

SPECIFICATION

APPARATUS FOR WIRE ROPE INSPECTION, APPARATUS, METHOD, AND PROGRAM FOR WIRE ROPE DAMAGE DETERMINATION

Technical Field

5 The present invention relates to an apparatus for wire rope inspection, an apparatus, method and program for wire rope damage determination.

Background Art

 There has been known an apparatus for inspecting,
10 using a leakage magnetic flux method, a defect in a wire rope for elevators and cranes. The inspection apparatus is carried to a site where a wire rope is to be inspected. The inspection apparatus is attached and set on the wire rope manually using a fixing jig. A signal cable, a power
15 supply cable, a waveform monitor, and the like are also connected to the inspection apparatus at the site. An operator looks at a leakage magnetic flux-based waveform appearing on the waveform monitor and determines, for example, whether or not the wire rope is damaged.

20 Thus, carrying the inspection apparatus to each site for every inspection of a wire rope naturally requires an operator to move to the site and therefore requires paying labor costs. This also requires a long inspection time. Further, the determination of whether or not the wire rope
25 is damaged depends highly on the subjectivity of the

operator.

The inspection apparatus might be installed fixedly and permanently on an elevator, for example. However, fixed and permanent installation of the inspection apparatus would cause the inspection apparatus (sensor unit thereof) and the wire rope to be in constant contact with each other, thereby both the wire rope and the inspection apparatus would become worn. In particular, using such a sensor unit as described in International Patent Publication No. WO2011/148456 having a shape surrounding a major part of the outer peripheral surface of the wire rope could cause the wire rope and the sensor unit to be in contact with each other via a large area and thereby to be worn acceleratedly. The acceleration of wear could occur even if the wire rope might be magnetized strongly and brought into tight contact with the sensor unit.

Disclosure of the Invention

It is an object of the present invention to provide a wire rope inspection apparatus suitable for permanent installation.

It is another object of the present invention to provide an easily installable wire rope inspection apparatus that comes into contact with a wire rope via a small area.

It is a further object of the present invention to remotely confirm results of a wire rope inspection.

The present invention is directed to a wire rope inspection apparatus including a sensor device provided
5 (installed) along a passage through which multiple wire ropes arranged in parallel with each other travel and adapted to sense a leakage magnetic flux leaking from the wire ropes that have been magnetized, in which the sensor device includes a sensor surface formed in a plane and
10 having a length (width) greater than the entire width of the multiple parallel-arranged wire ropes, and in which, upon sensing of the leakage magnetic flux, the sensor surface of the sensor device is disposed parallel to a plane defined by the multiple parallel-arranged wire ropes
15 to be in line contact with the multiple wire ropes and across the entire width of the multiple parallel-arranged wire ropes.

In accordance with the present invention, since the sensor surface of the sensor device for sensing a leakage
20 magnetic flux leaking from the wire ropes that have been magnetized is formed in a plane and, upon sensing of the leakage magnetic flux, the sensor surface comes into line contact with the multiple wire ropes, the contact area between the sensor surface and the wire ropes is small and
25 therefore the sensor surface and the wire ropes are less

likely to be worn.

Also, the sensor device, which employs the planar sensor surface, can be used commonly even if the wire ropes to be inspected may have different diameters or the multiple wire ropes may be arranged in parallel with each other at different intervals. For example, it is not necessary to prepare different sensor devices according to the diameters of the wire ropes to be inspected. Upon installation of the sensor device, it is only required to place the planar sensor surface of the sensor device along the multiple travelling (running) wire ropes, which can save time and effort.

It will be understood that the both longitudinal end portions of the planar sensor surface may be curved in the same direction and, upon sensing of the leakage magnetic flux, the both longitudinal ends of the sensor surface may be lateral to the two respective end side wire ropes among the multiple parallel-arranged wire ropes. This can increase the sensitivity of damage sensing for the two end side wire ropes, which are relatively likely to be damaged seriously.

In an embodiment, the sensor device includes a sensor coil for sensing the leakage magnetic flux. The sensor device preferably further includes a magnetizer for magnetizing the multiple wire ropes. The only one sensor

device can be used to both magnetize the multiple wire ropes and sense the leakage magnetic flux. The multiple wire ropes are preferably limited to undergo an unsaturated magnetization so as not to be saturated.

5 It is preferred that the wire rope inspection apparatus further includes a movement mechanism for moving the sensor device, in which the movement mechanism is arranged to, upon sensing of the leakage magnetic flux, make the sensor device close to the wire ropes to bring
10 the sensor surface into line contact with the wire ropes and, off sensing of the leakage magnetic flux, move the sensor device away from the wire ropes. The sensor surface of the sensor device comes into contact with the wire ropes only during inspection of the wire ropes
15 (sensing of the leakage magnetic flux), which can further reduce the wear.

The movement mechanism may include, for example, a rotary mechanism for rotating the sensor device.

In an embodiment, the wire rope inspection apparatus
20 further includes two, first and second, sensor coils arranged separately in parallel with each other, in which the spacing between portions of the respective first and second sensor coils through which the leakage magnetic flux passes is the integral multiple of the distance
25 between adjacent ones of multiple strands constituting the

wire ropes. If the wire ropes are each formed by twisting multiple strands, a leakage magnetic flux may also leak from concavo-convex portions existing between the multiple strands. If the two, first and second, sensor coils
5 arranged separately in parallel with each other are thus provided and the spacing between portions of the respective first and second sensor coils through which the leakage magnetic flux passes is the integral multiple of the distance between adjacent ones of the multiple strands
10 constituting the wire ropes, even a leakage magnetic flux leaking from concavo-convex portions between the strands can be detected averagely. Leakage magnetic fluxes leaking due to the existence of such a concavo-convex portion can be distinguished easily from leakage magnetic
15 fluxes leaking due to damage in the wire ropes.

The present invention also provides a determination apparatus suitable for automatically determining, using inspection data acquired by the wire rope inspection apparatus, whether or not a wire ropes is damaged.

