Industrial Nucleonic Gaging*

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In any production-control system, several functions are always performed, describable as: measuring, controlling, monitoring, recording, and classifying.

Noncontact isotope gages have been developed to a high level of accuracy, reliability, and speed to meet these needs.

Production-control systems using this type of measuring unit are in operation throughout industry on many different applications for metalworking, paper making, rubber and plastics calendaring and extruding, paper converting, food processing, cigarette making, and textile combing. In all cases, greater precision in the control of the process is obtained through the use of noncontacting radiation measurement equipment and related automatic controls.

GENERAL DISCUSSION

Consider the staggering quantity of material produced in continuous sheet form—paper, plastics, metal, textiles, and abrasives are only a few. In every case, standards of quality are strict. It is not difficult to appreciate the tremendous significance of an automatic, continuous, noncontacting gage using radiation to measure and control product thickness. These systems form the basis for complete production-control systems on continuous processes.

In any production-control system, there are several functions that are always performed, regardless of the product. For convenience, these can be described as: (1) measuring, (2) controlling, (3) monitoring, (4) recording, and (5) classifying.

It is elementary that the output of any process must be measured in some way. Perhaps there is nothing more than periodically glancing at the product, or very extensive and precise analysis may be involved; but, in any case, some measurement must be made. Second, if the measurement indicates that the product is not exactly what is desired, some corrective or control action is taken. Third, the proper performance of the first two functions must be monitored, to insure that the measuring equipment or techniques have not gone awry or that the controller is not initiating faulty action. Fourth, production records must be kept; these are of use not only to the Production Department, but also to the Accounting Department, Sales Department, and others. Fifth, and finally, the output must be classified and the out-of tolerance product rejected, for, if this is not done by the producer, it certainly will be done by the customer.

All five of these functions are of equal importance, and everyone can think of examples wherein improper performance of any one of them has caused serious trouble. Performance of the last four of the outlined functions depends completely on the accuracy, reliability, and speed of performance of the first. Hence, development of any continuous and automatic control system must be dependent upon the development of a continuous and automatic gage to measure the variable to be controlled. Noncontact gages for measurement of thickness have been developed to a high level of accuracy, reliability, and speed.

Practically all noncontact thickness gages utilize some sort of radiation, commonly either x-ray or beta ray, to make the measurement. In measuring total strip thickness, a source of radiation is mounted underneath the strip, and a detector above. The radiation that penetrates the strip is inversely proportional to the weight of the strip.

In the design of equipment for cinematically performing the functions of production control, there are certain requirements that must be satisfied. The measuring gage must have tl)ree basic characteristics: (1) accuracy, (2) dependability, and (3) high speed of response. It must maintain its accuracy under all conditions of operation. For the entire system to be truly automatic, the measuring *gage* must be truly automatic and permanently calibrated. It is evident that any radiation *gage* sees everything that appears between its source of radiation and its detector; this includes not only the strip of material being measured, but also any rolling oil, dirt, grit, or other extraneous material that may accumulate on the measuring head.

Hence, it is incumbent on the designer to furnish some method of automatically recalibrating or standardizing out such extraneous effects to insure dependability and accuracy not subject to human error or forgetfulness.

Equipment designed to perform the second function, controlling, must be designed not only to cause the proper control action to be taken when necessary, but also to be completely fail-safe. This leads into the third function, monitoring.

It is axiomatic that everything that has ever been built can fail. The designer of a truly automatic control must provide monitors that will do two things: (1) make any failure immediately apparent to all concerrned, and (2) shut off all control action in a safe manner, that is, so that no damage can be done to the process machinery. Ideally, the non contacting *gage* should be like an adding machine in that either it will give the right answer.

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or it will give no answer at all. If the measuring system should fail in a manner that would otherwise give an erroneous measurement, the monitor should shut off the gage, shut down the control or perhaps the entire process, and sound an alarm. Sometimes, in the final design of a control system, the monitoring and safety circuit is more involved than all the rest of the equipment.

