

# RESEARCH ON KEY PROCESS TECHNOLOGY FOR PROFILE ELECTROLYTIC FINISHING OF LARGE MARINE PROPELLER IMPELLER

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## ABSTRACT

*An electrolysis process method for free-form blade surface finishing is proposed for a free-form surface impeller, and a stepwise method is used to process the inter-blade channel of the overall impeller. The forming cathode is then used to finish the blade to meet the blade processing requirements. In the design, the forming cathode structure was improved by using motion simulation software, and the flow field simulation software was used to simulate and analyze the cathode flow channel. The cathode shape and the electrolyte flow rate between the electrodes meet the processing requirements. In the process of processing experiments, the motion path of the cathode was analyzed and optimized. The effect of the feed direction on the uneven distribution of the blade machining gap was reduced through optimization, and high-frequency pulse power processing was used to reduce the machining gap and improve the machining accuracy of the blade. The experimental results show that the process scheme is feasible and the precision of the processed impeller free-form surface is significantly improved. The material is a monolithic turbine disk of high-temperature alloys, and its large twisted blade processing has always been a problem in the manufacturing industry.*

**Keywords:** Integral impeller; Electrolysis processing; Blade

## INTRODUCTION

In order to improve the precision of the overall impeller electro-chemical machining, it is planned to use the electrolytic machining method combined with numerical control and forming cathode copy forming to perform free-form surface impeller blade finishing. The combined electrolytic machining method divides the blade machining of the integral impeller into two basic steps of the inter-leaf path machining and the blade surface finishing. In the process of process design, digital manufacturing technology is used to solve the problems of cathode design, parameter selection and machining path in the process of free-form surface impeller blade [1, 2, 3]. In the design of electrolytic machining device for blade finishing, the structural forms that can be considered are open and closed. The closed structure uses a sealed chamber to form a closed electrolyte flow interval. Through the construction of the closed space to control the direction of flow of the electrolyte, so that the electrolyte flow according to the design of the path, the

pressure of the import and export is easy to control [4, 5, 6]. Due to the small space between the two blades of the impeller, the design of the sealing device is difficult. The open processing device uses a high-speed flowing electrolyte to form a machining gap flow field to meet the processing requirements. Since the open processing device does not require excessive sealing, the cathode movement is limited. Therefore, the open machining device is used to develop the overall impeller finishing process experiment [7, 8, 9].

The channel of the shaped cathode consists of an inlet, a delivery zone, a transition zone, an outlet, and a diversion zone. It also changes the flow of the electrolyte from columnar to slit-like, through the outlet of the liquid outlet, and then flows along the surface of the cathode into the processing gap under the action of the deflector. In order to grasp the flow velocity distribution in the machining gap, the flow field analysis was performed using CFX software in the design. When designing a shaped cathode shape, it must be done in the inter-blade channel space that has been machined [10, 11, 12]. Due to blade

distortion, the formation of the cathode must be considered. To prevent the occurrence of motion interference, the initial shape of the cathode is first determined according to the size of the leaves during the design, and then numerical simulation software is used to simulate the path of the cathode into the inter-leaf channel to observe the collision or interference between the cathode and the blade. In order to simulate the cathode movement during the design of the cathode design using motion simulation software, the cathode structure was modified by simulation result to avoid the interference between the cathode and the blade and the tooling. The cathode can smoothly enter the inter-leaf channel and complete the processing feed movement. In addition to considering the cathode profile, cathode profile design is also required. In the profile design, the influence of the flow field and feed motion on the blade machining accuracy is considered. In the design, the profile of the blade is used as the initial surface of the cathode. Based on this, the effects of the flow field and the feed direction on the profile are taken into consideration [13, 14, 15]. The profile is corrected and the machining requirements are achieved after multiple corrections. Figure 1 is the finished blade shape.