20 The wire rope damage determination apparatus according to the present invention includes: inspection data receiving means for receiving an input of voltage data according to the magnitude of a leakage magnetic flux leaking from a magnetized wire rope, said voltage data
25 being output from a sensor coil provided along a passage

through which one or more wire ropes travel and adapted to generate an electromotive force caused by the leakage magnetic flux; peak voltage detecting means for detecting a maximum voltage value using the voltage data received by
5 the inspection data receiving means; first determining means for determining whether or not the maximum voltage value detected by the peak voltage detecting means is equal to or greater than a first threshold value; and first determination data outputting means for outputting
10 first determination data to be used at least for calling attention if the first determining means determines that the maximum voltage value equal to or greater than the first threshold value is recorded in the voltage data.

The more seriously a wire rope is damaged (e.g. the
15 more the number of breaks per pitch), the more the number of leakage magnetic fluxes, and accordingly a higher electromotive force occurs on the sensor coil, that is, a higher voltage value is to be measured. Setting a threshold value (first threshold value) in advance and
20 outputting first determination data for calling attention if the existence of a maximum voltage value equal to or greater than the first threshold value is sensed allows to objectively determine that the wire rope is damaged without depending on the subjective criterion for
25 determination by an operator.

The wire rope damage determination apparatus may further include second determining means for determining whether or not the maximum voltage value is equal to or greater than a second threshold value that is greater than
5 the first threshold value and second determination data outputting means for outputting second determination data to be used for calling alert if the second determining means determines that the maximum voltage value equal to or greater than the second threshold value is recorded in
10 the voltage data. This allows to objectively determine that the wire rope is damaged more seriously.

The wire rope damage determination apparatus may further include third determining means for determining whether or not multiple separate voltage values equal to
15 or greater than the first threshold value and smaller than the second threshold value exist within a data range corresponding to one pitch of multiple strands constituting the wire rope if the first determining means and the second determining means determine that the
20 maximum voltage value is equal to or greater than the first threshold value and smaller than the second threshold value, and the second determination data outputting means may be adapted to output second determination data to be used for calling alert also if
25 the third determining means determines that multiple

voltage values equal to or greater than the first threshold value and smaller than the second threshold value exist within the data range corresponding to one pitch. This allows to automatically determine whether or
5 not damages of relatively low seriousness occur concentrically in one portion (within the length of one pitch).

The wire rope damage determination apparatus may further include fourth determining means for determining
10 whether or not the maximum voltage value is smaller than a third threshold value that is smaller than the first threshold value and third determination data outputting means for outputting third determination data for notifying that the damage determination apparatus is in an
15 abnormal state if the fourth determining means determines that the maximum voltage value is smaller than the third threshold value. If the wire ropes are each formed by twisting multiple strands, concavo-convex portions exist structurally on the surface of the wire ropes, which
20 causes a small number of leakage magnetic fluxes even if the wire ropes are not damaged and therefore a low voltage value to be detected. Using the third threshold value, which is smaller than the first threshold value, and determining that only a voltage value smaller than the
25 third threshold value is detected (including the case

where no voltage value is detected) allows to determine that the damage determination apparatus is in an abnormal state (including that the inspection apparatus including the sensor coil is not installed properly).

5 The wire rope damage determination apparatus may further include a transmission device for transmitting the first and second determination data and the third determination data externally through a network. This allows the wire ropes to be monitored remotely.

10 The present invention also provides a method and program suitable for controlling the wire rope damage determination apparatus and a recording medium (e.g. optical recording medium, magnetic disk, semiconductor memory) recording the program.

15 Brief Description of the Drawings

Fig. 1 shows the structure of an elevator;

Fig. 2 shows the structure of a movement mechanism;

Fig. 3 is an enlarged perspective view of a rope tester;

20 Fig. 4 is a cross-sectional view taken along the line IV-IV of Fig. 3;

Fig. 5 is a cross-sectional view taken along the line V-V of Fig. 3;

Fig. 6 is a graph showing a measured voltage
25 (inspection data);

Fig. 7 is a graph showing a measured voltage
(inspection data);

Fig. 8 is a flow chart showing an algorithm of wire
rope damage determination processing;

5 Fig. 9 is a flow chart showing the algorithm of wire
rope damage determination processing;

Fig. 10 is a flow chart showing the algorithm of
wire rope damage determination processing;

Fig. 11 is a table showing results of a test
10 measuring damaged wire ropes;

Fig. 12 is a graph drawn based on the test results
shown in Fig. 11;

Fig. 13 shows the positional relationship between a
wire rope and the rope tester;

15 Fig. 14 is a table showing results of another test
measuring damaged wire ropes;

Fig. 15 is a graph drawn based on the test results
shown in Fig. 14;

Fig. 16 shows the positional relationship between a
20 wire rope and the rope tester, and

Fig. 17 is a cross-sectional view, corresponding to
Fig. 4, of a rope tester according to another embodiment.

Best Mode for Carrying out the Invention

Fig. 1 shows the structure of an elevator.

25 The elevator includes a hoistway 1, a machine room 2

provided over the hoistway 1, an elevator car 3 arranged to move up and down in the hoistway 1 to carry passengers and cargoes, and a wire rope 5 with one end thereof fixed to an upper part (outside of the ceiling) of the elevator car 3 and the other end thereof fixed to a balancer weight 4. In general, multiple wire ropes 5 arranged in parallel with each other are used for elevators. In this embodiment, four parallel-arranged wire ropes 5 are used. In Fig. 1, one of the wire ropes 5 is only shown for the sake of clarity.

The middle portion of each of the four wire ropes 5 travels (runs) through the machine room 2 to be wound around a hoist 6 and applied to a deflector sheave 7 provided in the machine room 2. An elevator control panel 8 including a communication device 10 is provided in the machine room 2 to control the hoist 6. As the hoist 6 rotates forward and backward, the wire rope 5 moves and accordingly the elevator car 3 moves up and down in the hoistway 1.