The fourth function, recording, must be considered in terms of which departments of the company are to use the records. Records of interest to production personnel and also perhaps the research and maintenance departments should include the maximum possible detail. Therefore, a wide strip recorder is ideal. Such a record, however, is entirely too detailed and not in the proper form to be of use to management, accounting, or other departments.

A completely mechanized control system should include data-reduction equipment, which, for example, may total the number of feet of strip within tolerance versus those out of tolerance. Such equipment should read-out either on counter dials or directly on punch cards or tapes for further processing through accounting machinery.

The fifth function, classifying, is necessitated by the fact that any control system is limited finally by the inherent characteristics of the process machinery. For example, it will probably always be necessary to shear off and reject some material from the head and tail end of rolled coils or reels, regardless of how fine a machinery control system can be developed.

Since practically all flat products are produced in the form of coils or reels and later sheared, punched, or otherwise cut into smaller pieces by either the producer or the fabricator, it would seem most economical for the classifying function to be performed in conjunction with a shear or punch. For a producer of sheet, this presents a little problem. Classifying or sorting conveyors with electrically controlled gates to drop sheets into different bins have long been available and are in use, activated by thickness gages, pinhole detectors, and other sensing devices. Coil or reel stock, on the other hand, presents a different problem. Although some large con consumers have installed automatic classifying equipment and others have very involved incoming inspection procedures, it may be desirable, for sales reasons, for the producer to assume this function. This means classifying to a much finer degree than merely guaranteeing that the product is within commercial tolerances, for variations well within this magnitude can cause trouble in many fabricating operations. Perhaps many of the problems facing users of coil or reel stock could be solved if the strip were marked in some way to show the exact characteristics of the strip at each point. Many types of marking devices are available that could be activated by thickness gages or other measuring or sensing devices.

A final type of classifying situation is that of handling sheets after they have been sheared or cut from the coil or reel. This is commonly encountered in re-classifying sheets that have been rejected by some previous classifying operation, so that those that can be sold in a different tolerance range can be salvaged from those that must be scrapped. This is commonly referred to as *regrading.* Because of the gaps between successive sheets, the designer of automatic gaging and classifying equipment must provide very high-speed response, so that the line can move at any reasonable speed and yet allow each sheet to be accepted or rejected.

INDUSTRIAL APPLICATION

The Metalworking Industry

It has long been recognized that some, if not most, of all the variations in the gage of the output of a cold-reduction mill have their origin in the hot-rolling process. In many cases, it has been shown that every coil coining from a cold mill has four clearly definable heavy spots along its length directly resulting from the water-cooled skids in the slab-heating furnace ahead of the hot-strip mill. Another common characteristic is the gradually increasing *gage* from head to tail end due to the cooling of the slab in the hot mill, particularly on the run-out table ahead of the finishing train. It is the proper function of cold-reduction mills to iron out these variations within the coil and also to put the average thickness of each coil on specification.

The first step in the control of a tandem cold-reduction mill is considered to be the elimination of the variations in the incoming strip. It is felt that, if the strip entering the second stand of the mill were uniform in gage, then it and all succeeding stands would require little adjustment within any one coil to maintain a constant finish *gage.* The best way to accomplish this is to apply automatic screw control to the first stand, since at this point the steel is still relatively soft and also moving slowly, so that the mill screws have enough time to act. The first known successful installation of a noncontacting radiation-gage type of control system on a tandem steel mill was at the Republic Steel Corporation, Niles, Ohio, plant by the Industrial Nucleonics Corporation in November, 1953, and the expected results were obtained. Since that time, many such installations have proved the effectiveness of this type of control in increasing yield percentage and causing a more uniform product. In this case, the measurement and control system consists of a noncontacting radiation gage mounted between the first and second stands and an automatic controller coupled with this measuring unit controlling the screw-downs of the first stand.

