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(54) MAGNETIC DETECTOR

(71) We, IMI KYNOCH LIMITED, formerly known as Imperial Metal Industries (Kynoch) Limited, a British Company, of Kynoch Works, Witton Birmingham, B6 7BA; and SCIENCE RESEARCH COUNCIL, a British body corporate, incorporated by Royal Charter of Scientific Administration Group, Rutherford Laboratory, Chilton, Didcot, Oxfordshire, OX11 0QX, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to the detection of ferromagnetic material, in a background of paramagnetic material of metallic or non-metallic character and has particular but not exclusive relevance to the detection of ferromagnetic impurities in titanium scrap.

The use of titanium scrap as a source of secondary material is subject to a number of constraint. For applications where extremely high integrity of the product is required such as air in aero-engine components it is essential that the secondary material be completely examined to extract impurities. The impurities which cause most problems are those which come from the machining of titanium and in particular the tool tips used in machining can break off and fall into the titanium swarf. These tool tips are extremely dense and hard and are often not completely broken down by the subsequent melting. They are therefore a potential source of mechanical failure in the final product. So far as is known there has been no method of automatically detecting ferromagnetic materials in a non-magnetic matrix such as titanium swarf which gives sufficiently reliable operation to enable it to be relied upon.

By the present invention there is provided a method of detecting ferromagnetic particles in non-ferromagnetic metallic particulate material which comprises the steps of passing the material through a detector unit the detector unit comprising magnetic sensor means located within an area of applied magnetic field, the applied magnetic field having a substantially constant zone in which the magnetic sensor means is located, characterised in that the applied magnetic field is generated by an electromagnet, which is so disposed that the uniform magnetic field has parallel lines of flux in a vertical direction, and in that the material is passed vertically downwardly through the field parallel to the lines of flux at least in part under the action of gravity.

The coid produces, in use, an electric output signal when ferromagnetic material moves past it.

The particulate material may be fed to the detector unit by a travelling wave vibratory feeder the exit of which may be disposed vertically above the parallel lines of force. The exit end of the vibratory feeder may have a smaller gate size than the cross-sectional size of the parallel lines of flux through which the material falls. The particulate material may be passed through the magnetic field in a forced air flow which accelerates the particles before passing the particles through the field.

Preferably there are two search coils connected in series opposition so that their response to perturbations in the uniform external field is zero.

The sensor may be of tubular or ring-like formation the material passing through the tubular or ring-like structure.

There is preferably provided an iron shield around the magnetic sensor and field generating member. Further, there is preferably provided an electrostatic screen within the tubular or ring-like sensor.

The present invention also provides a detector for detecting ferromagnetic material in non-ferromagnetic material comprising an electromagnet generating in use an electromagnetic field of substantially constant strength having a plurality of lines of flux disposed in a vertical direction, sensor means including a search coil located within the said electromagnetic field, means for dropping particulate material along the parallel lines of flux in a vertical direction under the action of gravity, and means for detecting in use a voltage generated across the search coil in the passage of a ferromagnetic particle therethrough.

There may be two search coils connected in series opposition so that their response to a uniform external field is zero. The search coils may be movable one relative to the other for setting-up purposes whereby the detector may be zeroed by relative movement of the two search coils, the search coils being then fixed relative one to the other during normal operation of the unit. There may be provided further means to remove the ferromagnetic material from the non-ferromagnetic matrix after detection thereof.

The means may comprise an interrupter to interrupt the flow of material through a passageway to prevent that portion of the material containing the ferromagnetic material from passing to a receptacle. The interrupter may comprise a plate or air jet.

The means for dropping particulate material may be a travelling wave vibratory feeder the exit end of which is disposed vertically above the parallel lines of force.

By way of example only an embodiment of the invention will now be described with reference to the accompanying diagrammatic drawings of which:—

Figure 1 is a schematic cross-section of a magnet and search coil assembly;

Figure 2 is a schematic cross-section of a detector and separator unit; and

Figure 3 is a schematic view of the deflector plate of Figure 2.

