

Defect analysis and safety assessment of mine hoist wire rope based on hierarchical analysis

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Abstract. The hoisting wire rope is an important load-bearing component in the mine hoisting system, and its safety condition is directly related to the normal production of the mine and the life safety of the personnel. Therefore, it is necessary to carry out the research of online inspection technology and safety evaluation method of hoisting wire rope. In this paper, first of all, using denoising and sample interpolation has given the data of six wire ropes ten times round trip for data processing, using the quadrature method for defect analysis; secondly, the wire rope defect density, the number of defects, the spacing of adjacent serious defects and defect size and other 5 factors using hierarchical analysis method processing, its safety performance for the overall assessment.

Keywords: Wire Rope, Defects, Noise Reduction, Hierarchical Analysis Method.

1. Introduction

Mine hoist is similar to elevator, mainly used to realize the transportation of people and things in the mine[1]. The hoisting wire rope is an important bearing component in the mine hoisting system, and its safety condition is directly related to the normal production of the mine and the life safety of the personnel. For this reason, China's "Coal Mine Safety Regulations" stipulates the safety coefficient of hoisting wire rope: at the same time, there are also clear provisions for daily regular maintenance inspection and chopping head test [2]. Nevertheless, in the process of mine production, trapped wire rope breakage and major accidents still occur from time to time. At present, most mines in China to lift the wire rope to take regular replacement method, that is, the wire rope running for a period of time (each mine regulations are not the same), no matter how its condition, all replace down to scrap[3]. Obviously, this approach can neither ensure the safe operation of the wire rope in the use period, nor make the wire rope to achieve the best use of the wire rope, resulting in a huge waste. Therefore, this paper uses the denoising and sample interpolation has given the data of six wire ropes ten times back and forth for data processing, using the quartile method for defect analysis[4]; the wire rope's defect density, the number of defects, the spacing of adjacent serious defects and defects size and other 5 factors using the hierarchical analysis method to deal with the overall assessment of its safety performance[5].

2. Defect degree analysis and the establishment and solution of comprehensive evaluation model based on hierarchical analysis

2.1 Defect degree analysis

2.1.1 Denoising process

The 'frame-count-voltage' waveform plot is denoised for the given data of the first upstream wire rope 1, and the results are shown in Figure 1.

