

DESCRIPTION

WIRE ROPE LIFE MANAGEMENT APPARATUS AND METHOD

Technical Field

The present invention relates to a wire rope life  
5 management apparatus and method.

Background Art

A wire rope deteriorates with use. In particular,  
in the case of a wire rope for a crane used in  
transporting (moving) freight of comparatively heavy  
10 weight (such an overhead crane, jib crane, bridge crane,  
unloader, cable crane, telfer or stacker-type crane)  
(inclusive of mobile cranes and derricks),  
deterioration of the wire rope must be carefully  
ascertained.

15 The life of a conventional wire rope for a crane  
is predicted using the degree of fatigue of the wire  
rope that is based upon the number of times the wire  
rope is bent (the number of times it passes over  
sheaves). The reason for this is that, in the case of  
20 a crane, most of them use sheaves and deterioration of  
the wire rope is very large at the positions where the  
wire rope passes over the sheaves. The specification  
of Japanese Patent No. 2748836 describes a life  
predicting apparatus that divides a wire rope into a  
25 plurality of unit regions and calculates life

(cumulative degree of fatigue) on a per-unit-region basis taking into consideration the fact that deterioration of the wire rope is large at the sheave positions.

5           At an actual site where work using a crane is carried out, a factor that is strongly related to wire rope deterioration exists in addition to the number of times the wire rope is bent (the number of times it passes over sheaves). This factor is a load (referred  
10 to below as "shock load") that is produced temporarily when freight is lifted using a crane. The size of shock load depends upon the skill of the crane operator. The prediction of wire rope life according to the prior art does not go beyond prediction using the structure  
15 (inclusive of number of sheaves and sheave diameter, etc.) of the crane per se, and it does not take into consideration the effect of shock load upon the life of the wire rope.

#### Disclosure of the Invention

20           An object of the present invention is to calculate the life of a wire rope accurately taking into consideration the damage that the wire rope would sustain due to shock load.

          A wire rope life management apparatus according to  
25 the present invention comprises: life calculating

means for calculating estimated life (remaining number of times use is possible) of a wire rope in accordance with a prescribed life estimation formula, the wire rope being used in a crane that hoists, transports and  
5 then lowers freight via the wire rope and a sheave, with which the wire rope is engaged, by paying out the wire rope from a drum and rewinding the wire rope onto the drum; load data input means for accepting input of load data of the freight from lifting of the freight  
10 until subsequent lowering thereof, the load data being output from a load cell provided on the sheave; actual load calculating means for calculating actual load of the freight based upon the load data that has been input from the load data input means; shock load  
15 sensing means for sensing whether a shock load that exceeds the actual load by a prescribed amount is present based upon the load data that has been input from the load data input means; and life updating means for calculating a new estimated life of the wire rope,  
20 if presence of the shock load has been sensed by the shock load sensing means, by subtracting, from the estimated life, a value obtained by multiplying a life subtraction value that prevails when presence of the shock load is not sensed by a correction coefficient  
25 having a value greater than unity.

A wire rope life management method according to the present invention comprises the steps of:  
calculating estimated life of a wire rope in accordance with a prescribed life estimation formula, the wire  
5 rope being used in a crane that hoists, transports and then lowers freight via the wire rope and a sheave, with which the wire rope is engaged, by paying out the wire rope from a drum and rewinding the wire rope onto the drum; accepting input of load data of the freight  
10 from hoisting of the freight until subsequent lowering thereof, the load data being output from a load cell provided on the sheave; calculating actual load of the freight based upon the load data that has been input; sensing whether a shock load that exceeds the actual  
15 load by a prescribed amount is present based upon the load data that has been input; and if presence of the shock load has been sensed, calculating a new estimated life of the wire rope, by subtracting, from the estimated life, a value obtained by multiplying a life  
20 subtraction value that prevails when presence of the shock load is not sensed by a correction coefficient having a value greater than unity.

The estimated life of a wire rope is calculated in accordance with a prescribed life estimation formula.  
25 The present invention is such that when a wire rope

having the estimated life that will be calculated is actually used in a crane, the extent to which rope life will be shortened thereafter (after freight has been transported using the crane) is ascertained (and as a  
5 result, the new estimated life of the wire rope is calculated).

Any of various life estimation formulae that have been proposed heretofore can be used as the prescribed life estimation formula. For example, the life of a  
10 wire rope is estimated using the Niemann formula as the life estimation formula. Naturally, other life estimation formulae (the Zhitkov & Posoekhov formula, the E.L. Klein formula and the V. Zignoli formula, etc.) may also be used. The various life estimation  
15 formula cited above are described in the "Wire Rope Handbook" (Wire Rope Handbook Editing Committee, Nikkan Kogyo Shimbunsha, published March 30, 1995, pp. 352 - 353) and in "All About Wire Rope (Last Volume) - The Road to Safety" Kaizuka Chamber of Commerce and  
20 Industry, Steel Manufacture Activation Research Society, Kaizuka Chamber of Commerce and Industry, published July 25, 1995, pp. 153 - 158).

