DESIGN AND CONSTRUCTION OF A 10 kW HORIZONTAL AXIS WIND TURBINE (HAWT) WITH VARIABLE SPEED

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Abstract. *This paper presents aspects of the conception, design and manufacture of mechanical parts of a small horizontal axis wind turbine (HAWT) with variable speed. Initially, the mechanical design of the hub and pitch adjustment mechanism was developed. After that, the aerodynamic and structural designs were made. Finally, the turbine blades and the blade-to-hub fitting were constructed. High aerodynamic efficiency was obtained with a low cost system and simple constructive solutions. Computer programs were developed for aerodynamic analysis. Also, a design methodology was used in order to modify the optimum blade shape to match manufacturing requirements. Reduced loss of aerodynamic efficiency was achieved. Results for preliminary structural tests concerning blades strength and rigidity are presented.*

Keywords*: wind turbine, alternative energy, variable speed*

1. Introduction

Wind energy had attracted great interest as an alternative to the conventional sources of energy. It is renewable, it produces reduced impact on the environment and the neighboring communities and the experience and rehabilitees acquired in the last decades of operation of large wind generation systems around the world (Freris, 1989) certifies its viability.

A great potential, detected for Brazil, of about 10GW of usable power (CEMIG, 1994), is still not explored.

Import of complete wind turbines faces the problem of difficult adaptation of these equipment to conditions imposed by the Brazilian environment implying in high operational and maintenance costs. This fact indicates the need and urgency of developing a local technology.

Since the ‘60, the Center of Aeronautical Studies of the Department of Mechanical Engineering of the UFMG (CEA-UFMG) had developed skills in the design and manufacture of aircraft and propellers. Therefore, the possibility of using this knowledge for the development of small wind turbines suitable to Brazilian conditions was considered by CEA research team.

In this work several aspects of the design and manufacture of a 10kW horizontal axis wind turbine (HAWT) of variable speed are pointed out.

2. Design Philosophy

For a power output of 10kW rotor blade design parameters were analyzed and the final configuration lead to a design tip speed ratio λ=7 for wind speed of 10m/s and rotor diameter of 7m.

While lower cost presented by a two blades configuration a three blade turbine was adopted in order to reduce vibration levels.

Use of materials and processes of low cost and great availability, in regions away from the great urban centers, are goals considered in this project.

Beside the use of simplified constructive methods efforts are made to preserve aerodynamic efficiency.

Wooden spars were elected to ensure both high structural efficiency and fatigue strength with low cost and simple manufacturing tools. For the skin, fiber glass fabric/epoxy was chosen looking for low cost and easy construction compared with molding system blades. Ribs had been manufactured in plywood. The choice of NACA 23015 airfoil (Abbott, 1959), with low constructive sensitivity helps keeping high aerodynamic performance while simplified constructive process is preserved.

Experience in aeronautical construction developed by CEA-UFMG allowed obtaining light blades, around 60dN each, with adequate strength and rigidity.

The dissemination of this technology is facilitated by use of simplified manufacture processes. Blades can be fabricated with resources that can be found in small wood plants: a plain glass table for hand lay-up of skin plates; saw and planer for the manufacture of the wooden spars; saw for the manufacture of the ribs and manual stapler for the glue processes. Structural joints had been made by adhesive epoxy.

Figure 1 shows the hub/blades assembly in the early stage of the fabrication.

