

## Research on Lay-up Algorithm and Forming Technology of 1.2 MW Composite Wind Turbine Blade

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**Abstract:** In order to enhance its performance and quality, lay-up molding method is adopted to form large-scale composite wind turbine blade. Composite fibre lay-up of wind turbine blades must be multi-directional lay-up because of its complexity of bearing load and multi-direction of internal stress. Two lay-up algorithms of equidistant lay-up angle method and equidistant line method for free curved face of large-scale composite molding component are studied in this study. Lay-up path solution of  $0^\circ$ ,  $\pm 45^\circ$  and  $90^\circ$  for wind turbine blade are researched and their lay-up paths of some 1.2MW blade are formed in UG NX.

**Keywords:** Composite fiber, lay-up algorithm, lay-up angle, path solution, wind turbine blade

### INTRODUCTION

As the renewable, green and environmental protection energy, wind energy resource is one of the most developing hi-technologies in energy field. Blade is the main component captured wind energy and is regarded as the most critical component of wind turbine system. Because of its special functions, such as high specific stiffness and specific strength, better designability, high performance of anti-fatigue and anti-failure, easy integral molding of large-area and wonderful corrosion resistance, reinforced composite material is widely applied in large scale wind turbine blades. With the development to large power, light weight and high performance ratio and low cost, large scale wind turbine blades is basically made of reinforced material and thermosetting base-resin and produced through lay-up process at present (Shao-Jie, 2007; Huang *et al.*, 2007).

Lay-up molding component is molded through laminating and compacting of fibre bundle. In order to utilize its high strength and rigidity of axial direction farthest, fibre axes is in accord with the tensile and compressive stress direction of component. Lay-up angle can be arbitrary between  $-90^\circ$  and  $90^\circ$  in theory, but four lay-up angles of  $0^\circ$ ,  $+45^\circ$ ,  $-45^\circ$  and  $90^\circ$  are often selected.  $0^\circ$  lay-up is used to bear axial stress,  $\pm 45^\circ$  lay-up is used to bear shearing stress and  $90^\circ$  lay-up is used to assure enough radial compressive strength. Fibre lay-up of wind turbine blades must be multi-directional lay-up because of its complexity of moving state and bearing load and multi-direction of internal stress (Ying-Shu and De-Gang, 2005; Dong-Xiao *et al.*, 2007; Kong *et al.*, 2005).

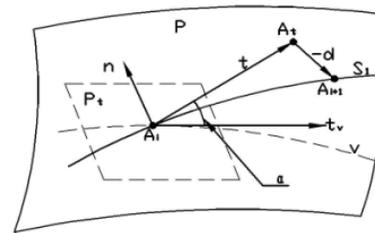


Fig. 1: Principle for equidistant lay-up angle method of curve in space

Lay-up algorithm is the basis of fibre mold. Its task is to design and optimize fibre lay-up path of every angle for the whole component according to space geometry, internal stress, performance requirement and lay-up technology etc. Lay-up algorithm and forming technology of  $0^\circ$ ,  $\pm 45^\circ$  and  $90^\circ$  for larger-scale wind turbine blade are studied in this study.

### LAY-UP ALGORITHM OF FREE CURVE FOR LARGE-SCALE COMPOSITE MOLDING COMPONENT

**Equidistant lay-up angle method of curve in space:** Effective lay-up angle' theoretical value of arbitrary one point on spatial curve obtained by equidistant lay-up angle method is equal. This method is used for random and initial spatial curve' calculation in all curves offset discretionarily on curved face in space. The process of calculating spatial curve  $S_1$  used equidistant lay-up angle method is showed in Fig. 1.

