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Sandia Vertical-Axis Wind Turbine Program Technical Quarterly Report

July - September 1976

Robert D. Grover, Anthony F. Veneruso

Prepared by Sandia Laboratories, Albuquerque, New Mexico 87115
and Livermore, California 94550 for the United States Energy Research
and Development Administration under Contract AT (29-1) 789
Printed June 1977

Sandia Laboratories

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SANDIA VERTICAL-AXIS WIND TURBINE PROGRAM TECHNICAL QUARTERLY REPORT

July - September 1976

Edited by

Robert D. Grover
Anthony F. Veneruso
Advanced Energy Projects Division 5715
Sandia Laboratories
Albuquerque, NM 87115

ABSTRACT

This quarterly report describes the activities of the Sandia Laboratories' Vertical-Axis Wind Turbine (VAWT) project during the period July-September 1976, transitional Quarter of fiscal year 1976. Included are the highlights of the quarter; review of the status of general design efforts in the areas of aerodynamics, structures, and testing.

FOREWORD AND ACKNOWLEDGMENTS

The work covered herein was performed by Sandia Laboratories under a contract administered by the Wind Energy Conversion Branch (Division of Solar Energy) of the Energy Research and Development Administration. The time period covered is from July 1, 1976 to September 30, 1976. Previous work has been reported in reports 1, 2, and 3 for each quarter since October-December 1975.

This report was edited from the contributions of the following Sandia staff members:

J. F. Banas (System Studies)
B. F. Blackwell (Aerodynamics)
L. V. Feltz (Mechanical Design)
R. D. Grover (Mechanical Design)
E. G. Kadlec (Project Engineer)
D. W. Lobitz (Structural Analysis)
R. C. Reuter (17-M Blades)
R. E. Shedldahl (Aerodynamic Tests)
B. Stiefeld (Automatic Control, Data Acquisition)
W. N. Sullivan (Structural Analysis, System Tests)
A. F. Veneruso (Electrical Design)
L. I. Weingarten (Blade Analysis)

In addition, Dr. Curtis Dodd, an Associate Professor of Electrical Engineering, on sabbatical from Southern Illinois University, joined Sandia's Advanced Energy Projects Division for one year beginning August 15, 1976. Since joining the division, Dr. Dodd has been engaged primarily in the electrical aspects of the 17-meter VAWT design such as lightning and static electrical discharge, and he has also initiated efforts for cost effective speed increase and power conversion system design.

The following personnel contributed significantly to hardware development for the project:

K. G. Grant
C. E. Longfellow
J. Lackey
R. S. Rusk
J. E. Martinez, Jr.

ILLUSTRATIONS

SUMMARY

Sandia has collected data from the 5-meter VAWT by the employment of an Intellec-80 micro-computer based data acquisition system. This system will be replaced by a larger, more flexible acquisition and control system. This unit can acquire data and control the operation of the 5, 17, and 2-meter turbines.

Two parallel analysis (one analytical and one numerical) have been undertaken to investigate loading configurations which may lead to buckling in the 17-meter VAWT blade assembly.

A final iteration in the design of the blades to strengthen the trailing edge root end fittings of the straight segments was made.

An anemometer tower was designed for the top of the 17-meter VAWT. Purchase orders have been placed for all of the VAWT parts and delivery is scheduled for the next three months. A lightning protection system for the 17-meter VAWT has been designed to protect the blades, bearings, and electrical equipment from the brief currents associated with lightning.

I. Aerodynamics

The 5-Meter Turbine - Field Testing

During the previous quarter an automated data collection system became operational and was utilized to measure the aerodynamic performance of the 5-meter turbine configured with three blades. This section briefly describes the data collection system and the test results.

Figure 1 presents a block diagram of the data collection system. This system is basically a hardware implementation of the aerodynamic performance measurement technique BINS.[1] The components consist of the wind speed and turbine shaft torque transducers, the analog/digital converter, the microprocessor, and output devices (keyboard and paper tape punch). Samples of wind speed and turbine shaft torque can be taken at a programmable rate up to a maximum of 1 per second. Accumulators representing number of samples and sum of sampled torques, are provided which correspond to wind speed intervals of 0.5 mph between 0 mph and 60 mph. For example, if the wind speed sample is 10.2 mph, the 20th sample accumulator is incremented by 1 and the torque measurement is added to the 20th torque accumulator.