An input of load data of freight from hoisting of the freight until subsequent lowering thereof is  
25 accepted, this being output from a load cell provided

on a sheave. The load data includes continuous load values (load values detected by a load cell) from hoisting of the freight until transporting (moving) and lowering thereof by the crane. A continuous graph  
5 along elapsed time can be delineated by the load data.

The actual load of the hoisted freight is obtained based upon the load data from the load cell. For example, the load prevailing at a point in time upon elapse of a prescribed period of time from hoisted of  
10 the freight may be adopted as the actual load, or a value obtained by averaging the load starting from a point in time upon elapse of a first prescribed period of time from hoisted of the freight until a subsequent point in time upon elapse of a second prescribed period  
15 of time may be adopted as the actual load.

Immediately after the freight is hoisted, a load that exceeds the actual load acts upon the load cell. The load that acts upon the load cell immediately after the freight is hoisted depends greatly upon the  
20 operation of the crane by the crane operator. If the crane operator lifts the freight quickly, the load applied will be greater in comparison with slow lifting of the freight.

Whether a load that exceeds the actual load by a  
25 prescribed amount is present is sensed based upon the

load data. For example, if a load exceeding 110% of the actual load appears in the load data, then it is determined that shock load is present.

In a case where the presence of shock load has  
5 been sensed, a new estimated life of the wire rope is calculated by subtracting, from the above-mentioned estimated life, a value obtained by multiplying a life subtraction value that prevails when the presence of shock load is not sensed by a correction coefficient  
10 having a value greater than unity. As an example of a life subtraction value that prevails when the presence of shock load is not sensed, use is made of a value obtained by dividing estimated life of the wire rope, which is obtained by applying a value based upon the  
15 maximum hoisting load of the crane to the above-mentioned Niemann formula, by estimated life of the wire rope obtained by applying a value based upon the detected actual load to the Niemann formula.

In accordance with the present invention, if the  
20 presence of shock load has been sensed in the load data, a value obtained by multiplying a life subtraction value that prevails in the absence of shock load by a correction coefficient having a value greater than unity is subtracted from the above-mentioned estimated  
25 life. The case where shock load exists and the case

where shock load does not exist are compared, therefore,  
and a short life is calculated. A new estimated life  
of the wire rope, which takes into consideration damage  
to the wire rope produced in accordance with the  
5 occurrence of shock load, can be calculated.

The wire rope life management apparatus may have a  
display unit for displaying the new estimated life of  
the wire rope calculated. The timing for replacing a  
wire rope that is in use can be ascertained visually.  
10 Further, estimated life of the wire rope can be  
calculated and displayed in real-time and the operator  
or on-site supervisor can be notified thereof. An  
unexpected rope severance accident can be prevented.

The wire rope life management apparatus preferably  
15 has shock-load excess amount calculating means for  
calculating, with regard to the shock load, an excess  
amount that exceeds the actual load. The life updating  
means uses a certain value as the correction  
coefficient, wherein the larger the excess amount  
20 calculated by the shock-load excess amount calculating  
means, the larger the value used. A new estimated life  
of the wire rope can be calculated based not only upon  
the presence or absence of shock load but also upon the  
size of shock load if shock load is present.

25 Brief Description of the Drawings

Fig. 1 is a block diagram illustrating the abbreviated structure of a crane;

Fig. 2 is a graph illustrating load data that is output from a load cell;

5        Fig. 3 is a perspective view illustrating the external appearance of a rope life management apparatus;

Fig. 4 is a block diagram illustrating the electrical configuration of a rope life management  
10    apparatus;

Fig. 5 illustrates an example a setting screen;

Fig. 6 illustrates an example of an operation screen;

Fig. 7 illustrates an example of settings data;

15        Fig. 8 illustrates an example of settings data; and

Fig. 9 is a flowchart illustrating the flow of processing executed by a rope life management apparatus.

Best Mode for Carrying Out the Invention

20        Fig. 1 illustrates the abbreviated structure of a crane that hoists, transports and then lowers freight. The traveling (moving) mechanism (runway) of the crane is not illustrated in Fig. 1.

