

Application and Research in the Drill Reliability Design Based on Fuzzy Theory

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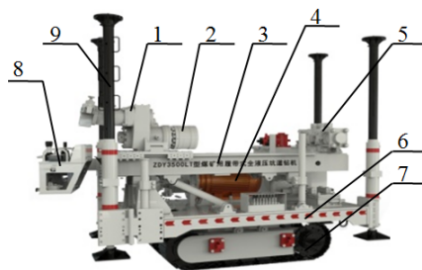
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Abstract—In order to improve the reliability of the coal mine tunnel drilling rig in the absence relevant data at the primary design stage, the reliability fuzzy prediction model and the fuzzy comprehensive evaluation process was established based on the fuzzy theory in this paper. The reliability of hydraulic chuck was predicted by the reliability index of some key slips, further the whole drill reliability index was analyzed, it provided a new way for tunnel drill design. The experimental results showed that the theory of fuzzy reliability prediction could improve drill reliability and provide theoretical basis and technical support for design.

Keywords—formatting; style; styling; insert

I. INTRODUCTION

China is the biggest coal-producing country in the world, it is a multiple tectonic plate through multiple order tectonic movement patchwork of land, and the condition of geological structure is very complicated. There is large difference of coal resources distribution, poor geological conditions, especially the gas, water and other disasters threaten seriously. With the mining depth increasing, all kinds of the disasters threat has become increasingly worse^[1]. Coal mine tunnel drilling is widely used in gas extraction, drain construction, geological exploration, it is the essential equipment of coal mine safety and efficient production. As the Fig.1 shows the system of coal mine tunnel drilling rig. If any part is the failure, the machine will not work^[2]. Because of the particularity environment, the drill rig was long stored under harsh conditions and repeated use, it puts forward higher requirements on the reliability of the drilling rig. Therefore, it is very necessary that proposed to analysis and study about the prediction, analysis and evaluation on the reliability of drilling rig.



1-gyrotor; 2-chuck; 3-feed device; 4-motor pumps; 5-holder; 6 - bodywork platform; 7 - track; 8 - console; 9 - solid device

FIGURE 1. THE SYSTEM OF COAL MINE TUNNEL RIG

The core of reliability design is through the basic unit of the reliability index to estimate the system reliability index of reliability prediction and allocation, optimization and management, both applied to various engineering system of common theoretical foundation and calculation principle, and involves specific attributes and characteristics of each system^[3]. It is considered that the influence of some factors such as functional, technical level, the influence of the working condition of environment, economy and so on, in addition to the geometric relationship and movement. There are the fuzziness in these factors that are difficult to determine with value, it leads to the ambiguity tunnel drill design. Fuzzy theory is widely used in the robot, the complex mechanical and electrical system, electric power, agriculture and other fields^[4-7], but in the coal mine equipment and the application of reliability prediction research is less. The reliability fuzzy prediction model and the fuzzy comprehensive evaluation process was established based on the fuzzy theory in this paper, it provided a new way for tunnel drill design.

II. THEORY OF RELIABILITY FUZZY PREDICTION

A. The Establishment of the Fuzzy Evaluation Factor

According to the characteristics and main performance index of the predicted equipment, many factors that will affect the certain properties of the equipment reliability was divided into p class, the factors set $U = (u_1, u_2, \dots, u_n)$ was divided into p subsets: $U = (U_1, U_2, \dots, U_p)$. Among them, $U_i (i=1, 2, \dots, p)$ was expressed the i class, and meet: $U_1 \cup U_2 \cup \dots \cup U_p = U$ and $U_i \cap U_j = \emptyset (i \neq j)$.

B. The Establishment of the Weight set

Establishment of the weight set is fuzzy membership degree of each factor. Membership can reflect the factors status and role in comprehensive evaluation, it directly affects the final fuzzy evaluation values. Generally, coal mine hydraulic tunnel drilling rig as a complex system of mutual correlation operation, all aspects of the various parts and components should have the same importance, but in different circumstances, the demonstrated importance of various factors are different. The weight set $A = (a_1, a_2, \dots, a_p)$, meet $0 < a_i \leq 1$, $\sum_{i=1}^p a_i = 1$.

C. The Establishment of the Fuzzy Relationship Matrix

The factors of evaluation set for: $b_i = (b_{i1}, b_{i2}, \dots, b_{im})$, $(i=1,2,\dots, p)$. There is a relative membership degree for each judge, it can be seen as the standard values of each level are: $S = (S_1, S_2, \dots, S_m)$. Each single factor evaluation is jointed, it can get a set of factors from the fuzzy relation matrix of the evaluation Q , marked as:

$$Q = \begin{pmatrix} b_1 \\ b_2 \\ \vdots \\ b_p \end{pmatrix} = \begin{pmatrix} b_{11} & b_{12} & \dots & b_{1m} \\ b_{21} & b_{22} & \dots & b_{2m} \\ \vdots & \vdots & \dots & \vdots \\ b_{p1} & b_{p2} & \dots & b_{pm} \end{pmatrix}_{ij}$$

Among them, each line in the Q $b_i = (b_{i1}, b_{i2}, \dots, b_{im})$, $(i=1,2,\dots, p)$ are the evaluation results of the i factor, the b_{ij} is the j membership degree for each i judge, it reflects fuzzy relationship between the evaluation factors and expressed in membership degree. The establishment of the fuzzy evaluation matrix is used by expert evaluation method, which experts use experience on factors relative to its evaluation factors focused on the subjective evaluation. The d shows the number of the participated evaluation experts in the Q , the d_{ij} shows the number of the j membership degree for each i judge evaluation experts.

