BETA RADIATION GAUGING METHODS

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Fig. 1. Consoles which house the electronic circuitry for dual beta gauge installation.

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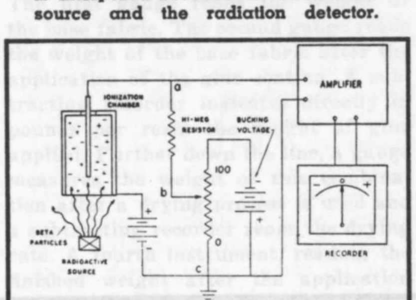
The weight-per-unit area of a material made in a continuous process can be accurately measured and controlled by means of beta radiation gauges.

THE manufacturer in a continuous process industry faces a serious problem today. His costs are made up of raw material, labor, overhead and taxes; his income is directly affected by the prevailing price level. In today's situation, with costs rising generally, it is a disturbing fact that the price level has not moved correspondingly. This situation has resulted in higher "break-even" operating levels for more and more industries. In examining ways and means of reducing costs, the manufacturer finds that he has no control over taxes, and little control of overhead and labor. The one quantity which can spell the difference between profit and loss is the cost of his raw material.

Virtually all of the raw materials entering into the manufacturing process are purchased on a weight basis, but the majority of finished goods is sold on a unit basis. Thus, control of the weight per unit becomes a vitally important factor. Since a unit—whether it be a filing cabinet, a plastic table cloth or an automobile tire—is finished to a given dimension, it constitutes a fixed area of material used in its fabrication. Thus, the finished weight is a direct function of the weight-per-unit area.

The availability of radioisotopes, which are essentially a by-product of the nation's atomic energy program, has opened up a whole new field of instrumentation. These radioactive materials have the property of extreme stability in the nature of their radiations. This means that it has become possible for the first time to construct noncontacting instruments which read the quantity "weight-per-unit area" directly. The use of beta radiation in a suitably designed gauge will give the same information that is obtainable by cutting out a sample of material, determining its area, and weighing it in a chemical balance. The importance of the information obtainable from measurements with a balance is readily apparent in plastic film and coated fabric industries. In many instances, a festooning stack has been installed to give the machine operator time to die out a sample of the material which he then places in a balance to determine the square-yard weight. The machine operator makes adjustments in accordance with the information obtained from this sample. His conclusions concerning the adjustments required are about as effective as predicting the outcome of a presidential election after interviewing one thousand voters. This is because the operator has no way of knowing at what point on the normal cyclical process variation he cut his sample.

Fig. 2. Basic elements of a beta radiation gauge. Material being measured is interposed between the radioactive source and the radiation detector.



The use of a gauge which reads the weight-per-unit area continuously, immediately, and at any point across the sheet permits control of the process to tolerances which are dictated only by the limitations of the machine. To achieve this control a continuous record of the material weight, as produced, must be available. In order to have meaning, this record must be both accurate and reliable. It must not rely upon the skill or memory of a machine operator to make adjustments at periodic intervals. The accuracy of the instrument must be independent of plant environment or gauge operating conditions. In particular, it must not be dependent upon an instrument technician who is required to insert standard samples, or adjust "zero set," "calibrate control," or "deflection sensitivity" controls.

In determining the operating characteristics which would meet the requirements of the continuous process industries, beta gauge designers spent a great deal of time interviewing engineers, production men and quality control managers who would be concerned with the results of an improved instrumentation program. Their experience with contacting, capacitance, and magnetic-reluctance gauging equipment all pointed to the necessity for reliability, accuracy and trouble-free operation. These objectives have been achieved. There is now available to industries processing sheet materials an instrument that will measure and record their products on direct-reading scales, and with automatic standardization which maintains an accuracy of 1%.

Figure 2 shows the basic elements of a beta radiation gauge. A source of radiation shines upward toward the detector. The amount of radiation reaching the detector is a function of the weight of material interposed between the detector and the source. Within certain limitations, the nature of the material does not affect the reading of the basic quantity, weight-per-unit area. This permits calibration of the instrument in discrete increments of weight, as opposed to "deflection from zero" presentation. The latter depends upon the machine operator's judgment while the former constitutes a measurement standard.

