Aug. 25, 1959 H. FRIEDMAN 2,901,629

METHOD AND APPARATUS FOR SLAG DETECTION IN METAL SHEETS

Filed Jan. 26, 1954 2 Sheets-Sheet 1

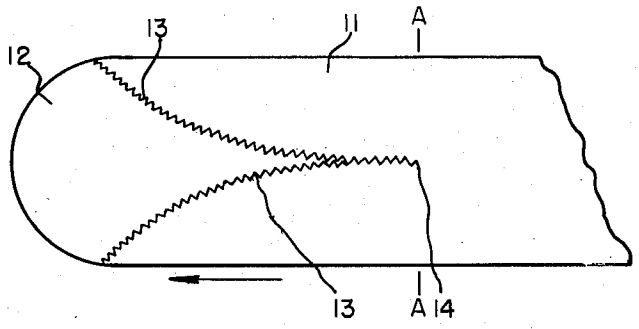

FIG. 1.

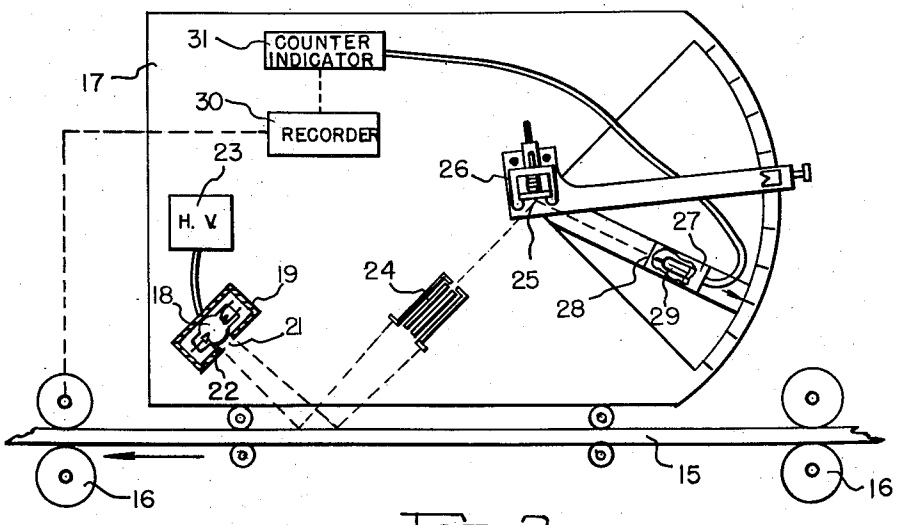

FIG. 2.

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METHOD AND APPARATUS FOR SLAG DETECTION IN METAL SHEETS

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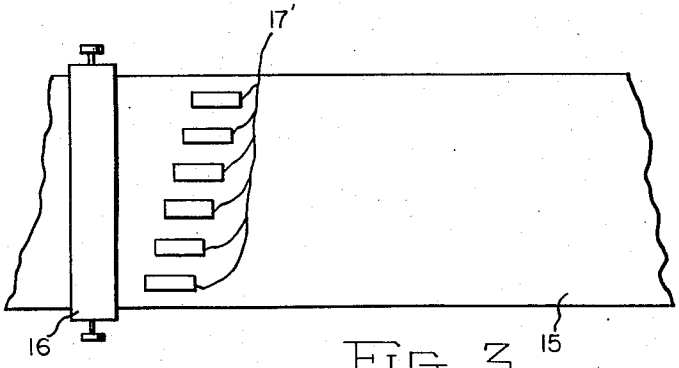


FIG. 3.