The crane has a hoisting drum 1 on which a wire  
25    rope 2 has been wound. Both ends of the wire rope 2

are fixed near both ends of the hoisting drum 1. When the hoisting drum 1 rotates forwardly, the wire rope 2 is paid out from the hoisting drum 1. When the hoisting drum 1 rotates in reverse, the wire rope 2 is rewound upon the hoisting drum 1. The shaft of the hoisting drum 1 is coupled to a hoisting/rewinding motor 2A. The hoisting drum 1 is rotated in forward and reverse by rotative driving of the shaft by the hoisting/rewinding motor 2A. Driving of the hoisting/rewinding motor 2A (control of direction of rotation, rotation start-and-stop control and control so rotating speed, etc.) is carried out by the crane operator.

A plurality of sheaves on which the wire rope 2 has been wound is provided below the hoisting drum 1. With the crane shown in Fig. 1, an equalizer sheave 3 is placed at the loopback position of the wire rope 2. A fixed sheave 4 and two movable sheaves (hook sheaves) 5, 6 are placed in left-right symmetry embracing the equalizer sheave 3 on respective sides thereof. A hook 7 from which freight hangs is coupled to the movable sheaves 5, 6.

Since the wire rope 2 is paid out from the hoisting drum 1 when the hoisting drum 1 rotates forwardly, the movable sheaves 5, 6 upon which the wire

rope 2 has been wound move downward. Since the wire rope 2 is wound up upon the hoisting drum 1 when the hoisting drum 1 rotates reversely, the movable sheaves 5, 6 move upward. The freight hanging from the hook 7 is hoisted or lowered as the movable sheaves 5, 6 ascend or descend.

A load cell 8 for detecting the load that acts upon the equalizer sheave 3 is mounted on the equalizer sheave 3. The load cell 8 may be of the desk type, compression type, tension type, amplifier type, bearing type or pin type, etc. A voltage that corresponds to the load is output from the load cell 8. The voltage that has been output from the load cell 8 is applied to a rope life management apparatus 10.

Fig. 2 illustrates, in the form of a graph in which time is plotted along the horizontal axis and load (voltage corresponding to the load) along the vertical axis, data that is output from the load cell 8 and applied to the rope life management apparatus 10 from hoisting of the freight until subsequent lowering thereof. The particulars regarding the terms shown in the graph will be described later.

As mentioned above, the freight hanging from the hook 7 is hoisted, moved and subsequently lowered by the crane. Immediately after the freight in the

stationary state is hoisted, a generally large load acts upon the equalizer sheave 3. The load that acts upon the equalizer sheave 3 immediately after the freight is hoisted is larger than the freight itself.

5 A large load that acts upon the equalizer sheave 3 temporarily immediately after the freight is hoisted will be referred to below as the "shock load". The size of the shock load depends greatly upon the skill of the crane operator.

10 When the freight is hoisted, the wire rope 2 is in a state in which it has been paid out from the hoisting drum 1. As a consequence, a strong impact is applied to the wire rope 2 owing to shock load. If shock load is large, the extent of damage inflicted upon the wire  
15 rope 2 is greater in comparison with a case where shock load is small. Damage to wire rope 2 that is continuously subjected to large shock load progresses faster in comparison with wire rope 2 that is not.

Taking into consideration not only the number of  
20 times the wire rope 2 is used but also the effects of shock load, the rope life management apparatus 10 predicts replacement timing (calculates the life) of the wire rope 2 being used in the crane.

Fig. 3 is a perspective view illustrating the  
25 external appearance of the rope life management

apparatus 10 and Fig. 4 is a block diagram illustrating the electrical configuration of the rope life management apparatus 10.

The front side of the rope life management apparatus 10 is provided at its upper portion with a display unit 12 having a display panel capable of displaying text, and at its lower portion with an input unit 13 having an input panel that includes numeric keys. A setting screen (a screen used to input settings data) and an operation screen (a screen for displaying the operating status, etc., of the crane) are displayed on the display panel of the display unit 12.

Fig. 5 illustrates an example of the setting screen displayed on the display panel of the display unit 12, and Fig. 6 illustrates an example of the operation screen displayed on the display panel of the display unit 12. Switching between the setting screen and the operation screen, etc., is performed using the input panel of input unit 13.

With reference to Fig. 5, the names of multiple items to be input (set) are displayed on the setting screen displayed on the display panel of display unit 12. The input unit 13 is used to input a numerical value corresponding to a displayed item name or

characters for specifying the numerical value. With reference to Fig. 6, the operating status [actual load of hoisted freight, number of times wire rope has been used (cumulative number of times used) and number of  
5 times left for use (remaining number of times use is possible) (described later), etc.] is displayed on the operation screen displayed on the display panel of the display unit 12 during or after operation of the crane.

With reference again to Figs. 3 and 4, an  
10 input/output port 14 (not visible in Fig. 3) to which is input the voltage supplied from the load cell 8 described above is provided on the back side of the rope life management apparatus 10. The load cell 8 and the input/output port 14 of the rope life management  
15 apparatus 10 are electrically connected by a signal line (coaxial cable, etc.).