In the machine room 2, there are further provided a rope tester 20 for detecting a damage (the existence and seriousness of a break or flaw) in the wire rope 5, a movement mechanism 30 for moving the rope tester 20, and a controller 9 for controlling the rope tester 20 and the movement mechanism 30 to inspect the wire rope 5.

As mentioned above, the elevator control panel 8 provided in the machine room 2 includes the communication device 10. The communication device 10 is connected through a network to a monitoring system 11 of an elevator management firm. Data representing the elevator situation is transmitted from the elevator control panel 8 via the communication device 10 to the monitoring system 11, and the elevator situation is constantly monitored by the monitoring system 11.

10 The elevator control panel 8 is also connected to the controller 9 through a signal line. As will be described hereinafter, data representing inspection results (determination results) for the wire rope 5 is also sent from the controller 9 through the signal line to the elevator control panel 8 and then transmitted from the elevator control panel 8 to the monitoring system 11 of the elevator management firm.

Fig. 2 is a side view in which the movement mechanism 30 for moving the rope tester 20 provided in the machine room 2 is shown together with the wire rope 5.

The movement mechanism 30 is fixed in the machine room 2 and comprises an induction motor 31 including a rotor (not shown) adapted to rotate forward and backward within a predetermined angular range. One end of a first arm 32 is fixed to a rotary shaft 31A coupled to the rotor

of the induction motor 31, and one end of a second arm 33 extending perpendicularly to the longitudinal direction of the first arm 32 is fixed to the other end of the first arm 32. A rope tester attachment 34 is fixed to the other
5 end of the second arm 33, and the rope tester 20 is attached to the rope tester attachment 34. When the induction motor 31 is driven, the rope tester 20 moves on an arc trajectory by a predetermined angle about the rotary shaft 31A.

10 When the rope tester 20 does not inspect the wire rope 5, the movement mechanism 30 keeps the rope tester 20 in a standby position. In Fig. 2, the alternate long and short dash line indicates that the rope tester 20 is kept in the standby position. The rope tester 20, when kept in
15 the standby position, is not in contact with the wire rope 5. Applied with a drive voltage from the controller 9, the induction motor 31 starts to rotate forward (clockwise in Fig. 2). The rope tester 20 gradually comes close to the wire rope 5, and a planar sensor surface (front face)
20 of the tester is made in parallel with a plane defined by the multiple wire ropes 5 and brought into contact with the wire ropes 5, where the induction motor 31 stop rotating forward. This position of the rope tester 20 is called detecting position. In Fig. 2, the solid line
25 indicates that the rope tester 20 is in the detecting

position. When the rope tester 20 comes to the detecting position and the sensor surface of the rope tester 20 is in contact with the wire rope 5, the wire rope 5 is to be inspected as will be described hereinafter. Since the
5 wire ropes 5 each have an approximately circular cross-sectional shape, the sensor surface of the rope tester 20 and the four wire ropes 5 come in line contact with each other.

When the inspection of the wire rope 5 is completed,
10 the controller 9 applies an antiphase drive voltage to the induction motor 31. The induction motor 31 then starts to rotate backward (counterclockwise in Fig. 2) to put the rope tester 20 back to the original standby position.

One to three times per day at a specific time, for
15 example, the controller 9 controls the movement mechanism 30 to move the rope tester 20 from the standby position to the detecting position and, at this timing, the wire rope 5 is inspected. Since the rope tester 20 moves to the detecting position only upon inspection of the wire rope
20 5, the rope tester 20 and the wire rope 5 are not in constant contact with each other, whereby the wear due to the line contact between the sensor surface of the rope tester 20 and the wire rope 5 can be reduced.

Fig. 3 is an enlarged perspective view of the rope
25 tester 20 in a view on the sensor surface (front face)

with a cover 21 partially removed. Fig. 4 is a cross-sectional view taken along the line IV-IV of Fig. 3 and Fig. 5 is a cross-sectional view taken along the line V-V of Fig. 3, shown together with the wire ropes 5. In Figs. 4 and 5, the cover 21 is not shown.

Referring to Figs. 3 and 5, and based on Fig. 5, the rope tester 20 comprises a rectangular parallelepiped yoke 22, a pair of rectangular parallelepiped magnets 24, 25 fixed to the lateral ends on the upper surface of the yoke 22, a rectangular parallelepiped coil base 23 fixed to the upper surface of the yoke 22 between the pair of magnets 24, 25 in a manner spaced from the magnets 24, 25, and a pair of planar sensor coils 26L, 26R fixed to the upper surface of the coil base 23. Referring to Fig. 3, the yoke 22, magnets 24, 25, coil base 23, and coils 26L, 26R are covered with the cover 21. The side on which the coils 26L, 26R are positioned corresponds to the sensor surface (front face) of the rope tester 20, which is formed in a plane.

The length (width) of the rope tester 20 (dimension in the longitudinal direction of the yoke 22, magnets 24, 25, coil base 23, and sensor coils 26L, 26R) is greater than the entire width of the four parallel-arranged wire ropes 5 (i.e. diameter $\times$ number of the wire ropes 5 + spacing distance $\times$ number of spaces between adjacent wire

ropes 5). The length of the rope tester 20 is adjusted appropriately according to the number of wire ropes 5. At any rate, the rope tester 20 (sensor surface and sensor coils 26L, 26R) is provided across the entire width of the multiple wire ropes 5 to be inspected.