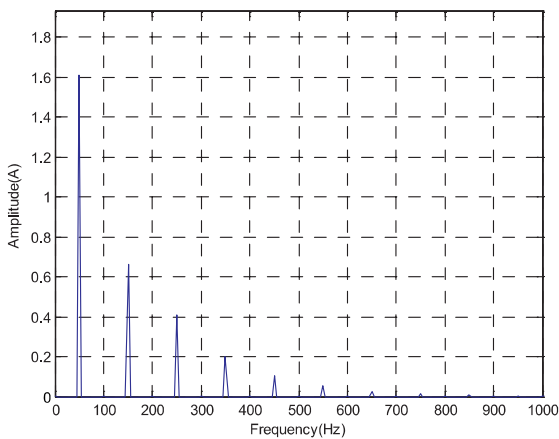


Fig. 1. Finished integral impeller

## BLADE FINISHING DEVICE DESIGN

In the simulation software developed based on UG, the machining model was compared with the original blade geometry model. Sample data points are taken from the original blade surface as the analysis target of the machining error. After these points are used as normal to intersect with the machining blade geometry model, the distance between the two intersection points is obtained. This distance is the machining error. Compared with the generative method, the precision of the blade using the forming cathode machining has been greatly improved, but there is still no requirement for processing. The cathode surface correction method is used to further improve the machining accuracy. Because it is very difficult to directly measure the machining clearance of the blade, there is currently no direct method for measuring the machining gap of the formed cathode blade, but the gap distribution of the blade forming cathode machining can be indirectly calculated. Using the CAD software and its analysis tools to compare the blade geometry model with the cathode profile, the gap distribution

of the electrolytic machining of the blade can be obtained. Take some sampling points on the surface of the cathode and calculate the normal distance from the sampling point to the processing surface of the blade or set the distance in the direction of the self. The distance is the processing gap of the blade obtained through analysis and calculation. By correcting the profile of the cathode by the distribution of machining gaps, the machining accuracy of the blade is improved.

Using simple-form cathode NC machining to produce pre-channel pre-channels, and then using a shaped cathode for precision electrolytic machining can significantly improve the machining accuracy of the blade profile. This is an effective technical approach to achieve efficient and precise overall manufacturing of the free-form blade vanes. The forming cathode and special tooling design method used in the experiment can meet the flow field requirements of the overall impeller blade profile electrolytic machining, and the processing process is stable. The proposed method for determining and optimizing the forming direction of the cathode feed can significantly improve the distribution of gaps in the machining of complex profile electrolysis machining, and it is beneficial to improving the machining accuracy. They operate at high temperatures, high pressures, and high rotational speeds. Such turbines must use high-temperature heat-resistant alloy materials, and machining is very difficult. In particular, the twisted blade profile machining of integral turbine disks has always been a problem in the manufacturing industry. Develop an electro-chemical machining integrated turbine. According to the electro-technical gap and the theoretical plane of the blade to determine the generative feed trajectory, refer to the characteristics of the machine tool numerical control system, and use computer-aided programming software to generate a multi-axis linkage NC program. The cathode must be designed according to the minimum cross-section of the inter-bay channel. The one-time production process can meet the accuracy of one side of the blade, and then the channel is formed. Electrolyte leak due to no back pressure, can no longer use the same method of processing the other side, variable cross-section residual processing margin must be hand polished. Fig. 2. is the establishment of a differential equation.

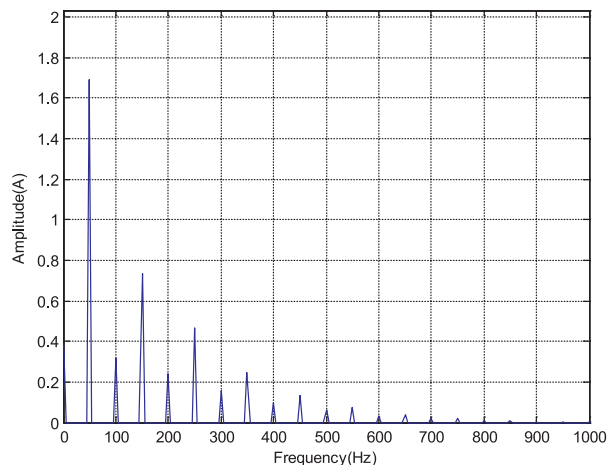


Fig. 2. Multi-axis linkage and composite plane swing development electrolysis schematic

There are many factors affecting the accuracy of CNC integral electrolysis machining of impeller blades, including cathode and fixture manufacturing errors, machine tool movement errors, machining movement trajectory, electrochemical machining cuts, and initial machining gaps. The discussion of the manufacturing error between the cathode and the fixture is not discussed here. Due to the special nature of the impeller's electrolytic processing, there is also the deviation of the processing trajectory caused by electrolytic secondary corrosion processing, processing principles and machining gap. They are the main cause of electrolytic machining errors in the overall impeller blade.