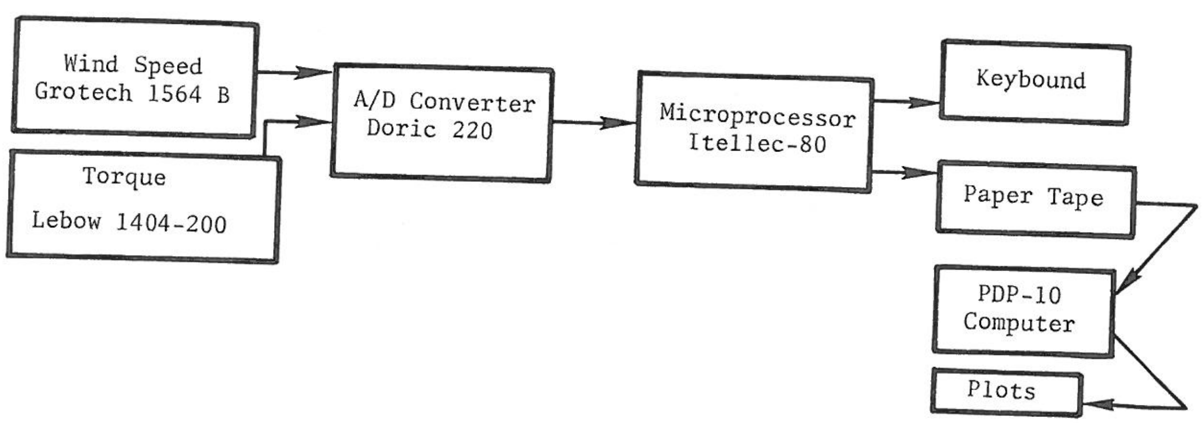


Figure 1. Aerodynamic Performance Data Collection System for the 5-Meter Turbine

TABLE II

Lightning Strike Probabilities in the Albuquerque Area*

	J	F	M	A	M	J	J	A	S	O	N	D	Years Total
(1) Thunderstorm Days	0.5	0.7	1.0	3.0	5.0	7.0	14	14	6	2.5	0.7	0.6	55
(2) Flashes/km^2	0.1	0.15	0.2	0.5	0.8	1.0	4.5	4.5	0.8	0.3	0.15	0.1	13
(3) Flashes to Wind Turbine	0.006	0.008	0.011	0.028	0.045	0.056	0.254	0.254	0.045	0.017	0.008	0.006	.738

Flashes to turbine = Effective Area x Flashes/km^2

Effective Area = 0.0565 km^2

*Note. (C. Jackson and W. Wagner of Sandia Laboratories were helpful in providing data and advice for the lightning protection system).

It is possible to determine the number of strikes per year to a tower in any area of the United States by using Figures 5 and 6. To make a comparison with the results of the method of Table II the chances of a strike in the Albuquerque area will again be determined. Figure 6 shows Albuquerque lies on the 60 thunderstorm per year line. If we examine Figure 7 it can be determined that a 110 ft tower is struck .15 times per year. Since Figure 5 is for an area where the average number of thunderstorm days per year is 35, we obtain by linear interpolation

$$\text{Strikes per year} = \left(\frac{60}{35}\right)(.15) = 0.257.$$

This means that we can expect one strike every 3.9 years $\left(\frac{1}{0.257}\right)$.

It is obvious that this second technique gives different results than the first. Another technique[10] will give a third result. Furthermore, none of the techniques consider these characteristics of lightning in mountainous areas. Because of the variation in results from the different techniques the only statement that can be made with certainty is, there is a chance of lightning striking the wind turbine.