Referring to Fig. 5, a magnetic flux generated from the pair of magnets 24, 25 forms a magnetic loop that passes through the magnet 25, wire rope 5, magnet 24 and yoke 22, so that the wire rope 5 is magnetized. The wire rope 5, which may undergo a saturated magnetization or an unsaturated magnetization, is preferably limited to undergo an unsaturated magnetization. The degree of magnetization of the wire rope 5 can be adjusted according to the type of the magnets 24, 25, the distance between the magnets 24, 25 and the wire rope 5, the cross-sectional area and/or the length of the yoke 22. For example, if the magnets 24, 25 are not neodymium but ferrite ones, the degree of magnetization of the wire rope 5 can be lowered. Limiting to an unsaturated magnetization allows the signal-to-noise ratio (S/N ratio) of inspection data to be described hereinafter to be improved and further the wear due to the contact between the wire rope 5 and the rope tester 20 to be reduced.

Referring now to Fig. 4, the wire ropes 5 each include a bundled fiber core 5A and eight strands 5B

twisted around the fiber core 5A. The strands 5B are each formed in a seal structure including a core wire (steel wire) 5a, nine inner-layer element wires (steel wires) 5b twisted around the core wire 5a, and nine outer-layer
5 element wires (steel wires) 5c twisted further around the inner-layer element wires 5b (denoted "8×S (19)", for example). Magnetic fluxes from the magnets 24, 25 pass through outer circumferential strands 5B of each wire rope 5.

10 In the wire ropes 5, the strands 5B are likely to be damaged earlier than the centrally-located fiber core 5A and, focusing on the strands 5B, the outer-layer element wires 5c are likely to be damaged earlier than the core wire 5a and the inner-layer element wires 5b. When a
15 break occurs in the outer-layer element wires 5c, magnetic fluxes passing through the strands 5B are disturbed and leak out of the wire rope 5 at the broken portion. A magnetic flux leaking out of the wire rope 5 will hereinafter be referred to as "leakage magnetic flux".
20 When the broken portion of the magnetized wire rope 5 passes by the rope tester 20, the leakage magnetic flux causes an electromotive force on the sensor coils 26L, 26R. The existence and seriousness of the damage in the wire rope 5 can be detected according to the existence and
25 magnitude of the electromotive force on the sensor coils

26L, 26R.

Figs. 6 and 7 are graphs each showing a measured voltage (inspection data) based on an electromotive force occurring on the sensor coils 26L, 26R. The vertical axis represents the voltage value based on the electromotive force occurring on the sensor coils 26L, 26R, amplified by 6,000 times. The horizontal axis represents the time on which the voltage value was acquired over time from left to right. In Figs. 6 and 7, the time width (data range) corresponding to the length of one pitch of the strands 5B constituting the wire rope 5 is also indicated by the solid line.

The more seriously the wire rope 5 is damaged (e.g. the more the number of breaks per pitch), the more the number of leakage magnetic fluxes, and accordingly a higher electromotive force occurs on the sensor coils 26L, 26R, that is, a higher voltage value is to be measured (found by comparison between Figs. 6 and 7). If multiple longitudinally-separate damages exist at short intervals in the wire rope 5, multiple measured voltage peaks appear within a narrow data range in the graph (see Fig. 7).

Referring further to Figs. 6 and 7, it is found that a low voltage value is measured constantly. This is for the reason that since the wire rope 5 is formed by twisting eight strands 5B as mentioned above, concavo-

convex portions resulting from twisting the eight strands
5B exist on the surface of the wire rope 5. That is, a
leakage magnetic flux from concavo-convex portions between
eight strands 5B inevitably exists even on a non-damaged
5 wire rope 5 to emerge as a low measured voltage waveform
in the graph. This kind of waveform emerging due to the
existence of concavo-convex portions between the strands
5B is generally called strand noise. The strand noise
causes a voltage value having a peak of about 0.3V to be
10 measured.

Referring again to Fig. 5, in order to keep the
variation in the measured voltage (strand noise) due to
the existence of concavo-convex portions between the
strands 5B as low as possible, the rope tester 20 includes
15 the pair of sensor coils 26L, 26R and the distance "b"
between the two sensor coils 26L and 26R (the spacing
between portions through which the leakage magnetic flux
passes) is the integral multiple of the spacing "a"
between the tops (crowns) of adjacent strands 5B. Since
20 the number of leakage magnetic fluxes leaking due to the
existence of concavo-convex portions between the strands
5B and passing through the two sensor coils 26L, 26R is
thus averaged, the leakage magnetic fluxes leaking due to
the existence of concavo-convex portions between the
25 strands 5B can be distinguished easily from leakage

magnetic fluxes leaking due to a damage in the wire rope
5. That is, the variation in the strand noise emerging in
the measured voltage can be kept low.

A measured voltage (inspection data) representing
5 such a waveform as shown in the graph of Fig. 6 or 7 is
output from the rope tester 20 and fed to the controller
9. As will next be described, the controller 9 uses the
inspection data to inspect the wire rope 5.

Figs. 8 to 10 are flow charts showing an algorithm
10 of wire rope damage determination processing performed in
the controller 9. A program for executing the algorithm
shown in the flow charts is preliminarily programmed in a
computer or memory (not shown) included in the controller
9. The program may be recorded on a CD-ROM or the like
15 and installed in the controller 9 via a terminal device
(e.g. personal computer). The terminal device may be used
to modify (adjust) various parameters (e.g. multiple
threshold voltages for various determinations to be
described hereinafter) and transfer the modified
20 parameters to the controller 9.

As mentioned above, one to three times per day at a
specific time, for example, the controller 9 automatically
inspects the multiple wire ropes 5 used in the elevator.
An inspection start signal may be transmitted manually or
25 automatically from the monitoring system 11 to the

controller 9 and, based on the inspection start signal, the inspection may be performed. The controller 9 first cooperates with the elevator control panel 8 to move the elevator car 3 to the top floor (see Fig. 1), and then
5 controls the movement mechanism 30 to move the rope tester 20 from the standby position to the detecting position (see Fig. 2). The elevator car 3 is moved from the top floor to the bottom floor at a predetermined speed (e.g. 90m/min), during which the rope tester 20 acquires
10 inspection data (see Figs. 6 and 7). After determination processing using the inspection data to be next described, the controller 9 controls the movement mechanism 30 to put the rope tester 20 from the detecting position back to the original standby position. It will be understood that the
15 rope tester 20 may be put from the detecting position back to the original standby position immediately after the acquisition of the inspection data.