### COMPOUND PLANE SWING FEED FORMING STRIPE

Multi-axis linkage NC programming is generally based on the leaf basin surface, the cathode left blade vertex is based on the programming reference of the leaf cylinder root cylinder. Due to the large distortion of the blade, the right edge of the cathode in certain area will cut into the root cylinder. Large-deflection blade profile processing, x, y, and large rotary feed, electrolyte pressure fluctuations, in the liquid-liquid shortage area or weak electrolysis of small flow rate, easy to produce surface convex. A short circuit will scrap the turbine as a whole and cause major economic losses. During the processing, the electrolyte flow field is stable and the test system is reliable. The surface of the blade after machining has no flow and metallographic defects. The leaf basin surface is used as the programming basis for multi-axis linkage feed, and additional swing feed electrolytic machining eliminates the leaf back margin. There is a principle error in the data processing of the discrete points of the blade surface; due to the distortion of the profile, the feeding speeds of the cathode and the blade along the y-axis are different, and the electrolytic gaps at the points of the same section may also be different. Changes in electrolytic parameters can also cause gaps in different cross-sections to create machining errors.

The adoption of a composite swing feed processing scheme allows one-time feed electrolysis to produce leaf and blade back profiles, shortening the auxiliary time, and effectively increasing productivity. The design of a combined cathode with a fluid flow field can effectively solve the problem of over-cutting secondary corrosion of blade backs with processed blades. The stability of electrolysis parameters is maintained, and the will have good repeatability of accuracy. The composite swing feed development and electrolytic processing is particularly suitable for batch processing of the overall turbine with large twisted blades. The use of double-sided feeding can effectively eliminate hidden faults such as electrolytic short-circuit and ensure the stability and precision of machining process. The adoption of a composite swing feed processing scheme allows one-time feed electrolysis to produce leaf and blade back profiles, shortening the auxiliary time, and effectively increasing productivity. The design of a combined cathode with a fluid flow field can effectively solve the problem of over-cutting secondary corrosion of blade backs with processed blades. The use of double-sided feeding can

effectively eliminate hidden faults such as electrolytic short-circuit and ensure the stability and precision of machining process. Figure 3 is a decryption program.

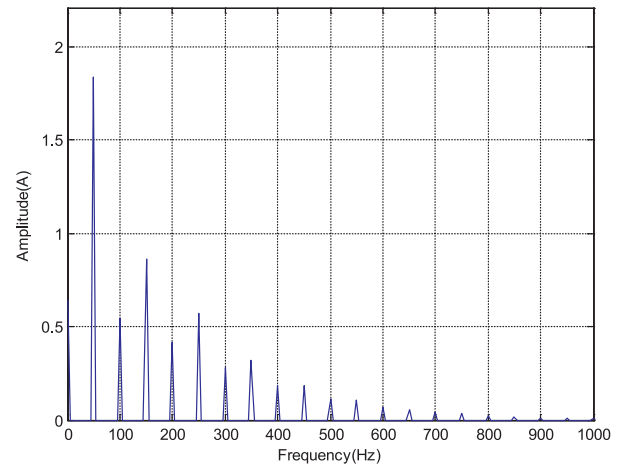


Fig. 3. Decryption program flow diagram

A cathode with a triangular cross-section has a good rigidity and a relatively large flow area, but when machining a small-sized integral impeller, the space between the leaves is limited due to the narrow passage between the leaves. The upper surface of the cathode has a large surface area facing the non-machined surface in the inter-bay channel, which can easily cause secondary corrosion of the non-machined surface. Furthermore, for cathodes of this structure, it is generally not easy to use the same cathode to process both the surface of the leaf pot and the back surface of the leaf, and it is necessary to design and fabricate cathodes for the surface of the leaf pot and the back surface of the leaf, respectively. The main parameters of the model are set up as shown in Tab. 1:

