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STATUS REPORT OF 100 KW EXPERIMENTAL WIND TURBINE GENERATOR PROJECT

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ABSTRACT

The Energy Research and Development Administration and the NASA Lewis Research Center have engaged jointly in a Wind Energy Program which includes the design and erection of a 100 kW wind turbine generator. This test machine consists of a rotor turbine, transmission, shaft, alternator, and tower. The rotor, measuring 125 feet in diameter and consisting of two variable pitch blades, operates at 40 rpm and generates 100 kW of electrical power at a wind velocity of 18 mph. The entire assembly is placed on top of a tower 100 feet above ground level. The machine is currently in the assembly phase and will be ready for operation in August, 1975.

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TURBINE GENERATOR PROJECT

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SUMMARY

The national wind energy program includes research and development on the many applications and concepts of wind energy systems. As a part of this program, the NASA Lewis Research Center (LeRC) has designed and is constructing a 100 kW wind turbine generator currently being installed at the Plum Brook Station of LeRC near Sandusky, Ohio.

This test machine consists of a rotor turbine, transmission, shaft, alternator and tower. The rotor contains two blades 125 feet in diameter operating at 40 rpm and generating 133 kW of power (100 kW at the generator) at an 18 mph wind velocity. The rotor is connected to a low-speed shaft (40 rpm) which drives a gear box. In the gear box the shaft rpm are increased from 40 to 1800 rpm. A high-speed shaft connects the 100 kW alternator to the gear box. The entire assembly is placed on top of a tower 100 feet above ground level.

The wind turbine will be utilized to obtain design, performance, and operational data necessary to evaluate the technology of large wind turbines, and the potential of wind as an alternative source of energy. The machine is currently in the assembly phase and will be ready for operation in August, 1975.

INTRODUCTION

Recent shortages in the supply of clean energy, coupled with increasing costs of fuel, have forced the nation to reassess all forms of energy including wind power to determine their practicality. The national wind energy program, which originated at the National Science Foundation (NSF), is now directed by the Energy Research and Development Administration (ERDA) and includes research and development on the many applications and concepts of wind energy systems. Agreement was reached that, under the overall program management of ERDA, the NASA-Lewis Research Center would provide project management for a portion of that program (ref. 1).

As a part of this program, LeRC has designed and is constructing a wind turbine generator large enough to assess the technology requirements and engineering problems of large wind-turbine generators, yet small enough that construction and development costs do not exceed available budgets. To meet these requirements, a 100 kW machine was selected as the candidate size (ref. 2). This machine will be mounted on a tower 100 feet high, and will utilize two large blades 125 feet in diameter which are capable of pitch change and full feather. A test program will be conducted on the machine over the coming two to three years.

Data from this test program is aimed at providing technology, designs, operating experience, and performance data on wind-energy conversion systems needed to determine if wind energy can be utilized to help meet the nation's energy needs at costs that are competitive with other existing systems. This report describes the present status of the 100 kW test machine project.

PROJECT OBJECTIVE

The objective of this experimental wind turbine generator project is to provide, as soon as possible, engineering data for use as a base for the entire wind-energy program and to serve as a test bed for components and subsystems. The performance evaluation of the machine will emphasize the following:

1. To collect engineering performance data for use as a base for program direction, and for design of other follow-on wind-turbine generators of all sizes. This data will include energy and power output at various wind speeds, performance data on control systems, and loads, stresses, and dynamic response data on components such as blades, hub, and tower.

2. To identify the components and subsystems whose costs and maintenance need to be reduced; to acquire a basis for making realistic cost estimates for future designs.

3. To acquire data and experience on erecting and servicing a WTG for both attended and unattended operation.

4. To provide a test bed for field testing new and improved components and subsystems for windmills of this and other sizes.

5. To evolve design concepts for alternate applications.

SYSTEM DESCRIPTION

The 100 kW experimental WTG consists of a rotor turbine, transmission train, yaw assembly, and tower (figs. 1 and 2). The rotor turbine operates at 40 rpm, generating 100 kW of electrical power at 18 mph wind velocity (fig. 3). The rotor blades are located downwind of the tower. This arrangement provides maximum safety from blades striking the tower; also, with this orientation, the tower is subject to less dynamic interference. The hub and blades are connected to a low-speed shaft (40 rpm) which drives a gear box. In the gear box the shaft rpm is increased from 40 rpm to 1800 rpm. A high-speed shaft connects the gear box to the 100 kW alternator. This entire assembly is placed on top of a tower 100 feet above ground level.

Table I lists the general specifications of the 100 kW experimental WTG. The coefficient of power (C_p) as a function of rotor tip speed to wind speed (λ) is plotted in figure 4 for a number of blade pitch angles. The coefficient of power (C_p) is defined as the ratio of rotor power extracted by the rotor to the power of the wind in the rotor disk area.

Rotor Turbine

Blades. - The rotor has two all-metal blades; each blade is 62.5 feet long and weighs approximately 2000 pounds. Table II summarizes the blade specifications. The blades are designed to provide 133 kW of power at 18 mph wind speed when rotating at 40 rpm. They are twisted a total of 26.5° (non-linear) and have an NACA 23000 airfoil contour. The blades were fabricated by the Lockheed Company (fig. 5). Figure 6 shows a blade being unloaded at the Flight Research Building, LeRC. Two blades have been delivered to LeRc and are being inspected and checked prior to assembly to the hub.

Hub. - The hub connects the blades to the low-speed shaft. It is of the fixed type, i.e., it is bolted rigidly onto the main shaft allowing only the blade pitch-change degree of freedom. It also houses the mechanical gears, linkages, actuators, etc., necessary for changing the pitch of the blades (figs. 7 and 8). Wind loads, both steady and gusting, and centrifugal loads are absorbed by the hub and transmitted to the low-speed shaft.