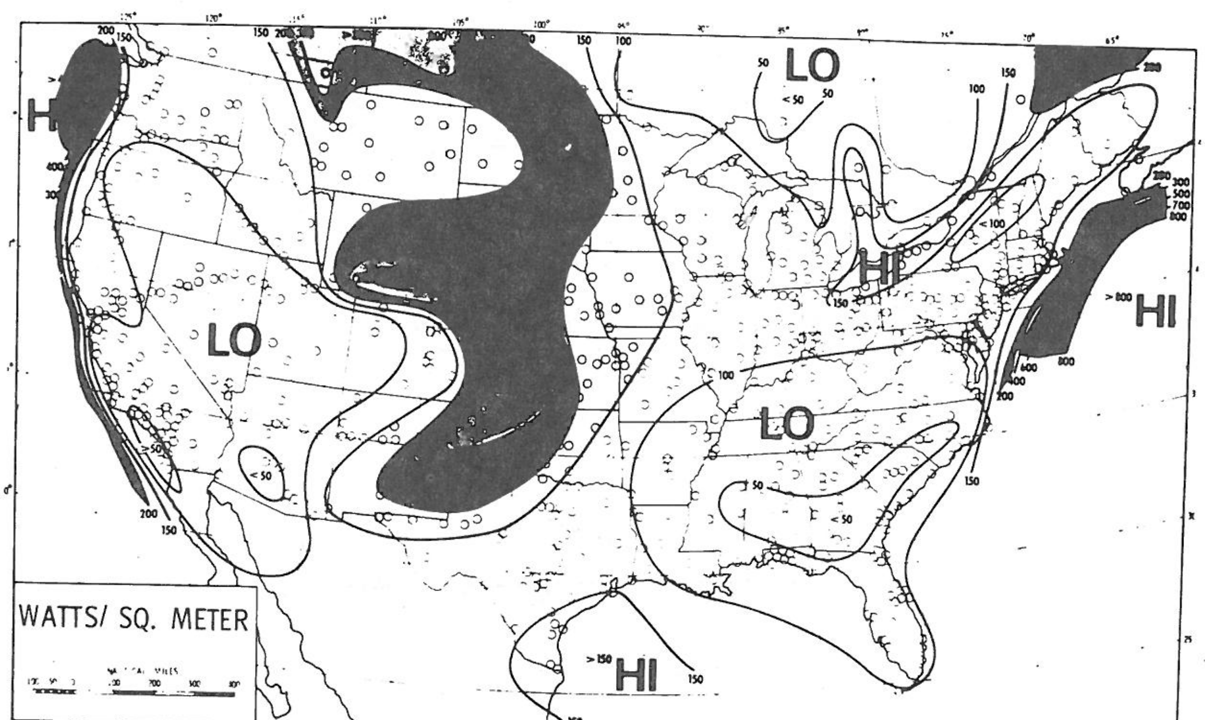


Figure 5. Available Wind Power - Annual Average

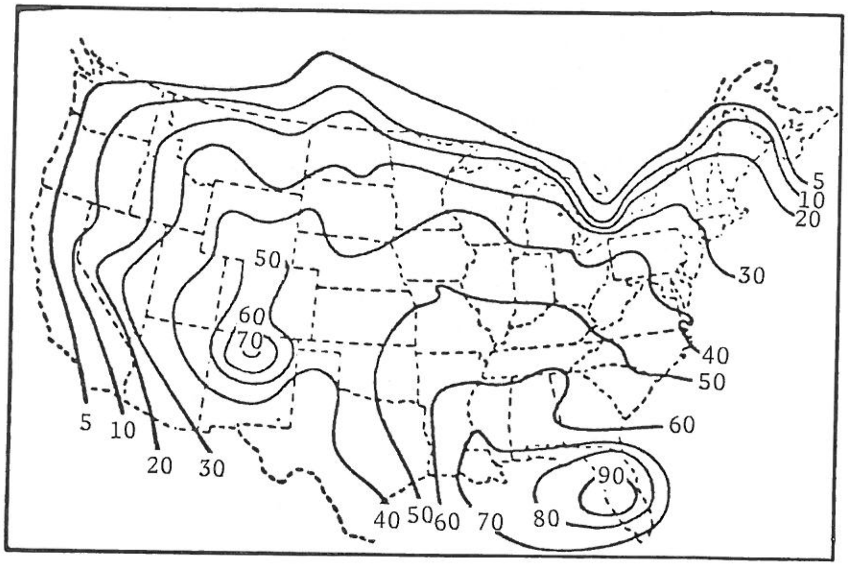


Figure 6. Map Showing the Average Number of Thunderstorm Days Per Year in the United States.

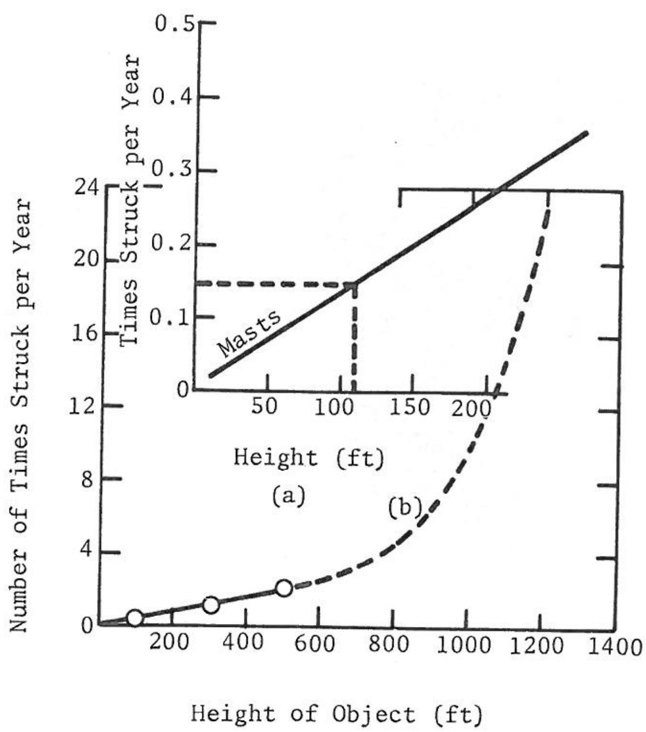


Figure 7. Frequency of Lightning Strike as a Function of Object Height: (a) Calculated Effect of the Area of a Structure at Various Heights; (b) Curve Plotted from Actual Records in Areas With an Average of 34 Thunderstorm Days per Year.

