

3D solid modeling method of Francis turbine blade based on UG

Zhang Li-da, Lian Ling-jun, Ren La-chun, Mao Jin-duo, Chen Rong-sheng

School of Energy and Environment of Xihua University, Chengdu

Sichuan610039, China

Abstract: In this paper, 3D solid modeling method of Francis turbine blade is researched. Based on powerful capacity of materializing surface of UG NX 4.0 and the data of original wooden patterns, the blade spline modeling was established by NURBS, and the blade space surface was constructed. Meanwhile making a mathematical analysis for the free surface extension of Francis turbine blades and proposing new solutions. A good result of Smoothness test for runner blades shows that the solid modeling method is feasible. 3D solid model lays possibility for analysis and CNC machining of follow-up blades.

Key words: blade; UG; NURBS; wooden patterns

1 foreword

Runner is one of important key parts of Francis turbine. Blades are important parts of the runner, their surfaces are non-structural, spatial twisted free-form surface. For a long time, people machine and set out of blades based on wooden patterns, but with the development of Computer Aided Design and Computer Aided Manufacture(CAD/CAM), there are many disadvantages of wooden patterns. First, now three dimensional CAD modelling and manufacturing technology of blades overcome many disadvantages of traditional blade manufacture craft effectively(for example, great labour intensity, low efficiency, people cannot ensure accuracy and machining accuracy of blade surface and so on), but wooden patterns cannot be introduced into three dimensional CAD modelling and manufacturing technology of blades immediately; Second, wooden patterns that orient to manufacturing technique immediately cannot be applied to numerical calculation of flow field calculation, strength of blade and vibration of blades and so on^[1-2]. Therefore, based on powerful capacity of materializing surface of UG and the data of original wooden patterns, a new idea that is 3D solid modeling method of Francis turbine blade with NURBS is proposed.

2 3D solid modeling method of Francis turbine blade based on UG

2.1 Brief introduction of NURBS modeling

Here, NURBS is curved surface modeling. Curved surface modeling is a very excellent modeling method, it constructs a space curved surface body with B-Spline. Internal space of NURBS Models expresses structure and shape of model with curve and surface that are constructed by mathematic expressions, so curved surface modeling is better than traditional polygonal mesh model in curvature and degree of precise of object surface, thus more Smooth, fidelity, vivid model will be constructed.

2.2 Analysis of shape lines

Francis turbine blade is composited in front, back, curved surface that inlet waterside becomes arc radius and outlet waterside of complex surface. Traditional idea that expresses wooden patterns of blades is to draw the data (x, y) of every surface with the same Z . Figure 1 show, we may obtain data points of every section curve, then, sculptured surface parts hydro turbine blade will be expressed with 3D solid form immediately.