Tab. 1. DC voltage and flux of 3-phase knockdown transformer

U	I	$I_a(A)$	$I_c(A)$	M	$\psi_e(Wb)$
0	3.086	-0.0006	1.2732	-0.0907	1010.8835
50	4.574	0.1920	1.4134	27.6574	1010.9129
100	6.029	0.3217	1.6458	42.3184	1011.5332
200	54.250	1.9537	8.5633	74.8972	1013.0832
500	361.339	29.3409	91.7897	158.5843	1019.5658
1000	6.029	0.3217	1.6458	42.3184	1011.5332
1500	54.250	1.9537	8.5633	74.8972	1013.0832
2000	361.339	29.3409	91.7897	158.5843	1019.5658

At present, most of the researches on the overall impeller electrolytic machining are the NC development method, also known as sweeping method or envelope method. Different CNC machining methods have different machining accuracy in the leaf pot, leaf back, and root, and the applicable overall impeller type is also different. The controlled growth method is mainly applicable to the ruled surface integral impeller blade processing. If it is used to process the integral

impeller composed of non-pregnant surface, the processing error is large, especially the blade back and the blade root cannot satisfy the processing requirements of the freeform surface blade. Therefore, it is necessary to further study new processing methods in the overall impeller machining process.

### VALIDATION OF SIMULATION MODEL

Generally, stainless steel is more suitable. Since the shape of the cathode is very irregular, especially the cross-section of the internal flow passage is greatly changed, and the front-end size is small, it is difficult to manufacture it by the conventional cutting processing method, so the electro-discharge molding method is used for processing. The integral blade disk is the core component of the new aero engine. It integrates the blade and the wheel disk instead of the way the hammer head and tongue groove are connected through the locking plate, which reduces the number of engine parts and reduces the weight. This can effectively improve the engine's stability and weight-to-weight ratio. Fig. 4. is the machining gap and feed depth curve.

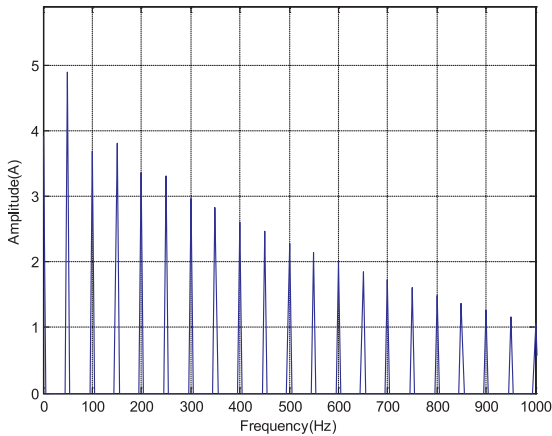


Fig. 4. Processing gap and feed distance

This paper first analyzes the genetic error theory to study the effect of genetic errors on the overall precision of leaf disk electrolysis processing. Before blade-surface electrolytic machining reaches an equilibrium state, the machining gap continuously changes with time, which belongs to the gap transition process of electroforming. Through the above-mentioned theoretical analysis, it can be known that the genetic errors and fluctuations of the blank after electrolysis rough machining of the overall blade cascade channel have little effect on the repeatability of electrolytic machining.

Therefore, the main factor causing the processing error is the fluctuation of the machining gap:

$$\begin{cases} (R_B - R_{AB}) / (R_A R_B - R_{AB}^2) = 1 / R_{AA} \\ (R_A - R_{AB}) / (R_A R_B - R_{AB}^2) = 1 / R_{BB} \\ -R_{AB} / (R_A R_B - R_{AB}^2) = -1 / M_{AB} \end{cases} \quad (1)$$

Consider the distance  $d$  between the two grounding bodies in the actual project is relatively large:

$$\begin{cases} R_{AA} = R_A \\ R_{BB} = R_B \\ M_{AB} = R_A R_B / R_{AB} \end{cases} \quad (2)$$

Equation of conductor potential and scattered current:

$$G_h \phi_N - G'_h V_M = I_M \quad (3)$$

In the process of leaf disk electrolysis, high-speed and high-pressure electrolytes flow through tiny machining gaps, making it difficult to detect them directly:

$$I_d^0 = \begin{bmatrix} I_{d(1)}^0 \\ 0 \\ M \\ 0 \end{bmatrix} = \begin{bmatrix} I_s \\ 0 \\ M \\ 0 \end{bmatrix} \quad (4)$$

According to the rule of electrolytic machining, when the feed rate of the tool electrode and the corrosion rate of the anode are basically the same, the electrolytic processing reaches an equilibrium state:

$$G_{k(i,j)} = \frac{1}{R_{g1(i,j)} + R_{g2(i,j)} + R_{l(i,j)} / 3 + R_{t1(i,j)} / 3 + R_{t2(i,j)} / 3} \quad (5)$$