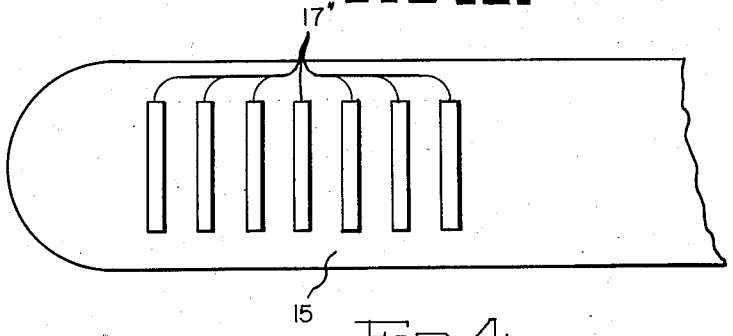
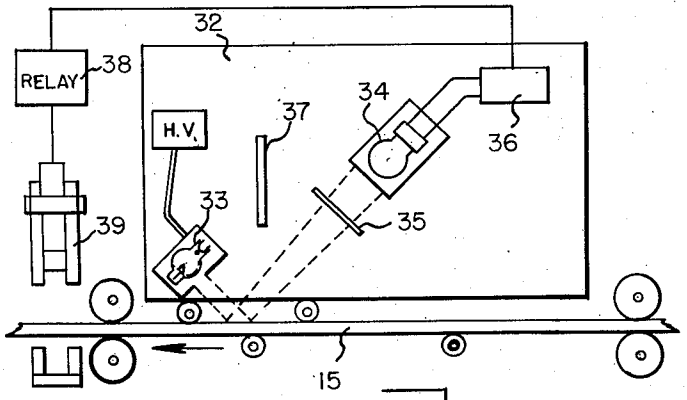


FIG. 4.

FIG. 5.



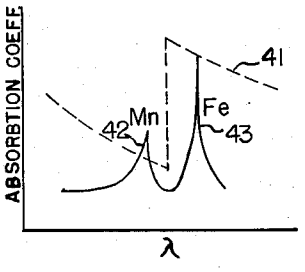


FIG. 6.

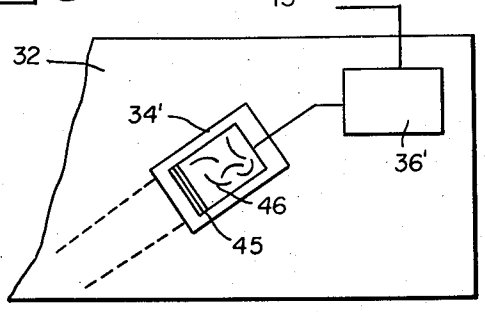


FIG. 7.

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METHOD AND APPARATUS FOR SLAG DETECTION IN METAL SHEETS

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Application January 26, 1954, Serial No. 406,214

17 Claims. (Cl. 250—53)

This invention relates generally to improved methods of and apparatus for detecting the presence of slag in rolled sheet metals such as steel, for example, and more particularly to such methods and apparatus which may be employed concurrently with one of the rolling operations or the like to which the sheet is subjected.

In the preparation of rolled sheet metal a billet of the metal is first obtained, generally by pouring the molten metal into a suitable mold. Where the molten metal batch includes slag or other impurities which differ in specific gravity from the desired metal, the solidified billet will exhibit a core. Steel is one of the more common metals having this characteristic core which contains slag inclusion. In hot rolling of a steel billet into a long sheet, the slag inclusion is rolled out with the billet and does not separate at the boundary between slag and slag-free metal. In subsequent cold rolling, however, the passage of a portion of the sheet steel containing the slag inclusion through the rolling process causes the sheet to tear and fracture along the slag boundary.

In order to prevent the damage to the rolling equipment which results upon the occurrence of a slag tear in a sheet which is being cold rolled, it is necessary to sever and discard the portion of the billet or hot rolled sheet containing the slag. Heretofore the location of the exact point at which to sever the hot rolled sheet could not be readily determined and the actual cut was made at a point which allowed a considerable margin of error. This procedure results in a continuous waste of a substantial amount of the slag-free sheet and introduces an element of uncertainty in that slag inclusions may extend beyond the point of severance. The damage resulting from an attempt to cold roll a sheet containing slag inclusion necessitates expensive repairs to the equipment and a loss of valuable production time.

It is an object of this invention to provide improved method and means for detecting slag inclusion in rolling sheet stock.

Another object is to provide method and means for accurately determining the longitudinal position in a rolled sheet of a discontinuity boundary.

A further object is to provide for the detection of the boundary between two portions of a sheet with the aid of a trace element present in the material of one of the portions.