An instrument of this type, which is capable of giving direct readings of square-yard weight, is useful only to the extent that its readings can be trusted for their accuracy. No matter how useful the information may be, if it cannot be relied upon 100% of the time, such an instrument has only marginal utility. An analogy might be drawn between this type of instrumentation and the operation of a calculating machine. It would not matter how easily and rapidly the solution to complex accounting problems could be obtained with such a machine unless it could be relied upon to give correct answers every time. If it gave correct answers *almost* all of the time, such a machine would not be employed in the computation of balance sheets or important accounting information. The answers would be worked out in longhand, however laboriously, in order to insure their reliability. Errors in an instrument employed for continuous process control cannot be tolerated any more than they would be permitted in the accountant's calculating machine. The results would be equally costly.

Figure 4 shows the absorption characteristic typical of beta-emitting radioisotopes. The function of the relative absorption of the beta particles vs. absorber weight is peculiar to the isotope used and is determined solely by the energy spectrum resulting from the decay scheme of the parent element. Strontium 90, one of the industrially useful beta emitters, is particularly attractive beause of its long half-life and good penetrating ability. This isotope, with a half-life of 25 years, will provide measurements of plastic material up to a thickness of .2" and up to .030" of steel. While the absolute level of the radiation is decreasing continually at a rate determined by the half-life, the function of the relative absorption vs. sample weight remains a constant. This relationship is expressed:

$$I = I_0\ (e^{-\mu_1 w} + e^{-\mu_2 w} + \ldots + e^{-\mu_n w})$$

where I represents the response in the detector of radiation at any weight-per-unit area w, I_0 represents the response in the detector with no absorber between the source of radiation and the detector, and $\mu_1, \mu_2 \ldots \mu_n$ represent absorption coefficients peculiar to the isotope employed. Through the use of suitable instrumentation, readings of the ratio of the absorbed to the unabsorbed radiation may be obtained independently of the absolute level of the radiation. Since the terms e and μ are constants, the readings become a function only of w, the weight-per-unit area, which is the quantity being measured. The response of the detector is shown to have been reduced to a quantity of 80% that of the initial value in the second curve of Fig. 4, with this unattenuated response designated I_0'. Such an attenuation could have occurred, for example, through the natural decay of the isotope used. Suitable circuitry must be provided to effect the compensation necessary to cancel these changes in amplitude as they affect the instrument readings.