It was recognized from the beginning that the control of the first stand of the tandem mill was only the first step. In actual practice, the producers who are using automatic screw control of the first stand are also using a noncontact measuring finishing stand to allow manual control of the rest of the mill. The next step was then quite obviously automatic circuitry actuated by the finish-stand gage. There are several methods by which control may be undertaken. First, the control signal may be cascaded to reset the control point of the first-stand controller, so that all automatic control action would be taken by the first-stand screws. Second, control signals from the finishing stand might be used to change the speed of the first stand. Third, the finishing-stand speed might be controlled directly. There are many other possible systems. The last system, however, is currently in use on several tandem cold-reduction mills at the present time. This system is utilizing both isotope- and x-ray-type noncontacting radiation gageing immediately following the last stand of the tandem train. Figure 1 shows a schematic sketch of a complete tandem-mill measurement and control system as it exists today.

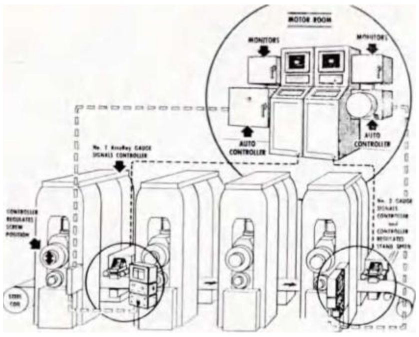


Figure 1—Automatic Control of Cold-Reduction Mills

Figures 2 and 3 are installations on the first and last stands, respectively. Continued accurate and reliable operation in adverse mill environment has proved the success of the isotope measuring system.

The reversing cold mill can be treated like the first stand of a tandem mill, and automatic screw-down control is capable of providing excellent control at every pass down to and including the finished gage. Two measuring gages are required, one on eacl, side of the mill, and the control circuits are automatically switched back and forth as the mill reverses. One slight difference in gage design results from the fact that most reversing mills run a wider range of alloys than most tandem mills. Figure 4 shows a typical installation on a four-high reversing mill. A closer coupled Sendzimer cold-reduction mill requires more compact measuring heads, such as shown in Figure 5.

Automatic control of hot-strip mills has not yet been accomplished, to this writer's knowledge. A great deal of engineering hours are being expended, however, in the study of these problems by the steel companies and by the equipment manufacturer. It is the dogma of automation that anything that can be measured can be controlled. Considering the speed with which developments are being completed, a hot strip mill should be equipped with automatic thickness control in the near future.

Up to this point, all characteristics discussed apply equally to any radiation gage; that is, of either the x-ray or the isotope type. However, in discussing noncontact measurement of coating thickness, the two types must be distinguished. It is understood that any x-ray coating-thickness gage operates on a fluorescent principle; that is, x-rays are beamed at the strip, penetrate through the coating, and ex-

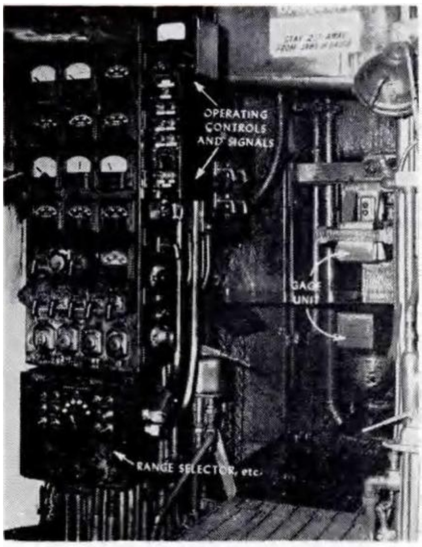


Figure 2—First Stand of Mill

cite the base metal, which, in turn, re-radiates x-ray waves of an entirely different length. It is this secondary radiation that is used to measure the coating thickness.