A pair of magnetic search coils 1, 2 which form a conventional magnetometer is located within the centre of a DC electromagnetic solenoid 3. The solenoid provides a zone, in which the coils 1, 2 are located of substantially constant field with the flux lines being disposed parallel to one another and in a vertical direction. Surrounding the solenoid 3 is an iron shield 4 and on electrostatic screen 5 defines a bore within the iron shield through which passes a tube 6 of dielectric material such as glass. Titanium swarf which may include ferromagnetic lumps passes vertically down through the tube 6 in a lamellar manner in the direction of the arrow 7 under the action of gravity. Any ferromagnetic material in the stream of scrap is magnetised by the solenoid 3 and movement of the magnetised particles through the search coil produces a voltage output from the coil and this can be detected by suitable voltage means not shown.

It is important, when using a titanium swarf that the passage of the particles through the solenoid should be parallel to the lines of force, if the particles were to move across the width of the tube 6 they would cross the parallel lines of flux, and in crossing the flux lines would generate eddy currents which would give rise to a magnetic field which would be picked up by the search coils. This would therefore give a false indication of the presence of a ferromagnetic material, consequently operating in error the rejection mechanism described below. It will be understood, therefore, that when using a conducting matrix it is important to use a method of feeding which provides for the passage of particles through the solenoid in a parallel manner. Particular examples of this method are described below.

The detector means may supply an output signal to any form of suitable indicator such as a meter or light signal. The meter may be connected to means to reject the particle from the stream. Such a means could be an air jet connected to the detector through a suitable delay circuitry. The ëlectrical circuitry is of a conventional type and is not part of the present invention. The use of two starch coils enables the system to be relatively insensitive to externally generated electromagnetic fields. Although a single coil could be used and electronic amplification of the necessary sensitivity is readily available the presence of fluctuating electromagnetic fields makes it difficult to use this sensitivity in practice.

Referring to Figures 2 and 3 these show a separator unit incorporating the detector of Figure 1. Titanium swarf is passed in the direction of arrow 10 into a feeder trough 11. The feeder trough 11 is a vibratory feeder which works by establishing a travelling wave in material located on the surface of the feeder. Particles on the moving surface of the feeder are moved forwards by the action of the travelling wave and eventually arrive at the exit end of the feeder which is located above a guide tube 12. The particles are simply moved over the end of the exit end without being given a forward component of movement thereby dropping straight down through the guide tube 12. If a conveyor belt, for example, were to be used to move material into the guide tube 12 it would give the particles a forward or translational movement which would not be damped by the guide tube and thus the particles would fall down through the guide tube and would richocet or bounce off the walls of the guide tube and would set up eddy currents within the search coils. An alternative method of passing the particles in a lamellar manner through the guide tube is to entrain them in a moving air stream such that the particles are accelerated initially to space out the particles and damp translational movement and have them moving in a parallel manner vertically downwards in the region of the search coils 1 and 2.

The exit end of the feeder 11 preferably is smaller than the guide tube 12 so that the particles can fall freely through the guide tube. The exit end of the feeder is conventionally referred to as the gate and the gate width is preferably less than the cross-sectional size of the tube 12.

This feeder passes the swarf into the guide tube 12 which is arranged vertically to permit the swarf to pass down through the detector unit indicated generally by 13. An inclined plate 14 can act to deflect swarf when in the position illustrated through chute 15 into receptacle 16. If the inclined plate 14 is not in position the swarf will fall through chute 17 into receptacle 18. The inclined plate is driven as is shown more clearly in Figure 3.

In Figure 3 the plate 14 is movable by means of air-operated cylinders 19, 20 to obscure hole 21 which is the extension of tube 12. Thus as long as plate 14 is in the retracted position as shown in Figure 3 swarf will fall through the tube 12 and 17 into receptacle 18.

Upon detection of a ferromagnetic particle cylinders 19 and 20 puch plate 14 over aperture 21, deflecting the particles through tube 15 into receptacle 16. Obviously the deflected particles will include non-ferromagnetic material as well as the ferromagnetic material because the response time of the equipment would not be sufficiently accurate only to deflect the ferromagnetic material. This swarf can, however, be recycled by periodically removing the contents of receptacle 16 and passing them through the machine again. In order that it can be obvious that the machine is working large balls of plastics material containing small quantities of ferromagentic material can be inserted through funnel 21 as shown at 22. These parts will operate the machine and be deflected thereby proving that the machine is functioning and acting as a continuous monitor and indicator. This visual signal can be used to reassure the operators that the machine is working satisfactorily.