Pitch Change Mechanism. - The pitch-change mechanism consists of a hydraulic pump, a pressure-control valve, actuator and gears for rotational movement of the blades. The type of pitch-change mechanism is similar to that used in the aircraft industry on some early propellers. This is a torque actuator (fig. 9), (in this case a rack-and-pinion type actuator) that turns a master gear which in turn rotates the blades through bevel gears mounted on the roots of the blades (fig. 7). The hydraulic pump is mounted separately on the structure and the hydraulic fluid brought into the shaft via rotating seals. Figures 8, 9, 10 and 11 show the hub, actuator, pitch change mechanism and the hydraulic system during assembly.

Drive Train Assembly and Yaw System

Bed Plate and Yaw Control. - The 100 kW WTG is supported on a large gear-bearing assembly and bed plate which is capable of rotating (yawing) the entire machine on top of the tower. The yaw rate is 1/6 of a rpm and is operational even when the machine is not generating power. The bed-plate supports the rotor, the transmission train, alternator, and all shafts and bearings. Figure 12 shows a sketch of the yaw control and bed plate with all the components mounted on it. Figure 13 shows a photograph of the yaw system mounted on the assembly stand. The yaw system is being assembled at LeRC for test prior to erection at the site.

Transmission Train. - From the hub the torque is transmitted to the alternator through a 45/1 ratio gear box (fig. 14). The hub transmits the high-torque low-rpm to the gear box via a large low-speed (40 rpm) shaft. Out of the gear box a high-speed (1800 rpm) shaft transmits the low-torque high-rpm to the alternator through a belt system. The entire assembly is supported on the bed plate. It is enclosed in a fiber-glass cylinder for protection from the environment. Figure 15 shows the transmission train assembled to the bed plate at LeRC. Checkout and operating test of the transmission train are presently underway at LeRC.

Alternator. - The alternator is an 1800 rpm synchronous two-bearing self-cooled type with a direct connected brushless exciter and regulator (fig. 16). The regulator includes power, potential, and current transformers. The alternator is rated at 125 kVA, 0.8 power factor, 480 volts. It is a three-phase, 60 hertz, Y-connected machine.

Tower

The tower is 100 feet tall, constructed of steel, and is of the pinned-truss design, resting on a concrete foundation (fig. 17). It must withstand the high wind and rotor-thrust loads, both steady and cyclic, during theoperation of the machine. It must also serve as part of a test bed by providing easy access to the machine for personnel to perform maintenance, etc. The weight of the tower is 40,000 pounds without the ladders and platforms and 60,000 pounds with all of the accessories. The tower is in final assembly at the test site, and is scheduled for completion by the middle of June, 1975.

Controls

The wind turbine will generate approximately 100 kW of electricity at wind velocities of 18 mph and greater. Between 8 mph and 18 mph the electrical power will be generated as a function of the wind velocity. From 18 to 40 mph wind velocities the machine generates 100 kW of electrical power; that is, the variable pitch blades rotate toward feather spilling the excess power. Below 8 mph and above 40 mph, the turbine blades will be placed in the feathered position. Initially the alternator will be operated asynchronously with a load bank. Later, the wind turbine will be connected to the local utility grid and operated synchronously with the local power grid.

Summary of Costs

Table III shows a cost breakdown for the 100 kW machine. These costs are approximate, and engineering costs and costs of spares have not been included. The purpose of this table is to show, in the first column, the approximate cost of this WTG in terms of dollars per kilowatt. Table III shows that the cost is approximately $5500 per kilowatt for the 100 kW Mod-O machine, with about 54 percent of the cost occurring in the rotor system and 23 percent in the tower and foundation.

The second column shows our present estimates for the cost of a 200 kW Mod-OA machine. This WTG is essentially the same as the Mod-O, with only minor changes. The major difference in the Mod-OA machine is the elimination of the test bed features, and the reduction of design margins of safety (in this case the machine is uprated to 200 kW). Present estimates indicate the cost of follow-on Mod-OA WTG's to be approximately $2300/kW.

CONCLUDING REMARKS

As a part of the Wind Energy Program, a 100 kW Wind Turbine Generator has been designed, and is being fabricated to be erected at the Plum Brook Station of LeRC. This test machine has been designed to generate 100 kW of electric power at wind velocities between 18 mph and 40 mph. Between 0 and 8 mph, and at wind velocities in excess of 40 mph, the turbine blades will be placed in a feathered position and will not operate. Between 8 and 18 mph the electric power generated will be a function of the wind velocities.

This wind turbine will be utilized to obtain design and operational experience necessary to evaluate the technology of large wind turbines. The goal of this project is to provide the technology, designs, operating experience and performance data to evaluate wind as an energy source. This report has briefly described the 100 kW machine and has presented the current status of the major components. The 100 kW machine is presently planned to begin operation in August, 1975.

REFERENCES

1. Thomas, R.; Puthoff, R.; Savino, J.; and Johnson, W.: Plans and Status of the NASA-Lewis Research Center Wind Energy Project. To be presented at Joint Power Conf., Portland, Oreg., Sept. 28 - Oct. 1, 1975.

2. Puthoff, Richard L.; and Sirocky, Paul J.: Preliminary Design of a 100 kW Turbine Generator. Presented at Intern. Solar Energy Soc., Ft. Collins, Color., Aug. 21-23, 1974.