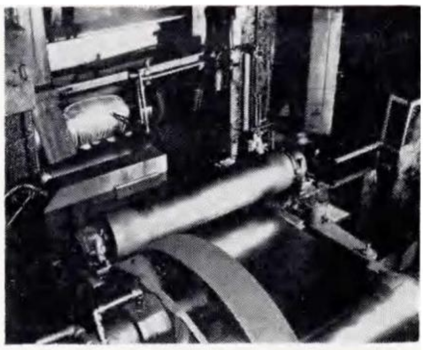
The beta-ray thickness gage is apparently almost a true reflection gage in that the beta or isotope rays are beamed at the strip, penetrate the coating, and bounce from the base material back through the coating, and are detected. As the coating weight increases, the number of beta rays that return to the detector either increases or decreases, depending upon the relative atomic weights of the base and coating materials.

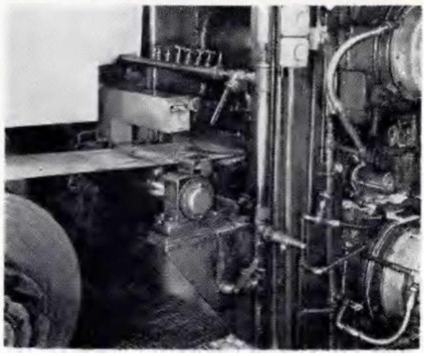
Essentially the same beta reflection system can be used to measure the coating of zinc, tin, aluminum, enamels, or other material on any homogeneous base material, such as steel. Figure 6 shows a typical isotope measuring head installed on a hot-dip galvanize line.

The design of a system for measurement and possible control of a continuous galvanize line presently in use includes two measuring heads, one for the top side, the other for the bottom, with a summation computer to add the two coating weights. The gages scan across the strip to indicate edge-to-edge as well as machine-direction variations. This system will give a continuous measurement with a high degree of accuracy. According to tests made by personnel of various steel companies, the reflection *gage* seems to show greater accuracy and repeatability or reproducibility than the destructive chemical striping tests used to check it. Now that a measuring system is available, automatic control of coating thickness has

become inevitable and will be accomplished in the near future.

Measurement of electrolytic coatings on tinplate presents much the same problems as measurement of zinc coatings, with the added factor that the *gage* must be of very





high sensitivity because of the light weights of coating applied.

Noncontacting, radiation gaging is

*Figure **3—Last** Stand of Mill*
Figure 4—Measuring Gage on a High Reversing Mill

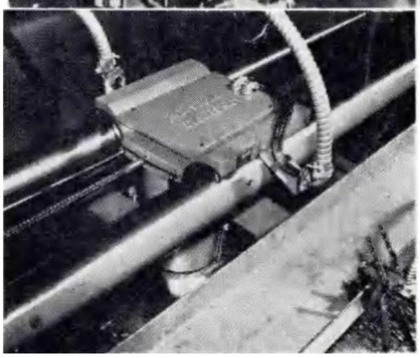


Figure 6—Measuring Head on a *Galvanize Line*

become inevitable and will be accomplished in the near future.

Measurement of electrolytic coatings on tinplate presents much the same problems as measurement of zinc coatings, with the added factor that the *gage* must be of very high sensitivity because of the light weights of coating applied. Noncontacting,radiation gaging is

also in limited use throughout the metalworking industry for checking of pipe or tube-wall thickness. In this particular application, the measuring equipment is normally coupled with a classifying system in order to signal out-of-tolerance pipe- or tube-wall thickness and provide the operator with a visual signal in order that he may properly crop or shear off the out-of-tolerance ends of extruded pipe or tube.

Other applications of radiation measuring equipment are being developed for the metalworking industry. Examples of two such applications are: (1) the measurement of fill. in a closed crucible or in a blast furnace, and (2) the density measurement of various types of slurries.

Rubber

The acceptance of noncontacting radiation measurement in this industry has been practically universal in this country. All U. S. tire producers have purchased this type of equipment for their tire-fabric calenders. Two of these companies have equipped all of their calenders with isotope units.

The principal applications in the rubber industry include: (1) tire-fabric calenders, (2) tire-tread extruders, (3) secondary calenders for other rubber on tires, that is, interliners and the like, (4) rubber extruders for molding blanks, (5) sponge and foam-rubber calenders for footwear and mechanical goods, (6) asphalt-tile-flooring calenders, (7) rubber-coated-fabric calenders, (8) aircraft-fuel cells, (9) rubber-tread calenders — webbing, threads for golf balls, etc., and (10) hard-rubber calenders — battery separators, heels, soles, and the like.

