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A CAPACITIVE TECHNIQUE FOR REAL-TIME MONITORING POLYMER COATING THICKNESS ON CARBON FILAMENTS DURING PREPREGGING PROCESS

ABE EFTEKHARI AND JOHN J. CHAPMAN

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National Aeronautics and
Space Administration

Langley Research Center
Hampton, Virginia 23665-5225

ABSTRACT

A technique for gauging the coating thickness during prepreg processing of carbon fibers has been developed. It is based on the concept of measuring the capacitance of a cylindrical condenser through which a bundle of prepregged fibers is passed axially. Empirical results indicate the capacitance of this condenser element is linearly related to the polymer coating thickness on the fibers in the bundle. The capacitive transducer has been successfully used to measure the polymer thickness on several test fiber bundles under static conditions.

INTRODUCTION

NASA-Langley and Old Dominion University have built a prototype continuous tow carbon filament thermoplastic prepreg system.[1] The polyimide coating thickness on the fibers is variable but should be held at 30% ±5% by weight for optimal results. A real-time polymer coating thickness measurement technique is needed to ensure the production of prepregged fibers with the desired coating thickness. A prototype instrumentation system for capacitively gauging the coating thickness on the fibers has been developed and used to monitor the coating process. The theory and some experimental results are presented.

EXPERIMENTAL PROCEDURE

A capacitance-based, on-line, process monitoring technique has been experimentally demonstrated to be a sensitive means for monitoring the thickness of polymer coatings on carbon filaments during the prepregging process.

The transducer consists of an aluminum cylinder of length ℓ (approximately 6 cm) and radius r_1 (approximately 0.5 cm). A segment of teflon tubing of length ℓ and wall thickness t_1 is inserted to snugly fit within the aluminum cylinder. The polymer coated graphite fibers of (approximately 3 μm) are passed axially through the transducer cylinder in a bundle of about 3,000 fibers of radius r_2. The cylindrical condenser thus consists of an outer aluminum cylindrical electrode of radius r_1, an effective inner graphite fiber electrode of radius r_2, and a dielectric medium made up of teflon tubing of thickness t_1, air layer of thickness $(r_1-r_2-t_1-t_2)$, and an effective polymer coating of thickness t_2 on the bundle of graphite fibers. Figure 1 shows geometrical details of the condenser element. A diagram of the capacitor gauge is shown in figure 2. The capacitance c of this cylindrical condenser is given by the following expression:

$$c \; \alpha \; \frac{\epsilon \ell}{\log\left(\frac{r_1}{r_2}\right)} \qquad (1)$$

where ϵ = effective dielectric constant of the medium between the two concentric cylinders.

For the transducer geometry and configuration described here, equation (1) can be approximated to:

$$c = a + bw \qquad (2)$$

where a and b are constants and w is the weight percent of the polymer on the graphite fiber.

It follows from equation (2) that the value of c is linearly related to the weight of the polymer coating on the graphite fiber. If this transducer is calibrated using known values of polymer loading on the graphite fibers, it can provide a real-time sensing of the polymer coating thickness.

EXPERIMENTAL RESULTS

The capacitance gauge was employed to sense a stationary axially positioned bundle of 3,000 polymer coated graphite fibers. The condenser capacitance was measured using a precision digital capacitance bridge capable of resolving ±0.1 picofarad. The empirical results are summarized in the table below:

Summary of Capacitance Measurements Under Static Conditions

Known Polymer Coating (Weight % ±0.2%)	Nominal Coating Thickness (μm ±0.01 μm)	Measured Capacitance (Picofarad ±0.1 pf)
23.1	0.63	2.7
26.6	0.71	9.8
37.7	0.97	10.4
41.2	1.05	14.1

These results are plotted in figure 3. There is considerable scatter in the measured values of the capacitance, particularly, at lower polymer coating levels. It arises from nonuniformity of coating thickness and fiber bundle diameter. It, however, appears that the major part of the error arises from partial debunching of the graphite filament bundle inside the transducer cylinder. This debunching can be reduced by locating appropriate size apertures at the entrance and exit of the condenser tube.

DISCUSSION

The capacitor gauge output shows considerable scatter at the lower coating levels. For real-time monitoring at these levels, it will be necessary to use a time-averaging filter. The linear distribution of irregularities in the test sample coating thicknesses and fiber bundle diameter will be transformed into a fluctuating output signal. By employing a true root mean square filtering network following the capacitance bridge electronics (or by employing software-based sample time averaging or filtering within the controlling computer), the effects of coating thickness and fiber bundle diameter fluctuations can be smoothed out.[2] The filtered output of the thickness gauge system, when interfaced as a feedback signal to the process controlling computer in figure 3, may then be used to enhance the accuracy of the measurement.

