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PATENT SPECIFICATION (11) 1 548 973

(21) Application No. 34646/76 (22) Filed 19 Aug. 1976
(31) Convention Application No. 50/100210
(32) Filed 20 Aug. 1975
(31) Convention Application No. 50/124395
(32) Filed 17 Oct 1975 in
(33) Japan (JP)
(44) Complete Specification published 18 July 1979
(51) INT CL² G01N 21/48
(52) Index at acceptance
G1A A9 C10 C12 C3 D10 G17 G1 G2 G5 G6 MC P16 P17 P1 R7 S10 S3 T14 T21 T3 T4 T8

(19)

(54) SURFACE-DEFECT DETECTING DEVICE

(71) We, HITACHI LTD., a Corporation organised under the laws of Japan of 5—1, 1-chome, Marunouchi, Chiyoda-ku, Tokyo, Japan, 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 a surface-defect detecting device for optically detecting damage in, or foreign matter sticking to, the surface of a material to be inspected.

One of the prior art methods for use in inspection for damage in, or foreign matter sticking to, the surface of a material is a mechanical one which detects irregularity on the surface due to the presence of damage or foreign matter thereon by using piezo-electric elements which are maintained in contact with the surface of a material being inspected. However, this attempt poses problems in vibration of a material being inspected, mechanical service life of a detector, and capability for detecting minute defects.

Another method is to detect optically damage by a scanning illumination of the surface of the material in a spot or slit-like pattern, thereby detecting by photoelectric elements a variation in intensity of reflected light from the aforesaid dagade in, or foreign matter sticking to, the surface of the material being inspected. The latter attempt is successful in a sense to inspect a material at a high accuracy, while still suffering from the shortcomings as are experienced with the former attempt, i.e., a plurality of detecting elements need be arranged in a plane perpendicular to the axis of a material being inspected so as to inspect the entire surface of a material, thus resulting in space, maintenance and cost problems.

It is a principal object of the present invention to provide a surface-defect detecting device which may save space and is simple in construction, without sacrificing the surface-defect detecting capability and reliability of the device.

According to the present invention there is provided a surface-defect detecting device comprising: illuminating means for illuminating a closed peripheral zone on the surface of elongate material to be inspected, the zone extending about the axis of longitudinal extent of the material; reflecting means including at least a pair of spheroidal reflecting surfaces for reflecting and focussing light being irregularly reflected at said illuminated zone by the presence of defects, said reflecting surfaces each having a first focal point at said illuminated zone and a second focal point to which said irregularly reflected light is reflected by said reflecting surfaces, a non-reflecting region being provided between the reflecting surfaces whereby light regularly reflected from the said zone of the surface of material being tested is not reflected by said reflecting surfaces to said focal points; and photoelectric detecting means positioned at said second focal points for converting said irregularly reflected light into electrical signals being representative of defects on the surface of material inspected. The device can operate on the principle that a minute zone (circular or polygon in section) on the surface of a material to be inspected is illuminated within a plane perpendicular to the axis of the material in every direction, and in case the aforesaid minute annular zone presents a uniform surface, then the light therefrom is regularly reflected thereby so as not to be received by the photoelectric elements, and on the other hand, in case damage or foreign matter is present on the minute illuminated zone, then the light therefrom is irregularly reflected in various directions for subsequent focussing on the photoelectric elements.

Preferably electric signals obtained from different ones of the photoelectric elements are amplified and then added, after which a signal thus added is thresholded with respect to one or more given levels, so that when a signal exceeds a given level, then the surface of a material is regarded as including a defect and when a signal is lower than the given

level, then the surface of a material is regarded as including no defect.

The invention will be further described, by way of example, with reference to the accompanying drawings, in which:

Figure 1 is a view of one embodiment of a mirror and photoelectric element system in a surface-defect detecting device according to the present invention;

Figure 2 is a horizontal cross sectional view of the embodiment of Figure 1, as viewed from above;

Figure 3 is a front view of an outline of one embodiment of illuminating means in the surface-defect detecting device according to the present invention;

Figure 4 is a plan view of Figure 3;

Figure 5 is a horizontal cross-sectional view showing an embodiment of the surface-defect detecting device according to the present invention;

Figure 6 is a cross-sectional view taken along the line VI—VI of Figure 5; and

Figure 7 is a view showing an outline of the arrangement of a signal processing circuit for signals fed from photoelectric elements shown in Figures 1, 2 and 5.

