WTG ENERGY SYSTEMS' ROTOR - STEEL AT 80 FEET

Robert E. Barrows
WTG Energy Systems, Inc.
Buffalo, New York 14203

INTRODUCTION

The 80 foot diameter rotor discussed in this presentation has been installed and operational on WTG Energy Systems' MP1-200 wind turbine generator system since the summer of 1977. The MP1-200 wind turbine is installed as part of the Island of Cuttyhunk's electric power utility grid system. Cuttyhunk Island is located approximately 14 miles off the coast of southern Massachusetts (fig. 1).

The MP1-200 wind turbine was developed, fabricated and installed by WTG Energy Systems as a production prototype. The MP1-200 is a synchronous generating system rated at 200 kilowatts at 28 mph wind velocity. Constant 60Hz, 480VAC current is produced directly from the wind turbine's generator at +/- 1% accuracy throughout the machine's operating range. A micro-processor based control system utilizing electrical load modulation is utilized to maintain constant rotor speed.

The MP1-200 rotor is a fixed pitch design. This configuration was chosen for its low cost and adaptability to sophisticated electronic control systems. As part of the Company's development program, WTG Energy Systems conducted a study of both fixed pitch and variable pitch rotors as speed control devices for synchronous generating systems. This study resulted in a specification for the speed control with a response time of .5 seconds. This criteria eliminated the variable pitch rotor configuration as a rotor speed control device since response time to speed changes caused by changes in wind velocity was far to slow to meet the requirements of synchronous power generating systems.

MP1-200 ROTOR DESIGN

The MP1-200 rotor shown is of all steel construction for reasons of simplicity, low cost and high inertia. The high inertia obtained by this type of construction greatly reduces the rotor's acceleration due to wind gusting and thus simplifies the control system. The blades are twisted from tip to root 14 degrees. The twist distribution used is the best straight line fit to the analytical exact pitch vs. rotor radius curve. An untwisted blade will suffer badly in the loss of startup capability in a fixed pitch type machine, and running efficiency in all types of machines. The fixed pitch, constant speed rotor design of the MP1-200 was chosen for its high reliability and cost effectiveness.

The tips of each blade rotate in the pitch plane to an angle of 60 degrees. This function is used primarily as an overspeed shut down device. The tips are held in the run position against heavy duty springs by hydraulic pressure. When the hydraulic pressure is lost the tips are sprung into the shut down position.

The preliminary design of the rotor was predicated on the required power output at 28mph wind velocity, the site's wind regime and energy requirements at the proposed site. The NASA developed GA(W)-1 air foil section was chosen for its high lift coefficient and good start up characteristics. The blade plan form and thickness distribution was chosen so that there is mimimum blade interaction. The maximum Reynolds Number was obtained with this configuration. The tip losses due to the rectangular plan form are an important factor except at very high angles of attack. In this operating mode the rotor is already putting out maximum power and the lower efficiency is helpful in keeping the machine from exceeding its name plate rating.

ROTOR DESIGN SPECIFICATIONS

The structure of the rotor was designed to withstand many different loads some of which are shown in Figure 2. The major loads involved are the gravitational loads and the hurricane wind loads on the blade spars. The major dynamic vibrational force drivers are the gravity loads and the wind shear loads. The major stresses occur in the rotor spar at the connection of the spar to the hub and the reduction end of the spar section (see fig. 3). In relation to the fatigue sensitive areas the stresses are kept below 15,000 psi. basic stress. In the non-fatigue sensitive areas the stresses are below 30,000 psi. basic stress. The first natural harmonic of the blade perpendicular to and in the plane of rotation is over 2.5 cps.

The blade spars are constructed of SAE 1026 seamless steel tubing, the stamped reinforced ribs are of 18 Ga. steel, welded to the spar on 12 inch centers, and the blade skin is 18 Ga. galvanized sheet steel riveted and bonded to the ribs. The hub is cast in two sections. The hub material is of high toughness, 60-40-18 ductile iron. The pitch of the rotor is set to produce maximum efficiency at approximately 2 mph higher then the installation site's annual mean wind velocity (16.9mph @ Cuttyhunk Island). The rotor blade pitch is set at the time of field assembly. The pitch is maintained by the clamp fit of the blade spars installed between the two halves of the hub.

ROTOR PERFORMANCE

Within the operational envelope it can be shown that the fixed pitch rotor on the MP1-200 has a power cofficient of over .4. The reason behind this is at low wind velocities the blade angle of attack to the relative wind is minimum, thus a low drag factor exists. In high winds the blade is working at a high coefficient of lift, high angle of attack and has the torque to over come the higher drag related to this operating condition.