It is assumed that the inspection data (measured voltage V_s) is not 0V (waveform-less data). If the
20 measured voltage V_s were 0V, the controller 9 might be in an abnormal state such as a power-off state or in a state where power is supplied but a short-circuit occurs on the circuit board of the controller 9. The movement mechanism 30 might be in an abnormal state and could not move the
25 rope tester 20 from the standby position to the detecting

position, resulting in that inspection data with no voltage value recorded therein might be generated. The elevator control panel 8, for example, may detect that valid inspection data cannot be acquired (including that
5 no inspection data is output from the controller 9). In this case, the elevator control panel 8 outputs and transmits, for example, a determination bit of 0 to the monitoring system 11. The monitoring system 11 informs observers of the occurrence of such an abnormal state with
10 a blue warning light, warning sound, etc. A warning light and/or a speaker may be provided on the elevator control panel 8 or the controller 9 in the machine room 2 and the warning light may be turned on and/or a warning sound may be made.

15 Inspection data (measured voltage V_s) output from the rope tester 20 (see Figs. 6 and 7) is first fed to the controller 9 (step 41).

 If the measured voltage V_s is within the voltage range of $0V < V_s < 0.2V$, though not $0V$, that is, no peak
20 voltage equal to or higher than $0.2V$ emerges in the waveform of the measured voltage V_s ("YES" at step 42), the controller 9 outputs and transmits a determination bit of 0 to the monitoring system 11 via the elevator control panel 8 (communication device 10) (step 43). This is for
25 the reason that a strand noise exists even on a non-

damaged wire rope 5, as mentioned above, and the strand noise has a peak of about 0.3V. If there is no peak voltage equal to or higher than 0.2V, a short-circuit fault or an open-circuit fault, for example, might occur
5 on the sensor coils 26L, 26R. Also in this case, a determination bit of 0 is transmitted to the monitoring system 11 to inform observers of the occurrence of such an abnormal state with a blue warning light, warning sound, etc.

10 If a voltage value equal to or higher than 0.2V is included in the waveform of the measured voltage Vs ("NO" at step 42), the maximum instantaneous voltage value (hereinafter referred to as peak voltage Vp) in the measured waveform is acquired and it is determined whether
15 or not the peak voltage Vp is lower than 0.6V (steps 44 and 45). If the peak voltage Vp is lower than 0.6V, it is determined that the wire rope 5 is not damaged. In this case, the controller 9 outputs a determination bit of 1 ("YES" at step 45 and step 46). Observers are informed of
20 the normality of the wire rope 5 with a green light, for example.

 If the peak voltage Vp is equal to or higher than 0.6V ("NO" at step 45), the voltage value does not indicate a strand noise but might be detected due to a
25 damage in the wire rope 5. The controller 9 makes a two-

level determination of the seriousness of the damage in the wire rope 5 as follows.

It is first determined whether or not the peak voltage V_p is equal to or higher than 1.4V (step 47).

5 If the peak voltage V_p is equal to or higher than 1.4V (" $1.4 \leq V_p$ " at step 47), a damage of relatively high seriousness may occur in the wire rope 5. In this case, the controller 9 outputs a determination output bit of 3 and accordingly the monitoring system 11 notifies, with a
10 red warning light, warning sound, etc., that the wire rope 5 is damaged (step 51). When it is notified that the wire rope 5 is damaged, a minute inspection for identifying which one of the multiple wire ropes 5 is damaged is to be performed in general.

15 If the peak voltage V_p is equal to or higher than 0.6V but lower than 1.4V ("YES" at step 47), the number of voltage values (peaks) within the range of $0.6V \leq V_p < 1.4V$ is next counted within the length of one pitch of the strands 5B (data range corresponding to one pitch) (see
20 Figs. 6 and 7), and then it is determined whether the number is one or more (steps 48 and 49). This determines whether or not damages of relatively low seriousness occur concentrically in one portion.

 If the number of voltage values within the range
25 equal to or higher than 0.6V but lower than 1.4V is one

within the length of one pitch, the damages might not occur concentrically in one portion of the wire rope 5. In this case, the controller 9 outputs a determination output bit of 2 and accordingly a yellow warning light, 5 for example, is used to call attention to observers ("YES" at step 49 and step 50).

On the other hand, if the number of voltage values within the range equal to or higher than 0.6V but lower than 1.4V is two or more within the length of one pitch, 10 the damages might be of relatively low seriousness but may occur concentrically in one portion. In this case, the controller 9 outputs a determination output bit of 3 and observers are informed of the abnormality with a red warning light, warning sound, etc., as is the case where 15 the peak voltage V_p is equal to or higher than 1.4V ("Two or more" at step 49 and step 51).

The above-described algorithm uses the first threshold voltage of 0.2V for determination of whether or not the rope tester 20 (sensor coils 26L, 26R) is in an abnormal state, the second threshold voltage of 0.6V for 20 determination of whether or not the wire rope 5 is damaged, and the third threshold voltage of 1.4V for two-level determination of the seriousness of the damage. These three threshold voltages were obtained through a 25 test, the details of which will hereinafter be described.

Fig. 11 shows results of a test measuring damaged wire ropes 5 using the rope tester 20, showing values of the peak voltage V_p measured using the rope tester 20 (amplified by 6,000 times). Fig. 12 is a graph drawn based on the test results shown in Fig. 11, showing the relationship between the peak voltage V_p (vertical axis) and the defect pass-by position (angle) (to be described hereinafter) (horizontal axis). Fig. 13 shows the positional relationship between the wire rope 5 and the rope tester 20. In the table of Fig. 11, some of the values of the peak voltage V_p have no symbol on the upper right thereof, some have two symbols (**) on the upper right thereof, and the other have one symbol (*) on the upper right thereof. The values with two symbols (**) indicate that the occurrence of abnormality is to be notified (step 51) in the determination processing according to the algorithm (Figs. 8 to 10). The values with one symbol (*) indicate that at least attention is to be called (step 50) in the determination processing according to the algorithm. The values with no symbol indicate a determination that there is no abnormality.