TABLE I. - GENERAL SPECIFICATIONS OF 100 KW EXPERIMENTAL WTG

Power:	
Blade power (assuming 7° coning; 0° inclination, kW	133
Generator output, kW	100
Desired rotor power coefficient	0.375
Cut-in wind speed (first load applied), m/sec	3.52 (8 mph)
Rated wind speed (100 kW bus), m/sec	7.92 (18 mph)
Feather wind speed, m/sec	26.4 (60 mph)
Hurricane wind speed, m/sec	66 (150 mph)
Location to rotor with respect to tower	downwind
Direction of rotation (looking up-wind)	counterclockwise

TABLE II. - BLADE SPECIFICATIONS

Number of blades	2
Diameter, m	37.5 (125 ft)
Cong angle - fixed, deg	7
Effective diameter of circle swept by airfoils, m	37.2 (124 ft)
Inclination of axis of rotation relative to horizontal, deg	0
Effective circular area swept by airfoils, m^2	1071.9 11,910 ft^2)
Area of one blade projection on swept circular area, m^2	16.1 (179 ft^2)
Slenderness ratio relative to blade radius	22
Rotor rpm	3
Maximum thrust from the wind (two blades), newtons	44 482 (10 000 lbf)

TABLE III. - SUMMARY OF COSTS FOR 100 KW EXPERIMENTAL WTG AND SIMILAR FOLLOW-ON WTG SYSTEMS

	First 100 KW Experimental WTG		Follow-On 200 kW WTG Systems	
Rotor				
Blades	200K	54%	160 K	55%
Hub/Pitch Change	95K		95 K	
Mechanical				
Gear Box	16K	11%	17.5 K	13%
Bedplate, Shafts, etc.	43K		45 K	
Electrical Generator, Controls	68K	12%	50 K	11%
Tower, Foundation	128K	23%	100 K	21%
TOTAL	550K		467.5 K	
	$/kW ~ $5500/kW		$/kW ~ $2340/kW	

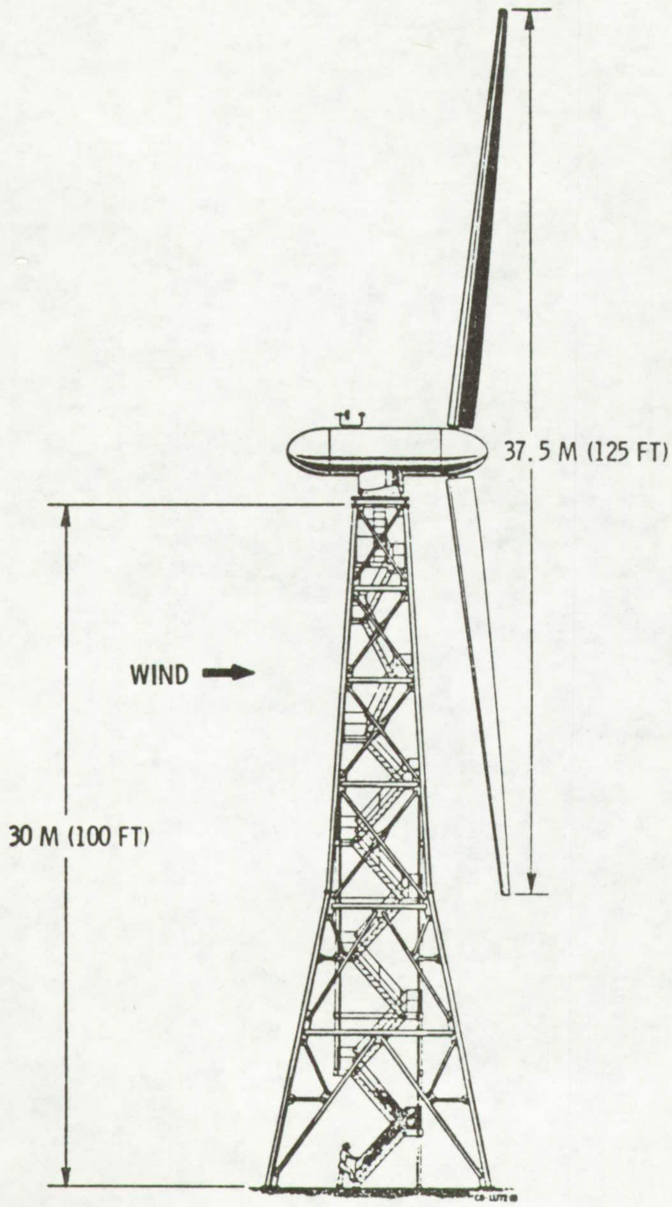


Figure 1 - 100-kilowatt experimental wind turbine generator.

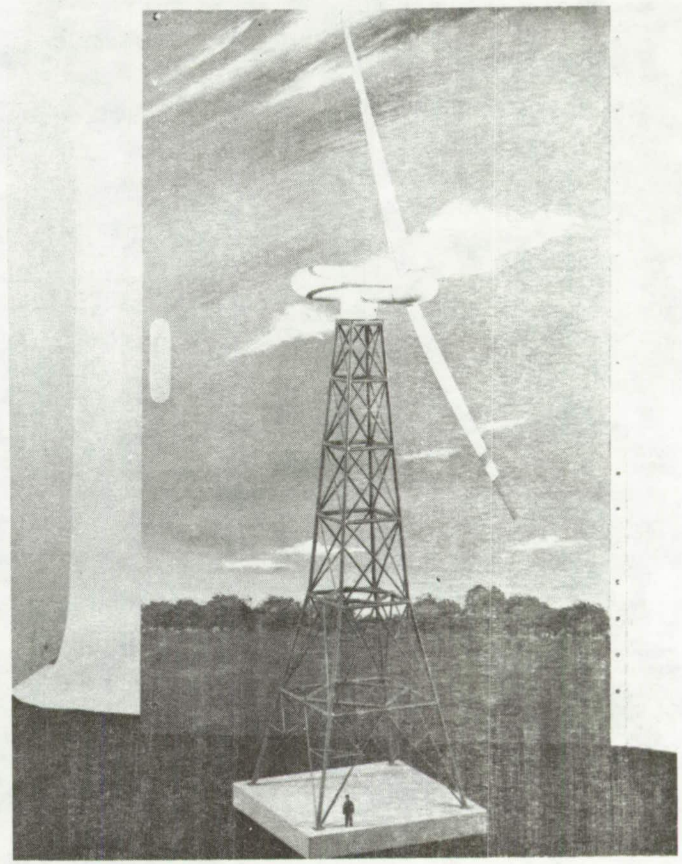


Figure 2. - Model of 100 KW wind turbine generator.

