

[54] **COATING A CONTINUOUS METALLIC STRIP WITH PULVERANT MATERIAL WITH A NON-DESTRUCTIVE MEASURING METHOD**

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[73] Assignee: **Caterpillar Tractor Co., Peoria, Ill.**

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[21] Appl. No.: **62,019**

[52] U.S. Cl. **117/31, 73/150, 88/14, 117/33, 117/DIG. 2, 118/2, 118/9, 222/55, 250/216, 250/222**

[51] Int. Cl. **B44d 1/34, C23c 17/00, B23p 3/06**

[58] Field of Search **117/31, 33, DIG. 2, 131; 222/55; 73/150; 118/9, 2; 250/216, 220**

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Primary Examiner—William D. Martin

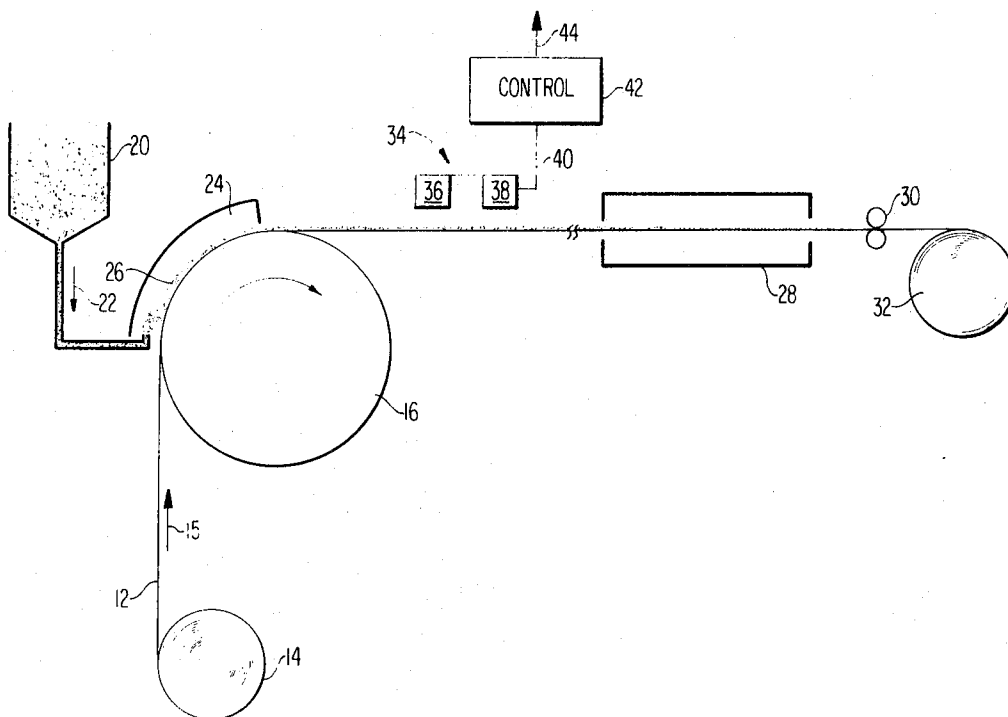
Assistant Examiner—William R. Trenor

Attorney, Agent, or Firm—Shanley and O'Neil

[57] **ABSTRACT**

Characteristics of a pulverant material coating or its supporting surface can be determined by measurement of diffused energy return after impingement with beam of light, ultraviolet, infra-red, monochromatic light, or the like. Methods and apparatus for non-destructive measurement of characteristics such as coating thickness during electrostatic coating process for metallic powder on a continuous metallic strip are provided.