Another object is to provide slag detection in a continuous process sheet and include means responsive to the slag detection for indicating or severing the sheet at the slag boundary.

These and other objects will appear as the invention is more fully understood. One arrangement of the invention provides for a continuous relative motion between the sheet material to be examined and a detection apparatus capable of sensing the presence of an element characteristic of the material on one side of the boundary to be detected. The detection apparatus is arranged to be selectively responsive to the wavelength of fluorescent X-rays excited from the characteristic element to provide

rapid and certain determination of the boundary of the area containing the element.

In the drawings:

Fig. 1 is a plan view of a sheet having a slag inclusion;

Fig. 2 is an elevational view of one form of the invention;

Fig. 3 is a plan view of a modification employing a plurality of detectors;

Fig. 4 is a plan view of an arrangement for element detection on a stationary sheet;

Fig. 5 is an elevational view of a modification using an alternative detector;

Fig. 6 is a chart for describing a feature of the invention; and

Fig. 7 is a fragmentary view of an apparatus similar to that shown in Fig. 5 but having a scintillation counter type detector.

In Fig. 1 a representative sheet of material **11** such as hot rolled sheet steel which is to be examined for a slag inclusion **12** is shown. The slag inclusion **12** is drawn with the sheet **11** during the hot rolling process in a manner which forms an indeterminate boundary **13** between the slag-free sheet **11** and the portion which includes the slag **12**. At some longitudinal position **14** of the sheet **11** the slag inclusion terminates and this position **14** may be satisfactorily defined for many purposes by a transverse axis A—A. In other applications it may be desirable to locate the actual limits defined by the boundary **13—13** which, it will be understood, does not necessarily exhibit a visible manifestation.

This invention provides for the location of the boundary **13—13** or the point **14** corresponding to the axis A—A by subjecting the sheet to be inspected to an element detecting process which is adjusted to detect an element which is present in the slag **12** but is not present in the steel sheet **11** or vice versa. In certain applications the invention contemplates the detection of the quantitive change at the boundary **13** of the same element which appears in the portions **11**, **12** in different concentrations. The later method can be practiced by those skilled in the art pertaining to the metal being analyzed by detecting the presence of an element which is contained in the slag **12** and the slag-free sheet **11** in sensibly different percentages and noting the change in magnitude of responses on opposite sides of the boundary **13**. In the hot rolling of certain manganese steels, for example, the concentration of manganese in the slag **12** is approximately six percent (6%) while that of the sheet **11** is one-half percent (½%). This difference provides a wide margin for the selective adjustment of magnitude response of the apparatus to be hereinafter described.

An important feature of this invention which may be employed, for example, when the previously described method is not used provides the addition of a trace element in a molten batch which is to be poured into billets. The trace element preferably is chosen as one which follows the chemistry of the slag present in the molten batch and not the chemistry of the batch metal. The added trace element, therefore, is present in the slag inclusion **12** when the billet is rolled into a sheet but is not present in the sheet **11**. The extent of the slag inclusion **12** can thus be determined using a detector adjusted to be responsive to the trace element. As an example of this process a small percentage of an alkaline earth, such as barium, or rare earth element such as cesium can be added to a molten batch of steel and will be present in the slag as a trace element while not appearing in the steel itself. By detecting the presence of the trace element in the rolled sheet the slag boundary **13—13** can be determined.

It will be understood that the preceding examples of detecting a change in concentration of an element and

detecting the presence or absence of a trace element are exemplary only and the invention is not to be considered as limited thereto. The elements which appear in different concentrations in any particularly slag and slag-free metal mixture are well known in the metallurgical art and can be readily selected by inspection of the quantitive analysis records which are obtained for all such manufactures. Likewise the choice can be made, by one skilled in the art, of a trace element for addition to a particular molten batch which will combine with the slag but not the batch metal. The slag therefore will be identifiable by the presence of the trace element and the characteristics of the batch metal will be unaltered by the addition of the trace element to the molten batch.

