NASA INDUSTRIAL APPLICATIONS STUDY

Industrial Review

for

FILAMENT-WOUND PLASTIC, HIGH-VOLTAGE TRANSMISSION TOWER

R. N. Sampson

4 December 1964

Contract NASw 952

Presented to

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Office of Technology Utilization
Washington, D.C.

by

WESTINGHOUSE ELECTRIC CORPORATION
Defense and Space Center
Systems Operations
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INTRODUCTION

The studies conducted by NASA over the past few years in connection with constituents of filament-wound materials has potential application to the electrical industry.

Attention is invited to the data contained in NASA Contractor Report CR-71 "Structural Behavior of Composite Materials, " by Stephen W. Tsai, Contract Number NAS 7-215, July 1964. This report is directed to an analysis of the relationships between the various material coefficients of the composite and the parameters of the constituents. This analysis makes available data on filament-wound materials in a form which permits investigation of structures. The contributions of changes in resin content and glass arrangements to ultimate properties are shown.

This data provides a starting point for the design and development of all-plastic high-voltage transmission towers. Such development has been inhibited in the past by a lack of suitable design information and by insufficient knowledge of the contribution of each of the constituents of a fiberglass composite.

FILAMENT WINDING OF PLASTIC MATERIALS

The fabrication of plastic materials by the technique of filament winding makes available structural components with the highest specific tensile and compressive strengths. For parts where the loading is in tension or compression, filament winding can result in drastic weight reductions. Where inertia of moving parts affects machine response, filament winding can substantially reduce the inertia loads. If the form of the part is relatively simple, filament winding costs are often less than for equivalent metal components.

The process of filament winding consists of wrapping resin impregnated reinforcing materials around a forming mandrel. The resin is cured by heat, and the mandrel is removed. This process is limited to surfaces of revolution, since the fibers must remain in tension and in contact with the mandrel. Filament winding provides parts with exceptional tensile, compressive, and flexural properties, but only moderate shear and bearing strength.

NASA SUPPORTED STUDY OF COMPOSITE MATERIALS

NASA Contractor Report CR-71, "Structural Behavior of Composite Materials," provides information and techniques applicable to developing plastic transmission towers. The report is concerned with the structural performance of unidirectional fiber-reinforced composites, wherein the fibers are aligned parallel and packed randomly and of laminated composites consisting of unidirectional composites bonded together with the plane of orientation of each layer at some angle with respect to the next layer.

Calculations are made and verified experimentally as to the effect on stiffness, Poisson's ratio, and modulus of modifying the physical properties and interrelationships of the fibers and matrices comprising the composite structures. The most common technique for designing filament-wound parts (i. e., netting analysis) is shown to be inferior to continuum analysis and design equations are generated.

This report provides a starting point for designing and developing filament-wound high-voltage transmission towers.

PROBLEMS ASSOCIATED WITH CONVENTIONAL TRANSMISSION LINE TOWERS

High-voltage power transmission towers are used in an electrical power system to support the conductors which deliver electricity from the generator to the secondary distribution center. The towers must be designed to support the loads of its own weight, conductors, insulators, and attachments as well as the transient forces caused by ice loading, wind, line tension, and line fracture.

Transmission towers are generally made of steel. These towers are the strongest of all commonly used supports for a given weight not only for the horizontal tensions caused by the conductor cables but also for the torsional forces generated by wind loading. Steel towers are free from injury by fire, insects, birds, and lightning. With proper maintenance they can last as long as 25 years or more.

However, attractive steel transmission towers may be, there are disadvantages associated with their use. Steel towers are extremely heavy. Since it is not always possible to build a transmission line along an existing highway, transportation of the towers frequently becomes difficult. The towers must often be carried through rough terrains to the erection site, requiring service roads and heavy equipment. In recent years, helicopters have been used to lift tower sections into remote areas. The sections are then assembled at the site and erected. It is necessary to perform such lifts in sections because of the weight of the steel members.

Frequent maintenance is necessary on steel towers to control corrosion. For proper protection, the steel should be painted every 2 years. This painting becomes more costly as the complexity of the towers supporting and reinforcing members increases.