The rope life management apparatus 10 includes a CPU 11 for overall management of operation of the rope life management apparatus 10. The above-mentioned  
20 display unit 12, input unit 13 and input/output port 14 are connected to the CPU 11. Further connected to the CPU 11 are a RAM 15 for storing programs and data temporarily, and a ROM 16 for storing settings data and programs, etc.

25 Figs. 7 and 8 illustrate settings data that has

been input using the setting screen and stored in the ROM 16 of rope life management apparatus 10.

The settings data includes data relating to the crane and wire rope 2 and data relating to evaluation  
5 criteria (criteria for determining that loading/unloading has been performed, for example). The settings data illustrated in Fig. 7 is settings data relating to the crane and wire rope 2. The settings data illustrated in Fig. 8 is settings data  
10 relating to the evaluation criteria.

With reference to Fig. 7, the settings data relating to the crane and wire rope 2 includes the following data:

Rope diameter d: this is the diameter of wire  
15 rope 2 used in the crane.

Sheave diameter D1: this is the diameter of the sheaves (the above-mentioned equalizer sheave 3, fixed sheaves 4 and movable sheaves 5, 6) used in the crane.

Drum diameter D2: this is the diameter of the  
20 hoisting drum 1.

Cross-sectional area A: this is the effective cross-sectional area of wire rope 2.

Working load W: this is the maximum value (rated value) of the load essentially applied to the wire rope  
25 2 used in the crane. In the case of the crane

illustrated in Fig. 1, the wire rope 2 has eight falls  
(load is handled as being distributed among eight wire  
ropes 2) owing to the fact that it is wound upon the  
equalizer sheave 3, fixed sheaves 4 and movable sheaves  
5, 6. If we assume that the hoisting load (rated load)  
of the crane is 40 tons, then  $40/8 = 5$  tons is assumed  
to be the working load  $W$  regarding the wire rope 2.

Number  $X$  of rope falls: this is essentially the  
number of wire ropes 2 used in the crane, this being  
obtained based upon the number of sheaves possessed by  
the crane, as mentioned above.

Number  $n_1$  of times rope passes (bends) over  
sheaves: this is the number of times one point (a  
prescribed region) on the wire rope 2 passes over  
sheaves during hoisting and lowering (one cycle) of  
freight. In the case of the crane illustrated in Fig.  
1, three sheaves (the fixed sheave 4 and two movable  
sheaves 5, 6) are arranged on each side of the  
equalizer sheave 3. Therefore the wire rope 2 passes  
over sheaves three times when the freight is hoisted  
and three times when the freight is lowered (for a  
total of six times). Thus the number of times the rope  
passes (bends) over the sheaves of the crane shown in  
Fig. 1 is six.

Number  $n_2$  of times rope passes (bends) over drum:

this is the number of times one point (a prescribed region) on the wire rope 2 passes over the hoisting drum 1 during hoisting and lowering (one cycle) of freight. In the case of the crane illustrated in Fig. 1, there is one hoisting drum 1 and therefore the wire rope 2 passes over the drum one time in one cycle. Thus the number of times the rope passes (bends) over the drum of the crane shown in Fig. 1 is one.

Sheave coefficient a: this is a value (coefficient) decided in accordance with the groove shape (U-shaped groove, V-shaped groove, undercut-shaped groove, etc.) of the sheaves used in the crane. The sheave coefficient a is used in computing, through use of the Niemann formula described later, the remaining number of times use of the wire rope 2 is possible (the estimated life) and the number of times the wire rope 2 has been used (the life subtraction value). In general, sheaves having a U-shaped groove are frequently used for the sheaves employed in the crane.

Rope coefficient b: this is a value (coefficient) used in computing, through use of the Niemann formula, the remaining number of times use of the wire rope 2 is possible and the number of times the wire rope 2 has been used. The rope coefficient b is stipulated in

accordance with the structure of the wire rope 2 used (e.g., whether the rope structure is "ordinary lay" or "Lang's lay").

Structural correction coefficients  $k_1$ ,  $k_2$ ,  $k_3$ :

5 these are values (coefficients) used in order to correct the remaining number of times use of the wire rope 2 is possible and the number of times the wire rope 2 has been used, in accordance with the structure of the wire rope 2 in a manner similar to that of the  
10 rope coefficient  $b$  mentioned above. The structural correction coefficient  $k_1$  is a value (coefficient) that conforms to the number of strands that constitute the wire rope 2. The structural correction coefficient  $k_2$  is a value (coefficient) that conforms to the core  
15 material of the wire rope 2 (steel core or fiber core). The structural correction coefficient  $k_3$  is another value (coefficient) that conforms to the structure of the wire rope 2 {the cross-sectional shape of the strands constituting the wire rope 2 [whether the cross  
20 section is circular or non-circular (an oddly shaped line)], whether the surface of the wire rope 2 is coated or not, etc.}.