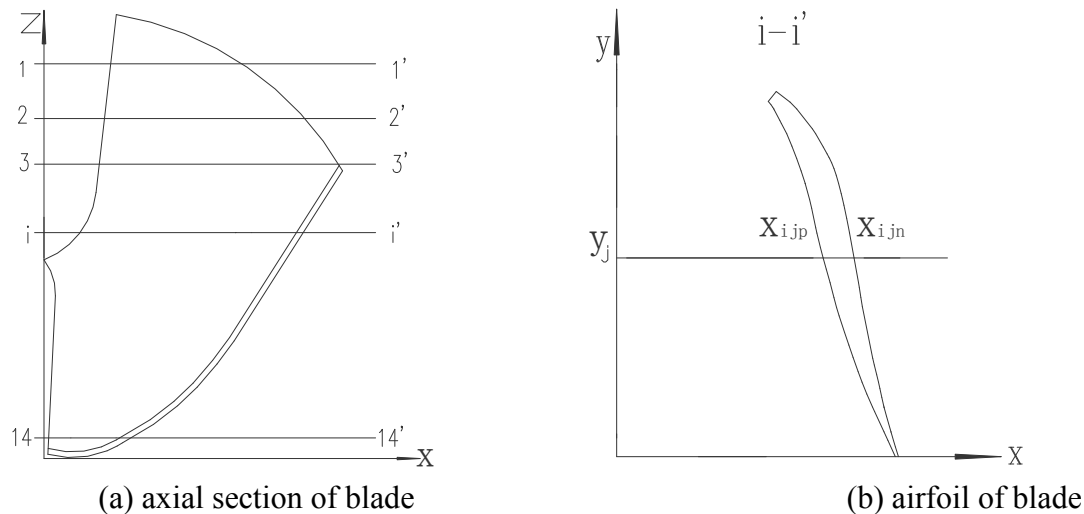


Figure 1 wooden patterns of Francis turbine blade

2.3 3 d solid modeling of blade

2.3.1 data points acquisition of blade

In general case, data points acquisition is realized by three-coordinate measuring machine, but surface with the same Z of blade wooden patterns is given in this paper, so coordinates $((x_i, y_i)(i = 1, 2, \dots, n))$ of data points of every cross-section are only found out. First a series of lines that are parallel to axis X should be made, line density should be adjusted according to the change of section curve, that the parallel lines are high density when curvature change is bigger, otherwise, diluted. Data points $(x_i, y_i)(i = 1, 2, \dots, n)$ of section curve are obtained by intersection between and section curves and lines that are parallel to a group of lines with the same Y . As space is limited, only data points of fifth section is listed out here,

underside surface 1:

Tables 1 Data points of section curve of the surface 5—5' with the same Z

<i>data points</i>	x_i	y_i	z_i	<i>data points</i>	x_i	y_i	z_i
1	128.00	294.00	196.00	18	214.40	20.00	196.00
2	144.40	280.00	196.00	19	205.20	40.00	196.00
3	159.60	260.00	196.00	20	196.80	60.00	196.00
4	170.80	240.00	196.00	21	189.60	80.00	196.00
5	178.00	220.00	196.00	22	182.80	100.00	196.00
6	182.80	200.00	196.00	23	176.40	120.00	196.00
7	186.80	180.00	196.00	24	171.20	140.00	196.00
8	190.40	160.00	196.00	25	165.60	160.00	196.00
9	194.00	140.00	196.00	26	161.20	180.00	196.00
10	197.20	120.00	196.00	27	156.40	200.00	196.00
11	201.20	100.00	196.00	28	151.20	220.00	196.00
12	205.20	80.00	196.00	29	144.40	240.00	196.00
13	210.00	60.00	196.00	30	136.40	260.00	196.00
14	214.40	40.00	196.00	31	126.00	280.00	196.00
15	220.00	20.00	196.00	32	121.60	286.00	196.00
16	226.00	0.00	196.00	33	128.00	294.00	196.00
17	223.60	0.00	196.00				

2.3.2 curved surface fitting of blades

under the environment of UG modeling, according to cross-section sequence of blades, data files (*.dat) that are composed by real coordinate space of data points of every cross-section are successively introduced into UG, spline curves are held that NURBS curves in UG, so cubic spline curve is selected to draw every cross-section curves, and making every cross-section curves more regular by adjusting cross-section curves little(Figure 2 show), then selecting commands that is [insertion][curved surface mesh][through series of curves], last oral every cross-section curves are fitted. If there are unsmoothed and concavoconvex phenomenons on the curved surface fitting, curves near abnormal zones should be found out, and adjusting and fitting individual points of the curve, renewedly fitting curves and surfaces, then observing and adjusting again and again until you are satisfied to the camber figure.

2.3.3 making blade curved surface into solid by suturing

First choosing the commend that is [insertion][combination solid][suturing] in UG, then choosing every demi-body of blade, and clicking the command [determination], so solid model of blade is created, Figure 3 show.

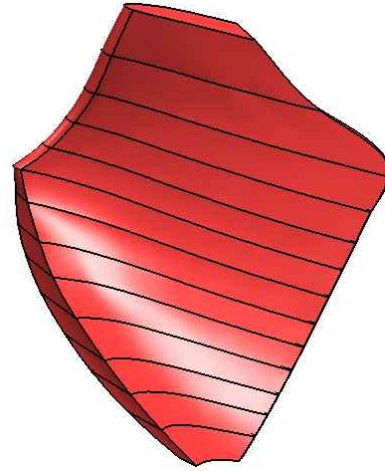
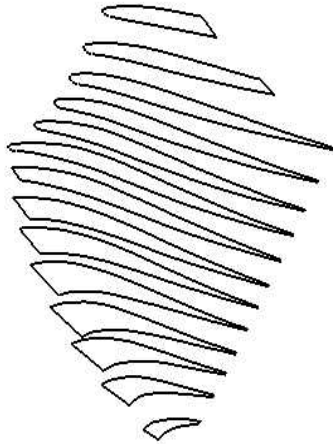


Figure 2 section curve of Francis turbine blade Figure 3 solid model of Francis turbine blade

2.3.4 Free curves extension of Francis turbine blade

Francis turbine blade is not complete in figure 3, because data points of the section 1–1' above and 14–14' down cannot be obtained in the wooden patterns; And the place that exceed the zone of data points cannot be defined by NURBS. Method of free curves extension of blade is listed out.