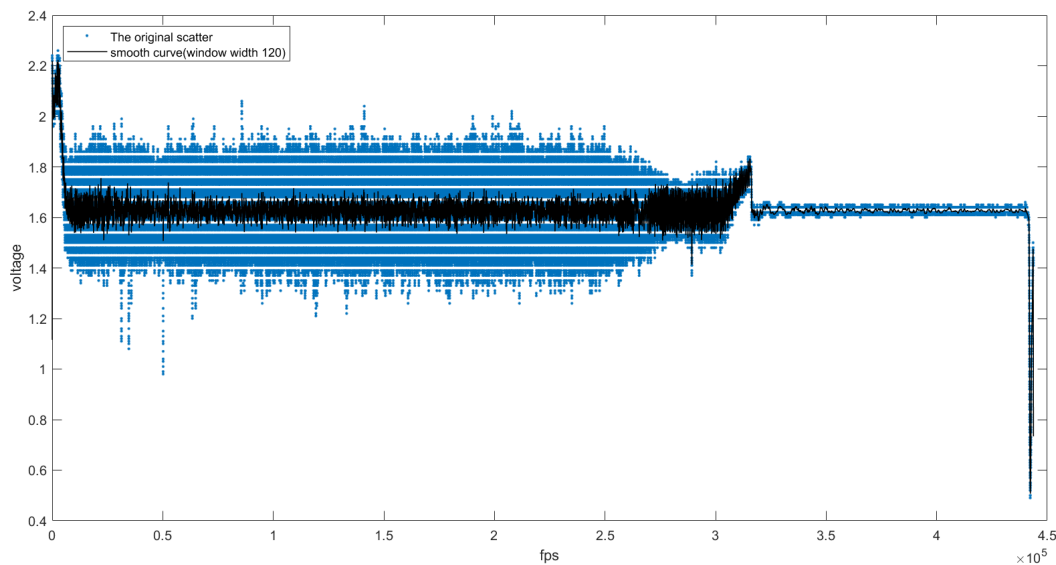


Figure 1 Wire Rope 1 'Frame-Voltage' curve after denoising

2.1.2 Quadrature method for outliers

In statistics, all values are arranged from smallest to largest and divided into quartiles, and the value at the three division points is the quartile. Among them, the number in the 25th position after the sorting of the series is called the lower quartile, recorded as Q_1 ; the number in the 50th position is the median, recorded as Q_2 ; the number in the 75th position is called the upper quartile, recorded as Q_3 .

The distribution characteristics of the quartiles can reflect the distribution characteristics of the data, so the use of quartiles on the degree of offset processing can not only more accurately represent the change in the degree of offset of the wire rope in a certain statistical time period, but also better deal with the impact of extreme values on the overall data[6].

$$R_1 = Q_3 - Q_1 \quad (1)$$

$$Q_{up} = Q_1 + 1.5R_1 \quad (2)$$

$$Q_{down} = Q_1 - 1.5R_1 \quad (3)$$

The difference between the upper and lower quartiles of $Q_3=M_{0.75}$ and $Q_1=M_{0.25}$ becomes the quartile extreme difference (or half-quartile difference), denoted as R_1 and R_2 . The lower and upper cutoff points are used as the data. The data greater than the upper cutoff point is then considered as an extra value, and the data less than the upper and lower cutoff points is considered as an extra small value. Both are considered as outliers and rejected. The final optimization results after eliminating the outliers are shown in Figure 2 below.

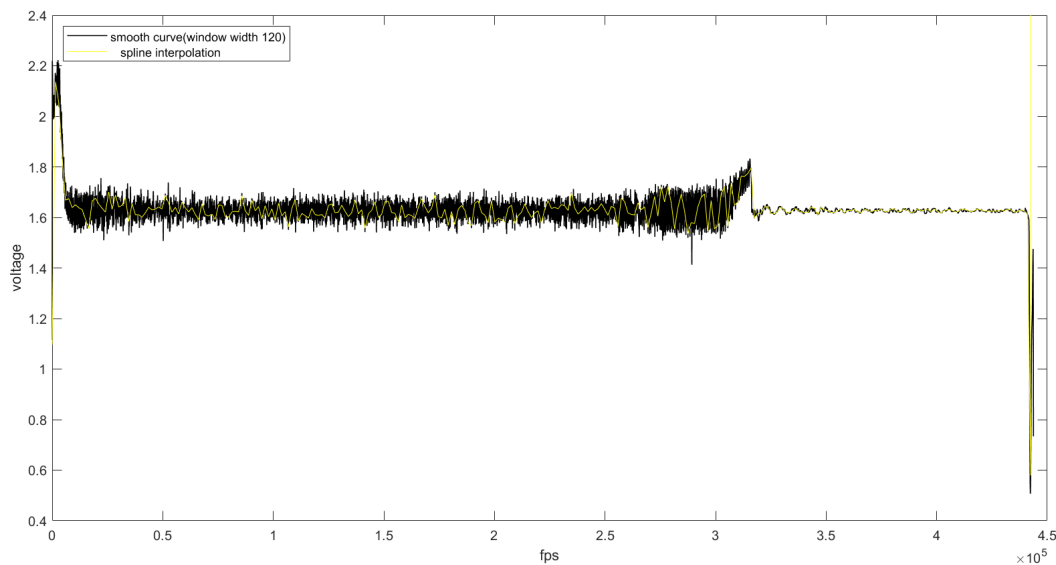


Figure 2 Wire rope 1 'Frame-voltage' waveform after excluding outliers

2.1.2 Defective data processing

Screen out each defect specific corresponding defect degree and number, part of the results are shown in Table 1 below.