$n$  = The normal vector of point  $A_i$  in curved face  $P$  of composite fibre lay-up

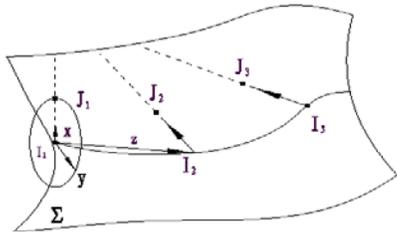


Fig. 2: Principle for algorithm based on curved equidistant line

- $P_t$  = The tangent plane through  $A_i$ . After rotating tangential vector  $t_v$  of  $A_i$  in  $P_t$  angle  $\alpha$  around  $n$ , lay-up direction  $t$  of  $A_i$  can be obtained
- $A_i$  = The initial point
- $A_t$  = Defined along the  $t$  direction by  $|A_i A_t| = l$
- $l$  = Calculated step size of spatial curve
- $A_{i+1}$  = Can be defined by projecting  $A_t$  along the  $-n$  direction onto curved face  $P$  and  $A_{i+1}$  is the curved point of lay-up angle  $\alpha$  in mandrel surface

A series of space points can be defined through the same method. Fitting those points sequentially, curve  $S_1$  of equidistant lay-up angle on curved face  $P$  can be obtained. Lay-up angle accuracy of any point on  $S_1$  is decided by  $l$ . Calculated step size of spatial curve is varied with the curvature of mandrel curved surface. Composite forming path of lay-up angle  $\alpha$  can be gained by input  $\alpha$  value (Gliesche *et al.*, 2003).

**Equidistant line method:** According to the features of ISMR, inspired by the metasynthesis, the ways and means of achieving comprehensive and integrated are concluded as follow.

Equidistant line method is the algorithm that base path is adopted as reference line and each lay-up path of whole component is formed in turn. Space length between lines is definite and the distance is related to width of fibre bundle and lay-up precision.

Hypothesizing that curved face component needed to be lay-up is  $\Sigma$ . Other lay-up paths will be gotten through the known lay-up path  $I_1 I_2 I_3$ . As showed in Fig. 2.

Path  $I_1 I_2 I_3$  is divided to finite points  $I_1, I_2$ , and  $I_3$  etc. Line sections are formed through adjacent two points and the reference lay-up path is constituted by those line sections.

Three-dimensional system of coordinate is built on starting point of each line section.  $I_1 I_2$  as coordinate  $Z$ ,  $I_1$  as center of circle,  $XY$  as drawing plane and the given path space as radius, circle is done. The crossing point  $J_1$  is gained by the circle and curved face. In like manner, the same coordinate system can be built between  $I_2$  and  $I_3$  and crossing point  $J_2$  can be gained. A new path  $J_1 J_2 J_3$  can be formed through curved fitting  $J_1, J_2$  and  $J_3$  (Guan-Jun *et al.*, 2005; Honyuen *et al.*, 2004). So the whole lay-up paths of curve face can be implemented.

## LAY-UP PATH PLAN AND GENERATION OF 1.2MW WIND TURBINE BLADES

**Establishing mandrel and solving its centre line of figure:** Lay-up mold of composite fibre is belong to processing mode of adding material. In lay-up process, supporting surface is needed to be provided in advance. Mandrel should be designed firstly according to geometric model of component and lay-up path is laid