Figure 3. - ROTOR POWER AS A FUNCTION OF WIND SPEED

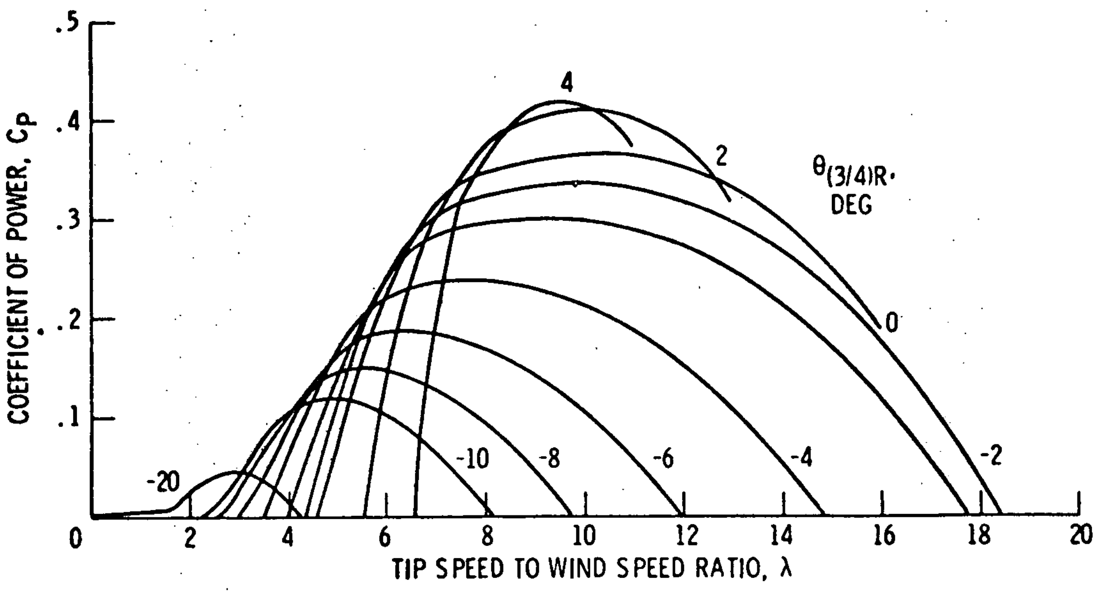
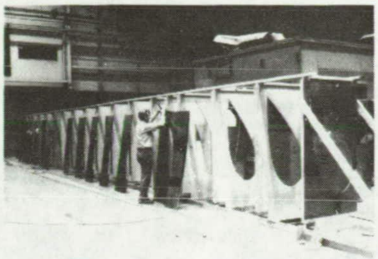
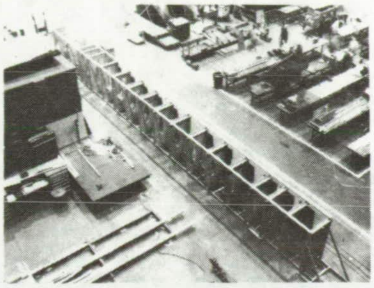


Figure 4 - Coefficient of power for 100-kilowatt experimental wind turbine generator.



BLADE TEMPLATES



ASSEMBLY FIXTURE

BLADE ROOT END FORGINGS

Figure 5. - 100 KW experimental wind turbine metal blades - Lockheed. CS-73753

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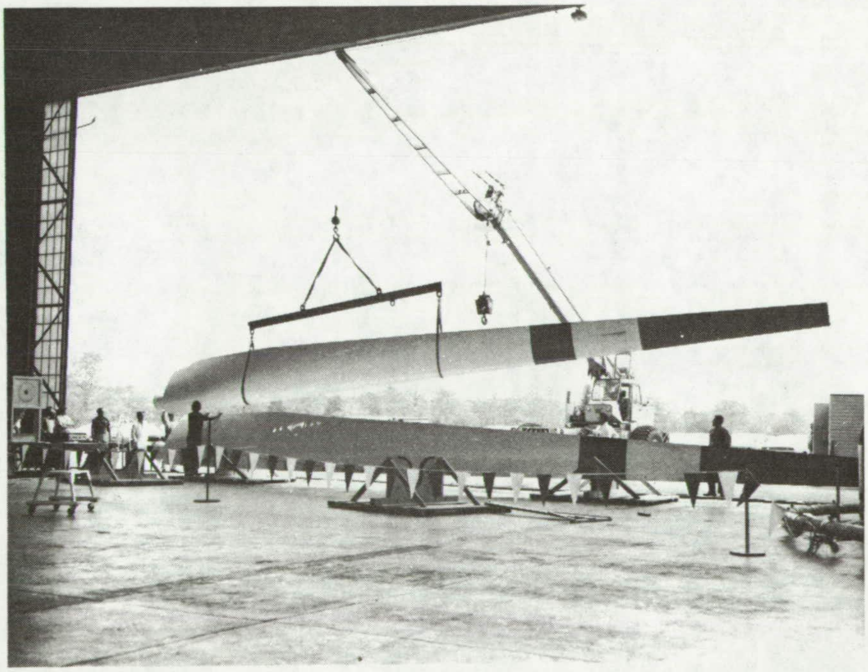

Figure 6. - Unloading a 100 KW wind turbine blade.