8 Claims, 10 Drawing Figures



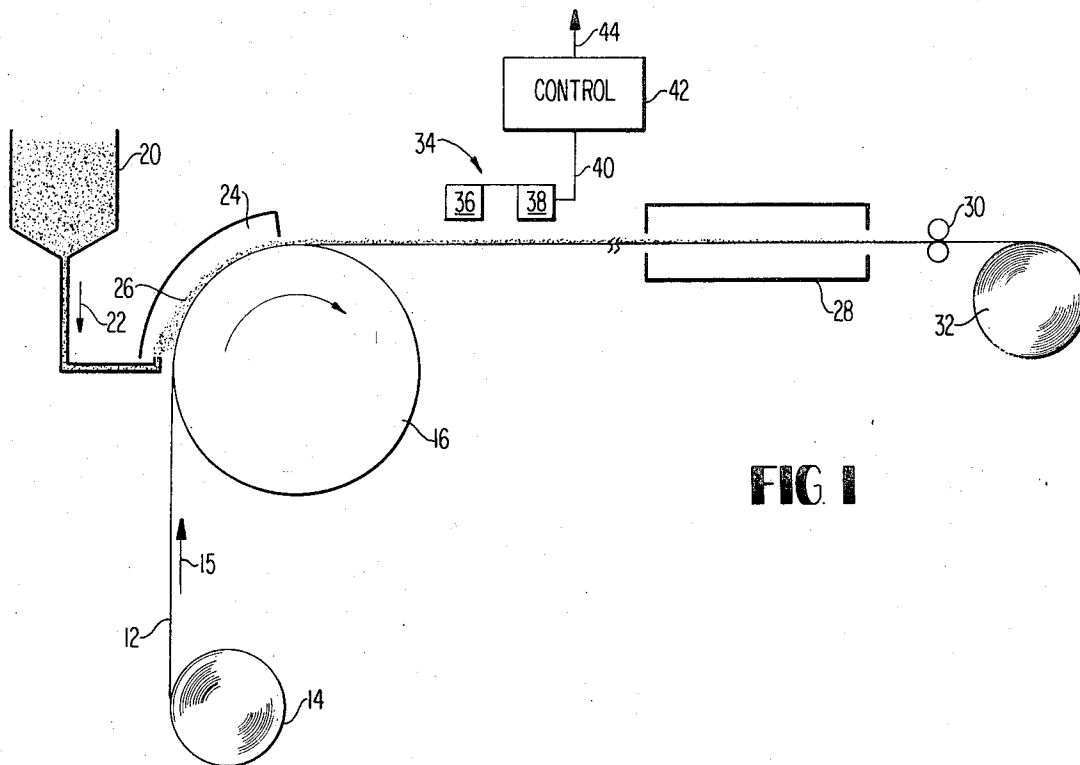


FIG 1

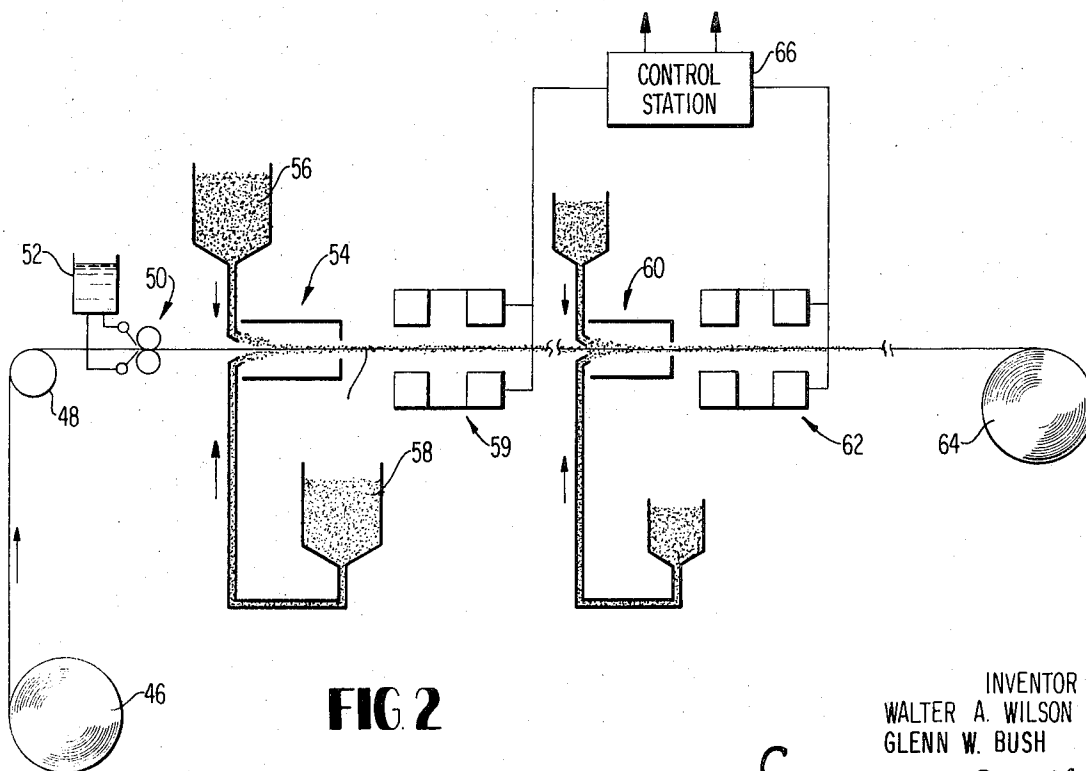


FIG 2

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