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PERFORMANCE OF A COMMERCIAL BACKSCATTER INSTRUMENT
ADAPTED FOR NONCONTACTING AREAL DENSITY MEASUREMENTS
ON SMALL-DIAMETER SURFACES

P. B. Higgins

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MEASUREMENTS ON SMALL-DIAMETER SURFACES

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ABSTRACT

Measuring the local areal density of a sensitive explosive deposited on a small-diameter surface requires noncontacting technique and good resolution. The side effects of spacing the sensing platen of an NX-500 "Betascop" 2.54 mm from the surface of cylinders as small as 13-mm diameter are examined. Resolution in two directions and offset error sensitivity of the system are defined and determined using coatings of simulated explosive. An eddy-current system is described which can be easily added to reduce offset errors caused by fixture misalignment.

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CONTENTS

	<u>Page</u>
Introduction	6
Equipment Setup	7
Direct Calibration	7
Indirect Calibration	8
Resolution Studies	10
Offset Sensitivity	11
Data Reduction	13
Summary and Conclusions	13
References	14
Figures	15

LIST OF FIGURES

Figure 1 - Backscatter Equipment	15
Figure 2 - Backscatter from SASN and Silver Foil on a Flat Aluminum Substrate	16
Figure 3 - Effect of Small Radius on Composite Backscatter Counts	17
Figure 4 - Setup for Resolution Study Along the Platen Slot Axis	18
Figure 5 - Resolution Along Slot Axis Using 0.1 mm Silver Foil Tape Composite	19
Figure 6 - Resolution Along Slot Axis Using 5-Layer Foil Tape Composite	20
Figure 7 - Setup for Resolution Study Across the Platen Slot	21
Figure 8 - Resolution Across Slot Using 0.76 mm (3 mil) Silver Foil	22
Figure 9 - Backscatter Count Error as a Function of Offset from a Flat Surface	23
Figure 10 - Setup for Measuring Offset Sensitivity of Eddy Current System	24
Figure 11 - Eddy Current Setup	25

TABLES

Table 1 - Silver Foil-Tape Composite Measurements	10
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PERFORMANCE OF A COMMERCIAL BACKSCATTER INSTRUMENT
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MEASUREMENTS ON SMALL-DIAMETER SURFACES

Introduction

The relationship between the areal density of silver acetylide-silver nitrate (SASN) spray-painted on the surface of large cones and the impulse delivered to such surfaces when the SASN is photoinitiated has been established empirically.¹ During the spray procedure, the SASN areal density profile is determined by repeatedly removing and weighing replaceable coupons from fixed locations on the surface. For surfaces of rotation having diameters greater than 75 mm, the surface curvature has not significantly affected the use of 19-mm-diameter coupons.

A second method of measuring the areal density of SASN deposited on low curvature surfaces utilizes a servo-positioned Beta Backscatter (BBS) instrument.² The measurement is averaged over an area on the sprayed surface of approximately 600 mm.²

A new requirement for measuring the areal density of SASN at intervals of approximately 20 degrees on the surface of cones as small as 13 mm diameter exceeds the resolution capabilities of both the coupon technique and existing servo-positioned backscatter system. Investigation suggested, however, that the backscatter approach would be applicable if the cross-sectional area of the beta (electron) beam was reduced.

This report covers the evaluation for that purpose of an available commercial instrument - an NX-500 "Betascope" built by Twin Cities Testing Corp. The NX-500 requires manual operation in the presence of a primary explosive, as opposed to the remote servo-positioned BBS system formerly used, but the greatly reduced quantity of explosive deposited on small cones results in a corresponding reduction in the hazard to personnel.

Equipment Setup

The NX-500 system was initially modified as follows:

1. Following the instructions of the manufacturer, an access connection to the internal counting circuitry was added. This change, in conjunction with a 7-digit external counter, HP-5304, provided an additional digit of useful resolution to the counting circuit that tallies the backscattered particles.
2. The AT probe, which includes the beta particle source and the Geiger-Muller tube for detecting backscattered betas, was rotated to sense in a horizontal plane. This mode gives easier access to the flat and cylindrical targets used in this evaluation.

A block diagram of the equipment setup is given in Figure 1.

A Strontium-90 ($^{90}\text{Sr} + ^{90}\text{Y}$) source has proven effective for measuring the areal densities of SASN when sprayed on aluminum and carbon surfaces² and was used for all experiments described herein.

Several platens are provided by the NX-500 manufacturer to shape the electron (beta) radiation beam from the selected source. In our experiments the Model 25C platen, with a 0.63-mm-wide rectangular slot, was utilized. The long dimension of the slot was always vertical; in the case of cylinders the slot ran parallel to the axis. During all backscatter measurements an offset spacing of 2.5 mm was maintained between the external platen surface and the aluminum flats and cylinders used to simulate actual experimental surfaces.