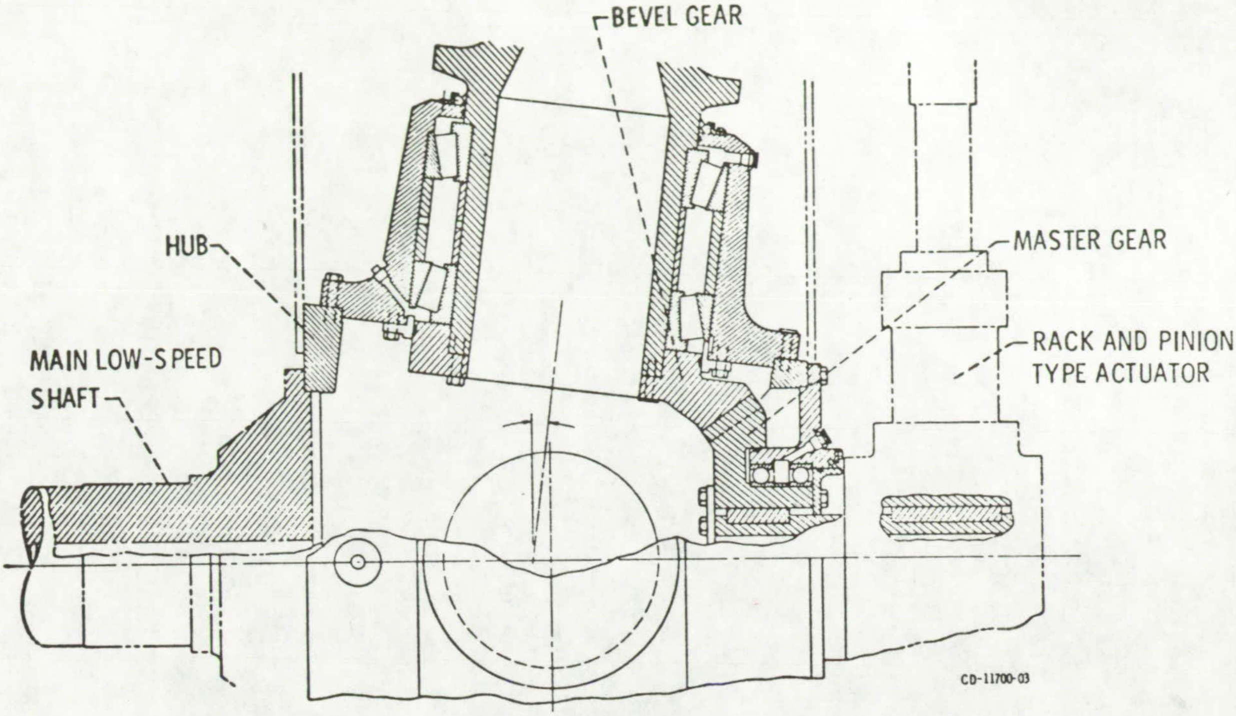

Figure 7. - Hub and pitch change assembly - fixed hub.

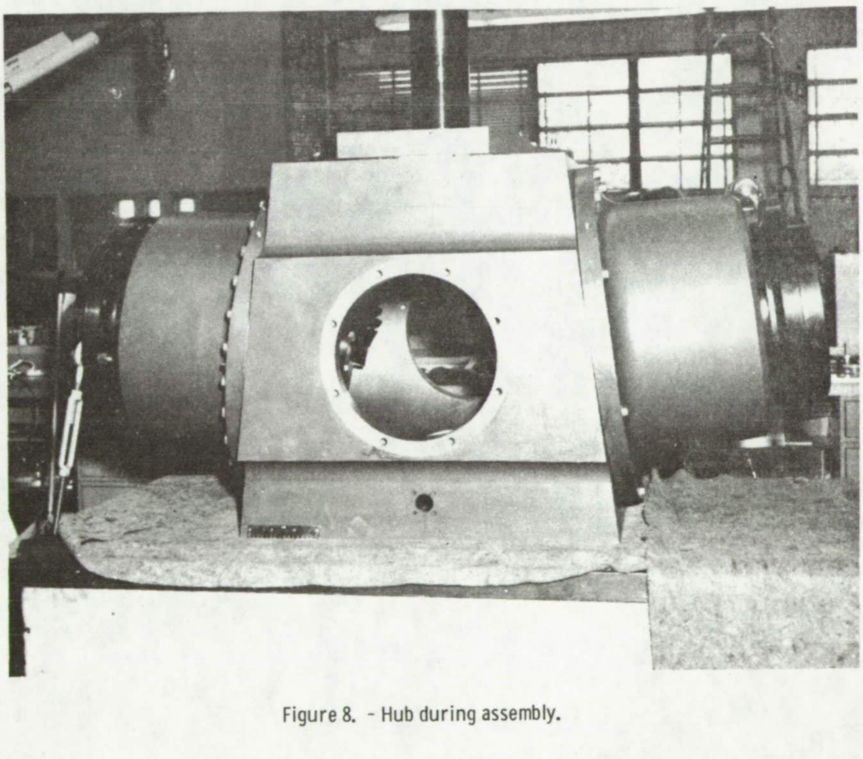

Figure 8. - Hub during assembly.