In Fig. 2 an arrangement for practicing the invention is shown in which a steel sheet **15** is passed through successive rolling stages **16** of a conventional hot rolling mill. At any suitable location a detector panel **17** is positioned to examine the moving sheet **15**. The detector panel **17** has an X-ray tube **18** supported thereon and encased in a radiation shield **19**. The shield **19** has an aperture **21** which is arranged to direct X-ray radiation from the tube **18** upon the moving sheet **15** at any convenient angle, such as 45°. The tube **18** may have a target **22** of molybdenum or copper for the analysis of steel and is suitably energized from a direct power supply **23**. The power supply **23** may apply a voltage between 10 and 50 kilovolts and need not be mounted on the detector panel **17**, as shown.

The X-ray radiation falling on the sheet **15** excites fluorescent X-rays in the elements therein causing the radiation of a spectrum characteristic of the fluorescing elements. This radiation passes through a collimator **24** which may comprise a plurality of parallel sheets of nickel foil spaced about 0.5 millimeter apart. The narrow beam emerging from the collimator **24** is incident upon a crystal **25** which is supported in a crystal holder **26**. The holder **26** supports the crystal **25** for rotation to provide a selective angle of incidence of the collimated beam on the surface of the crystal **25**. Also mounted for rotation about the same axis is a radiation shield housing **27** having an aperture **28** and containing a Geiger-Mueller detector tube **29**. The tube **29** is in circuit with suitable power supply, counter and indicator circuits **31** which are well known for responding to the level of energization of the Geiger-Mueller tube.

As is known in the art of analyzing samples with fluorescent X-rays, the beam incident upon the crystal **25** is reflected thereby to provide components of the beam at various angles to the normal determined by their respective frequencies because of the diffraction of the beam occurring in the crystal. By means of the rotative adjustment for the crystal **25** and the detector tube **29** the monochromatic component corresponding to any angle may be selected and directed toward the detector **29**. The frequency of the given element will be known and the apparatus can be adjusted to detect only that frequency whereupon the response obtained in the counter circuit **31** will be proportional to the concentration of the selected element in the portion of the sheet **15** beneath the beam emanating from the X-ray tube **18**.

If desired, the counting rate of the circuit **31** can be recorded with respect to the length of the sheet **15** passing the detector panel **17** by means of a recorder **30**. With the crystal **25** and tube **27** set at angles to detect one of the elements present in different concentrations in the two portions **11, 12** of the sheet **15** or to detect a trace element absent in one of the portions **11, 12** as hereinbefore described, the location of the slag termination **14** will be recorded. The sheet **15** can be subsequently severed along axis A—A as determined from the recording. For inclusions **12** of the type illustrated in Fig. 1 it is desirable to locate the detector panel **17** centrally of the transverse dimension of the sheet **15**. In the event that the location of the boundaries **13—13** is desired, a more detailed analysis could be made, as shown in Fig. 3 for example, using a battery of independent analyzers **17'** extending transversely across the sheet **15**. Also, if desired, means can be made responsive to a predetermined counting rate of the circuit **31** to automatically mark or sever the sheet **15** at the axis A—A as will be described hereinafter.

In the event that analysis of a stationary sheet is desired, the arrangement of Fig. 4 can be used to locate the slag boundary. With this method during the processing or storage of the sheet **15** some period is selected when the sheet **15** is relatively at rest. At this station the sheet **15** is subjected to a battery of independent analyzers **17''** disposed longitudinally of the sheet **15**. Simultaneous readings of the presence of slag element indicated by the analyzers **17''** while the sheet **15** and analyzers **17''** are relatively stationary will permit determination of the longitudinal position where the slag disappears.

In Fig. 5 a modification of the invention is arranged on a panel **32** with respect to the rolling sheet **15** similar to the arrangement of Fig. 2. The sheet **15** also receives energy from an X-ray source **33**. The fluorescent X-rays emanating from the energized portion of the sheet **15** are received by a radiation detector **34** either directly or through a suitable filter **35**. Circuits **36** are provided which respond to the detection of predetermined X-ray frequencies by the detector **34**. To prevent the detector **34** from detecting energy directly from the source **33** suitable shielding **37** may be required. The presence of a given element in the sheet **15** as hereinbefore described produces a response in the circuit **36** which may be utilized to actuate a relay **38**. The relay **38** may control any desired apparatus **39** such as a marking mechanism or a power shearing machine.