Included among materials to be inspected according to the present invention are enamelled wires 1 and the like which can be fed in a continuous manner, and the inspection is directed to damage in, or foreign matter sticking to, the surface of the enamel wire 1.

Referring to Figure 1, there is shown one embodiment of a surface-defect detecting device according to the present invention. The light from light sources 2, 3, 4 and 5 is focussed through lenses 6, 7, 8 and 9 on a minute annular zone on the surface of the enamel wire 1. Spheroidal surfaces (defined by the rotation of a part of ellipse) of mirrors 10, 11 are provided for focussing onto the surfaces of photoelectric elements 12, 13 light reflected from any irregularities on the surface of the wire 1 in the aforesaid minute annular zone. For better understanding, the light sources 2, 3, 4 and 5 are arranged radially around the enamel wire 1 as shown in Figure 1. As an alternative, a single light source may be used and the light from the light source directed through a known focussing system, such as lenses, mirrors or optical fibers so as to be focussed on a minute annular zone on the surface ofthe enamel wire 1. It is mandatory that in case the cross section of a material to be inspected, such as an enamel wire 1, is circular, illumination be given at least from three angular positions which are angularly spaced 120°, and that in case the cross-section of a material to be inspected is of a polygonal shape having at least four sides, illumination be given from four angular positions which are spaced 90°.

Referring to Figure 2, there is shown a horizontal cross-sectional view of the embodiment, taken through a centre thereof. In this Figure, the light sources 2, 4 and lenses 6, 8 are omitted. The light from the light sources 2, 3, 4 and 5 is focussed on the minute annular zone on the entire circumferential surface of a material, i.e., an enamel wire 1. Meanwhile, the enamel wire 1 is fed in or out through holes provided in the mirrors 10, 11. If the surface of the minute annular zone is smooth and cylindrical, then the light reflected from the minute annular zone is regularly reflected within the plane at right angles to the axis of the wire in which the incident light has been directed, providing reflected light 15, 16. Accordingly, there is provided a gap S between the spheroidal mirrors 10, 11 so as to allow the passage of incident light and reflected light 15, 16 therethrough. Instead of having the gap completely surrounding the minute annular zone of the wire the mirrors may be joined by a black portion which absorbs a substantial amount of the light and does not reflect the light impinging thereon.

When damage or foreign matter is present on the surface of the minute annular zone, this irregularly reflects incident light as reflected light 17, 18 directed towards the spheroidal mirror 10, without escaping through the gap S. The surface of the mirror 10 is part of a spheroidal surface, while the remaining portion of the spheroidal surface, except for the reflecting surface, is shown by a broken line. The two focal points of the spheroidal surface of the mirror 10 lie in the minute annular zone 14 and at a photoelectric element 12 respectively. Accordingly, the light from the minute annular zone 14 is necessarily focussed on the photoelectric element 12. The same is true of the spheroidal mirror 11 and the photoelectric element or sensor 13.

Figures 3 and 4 show illuminating means for use in illuminating a minute annular zone on the surface of a material to be inspected in a surface-defect detecting device. The illuminating means consists of a light source 19, a first lens 20, a slit 21, a second lens 22, and mirrors 23, 24. The light from the light source 19 is focussed through the first lens 20 on the slit 21. The light which passes through the slit 21 is focussed through the second lens 22 so as to form an image of the slit 21. In this case, the second lens 22 is selected so as to provide an increased depth-of-focus for an image of the slit 21. The material 1 to be inspected is positioned immediately in the front of the aforesaid image, while the mirrors 23, 24 are positoned immediately in the rear of the aforesaid image. As shown in Figure 4, the mirrors 23, 24 are positoned at an angle of $\pm 60°$ to the optical axis of incident light. Thus, the mirrors 23, 24 make an angle of 120°. In addition the widths of the mirrors 23, 24 are the same as that of an image of the slit 21. As shown in Figures 3 and 4, the direction

of the slit 21 is at right angles to the axis of the material 1. Still furthermore, the width of slit 21 should be such that the width of an image of the slit 21 may coincide with a desired length of a minute annular zone on the surface of a material to be inspected, while the length of the slit 21 is at least three times as long as the diameter of the material 1 to be inspected. Part of an image of the slit 21 directly illuminates the side of material 1 on the side of a light source 19, while the remaining part of the image is reflected on mirrors 23, 24, illuminating the rear side of a minute annular zone in the directions making an angle of 120° to the optical axis.

