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Yokoyama, Y.

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Development of Life Prolongation Technology for Crane Wire Rope*

Yasuo Yokoyama
Staff Assistant Manager, Equipment Technology Sec., Equipment Technology Dept., Mizushima Works

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1 Introduction

Wire rope is one of the most important parts of cranes and the cost for replacement of these wires has been very expensive.

Judgment of a wire rope's life in Kawasaki Steel in the past was according to the ordinary method of confirming the presence of wire breakage through visual inspection of the external view. Other methods such as using wire breakage detectors or to make judge from the results of tensile tests applied to wire ropes after usage were adopted, but only in special cases. According to the conventional methods of judgment, worn ropes need to be replaced while still possessing a long residual life. Furthermore, it was difficult by these conventional methods to find breakage of wires in wire ropes used in environments with a lot of powder and dust and the possibilities of wire rope breakage remained. As a countermeasure, an original method for the quantitative judgment of a wire rope's life was developed and applied to cranes used by Kawasaki Steel. Consequently, it has become possible to prolong the life of wire ropes by about 1.6 times. Furthermore, by using this method, causes for the life of wire ropes used for high lift cranes, such as ladle cranes, were elucidated and a long life wire rope was developed. This report describes the details of this development.

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2 Conventional Methods of Life Judgment and Problems

The common operating condition of the use of wire ropes in Kawasaki Steel is shown in **Fig. 1**. The life of wire ropes had been determined by the fatigue life due to repeated bending applied to wire ropes when the ropes pass through sheaves. Wire ropes in use are of the type 6 × Fi (29) of JIS 13 or 18. In the past, wire ropes were replaced periodically according to the period determined from an experience of wire breakage or when wire breakage had been found during an inspection. Wire ropes replaced had several wires broken, however, damage such as wear on other wires were found to be still slight and the wire ropes were in such conditions that the limit for use was hardly considered to have been reached. Furthermore, the results of measuring the strength of those used wire ropes indicated only a slight

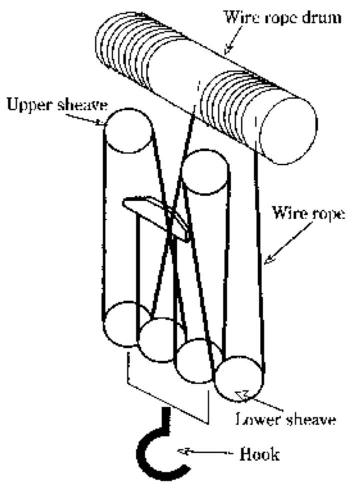

Fig. 1 Operation condition of crane wire rope

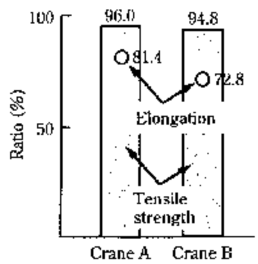

Fig. 2 Strength of used wire

decrease in strength as shown in **Fig. 2**. As for wire ropes that were periodically replaced, no regular investigation had been made on residual strength, etc. therefore, there was no way to judge the adequacy of the values shown in Fig. 2. For these reasons, it was considered necessary to develop a method which would enable a more quantitative evaluation of the life of wire ropes, thus making judgment on adequate replacement time possible. Development of such a method should result in the fullest use of the life of wire ropes and accordingly, in the reduction of maintenance costs.

3 Wire Rope Life Estimation Formula

With respect to bending fatigue like in wire ropes, various estimation formulas have been proposed.[1,2] Comparisons were made between the results calculated using these formulas and actual cases occured in the past in which wire ropes faced immediate breakage. The results are shown in **Fig. 3**. Even using the same formula, there were cases that the results of calculation were in good agreement with actual experience in some cases and cases that greatly deviated from actual experience in other cases. It was found that the formula proposed by G. Niemann expressed by Eq. (1) is the one which is on the safe side and gives results with comparatively less scattering.[3]