If we assume the second technique is valid, calculations show a 1.5 MW turbine of height 300 ft can be expected to be struck .75 times per year in an area of 60 thunderstorm days per year. A wind turbine farm of 30 MW capacity consisting of 20 units rated at 1.5 MW will be struck 15 times per year. Hence the development of a lightning protection system for the 17-meter VAWT will serve not only to protect this experimental model but will give data which can be used for the design of lightning protection for larger turbines.

Lightning Protection Design

When designing a lightning protection system the characteristics of lightning must be known. Since lightning is a charge transfer process the current characteristics give a sufficient description of a strike. In the 1.5 MW turbine design for NASA the lightning model is as shown in Figure 8. This model is in close agreement with the characteristics of lightning found in standard texts[5,7,10] on lightning and is satisfactory for the design of a protection system. It should be noted that less than 2% of lightning has peak current greater than these shown in the model.

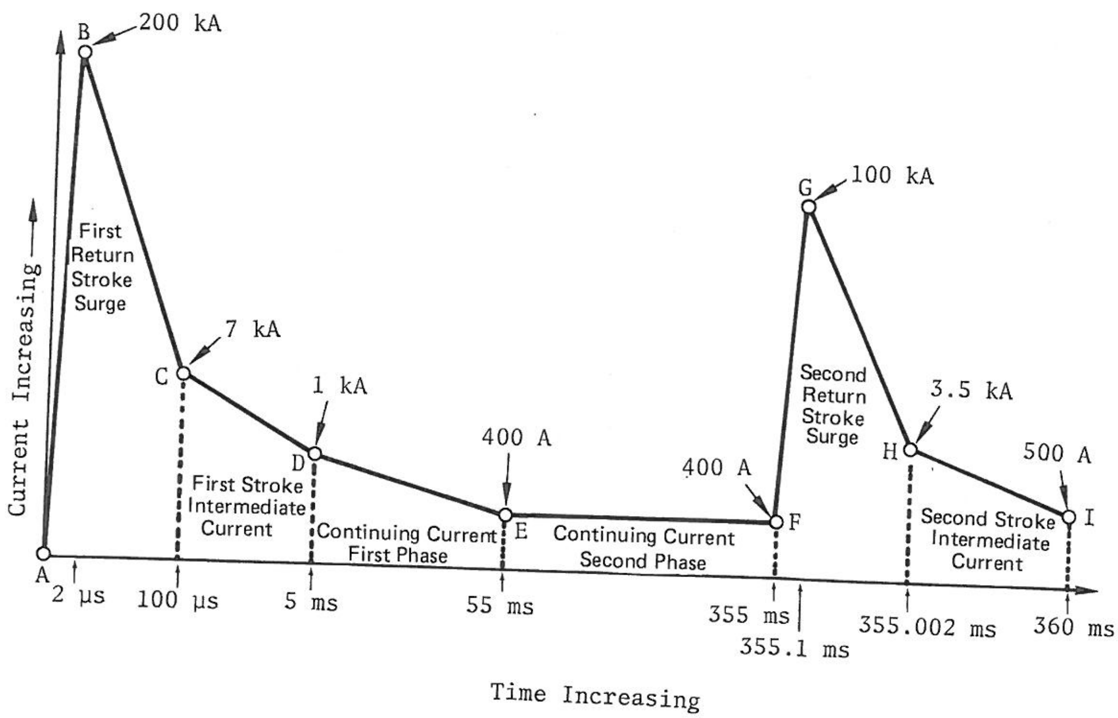


Figure 8. Diagrammatic Representation of Lightning Model. (Note that the diagram is not to scale.) From Reference 11.

As can be seen in Figure 9 there are five possible paths for lightning current to flow should a strike occur at the top of the turbine. Currents going down each of the four guy wires should do no damage to the turbine. If current goes down the turbine shaft, the most probable damage would be to the turbine's bearings and electrical equipment. It is doubtful that blade damage would occur unless a strike directly to the blade occurs. Because of the height of the anemometer tower on top of the turbine, a strike directly to a blade is improbable.