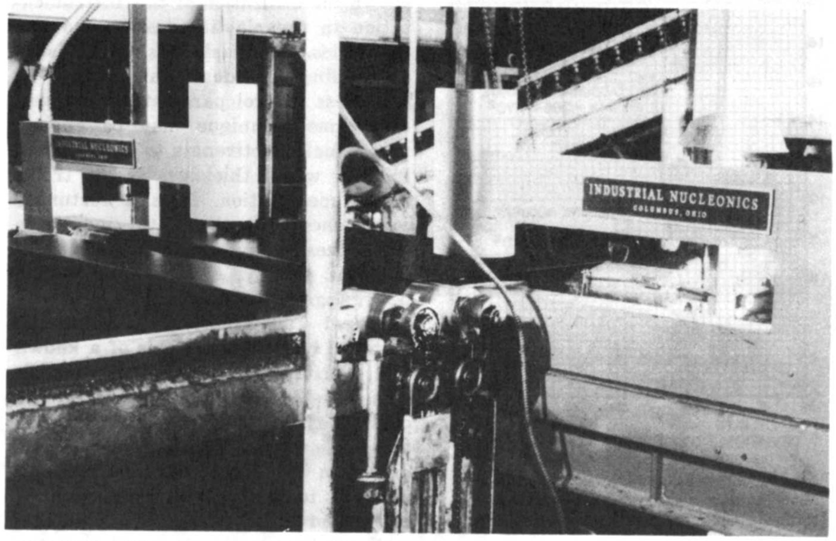


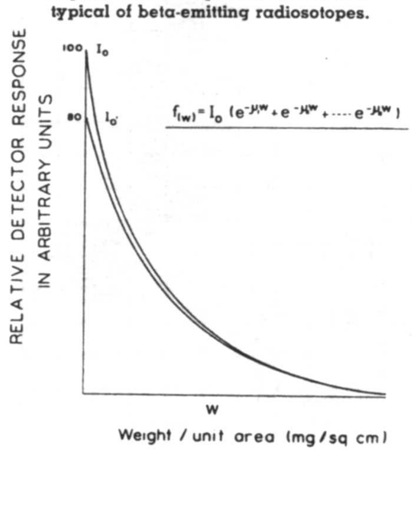
Fig. 3. Typical dual installation on a coated textile calendering machine. Source and detector are mounted on a transverse carriage.

A typical dual installation on a coated textile calendering machine is illustrated in Figs. 1 and 3. The use of two gauging elements provides continuous indication of the levelness of the sheet as produced. Readings from each detector are combined on a two-pen strip chart indicator-recorder. Use of different colored inks provides differentiation between the traces. Gauging elements are mounted on a traversing carriage supported by a heavy beam structure. The operator may select at will the point across the web which he desires to measure. This traversing feature also makes it possible to obtain information on the profile of the sheet.

A typical trace from a dual installation shows good operation of a calendering process through routine use of beta gauge instrumentation. The absence of sample holes, which is particularly noticeable on such a chart, represents a considerable saving in material which was formerly wasted in cutting samples.

The single-pen chart trace in Fig. 6 was taken from a tire fabric calender by using the beta gauge as an indicating device only, and not as a controlling instrument. A wide cyclical variation occurs shortly after restarting the calender following a period of shutdown. The sharp swing to light weight, which shows up shortly after restarting, is due to the squeeze that was exerted on the section of material left in the pinch between the rolls during the shutdown. The wide bandwidth of repetitive variation was determined to have been caused by roll eccentricity resulting from temperature distortion of the rolls while stopped. It is apparent that this bandwidth slowly narrows as a more even circumferential temperature distribution is achieved. A residual bandwidth remains due to residual roll eccentricity and bearing run-out. The difficulty which a machine operator

Fig. 4. The absorption characteristic typical of beta-emitting radiosotopes.



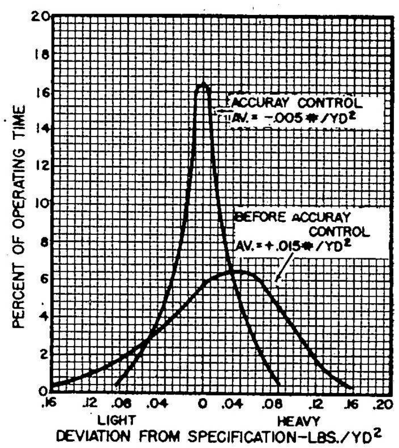


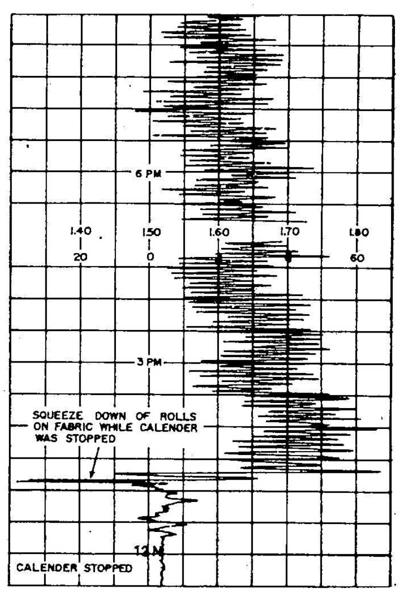
Fig. 5. Frequency distribution curves showing the close process control attainable with beta radiation gauging.

would have in controlling the process illustrated, if he were to rely upon cutting out samples, can be readily appreciated. He would have no way of determining whether the sample was cut at the peak of a "zig" or a "zag" or at the average weight.

Improvement in the operation of a machine process is readily apparent in the frequency distribution curves of Fig. 5. The curve of operation prior to beta gauge control showed that material was produced as much as .16 pounds per square yard below specification.