Referring again to the detector **34** and circuits **36**, any of the arrangements which are frequency selective to X-ray radiation can be used. For example, any X-ray responsive tube **34** can be used if the absorption filter **35** is used to block almost all radiation other than the wavelength of the element to be detected from energizing the tube **34**. The absorption filter **35** can be in the form of a thin film of metal having an absorption edge (i.e. maximum absorption) adjacent the wavelength of the element to be detected. This filtering action is shown in Fig. 6 where the response curve **41** of a thin chromium film is plotted together with a typical response curve obtained from irradiating a steel which contains manganese. As can be seen the manganese response peak **42** falls in a region of low absorption while the iron response peak **43** is greatly attenuated. For manganese present in both slag **12** and steel sheet **11** the circuits **36** can be arranged to be amplitude selective to the increased response of the tube **34** to the higher concentrations of manganese.

Another form for the detector **34** which permits the filter **35** to be eliminated or may be used in conjunction with it if desired, is the proportional counter. Proportional counting is utilized to resolve frequencies of the X-ray spectrum by selective response to the pulse amplitudes obtained as a result of the incident radiation. It has been shown that the amplitude response of a proportional counter varies in accordance with the energy of the radiation quantum which enters the tube. This energy in turn varies with the element being fluoresced and thus the amplitude of the pulse output is a measure of the element present in the sheet **15**. By adjusting the circuit **36** to bias tube **34** for selective response to pulses of predetermined amplitude, slag detection may be accomplished on the basis of the presence of the element corresponding to that amplitude. It will be understood, of course, that in addition to amplitude bias adjustment for tube **34**, the circuits **36** include counter circuits for determining the rate of the selected pulses and controlling the indication or actuation desired in accordance

therewith. Other detectors which produce pulse amplitude responses in accordance with the wavelength of the detected radiation can be used with suitable amplitude selection and pulse counting techniques. An example of such a detector, shown in Fig. 7, which is especially useful at the shorter wavelengths is the scintillation counter 34' comprising a phosphor 45, a photomultiplier 46 and counter and power supply circuits 36'.

The methods and apparatus herein disclosed may be readily applied to the practice of the invention by those skilled in the art for all materials exhibiting the requisite properties. These applications as well as the equivalent of the methods and apparatus of the present preferred embodiments are to be considered as within the scope of the appended claims.

I claim:

1. The method of locating the extent of a slag inclusion in a rolled sheet of metal alloy comprising the steps of determining in the slag and slag-free alloy the presence of sensibly different concentrations of one or more elements, selecting one of said elements suitable for fluorescent X-ray analysis, subjecting successive elemental areas of said sheet to fluorescent X-ray analysis of the presence of said selected element, detecting the change in response corresponding to said change in concentration, and utilizing the detected change in response for locating the extent of said slag inclusion.

2. The method of locating the extent of a slag inclusion in a rolled sheet of manganese steel comprising the steps of determining in the slag and slag-free steel the presence of sensibly different concentrations of manganese, subjecting successive elemental areas of said sheet to fluorescent X-ray analysis of the presence of manganese, detecting the change in response corresponding to said change in concentration and utilizing the detected change in response for locating the extent of said slag inclusion.

3. The method of locating the extent of a slag inclusion in a rolled sheet of metal alloy comprising the steps of adding to the molten batch of said alloy a trace element which combines with the slag but does not combine with or deleteriously affect said alloy, pouring said molten batch into billets having slag inclusion, rolling said billets into sheets, subjecting said sheet to fluorescent X-ray analysis for said trace element, detecting the presence of said trace element and utilizing the detection of said trace element for locating the extent of said slag inclusion.

4. The method of locating the extent of a slag inclusion in a rolled sheet of steel comprising the steps of adding to the molten batch of said steel a trace element selected from the group consisting of the alkaline earths, pouring said molten batch into billets having slag inclusion, rolling said billets into sheets, subjecting said sheet to fluorescent X-ray analysis for said trace element, detecting the presence of said trace element, and utilizing the detection of said trace element for locating the extent of said slag inclusion.