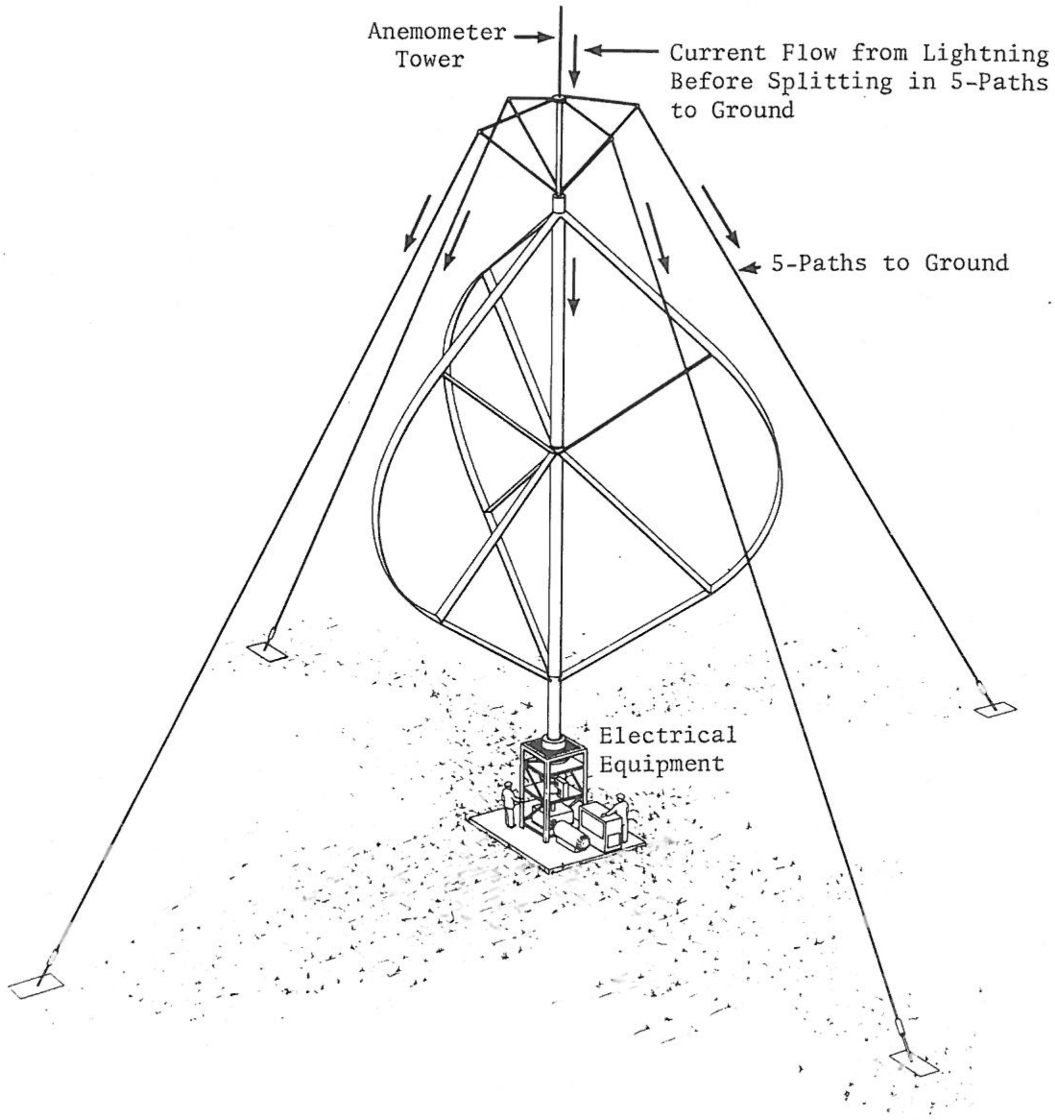


Figure 9. The 17-Meter VAWT - An Artist's Conception. The current splits in 5 paths after leaving the anemometer tower.

Insulator Design

One method to keep lightning currents from going down the turbine shaft would be to place insulators between the guy wires and the turbine shaft and the anemometer tower and shaft as shown in Figure 10. The amount of insulation required can be determined by finding the L(du/dt) drop on the guy wires. The guy wires have a one-inch diameter and are 130-ft long. If the path is shortened by taking path ABC, which will reduce the inductance,

$$L = .2\ell \left(\ln \frac{4\ell}{d} - 1 + \frac{\mu}{4}\right)$$

$$L = .2(31)\ \ln \frac{4(31)}{.0254} - 1.0 + .25 \ = 48\ \mu H$$

Where ℓ is the length in meters by path ABC and d the diameter in meters. The constant, μ, is one for air. The four parallel guy cables have a combined inductance of 12 μH. The rate of change of current taken from the model is 100,000 KA/μs which means the insulator material must have a standoff protection of

$$L\frac{di}{dt} = 12\ \mu H\ 100{,}000\ KA/\mu s = 1200\ KV.$$

One candidate for insulator would be the porcelain insulators used in transmission lines and power substations. It was found that standard size porcelain suspension insulators do not have the tensil strength necessary to support the load variations at the safety factor required in the guy cables. Preliminary calculations indicated that off the shelf post type insulators have sufficient mechanical and electrical strength to support a lightning rod on field models, but not the 30 ft anemometer tower or the 17-meter experimental model. Typical porcelain insulators are shown in Figure 11.