In this test, four wire ropes 5 having the structure of 8×S (19) described above and a diameter of 10mm were used arranged in parallel with each other with a space of 3mm between adjacent wire ropes 5. The test was tried

several times after all of the four wire ropes 5 had been demagnetized in advance. Figs. 11 and 12 show inspection data acquired not in the first trial (in which the wire ropes 5 passed by the rope tester 20 for the first time after demagnetization) but in the second trial without demagnetization. This is for the reason that through the several trials, the data acquired in the second and following trials had only a small divergence between the trials, but the data acquired in the first trial differed significantly from the data acquired in the second and following trials. In the second and following trials, the wire ropes 5 had residual magnetism because they had been magnetized in the previous trial(s) and were magnetized in total with the residual magnetism and the magnetism during the trial. The degree (magnitude) of the magnetization during the trial was adjusted so that the residual magnetism and the magnetism during the trial did not undergo a saturated magnetization in total.

The wire ropes 5 were each prepared by twisting multiple strands 5B as mentioned above, and the strands 5B were each prepared by twisting multiple element wires. The wire ropes 5 are likely to be damaged in the outer-layer element wires 5c among the element wires constituting the strands 5B. In the measuring test, firstly, a specific one of the four wire ropes 5

(excluding the two end ones) was selected and various numbers of breaks were made purposely within one pitch of the outer-layer element wires 5c of one of the eight strands 5B constituting the wire rope 5, and then the four wire ropes 5 including that with the broken outer-layer element wires 5c were passed by the rope tester 20.

In the table of Fig. 11, the number of breaks within one pitch of the outer-layer element wires 5c is shown in the column "Number of breaks". However, the undermost "One strand" shows results of a test in which one strand 5B including not only the outer-layer element wires 5c but also the inner-layer element wires 5b and the core wire 5a was entirely broken.

For example, the number of breaks "One in the element wires" means that a specific strand 5B constituting a specific one of the two wire ropes 5 between the two end ones of the four parallel-arranged wire ropes 5 was selected and one break was made within one pitch of an outer-layer element wire 5c constituting the strand 5B.

Referring now to Fig. 13, the outer-layer element wires 5c can be categorized into three types: (i) crown element wires: ones in contact with only the outer-layer element wires 5c adjacent on both sides in the same strand 5B; (ii) nip element wires: ones also in contact with the

outer-layer element wires 5c in the adjacent strands 5B;
and (iii) bed element wires: ones in contact with the
fiber core 5A. The crown, nip and bed ones of even the
outer-layer element wires 5c included in the same strand
5 5B have their respective different distances to the rope
tester 20 (sensor coils 26L, 26R). In the measuring test,
secondly, not only the number of breaks but also the
position of breaks in the outer-layer element wires 5c was
made different.

10 Referring to Fig. 11, the column "Type of breaks"
indicates which of the bed element wires, the nip element
wires and the crown element wires was broken. For
example, the number of breaks "One in the element wires"
shows test results for the three types of breaks "Bed wire
15 break", "Nip wire break" and "Crown wire break". This
means that one break occurs, which is a common condition,
within one pitch of a "bed", "nip", or "crown" outer-layer
element wire 5c.

Further, since the rope tester 20 is provided only
20 on one side of the wire rope 5 (see Figs. 1, 2 and 13),
when the wire rope 5 with a break passes by the rope
tester 20, the closer the break to the rope tester 20, the
higher the peak voltage becomes, while the more distant
the break from the rope tester 20, the lower the peak
25 voltage becomes. Hence, in the measuring test, thirdly,

the angular position of the break with respect to the rope tester 20 was also made different. Referring to Fig. 13, the test was conducted for different cases where the positional relationship between the rope tester 20 and the break in the wire rope 5 was defined by different angular positions of 0, 45, 90, 135, and 180 degrees (corresponding to the above-described "defect pass-by position (angle)"), where 0 degree means that the break is closest to the rope tester 20 and 180 degrees means that the break is most distant from the rope tester 20.

In the table of Fig. 11, voltage values (stationary voltage values) that might be due to a strand noise as mentioned above are further shown in the column "Noise (V)".

Referring to the table of Fig. 11, the strand noise-caused voltage values are 0.3 to 0.4V in all the test results. This is why the first threshold voltage for determination of whether or not the rope tester 20 (sensor coils 26L, 26R) is in an abnormal state was set to 0.2V. The strand noise-caused measured voltages can hardly be equal to or lower than 0.2V and, when a peak voltage equal to or lower than the first threshold voltage of 0.2V is only acquired, it is determined as mentioned above that the rope tester 20 (sensor coils 26L, 26R) is in an abnormal state (step 43).

Referring to the table of Fig. 11 and the graph of Fig. 12, for almost all the test results, the peak voltage becomes high at the defect pass-by position of 0 degree (the break is closest to the rope tester 20), while the peak voltage becomes low as the defect pass-by position approaches 180 degrees (the more distant the break from the rope tester 20), for the same type of damages. At the defect pass-by position of 180 degrees, where the sensitivity is lowest, no peak voltage equal to or higher than 0.6V is shown except for the number of breaks "One strand". At the defect pass-by position of 180 degrees, a peak voltage V_p of 1.3V, which is higher than the second threshold voltage of 0.6V, is shown for the entirely broken strand 5B, and therefore attention is to be called (see steps 49 and 50).

