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FIBERGLASS COMPOSITE BLADES FOR THE 4 MW - WTS-4 WIND TURBINE

R.J. Bussolari
Wind Energy Systems
Hamilton Standard Division of United Technologies
Windsor Locks, Connecticut 06096

ABSTRACT

The WTS-4 is a four-megawatt, horizontal-axis wind turbine presently being fabricated for the U.S. Department of Interior, Bureau of Reclamation, by United Technologies' Hamilton Standard division. The blade consists of a two-cell, monolithic structure of filament-wound, fiberglass/epoxy composite. Filament winding is a low-cost process which can produce a blade with an aerodynamically efficient airfoil and planform with nonlinear twist to achieve high performance in terms of energy capture. Its retention provides a redundant attachment for long, durable life and safety. Advanced tooling concepts and a sophisticated computer control is used to achieve the unique filament-wound shape.

INTRODUCTION

The Hamilton Standard WTS-4 is a 4 MW downwind, horizontal-axis wind turbine being fabricated for the U.S. Department of Interior, Bureau of Reclamation, for installation at Medicine Bow, Wyoming. The downwind teetered rotor contains two fiberglass blades which span a diameter of 78.1 meters (256.4 ft). The design of the blades was initiated as part of a joint program between Hamilton Standard and Karlskronavarvet in Sweden, to develop the 3 MW WTS-3 for the Swedish government, and was upgraded to meet the needs of the WTS-4.

The blades consist of a filament-wound, fiberglass epoxy structure designed for minimum weight and cost embodying long life and a large margin of structural integrity. They are built by Hamilton Standard at its wind turbine manufacturing facility in East Granby, Connecticut.

FEATURES

The WTS-4 blade is shown in Figure 1. The blade consists of a glass fiber composite structure, 38 meters (125 ft) long, joined to two steel retention rings at the blade root. The blade is 15 feet wide at its maximum chord dimension. The diameter at the retention is 6 feet.

FIGURE 1. WTS-4 FIBERGLASS COMPOSITE WIND TURBINE BLADE

The blade assembly weighs approximately 29,000 pounds, consisting of 19,000 pounds of fiberglass and 10,000 pounds of steel retention hardware. The blade has 23,0XX series NACA airfoil with 11° nonlinear twist and optimum planform for high performance.

The following features are embodied in the design of the blade:

- Monolithic filament-wound fiberglass structure.
- Redundant retention.
- Lightning protection.

Figure 2 shows a cross-section depicting the monolithic construction of the blade. The advantage of this construction is that the simple spar-shell structure has no primary bond joints. This results in an efficient structural shape allowing the optimum use of strong, stiff, light material with continuously variable wall thickness. The two-cell monolithic construction is achieved by first winding epoxy impregnated glass filaments on a spar mandrel, followed by a second filament winding over a shell mandrel with the two sections co-cured forming a single composite structure. Filament winding provides an efficient low-cost process which can be adapted to achieve the optimum airfoil shape, planform and twist needed for high performance and resulting high energy capture.

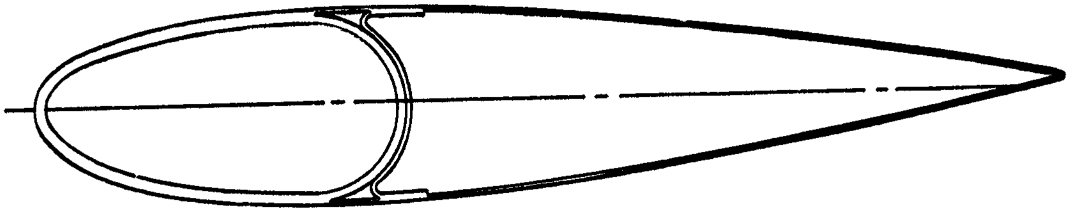

FIGURE 2. CROSS-SECTION OF WTS-4 BLADE SHOWING MONOLITHIC CONSTRUCTION

The retention at the root end of the blade, to provide attachment to the hub, is implemented by two concentric steel rings that are pinned and bolted together, the latter acting as a load transfer point between the fiberglass structure and the rings (Figure 3). The bolted joint is designed to withstand all of the normal and extraordinary loads, both steady and vibratory, expected during the blade service life. Redundancy is provided by bonded joints between the fiberglass and the outer and the inner ring. Each of these joints also is capable of handling all expected loads.

The outer retention rings also serve two additional functions. They provide the seat for the retention bearing and an integral attachment for the dual redundant pitch change actuators.