Table 1 The degree of defects and the corresponding number of wire rope 1

Defect level	Tiny	Shape change	Mildly	Heavy	Internal broken
number	45129	36135	151772	70642	14967

2.2 Establishment and solution of comprehensive evaluation model based on hierarchical analysis

2.2.1 Hierarchical analysis model concept and framework Construct all judgment matrices in each level

Analytic Hierarchy Process (AHP) is a qualitative and quantitative system analysis method, which decomposes the problem into a number of factors according to the total objective of the problem, and then uses the method of two-by-two comparison to determine the importance of decision options, so as to obtain a satisfactory decision. We can evaluate the factors affecting the safety of wire rope through the hierarchical analysis and get the influence degree percentage of each factor. The structure is shown in Figure 3.

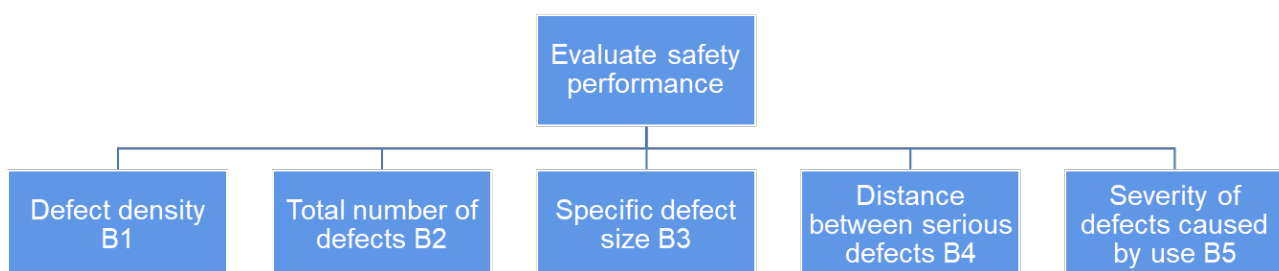


Figure 3 Hierarchical analysis model architecture diagram

2.2.2 Construct all judgment matrices in each level

Judgment matrix is a matrix formed by comparing the elements of the same level in the hierarchical model relative to a factor of the upper level by making pairwise comparisons among each other. In determining the weights among the factors in each level, it is often not easy to be accepted by others if the results are only qualitative, thus the consistent matrix method proposed by Santy et al. is used, i.e., instead of comparing all factors together, they are compared with each other two by two, at which time the relative scale is used to minimize the difficulty of comparing the factors of different nature with each other to improve the accuracy. The judgment matrix is a comparison of the relative importance of all factors in this layer against a factor in the previous layer. The elements of the judgment matrix are scaled by Santy's 1~9 method as shown in Table 2 below.

Table 2 The Analytic Hierarchy Process 1-9 Comparison Scale

Scale	Meaning
1	The two elements are equal
2	One element is equally to moderately favored
3	One element is moderately favored
4	One element is moderately to strongly favored
5	One element is strongly favored
6	One element is strongly to very strongly favored
7	One element is very strongly favored
8	One element is very strongly to absolutely favored
9	One element is absolutely favored

According to the literature on the influence of wire rope safety performance of the evaluation analysis of the weight percentage judgment, 1-9 ratio scale method (see table above) to determine the relative importance of each benchmark, to establish a judgment matrix. The judgment matrix of each criterion layer B to the target layer A indicators is shown in Table 3 below.

Table 3 Judgment Matrix

Element	B1	B2	B3	B4	B5
B1	1	1/2	1/4	1/9	1/3
B2	2	1	1/3	1/6	1/4
B3	4	3	1	1/2	4
B4	9	6	2	1	2
B5	3	4	1/4	1/2	1

2.2.2 Calculating weights

Generally speaking, the values of the judgment matrix are given after balancing them based on data information, expert opinions and analysts' perceptions. However, due to the complexity of objective things and the diversity of people's perception, one-sidedness may arise, so it is obvious that it is impossible to require every judgment matrix to have complete consistency, especially for problems with many factors and large scales. In order to examine whether the results obtained by hierarchical analysis are basically reasonable, a consistency test ($CR < 0.10$) is required for the judgment matrix. In this paper, for the convenience of calculation, the square root method is used to calculate the judgment matrix weights in Matlab.