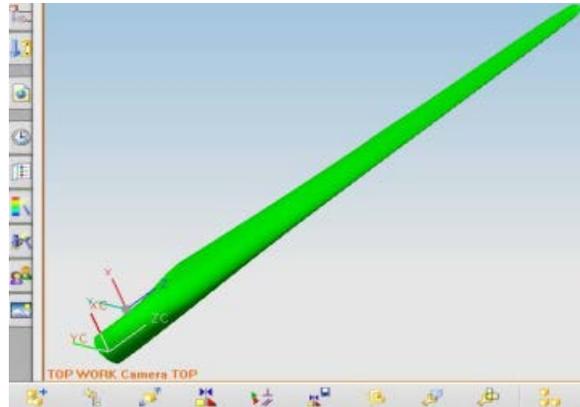


Fig. 3: Mandrel of 1.2WM blade

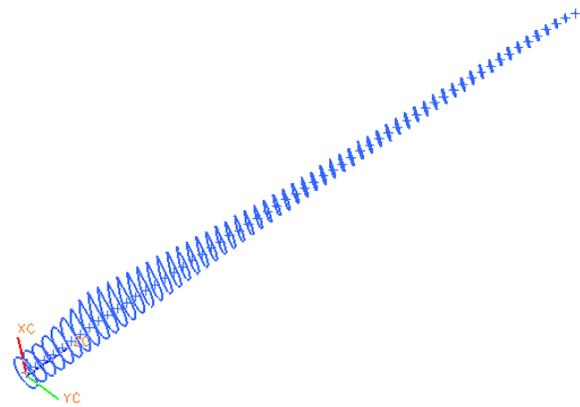


Fig. 4: Geometric centre of mandrel of 1.2WM blade

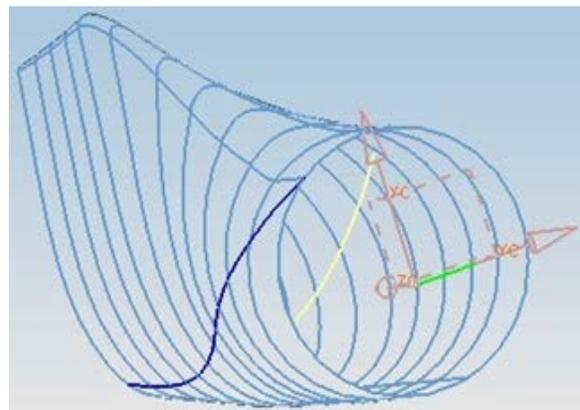


Fig. 5: Reference bud bar of lay-up

out on it. Lay-up of composite fibre is finished according to definite lay-up path. Formed component is gained after dividing it from mandrel.

According to 3D model and thickness of 1.2MW wind turbine blade, its mandrel established in UG NX is showed as in Fig. 3.

Choosing a set of equidistant planes which spacing is the maximal width of fibre bundle and parallel to back surface, they intersect the mandrel and a group of sectional profile can be obtained. Their geometric centre of figure is solved. As showed in Fig. 4.

The cubic spline curve gained through interpolating those points is the line of geometric centre and the line is bus bar of lay-up path. Lay-up reference line is formed through projecting the bus bar to mandrel surface. As showed in Fig. 5.

**Generation of lay-up path:**

- **Solution and generation of 0° lay-up path:**  
According to definition of lay-up angle, orientation of 0° lay-up path is the direction of lay-up reference line. Known from the generation of lay-up reference line, the maximal space between adjacent reference lines is the width of fibre bundle and that ensures that lay-up paths can overspread the whole mandrel surface. So those reference lines are the 0° lay-up paths.

In loads borne by wind turbine blade, 0° corresponds to the direction of centrifugal force and 0° lay-up fibre bears major centrifugal force. Equidistant line method is mainly adopted to implement 0° lay-up algorithm. The bus bar is divided into n portions by lay-up width. Coordinate systems are created in each nodal point and circles are drawn which radius is lay-up width. The connecting lines of crossing points generated by those circles and curved face is the generated lay-up paths. As showed in Fig. 6.

- **Solution and generation of ±45° lay-up path:**  
±45° lay-up path mainly bears the torsional shearing stress generated by centrifugal force torque, gravitational force torque and pneumatic torque. Its basic algorithm is shown in Fig. 7.

Hypothesizing that starting point of selected ±45° lay-up path is named as M, the lay-up path passed M is line 1 and the intersection line between lay-up surface and plane passed M and paralleled to back surface of mandrel is S. Hypothesizing that the tangent line vector of line 1 at point M is axis Y and the tangent line vector of line S at point M is axis Z. Plane A is generated through axis Y and Z. Vector axis X is formed through counterclockwise rotating Y through 45° around point M in plane A. Using axis X as normal direction, plane