Since the steel towers are conductors and well grounded, the bushings and insulators supporting the conductors must be designed to resist the line voltage. Because of this requirement, the cost and complexity of the insulators increases rapidly as the voltage increases.

APPLICATION OF GLASS REINFORCED PLASTICS TO TRANSMISSION LINE TOWERS

Power transmission towers made by filament winding should be investigated. The stress members of the towers can be designed to be surfaces of revolution and the excellent physical properties obtainable are required for the service intended. Plastic materials have excellent dielectric properties. With a knowledgeable design, a tower could be built which provides the structural and insulating function in one homogeneous unit.

A transmission tower constructed from glass reinforced plastics would eliminate many of the disadvantages of steel tower construction while retaining many of the advantages.

Plastic members are much lighter than steel on an equal weight basis. Glass reinforced plastic (filament wound) has a density of 0.07 lb/cu in. compared to 0.28 lb/cu in. for steel and a tensile strength of 250,000 psi compared to 280,000 psi for steel. This results in a specific tensile strength (strength divided by density) of 3.6×10^6 inches for plastic and 1×10^6 inches for steel. Therefore, plastic towers can be designed which will weigh much less than steel, easing the transportation and erection problems. Substantially lighter towers would enable increased air lifting of towers and components to remote areas and decreased installation costs.

Plastic materials are inert to corrosive influences and do not require frequent painting and maintenance. Although sunlight is injurious to some polymers, recent developments in polymer chemistry have made available weather resistant plastics.

Another attractive feature of plastic towers lies in the possibility of simplifying or completely eliminating the insulators used to support the conductors.

PROGRAM FOR STUDY AND INVESTIGATION OF APPLICATION PROBLEMS

By starting with the technology generated by NASA, additional efforts could result in a high-voltage transmission tower which would meet all of the requirements. Such a program should be designed on the following format.

Tower Design

The structural elements of a tower should be designed specifically for filament winding. Fiber orientation and the geometry of the elements are critical. The designer should take advantage of the unique properties of filament wound parts as described in CR-71 and attempt to combine functions such as structural strength and insulation properties. The insulating properties of the materials should be utilized to eliminate the necessity for separate insulators; however, environmental factors such as wind and ice loading must be investigated as well as the damping properties of the composites and the effects of weather.

Economic Evaluation

When the tower has been satisfactorily designed, an economic analysis must be performed. Factors to be considered should include material cost, structure cost, transportation costs, erection costs, and maintenance costs. This analysis will prove the economic advisability of continuing the investigation.

Materials Evaluation

Some investigation of the materials to be used is desirable. The composites should be analyzed for their reaction to voltage stresses, weathering, painting, and effects of moisture. Much of this data can be taken from the literature.

Model Analysis

Models of the proposed towers should be examined and analyzed for stresses and interactions. Conventional scaling and analysis techniques can be used. The results of this investigation must be fed back into the preceding three analyses and the necessary adjustments made.

Full-Scale Evaluation

When the rest of the program has been concluded, a full-scale evaluation of a prototype should be made. This would consist of building a full-size unit and placing it into service where its behavior can be studied under service conditions. A program such as this would require the skills of a number of professions. It would be necessary to utilize the skills of structural designer, mathematicians, mechanical engineers, electrical engineers, and material engineers. It is estimated that the time required for each of the steps would be:

Tower Design - 4 months
Economic Evaluation - 2 months
Materials Evaluation - 6 months
Model Analyses - 12 months
Full-Scale Evaluation - 12 months

CONCLUSIONS

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This discussion described the opportunity to apply existing data generated by NASA to the design and development of a high-voltage transmission tower made of filament-wound plastic. A plastic tower probably cannot compete in cost with conventional steel tower construction, but it can compete if advantage is taken of the properties which plastics possess that are superior to the metals. For this reason, careful design and economic studies are critical to the success of the project. Once feasibility is shown, the engineering details are solvable.

Such a program would result in other desirable effects. The program data and technology would be directly applicable to low-voltage distribution poles, street lighting standards, and plastic bushings and insulators. It would also be applicable to radio, television, and microwave antenna structures.