Calculate the geometric mean of all elements in each row of the judgment matrix P to obtain the eigenvector M=(0.3413, 0.4884, 1.8882, 2.9302, 1.0845), where:

$$m_i = \sqrt[5]{\prod_{j=1}^5 p_{ij}}, i = 1, 2, 3, 4, 5 \quad (4)$$

Normalize the vector M to obtain the relative weight vector W= (0.0507, 0.0725, 0.2805, 0.4352, 0.1611), where:

$$w_i = \frac{m_i}{\sum_{j=1}^5 m_j} \quad (5)$$

Calculate the judgment matrix P with maximum eigenvalue $\lambda_{\max} = 5.3133$, where:

$$\lambda_{\max} = \frac{1}{5} \sum_{i=1}^5 \frac{(PW)_i}{w_i} \quad (6)$$

The final statistics of all the results obtained are shown in the following Table 4

Table 4 Result statistics summary table

Element	Feature vector	Weight	Maximum eigenvalue
B1	0.313	0.0507	
B2	0.4884	0.0725	
B3	1.8882	0.2805	5.3133
B4	2.9302	0.4352	
B5	1.0845	0.1611	

3. Safety assessment based on hierarchical analysis integrated evaluation model

3.1 Consistency check

Generally speaking, the values of the judgment matrix are given after balancing them based on data information, expert opinions and analysts' perceptions. However, due to the complexity of objective things and the diversity of people's perception, one-sidedness may arise, so it is obviously impossible to require every judgment matrix to have complete consistency, especially for problems with many factors and large scale. In order to examine whether the results obtained by the hierarchical analysis method are basically reasonable, it is necessary to conduct consistency tests on the judgment matrix. For any judgment matrix, when C.I. < 0.1, the judgment matrix has complete consistency; the larger the value of C.I., the greater the deviation from consistency[7].

(i) Construct the consistency test index C.I., which is constructed as follows.

$$C.I. = \frac{\lambda_{\max} - n}{n - 1} \quad (7)$$

(ii) Find the corresponding average random consistency index RI. For n = 1, ..., 9, Saaty gives the corresponding RI values, as shown in Table 5.

Table 5 Value of RI

n	1	2	3	4	5	6	7	8	9
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45

(iii) Calculate the consistency ratio CR.

$$CR = \frac{CI}{RI} \quad (8)$$

The solution yields C.I.=0.0783 and RI=1.11, at which time CR=0.0706<0.1, Then this judgment matrix has full consistency.

3.2 Hierarchical total ranking and consistency test

Above we get a vector of weights of a set of elements to an element in its upper level, and the total ranking weights are synthesized from top to bottom under a single criterion to get the final indicator weight breakdown (shown in Table 6 below). This ultimately leads to the scheme selection[8].

Table 6 The breakdown of the corresponding weights of the indicators

Element	B1	B2	B3	B4	B5
Weight	0.0507	0.0725	0.2805	0.4352	0.1611

Hierarchical analysis model judged the wire rope safety performance by B3 index (distance between serious defects of wire rope) has the biggest influence, by B1 index (defect density of wire rope) has less influence, in line with the actual prediction. Eventually the problem a obtained defect data for weighting operation analysis, the wire rope 4 and 6 in 10 times after the operation, the safety assessment level is C, safety performance decline seriously, need to be replaced. The rest of the safety performance to maintain a relatively good, assessment are B, the damage is better, temporarily do not need to be replaced, can continue to use[9].

4. Conclusions

4.1 Advantages of the model

- 1) Using the hierarchical analysis method for analysis, the combination of objective and intuitive data reflects the degree of determination of the impact of various factors on the performance of steel wire rope.
- 2) The model of finding defects and the influence of defects on the safety performance of wire rope is established and applied in real life, which can effectively carry out equipment detection and prevention of danger and has certain social significance[10].

4.2 Disadvantages of the model

Disadvantages of the model: Hierarchical analysis method still has a certain subjectivity and cannot accurately determine the degree of influence of factor indicators. It is possible to use entropy weight method and hierarchical analysis method together, which is more reliable for prediction results[11].

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