A typical installation of noncontacting measuring equipment on a tire-fabric calender (Figure 7) consists of two measuring units installed immediately after the last pass, continuously measuring area-weight and automatically controlling the positioning of their respective sides of the calender-adjusting rolls. With an installation of this type, cocked-roll conditions are quickly determined and eliminated and production is held continuously within much narrower tolerance limits.

Marked improvement in sheet profile, effected by improved feeding techniques fostered by continuous measurement, has resulted because smaller incremental roll corrections are required.

The accurate control of rubber distribution has achieved marked improvement of tire balance, with a corresponding increase in tire life and driving safety because of the decrease in tire failures.

Plastics Industry

Noncontacting radiation measuring and control systems have become the accepted standard in every segment of the plastics industry where continuous process measurement and control of area weight has been long desired but totally lacking. Numerous process refinements and improvements have been made possible because of the availability, for the first time, of reliable and accurate measurement and control instrumentation.

Typical of an application of this type of equipment is the installation of noncontacting radiation gages on a polyethylene-extrusion process. The extrusion lamination of polyethylene to paper is a process that has been in existence for about 6 or 7 years.

In this process, a conventional thermoplastic extruder melts the polyethylene and forces it continuously through a sheeting die to form a film at a temperature of 450 to 550 F. This hot film is pressed between a sheet of a paper and a water-cooled metal roll by a rubber pressure roll. The film adheres to most papers well enough to pull fibers and is cooled well below its melting point by the cooling roll by which it is released. Thus, a good protective film is laminated to paper, but no adhesives or solvents are used anywhere in the process to add costs or hazards.

This process, however, does not automatically place the convertor in Utopia. A quality paper coating must be uniform in thickness throughout to provide consistent protection, smoothness, dielectric properties, or whatever is to be desired of a paper coating.

The die for polyethylene-sheet formation may be considered as a

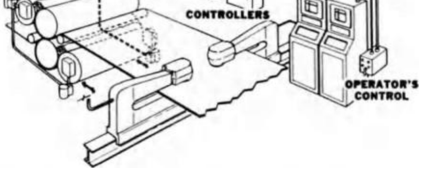


Figure 7—Measuring Equipment on a Tire-Fabric Calender

pipe of any dimension mounted horizontally. On the top side, equidistant from each end, is the entry pipe from the extruder. On the bottom side of this pipe is a slot, extending its full length. At the bottom of this slot is a slit orifice whose width is controlled by die blades. The gap between the blades is adjusted by alternate pusher and puller bolts spaced at 4- to 5-in. intervals. Dies have been constructed to make a sheet of polyethylene up to 120 in. wide.

One bad condition exists on a machine of this type where unlike metals are physically held together and are heated from one side. Warp is inevitable; no matter how carefully die blades are adjusted when the die is cold, corrections must be made when the die is hot. Additionally complicating this adjustment problem are the characteristics of polyethylene coming from the die, and level film can be obtained in one case only having the ends of the dies as much as 70 to 80 F cooler than the center. Polyethylene in the presence of air at 600 F decomposes, and the charred products accumulate on the edges of the die blades. Resins vary from lot to lot and from type to type in viscosity and flow characteristics. Adjustments to correct film weight are required therefore, at short intervals.

Initially, control of this type of process was accomplished by *miking* the coated sheet and noting weight differences between uncoated and coated papers. Shortly, it was found that paper-weight variations were greater than film variation, making measurements of the whole coated sheet unsatisfactory.

The next control procedure was to remove the paper from a coated strip taken across the width of each roll, caliper the film at short intervals with a precision micrometer, and check readings periodically against film weights obtained with an analytical balance. This procedure was quite effective but time-consuming. On a start-up with polyethylene, large amounts of unacceptable and highly expensive material might be made before the film was adjusted to satisfactory uniformity.