ATTORNEYS

FIG. 3

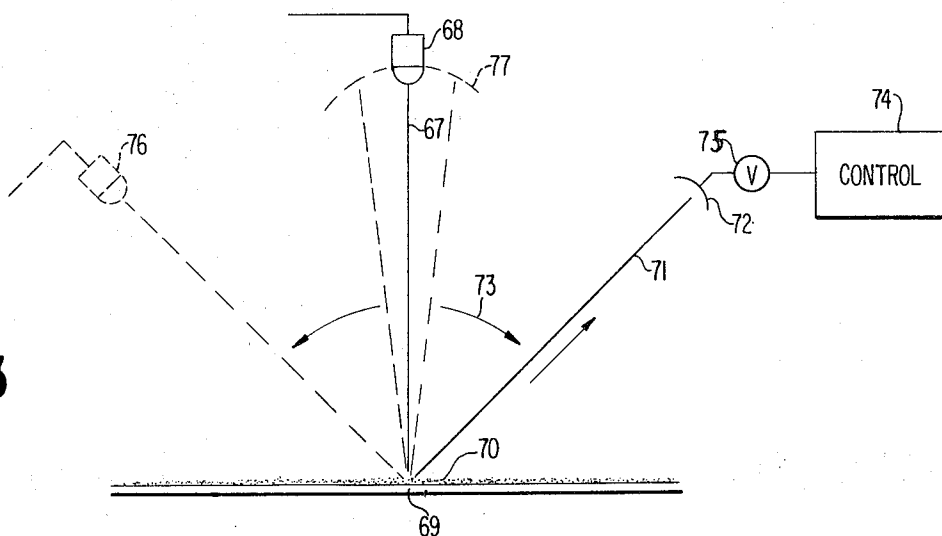


FIG. 4

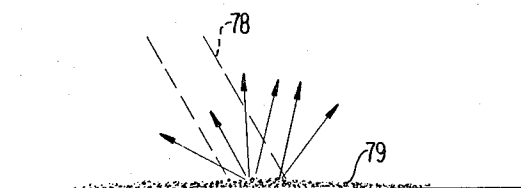
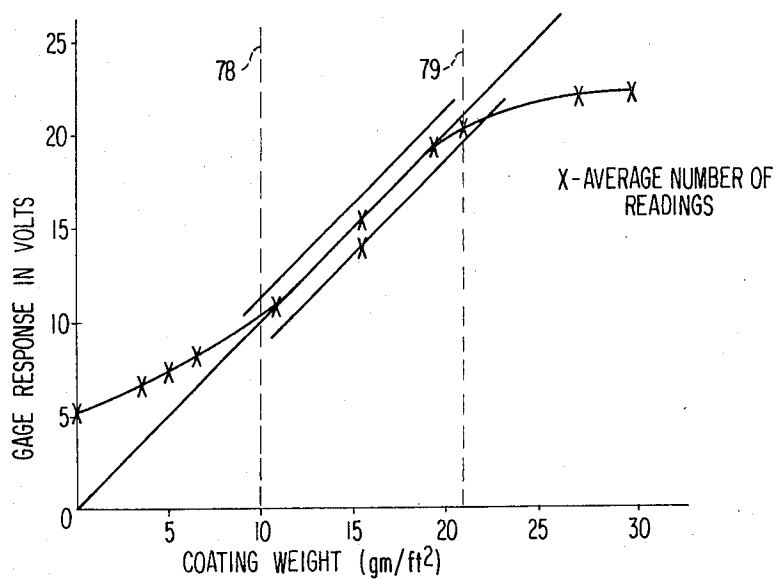