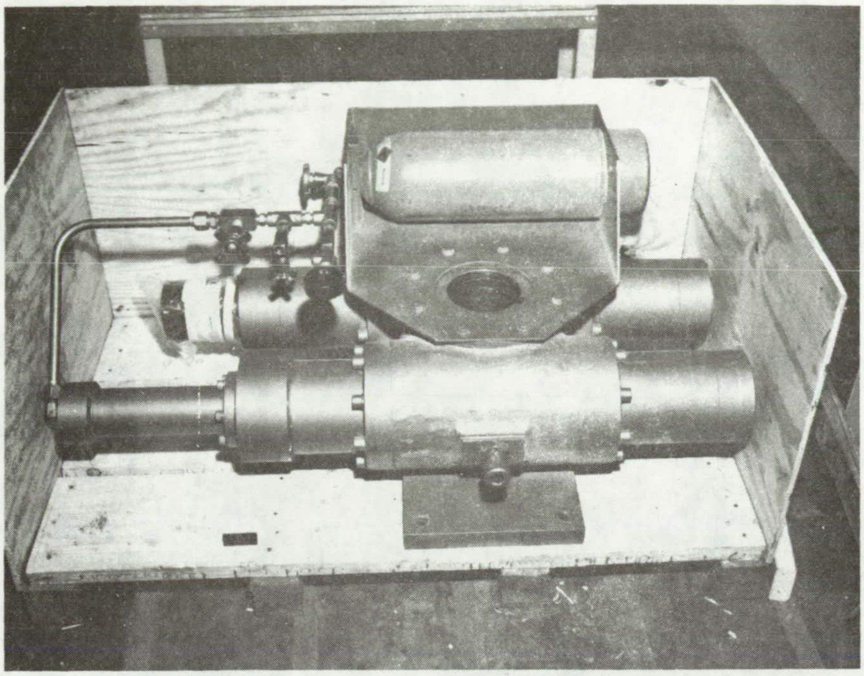

Figure 9. - Torque actuator for 100 KW experimental WTG.

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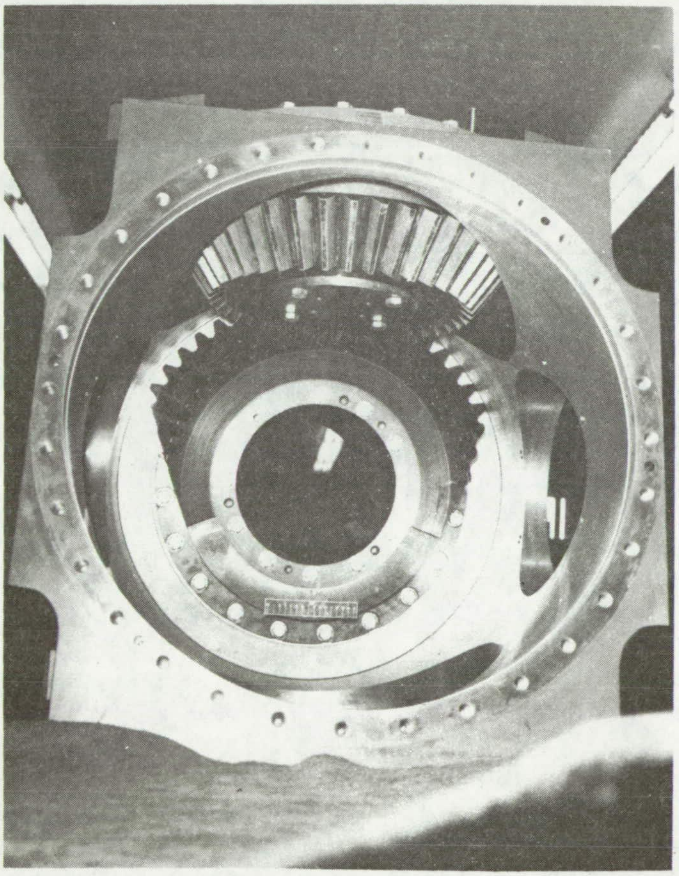

Figure 10. - Pitch change mechanism during assembly.

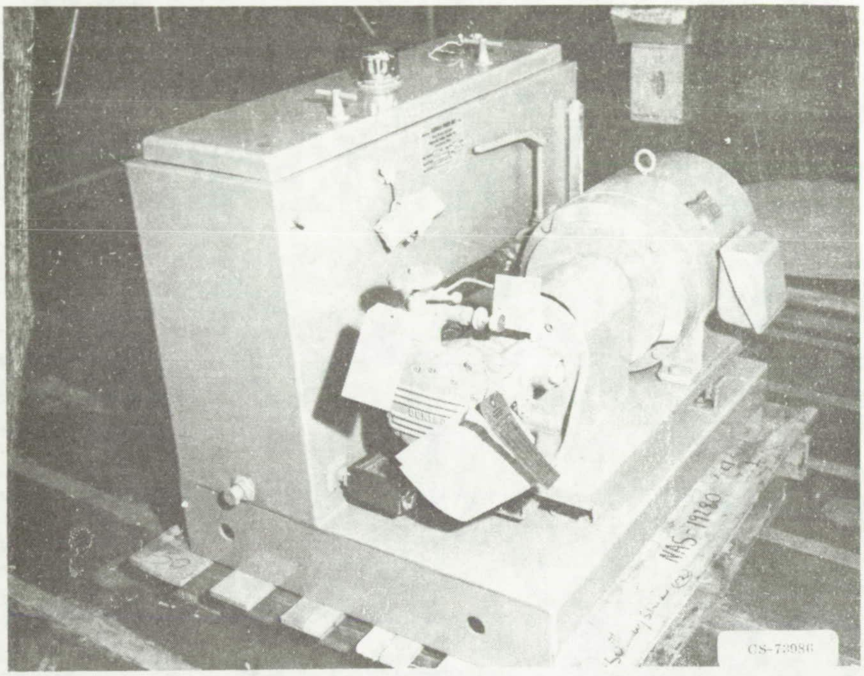

Figure 11. - Hydraulic power package.