The use of material other than porcelain in insulators was considered. One product that appeared suitable for use were some insulators made with a fiberglass core and coated with cycloaliphetic[13] epoxy weather rings. Cycloalyhetes are an epoxy specifically developed for outdoor use and can withstand weathering and ultra violet radiation from the sun. A picture of one of these insulators is shown in Figure 12. It is possible to build these insulators suitable for use as shown in the design of Figure 10. A technical evaluation of this insulator is presently being performed.

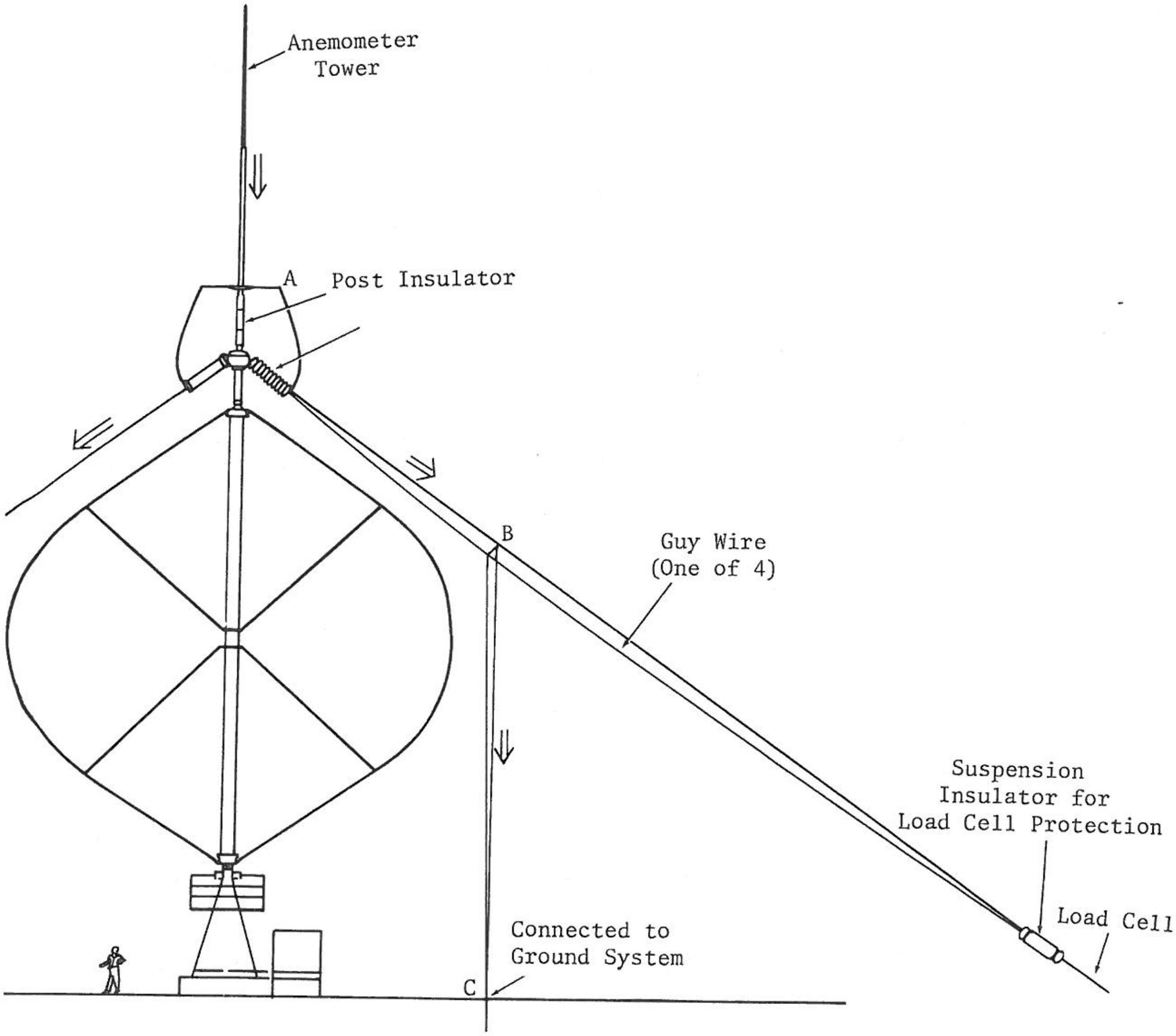
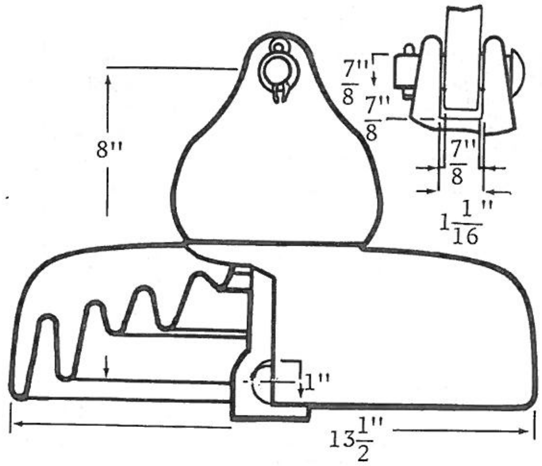