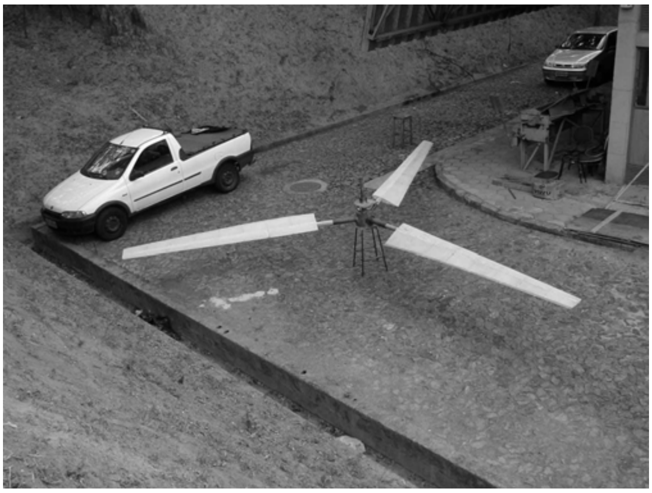

Figure 1. General view of the hub/blades assembly

3. Hub and Pitch Adjustment System Design

An overview of the feathering systems usually found in large turbines was made. High cost and complexity of these systems forced the development of a specific system for the turbine object of the present work, with both good performance and low price.

The proposed blade pitch change system works as follows: an electrical engine drives a spindle by belts. The spindle displacement leads to the axial displacement of a plate. Over this plate are three wheel mounted arm rods, each one linked to a blade. The arm rods are interconnected through springs that create forces to counterbalance the centrifugal effect. Figure 2 illustrates the system.

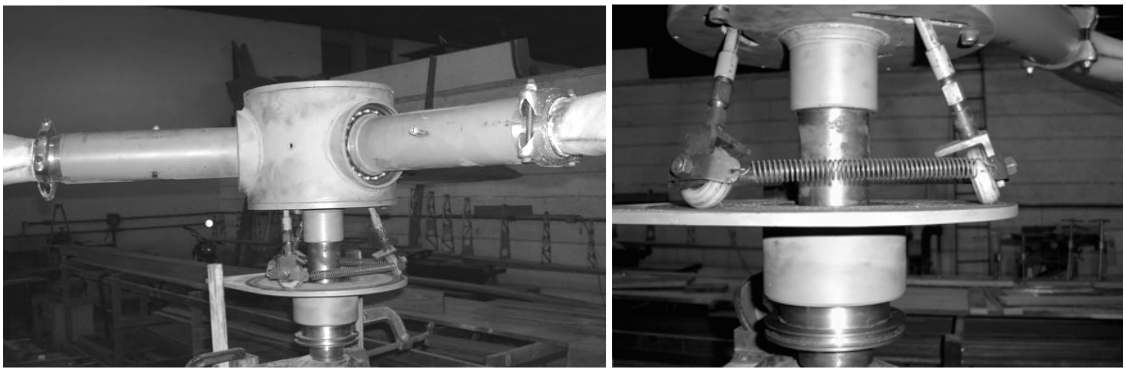

Figure 2. Pitch adjustment system view

4. Blades aerodynamic design

The main criteria for airfoil choice were aerodynamic efficiency (maximization of lift/drag ratio - L/D), low moment coefficient, low constructive sensitivity and low sensitivity to the superficial finishing.

Selected NACA 23015 airfoil was used in all blade span. This profile satisfactory fulfills the characteristics mentioned above and can be found in similar projects.

Aerodynamic design procedure is based on Glauert Theory or Vorticity Theory (Gourieres, 1980 and Burton, 2001).

This is a classic theory for rotary wings that allows the design of wind turbines with good efficiency. Glauert Theory is already being used in CEA-UFMG for the design of aircraft propellers (Ribeiro, 2000). Some more sophisticated theories, like the Panel Method, could be used, but they demand greater computational resources without offering significant differences in the results.

Two computer programs were developed: one for the attainment of the optimum blade geometry for a given operational condition - POT - and another one for the analysis of the blade aerodynamic performance of pre-established geometry - PAN.

Initially POT is used to determine optimum blade geometry. However, this geometry, calculated by POT, is often difficult to build. In the optimum blade leading and trailing edges curved lines imposes double bending in the blade skin.