According to Ohm's law and Faraday's law, the basic equation for electrolytic machining equilibrium gap is:

$$\begin{bmatrix} I_{d(1)}^1 \\ I_{d(1+n_1)}^1 \\ I_{d(1+n_1+n_2)}^1 \\ M \\ I_{d(1+n_1+n_2+\dots+n_a)}^1 \end{bmatrix} = \begin{bmatrix} I_{k(1)}^0 \\ I_{k(2)}^0 \\ I_{k(3)}^0 \\ M \\ I_{k(a)}^0 \end{bmatrix} \quad (6)$$

The relationship between the electrolysis of the current density is:

$$R = \frac{\rho}{2\pi^2 D} \ln \frac{16D^2}{hd} \quad (7)$$

It can be seen that the processing current is closely related to the machining gap. The current change leads to the fluctuation of the electrolytic machining gap, which makes the difference in blade thickness and profile after each processing, thereby affecting the consistency of the overall blade disk type surface electrolytic machining:

$$G_l \phi_N - G'_l V_M = I_d \quad (8)$$

In the past overall impeller machining test, a large-diameter integral impeller was processed using the blade back

modification method. It first processed the inter-blade channel on the basis of the leaf basin, and then finished the blade back. From the processing principle point of view, this processing scheme is feasible, and it can simultaneously improve the precision of electrolytic machining of leaf pots and leaves. From the test results, the main disadvantage is that the margin of one-pass machining in the blade back correction processing is small, and the number of cutting passes is relatively large. The processing based on the leaf pot still results in overcutting of the root. Based on the past processing technology and combined with the characteristics of the whole impeller, a new step-by-step method for impeller blade machining was proposed. The overall impeller blade electrolytic machining method divides blade processing into multiple steps.

In the alternative of blade root processing, it is difficult to design and process the profile of the shaped cathode, and a set of electrolyte sealing device is needed. The cathode needs to be rotated to enter the channel between the leaves. The cathode structure adopted in the NC generative method is simple. However, the calculation of the trajectory is relatively complex. Taking into account the above factors, the NC generative machining program is used to process the roots of the leaves. Through process simulation and other technical means, the processing area of each process is properly divided so that the shape processed by the previous process can meet the processing requirements of the next electrolytic processing process, thus achieving the continuous processing of the blade.

## CONCLUSIONS

For the liquid ejecting part of the front end of the cathode, the inside should be smoothly transitioned, and the cross-sectional area of the channel should be gradually reduced to avoid drastic changes. The angle between the discharge direction of the electrolyte and its inlet direction is large. This may result in insufficient electrolyte at the end of the liquid outlet during processing, causing a short circuit in severe cases, as well as damage to the cathode and the due to burns. In order to make the electrolytic processing work smoothly and ensure the cathode has a long service life, the cathode material should have good conductivity, high strength, and strong corrosion resistance. Generally, stainless steel is more suitable. Since the shape of the cathode is very irregular, especially the cross-section of the internal flow passage is greatly changed, and the front-end size is small, it is difficult to manufacture it by the conventional cutting processing method, so the electro-discharge molding method is used for processing. There is a principle error in the data processing of the discrete points of the blade profile; due to the distortion of the profile, the feeding speeds of the cathode and the blade along the y-axis are different, and the electrolytic gaps at the points of the same section may also be different. Changes in electrolytic parameters can also cause gaps in different cross-sections to create machining errors. The feed direction of the cathode is optimized in the axial plane, and the feed direction optimization process of the axial plane is the

same as the optimization process of the radial cross section. Because the blade surface is a space curved surface and the feed direction is space vector, the three-dimensional cathode feed optimization calculation is more complex. Therefore, the three-dimensional feed direction optimization of the cathode is divided into two steps: radial in-plane optimization and axial in-plane optimization. In addition to considering the cathode profile, cathode profile design is also required. In the profile design, the influence of the flow field and feed motion on the blade machining accuracy is considered. In the design, the profile of the blade is used as the initial surface of the cathode. Based on this, the effect of the flow field and the feed direction on the profile is taken into consideration. The profile is corrected and the correction is achieved after many corrections

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