As is apparent from the foregoing, the light from a single light source is focussed on a minute annular zone on the surface of the material 1 in the directions which are angularly spaced 120°. In this case, the direction of the slit is set at right angles to the axis of a material to be inspected, while the length of the slit is set such that the length of an image of the slit, which is focussed on a material to be inspected, is at least three times aslong as the diameter of the material 1. In addition, the width of slit is determined by the desired length of the portion of material to be illuminated, when an image of the slit is focussed on a material to be inspected. Positioned in the rear of a material to be inspected are two mirrors which are arranged following a 'V' shaped pattern so as to make an angle of $\pm 60°$ to the optical axis of incident light, the aforesaid mirrors having a width the same as that of an image of the slit. Thus, the light which passes without illuminating the material to be inspected is reflected on these mirrors, hereby illuminating the rear side of the material. In an alternative embodiment the slit 21 need not necessarily be provided where there is provided a lamp 19 whose filament is directed perpendicularly to the axial direction of a material to be inspected, the light emitted from the lamp 19 being focussed so as to provide an image having a length of at least three times as long as the diameter of a material, through a first lens 20 and a second lens 22, without being directly condensed through the slit 21. In other words, even if the slit is omitted, it is possible to illuminate the entire minute annular zone on the surface of a material to be inspected.

Description will be given in more detail of the surface-defect detecting device provided with mirrors 10, 11 having spheroidal reflecting surfaces, and photoelectric elements 12, 13 shown in Figure 2, and an illuminating device shown in Figures 3 and 4 (in this respect, the slit is omitted) in conjunction with Figures 5 and 6. Shown at 25 is a socket arranged to mount a lamp 19 in a manner that the length of its filament is directed perpendicularly to the axis of an enamelled wire 1. Shown at 26 is a cover which shields the light emitted from the light source 19 from leaking outside, with the socket 25 being secured to its top end by means of a screw 27. The cover 26 is formed with radiating fins 26a on its outer periphery. Shown at 28 is a focussing macro-lens which focuses the light from the light source 19 on the focal points, on one side of the mirrors 10, 11 so as to provide an image having a length of five to six times as long as the diameter of the enamelled wire 1. Shown at 29 is a flange fastened to the top surface of a housing-top-surface bracket 30. The cover 26 is attached to the bracket 30 by means of a screw 31 in a manner to be movable along the optical axis. The focussing macro-lens 28 is secured to the flange 29, with a male thread thereof being in meshing relation to a female thread formed on the inner peripheral surface of the flange 29. Shown at 32, 33 are housing side-brackets which retain the two mirrors 10, 11 having spheroidal reflecting surfaces and focal points, on one side, which are positioned at a point P. Holes 32a, 33a are provided in the mirrors 10, 11 in their centres so as to allow feeding-in or -out of an enamelled wire therethrough at a given speed. Although not shown, there is provided a guide for feeding an enamelled wire in or out past the point P. A gap S having a width H is provided between the mirrors 10, 11, so that the light for detecting a defect on the enamel wire is regularly reflected when no defect is present and directed outside through the gap S. Positioned on the focal points on the other side, of the mirrors 10, 11 having spheroidal reflecting surfaces are photoelectric elements 12, 13 adapted to convert the light received from the mirrors 10, 11 into electric signals. Shown at 35 is a cylindrical member secured to the under-surface of a housing lower-bracket 34. Shown at 36 is a plate which has a threaded hole engaged by a threaded lower end portion of a rod 40 having mirrors 23, 24 at its top end, the mirrors 23, 24 making an angle of 120°. The plate 36 is secured to the undersurface of the cylindrical member 35 by means of a plurality of screws 38, with a resilient material 37 being interposed between the undersurface of the cylindrical member 35 and the top surface of the plate 36. In this respect, the inclination of the mirrors 23, 24 may be adjusted by tightening different screws 38 to different extents so as to differentially to compress the resilient material 37 at different positions around the rod 40. Shown at 39 is a nut also threaded onto the rod 40. The top surface of the enamelled wire 1 is directly illuminated by the light which has been emitted from the light source 19 and focussed through the focussing macro-lens 28, while the lower surface of the enamelled wire 1 is illuminated by the light which has passed to either side