Direct Calibration

Where the curvature of the surface to be sprayed is low enough (76 mm diameter or greater) to accommodate coupons of reasonable size,

direct calibration of the beta backscatter system is possible. Six coupons of known weight were mounted alongside as many flat, 5-cm-square aluminum plates. Using a spray of constant cross-sectional density, each coupon-plate pair was sprayed with a uniform coating of SASN; loadings ranged from 3.8 mg/cm^2 to 52.5 mg/cm^2 . Knowing the area of the coupons and their weight with and without the explosive coating, the average areal density of the SASN on each coupon and its adjacent aluminum plate was determined. In Figure 2, the differential beta count, defined as the difference between a count for 120 s duration from a coated area and the count from the bare substrate for an identical period, is plotted against the corresponding coupon areal density for each of the six plates. Backscatter measurements from two silver foil samples similarly mounted and having areal densities which span the range of interest are also shown in order to emphasize the difference in counts between different materials of the same areal density.

Indirect Calibration

Calibration using coupons sprayed with SASN has been found unacceptable on cylinders or cones having diameters below 76 mm. The flat coupons do not conform closely enough to the greater curvatures of such surface and distort deposition of the sprayed explosive; furthermore, the minimum usable coupon diameter (19 mm) covers too large an area on 76-mm and smaller diameter surfaces to permit areal density measurements having adequate angular resolution. In these cases, calibration was achieved using indirect methods.

The indirect approach consisted of applying up to five layers of a composite substitute for SASN on three aluminum cylinders ranging from 13-mm to 75-mm-in diameter. Each layer of the composite consisted of a 0.0125-mm (0.5 mil) thick silver foil attached to a nominal 0.15-mm-thick segment of "double-sticky" tape; the combined thickness of five of these layers was 0.85 mm, which approximates the maximum depth of SASN generally applied.

It is assumed that while no direct correlation exists between the backscatter characteristics of composite coatings and those of SASN, a proportional count correction for substrates of equal radius can be inferred for the explosive-coated samples based on measurements made on roughly homogenous composites of approximately the same depth.

Prior to mounting the layers on the aluminum cylinders, the variation in areal density of each of the five "standard" foils was measured placing them individually on a flat (3.2 mm thick) aluminum plate and taking a reading with the NX-500 system; these measurements showed variations as great as 15% among the foil-double sticky composites. For graphing convenience, the composite giving the greatest backscatter was arbitrarily assigned an areal density of 1.0 and fractional areal densities were assigned to the other composites in proportion to their lesser backscatter counts.

Backscatter measurements on the flat substrate and on a 13-mm-diameter cylinder appear in Figure 3 and are tabulated in Table 1. Similar backscatter measurements on 26-, 51-, and 76-mm-diameter aluminum cylinders were also made, but the data for the larger structures clustered closely around the flat substrate data; for clarity, they are not plotted. Any cylinder equal to or greater than 26 mm in diameter is treated as a flat substrate.

From Figure 3 it is seen that the count for a given normalized areal density of composite coating on the 13-mm cylindrical surface produces a count approximately 10% lower than the count from a flat aluminum substrate.

Because the composite coating which produced these readings approximates SASN in homogeneity and actual depth (for a given count), it is believed the same percentage correction can be applied with confidence to backscatter measurements of SASN sprayed on 13-mm-diameter aluminum cylinders or cones. Proportionately smaller corrections to

larger structures up to 25 mm would be reasonable, at which point expected data scatter would dictate use of the flat substrate curve in Figure 2.

Table 1

Silver Foil-Tape Composite Measurements

Calibration Patch Number	Normalized Areal Density	Raw Differential Count, 120 s Interval	
		Flat Substrate	13 mm Dia. Substrate
1	1.0	5 846	5 764
2	0.97	11 086	9 684
3	0.85	15 347	13 497
4	0.94	19 218	17 860
5	0.85	23 024	21 739
*Cumulative	4.61		

*33 mil thick

Resolution Studies

In addition to the described calibration procedure, spatial resolution experiments were appropriate to determine the capabilities of the NX-500 system in the vicinity of thickness discontinuities or other surface anomalies.

For a particular source intensity, resolution within a fixed sampling period is determined primarily by the dimensions of the platen aperture, which shapes the emitted beta beam, and the (fixed) offset distance, dictated, in our case, by the noncontact requirement for explosive measurements.

For purposes of defining a repeatable test criteria, the system spatial resolution is defined by moving the edge of silver foil, mounted on a larger, flat aluminum substrate, in front of the platen and normal to the emitted beta particle beam, as illustrated in Figure 4. This exposed the system to a "step" discontinuity in coating material.

Figure 5 is a plot of relative counts VS displacement of an available 25-mm x 25-mm x 0.1-mm silver foil along the length of the platen slot. A constant offset distance of 4.5 mm was maintained between the 7.5-mm-thick aluminum substrate and the face of the 25C platen during all measurements, beginning with the foil completely out of the particle beam and ending with the foil intercepting the total beam.

Resolution along the slot is defined as the displacement required to change the backscatter count from 10% to 90% of Δ count, where Δ count is the difference between the substrate count (foil completely out of beta beam) and the final count (foil intercepting all of beta beam).