With reference to Fig. 8, the settings data relating to the evaluation criteria includes the  
25 following data:

Loading detection load: this is a load for determining that hoisting (loading) of freight has been performed by the crane. If a load equal to or greater than the loading detection load is detected, it is  
5 determined that the freight has been hoisted by the crane.

Unloading detection load: this is a load for determining that after the freight has been hoisted by the crane, the freight has been lowered (unloaded). If  
10 a load less than the unloading detection load is detected, it is determined that the freight has been lowered.

Load acquisition interval: a prescribed period of time that starts from the timing of acquisition of the  
15 above-mentioned loading detection load is the load acquisition interval, as shown in Fig. 2. If a load equal to or greater than the loading detection load is detected, a load less than the unloading detection load is detected and, moreover, a load equal to or greater  
20 than the loading detection load and equal to or greater than the unloading detection load is detected continuously for longer than the load acquisition interval, then it is determined that a single job by the crane, namely a series of operations (one cycle)  
25 consisting of hoisting, transporting and subsequently

lowering the freight, has been performed (i.e., that loading and unloading criteria have been satisfied).

Load reading type: load (actual load) of freight hoisted by the crane is calculated using the load in an average computation interval. With reference to Fig. 2, the average computation interval is a period that starts from a timing obtained upon elapse of a prescribed interval (average delay interval) from acquisition timing of the loading detection load and that ends at a timing at which the load acquisition interval ends. Either "instantaneous" or "average" can be selected as the load reading type. If "instantaneous" is selected, then the detected load at the timing at which the average computation interval ends (which is the same as that at which the load acquisition interval ends) is handled as the load (actual load) of the freight hoisted by the crane. If "average" is selected, then the average value of the detected load in the average computation interval is handled as the load (actual load) of the freight hoisted by the crane.

Average delay interval: as mentioned above, this is an interval that starts from acquisition timing of the loading detection load (see Fig.

2). The above-mentioned shock load (peak value) falls within the average delay interval.

Life-end preliminary warning condition: this sets whether a warning should be issued when the predicted  
5 remaining number of times use of the wire rope 2 is possible (the estimated remaining life) reaches a certain percentage of the remaining number of times use of a new wire rope 2 is possible (the initial life). For example, a life-end preliminary warning condition  
10 of 20% means that a warning will be issued when the remaining life of the wire rope 2 reaches 80% of the initial life. The warning may be issued aurally or visually as by a warning tone or a display presented on the display unit 12.

15 Excessive loads 1 - 3: a warning can be issued also when the detected actual load of freight has exceeded the hoisting load (rated load) of the crane. Excessive loads 1 - 3 are loads when this warning is issued. The warning relating to excessive load can be  
20 issued in multiple stages (levels). For example, in a case where the hoisting load of the crane is 40 tons, a warning is issued if the detected actual load of freight is equal to or greater than 45 tons. By changing the warning tone (or volume) or the display on  
25 the display unit 12 depending upon respective cases

where the detected actual load of freight is equal to  
or greater than 45 tons and less than 50 tons, equal to  
or greater than 50 tons and less than 55 tons, and  
equal to or greater than 55 tons, the operator, etc.,  
5 is notified of which level of excessive load has been  
applied (i.e., of the particular load level of the  
freight that has been lifted by the crane).

Correction coefficient: this is a value  
(coefficient), which is used in order to correct the  
10 number of times the wire rope 2 has been used, defined  
in accordance with the size of the above-mentioned  
shock load (i.e., the percentage by which the shock  
load exceeds the actual load of the freight). In this  
embodiment, processing using the correction coefficient  
15 to correct the number of times the rope has been used  
is executed in a case where a shock load equal to or  
greater than 110% of the actual load is sensed. The  
details of processing using the correction coefficient  
to correct the number of times wire rope has been used  
20 will be described later.

Before the wire rope 2 is placed in the crane and  
the crane operated, the remaining number of times use  
of the wire rope 2 is possible (the estimated life) in  
the initial state is calculated by the rope life  
25 management apparatus 10 using settings data (Fig. 7)

relating to the crane and wire rope 2 that has been stored in the ROM 16.

Described in this embodiment is calculation of the remaining number of times use of the wire rope is possible (the estimated life) using the Niemann (G. Niemann) formula from among the plurality of calculation formulae known heretofore. Details regarding the Niemann formula are described, by way of example, in the "Wire Rope Handbook", Wire Rope Handbook Editing Committee, Nikkan Kogyo Shimbunsha, published March 30, 1995, pp. 352 - 353) and in "All About Wire Rope (Last Volume) - The Road to Safety" Kaizuka Chamber of Commerce and Industry, Steel Manufacture Activation Research Society, Kaizuka Chamber of Commerce and Industry, published July 25, 1995, pp. 153 - 158).