Two noncontacting isotope gages were installed on the process. One gage measures the weight of the raw material, and the second measures the weight of the coated paper. The two gages can be adjusted for any combination of paper and coatings, so that the two traces on a dual-pen recorder chart, representing the coated and uncoated paper, are superimposed when the correct weight of coating is being applied.

With this system, it is possible to note and correct errors in relatively narrow strips of coating. Such corrective action is possible because adjustment centers, made up of the die-blade bolts, are less than 5 in. apart.

The total average coating weight is primarily selected by changing the web speed, since the rate of plastic extrusion is held as high as possible for most coating weights and is therefore relatively constant. Although this installation only measures, and does not control automatically, web-speed control is available and could be a valuable feature.

The measurement system includes an automatic standardization feature that virtually eliminates the need for periodic checks against standard samples.

Direct cost reductions can be attributed to: (1) shorter adjustment time to start producing acceptable coated paper; (2) no tear-outs or samples being required during the setup, thus reducing splices and conversion time; (3) no more making coating weights heavier than specification for safety, since thin spots can be quickly detected and corrected, eliminating any necessity for costly overweight; and (4) measuring the base paper weight so that the producer can give suppliers records of the exact manner in which the basic weight variations occurred, enabling them to spot troubles and produce a more uniform base sheet.

Numerous installations of this type have clearly demonstrated impressive savings and product improvements that have led to the installation of noncontacting measuring radiation equipment on several different processes in the plastics industry. These processes include: (1) film and sheet calenders, (2) film and sheet extruders, (3) photofilm casting and coating, (4) plastic fabric coaters, (5) plastic fabric calenders, (6) polyethylene paper coaters, (7) plastic flooring (linoleum) calenders, (8) cellophane, pressure-sensitive-and gummed-tape machines, (9) wall- and floor-tile calendars, and (I0) decorative and industrial lamination resin-impregnation process. Figures 7 and 8 show typical installations on rubber and plastics calenders.

The Paper Industry

The most important characteristic of paper is its basis weight. Noncontacting radiation (isotoype) measuring systems are used to measure this quantity directly and to control the weight by adjusting automatically either the stock flow through a stuff gate or the machine speed.

In the manufacture of box board, different grades of stock are used for the top and bottom liner versus that used for the filler. Most of the basis weight is made up by the filler stock. Radiation gaging systems are used to control the flow of filler stock into the respective vats to control the over-all basis weight.

There are many different types of paper-conversion process, but the main ones are coating and impregnating. Because the raw paper is not absolutely uniform in weight, control of the coating or impregnating weight requires two measurements, one of the weight of the raw paper and the other of the weight of the coated paper.

Noncontacting radiation measuring systems with computers are used to determine the weight of the coating or impregnate only. The automatic controllers in the system are then actuated by the reading of the computer.

The benefits derived from the use of these systems are basically two: improved product uniformity and lower production costs. The variations in weight commonly encountered in paper manufacturing and converting are normally cut to one-third through the use of these automatic process-control systems.

All paper products, in the ultimate, are used by the square foot, yet the raw materials are bought by the ton. Hence, the yield of square feet per ton of raw material determines the profitability of the operation. By eliminating material that is heavier than it need be, a higher yield results, leading to production cost savings.

In addition to increasing the yield, automatic control systems utilizing noncontacting measuring systems allow savings of machine time to be realized through faster start-up, faster order changes, higher average machine speeds, and less reject production.