To check the probable effect of SASN depth on spatial resolution, the previously described five-layer foil-tape composite was substituted for the 0.1-mm-thick solid foil originally used in the setup shown in Figure 4. The results given in Figure 6 indicate essentially the same 3-mm resolution as was found for the solid foil experiment.

Resolution in a direction normal to the platen slot is defined in angular terms for greater convenience. An expected minimum diameter of 13 mm was chosen as the standard substrate diameter in the experimental setup shown in Figure 7 and, again, resolution is defined as the angular increment of a 0.075-mm foil to produce a 10% to 90% change in the backscatter count. Figure 8 shows the system angular resolution to be 19 degrees, corresponding to a 2.2-mm displacement along the surface.

Offset Sensitivity

Normal usage of the unmodified NX-500 involves direct contact of the platen against a coated substrate; offset is not a consideration. Since our usage involves measurements of a primary explosive, a relatively generous offset spacing is mandatory. It was essential that the effects of errors in setting and maintaining offset spacing be determined.

Figure 9 is a plot of the count error recorded when the offset between the 25C platen and a flat aluminum substrate was ranged from 2.0 to 3.3 mm. The average error slope over the indicated range of offset settings was 70% per mm (2.8% per mil), where zero count error is defined at an offset of 2.5 mm. The importance of maintaining accurate offset spacing during backscatter measurements is evident.

In view of the above, some difficulty was anticipated in maintaining mechanical fixturing tolerances close enough to achieve adequate system accuracy in the process of rotating a sprayed cylinder or cone as much as 110 degrees, from the substrate access location to the desired measurement area. The system was therefore modified to include a noncontacting, eddy-current sensing system which permits the operator to adjust the offset spacing for zero offset error at the desired measurement point, without the necessity of accessing a "bare" area on the test surface in order to set the offset spacing. A conductive substrate must be stipulated, however, for operation of this system.

Validation of the eddy-current offset sensing system was performed with the setup shown in Figure 10. Seven turns of No. 30 copper wire were wrapped on a nonconductive, half-inch form and glued to the 25C platen "nozzle." The coil was centered so as not to impede beta particles from the source located behind the platen slot. When connected to an eddy-current generating and sensing circuitry, Figure 11, the system was adjusted for center-scale deflection on the 547 scope, the offset spacing having previously been adjusted to give a normal substrate count with the 25C "pointing" at the 3.2-mm-thick flat aluminum plate. The plate was then moved downward, at constant offset spacing, until the platen was centered in front of the aluminum foil. The resulting imbalance in the detector bridge produced 7.5 mV at the oscilloscope; at maximum gain (5 mV/cm) this gave a scope deflection of 1.5 cm as a result of introduction of the foil, which was located .25 mm (10 mil) above the substrate plane. Assuming a 2-mm deflection

can be readily detected on the scope, the eddy-current offset sensitivity for manual offset correction is $0.25 \text{ mm} \times (2\text{mm}/1.5 \text{ cm})$ or $.033 \text{ mm}$ (1.3 mil). This corresponds to a maximum backscatter count error of 3.6%.

Data Reduction

Backscatter recorded by the counter in Figure 1 can be conveniently reduced to areal density with a program written by R. Benham and B. Duggins, 1533. Figure 12 is a plot of backscatter counts from nine SASN-sprayed, flat samples against areal density, which was determined by weighing samples of known area. The counting interval was four minutes.

The solid line in Figure 12 is a plot of a third order polynomial fitted to the data. With it, counts from 76 mm and larger diameter cylinders are reduced directly. For smaller cylindrical shapes, down to 13 mm diameter, the program provides the required correction as shown in Figure 3.

Conclusions & Summary

The work described shows that the NX-500 Betascope, as modified, provides a usable system for the noncontacting measurement of areal density of SASN sprayed on cylinders or cones as small as 13-mm (.5 in) diameter.

Vertical resolution and horizontal resolution for the system were measured, as well as offset error sensitivity. In case fixture limitations make the latter specification intolerable, an eddy-current sensing system is shown to offer the potential of holding offset error to less than 4%.

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Figure 1. Backscatter Equipment

Figure 2. Backscatter from SASN and Silver Foil on a Flat Aluminum Substrate

Figure 3. Effect of Small Radius on Composite Backscatter Counts

Figure 4. Setup for Resolution Study along the Platen Slot Axis

Figure 5. Resolution Along Slot Axis Using 0.1 mm Silver Foil on Aluminum

Figure 6. Resolution Along Slot Axis Using 5-Layer Foil Tape Composite

Figure 7. Setup for Resolution Study Across the Platen Slot

Figure 8. Resolution Across Slot Using 0.76 mm (3 mil) Silver Foil

Figure 9. Backscatter Count Error as a Function of Offset from a Flat Surface

Figure 10. Setup for Measuring Offset Sensitivity of Eddy Current System

Figure 11. Eddy Current Setup.

Figure 12. Polynomial Fit of SASN Backscatter Counts VS Area Density

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