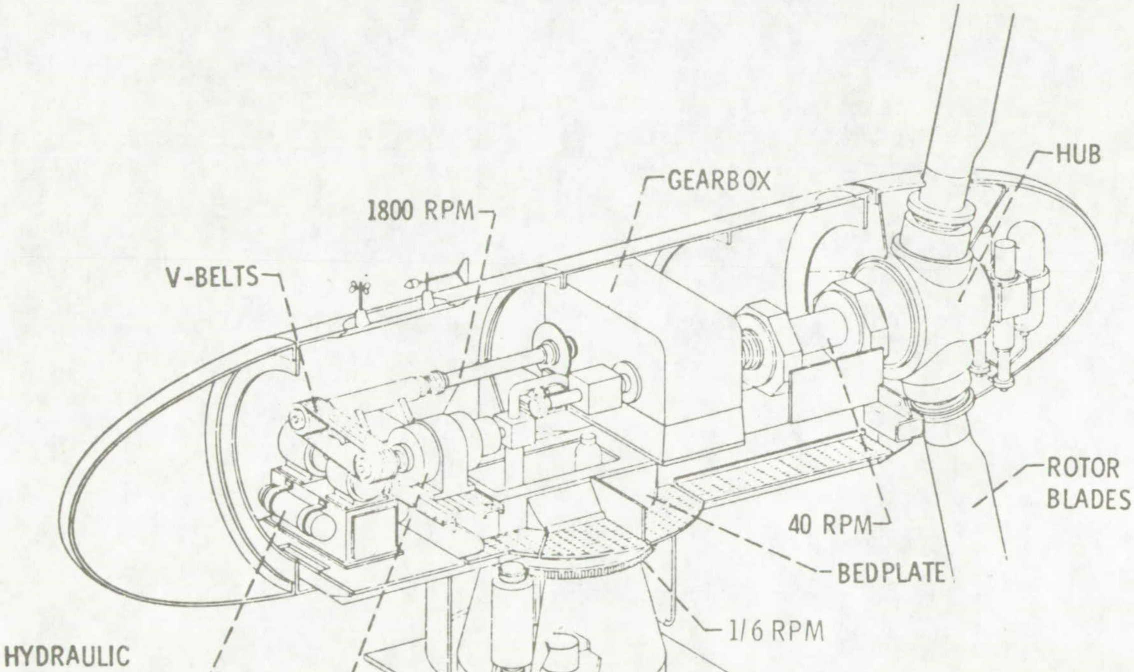

Figure 12. - 100-kilowatt wind turbine drive train assembly and yaw system.

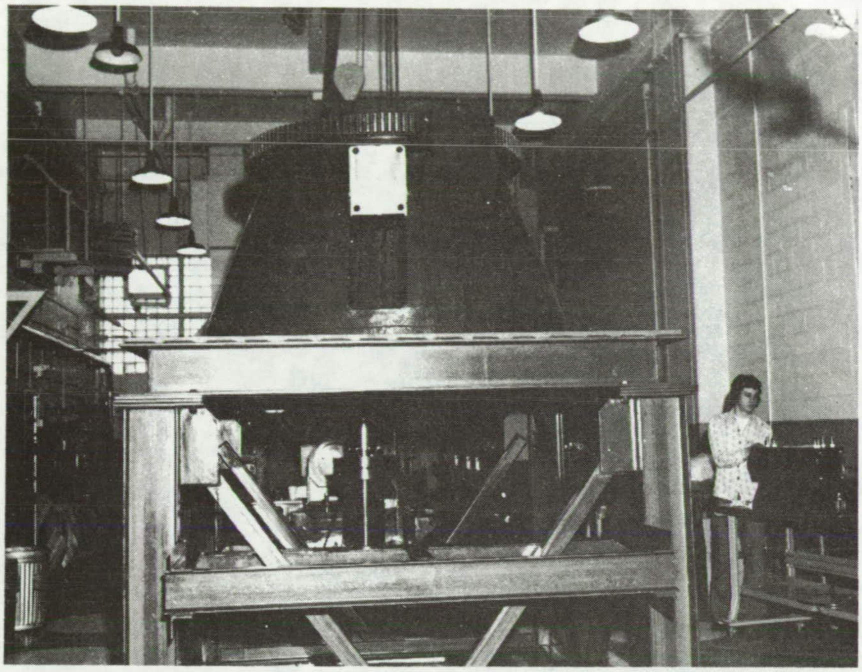

Figure 13. - Yaw system mounted on assembly stand.

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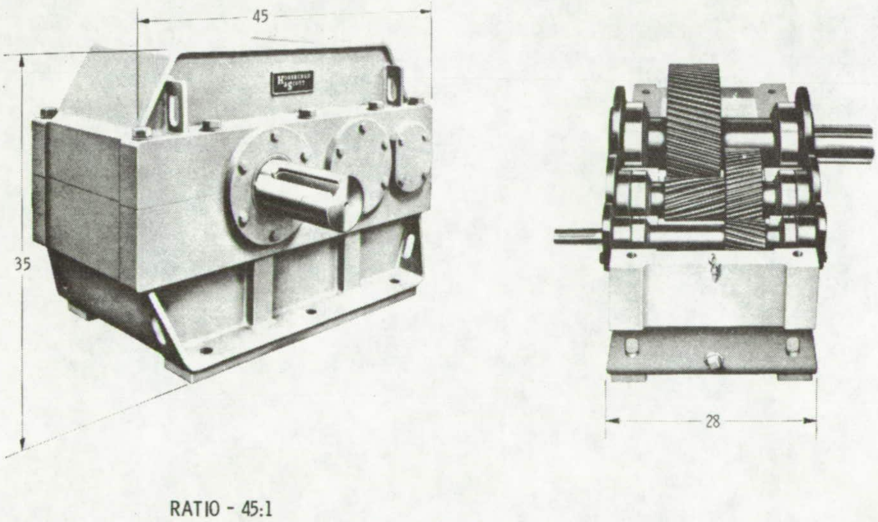

RATIO - 45:1
RATING - 176 KW (236 HP) AT 1800 RPM
APPROX. MASS - 2180 KILOGRAMS (WEIGHT = 4800 POUNDS)

Figure 14. - Gearbox for experimental 100 KW wind turbine generator.