of the enamelled wire 1, and then has been focussed and reflected on the surfaces of the mirrors 23, 24 so that the entire surface of a minute annular zone on the circumferential surface of the enamelled wire, then the light ated uniformly. In this case, if a defect is not present at the point P on the surface of the enamelled wire 1, then the light thus directed is regularly reflected thereby so as to be directed through the gap S between the mirrors 10, 11 having spheroidal surfaces, thereby preventing the reflected light from reaching the photoelectric elements 12, 13. In case a defect is present at the point P on the surfaec of the enamelled wire, then the light thus directed is reflected irregularly onto the spheroidal surftces of the mirrors 10, 11, respectively so as to be received by the photoelectric elements 12, 13. The light received by the photoelectric elements 12, 13 is converted into electric signals by the respective photoelectric elements 12, 13. Then, as shown in Figure 7, the electric signals are each amplified by amplifiers 41, 42, and the signals thus amplified are added by amplifier 43, after which the signals thus added are thresholded with respect to voltages V_L, V_M, V_S in threshold circuits 44, 45, 46, thereby producing output signals 47, 48, 49. The size of a defect detected on the enamelled wire 1 can be considered to be proportional to the level of the summed signal output from the aforesaid amplifier 43, if the level of the summed signal exceeds the threshold voltage V_L, and hence an output signal as "1" from the threshold circuit 44 indicates that a critical defect is present. When the leevl of the summed signal exceeds an intermediate threshold voltage V_M there is obtained an output signal 48 as "1" from the threshold circuit 45 which shows that a major defect is present. If the level of a signal exceeds a low threshold voltage V_S and there is obtained an output signal 49 as "1" from the threshold circuit 46, then this indicates that a minor defect is present. In addition the number of the different types of defect per given length of an enamel wire may be obtained by counting signals from the respective threshold circuits 44, 45, 46 by counter circuits 50, 51, 52. Meanwhile, there is obtained through a switch 56 a resetting signal which reads out counted values in the counter circuits 50, 51, 52 as signals 53, 54, 55 and nullifies the contents of the counter circuits 50, 51, 52.

WHAT WE CLAIM IS:—

1. A surface-defect detecting device comprising: illuminating means for illuminating a closed peripheral zone on the surface of elongate material to be inspected, the zone extending about the axis of longitudinal extent of the material; reflecting means including at least a pair of spheroidal reflecting surfaces for reflecting and focussing light being irregularly reflected at said illuminated zone by the presence of defects, said reflecting surfaces each having a first focal point at said illuminated zone and a second focal point to which said irregularly reflected light is reflected by said reflecting surfaces, a non-reflecting region being provided between the reflecting surfaces whereby light regularly reflected from the said zone of the surface of material being tested is not reflected by said reflecting surfaces to said focal points; and photoelectric detecting means positioned at said second focal points for converting said irregularly reflected light into electrical signals being representatiive of defects on the surface of material inspected.

2. A surface-defect detecting device as set forth in claim 1, which includes means for feeding through respective openings in said reflecting surfaces material to be inspected in the form of a continuous elongate member.

3. A surface-defect detecting device as set forth in claim 1 or 2, wherein said illuminating means is arranged to illuminate said surface of the material inspected in use of the device in a plane perpendicular to an axis of said material.

4. A surface-defect detecting device according to any preceding claim, wherein there are provided adding circuit means for adding respective electrical output signals from the photoelectric elements to provide an added output signal, and threshold circuit means for comparing the added output signal with signals representative of predetermined threshold levels to produce respective comparison output signals representative of a given size of defects on the surface of material inspected in use of the device.

5. A surface-defect detecting device as set forth in claim 4, wherein at least three threshold levels are provided.

6. A surface-defect detecting device as set further in claim 4 or 5, wherein counter circuits are provided to count the number of the comparison output signals such that the number of defects on the surface of material being inspected can be determined.

7. A surface-defect detecting device according to any preceding claim, wherein said illuminating means comprises light source means for emitting illuminating light, optical focussing means for focussing said illuminating light onto a zone positioned to be on the surface of the material to be inspected in use of the device, and at least a pair of mirrors so disposed opposite to incident light from the optical focussing means for uniformly illuminating the surface of said material to be inspected in use of the device from three directions such that a continuous illuminated zone about the surface of said material is produced, said pair of mirrors each being inclined at substantially 60° to the optical axis of the incident light.