Thus, in a next step, this geometry is modified in order to simplify and to adequate the blade shapes to manufacturing. A linearization of the chords is done by taking the values from the optimum configuration at r=0,5R and r=0,9R, as suggested by some authors (Kamal and Islan, 1995). This linearization allows the use of simple bending skin, offering significant reduction in manufacturing time and costs with small loss of power.

The new geometry, result of the linearization process, is further checked by PAN. If the aerodynamic efficiency of this new geometry is sufficiently close to the optimum one it is adopted. Otherwise, another geometry is tried.

Figures 3 and 4 present the comparison between optimum and linearized blades.

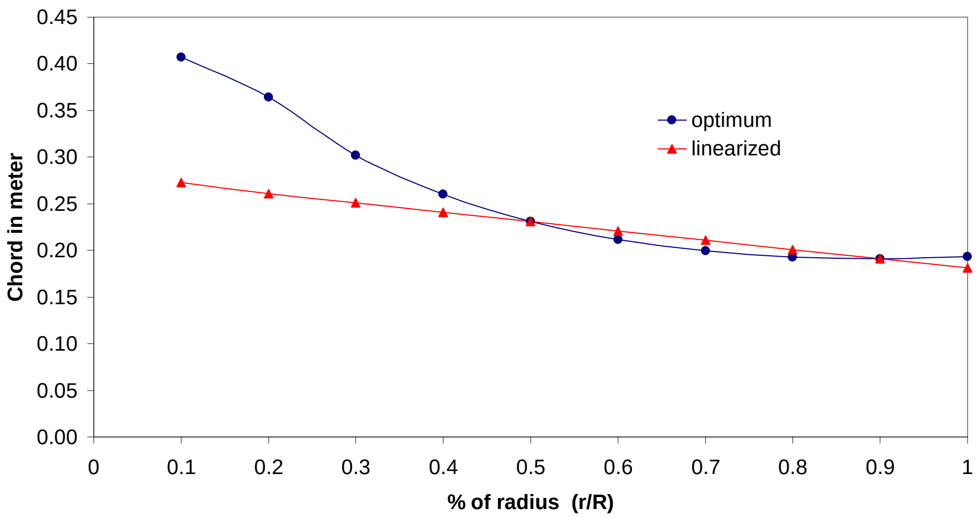

Figure 3. Optimum and Linearized Blade Chord Distribution

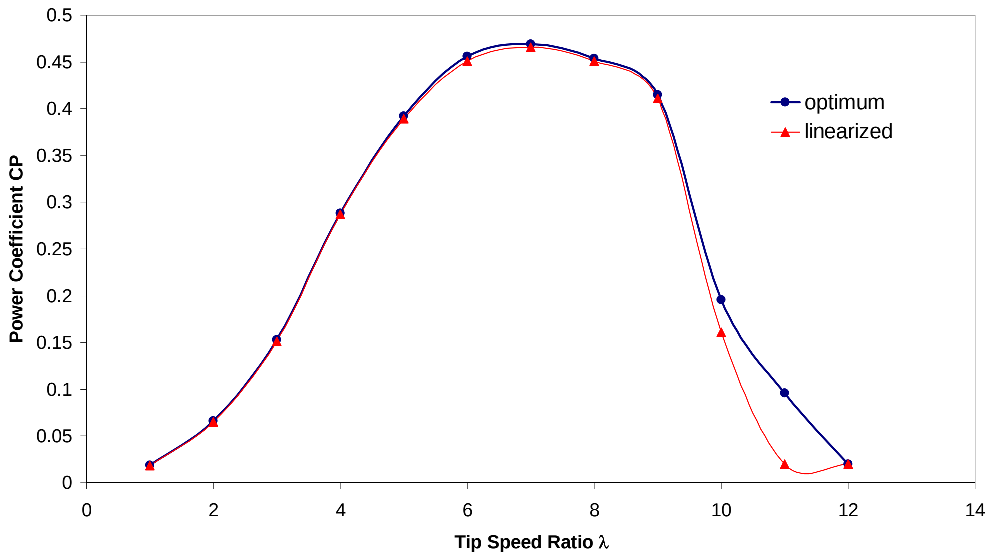

Figure 4. Variation of Power Coefficient with Tip Speed Ratio for Optimum and Linearized Blade