At the defect pass-by position of 135 degrees, the peak voltage V_p for the entirely broken strand 5B is higher than the third threshold voltage of 1.4V. The occurrence of abnormality is therefore to be notified (see steps 47 and 51). At the defect pass-by position of 135 degrees, a peak voltage V_p of 0.6V or higher is shown for the cases of "Seven in the element wires and Crown wire break", "Three in the element wires and Crown wire break", and "Two in the element wires and Crown wire break", and therefore attention is to be called.

At the defect pass-by position of 90 degrees, attention is to be called also for the case of "Four in the element wires and Nip wire break".

At the defect pass-by position of 45 degrees, a peak
5 voltage V_p higher than the third threshold voltage of 1.4V is shown not only for the one strand broken but also for the cases of "Seven in the element wires and Crown wire break" and "Three in the element wires and Crown wire break", and the occurrence of abnormality is therefore to
10 be notified. At the defect pass-by position of 45 degrees, attention is to be called further for the cases of "One in the element wires and Crown wire break", "Two in the element wires and Bed wire break", "Two in the element wires and Nip wire break", and "Two in the element
15 wires and Crown wire break".

At the defect pass-by position of 0 degree, not attention calling but abnormality notifying is to be performed for the cases of "Four in the element wires and Bed wire break" and "Four in the element wires and Nip
20 wire break".

Although the sensitivity at the defect pass-by position of 180 degrees is somewhat low, attention calling and abnormality notifying can be performed relatively successfully by setting the second threshold voltage for
25 determination of whether or not the wire rope 5 is damaged

to 0.6V and the third threshold voltage for two-level determination of the seriousness of the damage to 1.4V.

It will be understood that the first, second, and third threshold voltages are merely illustrative, and that the sensitivity for determining whether or not the wire rope 5 is damaged may be increased by lowering the second threshold voltage, and the number of cases where abnormality notifying is performed may be increased by lowering the third threshold voltage.

Figs. 14 and 15 show a table and a graph corresponding to those shown in Figs. 11 and 12, showing results of a simulation of the case where rope testers 20 are provided not on one side but on both sides of the wire rope 5 as shown in Fig. 16. Thus providing the two rope testers 20 in a manner putting the wire rope 5 from both sides allows the sensitivity at the defect pass-by position from 90 to 180 degrees to be increased. Referring to Fig. 14, providing the rope testers 20 on both sides of the wire rope 5 causes the frequency of attention calling (see the symbol *) and alert notifying (see the symbol **) to increase compared to the case where the rope tester 20 is provided only on one side of the wire rope 5. In the case of thus providing the rope testers 20 on both sides of the wire rope 5, the second and third threshold voltages may be set differently from

the case where the rope tester 20 is provided on one side.

Fig. 17 is a cross-sectional view, corresponding to Fig. 4, of a rope tester 20A according to another embodiment. The rope tester 20A differs from the rope
5 tester 20 shown in Fig. 4 in that the both longitudinal end portions of the sensor surface (sensor coils 26L, 26R; only the coil 26L is shown in Fig.17) are curved upward (toward the wire ropes 5). The coil base 23 supporting the sensor coils 26L, 26R also has raised portions formed
10 on the both ends thereof.

If the entire width of the four parallel-arranged wire ropes 5 (spacing between the wire ropes 5) is greater than the width of a groove in a sheave used in the hoist 6 and/or the deflector sheave 7 (see Fig. 1), the surfaces
15 of the two end ones of the four wire ropes 5 to be in contact with the sheave are deflected outward and thereby come into tight contact with the sheave to be damaged more acceleratedly than the two remaining wire ropes 5. The both end portions of the sensor surface (sensor coils 26L,
20 26R) of the rope tester 20A are thus curved to be lateral to the two respective end side ones of the four wire ropes 5, which can increase the sensitivity of damage sensing for the two end side wire ropes 5.

CLAIMS:

1. A wire rope inspection apparatus comprising a sensor device provided along a passage through which a plurality of wire ropes arranged in parallel with each other travel
5 and adapted to sense a leakage magnetic flux leaking from the wire ropes that have been magnetized, wherein

the sensor device includes a sensor surface formed in a plane and having a length greater than the entire width of the plurality of parallel-arranged wire ropes,
10 and wherein

upon sensing of the leakage magnetic flux, the sensor surface of the sensor device is disposed parallel to a plane defined by the plurality of parallel-arranged wire ropes to be in line contact with the plurality of
15 wire ropes and across the entire width of the plurality of parallel-arranged wire ropes.

2. The wire rope inspection apparatus according to claim 1, further comprising a movement mechanism for moving the sensor device, wherein

20 the movement mechanism is arranged to, upon sensing of the leakage magnetic flux, make the sensor device close to the wire ropes to bring the sensor surface into line contact with the wire ropes and, off sensing of the leakage magnetic flux, move the sensor device away from
25 the wire ropes.

3. The wire rope inspection apparatus according to claim 2, wherein the movement mechanism includes a rotary mechanism for rotating the sensor device.

4. The wire rope inspection apparatus according to any one of claims 1 to 3, wherein the both longitudinal end portions of the planar sensor surface are curved in the same direction and, upon sensing of the leakage magnetic flux, the both longitudinal ends of the sensor surface are lateral to the two respective end side wire ropes among the plurality of parallel-arranged wire ropes.

5. The wire rope inspection apparatus according to any one of claims 1 to 4, wherein the sensor device includes a sensor coil for sensing the leakage magnetic flux and a magnetizer for magnetizing the plurality of wire ropes.

6. The wire rope inspection apparatus according to claim 5, further comprising two, first and second, sensor coils arranged separately in parallel with each other, wherein

the spacing between portions of the respective first and second sensor coils through which the leakage magnetic flux passes is the integral multiple of the distance between adjacent ones of a plurality of strands constituting the wire ropes.