FIG. 5



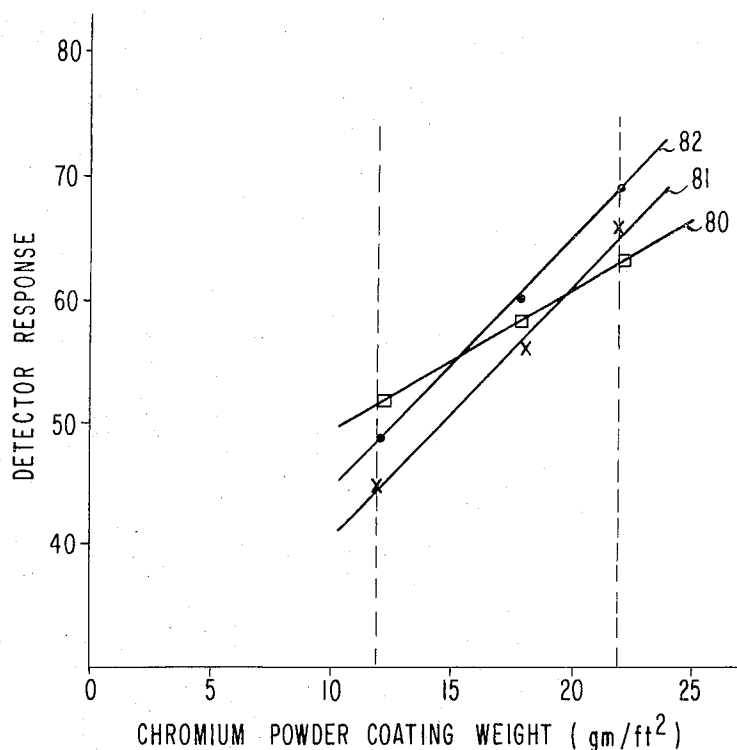


FIG. 6

DATA PT.	ANGLE OF INCIDENCE
□	0°
x	30°
•	40°

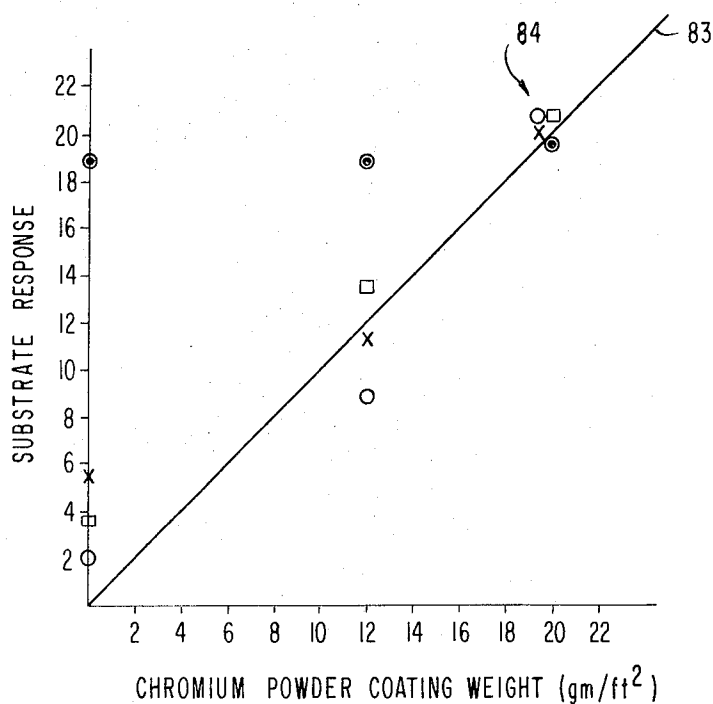


FIG. 7

DATA PT.	SURFACE
⊙	"JP" (DIFFUSOR)
□	MINIMIZED SPANGLE
x	COLD ROLLED STEEL (BLACK PLATE)
○	FLOW BRIGHTENED TINPLATE

FIG 8

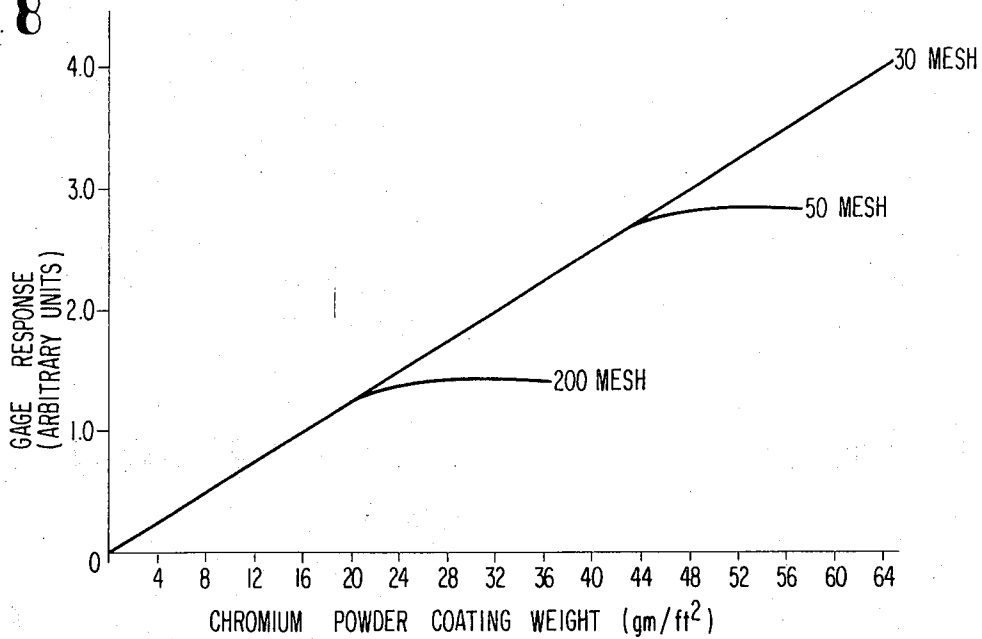


FIG 9

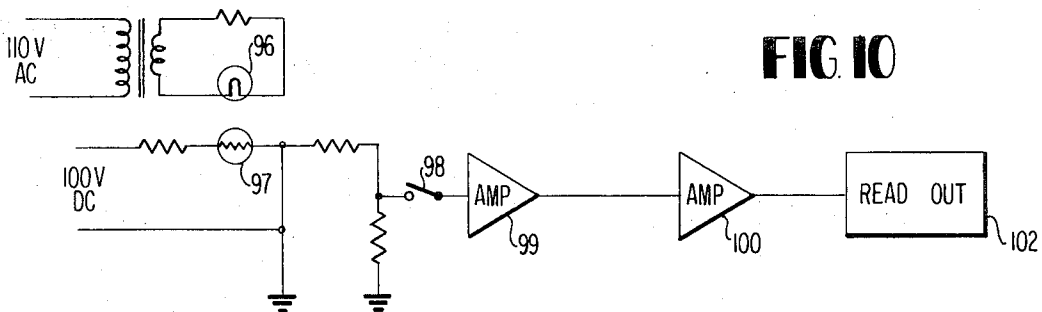
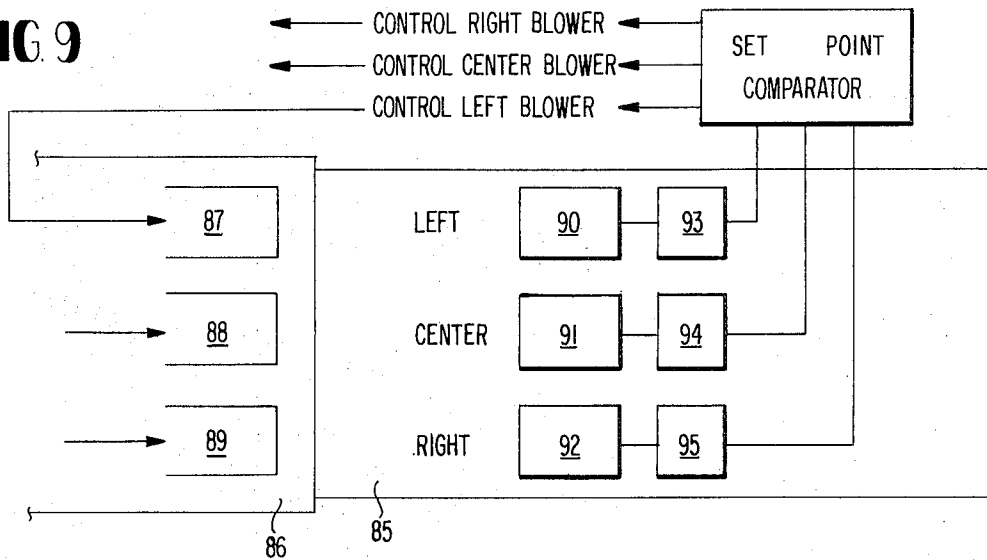