5.1 Preliminary Structural Analysis

Aerodynamic, gravitational and inertial loads were considered in a preliminary structural analysis of the components of the wind turbine. Loads due to gyroscopic effect represent only 5% of the maximum load imposed by flexional moment (Burton, 2001). Thus, in this structural analysis they will not be considered. Also, dynamic loads are not included in this preliminary study.

The IEC- International Eletrotechnical Commission 61400-1 Wind turbine generator systems – Part 1 Safety Requirements was used to establish structural design criteria as wind intensity classification and partial safety factors for loads. The critical conditions are not explicit in the literature. So, a combination of wind speed and rotational speed of the rotor was analyzed and limit curves were proposed delimiting safety regions in the graphics for tip speed ratio λ *versus* wind speed and rotational rotor speed *versus* wind speed, shown in Fig. 5 and Fig. 6.

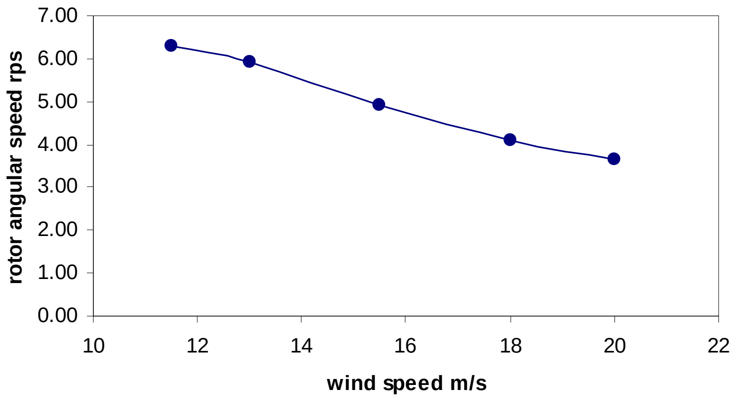

Figure 5. Safety operational zone for rotor angular speed versus wind speed

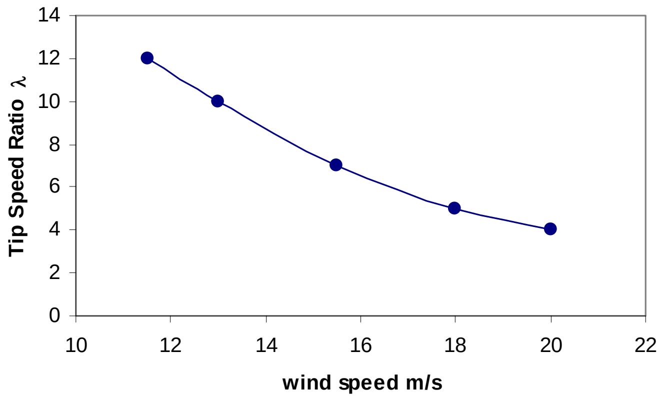

Figure 6. Safety operational zone tip speed ratioλ *versus* wind speed

It is assumed that wooden spars supports all flexural moment stress. A balance of aerodynamic loads and inertial loads actuating in axial direction was performed to determine this moment, as on models used for helicopter rotor structural calculus. The loads were calculated throughout 20 transversal sections. A Brazilian wood named freijó (*Cordia goeldiana*), usually applied in aircraft construction, was used to fabricate the massive section wooden spars.

Skins were made in fiber glass fabric/epoxy. A torsion box structure supports all the torsion load stress generated by the aerodynamic moment. Part of the skin only, located forward of the spars, is considered to support tensions. Also, torsion loads were calculated in 20 sections along the span.

Spars shall be designed in accordance with some constructive limits, as for example the height available that depends of chord length and thickness/chord ratio for each considered station.

The freijó ultimate stress of 117MPa (Ribeiro, 2001) was considered.

For the linearized chord distribution initially proposed the maximum available height for spar would be very short. Therefore, a new chord distribution was proposed in order to obtain stress values compatibles with the wooden spar use.

This new adjusted chord distribution is shown in Fig. 7.

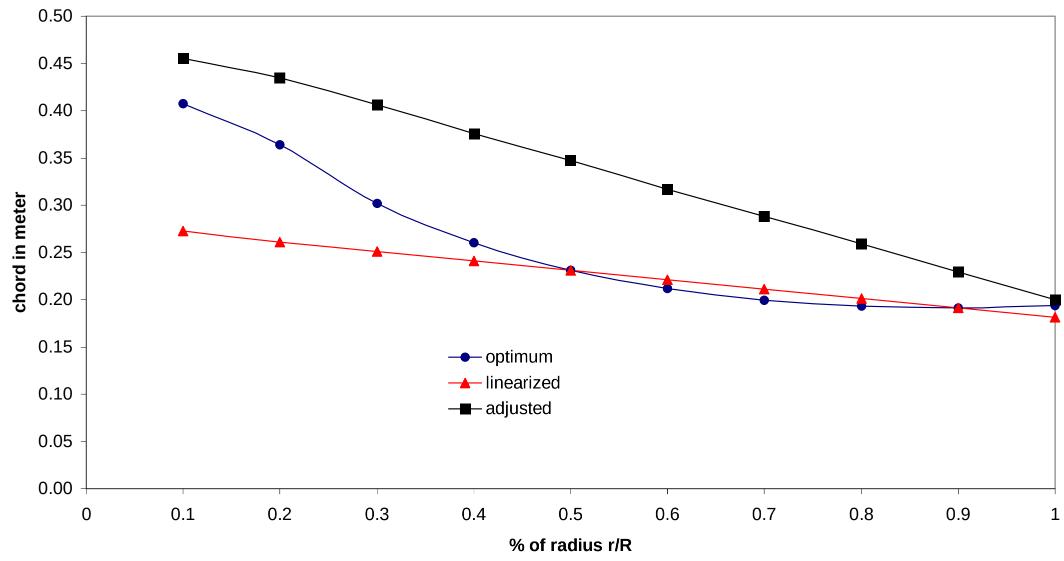

Figure 7. Optimum, Linearized and Adjusted Blade Chord Distribution

The new proposed blade shape was analyzed by PAN. A small reduction in maximum Power Coefficient was observed. Also, the Tip Ratio Speed where the CPmax occurs was lower than in the optimum blade shape.

Adopting a pitch angle of -2 degrees a flat region on the curve is observed indicating a good operational flexibility gain. Figure 8 illustrates this behavior.

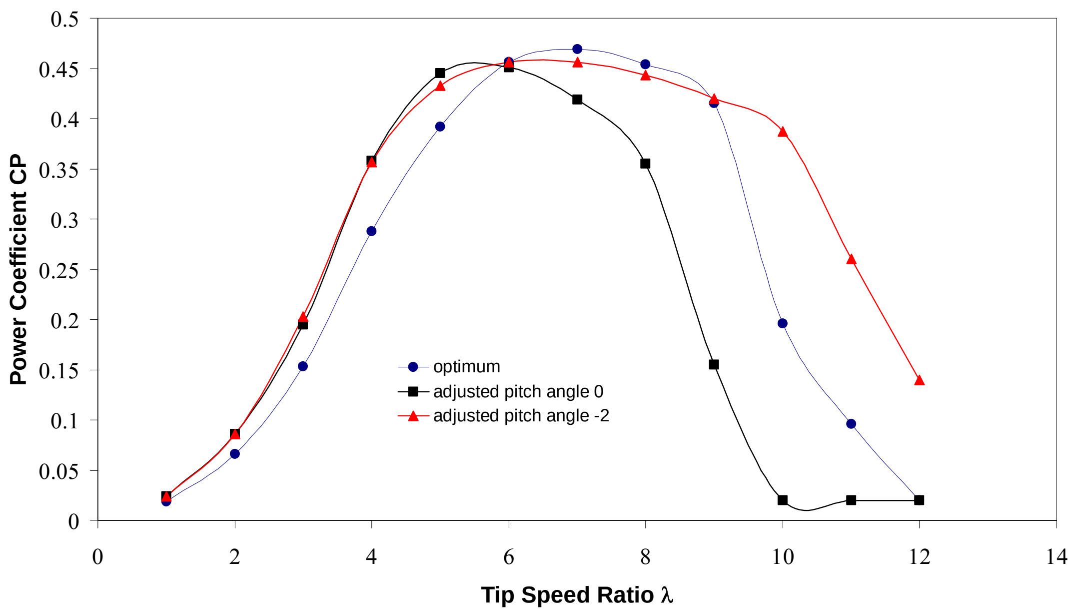

Figure 8. Variation of Power Coefficient with Tip Speed Ratio for Optimum and Adjusted Pitch Angles

6. Blade structural tests

The methodology used for the static structural tests of the blades is normally applied in aircraft industry. A complete loading set simulation included simultaneous application of aerodynamic loads and the relief produced by the centrifugal reaction at the blade/hub assembly. Load distribution was reproduced by means of bottles filled with adequate weight of water and hang along blade stations. The blade tests confirmed the strength of the blade structure and the hub fitting. Deformation values will be further used to feed the calculus routine in order to obtain more accurate data for centrifugal effects and dynamic behavior.

Figure 9 shows a local compression failure observed in the skin. The failure was totally elastic and no permanent deformation was registered after the withdrawal of the test load.

Figure 9. Local compression failure on the torsion box

Figure 10 shows a superposed view of one blade – with/without test load. In this test was simulated loads for wind speed of 10m/s and tip speed ratio λ =7. The total distributed load is of 550 N. At the blade tip vertical displacement of 0.515m was measured.

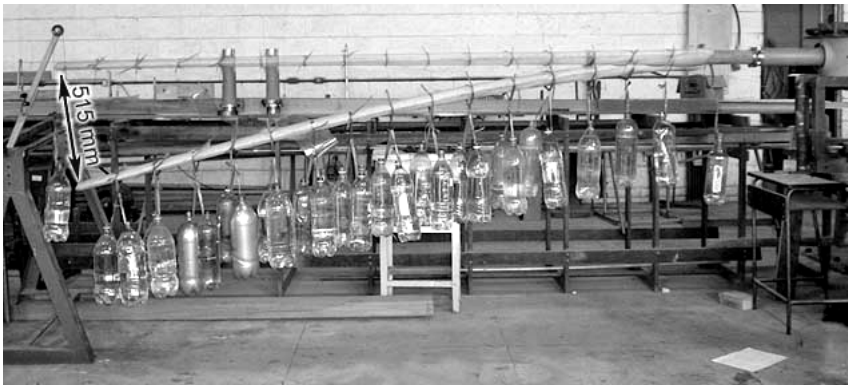

Figure 10. Superposed view of one blade – with/without test load

7. Conclusions

Methodologies normally used in light aircraft design, construction and tests were adopted in this wind turbine design with good results. The blades are light compared with blades build with conventional technologies, about 30% in mass reduction was observed.

The adopted wooden spars provided high specific strength eliminating fatigue problems that usually appears in metallic spars.

The original pitch adjustment system developed seems to work well and costs of the prototype are very low. Soon the wind turbine will be submitted to preliminary tests to confirm the estimated performance.

8. Acknowledgements

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