Tapping	M10 tap	Tapping
T17	Face milling cutter	D63R6	Rough milling of keyway
T18	End mill	D32 blade	Corner clearance key slot
T19	End mill	D20 alloy	Fine milling of key slot
T20	drilling	D20-60 degrees	Repair the central hole

8 Process design

Table 5 lists the process sequence of each step in the combined turning and milling finishing process, along with a brief description of each procedure. From the design of the entire process route, it can be seen that the combined turning and milling process completes 90% of the machining content in a single setup, which not only has high machining efficiency but also effectively guarantees the accuracy of various dimensions and positional shapes. This fully leverages the advantages of combined turning and milling, allowing for flexible adjustments to the process and related process resources according to actual needs. This article is for reference only.

Next, we will conduct a simple process breakdown of some issues that should be noted during certain procedures in processing.

8.1 OP1 installation

As shown in Figure 6, after installing the parts, set the position of M842, with G54 set on the right end face of the part. Use a Renishaw probe to measure the machining origin of the part, and set up the coordinate axes on the machine tool.

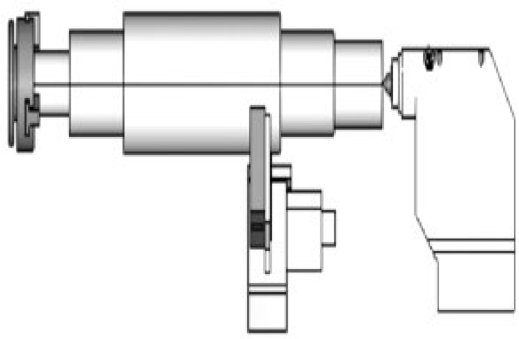

Figure 6 Installation

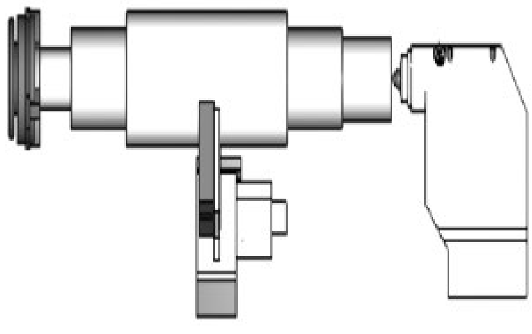

Figure 7 Center frame position

8.2 OP3 center frame position

The position of the center frame should be placed in the middle of the shaft as shown in Figure 7. A roughness of Ra1.6 for the frame position is good. Soft material should be added on top of the center frame for protection as shown in Figure 8, because during rough turning, the iron chips are in block form,

Table 5 Work Step Design

Operation Step	Content
First Clamping	
OP1	One clamp and one support, clamp the small head and support the large head, with the coordinate system G54 on the right end face.
OP2	The maximum external diameter of the rough turning is D520.6, with a roughness of Ra1.6, and it is the position for the center frame.
OP3	Place the mobile center frame in the middle of D520.
OP4	Roughly machine the outer circumference of each part, with a radial allowance of 0.3 and an end face allowance of 0.1.
OP5	Fine-turn the outer circle and each part of the 1:12 conical surface, with a surface roughness of Ra1.6.
OP6	Fine turning of square groove and relief groove.
OP7	Dynamic precision turning of R6 circular arc groove.
OP8	The trapezoidal thread P6 of the vehicle, with both left-hand and right-hand threads.
OP9	Move the central frame to D380.
OP10	The maximum external diameter of the precision-turned part is D520.
OP11	Retreat to the original point M841.
OP12	Pre-drill a D15 bottom hole, with a pilot hole depth of 1.5D.
OP13	Gun drill D15 hole, depth 800 mm.
OP14	Drill a hole of D24.5.
OP15	Tap thread Rc3/4.
OP16	Spot face the D10 hole to ensure the guiding depth.
OP17	Gun drill D10 hole.
OP18	Roll back the top to M842.
OP19	Place the mobile center frame in the middle of D520.
OP20	Drill a water channel hole D60 with a depth of 250 mm.
OP21	Loosen the center frame.
OP22	Lifting, returning the top point to zero, and unloading the load.
Second Clamping	
OP23	One clamp and one support, clamp the larger head and support the smaller head, with the coordinate system G54 on the right end face.
OP24	When measuring with a dial gauge, if the runout is less than 0.02, it is considered unqualified. Repair the top hole.
OP25	Move the central frame to D380.
OP26	Roughly machine the outer circumference of each part, with a radial allowance of 0.3 and an end face allowance of 0.1.
OP27	Vehicle retractable knife slot.
OP28	Fine machine all external circles, Ra1.6.
OP29	Thread M200×3.
OP30	Ladder drill, Rc3/4 bottom hole and D15 gun drill bottom hole.
OP31	Drill D15 hole.
OP32	Tap thread Rc3/4.
OP33	Spot face the D10 hole to ensure the guiding depth.
OP34	Gun drill D10 hole.
OP35	Drill a bottom hole from M10 to D8.5
OP36	Tap thread M10.
OP37	Loosen the center frame.
OP38	Lifting, returning the top point to zero, and unloading the load.