7. A wire rope damage determination apparatus comprising:

inspection data receiving means for receiving an
input of voltage data according to the magnitude of a
leakage magnetic flux leaking from a magnetized wire rope,
said voltage data being output from a sensor coil provided
5 along a passage through which one or more wire ropes
travel and adapted to generate an electromotive force
caused by the leakage magnetic flux;

peak voltage detecting means for detecting a maximum
voltage value using the voltage data received by the
10 inspection data receiving means;

first determining means for determining whether or
not the maximum voltage value detected by the peak voltage
detecting means is equal to or greater than a first
threshold value; and

15 first determination data outputting means for
outputting first determination data to be used at least
for calling attention if the first determining means
determines that the maximum voltage value equal to or
greater than the first threshold value is recorded in the
20 voltage data.

8. The wire rope damage determination apparatus
according to claim 7, further comprising:

second determining means for determining whether or
not the maximum voltage value detected by the peak voltage
25 detecting means is equal to or greater than a second

threshold value that is greater than the first threshold value; and

second determination data outputting means for outputting second determination data to be used for
5 calling alert if the second determining means determines that the maximum voltage value equal to or greater than the second threshold value is recorded in the voltage data.

9. The wire rope damage determination apparatus
10 according to claim 8, further comprising third determining means for determining whether or not a plurality of separate voltage values equal to or greater than the first threshold value and smaller than the second threshold value exist within a data range corresponding to one pitch
15 of a plurality of strands constituting the wire rope if the first determining means and the second determining means determine that the maximum voltage value is equal to or greater than the first threshold value and smaller than the second threshold value, wherein

20 the second determination data outputting means is adapted to output second determination data to be used for calling alert also if the third determining means determines that a plurality of voltage values equal to or greater than the first threshold value and smaller than
25 the second threshold value exist within the data range

corresponding to one pitch.

10. The wire rope damage determination apparatus according to claim 7, further comprising:

fourth determining means for determining whether or
5 not the maximum voltage value is smaller than a third threshold value that is smaller than the first threshold value; and

third determination data outputting means for
outputting third determination data for notifying that the
10 damage determination apparatus is in an abnormal state if the fourth determining means determines that the maximum voltage value is smaller than the third threshold value.

11. The wire rope damage determination apparatus according to any one of claims 7 to 10, further comprising
15 a transmission device for transmitting the determination data externally through a network.

12. A computer-readable wire rope damage determination program adapted to control a computer to:

receive an input of voltage data according to the
20 magnitude of a leakage magnetic flux leaking from a magnetized wire rope, said voltage data being output from a sensor coil provided along a passage through which one or more wire ropes travel and adapted to generate an electromotive force caused by the leakage magnetic flux;

25 detect a maximum voltage value using the received

voltage data;

determine whether or not the detected maximum voltage value is equal to or greater than a first threshold value; and

5 output first determination data to be used at least for calling attention if it is determined that the maximum voltage value equal to or greater than the first threshold value is recorded in the voltage data.

13. The wire rope damage determination program according
10 to claim 12, further adapted to control the computer to:

determine whether or not the maximum voltage value is equal to or greater than a second threshold value that is greater than the first threshold value; and

output second determination data to be used for
15 calling alert if it is determined that the maximum voltage value equal to or greater than the second threshold value is recorded in the voltage data.

14. The wire rope damage determination program according to claim 13, further adapted to control the computer to:

20 determine whether or not a plurality of separate voltage values equal to or greater than the first threshold value and smaller than the second threshold value exist within a data range corresponding to one pitch of strands constituting the wire rope if it is determined
25 that the maximum voltage value is equal to or greater than

the first threshold value and smaller than the second threshold value; and

output second determination data to be used for calling alert also if it is determined that a plurality of
5 voltage values equal to or greater than the first threshold value and smaller than the second threshold value exist within the data range corresponding to one pitch.

15. The wire rope damage determination program according
10 to claim 12, further adapted to control the computer to:

determine whether or not the maximum voltage value is smaller than a third threshold value that is smaller than the first threshold value; and

output third determination data to be used for
15 notifying that the determination apparatus is in an abnormal state if it is determined that the maximum voltage value is smaller than the third threshold value.

16. A computer-readable recording medium recording a program according to any one of claims 12 to 15.

20 17. A wire rope damage determination method adapted to control a computer comprising the steps of:

receiving an input of voltage data according to the magnitude of a leakage magnetic flux leaking from a magnetized wire rope, said voltage data output from a
25 sensor coil provided along a passage through which one or

more wire ropes travel and adapted to generate an
electromotive force caused by the leakage magnetic flux;

detecting a maximum voltage value using the received
voltage data;

5 determining whether or not the detected maximum
voltage value is equal to or greater than a first
threshold value; and

outputting first determination data to be used at
least for calling attention if it is determined that the
10 maximum voltage value equal to or greater than the first
threshold value is recorded in the voltage data.

18. The wire rope damage determination method according
to claim 17, further adapted to control the computer
comprising the steps of:

15 determining whether or not the detected maximum
voltage value is equal to or greater than a second
threshold value that is greater than the first threshold
value; and

outputting second determination data to be used for
20 calling alert if it is determined that the maximum voltage
value equal to or greater than the second threshold value
is recorded in the voltage data.

19. The wire rope damage determination method according
to claim 18, further adapted to control the computer
25 comprising the steps of:

determining whether or not a plurality of separate voltage values equal to or greater than the first threshold value and smaller than the second threshold value exist within a data range corresponding to one pitch of strands constituting the wire rope if it is determined that the maximum voltage value is equal to or greater than the first threshold value and smaller than the second threshold value; and

outputting second determination data to be used for calling alert also if it is determined that a plurality of voltage values equal to or greater than the first threshold value and smaller than the second threshold value exist within the data range corresponding to one pitch.

20. The wire rope damage determination method according to claim 17, further adapted to control the computer comprising the steps of:

determining whether or not the maximum voltage value is smaller than a third threshold value that is smaller than the first threshold value; and

outputting third determination data to be used for notifying that the determination apparatus is in an abnormal state if it is determined that the maximum voltage value is smaller than the third threshold value.

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