With the two search coils mounted inside the magnetising solenoid and being connected in series opposition their response to a change in external field is zero. As the magnetic particles fall consecutively through each coil a voltage pulse in the series circuit is produced as each particle leaves the upper search coil and enters the lower.

If the search coils each enclose the same number of area turns (area of cross-section times the number of turns) and are mounted in the magnetic centre of the magnet the system does not respond the fluctuations in the magnetising current. Fine corrections may be made by slightly moving the two coils within the magnet to the place where the minimum electrical noise is picked up. The iron shield is used because without it the system tends to respond to non-uniform external fields as the fields in each of the search coils may be different. Electrostatic screening is provided as shown and of course the electrical leads from the search coils to the amplification means should also be screened.

Because the magnetic flux enclosed by the pair of search coils depends on the position of the coils within the solenoid relative motion between the two will also cause electrical noise. It is important therefore that the search coils be rigidly attached to each other and to the solenoid. In addition the central tube down which the particles fall should be separated from the search coils in order that mechanical vibration or electrostatic pick up be reduced.

A version of the invention having a solenoid which produced a field of 0.1 Tesla in a bore of 72mm diameter was tested with search coils each having 67 000 turns at a diameter of 30 mm. Titanium swarf containing particles of tungsten carbide tool tip of mass 2×10^{-3}g was dropped through the central tube. A pulse of 0.2mV and 20ms duration was generated. The background from the uncontaminated titanium swarf was small, being less than 0.02mV.

It will be appreciated that typical tool tip material comprises only 5 to 15% by mass of ferromagnetic material. Consequently, the detector is capable of determining the presence of 0.1mg of material with ferromagnetic susceptibilty.

It will be appreciated that the invention is not limited to the detection of ferromagnetic material in titanium swarf. The apparatus may simply be used if necessary after calibration to detect any ferromagnetic material in any other non ferromagnetic metallic material such as brass, or copper.

WHAT WE CLAIM IS:—

1. A method of detecting ferromagnetic particles in non-ferromagnetic metallic particulate material which comprises the steps of passing the material through a detector unit, the detector unit comprising magnetic sensor means located within an area of applied magnetic field, the applied magnetic field having a substantially constant zone in which the magnetic sensor means is located, characterised in that the applied magnetic field is generated by an electromagnet, which is so disposed that the uniform magnetic field has parallel lines of flux in a vertical direction, and in that the material is passed vertically downwardly through the field parallel to the lines of

flux at least in part under the action of gravity.

2. A method as claimed in Claim 1, in which the particulate material is fed to the detector unit by a travelling wave vibratory feeder the exit end of which is disposed vertically above the parallel lines of force.

3. A method as claimed in Claim 2 in which the exit end of the vibratory feeder has a smaller gate size than the cross-sectional size of the parallel lines or flux through which the material falls.

4. A method as claimed in Claim 1 in which the particulate material is passed through the magnetic field in a forced air flow which accelerates the particles before passing the particles through the field.

5. A method as claimed in any one of Claims 1—4 in which there are two search coils connected in series opposition so that their response to perturbations in the uniform external field is zero.

6. A method as claimed in any one of Claims 1—5 in which the sensor is of tubular or ring like formation.

7. A method as claimed in any one of Claims 1—6 in which there is provided an iron shield around the magnetic sensor and field generating member.

8. A method as claimed in any one of Claims 1—7 in which there is provided an electrostatic screen within the sensor.

9. A detector for detecting ferromagnetic material in non-ferromagnetic metallic particulate material comprising an electromagnet generating in use an electromagnetic field of substantially constant strength having a plurality of parallel lines of flux disposed in a vertical direction, sensor means including a search coil located with the said electromagnetic field, meansf or dropping particulate material along the parallel lines of flux in a vertical direction under the action of gravity, and means for detecting in use a voltage generated across the search coil in the passage of a ferromagnetic particle therethrough.

10. A detector as claimed in Claim 9 in which there are two search coils connected in series opposition so that their response to a uniform external field is zero.