and whether moving from left to right or from right to left, the iron chips flow towards the middle. They are prone to jumping into the center frame rollers, causing damage to both the center frame and the parts. To effectively solve this problem, a magnet is used to attract the iron chips to the left and right surfaces of the center frame.

8.3 OP4 rough turning

The radial allowance for rough turning is 0.3, and the end face allowance is 0.1. It is not advisable to leave too much end face allowance; 0.1 is more appropriate. Because we are using Sandvik CNMG120408, with an Ap of more than 3 mm, which can ensure good chip breaking. In the CAM software, the machining depth should be optimized to ensure equal spacing, and rough turning should ensure good chip breaking.

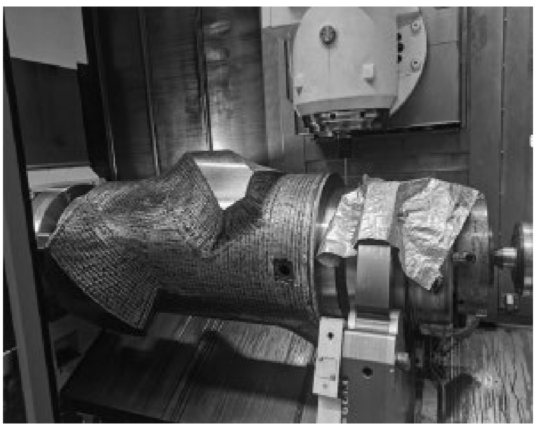

Figure 8 Actual photo of the protection site, showing the precision milling of the rotor body.

8.4 OP5 finish turning

Fine-tune each external circle, setting the rotational speed to CCS. Given the multitude of rotor shaft models, setting the linear speed and maximum rotational speed can save programming time and eliminate the need for extensive calculations. Of course, nowadays, automated programming is prevalent, especially for such high-end equipment. It is also feasible to automatically calculate the speed for each part, depending on individual needs and preferences.

G92 S250 R1

G96 S200 P1 R1 M204

Fine-tune each conical surface, set the rotational speed to RPM, and maintain a constant speed.

G97 S200 R1 M204

Due to the milling of small diameters, a relatively high rotational speed is required. The MAZAK equipment has two speed settings: M238 for diameters smaller than S320 and M239 for diameters larger than S320, which control the rotational speed settings.

8.5 OP6 dynamic turning

Using the Profit dynamic turning and cycloidal turning methods in ESPRIT, turning slots can save 50% of the time, with smoother machining of curved movements and reduced tool wear.

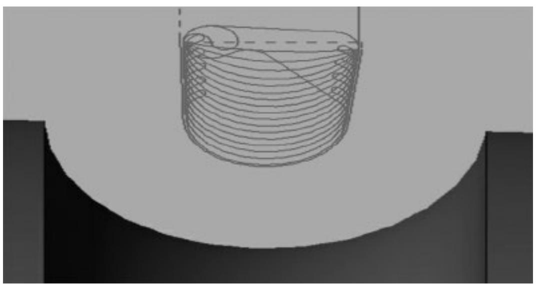

Figure 9 Dynamic turning tool path

8.6 Gun drill

In the past, a guide bushing was used for guiding the gun drill during machining. Nowadays, in the application of machining centers, a guide hole is used instead of a guide bushing, as shown in Figure 10. The diameter of the pre-drilled guide hole is slightly larger than the basic size of the gun drill, and its length is approximately 1.5 times the diameter. This allows the gun drill, which enters the machining state later, to use the guide hole as a guide bushing. The cooperation between the guide bar on the gun drill and the guide bar of the guide hole ensures the linear feed of the gun drill.

Insufficient length of the pilot hole can easily cause gun drill deflection, vibration, or even breakage. Both too large and too small a pilot hole make it difficult to form an oil film between the guide bar and the pilot hole, which can easily lead to wear of the guide bar.

In this document, the D15 hole, with a length of 800 mm, is pre-drilled using a D15 alloy drill bit, D15 (+0.015 to 0.04), with a drilling depth of 1.5D=22.5.