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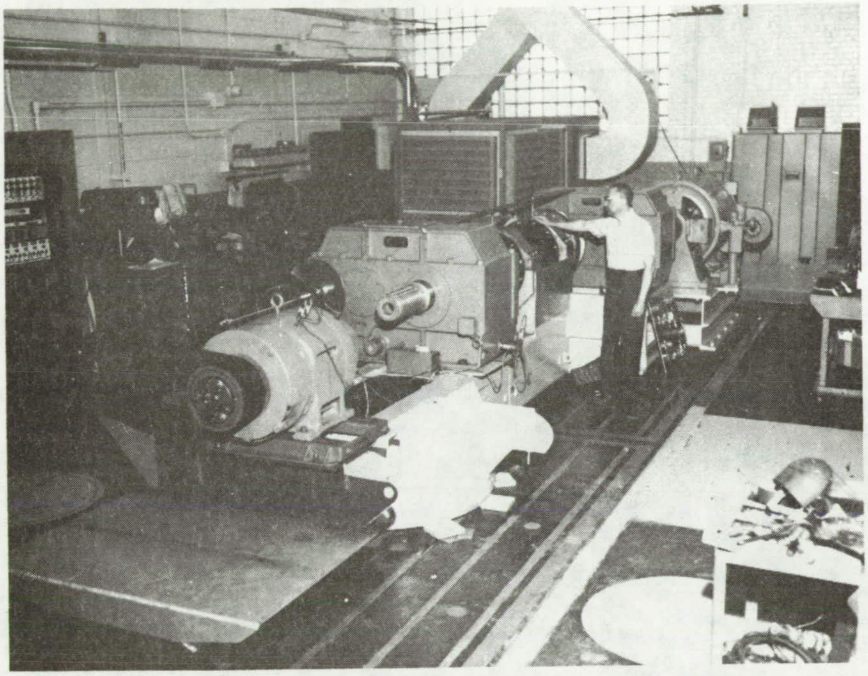
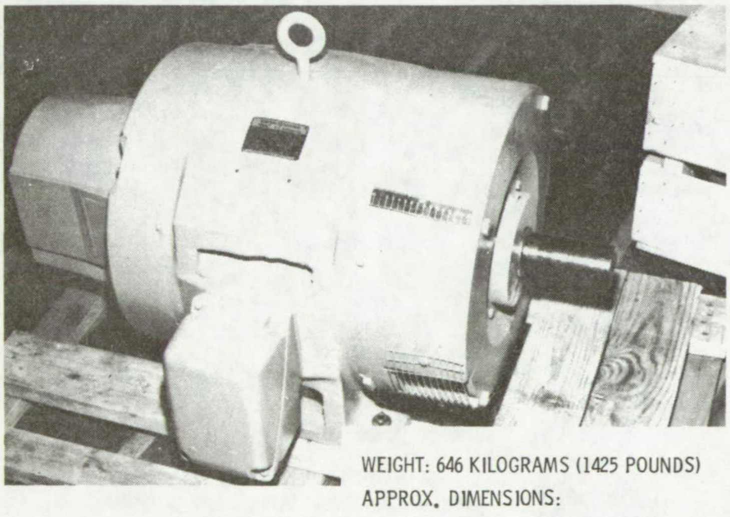


Figure 15. - Transmission train assembled to bed plate.



WEIGHT: 646 KILOGRAMS (1425 POUNDS)
APPROX. DIMENSIONS:
0.61 M DIAMETER (2 FT)
0.91 M LONG (3 FT)

Figure 16. - Synchronous generator for 100 KW experimental WTG. CS-73756

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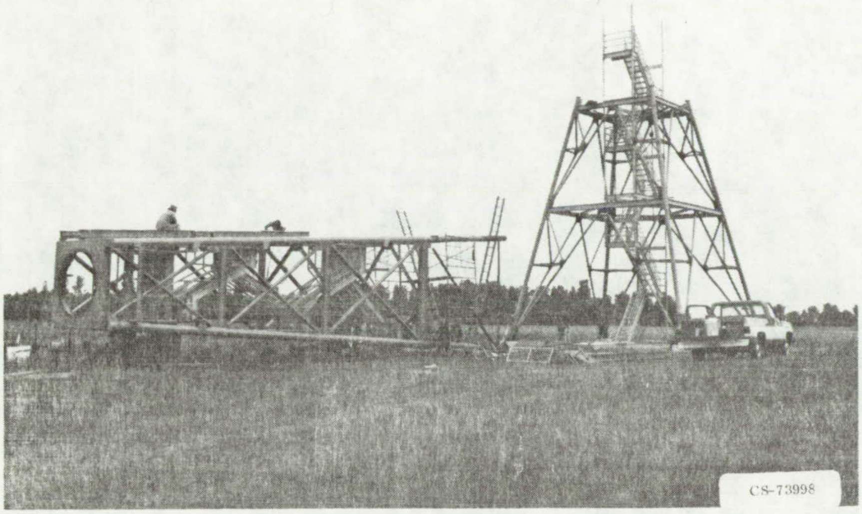

Figure 17. - Assembly of the 100 KW wind turbine generator tower.