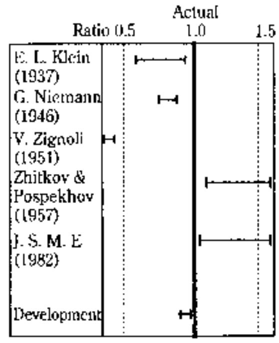

Fig. 3 Comparison between actual rope breakage and calculation

Table 1 Coefficient of configuration, b

	Ladle crane	Other crane
Round wire 6 × Fi (29)	0.9	1.1
Profile wire 6 × Fi (29)	1.0	1.4

$$N = 170\,000 \times \left(a \times b \times \frac{\frac{D}{d} - \frac{9}{a}}{\sigma + 4} \right)^2 \cdots\cdots (1)$$

N: Number of bending at rope breakage
a: Coefficient of sheave shape
b: Coefficient of configuration
D: Sheave diameter
d: Rope diameter
σ: Stress of rope

In the case of the Niemann's formula, however, the configuration of wire ropes is of 6 × 37 and is different from the filler wires presently in use. Various values for the coefficient b, which depends on the wire rope's configuration, have been proposed by those concerned including wire rope manufacturers. However, in order to further improve the estimation accuracy, the value of coefficient b, which makes highly accurate estimation of life possible, was pursued on the basis of the results of sample analyses on wire ropes which were used in actual cranes. The results are shown in **Table 1**. In addition, a comparison between the results of calculations using this coefficient and the actually experienced life of wire ropes is included in Fig. 3. However, because the values shown in Table 1 are those for facilities, service conditions and environment at Kawasaki Steel detailed studies are necessary to investigate whether or not the results shown in this table are also applicable to those for cranes used by other companies.

4 Residual Strength of Wire Ropes

Studies were made on the residual strength of wire ropes which were replaced due to the occurrence of wire breakage. Various analyses were made on whether or not any correlation with the life obtained in Chapter 3 exists. Two samples were taken from one wire rope. The first one was from the extra-wound part on the drum and in brand-new condition and the other was from the part most frequently passed through sheaves. The results of analysis were expressed in terms of the residual strength ratio (%) obtained by dividing the data on the deteriorated part by the data on the brand-new part. As the indices for strength, wire rope diameter, wire diameter, wire tensile strength and torsional strength of wires were selected. Furthermore, in order to make it possible to equally compare the period of use of each wire rope, the residual life ratio (%) was used. This ratio is obtained by dividing the actual number of bendings or the actual number of days in service by the calculated number of days to breakage.

The relationships between each strength index and the residual life are shown in **Figs. 4~7**. Except for the results of torsional tests, correlations are not clear and highly accurate judgment is impossible. On the other hand, it was made clear that a definite correlation exists between the residual life and the results of torsional tests for wires.

Therefore, it was made possible to promptly calculate the residual life from the results of torsional tests applied to used wire rope wires without using the Niemann's formula when newly judging the residual life by using the regression formula between the results of torsional tests and the life.[4] As a result, although wire ropes had been replaced with a residual life of about 50% according to conventional methods for judgment, it has become possible to prolong the usage period before replacement to an extreme limit by making the residual life 20%, allowing for some scattering. At the same time, it has also become possible to prevent accidents of wire rope breakage using this method for highly accurate and quantitative deterioration judgment. (**Fig. 8**)

5 Life Prolongation for Ladle Wire Ropes

Ladle cranes used for steel production are used under the severe conditions of heavy load and high lift; therefore, extra high quality is required also for wire ropes used for these cranes. Furthermore, these wire ropes are of a large diameter and are long; therefore, the cost of replacement has been very high. For this reason, life prolongation for ladle crane wire ropes had been a long-standing subject, however, it was difficult to realize because ladle cranes carry high temperature molten metal and are important production rigs. Development was successfully completed this time so that the difficulties with the ropes for ladle cranes could be resolved and the usable life greatly improved. The details of this development are described hereunder.