CONCLUDING REMARKS

A capacitance technique for measuring the polymer coating thickness on bundles of graphite fibers has been developed and tested on samples with various levels of coating. As theorized, the capacitance of the gauge is found to be linearly related to the weight of the polymer coating on the fiber. The ultimate goal of this effort is to develop a technique to monitor in real-time the thickness of fiber coatings as the bundle exits the prepreg fusion heater.

REFERENCES

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2. A. V. Oppenheim and R. W. Schafer, "Discrete-Time Signal Processing" Prentice Hall, New Jersey, 1989.

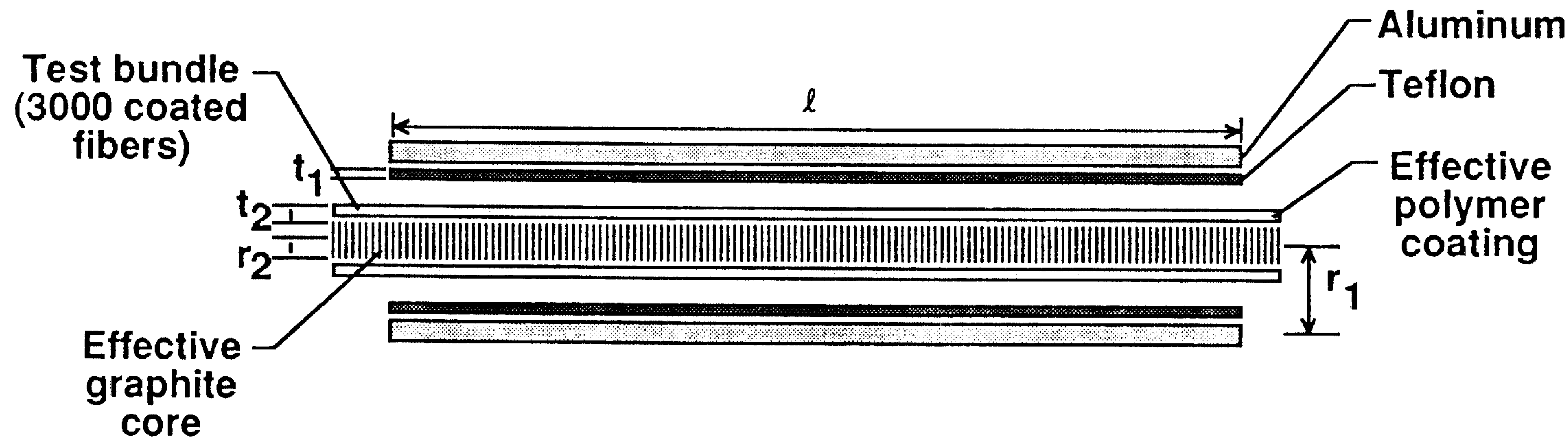

Figure 1. Geometrical details of cylindrical condenser element

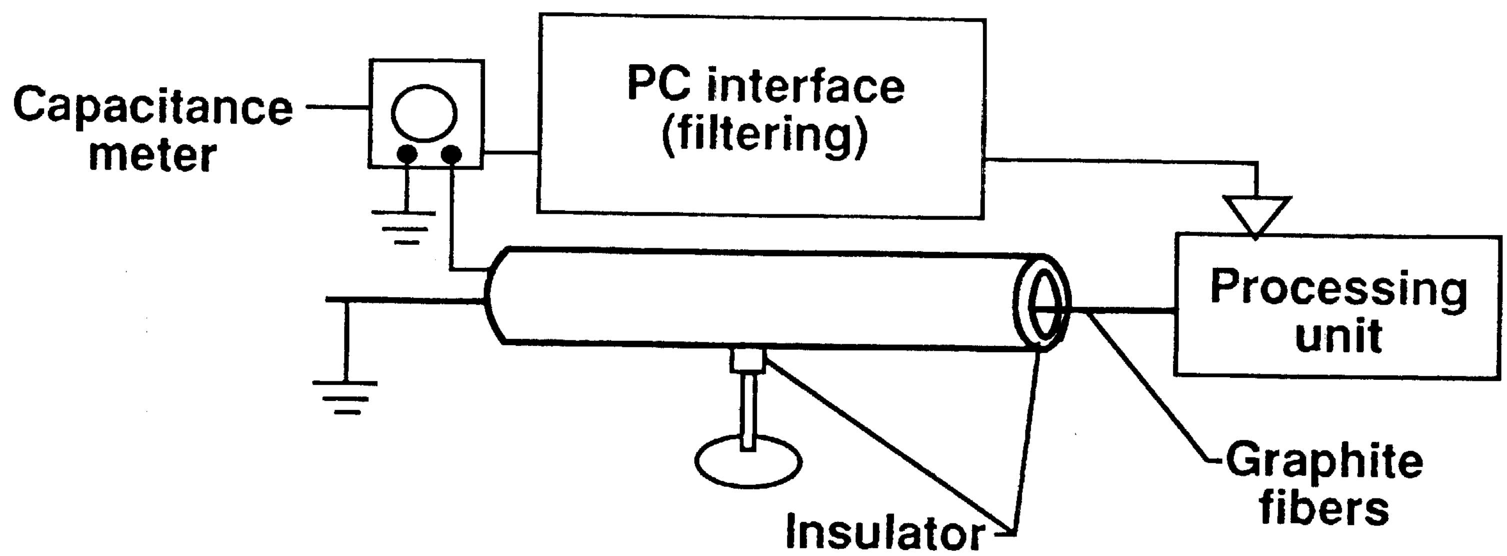

Figure 2. Diagram of the cylindrical capacitance gauge system

MEASURED CAPACITANCE VS POLYIMIDE COATING

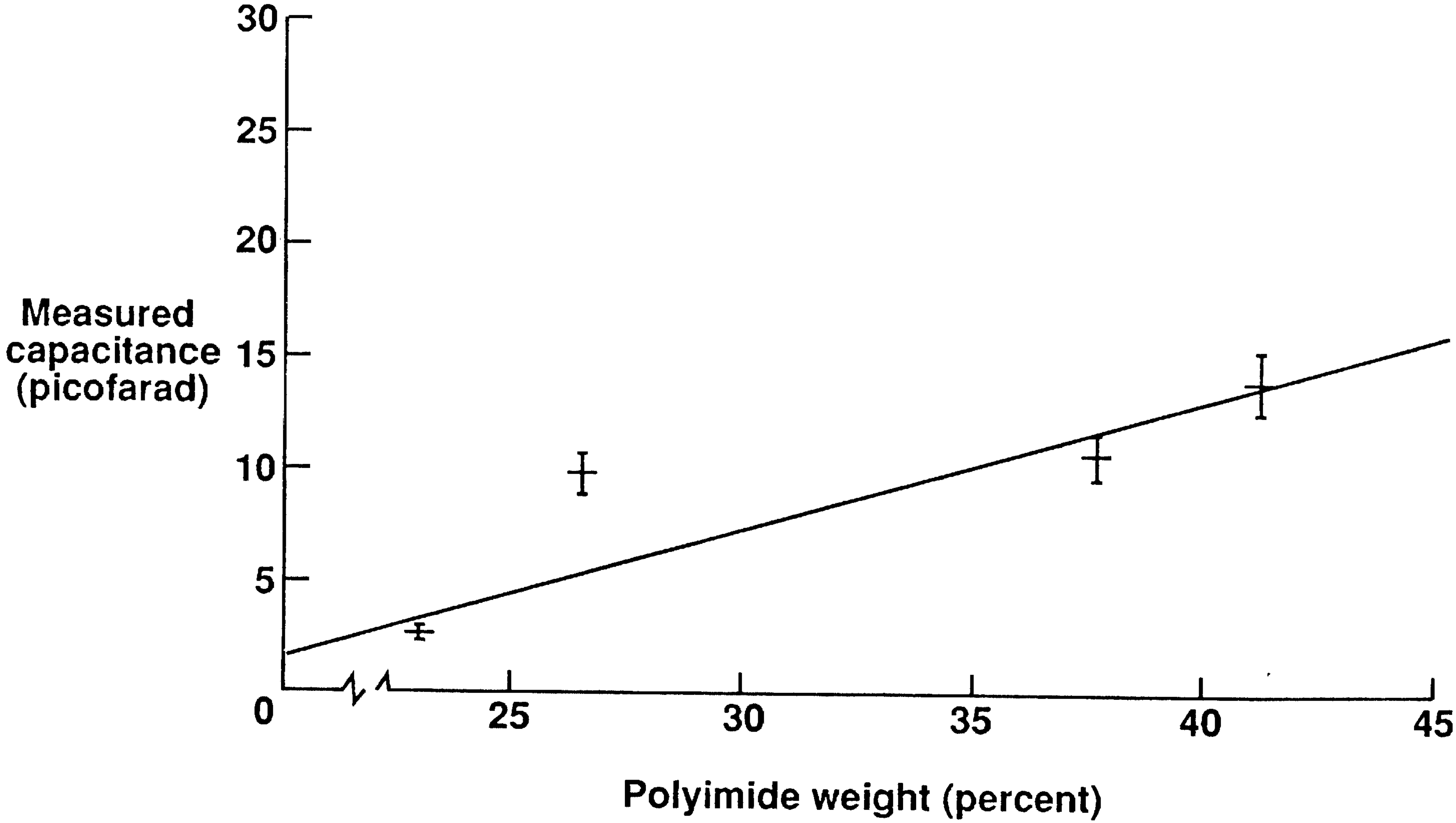

Figure 3. Static calibration of the capacitance gauge

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Abe Eftekhari: Analytical Services and Materials, Inc., Hampton, Virginia.
John J. Chapman: Langley Research Center, Hampton, Virginia.

16. Abstract

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