11. A detector as claimed in Claim 10 in which the search coils are movable, one relative to the other, for setting-up purposes whereby the detector may be zeroed by relative movement of the two search coils, the search coils being then fixed relative one to the other during normal operation of the units.

12. A detector as claimed in Claim 9 in which there is provided further means to remove the ferromagnetic material from the non-ferromagnetic matrix after detection thereof.

13. A detector as claimed in Claim 12 in which the means comprises an interrupter to interrupt the flow of material through a passageway to prevent that portion of the material containing the ferromagnetic material from passing to a receptacle.

14. A detector as claimed in Claim 13 in which the interrupter comprises a plate or air jet.

15. A detector according to any of Claims 9—14 wherein the means for dropping particulate material is a travelling wave vibratory feeder the exit end of which is disposed vertically above the parallel lines of force.

16. A method of detecting ferromagnetic material substantially as herein described with reference to and as illustrated by the accompanying drawings.

17. A detector for detecting ferromagnetic material substantially as herein described with reference to and as illustrated by the accompanying drawings.

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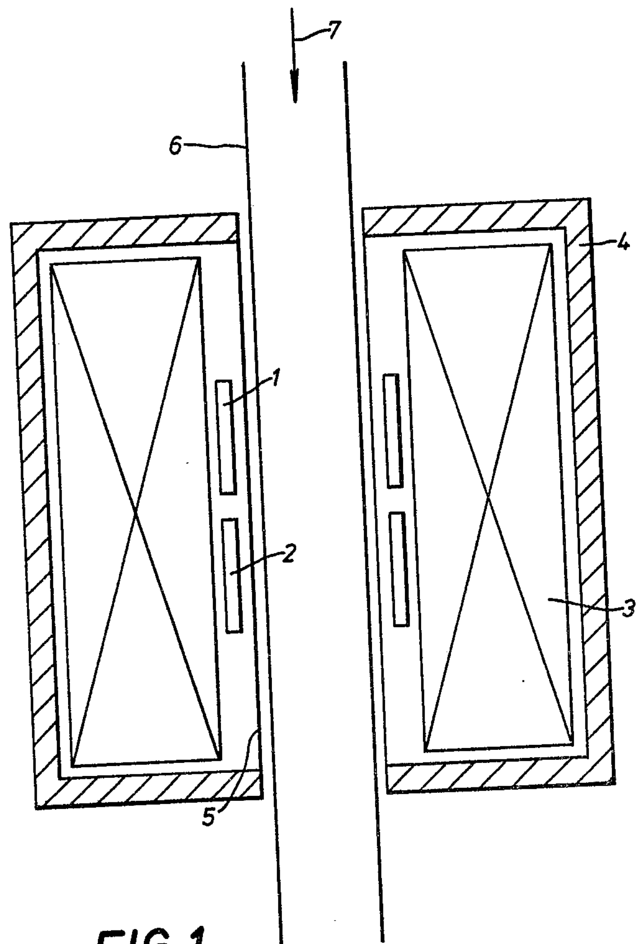

FIG. 1.

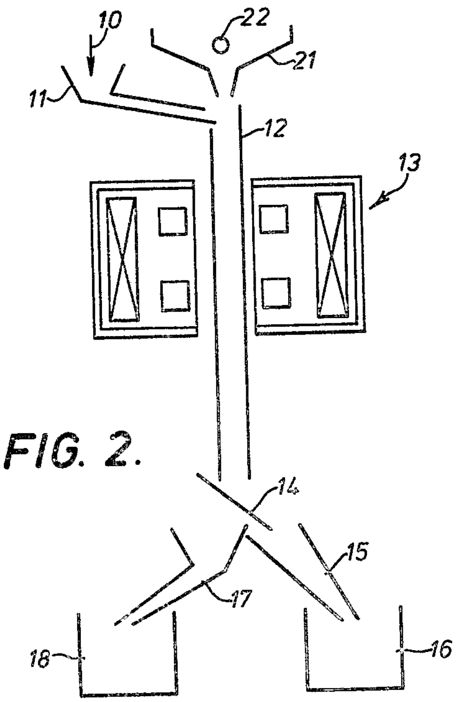

FIG. 2.

FIG. 3.