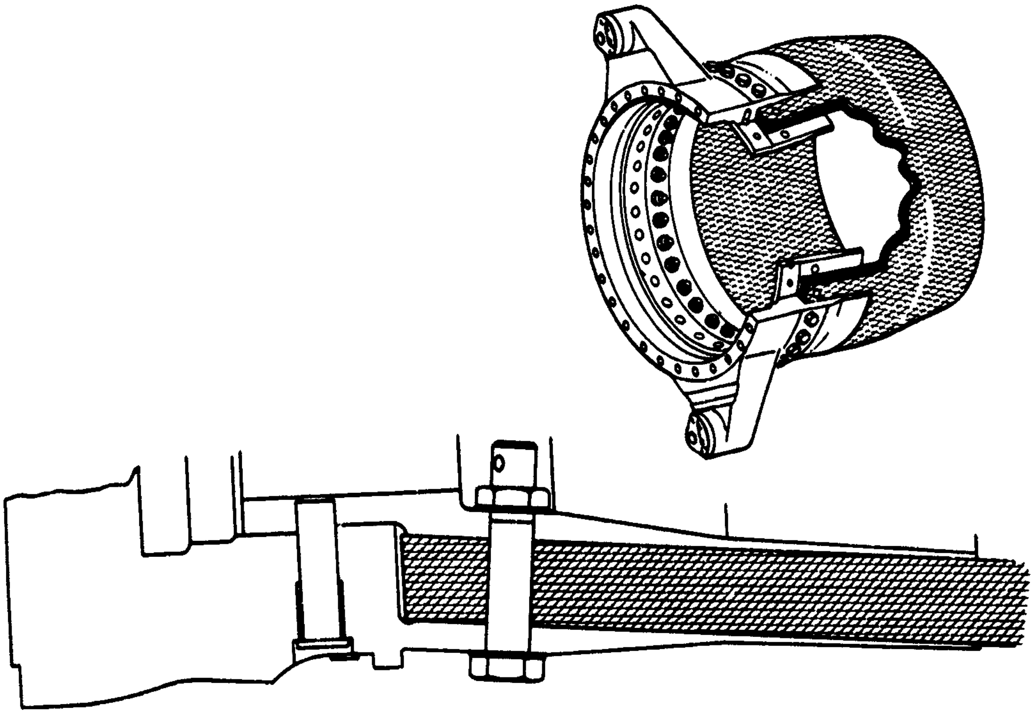

FIGURE 3. REDUNDANT BONDED AND BOLTED RETENTION

Lightning protection is provided by thin aluminum strips applied on the leading and trailing edges with connecting cross strips, as shown schematically in Figure 4. This system was successfully tested on sample sections from a similarly constructed one-half scale fiberglass blade.

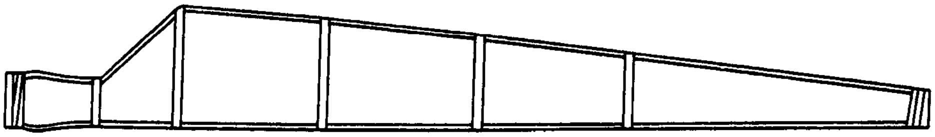

FIGURE 4. THIN STRIPS OF ALUMINUM TAPE PROVIDE LIGHTNING PROTECTION

MANUFACTURING PROCESS

The basic filament winding process used to fabricate the composite structure of the blade is widely used in industry to fabricate cylindrical shapes such as rocket casings and high-pressure pipes. A rotating mandrel, previously covered by a release agent, is wrapped by strands of fiberglass filaments which have been wetted with an epoxy or polyester resin. Filament winding noncylindrical shapes, such as the airfoil of a wind turbine blade, requires a unique systems operation of the filament winding equipment.

To provide the correct direction lay of the filaments, multiple axis control of the machine is necessary. Figure 5 shows schematically the operation of this winding process.

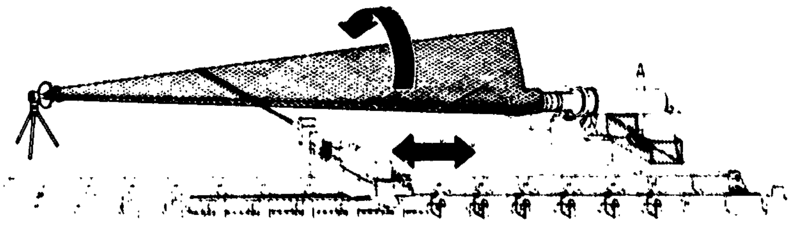

FIGURE 5. THE WIND TURBINE BLADE FILAMENT WINDING MACHINE CONTROLS ALL VARIABLES DURING WINDING

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The carriage, containing the spools of fiberglass filament and resin bath, travels along a track parallel to the rotating blade mandrel. All motions of the carriage are computer-controlled to follow the rotational position of the blade. This provides a specially-designed path of filaments. This unique orientation of the fibers creates the specially-designed composite structure. The complete winding of the blade requires over 400,000 program commands. Less than 100 hours of winding time is required. This is equivalent to an average fiberglass lay down rate of 200 pounds/hour.