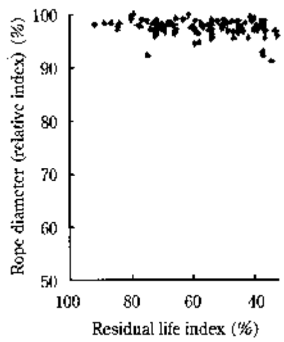

Fig. 4 Relationship between rope diameter and residual life

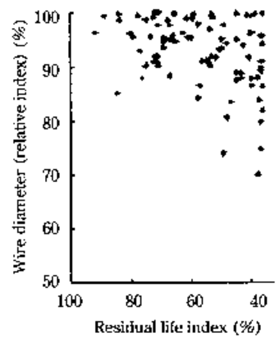

Fig. 5 Relationship between wire diameter and residual life

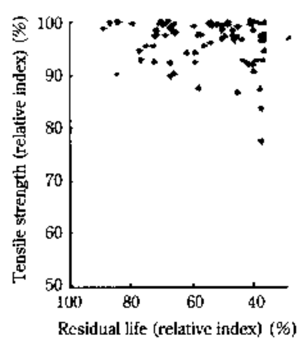

Fig. 6 Relationship between tensile strength and residual life

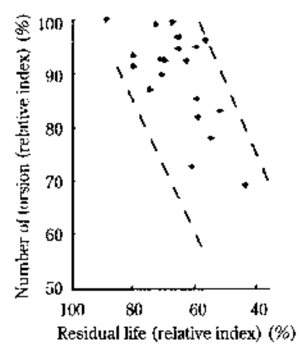

Fig. 7 Relationship between number of torsion and residual life

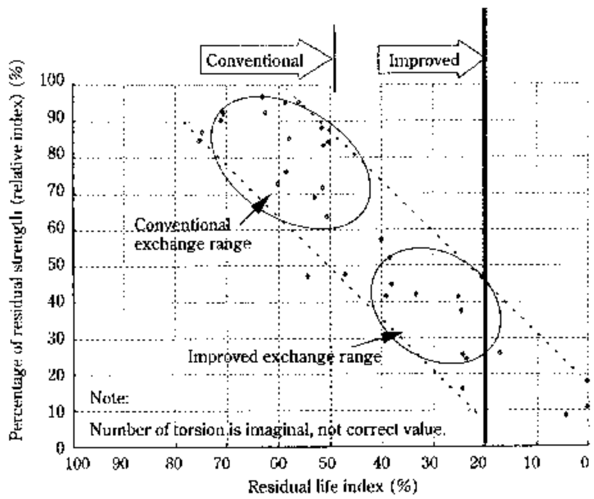

Fig. 8 Test result of wire rope strength

5.1 Expansion of the Actual Application of Profile Wire Ropes

Profile wire ropes have been produced for many years as high strength wire ropes, however, they have been regarded as unsuitable for such equipment as overhead cranes and ladle cranes with which bending is applied frequently to the ropes due to the presence of sheaves. When profile wire ropes were used for actual cranes in order to investigate the properties of these ropes, various problems due to the configuration such as deformation of the profile within a short period of time were frequently experienced. However, through applying improved manufacturing techniques, while repeatedly carrying out various tests, it has become possible to stably extend the life by more than 1.6 times that of conventional profile wire ropes. At present, the application of profile wire ropes has been expanded to about 30% of the cranes in Kawasaki Steel and has thus been making a large contribution (**Fig. 9**).

5.2 Development of Non-rotating Profile Wire Ropes

Comparison of wire rope samples after use were made for ordinary overhead cranes and ladle cranes. The results of comparison are shown in **Table 2**. The data were taken from 9 ladle cranes and 43 universal cranes and the average values are shown in the table. It was found that the lowering ratio in torsional strength is larger with ladle cranes, whereas the ratios of lives are

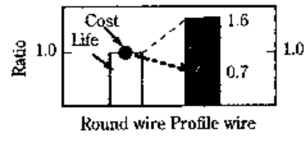

Fig. 9 Comparison between round wire and profile wire

about 50% for both types of cranes.

As is clear from the table, the major difference for both cranes is the lift. Therefore, by using wire ropes of the same type and the same diameter, the states of wire rope rotation were compared and observed using two cranes having different lifts. The results are shown in **Fig. 10**. Ladle cranes are of a high lift and the pay-out length is high, therefore, wire ropes rotate and turn by 180°. This means that the condition of bending at sheaves changes from a U-shape to an S-shape. It was presumed that because of this phenomenon, deterioration progressed faster than estimated from the intrinsic life of wire ropes.