FIG 10

COATING A CONTINUOUS METALLIC STRIP WITH PULVERANT MATERIAL WITH A NON-DESTRUCTIVE MEASURING METHOD

This invention is concerned with measuring methods and apparatus applicable to pulverant material on a supporting surface for determining characteristics of the pulverant material or the support surface. In its more specific aspects the invention is concerned with non-destructive measurement of pulverant material distribution on a supporting surface and with providing methods and apparatus for control of processes involving pulverant material deposition including automated control for such processes. One embodiment of the invention is concerned with distribution of pulverant material on a solid substrate, for example, uniform distribution of a metallic, corrosion-protective, powdered metal on flat rolled steel.

Significant opportunity exists for wider commercial application of powder coating methods but no satisfactory method has existed for making non-destructive coating weight determinations. The problem is compounded by the need for a satisfactory gage to be able to function with differing powders, wet or dry application methods, and substrates of varying thicknesses and compositions. Such factors eliminate x-ray gages, beta ray gages, and the like, because the penetrative character of the radiation in such gages does not permit the adaptability required for coating lines in which the coating material, thickness of the substrate, and the like, are subject to change. As a result no practical method of making a non-destructive determination of coating distribution, coating weight, or coating thickness of pulverant materials for commercial coating processes, such as continuous steel strip coating processes, has existed, notwithstanding the obvious and pressing need in the powder coating field.

The present invention provides commercially acceptable and reliable non-destructive methods and apparatus for measurement of pulverant material deposition on multipurpose lines suitable for differing powders, wet or dry application methods, varying substrates, and the like. The invention teaches use of what is described as a non-penetrative (sometimes referred to as non-ionizing) type of wave energy, such as ultraviolet, regular light, monochromatic light, infra-red, and the like, extending into the quasi-optical region of the electromagnetic wave spectrum. Selective measurement of returned wave energy without mechanical contact of the work product is made. Such selective, non-destructive measurements provide the accuracy required for commercial processing and rapid results for substantially any process, including high speed continuous strip processing. The pulverant material can be metallic or non-metallic finely divided particles of spherical or other shape, such as flake particles. The thickness of a substrate, such as continuous strip flat rolled steel can vary without affecting the measurement.

A typical commercial application for the invention exists in the coating of flat rolled steel product with a metallic powder, such as chromium powder. The invention will be disclosed in that environment. It will be apparent that other substrates, other coating materials, and other processes fall within the scope of the invention. In making a detailed disclosure, the accompanying drawings, briefly described below, will be referred to:

FIG. 1 is a schematic elevational view of a coating line, for coating a single surface of a substrate, embodying the invention,

FIG. 2 is a schematic elevational representation of a coating line, for coating both surfaces of a substrate, embodying the invention,

FIG. 3 is a schematic elevational view of measuring apparatus embodying the invention, and

FIG. 4 is a schematic elevational view of pulverant material on a supporting surface used for disclosing a concept of the invention,

FIGS. 5 through 8 are graphical representations of data illustrative of the invention,

FIG. 9 is a schematic plan view of a portion of a coating line embodying the invention, and

FIG. 10 is a schematic circuit diagram embodying the invention.

In FIG. 1 continuous strip material 12 is fed from coil 14 in the direction indicated by arrow 15 around coating drum 16. Pulverant material from hopper 20 is fed in the direction indicated by arrow 22 into a deposition chamber 24. The pulverant material is directed as indicated at 26 and deposited on strip 12 during its travel around the coating drum 16. The strip is then directed for further treatment of the coating, usually involving compaction by passage through a sintering furnace 28 and a compaction roll stand 30. The strip is then coiled on take-up reel 32. Line speed can be measured at coating drum 16 or other locations along the line and indicated as required. Line speed and the rate of powder deposition are controllable. Further details of an electrostatic powder coating line can be obtained from the copending patent application entitled "Electrostatic Coating of Metal Powder on Metal Strip," filed by Edwin J. Smith et al, on Aug. 15, 1967, Ser. No. 660,787 refiled as continuation application Ser. No. 63,896, now U.S. Pat. No. 3,745,034.

Apparatus 34 for making quantitative measurements of the surface coating is located downstream of coating roll 16. Measuring apparatus 34 (shown diagrammatically) is positioned between coating applicator means and subsequent treatment means permitting viewing of the strip as coated with pulverant material. Measuring apparatus 34 includes wave energy source 36 and detector apparatus 38. Signals from detector apparatus are sent over line 40 to control apparatus 42. A control signal from control apparatus 42 is directed over line 44 to control processing line variables affecting coating weight, particle distribution, and the like.

In the processing line shown in FIG. 2, continuous strip is fed from coil 46 around guide roll 48 toward wetting station 50. A binder solution is directed from tank 52 to wet one or both surfaces of the strip material prior to coating. At coating station 54, hoppers 56 and 58 feed powder to be deposited on opposite sides of the strip forming a slurry coating on the strip.