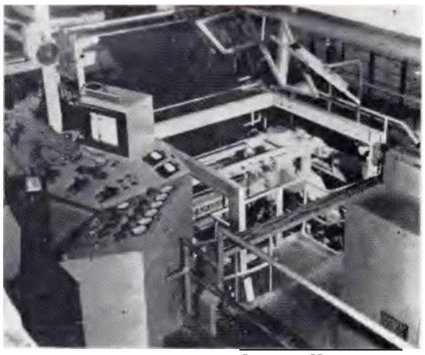


Figure 8—Typical Installation

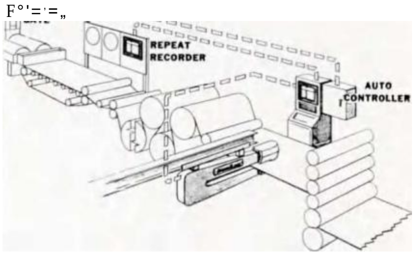


Figure 9—Typical Measuring and Control System Used on a Paper Machine

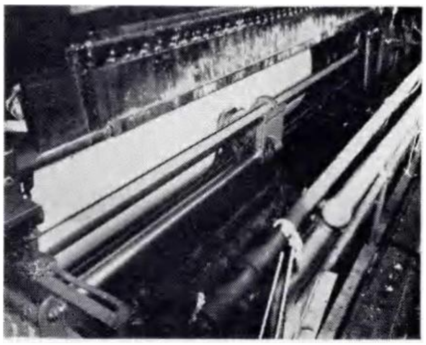


Figure 10—Typical Paper-Machine Installation

Figure 1I—Typical Paper-Machine Installation

A typical measurement and control system (Figure 9) of this type used on a paper machine is one where the stuff gate is controlled by a system composed of the following components: (1) a radiation measuring unit, located at the dry end, acting as a sensing clement for the control system (this radiation measuring unit may be of either a transmission or a reflection type); (2) a scanning mechanism that provides measurement across the width of the sheet; (3) a profile-averaging computer that averages the weight of the sheet; (4) a proportional automatic controller; and (5) a control-system monitor that maintains constant vigilance over the entire system to protect product and process equipment.

The measuring unit scans slowly across the width of the sheet, presenting its reading of the sheet profile on a recorder. When the gage reaches the end of its scan, the recorder pen clamps and the gage retracts quickly to begin a new scan.

At the end of each scan, the basis weight across the sheet is averaged by the profile-averaging computer that is an integral part of the system, and its signal is sent to the controller. If the average is beyond the control band set into the controller, appropriate control action is initiated to adjust the flow of *stuff* onto the wire. Control is proportional; that is, the larger the error, the larger the correction.

This system operates continuously, but control action occurs only when necessary. Control-system monitors are incorporated in the system to insure product and process protection. If unusual process conditions prevent the controller from making its proper corrections, automatic control terminates and an alarm sounds to inform the operator of the situation.

Process-control systems of this type utilizing noncontacting radiation measurement coupled with automatic controllers are widely used in the American paper industry. Figures 10 and 11 show typical paper machine installations.

CONCLUSIONS

Further extension of the technique of utilizing noncontacting radiation measuring equipment into more *specialized* fields is best illustrated by the recent application of nuclear radiation measuring equipment to the cigarette-making process. In this instance, a nuclear gage passes a continuous stream of electrons through a cigarette and analyzes the cigarette while it is actually being made. This nuclear stream transmits what it *sees* through the electronic controller or brain, which adjusts the position machinery down to millionths of an inch. By now you are probably all familiar with the phrase *Made the Modern Way With AccuRay.*

Another development contingent upon accurate and reliable measurement is in the realm of improved quality and cost records, with a subsequent reduction in the time required to obtain them. These records then form the basis for improved over-all production or managerial control systems.

Data-reduction and data-readout systems are now available for providing accurate records for continuous processes having suitable transducers. A typical example is a complete data-readout system as it would be applied to an electrolytic tinning line. The data thus obtained form a major part of the quality and costing records for administrative control of such a process. In this case, noncontacting radiation gages, along with other nondestructive transducers (testing equipment), form the basis for a profit-control system, as well as being a single process-control element.

The consequence of process-control installations of the types described in bringing precision and accuracy to heretofore difficult process problems will no doubt reach into many other industries. The systems described in this paper are merely examples of what has been done to date. It is expected that not only will customers benefit from improved quality, but techniques will improve correspondingly, making practical greater precision in the control of industrial processes through the use of noncontacting radiation measurement equipment and related automatic control systems.