The life prolongation effect due to the degree of rotation is shown in **Table 3**. The table compares the life of wire ropes used for the two crane types under the same load conditions using conventional wire ropes of two types. The only point different for these two cranes is that crane A is of a high lift and crane B is of a low lift. Crane B is of a low lift, therefore, the rotating angle of the wire rope is small and almost none. It is clear from this table that the life of wire ropes can be prolonged by decreasing rotation and it was also found that the life prolongation effect is larger with profile wire ropes than with round wire ropes. In order to prevent rotation, non-rotating type wire ropes are preferable. It was decided to develop original wire ropes that have superior fatigne propeties and can be manufactured without cost increase.

5.2.2 Points of development

The targets of development are a non-rotating character, bending fatigue resistance properties and inner stress lightening, and the following measures were taken

Table 2 Comparison between ladle crane and other crane

	Ladle crane	Other crane
Ratio of life $\frac{\text{Actual life}}{\text{Calculated life}} \times 100$ (%)	53.4	49.5
Ratio of torsion $\frac{\text{Used rope}}{\text{New rope}} \times 100$ (%)	48.5	63.5
Lift (m)	22.7	9.2
Stress (kN/mm²)	147.0	159.7
D/d	26.9	25.4

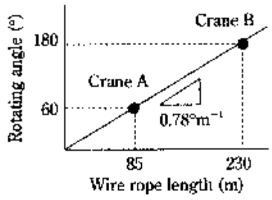

Fig. 10 Rotating angle of ladle crane

Table 3 Influence of wire rope life caused by rotation

	Round wire		Profile wire	
	Crane A 180° rotation	Crane B A few rotation	Crane A 180° rotation	Crane B A few rotation
×1 000 times*1	93.1	142.1	128.8	252.7
Ratio	1.0	1.53	1.0	1.96

*1 Number of bending at 10% wire breakage

Table 4 Test result of developed rope

	Conventional rope	Developed rope
Configuration	IWRC 6 × Fi (29) 0/0 grade B	8 × P·Fi (29) + 7 × S (19) 0/0 grade B
Rope diameter (mm)	35.5	35.5
Breaking load (kN)	1 000~1 065	1 019
Elongation (%)	2.0~5.0	6.3
Rotating coefficient	0.09	0.04
Endurance test*2	114.0 × 1 000 times	137.0 × 1 000 times

*2 Number of bending at 10% wire breakage.
The load is 17% of the breaking load and D/d is 20.

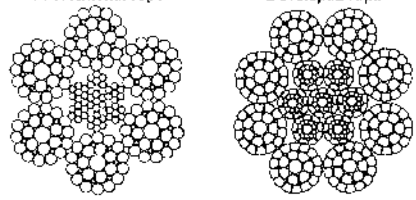

Fig. 11 Cross section

in order to achieve these targets.[5]

(1) Non-Rotating Character

The twisting directions of side strands and the core were reversed and the pitches of wire ropes, strands and the core were optimized.

(2) Bending Fatigue Resistance Properties

Flexibility of wire rope was improved by using a seal type S (19) core.

(3) Lightening of Wire Stress

By using an 8-strand wire rope configuration and adopting profile wires for both side strands and the core, the contact stress with sheaves as well as the contact stress between the wires themselves was lightened.

5.2.3 Performance of the developed wire ropes

The test results of the developed wire rope are shown in **Table 4** and a comparison of the cross sections of conventional rope and the developed rope is shown in **Fig. 11**.

The test results of the non-rotating character of the developed wire rope are shown in **Fig. 12** and it can be seen that the non-rotating character is improved to a large extend and is nearly equal to that of 18 × 7 wire rope which is a non-rotating wire rope.[6,7]

As a result of making the shape of wire profiled in order to reduce stresses at the part of the wires in contact with each other and with sheaves, a drastic reduction was achieved in the bending stress of the wire rope as well as in the maximum contact pressure on wires, although this is based on calculations. The results of calculations are shown in **Table 5**. In IWRC6 × Fi (29), the contact pressure became high and is calculated as 4 391 KN/mm^2, while in fact, plastic deformation occurred and the actual pressure does not exceed 1 764 KN/mm^2. The ratios against this value of contact pressure are shown in parentheses.

Furthermore, the stress generated when a wire rope is bent by sheaves varies due to the section performance of wire ropes. A comparison in section performance is shown in **Table 6**. In the table, wire ropes were relatively evaluated in restricted conditions according to the moment of inertia of the area, instead of determining of the real values was avoided because wire ropes are constructed with both the wires and the strands being twisted in a spiral shape and complicated phenomena such as slipping and changes in shape occur together when the wire ropes are bent.