Coated strip 56 can be fed directly to compacting apparatus or, as shown in FIG. 2, after passing measurement station 59, coated strip can be fed through a tandem coating apparatus 60 where pulverant coating material is added to one or both sides. The strip can then be fed directly through compacting apparatus, not shown, and/or through an additional measuring station 62. Further tandem deposition and measuring apparatus can be included in the line. After coating and compaction the strip is coiled at reel 64. Line speed can be measured at roll 48 or otherwise along the line and

powder deposition rate at each station can be controlled. Additional details of an electrostatic wet process powder coating line can be obtained from the copending application, entitled "Electrostatic Coating of Metal Powder on Metal Strip," filed by Lowell W. Austin et al, on Jan. 5, 1968, Ser. No. 695,957 now U.S. Pat. No. 3,575,138.

The coating measurement stations 59 and 62 each include top surface and bottom surface gage means. One or both surface gages may be used at each station dependent on whether coating is added on both surfaces at each station. Signals from each detector means of these measuring apparatus are fed separating over the signal line shown into control station 66. Means are provided at control station 66 for accepting and storing information, read-out of information, making comparisons and calculations for generating control signals for controlling line variables, such as the rate of particle feed at each station, application of wetting agent, line speed, and the like.

The coating measuring apparatus shown diagrammatically in FIGS. 1 and 2 can be used to determine quantitative characteristics of particle coatings, such as uniform distribution of the particles, coating thickness, or coating weight per unit area, and other characteristics. It has been discovered that diffusion of wave energy, such as a collimated light beam, by pulverant material, such as powdered metal, deposited on a solid substrate can be used to measure coating deposition between a "coating-free" stage and a complete coverage stage; also such determination can be utilized for ascertaining rate of deposition which can be used to control additional coating by proportioning. Detailed examples of these operations will be presented later.

As shown schematically in FIG. 3, a collimated light beam 67 from source 68 is directed downwardly in angled relationship toward strip material 69 which is coated with pulverant material layer 70.

Returning light energy beam 71 is measured at detector 72 positioned at angle 73 with respect to perpendicular beam 67. The signal from detector apparatus 72 is fed to control apparatus 74 which may include meter, or a separate indicator, e.g., voltmeter 75, may be used.

It has been discovered that light energy diffusion caused by a granular coating on a supporting surface, which surface is a better reflector than is the granular coating, can be used as a measure of coating characteristics. In practice of the invention, incident light energy can be directed at substantially any angle toward the coated surface. For example in FIG. 3, light source 68 can be changed from the perpendicular relationship to the position indicated in dotted lines from source 76. For practical purposes the angular relationship between the incident light and the coated surface is selected within about 60° on either side of normal (beam 67). If required, larger angles could be used but the light diffusion effect may be decreased due to greater reflection of incident light by the outer surface of the coating at substantially greater angles.

The angle of view for detector 72 is also selected for maximum sensitivity and intensity of light return. Angle 73 can vary from about 0° immediately adjacent to or in circumscribing relationship to source 68 as indicated in dotted lines to detector 77, to as high as 120° from the direction of incident light impingement. Generally the angle between the incident light and the light is se-

lected to be less than about 90° and, preferably significantly less, e.g., less than about 45°.

Either the light source or the detector can be positioned first in making a set-up for measurement. The angular relationship, providing suitable intensity of return light energy, can then be selected empirically. Such angular relationships are then maintained throughout the measuring period. The source and detector can also be mounted in a structure in which the angular relation is fixed and this is followed in practice with the light source being along the angle of incidence and the detector along the angle of reflection.

Referring to FIG. 4, light energy from beam 78 shown in dotted lines strikes coating surface 79 as indicated. Because of the granular nature of the material, diffusion of the light occurs as the material builds up. In the embodiment described for disclosure purposes electrostatically deposited chromium powder on flat rolled steel is considered. Diffusion of the impinging light energy results from the granular structure of the deposited metallic powder. Diffusion also results from the refraction and reflection of light rays at the interfaces of the particles and between the particles and the surface of the flat rolled steel.

Conventional flat rolled steel, free of powder coating, is principally a reflector. Light which is diffused through a particle coating on the steel to the substrate surface returns to the outer surface and leaves in all directions. A non-coated surface provides maximum reflectivity and an optically opaque coating of pulverant material provides maximum diffusion with the effect of decreasing light return. It has been discovered that an area of substantially linear response exists between these extremes. Such area is of sufficient range to be readily useful for practically any commercial coating operation. In this range of linear response, reflection and diffusion, it is believed, can effect the light return but, the diffusion effect is considered the basic mechanism of measurement in accordance with the invention.

This linear response is shown in FIG. 5 wherein the gage response (light return measurement) versus coating weight is graphed. The linear relationship between the returned light detected and the coating weight exists in the zone between dotted lines 78 and 79. This figure sets forth typical gage responses versus the coating weight in grams per square foot. The coating powder used for collecting the data of FIG. 5 was 200 mesh chromium. The substrate was cold rolled steel. The light return decreases with increase in coating weight due to diffusing of the light by the pulverant material. The detector can be conveniently connected to provide readings in the direction shown, that is, increasing with increasing coating thickness. The detector can be connected otherwise with no effect on accuracy.