The fixed pitch design also allows us to use the stalling effect above the system's rated wind velocity to limit the power output. Blade stall has proved not to affect a rapid change in power output, but, rather a gradual loss of efficiency, as desired. This affect can be seen in Figure

The three blades have been used in order to improve the startup characteristics of a fixed pitch rotor. As shown in Figure 4, start up and power production regularly occur in an 8 mph wind.

COST

The sale price FOB the plant in Buffalo, New York as described, is approximately $40,000. This price represents approximately 18% of the total cost of the MP1-200 system. The cost breakdown of the rotor, by components, see Figure 5, shows that the two most expensive parts are the rib and hub fabrication, each accounting for 18.4% of the total rotor cost.

The largest single cost is for labor, accounting for 26.8% of the total. The labor rate is $18.90/hr (1978 $). In an analysis of the production and design of this rotor system, WTG Energy Systems concluded that, with a limited production schedule of five units tooling, material and fabrication costs could be cut by 20%, and assembly labor costs cut by 30%. Therefore the potential savings for a production run of five units would be 50% for a total FOB price of approximately $20,000(all dollars are assumed to be 1978 $), or $100 per rated kilowatt.

FUTURE R & D REQUIREMENTS AND SUGGESTIONS

The areas in the design and operation of the MP1-200 rotor system, in particular, and fixed pitch rotor systems, in general, requiring additional research and development are listed below.

1. A detailed analysis of the stalling characteristics of large, fixed pitch rotors should be carried out. This should include field testing to document the rotor thrust and torque forces, and, rotor vibrational dynamics from startup,

pre-stall, to the fully stalled rotor and beyond to the machine's rated cut-out wind velocity.

2. During the field testing of the MP1-200 system it has become apparent that the rotor operation has some stabilizing effect with regard to the dynamics of the tower. A detailed analysis of the gyroscopic effect(s) of large rotors on tower stabilization should be carried out. This could lead to significant reduction in the cost of both the tower and foundation for large wind turbines.

CONCLUSION

To date the rotor has seen well over one million, fully reversing, maximum load, fatigue cycles in the maximum stress areas with no component failure or signs of metal fatigue. Since the stresses caused by the in plane gravitational loads are by far the most significant, we feel confident that the MP1-200 rotor system, as installed on Cuttyhunk Island, is a fatigue resistent design. The rotor on the MP1-200 has been subjected to wind velocities in excess of 100 mph on four separate occasions. Neither the rotor nor any part of the wind turbine has suffered any damage as a result.

The rotor has been subjected to overspeed conditions of approximately 70% of its rated speed (80 rpm) resulting in no adverse effects on the rotor, drive line components or support systems.

The rotor has demonstrated good startup characteristics and power production in 8mph wind velocities.

Figure 1. - MP1 - 200 wind turbine generator. (Photo courtesy of Eagle Signal Division, Gulf and Western Manufacturing Company.)

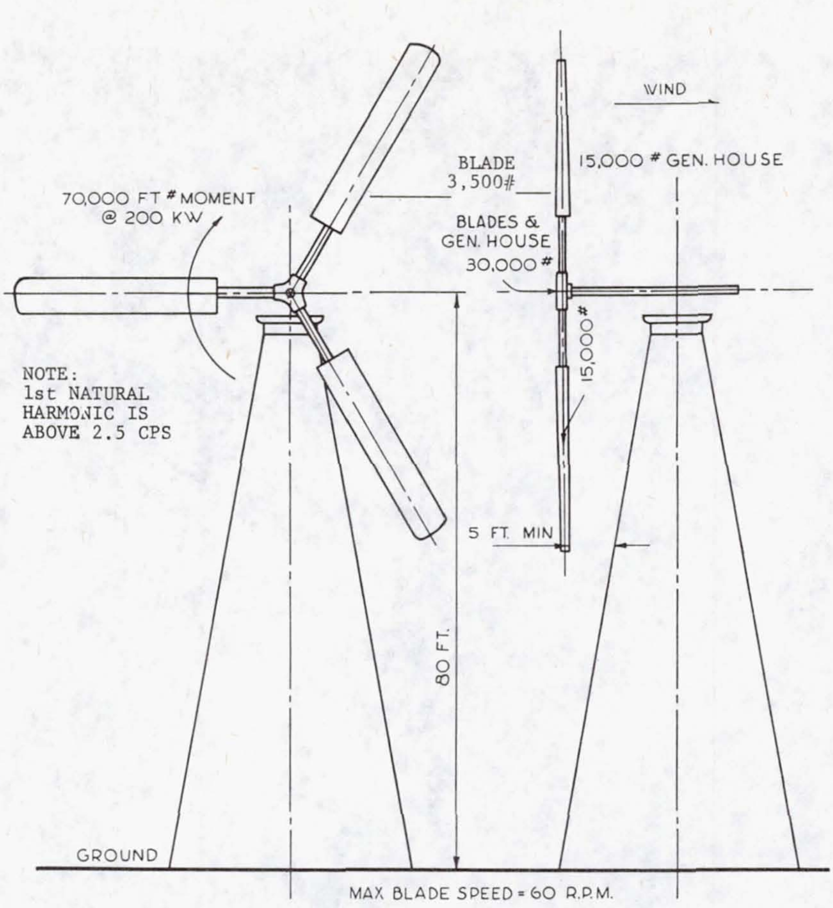

Figure 2. - Loads.