5.2.4 Effect of life prolongation

The developed wire ropes were then used with actual ladle cranes, and it was confirmed that the life was pro-

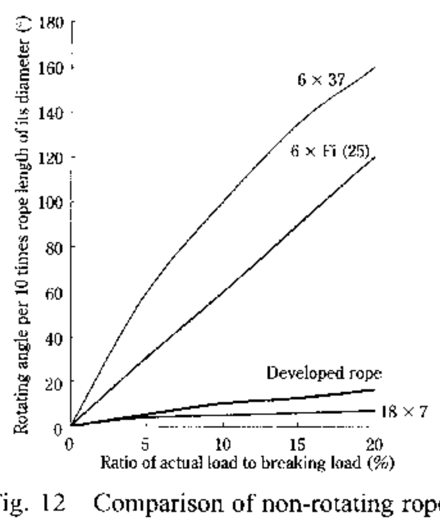

Fig. 12 Comparison of non-rotating rope

Table 5 Contact pressure[6,7]

	IWRC 6 × Fi (29)	IWRC 6 × P · Fi (29)	IWRC 8 × P · Fi (29) (Developed rope)
Contact pressure (kN/mm²)	4 391 (1 764)	1 741	1 672
Ratio	1.0	0.40 (0.99)	0.38 (0.95)

Table 6 Moment of inertia of area

	IWRC 6 × Fi (29)	IWRC 6 × P · Fi (29)	IWRC 8 × P · Fi (29) (Developed rope)
Moment of inertia of area (cm⁴)	4.46	5.23	5.99
Ratio	1.0	1.17	1.34

longed to 2.35 times that of conventional wire ropes (**Fig. 13**). It is considered that this improvement is because the reverse bending phenomenon which occurred when passing through sheaves was eliminated due to the non-rotating character and because stress lightening at the part of the wire rope in contact with the sheaves and on the inside of the wire rope where the wires contact each other could be achieved as planned by adopting an 8-strand construction and by improving the shapes of the wire ropes as well as of the wires.

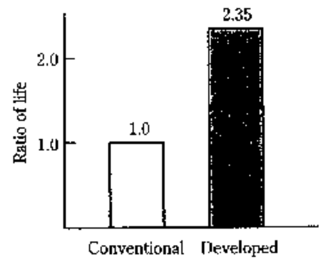

Fig. 13 Effect of life prolongation

6 Conclusion

The most important matter in crane facilities management in steel mills is how to maintain the facilities at the lowest possible cost together with eliminating all possibility of accidents or damage. From such a point of view, studies were made on the judgment of the life of wire ropes and on the life prolongation of these ropes. The following results were obtained.

(1) Based on the data obtained with actual equipment, the Niemann's formula was modified and a highly accurate life estimation formula was proposed.

(2) For judgment of the residual life of wire ropes, a torsional test was found suitable and a formula for judgment was proposed accordingly.

(3) It was clarified that the life of wire ropes for ladle cranes is shortened by rotation of the wire ropes and a better than doubling of life prolongation was achieved by developing non-rotating wire ropes.

The author expresses his sincere gratitude to those concerned including Kiswire Co., Ltd. who offered a great deal of support in developing the long-life wire rope.

References

1) JSME: "Crane-you Rope oyobi Rope-sha nadono Jumyou-chousa-kenkyuu-bunkakai Seika-houkokusho," (1983)
2) Wire Rope Handbook Henshuu-iinkai: "Wire Rope Handbook," (1995), [Nikkan Kougyou Shinbunsha]
3) Y. Aiba: "Wire Rope," (1995)
4) Kawasaki Steel Corp.: Jpn. Kokai 09-178611
5) Kawasaki Steel Corp.: Jpn. Appication 241663
6) T. Aida, S. Satoh, M. Nakai, and A. Kawabata: "Fukuyori-kousaku no jidou-seinou ni tuite," The First and the Second Report, JSME Proceedings, 173
7) T. Aida, S. Satoh, M. Nakai, et al: "Fukuyori-Kousaku no Jidou-seinou ni tsuite," The First and the Second Report, JSME Preprint, 144, 152