5. The method of locating the extent of a slag inclusion in a rolled sheet of steel comprising the steps of adding to the molten batch of said steel a trace element selected from the group consisting of the rare earths, pouring said molten batch into billets having slag inclusion, rolling said billets into sheets, subjecting said sheet to fluorescent X-ray analysis for said trace element, detecting the presence of said trace element, and utilizing the detection of said trace element for locating the extent of said slag inclusion.

6. The method of locating the boundary of a slag inclusion in rolled sheet steel comprising the steps of transporting said sheet at a substantially uniform speed along the direction of rolling, irradiating said moving sheet with a localized beam of X-rays of a wavelength which excites the fluorescent X-ray spectrum of a predetermined element present in different concentrations in the slag and slag-free sheet, selectively detecting fluorescent X-rays from said element, and utilizing the response of said detection for indicating the position on said sheet of a predetermined change in said concentrations.

7. The method according to claim 6 in which the step of detecting the fluorescent X-rays includes the steps of monochromatizing said fluorescent X-rays by reflecting from a crystal surface and adjusting a radiation detector to receive reflections from said surface at an angle determined by said element to be detected.

8. The method according to claim 6 in which the step of detecting the fluorescent X-rays includes the steps of filtering said fluorescent X-rays to increase the magnitude of the wavelength component of said element relative to other wavelengths and detecting said filtered X-rays with amplitude selection in accordance with said element to be detected.

9. The method according to claim 6 in which the step of detecting the fluorescent X-rays includes applying said fluorescent X-rays to a proportional counter and biasing said proportional counter for response to a predetermined wavelength characteristic of said element.

10. The method according to claim 6 in which the step of detecting the fluorescent X-rays includes the step of selecting the wavelength component of said element with a scintillation counter.

11. Apparatus for detecting the inclusion of slag in a sheet of material, said slag and slag-free material being characterized by different concentrations of a predetermined element, comprising means for irradiating an elemental area of said sheet with a beam of X-rays of a wavelength which excites the fluorescent X-ray spectrum of said element, means for moving said sheet past said area with substantially uniform speed, means for selectively detecting fluorescent X-rays of wavelength characteristic of said element and utilization means responsive to the detection of the change of concentration of said element.

12. Apparatus according to claim 11 in which said utilization means includes means for recording the detected concentrations of said element as a function of position along the direction of travel of said sheet.

13. Apparatus according to claim 11 in which said utilization means includes means responsive to the detection of a predetermined concentration of said element for marking on said sheet the boundary of said predetermined concentration.

14. Apparatus according to claim 11 in which said utilization means includes means responsive to the detection of a predetermined concentration of said element for severing said sheet substantially at the boundary of said predetermined concentration.

15. Apparatus for detecting the inclusion of slag in a sheet of material, said slag and slag-free material being characterized by different concentrations of a predetermined element, comprising means for irradiating an elemental area of said sheet with a beam of X-rays of a wavelength which excites the fluorescent X-ray spectrum of said element, means for moving said sheet past said area with substantially uniform speed, a plurality of detectors arranged transversely of said sheet adjacent said area for selectively detecting fluorescent X-rays of wavelength characteristic of said element, and means responsive to the detection by each of said detectors of the change of concentration of said element.

16. Apparatus for detecting the inclusion of slag in a sheet of material, said slag and slag-free material being characterized by different concentrations of a predetermined element, comprising a plurality of analyzers arranged in spaced positions longitudinally of said sheet, each of said analyzers including means for irradiating an elemental area of said sheet with a beam of X-rays of a wavelength which excites the fluorescent X-ray spectrum of said element, means for selectively detecting fluorescent X-rays of wavelength characteristic of said ele-

ment, and means for indicating the concentration of said element at the respective areas.

17. The method of locating the extent of a slag inclusion in a sheet of metal alloy comprising the steps of determining in the slag and slag-free alloy the presence of sensibly different concentrations of the same element, selecting one of said elements suitable for fluorescent X-ray analysis, subjecting longitudinally spaced elemental areas of said sheet to fluorescent X-ray analysis of the presence of said selected element, detecting the respective response corresponding to the concentration of said element at said areas, and utilizing said detected responses for locating the extent of said slag inclusion.

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