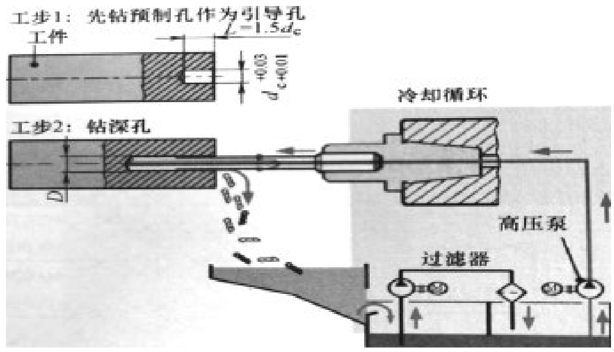

Figure 10 Using gun drill on turn-milling compound

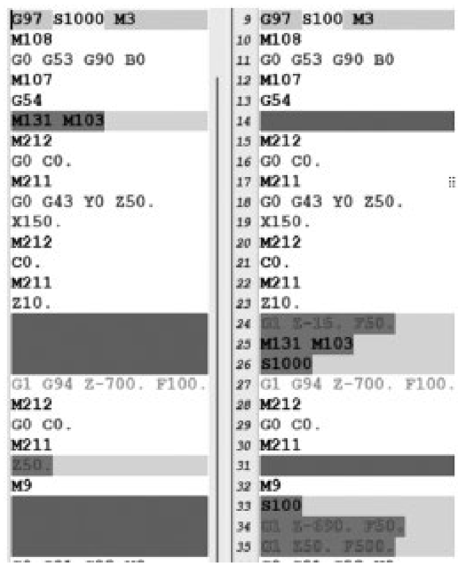

Figure 11 Using gun drill on turn-milling compound

Diameter range D/mm	Guide hole limit deviation /mm	The hole depth is approximately 10D	The hole depth is approximately 20D	The hole depth is approximately 25D	The hole depth is approximately 30D	The hole depth is approximately 35D	The hole depth is approximately 40D
		Guide hole depth L					
1.85-4.00	+0.010 +0.005	2D	3D	4D	6D	30mm	
>4.00-8.50	+0.020	1D	1.5D	2D	3D	35mm	
>8.50-12.00	+0.010	1D	1.5D	2D	3D		
>12.00-21.00		1D	1.5D				
21.00-31.00	+0.040	1D					
31.00-41.00	+0.015	1D					
41.00-51.00		1D					

Figure 12 Gun drill pre-drilling

Before the gun drill enters the guide hole, turn off the cutting fluid, and enter the guide hole at a lower speed and feed. When it is 1~2 mm away from the bottom of the hole, set the speed and feed to normal values for machining, turn on high-pressure internal cooling, and after drilling, turn off the cutting fluid and retract the tool. The basic action code is shown in Figure 11.

The requirements for the original cycle and the gun drill cycle are different.Some standard requirements for gun drill pre-drilling are shown in Figure 12. Based on this table, adjustments can be made according to actual needs.

9 Processing parameters

Table 6 lists the linear speed and feed per revolution or feed per tooth of the cutting tool. These values are based on the rotor shaft material being 45 steel, with a tempering HB220~250, a maximum outer diameter of D520 mm, and a length of 4,000 mm. Due to potential differences in cutting tools and machining conditions, the machining parameters are for reference only.

Table 6 Processing parameters

Number	Name	Vc	F
T1	CNMG120408-PR	200	0.3
T2	DNMX150608-WF	250	0.12
T2	DNMG150608-PP	250	0.12
T3	6R0.2	100	0.3
T4	R2.5	100	0.1
T5	trapezoidal thread P6	100	6
T6	D60U drill	150	0.15
T7	D15 alloy drill bit	80	0.1
T8	D15 gun drill	80	0.05
T9	D24.5U drill	120	0.1
T10	D10 alloy	50	0.05
T11	D10 gun drill	50	0.05
T12	Rc3/4		

Rotors are classified into shaft-through and integral types. When machining an integral rotor, the axle, due to the irregular surface of the rotor body, generates significant centrifugal force during turning. Depending on the actual situation, it is necessary to appropriately reduce the linear velocity to around Vc150-200.

10 Software, hardware and NC

10.1 Tool setting

Turning tools are divided into left-hand, right-hand, and center-mounted types. Our tools are uniformly left-hand tools. ID code A corresponds to T01.01, with the indexing angle standard facing the operator, enabling turning from right to left; B corresponds to T01.02, with the indexing angle reversed, facing away from the operator, enabling turning from left to right.

Figure 13 T01.01

Figure 14 T01.02

10.2 Thread machining

The following code represents the basic format of the thread cycle for MAZAK. The table details the control methods for the tool handle hand position and direction when machining trapezoidal and metric external threads. The code below is for machining right-hand threads using the same tool. It can be derived to obtain the directions for machining left-hand threads, right-hand threads, and for right-handed tools machining both left-hand and right-hand threads.

```
T28.01
G97 S80 R1
G0 G43 P1 Z-200.
G276 P020030 Q.1 R.1
G276 X300. Z-100. P3.5 Q.3 F6.
T28.02
G97 S80 R1
G0 G43 P1 Z-100.
G276 P020030 Q.1 R.05
G276 X300. Z-200. P3.5 Q.3 F6.
```

Table 7 Threads

Knife handle grip	Direction	Dextro-R	Levo-L
left	T28.01	> →	> ←
left	T28.02	> ←	> →
Trapezoidal Thread	Metric Thread		
Thread Pitch F	Thread Depth P	Thread Pitch F	Thread Depth *P*
4	2.25	2	1.3
5	2.75	3	1.95
6	3.5		

Trapezoidal thread: thread depth $P=0.5F+ac$; P=1.5~5ac=0.25; P=6~12 ac=0.5; P=14~44 ac=1

Metric thread: thread depth $P=0.65F$.

10.3 Cooling system

High-pressure cooling involves increasing the pressure of the cutting fluid to a specific level, allowing it to precisely reach the cutting area through internal cutting fluid channels for rapid cooling. The use of high-pressure cooling for turning tools, U-drills, and gun drills can achieve good results, as shown in Table 8. Of course, tool materials such as ceramic milling cutters and CBN are not suitable for using cutting fluid.

(1) In terms of cooling effect, high-pressure cooling technology involves precisely and quantitatively spraying coolant directly onto the cutting area of the blade using high pressure, thereby maximally removing heat from the cutting area and achieving rapid cooling.

(2) In terms of chip control ability, high-pressure cooling not only effectively reduces cutting heat but also increases cutting brittleness, making it easier to break.

(3) From the perspective of tool life, high-pressure cooling reduces tool wear and extends tool service life. Generally, increasing the cutting speed will exacerbate tool wear, but by increasing the feed rate after applying high-pressure cooling, the shortening of tool life is not as significant.

(4) The pressure for high-pressure cooling can be set in ESPRIT. Use M131 M100 or M131 K650 to control the pressure. Generally, using the middle section M103 is sufficient.

Table 8 High-pressure cooling control

User-defined	M code
< 400	M100
< 500	M101
< 700	M102
< 800	M103
< 900	M104
< 1 000	M105
⩾ 1 000	M106

10.4 Dimensional control

(1) In CAM software such as ESPRIT, for settings with precision dimension requirements, use the mid-range value. For those without precision dimensions, set it to 0.

(2) During the actual machining process, dimensions without tolerance and with lower requirements are taken. After machining, the dimensions are measured, and the value obtained by subtracting the measured dimensions from the programmed dimensions is compensated within the machine tool. If there are precision requirements for the trial cutting part, the CNC program should be modified or the trial cutting should be performed after compensation within the machine tool. After the trial cutting, wear compensation should be performed, as shown in Figure 15.

(3) After processing the two ends, before processing the middle section, change the cutting blade and repeat the second step.

Figure 15 Compensation Settings

10.5 Processing site

Figure 16 shows the GE1000T at the processing site.

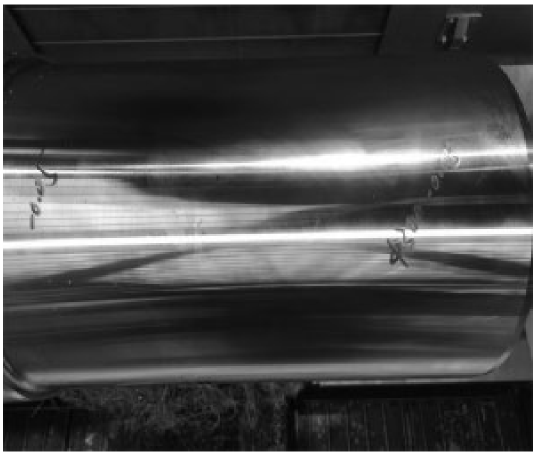
Figure 16 Processing site

Figure 17 shows partial measurements of the GE1000T shaft. The outer diameter dimensions are stable. Using a handheld roughness measuring instrument calibrated with a standard template, the roughness of the rotor shaft can be measured to be Ra0.8~1.0.