The Niemann formula is as indicated in Equation (1). A number  $N_1$  of times the wire rope 2 passes over sheaves until it breaks (the number of times the wire rope is bent by the sheaves until the rope breaks) is calculated based upon the Niemann formula.

$$N_1 = 170000 \left( a \times b \times \frac{D/d - 9/a}{\sigma_t + 4} \right)^2 \quad \dots \text{Equation (1)}$$

Here  $\underline{a}$  represents the sheave coefficient,  $b$  the rope coefficient,  $D$  the sheave diameter,  $d$  the rope

diameter and  $\sigma_t$  tensile stress of the wire rope. The tensile stress  $\sigma_t$  is found from  $W/A$  (where  $W$  is the working load and  $A$  the rope cross-sectional area). The numerical values used in calculating the number  $N_1$  of  
5 times the wire rope passes over sheaves have all been stored previously in the ROM 16 (see Fig. 7).

Next, a number  $N_2$  of times the wire rope passes over sheaves until it sustains 10% breakage is calculated based upon Equation (2) below using a safety  
10 coefficient. It should be noted that "10% breakage" is a concept used taking safety into consideration. Breakage is considered to be 100% breakage when the wire rope breaks completely, and "10% breakage" is assumed to be a state of breakage that is 1/10 of  
15 complete breakage.

$$N_2 = N_1 \times K_1 \quad \dots \text{Equation (2)}$$

For example,  $K_1 = 0.6$  is used as the safety coefficient  $K_1$  ( $1 > K_1$ ). That is,  $N_2 < N_1$  holds.

Next, a fatigue differential that is based upon  
20 the rope constitution is taken into account and the number  $N_2$  of times the wire rope passes over sheaves until it sustains 10% breakage is corrected based upon Equation (3) below using a structural correction coefficient  $K_2$ .

$$25 \quad N_3 = N_2 \times K_2 \quad \dots \text{Equation (3)}$$

The structural correction coefficient  $K_2$  is a coefficient decided in accordance with the rope structure of the wire rope 2 used; it is predetermined in conformity with the rope structure. The structural correction coefficients  $k_1$ ,  $k_2$ ,  $k_3$  (see Fig. 7) that have been stored in ROM 16 beforehand are used as the structural correction coefficient  $K_2$ . Any of the structural correction coefficients  $k_1$ ,  $k_2$ ,  $k_3$  or combination thereof (e.g., a value obtained by multiplying them together) is adopted as the structural correction coefficient  $K_2$  in accordance with the structure of the wire rope 2 used.

The value  $N_3$  obtained based upon Equation (3) above is referred to as a "limit bend count".

A usable cycle count  $N_a$  (a numerical value representing how many times a cycle of hoisting, moving and subsequently lowering freight can be repeated) regarding the sheaves is calculated by dividing the limit bend count  $N_3$  using the number of times the wire rope 2 is bent (the number of times the rope passes over the sheaves per cycle) per crane cycle (hoisting, moving and subsequently lowering freight).

sheave usable cycle count  $N_a = N_3/n_1$  ... Equation (4)

Here  $n_1$  represents the number of times the wire rope 2 passes over the sheaves per cycle. Use is made

of a numerical value that has been input (set) previously based upon the crane structure (number of sheaves), as illustrated in Fig. 7.

In a manner similar to that described above, a drum usable cycle count  $N_b$  ( $= N_3/n_2$ ) regarding the hoisting drum 1 is also calculated. The only difference is that the drum diameter (this value also has been stored in ROM 16 beforehand) (Fig. 7) is used instead of the sheave diameter as  $D$  in the Niemann formula of Equation (1). It should be noted that  $n_2$  is the number of times the wire rope 2 passes over the drum per cycle (Fig. 7).

The remaining number of times use of the wire rope 2 is possible is calculated upon assuming that bending of the wire rope at each of the sheaves and drum is compounded and that fatigue accumulates. A final remaining number  $N_x$  of times use of the wire rope 2 is possible is calculated according to the following equations using the above-mentioned sheave usable cycle count  $N_a$  and drum usable cycle count  $N_b$ :

$$1/N_x = (1/N_a) + (1/N_b)$$

$$N_x = 1/[(1/N_a) + (1/N_b)] \quad \dots \text{Equation (5)}$$

The calculated remaining number  $N_x$  of times use of the wire rope 2 is possible in the initial state

(namely the initial life) is stored in the RAM 15 or ROM 16.