of the enamelled wire 1, and then has been focussed and reflected on the surfaces of the mirrors 23, 24 so that the entire surface of a minute annular zone on the circumferential surface of the enamelled wire, then the light ated uniformly. In this case, if a defect is not present at the point P on the surface of the enamelled wire 1, then the light thus directed is regularly reflected thereby so as to be directed through the gap S between the mirrors 10, 11 having spheroidal surfaces, thereby preventing the reflected light from reaching the photoelectric elements 12, 13. In case a defect is present at the point P on the surfaec of the enamelled wire, then the light thus directed is reflected irregularly onto the spheroidal surftces of the mirrors 10, 11, respectively so as to be received by the photoelectric elements 12, 13. The light received by the photoelectric elements 12, 13 is converted into electric signals by the respective photoelectric elements 12, 13. Then, as shown in Figure 7, the electric signals are each amplified by amplifiers 41, 42, and the signals thus amplified are added by amplifier 43, after which the signals thus added are thresholded with respect to voltages V_L, V_M, V_S in threshold circuits 44, 45, 46, thereby producing output signals 47, 48, 49. The size of a defect detected on the enamelled wire 1 can be considered to be proportional to the level of the summed signal output from the aforesaid amplifier 43, if the level of the summed signal exceeds the threshold voltage V_L, and hence an output signal as "1" from the threshold circuit 44 indicates that a critical defect is present. When the leevl of the summed signal exceeds an intermediate threshold voltage V_M there is obtained an output signal 48 as "1" from the threshold circuit 45 which shows that a major defect is present. If the level of a signal exceeds a low threshold voltage V_S and there is obtained an output signal 49 as "1" from the threshold circuit 46, then this indicates that a minor defect is present. In addition the number of the different types of defect per given length of an enamel wire may be obtained by counting signals from the respective threshold circuits 44, 45, 46 by counter circuits 50, 51, 52. Meanwhile, there is obtained through a switch 56 a resetting signal which reads out counted values in the counter circuits 50, 51, 52 as signals 53, 54, 55 and nullifies the contents of the counter circuits 50, 51, 52.

WHAT WE CLAIM IS:—

1. A surface-defect detecting device comprising: illuminating means for illuminating a closed peripheral zone on the surface of elongate material to be inspected, the zone extending about the axis of longitudinal extent of the material; reflecting means including at least a pair of spheroidal reflecting surfaces for reflecting and focussing light being irregularly reflected at said illuminated zone by the presence of defects, said reflecting surfaces each having a first focal point at said illuminated zone and a second focal point to which said irregularly reflected light is reflected by said reflecting surfaces, a non-reflecting region being provided between the reflecting surfaces whereby light regularly reflected from the said zone of the surface of material being tested is not reflected by said reflecting surfaces to said focal points; and photoelectric detecting means positioned at said second focal points for converting said irregularly reflected light into electrical signals being representatiive of defects on the surface of material inspected.

2. A surface-defect detecting device as set forth in claim 1, which includes means for feeding through respective openings in said reflecting surfaces material to be inspected in the form of a continuous elongate member.

3. A surface-defect detecting device as set forth in claim 1 or 2, wherein said illuminating means is arranged to illuminate said surface of the material inspected in use of the device in a plane perpendicular to an axis of said material.

4. A surface-defect detecting device according to any preceding claim, wherein there are provided adding circuit means for adding respective electrical output signals from the photoelectric elements to provide an added output signal, and threshold circuit means for comparing the added output signal with signals representative of predetermined threshold levels to produce respective comparison output signals representative of a given size of defects on the surface of material inspected in use of the device.

5. A surface-defect detecting device as set forth in claim 4, wherein at least three threshold levels are provided.

6. A surface-defect detecting device as set further in claim 4 or 5, wherein counter circuits are provided to count the number of the comparison output signals such that the number of defects on the surface of material being inspected can be determined.

7. A surface-defect detecting device according to any preceding claim, wherein said illuminating means comprises light source means for emitting illuminating light, optical focussing means for focussing said illuminating light onto a zone positioned to be on the surface of the material to be inspected in use of the device, and at least a pair of mirrors so disposed opposite to incident light from the optical focussing means for uniformly illuminating the surface of said material to be inspected in use of the device from three directions such that a continuous illuminated zone about the surface of said material is produced, said pair of mirrors each being inclined at substantially 60° to the optical axis of the incident light.

* C L M S *

8. A surface-defect detecting device as set forth in claim 7, wherein said optical focussing means includes a slit for limiting or condensing the range of incident light being focussed by said optical focussing means on said zone.

9. A surface-defect detecting device constructed and arranged to operate substantially as hereinbefore described with reference to and as illustrated in the accompanying drawings.

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Printed for Her Majesty's Stationery Office, by the Courier Press, Leamington Spa, 1979
Published by The Patent Office, 25 Southampton Buildings, London, WC2A 1AY, from which copies may be obtained.