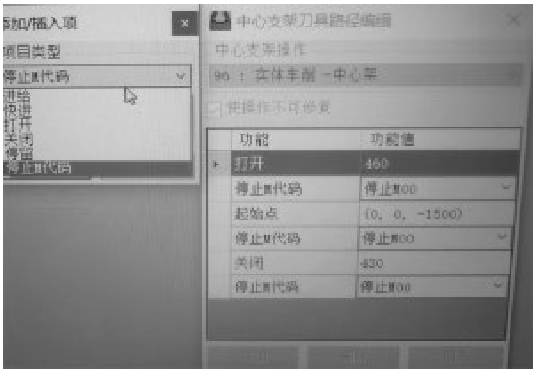

Figure 17 Processing site

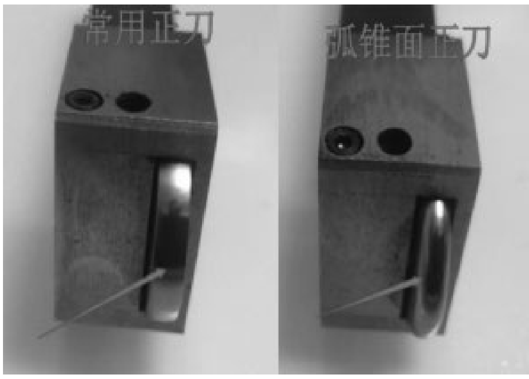

Figure 18 Center frame command setting

10.6 Center frame and tailstock control

(1) Center frame

The MAZAK E670H-4000U center frame has a clamping range of D135-D460, while the MAZAK E670H-6000U center frame has a clamping range of D350-D700. Parts processing should be arranged reasonably according to the clamping range, as shown in Figure 18.

N1 (Solid turning - Center frame)

G90

M286: Disconnection of cutting fluid for the center frame

M292 Release the center frame

M0

V-1500. Center frame position V-1500

M0

M285 Connect the center frame cutting fluid

M293 Center frame clamping

M0

(2) Tailstock

See Table 9 for tailstock thrust control.

M841 tailstock positioning "Position 1" is set to the "Tailstock Position 1" entered in the setting data.

M842 tailstock positioning "position 2" is set to the "tailstock position 2" entered in the setting data.

M831 tail thrust command, specifying the tail thrust.

Table 9 Tailstock thrust control

Tailstock thrust/KN	Tailstock thrust M-Code
2.0	M831
3.0	M832
4.0	M833
5.0	M834
6.0	M835
7.0	M836

10.7 Use of rolling process

Although we have achieved "using turning instead of grinding" for large shafts through turning, in order to more reliably control the roughness, we have added a rolling process to further enhance the roughness.

Figure 19 Form of rolling tool

(1) Selection of rolling tools

There are many types of rolling tools, as shown in Figure 19. Commonly seen are diamond and carbide rolling wheels. So how to choose for such large parts? For those with very long rolling times, such as rotor shafts, diamond rolling is prone to carbonization over time, so carbide rolling wheels are recommended.

(2) Rolling parameters

After some experimentation and manufacturer recommendations, and of course, considering economic costs, we chose a domestic brand, costing around 3,000 yuan. Imported ones would cost 15,000 to 20,000 yuan. The process parameters refer to domestic rolling cutter products. For this material, after multiple tests, for HB220-260 tempered steel, the linear speed is 50 m/min, the compression amount is 0.2~0.3

mm, and the feed rate is 0.3 mm per revolution.

11 Conclusion

Taking the GE1000T rotor shaft as an example, this article designs a complete machining process route, formulates a combined turning and milling process, clamping scheme, and tool selection, uses ESPRIT programming, and processes with MAZAK E670H 6000U. After optimizing various process parameters and tools, it has achieved good results in mass production. The multiple processes of turning, milling, drilling, boring, and scribing, which were previously completed in separate stations, are now completed in one station. This achieves the goal of using turning to replace grinding and difficult-to-machine processes such as deep-hole drilling, saving a lot of manpower and material resources, improving production efficiency, reducing manufacturing costs, and increasing rotor shaft machining efficiency by 100% and deep-hole drilling efficiency by 500%. This meets the requirements of mass production of rotor shafts, indicating that combined turning and milling machining can shorten the process chain, reduce machining cycles, and reduce equipment occupation. It is the trend of future CNC machining.

There are still few combined turning and milling equipment, and there is a scarcity of information and reference experiences for niche fields or product processing. It is necessary to start research and exploration from scratch, addressing various issues encountered during processing. Based on extensive testing, the application of this process technology meets the requirements for processing rotor shafts of all mixer models, providing a valuable reference for future processing of similar shaft components.