As will be described next, the obtained remaining number  $N_x$  of times use of the wire rope 2 is possible in the initial state is decremented in accordance with the crane operating conditions (upon taking into consideration the presence or absence of shock load and the size thereof, as mentioned above) and a new number of times use of the wire rope 2 is possible (remaining life, estimated life) is calculated.

Fig. 9 is a flowchart illustrating the flow of operation of the rope life management apparatus 10. This will be described while referring to the graph of load data illustrated in Fig. 2.

When the crane is operated, a voltage conforming to the load of the freight is output from the load cell 8 and supplied to the rope life management apparatus 10. The load data (voltage value) (see Fig. 2) provided by the load cell 8 is stored in RAM 15 of the rope life management apparatus 10 (step 31).

First, whether loading/unloading criteria are satisfied is determined (step 32). This is for the purpose of performing life management of the wire rope 2 on the condition that the crane has substantially

done work (one cycle of operation consisting of hoisting, moving and lowering freight).

Criteria data (settings data) shown in Fig. 8 is used in determining whether loading/unloading criteria are satisfied. With reference to Fig. 2, if a load equal to or greater than the loading detection load is detected, a load less than the unloading detection load is detected and, moreover, a load equal to or greater than the loading detection load and equal to or greater than the unloading detection load is detected continuously for longer than the load acquisition interval, then it is determined that a single job by the crane, namely a series of operations (one cycle) has been performed ("YES" at step 32).

For example, although the load cell 8 will output a voltage even in a case where the hook 7 swings owing to the effects of wind, the loading/unloading criteria are not satisfied in such case. If the load data from the load cell 8 does not satisfy the loading/unloading criteria, the rope life management apparatus 10 does not execute any particular processing ("NO" at step 32).

If load data that satisfies the loading/unloading criteria is provided by the load cell 8, it is determined whether the maximum value (peak value) (shock load) contained in the load data exceeds 110% of

the actual load (step 33). The actual load is the detected load prevailing when the average computation interval ends in the case where "instantaneous" has been selected at the load reading type, as mentioned  
5 above. If "average" has been selected, then the actual load is the average value of detected load over the average computation interval.

If shock load is equal to or less than 110% of the actual load, then it is construed that shock load has  
10 no effect upon the wire rope 2 (i.e., that there is no shock load) ("NO" at step 33).

In this case, control proceeds to general processing for subtracting the number of times the rope is used (processing for calculating the remaining  
15 number of times use is possible) (step 35).

The following computation is performed in processing for subtracting the number of times the rope is used (step 35):

Initially, the remaining number  $N_1$  of times use of  
20 the wire rope 2 is possible is calculated in accordance with Equations (1) to (5) using the actual load obtained based upon the load data from the load cell 8. The above-mentioned remaining number  $N_x$  of times use of the wire rope 2 is possible in the initial state is  
25 calculated using the working load  $W$  (e.g., if the

hoisting load of the crane is 40 tons and the crane has the structure shown in Fig. 1, then working load  $W = 5$  tons) (see Fig. 7) that is based upon the hoisting load (rated load) capable of being lifted by the crane

5 assuming the tensile stress  $\sigma_t (= W/A)$  used in the Niemann formula. On the other hand, there are cases where the load of freight actually hoisted is lighter (or heavier) than the hoisting load. For example, if 40-ton freight is handled by a 40-ton crane, then this

10 is assumed to be a single use of the wire rope 2. However, if freight (e.g., of 30 tons) lighter than 40 tons is handled, then this is assumed to be less than a single use of the wire rope 2.

A number (life subtraction value)  $H_1$  of uses of

15 the wire rope 2 is calculated according to Equation (6) below.

$$H_1 = N_x / N_1 \quad \dots \text{Equation (6)}$$

A new remaining number (remaining life, estimated life)  $H_{\text{remain}}$  of times use of the wire rope 2 is possible

20 is calculated according to Equation (7) below.

$$H_{\text{remain}} = N_x - H_1 \quad \dots \text{Equation (7)}$$

The calculated remaining number  $H_{\text{remain}}$  of times use of the wire rope 2 is possible is displayed on the display panel of the display unit 12 of rope life

25 management apparatus 10 together with the load (actual

load) hoisted and the number of uses thus far (an accumulated value of number of times the rope is used calculated whenever the crane performs substantial work), etc. (step 36; see Fig. 6).

- 5        If shock load exceeds 110% of the actual load, on the other hand, the wire rope 2 is handled as being subjected to damage by shock load ("YES" at step 33).

         In this case, use is made of a value obtained by multiplying the above-mentioned number (life subtraction value)  $H_1$  of uses of the wire rope 2 by a correction coefficient (a coefficient that exceeds unity) conforming to the size of shock load.