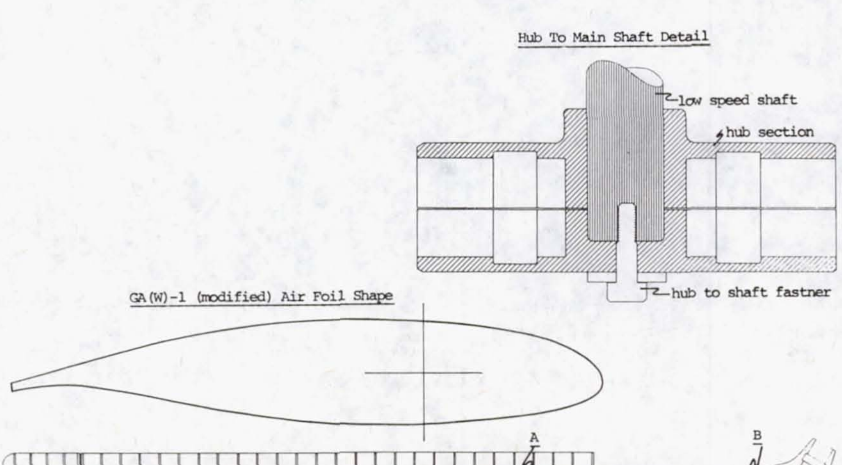

Figure 3. - Rotor assembly plan.

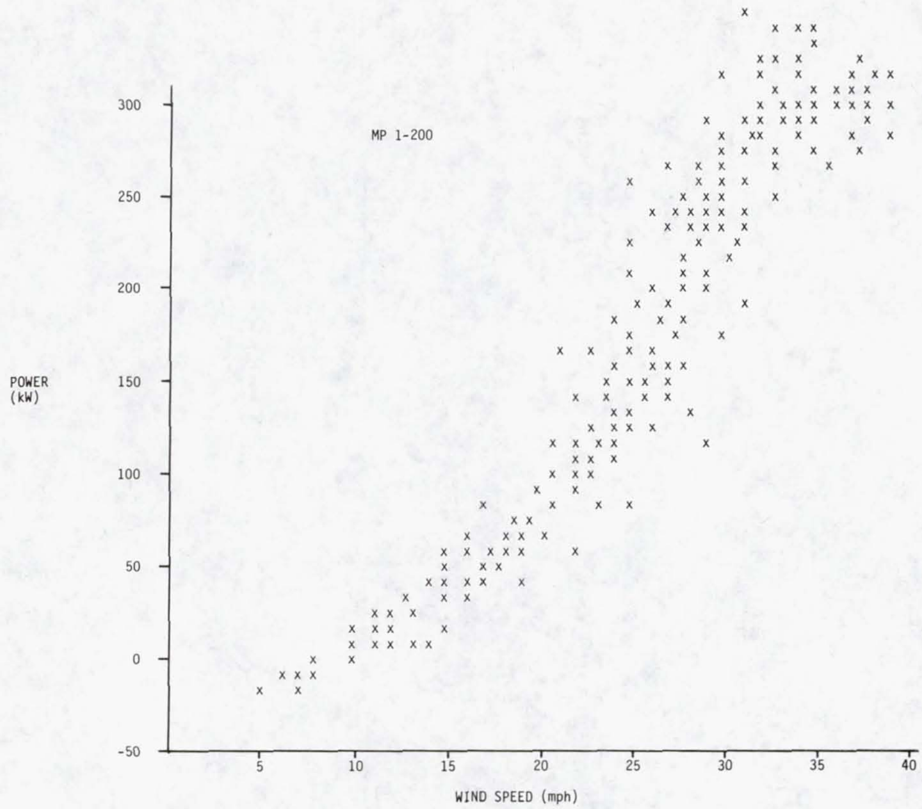

Figure 4. - Generator output curve.

COMPONENT	PER CENT OF TOTAL COST	COST
RIBS	18.4%	$ 7,560.00
SPARS	12.3%	5,040.00
HUB	18.4%	7,560.00
TIP FLAPS	13.8%	5,670.00
BLADE SKIN	5.4%	2,250.00
MISC. HARDWARE	4.9%	2,030.00
LABOR	26.8%	10,810.00
TOTAL	100%	$ 40,920.00

Figure 5. - Cost breakdown MP-1 200 rotor system by major components (sale price for limited production).