2.3.4.1 Knot insertion algorithm of curves and surfaces of NURBS

Here: there is a k-th order curve of NURBS:
$$P(u) = \frac{\sum_{i=0}^n B_{i,k}(u) W_i V_i}{\sum_{i=0}^n B_{i,k}(u) W_i}$$

Its control points is $\vec{V} = [\vec{V}_0, \vec{V}_1, \dots, \vec{V}_n]$, and node vector is $\vec{U} = [u_0, u_1, \dots, u_{n+k+1}]$

Now the new node u is inserted into the node section $[u_i, u_{i+1}]$, so the new node vector is

$$\vec{U}^* = [u_0, u_1, \dots, u_i, u, u_{i+1}, \dots, u_{n+k+1}] = [u_0, u_1, \dots, u_i, u_{i+1}, u_{i+2}, \dots, u_{n+k+2}]$$

The new control points is figured out by the new node vector, the method show:

$$\vec{V}_j^* = (1 - a_j) \vec{V}_{j-1} + a_j \vec{V}_j \dots \dots \dots \textcircled{1}$$

$$a_j = \begin{cases} 1, j = 0, 1, \dots, i+k \\ \frac{u - u_j}{u_{j+k} - u_j}, j = i-k+1, i-k+2, \dots, i-r \\ 0, j = i-r+1, i-r+2, \dots, n+1 \end{cases} \dots \dots \dots \textcircled{2}$$

R is repeatability rate of the knot insertion in above formulas. If the node u is not exist in the original sequence of nodes, $r=0$; If the node u appears with some times the original sequence of nodes, $r=m$.

Now the new control point $\vec{V}^*$ is alluded to three-dimensional space, here:

$$\vec{V}_j^* = \frac{(1-a_j)\vec{W}_{j-1}\vec{V}_{j-1} + a_j\vec{W}_j\vec{V}_j}{(1-a_j)\vec{W}_{j-1} + a_j\vec{W}_j} \dots\dots\dots ③$$

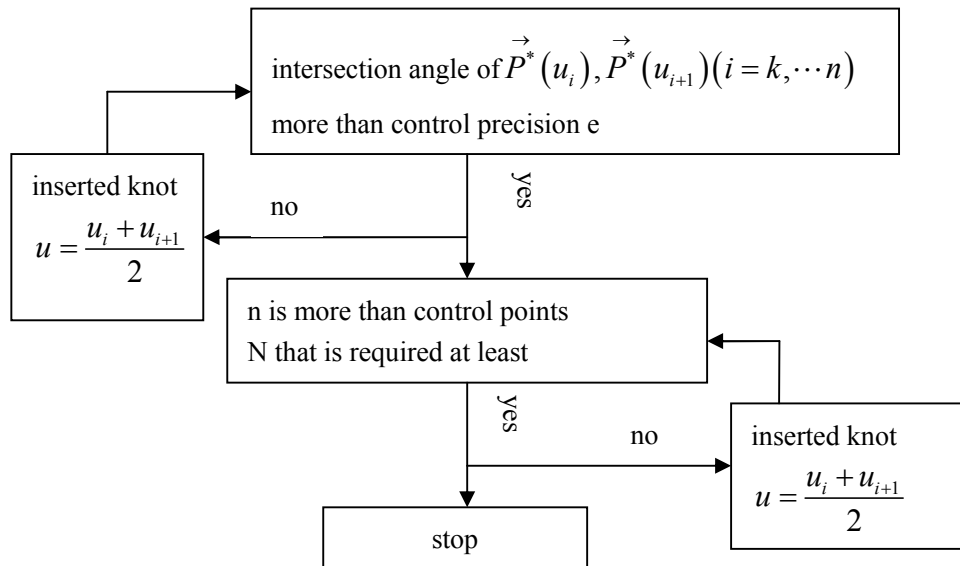
Relationship of pre-and post weight factor of knot insertion:

$$\vec{W}_j^* = (1-a_j)\vec{W}_{j-1} + a_j\vec{W}_j \dots\dots\dots ④$$

The new control point and weight factor of NURBS that inserts the node u one time in the zone $[u_i, u_{i+1}]$ is calculated by the formulas ②③④^[3].