10

         The correction coefficient conforming to the size of shock load has been set beforehand and stored in the ROM 16, as illustrated in Fig. 8. For example, when the shock load is 115% of the actual load, the result of multiplying the number  $H_1$  of uses of the rope by a coefficient 1.240 is handled as the number  $H_1$  of uses of the rope. The correction coefficient conforming to the size of shock load is found using the Niemann formula taking into consideration amount of load applied instantaneously and amount of load after removal of shock load.

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         The larger the shock load, the larger the value used as the correction coefficient (see Fig. 8).

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Therefore, the larger the shock load, the larger the value taken on by the number (life subtraction value)  $H_1$  of uses of the rope.

Calculation of the new remaining number  $H_{\text{remain}}$  of times use of the wire rope 2 is possible by subtracting the obtained number  $H_1$  of uses of the rope from the remaining number  $N_x$  of times use of the wire rope 2 is possible in the initial state is similar to that described above [Equation (7)] (step 34). The remaining number  $H_{\text{remain}}$  of times use of the wire rope 2 is possible that takes shock load into consideration is displayed on the display panel (step 36).

It goes without saying that in processing for calculating the remaining number  $H_{\text{remain}}$  of times use of the wire rope 2 is possible from the second time onward, the calculated number  $H_1$  of uses of the rope is subtracted from the previously calculated remaining number  $H_{\text{remain}}$  of times use of the wire rope 2 is possible.

When the remaining number  $H_{\text{remain}}$  of times use of the wire rope 2 is possible is calculated, it is determined whether this has reached a set number of uses before life ends (step 37). The set number of uses before life ends is calculated based upon the life-end preliminary warning condition set beforehand

(see Fig. 8). (Naturally, the value may be calculated in advance and then stored in the ROM 16). For example, if the life-end preliminary warning condition is 20%, then a value that is 80% of the remaining number of times use of the wire rope 2 is possible in the initial state (namely a value obtained by multiplication by 0.8) becomes the set number of uses before life ends. If the calculated remaining number  $H_{\text{remain}}$  of times use of the wire rope 2 is possible falls below the previously set number of uses before life ends, then a warning is issued as by a warning tone or a display presented on the display panel ("YES" at step 37; step 38).

CLAIMS:

1. A wire rope life management apparatus comprising:
  - life calculating means for calculating estimated life of a wire rope in accordance with a prescribed
  - 5 life estimation formula, said wire rope being used in a crane that hoists, transports and then lowers freight via said wire rope and a sheave, with which said wire rope is engaged, by paying out said wire rope from a drum and rewinding said wire rope onto said drum;
  - 10 load data input means for accepting input of load data of said freight from hoisting of said freight until subsequent lowering thereof, the load data being output from a load cell provided on said sheave;
  - actual load calculating means for calculating
  - 15 actual load of said freight based upon the load data that has been input from said load data input means;
  - shock load sensing means for sensing whether a shock load that exceeds said actual load by a prescribed amount is present based upon the load data
  - 20 that has been input from said load data input means;
  - and
  - life updating means for calculating a new estimated life of the wire rope, if presence of the shock load has been sensed by said shock load sensing
  - 25 means, by subtracting, from said estimated life, a

value obtained by multiplying a life subtraction value that prevails when presence of the shock load is not sensed by a correction coefficient having a value greater than unity.

5     2. A wire rope life management apparatus according to claim 1, further comprising shock-load excess amount calculating means for calculating, with regard to said shock load, an excess amount that exceeds said actual load;

10             said life updating means using a certain value as said correction coefficient, wherein the larger the excess amount calculated by said shock-load excess amount calculating means, the larger the value used.

3. A wire rope life management apparatus according to  
15     claim 1 or 2, further comprising a display unit for displaying the new estimated life of the wire rope that has been calculated by said life updating means.

4. A wire rope life management apparatus according to any one of claims 1 to 3, wherein the Niemann formula  
20     is used as said prescribed life estimation formula.

5. A wire rope life management method comprising the steps of:

           calculating estimated life of a wire rope in accordance with a prescribed life estimation formula,  
25     said wire rope being used in a crane that hoists,

transports and then lowers freight via said wire rope and a sheave, with which said wire rope is engaged, by paying out said wire rope from a drum and rewinding said wire rope onto said drum;

5        accepting input of load data of said freight from hoisting of said freight until subsequent lowering thereof, the load data being output from a load cell provided on said sheave;

          calculating actual load of said freight based upon  
10    the load data that has been input;

          sensing whether a shock load that exceeds said actual load by a prescribed amount is present based upon the load data that has been input; and

          if presence of the shock load has been sensed,  
15    calculating a new estimated life of the wire rope, by subtracting, from said estimated life, a value obtained by multiplying a life subtraction value that prevails when presence of the shock load is not sensed by a correction coefficient having a value greater than  
20    unity.