The foregoing illustrations have shown the utilization of this instrumentation in the plastics, textile and tire industries. Emphasis has been placed on readings of square-yard weight as a process control parameter. However, this same technique may be applied with equal effectiveness to those industries in which thickness is the traditional specification. It is a fortunate coincidence that the metal industries are processing materials of essentially constant density. A calibration of the beta gauge in terms of thickness is both practical and accurate, provided the material being measured is of a known and constant density. Thus, instruments are currently being used for the control of precision-rolled metal foils to an accuracy of 20 microinches. The extension of beta radiation gauging methods to the volume production of cold-rolled steel strip stock will find wide application in the steel industry with the first signs of a buyer's market. Commercial tolerances of ±10% will not sell steel when ±2% is attainable.

Fig. 6. Single-pen chart trace taken from a tire fabric calender using the gauge for indication only, not for control. The upper portion shows decreased cyclical fluctuations due to more even temperature distribution in rolls after calender was started.



In many ways, the technique of manufacturing a wide variety of products must be considered an art today. One of the more spectacular applications of beta radiation gauges to process control may be seen in the coated abrasive industry. This process involves the application of "maker" glue to a paper or fabric base, the deposition of an abrasive grit, a drying sequence, and the application of sizing glue. The operation is characterized by the term "100% scrap." This means that if the control of the process is inadequate at any point along the line, the total investment in material and machine time is lost. The cost of the cloth base is not only augmented by the amount of the glue and grit applied but a rejected roll will not even burn satisfactorily; the reject roll must be stored until someone can be obtained and paid to remove the debris from the premises. Beta gauges applied at every point in the process have afforded spectacular savings both in improved quality and reduction of scrap material. These gauges have, in effect, projected the art and experience of the machine operator onto direct-reading scales. It is no longer necessary to wait for Old Gus to put his finger into the glue pot before making proper machine adjustments. The first gauge reads the weight of the base fabric. The second gauge reads the weight of the base fabric after the application of the glue coating. A subtracting recorder indicates directly in pounds per ream the weight of glue applied. Further down the line, a gauge measures the weight of this combination after a drying process is used and a subtracting recorder reads the drying rate. A fourth instrument, reading the finished weight after the application of sizing glue, provides the information required to obtain a reading of the sizing glue alone. The availability of continuous records has provided management with a precision tool for the control of the process and an accurate measure of the costs.

Several basic questions must be answered before this new measurement technique can logically be applied to process control by the manufacturer. There must be a recognition of the fact that the variations in his product are of sufficient magnitude to constitute a serious limitation to the standards of quality which he can maintain. In those companies which have followed a consistent program of quality control, there are records which can demonstrate the existence of significant problems in process control. In other companies, this evidence has been made available only indirectly in the form of customer complaints and the rejection of material. A further consideration is the necessity for any instrumentation program to be able to assure accurate and reliable information on the process. Strip chart records of production must be accepted as the measurement standard not only by the machine operator but also by the production, accounting, quality control and sales departments.

The most important factor to be considered is the ability of this new measurement technique to assure the production of a better product at lower cost. In a process in which the machine characteristics require the setting of a nominal specification 15% above the minimum acceptable weight-per-unit area, this percentage can be reduced by accurate instrumentation. Take the case of a machine with a normal cyclical variation of ±5%, a 5% safety factor, and a gauging accuracy of 5%. An immediate reduction of 4% in the specification can be achieved with a gauge of 1% accuracy. When applied to a process involving an output of several million dollars annually, this saving rapidly mounts into hundreds of thousands of dollars. Experience in the rubber, plastics, abrasive and steel industries has shown that such savings are not merely projected or theoretical but are being achieved on a month-to-month basis.

To measure means the ability to control, and automatic process control has been achieved through the use of beta radiation gauging. It is a serious step to entrust the control of one's process to a gauge which supplants the twenty years' experience of the machine operator. Standards of reliability and accuracy required of an instrument that is to perform the function of automatic process control are very high. The beta gauge has met these standards.

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