2.3.4.2 Discretization of nurbs curves by inserted into node technology

Here, if a k-th order curve of NURBS $\vec{p} = \vec{p}(u)$ has been inserted knot, its knot vector becomes $u_0 = u_1 = \dots = u_k, u, \dots, u_{n+1} = u_{n+2} = \dots = u_{n+k+1}$, its definition domain is $[u_i, u_{i+1}]$, flow chart of step shows:



Attention: n is number that number of control points subtract 1

2.3.4.3 Curve extension that is satisfied with tangential continuous

There is a curve $\vec{P} = \vec{P}(t)$, now extending the line in its endpoint, the extension length is

s, and assumed the endpoint $\vec{P}_e$ that is obtained by extension, so the equation of extension curve $\vec{P}_e(t)$ is obtained that is satisfied with tangential continuous:

$$\vec{P}_e(t) = (1-t)\vec{P}_2 + t\vec{P}_e \quad t \in [0,1] \dots\dots\dots ⑤$$

Here: $\vec{P}_e = \vec{P}_2 + s \cdot \frac{\vec{P}_2^*}{\left| \vec{P}_2^* \right|}$, and $\vec{P}_2^*$ will be found out between the question ① and ②.

2.3.4.4 Extension of Francis turbine blade

Method one: (1) First boundary curve of Francis turbine blade surface is discreted according to precision by knot insertion algorithm of nurbs curve and surface, for example 2.3.4.1 and 2.3.4.2. Then parameter line corresponding to every discrete point extend according to curve is satisfied with tangential continuous, for example 2.3.4.3^[4]

(2) Simultaneous solution of analytic equation of runner crown and bottom ring of hydraulic turbine as limited and equation of extend boundary fitting equation of extend curve, and obtaining intersection points. In the same way, we obtained nodes of runner crown and bottom ring of hydraulic turbine.

(3) Then nurbs curves are interpolated according to aforesaid intersection point, so those are intersecting lines of runner crown and bottom ring of hydraulic turbine.

(4) Extension surfaces are generated by sweeping, and last solid is generated in UG.

Method two:(1) First choosing central shaft of Francis turbine as axis of rotation in UG, and using a piece of thin plate to cut blade(Figure 3:solid model of blade), and obtaining transversal of rotation axial plane by extracting.

(2) Then every axial plane curve is extended according to Curve extension that is satisfied with tangential continuous, for example 2.3.4.3, Figure 4 show.

(3) Surface fitting for axial plane transversal of blade that is extended and suturing into solid, last boolean operation in runner crown and bottom ring of hydraulic turbine, and obtaining a complete solid model of blade, Figure 5 show.

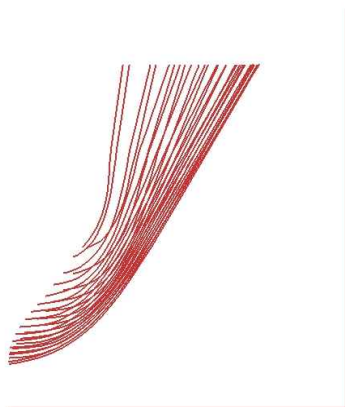


Figure 4 axial plane transversal of Francis turbine blade

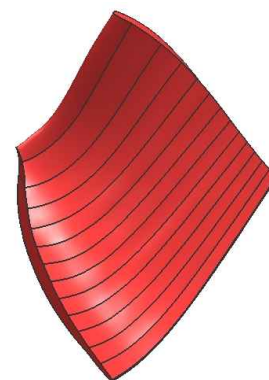


Figure 5 solid model of Francis turbine blade

2.4.4 Data is exported by using standard format

It is important that data is exported by using standard format in order to convenient for blade is analysed and researched in other software, of course concrete storage form is decided according to the format that posses in other software. In the paper we use the format IGS.