It will be noted in FIG. 5 that the response in the zone to the left of dotted line 78 provides a reading from which coating weight can be determined above about 2.5 grams per square foot. But a purely linear relationship between the diffused light measured and the coating weight does not exist throughout this zone. Also note in the zone to the right of dotted line 79 that when the base metal becomes opaquely coated with powdered chromium that the curve flattens off.

As pointed out earlier, diffusion properties of the supporting surface for the coating material should differ from those of the granular material being coated in

order to provide the desired relationship for accurate measurement when graphed, a 45° slope linear relationship would be the ideal. This will be considered in more detail in presenting data from various substrate surfaces later.

In making measurements it has been found that a number of areas of measurable sensitivity exist. These include the thickness of the coating itself, the particle size, relative diffusion characteristics of the powder and the supporting surface, and the attenuating characteristics of the binding agent (if a wet process is used). The effect of certain of these factors in making a coating thickness measurement setup, for example, are determined empirically and taken into consideration. Data relating to such factors will be presented later.

Referring again to FIG. 3, a detector means 72, sensitive to the wave energy used (visible light, infra-red, other monochromatic light, etc.) is positioned in a predetermined location providing strong light return over the measuring range of interest. The angular relationship between the angle of incidence and the angle of view for the light return means is determined empirically or can be preset based on experience with the powdered metal being coated. For practical purposes the angle can vary widely as discussed previously but an angle of less than about 90° is preferred for higher intensity diffused light return. Readings can be compared with previous calibration values determined with the same subsurface and coating material, or, the meter can be calibrated for the run based on a comparison of responses and weighed coating samples.

Referring to FIG. 6, a family of curves is shown displaying the detector responses as a function of the chromium powder coating weight with measurements being made at various angles of incidence for the impinging light. The angle of view for the detector was fixed at 25° from perpendicular to the base metal. The angle of incidence for impinging light was changed for each curve. The impinging light was directed perpendicularly against the strip (0° angle of incidence) in collecting the data for curve 80. With curve 81 the angle of incidence of the impinging light was 30° and with curve 82 the angle of incidence for the impinging light energy was 40°. This family of closely-spaced curves, with near identical slopes, demonstrates that the basic mechanism of the invention is measurement of the effect of diffusion, or stated otherwise, the effect on reflectivity, since the comparable measurement data is obtained even though the angle of incidence of the impinging light energy is varied widely.

FIG. 7 shows the effect on coating weight sensitivity of varying the substrate surface. Detector response for differing substrates coated with a chromium powder is plotted. Various surfaces of differing reflectivity and diffusion characteristics were measured first with no coating (indicated along the zero coating weight line). Values are then recorded at an intermediate coating between no coating and opaque, i.e. 12 grams per square foot. Finally, data measured with coating covering the entire surface so that the chromium powder made on opaque coating was recorded at approximately 20 grams per square foot. Line 83 is merely a 45° line for use as a reference.

Note first in FIG. 7, that at the opaque coating measurement condition all the readings were grouped together as indicated at 84. Then to consider a surface which has diffusion characteristics similar to the chromium powder, note the "JP" readings. "JP" is a trademark covering a product, made by National Steel Corporation, Pittsburgh, Pennsylvania, which is a special alloy of a zinc galvanizing spelter coating with flat

rolled mild steel base metal. The zinc coating is alloyed with the base metal in such a manner that the surface has a powdery appearance. The readings for JP (shown by a dot in a circle), indicate that the material has similar diffusion properties for visible light as chromium powder. Note that a line interconnecting the JP marks would be practically horizontal from zero to 20 grams per square foot.

The other products tested for example, minimized spangle, which has reflection properties approaching that of regular spangle galvanized material but is more uniform, cold rolled steel, and tinplate all exhibit sufficient difference between the diffusion characteristics of the surface before coating with powder and after coating that a satisfactory sloped curve results providing for accurate indications of coating weight by the method of the present invention without special procedures.

The data of FIG. 8 brings out teachings of the invention relating to the effect of and the sensitivity to particle size. Diffusion of the light energy increases as the particle size diminishes; therefore an opaque coating results with less coating weight. The curves of FIG. 8 show the response versus the coating weight for selected particle sizes of chromium powder applied to cold rolled steel with a water binder. It will be noted that the 200 mesh (finest powder) curve levels off earlier than the 50 mesh (coarser powder). The 200 mesh curve levels off at about 22 grams per square foot. The 50 mesh powder provides accurate indications up to about 45 grams per square foot before leveling off. Whereas, at 60 plus grams per square foot, accurate measurements continue with this coarsest of the three powders represented, 30 mesh.

The present invention finds greatest use in making coating weight, and the like, determinations. However, it is clear from the data presented that other areas of sensitivity can be used to make determinations such as average particle size of a pulverant material and roughness or other surface characteristic of the supporting surface. The average particle size can be determined when the powder becomes optically opaque to the non-penetrating type of radiation, i.e., when the curve levels off by comparison to previously collected data.

The "JP" is an example of a determination of a surface characteristic. The level response curve indicates its surface has substantially the same diffusion characteristic of the chromium powder. The invention provides a simple method of determining whether this desired powdery surface characteristic is being maintained in production by a powder application test method.