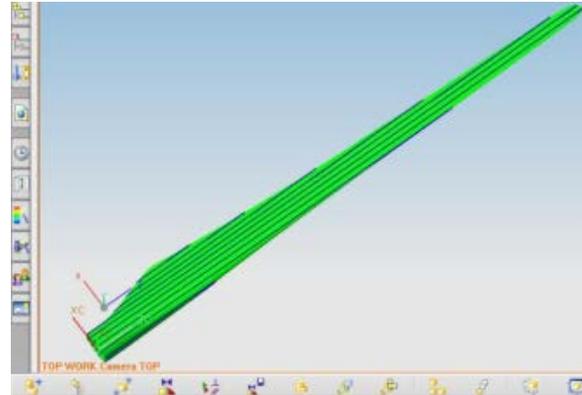


Fig. 6: 0° lay-up path of 1.2MW blade

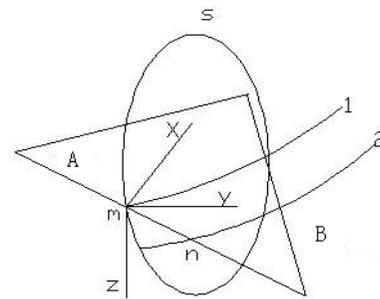


Fig. 7: Principle of ±45° lay-up algorithm

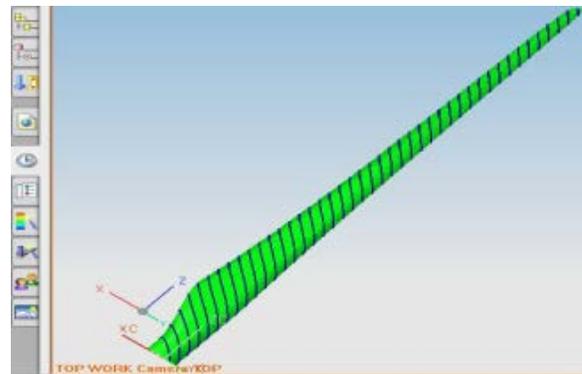


Fig. 8: 45° lay-up path of 1.2MW blade

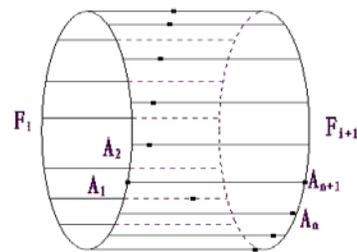


Fig. 9: Algorithm of 90° lay-up path

through point M is defined as B. Crossing point between plane B and line 2 is n and point n is the second point of selected ±45° lay-up path.

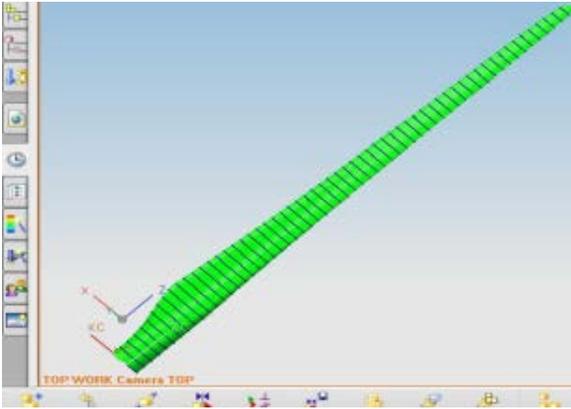


Fig. 10: 90° lay-up path of 1.2MW blade

In like manner, other discrete points can be solved through using point  $n$  as new basing-point. One  $\pm 45^\circ$  lay-up path can be gotten through fitting those discrete points and other  $\pm 45^\circ$  lay-up paths can be solved by equidistant line method (Lu-Ling *et al.*, 2007).  $45^\circ$  lay-up path of 1.2MW blade generated in UG NX is shown as in Fig. 8.

- **Solution and generation of 90° lay-up path:** Hypothesizing that blade section is regular cylinder shape,  $F_i$  and  $F_{i+1}$  are outlines of random two adjacent cross-sections. Part mandrel enclosed by  $F_i$  and  $F_{i+1}$  is shown as in Fig. 9.

Starting from point  $A_1$  on one reference line, points gotten on each reference line is used as discrete points of lay-up path. Through spline fitting those discrete points,  $90^\circ$  lay-up path is obtained.  $90^\circ$  lay-up paths of 1.2MW blade generated in UG NX is shown as in Fig. 10.

## CONCLUSION

Two lay-up algorithms of equidistant line method and equidistributed points densification method for free curved face of large-scale composite molding component are studied in this study. Lay-up algorithm of  $0^\circ$ ,  $\pm 45^\circ$  and  $90^\circ$  for wind turbine blade are researched. Through establishing mandrel model of blade, solving geometric centre curve of mandrel and lay-up reference line, lay-up path of  $0^\circ$ ,  $\pm 45^\circ$  and  $90^\circ$  for

1.2MW wind turbine blade are generated in UG NX based on lay-up algorithm mentioned above.

## ACKNOWLEDGMENT

This study is supported by The National Natural Science Foundation of China (51165028) and Inner Mongolia Natural Science Foundation of China (2011MS0710).

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