3 smoothness test of Francis turbine blade

3.1 Horizontal projection generationof wooden patterns

Traditional design method of Francis turbine blade is blade drawing to every calculated flow surface by conformal transformation, and drawing front axial plane transversal of blade. Then thickening and drawing back axial plane transversal of blade by one method. Last obtaining intersection points that are intersection of front and back axial plane transversal of blade and a piece of auxiliary transversal, and wooden patterns. In the paper, because solid model of blade has been established, horizontal cutting solid model of blade and extracting transversal in UG, then directly generating new wooden patterns(Figure 6).

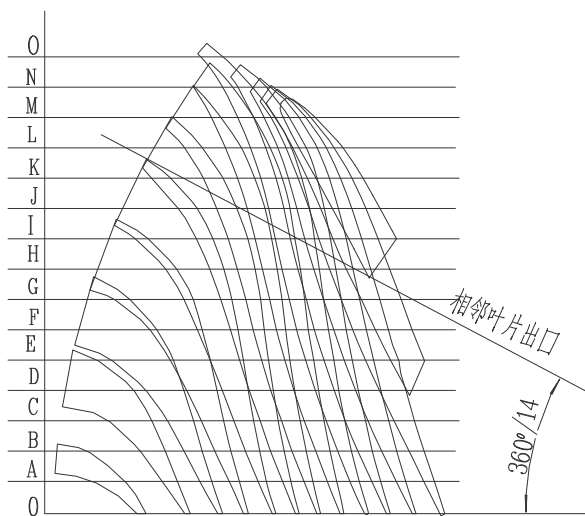


Figure 6 wooden patterns of Francis turbine blade

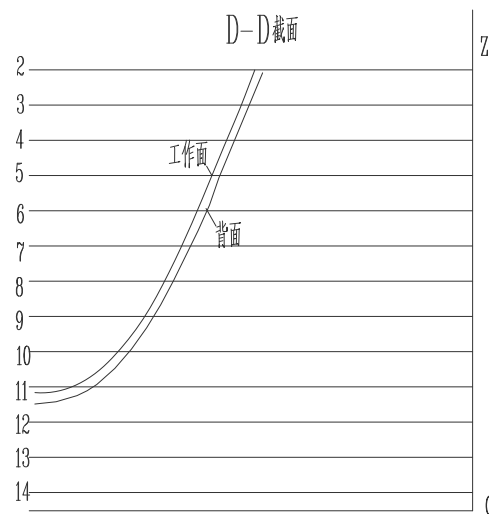


Figure 7 smoothness test that parallel to exit edge of blade

3.2 Smoothness test of runner blades surface

In order to reduce hydraulic loss and improve energy index of turbine, turbine blade surface must be smooth. In the paper two kinds of test methods are introduced based on UG.

3.2.1 Level group test methods

Intersection that is obtained by the method is level transversal of oral wooden patterns, figure 6 showing, we know that the level transversal is smooth and regular.

3.2.2 Plane group that parallel to blade trailing edge test methods

Some planes , for example AA、BB、CC、DD、..., that parallel to blade trailing edge are obtained from horizontal section. Now for example intersection line of cross-section DD and

blade:

First opening figure 5 in UG, then drawing a piece of thin plate based on datum plane that is the axial plane belong to blade outlet, the thin plate will rotating and cutting blade by central line of runner as rotating shaft and angle $\Delta\theta$ as interval, last intersection line of thin plate and blade are extracted and putted into software CAD, now for example intersection line DD(Figure 7 showing), we know that the section line is smooth and regular, so this prove that solid model method is right.

4 Ending words

- (1) Based on powerful capacity of materializing surface of UG NX 4.0 and the data of original wooden patterns, the blade spline modeling was established by NURBS, so reflecting surface shape of blade accurately and completely.
- (2) boundary curve is discreted by using multiple knot insertion techniques, blade curve is extended by tangential extension theory of B-spline curve, A good result of extension prove the method is dependable and practical.
- (3) A new method is proposed from wooden patterns of blade to 3 d solid model established, the method overcome some disadvantages of Computer Aided Design and Computer Aided Manufacture(CAD/CAM), and provides convenience for performance analysis and numerical control machining of blade,

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