Figure 10. Lightning Protection Using Insulators.
The Current Path is Shown by the Arrows.



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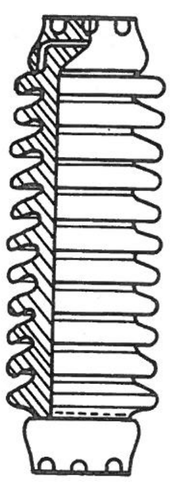
(a)



(b)

Figure 11. Porcelain Insulators; (a) Suspension Type, (b) Post Type

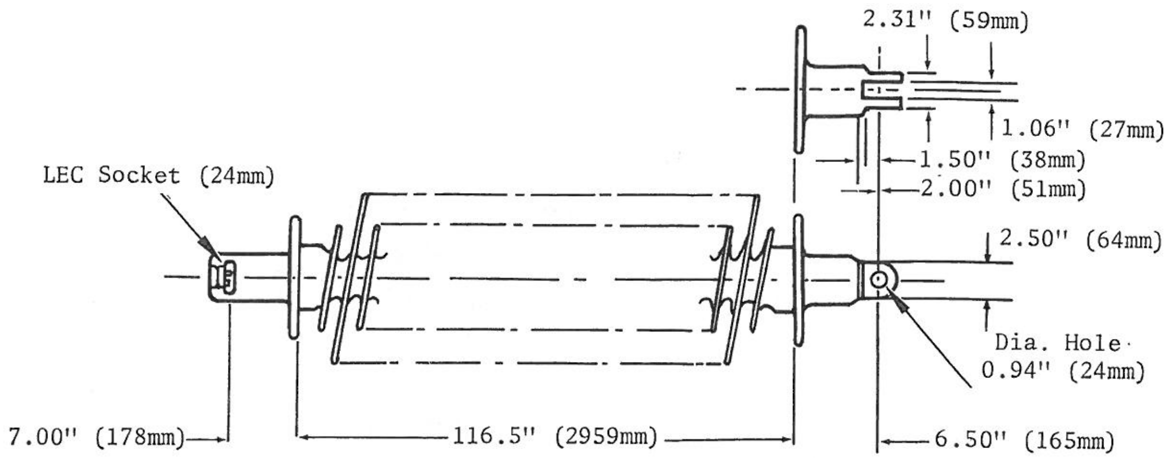


Figure 12. Fiberglass Cove Insulators with Cycloaliphatic Epoxy Weather Rings. This Tension Insulator has an Electrical Standoff Rating of 400 kV With 50,000 lb M & E.

Brush System

A second method to protect the bearings from lightning damage is to provide a low resistive parallel path to ground. The means chosen for providing a parallel path was carbon brushes. These brushes will be in contact with a rotating brass ring. The design used can be seen in Figure 13. This type of design has been successfully used for bearing protection on large dish antennas, although the rotational speed of these antennas has been slower than the wind turbines. The validity of this design can be verified by field tests on the turbines or by testing on a lightning simulator. Because of the time lag involved with setting up a test, the brush design was incorporated in the wind turbine with expectations that it will work. Besides providing a path for lightning current the brush system also provides a path for static charge developed on the blades.