FIG. 9 shows apparatus for making determinations of coating distribution across the width of the strip. In FIG. 9 strip 85 is moving toward the right from coating application chamber 86. Within chamber 86, individual powder blowers 87, 88, 89 are spaced across the width of the strip distributing powder on the left, center, and right portions of the strip, respectively. Measuring gages 90, 91 and 92 are located across the width of the strip, left, center, and right portions, respectively. Obviously a greater or lesser number of blowers and measuring gages can be used without departing from the

teachings of the invention. Each measuring apparatus has a signal-receiving and/or indicating station 93, 94, and 95, respectively. These are connected to a control apparatus, such as set point comparator 98 for comparing measured values to target values for coating weight across the strip. Deviations from the target value cause signals to be sent to control the feed rate of powder to one or more of the blowers 87, 88, and 89.

FIG. 10 shows a simplified schematic circuit diagram of apparatus used in accumulating the data discussed above. Light source 96 is a conventional instrument light, G.E. No. 1630, rated 6.5 V at 2.75 A, 18 watts. Detector 97 is a semiconductor photocell RCA No. 7163, 100 DC, regulated supply. The signal from the detector 97 is fed through switch 98 to buffer amplifier 99. The amplified signal from buffer amplifier 99 is fed to the signal conditioner amplifier 100 and continues on to digital read-out apparatus 102. Buffer amplifier 99 can be Model No. P85AU and the signal conditioner amplifier 100 can be Model No. P25AU, both manufactured by and available from Philbrick Researches, Inc., Dedham, Massachusetts. Signal read-out apparatus 102 can be a volt-meter calibrated in grams per square foot. Other sources and detectors and equivalent circuit apparatus will be readily available to those skilled in the art.

In practice of the invention the measuring apparatus can be set up from data obtained on the line at the start of a run, that is by comparison of electrical response to coating characteristics physically determined, e.g., by weighing powder from a unit area. Also, the measuring apparatus can be set up using precoated samples or known calibration data by comparison of responsive readings.

When the wet process of powder application is used possible attenuating characteristics of the wet binder are considered. Readings are taken while the binder is wet, that is while the powder is in the slurry form, before drying becomes apparent in order to avoid the different effects between the wet and the dry binder.

In practice the binder may be selected to be a clear liquid without attenuating characteristics or if a liquid having a tint is called for filters can be used on the light impingement and/or the angle of view sides to avoid any attenuating effect. For example, in wet process coating of chromium powder a halogen solution binding agent is utilized and compensation is made for the greenish tint of this material. Under certain circumstances, depending on the binding agent, it may be necessary to select a differing type of wave energy which is not attenuated by the binder.

For purposes of disclosing the invention specific steps, components, and various materials have been described; it is understood that other steps, materials, and components can be used without departing from the spirit of the invention. Therefore, in determining the scope of the invention reference will be had to the appended claims.

What is claimed is:

1. Coating method using non-penetrative radiant en-

ergy for non-destructive quantitative measurement of pulverant material coating within coating ranges below deposition of pulverant material which is fully opaque to such non-penetrative radiant energy, the pulverant material being distributed on a continuous metallic strip for purposes of obtaining a uniform thin coating, consisting essentially of the steps of

depositing metallic pulverant material of particle sizes between about 30 mesh and about 200 mesh on a continuous metallic strip of extended surface area, said pulverant material having scattering characteristics for non-penetrative type radiant energy differing from those of the continuous metallic strip and being deposited in a coating weight range between about 10 gr/ft² to about 90 gr/ft²,

directing non-penetrative type radiant energy in angled relationship onto such coated continuous metallic strip subsequent to deposition of pulverant material,

detecting and quantitatively measuring non-penetrative type radiant energy diffusion-scattered by the deposited pulverant material, at a location bearing an angled relationship which is less than about 45° to the direction of impingement of such radiant energy, as an indication of a quantitative characteristic such as uniformity of particle distribution and coating weight per unit area of the pulverant material, and treating such pulverant material coating by heating or mechanical compaction.

2. The method of claim 1 in which impingement of the non-penetrative type radiant energy is substantially normal to such strip.

3. The method of claim 1 including the step of controlling deposition of such pulverant material responsive to measurement of such scattered non-penetrative type radiant energy.

4. The method of claim 1 in which coating weight of the pulverant material per unit area of the continuous metallic strip is controlled responsively to such measurement of such scattered radiation.

5. The method of claim 1 further including the step of

wetting the surface of the continuous strip with a binding agent prior to deposition of pulverant material to coat the continuous metallic strip with a slurry of the pulverant material and the binding agent.

6. The method of claim 1 further including the steps

measuring the speed of longitudinal strip movement, and

combining the strip speed measurement with the scattered radiant energy measurement to determine the rate of pulverant material deposition.

7. The method of claim 1 wherein the pulverant material comprises powdered metal includes chromium.

8. The method of claim 5 wherein the binding agent includes a halogen containing solution.

* * * * *

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,801,349 Dated April 2, 1974

Inventor(s) Walter A. Wilson and Glenn W. Bush

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 4, line 26, "if" should read -- is --.

Signed and sealed this 15th day of July 1975.

(SEAL)
Attest:

RUTH C. MASON
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents
and Trademarks

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,801,349 Dated April 2, 1974

Inventor(s) Walter A. Wilson; and Glenn W. Bush

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

On the cover sheet, Item [73] : should read

-- National Steel Corp., a corp. of Delaware --.

Signed and sealed this 1st day of October 1974.

(SEAL)
Attest:

McCOY M. GIBSON JR.
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents