PASSIVE CYCLIC PITCH CONTROL FOR HORIZONTAL AXIS WIND TURBINES

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ABSTRACT

A new flexible rotor concept, called the balanced-pitch rotor*, is described. The system provides passive adjustment of cyclic pitch in response to unbalanced pitching moments across the rotor disk.

Various applications are described and performance predictions are made for wind shear and cross wind operating conditions. Comparisons with the teetered hub are made and significant cost savings are predicted.

INTRODUCTION

The two-bladed rotor with teetered hub has received almost universal acceptance as the most cost-effective configuration for multi-megawatt WECS. Despite this wide acceptance, the teetered hub has certain undesirable features which add to the cost and reduce reliability of the machine as a whole. These include:

- o Need for large tower clearances
- o Introduction of cyclic speed variations
- o Susceptibility to rotor damage during startup, shutdown, and survival conditions

The balanced-pitch rotor is expected to provide equal performance while avoiding these undesirable features. Savings on the order of 15 to 25 percent of rotor cost may be realized.

DESCRIPTION

The aerodynamically-balanced cyclic-pitch rotor (balanced-pitch rotor) is analogous to the teetered hub. Its main function is to reduce vibratory loads and improve yaw performance of wind turbine rotors. This is accomplished in the teetered hub by cyclic flapping in response to unbalanced thrust on the blades. In a similar manner, the balanced-pitch rotor produces cyclic pitch changes as a result of unbalanced pitching moments across the rotor disk.

The simplest balanced-pitch rotor configuration is shown in Figure 1. This is a two-bladed rotor with fixed collective pitch. The two blade root fittings are rigidly coupled together to form a single pitch shaft. This shaft is mounted in bearings so that the pitch axis of the two blades is free to rock back and forth. Blade airfoil and geometry are selected so that the blades pitch away from an increased angle of attack.

Also shown is an arm and bracket assembly rigidly fastened at right angles to the pitch shaft. This assembly couples the pitch axis to the rotor hub through the pair of springs shown, or through cushioned stops or dampers.

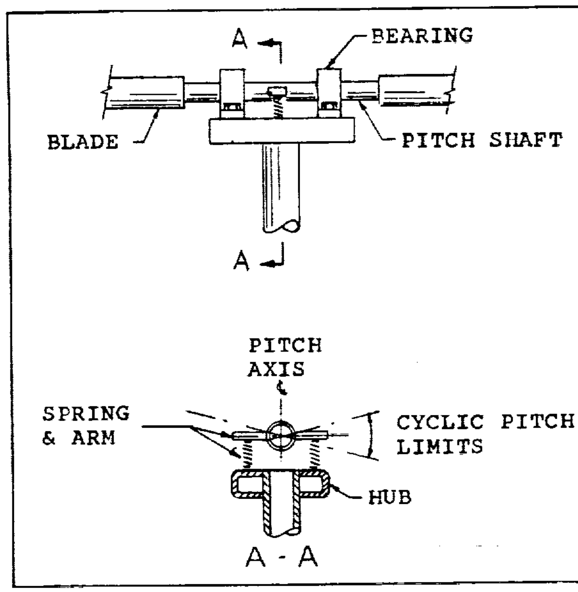

Figure 1 - Balanced-pitch rotor having two blades and fixed collective pitch.

WIND SHEAR EFFECTS

The schematic diagram, Figure 2, represents a conventional two-bladed rotor with rigid hub in the presence of wind shear. The rotor experiences high cyclic flapping,pitching, and yaw moments which have a large adverse effect on the cost and performance of horizontal axis wind turbines.

*Patent Pending

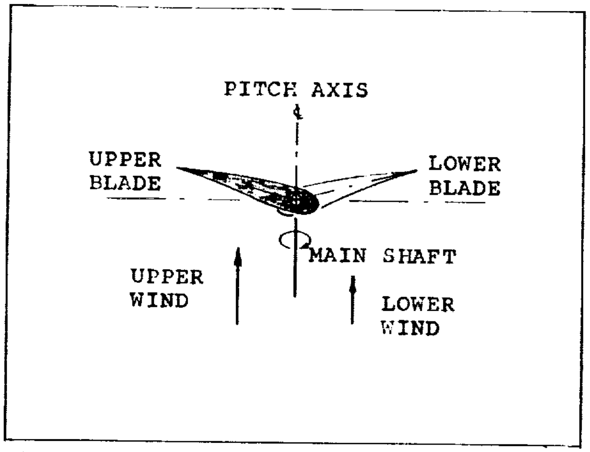

Figure 2 - Two-bladed rotor with rigid hub subject to wind shear

Figure 3 depicts the same wind shear conditions utilizing a balanced-pitch rotor. Areas of unequal wind velocity are seen to alter the pitch axis (not the fixed collective pitch) as the blades pass through. The result is a significant reduction or elimination of the cyclic loads and unstable yaw performance experienced by the conventional rotor with rigid hub. Tower shadow affects are expected to be compensated in a similar manner. This action also is expected to avoid the normal yaw angle deviation experienced by free yaw systems under wind shear conditions.

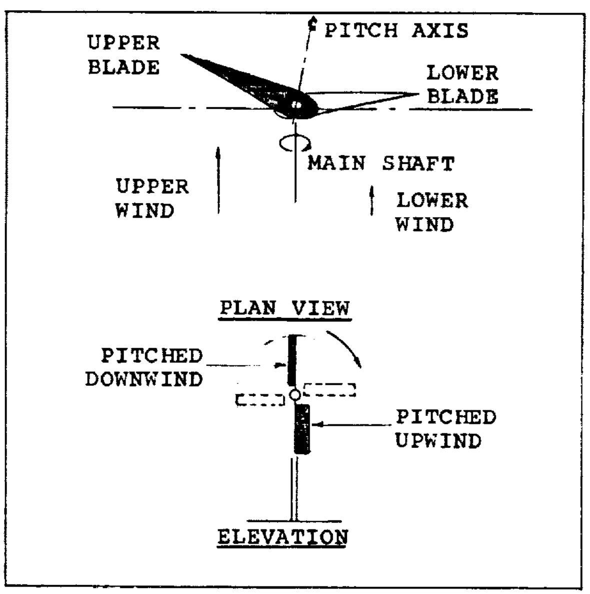

Figure 3 - Two-bladed balanced-pitch rotor subject to wind shear.

CROSS-WIND EFFECTS

As shown in Figure 4, the balanced-pitch rotor adjusts itself to cross-wind effects in much the same way it does under wind shear conditions. The result is expected to be a relatively small, steady yawing moment which, in a free-yaw system, aligns the turbine shaft to the new wind direction.

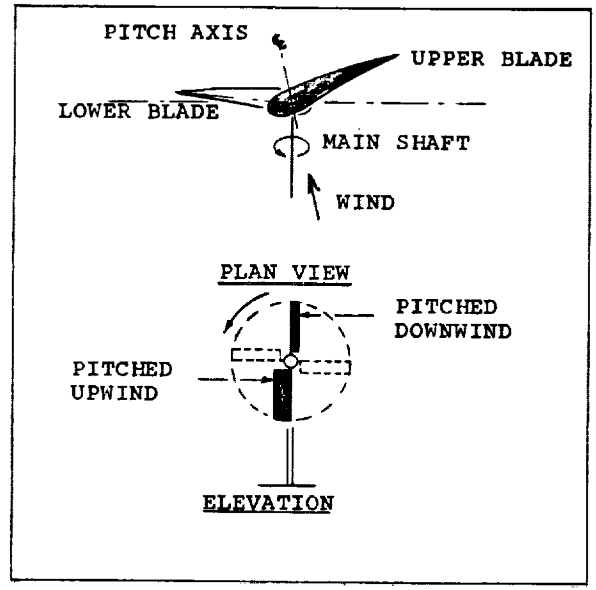

Figure 4 - Two-bladed balanced-pitch rotor subject to cross winds

APPLICATIONS

Fixed Pitch Configurations

As shown in Figure 1, the balanced-pitch rotor may easily be applied to fixed-pitch rotors simply by adding bearings at the hub. These bearings are not required to carry blade centrifugal loads. This same simple arrangement is applicable to rotors with partial-span collective pitch control. Pitch control linkages, of course, will have to be flexible where they pass between the hub and the rocking pitch shaft.

Variable Pitch With Rotating Actuators

The configuration shown in Figure 5 applies to units with full-span collective pitch control in which hub-mounted actuators are used. Passive cyclic pitch control is accomplished by interconnecting all actuators at a rocking yoke which is mounted in bearings and supported from an extension of the hub. Dampers are shown here which serve to limit the rate and extent of cyclic pitch excursions.

In most cases it is possible to design yoke geometry and that of the pitch linkage system to avoid substantial collective pitch changes through the full range of cyclic pitch excursions. In some cases, however, slight changes in collective pitch may be purposely introduced to effect turbine output power if cyclic pitch variations are extreme.

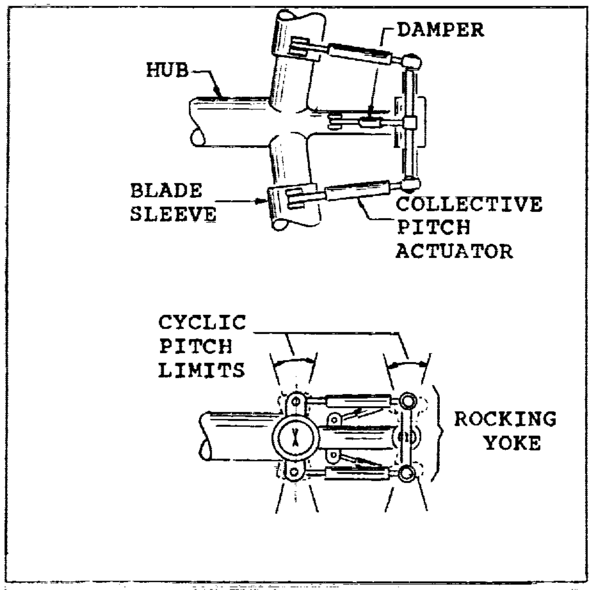

Figure 5 - Balanced-pitch rotor with rotating actuators for full-span collective pitch control.

Variable Pitch With Linear Actuators

Figure 6 shows an application utilizing a pitch control rod for full-span collective pitch control. Once again, it is only necessary to add a rocking yoke to which pitch control linkages are connected. In this design, cushioned stops are shown mounted on the pitch control shaft to limit the extent of cyclic pitch excursions.

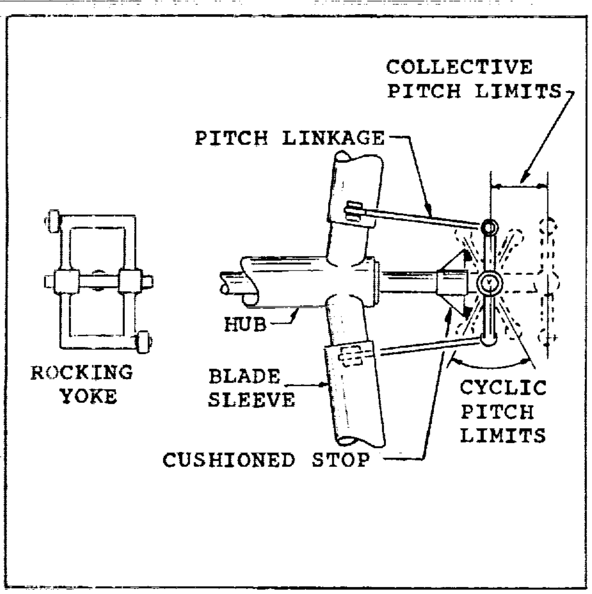

Figure 6 - Balanced-pitch rotor with linear actuator for full-span collective pitch control.

More Than Two Blades

For rotors having more than two blades, the rocking yoke shown in Figure 6 must be replaced with a ball joint or universal joint which is allowed to tilt in any direction. Blade linkages are then connected to arms extending around the periphery of the joint.

COMPARISON WITH TEETERED HUB

Tower Clearance

The teetered hub requires a very large distance between yaw axis and hub for adequate tower clearance at the blade tip. This distance is minimal for the balanced-pitch rotor, as shown by the comparisons of Figures 7, 8, and 9. Such a large overhang results in much higher costs for the low-speed shaft, bearings, nacelle and yaw structure.

Figure 7 compares configurations for a downwind rotor with coning. The teetered rotor does not gain much clearance from coning because of the need to gravity balance the rotor. This positions the teeter hinge far outboard from the intersection of the two blade axes.

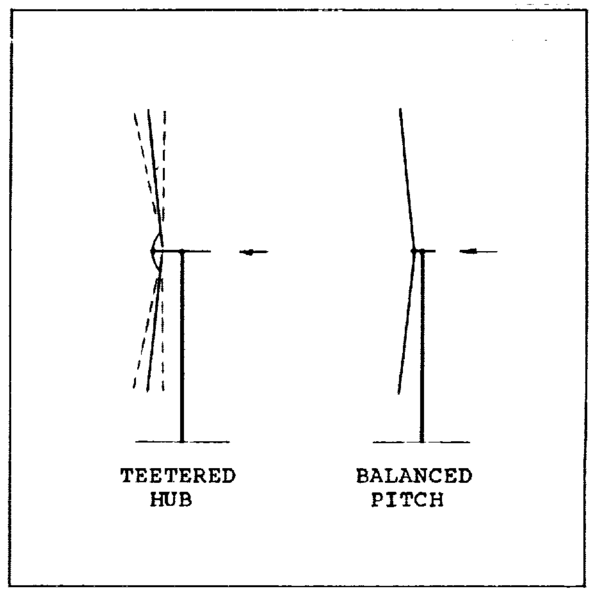

Figure 7 - Hub overhang with downwind rotors with coning.

Similarly, as shown in Figure 8, a tilted rotor provides extra clearance only if the normal wind direction is perpendicular to the tilted rotor disk. In the case of the balanced-pitch rotor, a tilt may be very effective regardless of the wind direction. Cyclic loads normally associated with such a tilt are greatly reduced or eliminated. Of course, any coning or tilt will cause a reduction in energy capture.

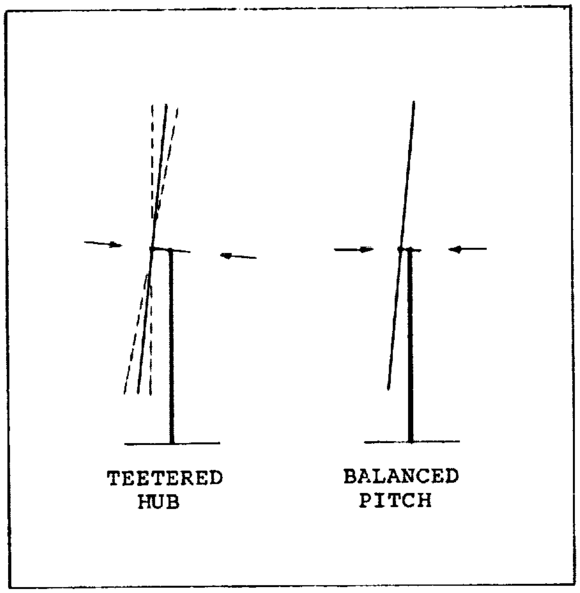

Figure 8 - Hub overhang with tilted rotors.

The unconed rotors shown in Figure 9 illustrate best the overhang advantage of the balanced-pitch rotor compared to the teetered hub.

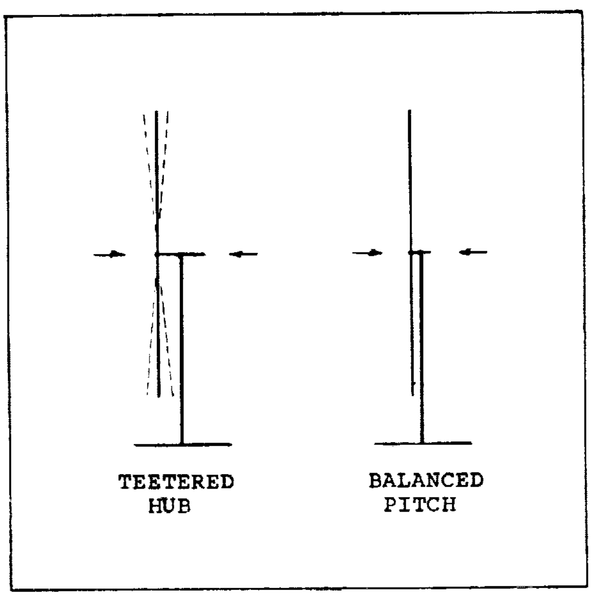

Figure 9 - Hub overhang with unconed rotors.

Cyclic Speed Variations

The teetered hub, in a sense, trades blade and hub cyclic loads for cyclic speed variations in the power train. These show up as large torque fluctuations in a constant speed machine. These torque fluctuations may be reduced to acceptable levels by means of a torsionally flexible low-speed shaft, flexible gear box mounting, or a slip coupling in the power train. These special features are costly in terms of capital investment and/or energy losses, and they all tend to increase maintenance costs and reduce reliability.

The balanced-pitch rotor is not expected to introduce any such speed or torque variations.

Survival Conditions

The teetered hub performs beautifully as long as aerodynamic and centrifugal loads are in balance. When not in balance, the huge teetered masses are very difficult to deal with. For this reason, all large WECS with teetered hubs must have brakes to prevent teeter operation during startup, shutdown, and parked conditions. These brakes are critical to the very survival of the unit and must be in operating condition through extended power outages.

No such startup, shutdown, or survival facilities are required with the balanced-pitch rotor.

Yaw Performance

The teetered hub and balanced-pitch rotor are expected to be equal in avoiding cyclic yaw moments. In a free-yaw system, however, the balanced-pitch rotor is expected to track more accurately than does the teetered rotor.

On the other hand, the teetered hub avoids cyclic gyroscopic forces while the balanced-pitch rotor does not.

CONCLUDING REMARKS

A new flexible rotor concept, called the balanced-pitch rotor, has been described and shown to be potentially equivalent to the teetered hub in performance. Certain advantages of the new concept have been pointed out, including reduced tower clearances, avoidance of cyclic speed variations, and superior survival characteristics. For two-bladed multi-megawatt wind turbines these features have been estimated to save some 15 to 25 percent of rotor cost and to increase reliability of the machine as a whole.

REFERENCES

1. Glasgow, J. C., and Miller, D. R.: Tip-controlled Rotor: Preliminary Test Results from MOD-0 100kW Experimental Wind Turbine, AIAA/SERI Wind Energy Conference, April 9-11, 1980, Boulder, Colorado.

2. Douglas, Richard R.: The Boeing MOD-2 - Wind Turbine System Rated 2.5 MW, NASA Conference Publication 2106, DOE Publication CONF-7904111.

QUESTIONS AND ANSWERS

G.W. Bottrell

From: L. Mirandy

Q: I can't see why the aero forces will automatically adjust the blade pitch in an optimum manner to reduce loads. Will you explain why?

A: *The system is only effective to reduce the difference in loads across the rotor disk. Load differences produce a differential pitching moment which increases the pitch of one blade and decreases that of the other until pitching moments are equal (assuming a frictionless system).*

From: F.W. Perkins

Q: What happens to your tower clearance when the rotor stalls? Why is this concept different from conventional pitch flap coupling?

A: *I would not expect blade deflection at rotor stall to be as large as that of a 6 degree teeter plus blade deflection. This concept and conventional pitch-flap coupling achieve the same results. We believe this concept will be far less expensive.*

From: Anonymous

Q: Does this concept also eliminate the pair of spindle thrust bearings in a normal two-bladed HAWT?

A: *No, not to my knowledge.*

From: G. Beaulieu

Q: What is the effect of this system on blade torsional frequencies? Is there any danger for blade flutter?

A: *I believe there is a danger of blade flutter and this will require further analysis. No flutter was observed in the limited tests performed to date.*