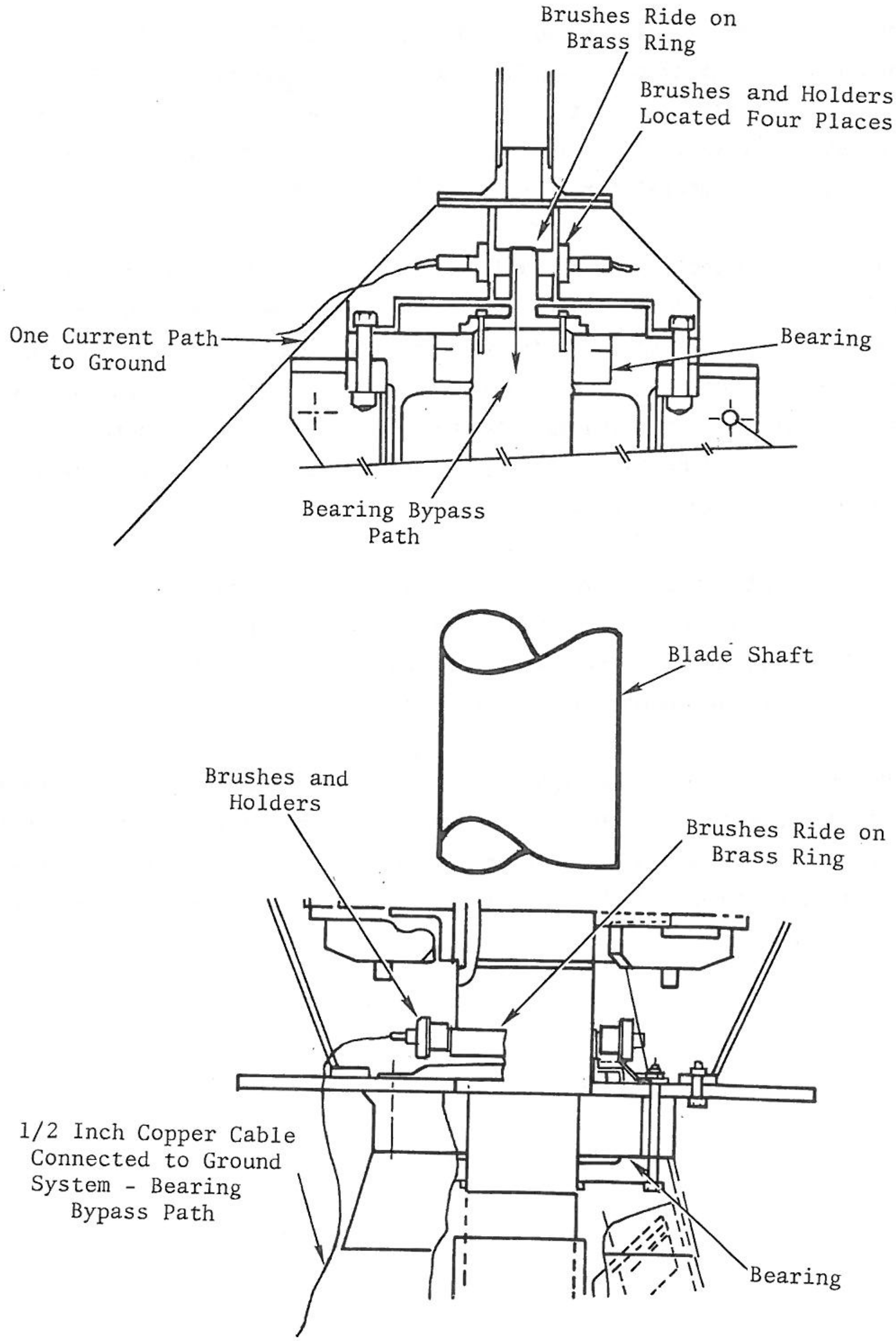


Figure 13. Lightning Protection Using a Brush Design

Conclusions

The bearing by-pass system using brushes is the lightning protection system that will be installed in the 17-meter VAWT. There is some question as to how well it will function. Until experience is obtained with the installed brush system, or laboratory verification shows different; it will not, at this time, be considered the design to be used on other experimental turbines.

The insulator protection system will be the best way to go if suitable insulators can be obtained. Tests are now being performed on some porcelain insulators to see if they have mechanical strength suitable for the variations in load on the turbines guy cables. Porcelain insulators have established an excellent record in the power industry, but are not normally made to withstand tension above 50,000 lb. There have also been questions raised concerning their ability to perform under the type of cyclic loading which can occur on the guy cables.

A series of tests on some porcelain insulators is now underway to determine their suitability for use in lightning protection for VAWT's. The fiberglass insulators with cycoaliphetic epoxy rings also will be evaluated. Some of these insulators have been ordered and will be evaluated at a later date.

In order to find a suitable lightning protection system for VAWT's both the brush protection system and the insulator system need further investigation. Because the insulator system is the most desirable of the two methods for protection, present efforts are directed toward finding and testing materials suitable for this design.

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