The process starts by winding a number of layers of epoxy-coated fiberglass filaments on a one-piece spar mandrel, as shown schematically in Figure 6.

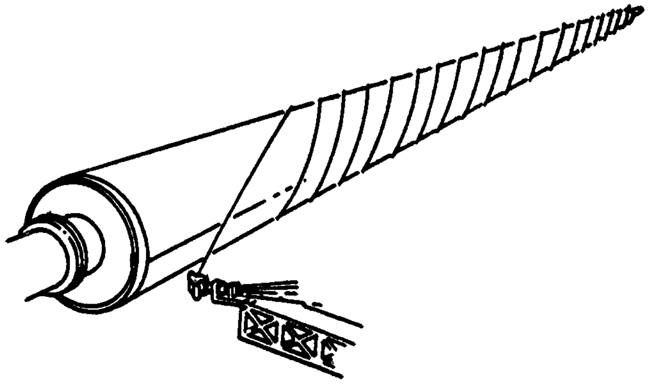

FIGURE 6. BLADE FABRICATION STARTS WITH FILAMENT WINDING OF THE SPAR

The mandrel is designed to be very stiff to obtain small deflections during operation. After the spar has been wound with the proper number of layers of filaments, it is air-cured briefly. A trailing edge shell mandrel of generally triangular cross-section is then positioned on the spar, as shown in Figure 7.

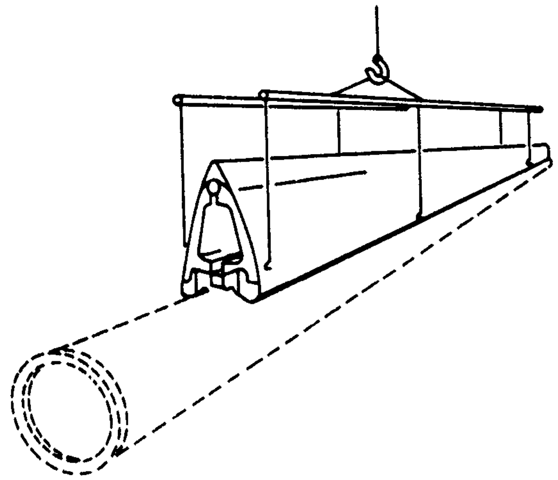

FIGURE 7. THE SHELL MANDREL IS MOUNTED ON THE FILAMENT-WOUND SPAR

This shall mandrel has an airfoil shape and twist which patterns the final blade shape. It is strapped in place and filament winding is resumed over the assembly. The straps are removed as the winding progresses and the winding continues until the proper number of glass filament layers have been applied. (Figure 8).

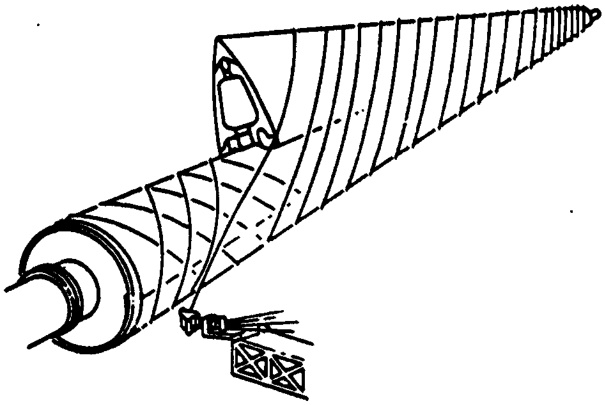

FIGURE 8. FILAMENT WINDING OF THE TRAILING EDGE TAKES PLACE RIGHT OVER THE SPAR/SHELL MANDREL ASSEMBLY

When the winding has been completed, the entire blade assembly is placed inside an oven and cured for several hours at an elevated temperature. The shell and spar mandrels are then removed. Attachment of the retention rings and bolts, as well as finishing operations, are then performed. Figure 9 shows a completed filament-wound blade before finishing operations in the factory, with another blade being prepared for shell winding.

Large wind turbine blades manufactured in the manner described have inherent advantages. Because the process is automatic, it lends itself to low-cost quantity production. Process variables are few and noncritical, simplifying quality control procedures. The structural characteristics result in long life and practically no inspection and maintenance. High performance is achieved because no compromise is required in aerodynamic planform and twist, and the resulting airfoil shape is smooth, accurate, and repeatable.

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FIGURE 9. ONE WIND TURBINE BLADE BEING FINISHED WHILE ANOTHER IS BEING PREPARED FOR SHELL WINDING.

QUESTIONS AND ANSWERS

R. J. Bussolari

From: O. Weinhart

Q: Can you say what the production cost per pound will be for the filament-wound blades? What reinforcement was used, E or S glass?

A: *Production cost will be four to five dollars per pound. E glass was used for reinforcement.*