D. The Establishment of the Evaluation Matrix and the Unit Score

The relationship between the factor weight set A and judging matrix Q was established, according to the principle of fuzzy transformation, available for fuzzy evaluation matrix model was: $B = A \circ Q = (B_1, B_2, \dots, B_s)$, comprehensive evaluation score was: $C = B \circ S^T$. According to the characteristic of the index system of fuzzy operator, this is the lower index upper composite index evaluation vector at various levels or value calculation method. The determination of fuzzy operator is the determination of fuzzy synthesis methods. There are five common evaluation models. The first is $M(\wedge, \vee)$, its synthetic operation is $B_j = \bigvee_{i=1}^p (a_i \wedge b_{ij})$, $(j=1,2,\dots, m)$. The second is $M(\bullet, \vee)$, its synthetic operation is $B_j = \bigvee_{i=1}^p (a_i \bullet b_{ij})$, $(j=1,2,\dots, m)$. The third is $M(\wedge, \oplus)$, its synthetic operation is $B_j = \min \left[1, \sum_{i=1}^p (a_i \wedge b_{ij}) \right]$, $(j=1,2,\dots, m)$. The fourth is $M(\bullet, \oplus)$, its synthetic operation is $B_j = \min \left[1, \sum_{i=1}^p (a_i \bullet b_{ij}) \right]$, $(j=1,2,\dots, m)$. The last one is $M(\bullet, +)$, its synthetic operation is $B_j = \sum_{i=1}^p (a_i \bullet b_{ij})$, $(j=1,2,\dots, m)$, $\sum_{i=1}^n a_i = 1$.

III. FUZZY PREDICTION OF SYSTEM RELIABILITY

Reliability prediction is defined as the method of fuzzy reliability prediction to quantitatively estimate the future product at the design stage, based on the reliability of the components of the system.

If system parts can be used normally after repaired, it will be called its average trouble-free working time, marked as $MTBF$, $MTBF = \sum_{i=1}^N t_i / N$, t_i shows the i part trouble-free working time and N shows the total failure times among them.

The longevity of the mechanical system parts obeys exponential distribution $f(t) = \lambda e^{-\lambda t}$, the unit failure rate λ is made as constant, then $MTBF = 1/\lambda$. If the system is composed of each unit series, the units are usually assumed independent and equal working time, system reliability R is equal to the

reliability of product each unit, $R = R_1 R_2 \dots R_n = \prod_{i=1}^n R_i$, $R_i = e^{-\lambda_i}$, $\lambda_i = \lambda C_i$, the λ_i shows the i unit failure rate, the λ shows the failure rate of a known unit, the C_i shows the i unit the integrated score coefficient.

IV. APPLICATION IN THE DESIGN OF TUNNEL DRILL CHUCK

Hydraulic chuck is an independent important part of drilling rig, due to its worse working conditions and frequent action, it was able to sustain the largest axial load and the maximum torque. The drilling efficiency and quality were affected by chuck's performance. The Fig.2 shows the chuck of coal mine tunnel rig, the main failure shows slip abrasion, and the reliability of the slip can be use to predict the reliability of the chuck.

The factors effecting the reliability of chuck slip were determined according to the actual working condition and experts in the set $U = \{u_1, u_2, u_3, u_4, u_5\} = \{\text{design level, importance degree, complexity, environmental conditions, working time}\}$, and the weight set $A = (0.15, 0.25, 0.10, 0.15, 0.35)$, the relative membership degree $S = (0.15, 0.25, 0.10, 0.15, 0.20)$. The Tab.1 shows the definition of evaluation grades $b_i = \{b_{i1}, b_{i2}, b_{i3}, b_{i4}, b_{i5}\}$, $(i=1,2,\dots,5)$.

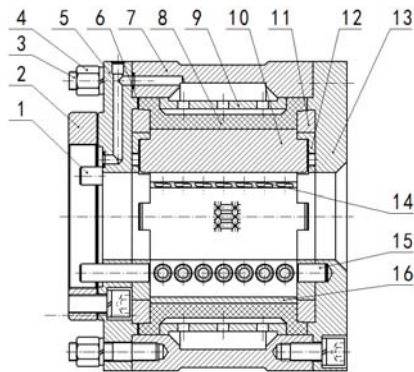
The fuzzy relationship matrix was listed according to the factor evaluation scale:

$$Q = \begin{pmatrix} 0.2 & 0.3 & 0.3 & 0.1 & 0.1 \\ 0.5 & 0.4 & 0.1 & 0 & 0 \\ 0.4 & 0.3 & 0.2 & 0.1 & 0 \\ 0 & 0 & 0.1 & 0.3 & 0.6 \\ 0.7 & 0.2 & 0.1 & 0 & 0 \end{pmatrix}$$

Fuzzy operator select weighted average model. It may retain all useful information, high credibility, the synthesis

operation for $B_j = \sum_{i=1}^p (a_i \bullet b_{ij})$, $(j=1,2,\dots, m)$, $\sum_{i=1}^n a_i = 1$.

Therefore, $B=A \circ Q=(0.440 \ 0.245 \ 0.140 \ 0.070 \ 0.105)$.



1 - long pin; 2 - the plate; 3-double end studs; 4-nut; 5 - rear end cover; 6 - pad ring; 7 - chuck body; 8 - rubber tube; 9 - support ring; 10 - slip; 11 - pressure ring; 12 - the twisting plate; 13 - front end cover; 14 - spring; 15 - short pin; 16 - plate

FIGURE II. THE CHUCK OF COAL MINE TUNNEL DIG

TABLE I. DEFINITION OF EVALUATION GRADES

Evaluation Factors	Grades				
Design level	highest	higher	general	lower	lowest
Importance Degree	much	more	most	less	little
Complexity	little	less	much	more	most
Environmental Conditions	good	better	best	bad	worse
Working Time	short	shorter	long	longer	longest

Comprehensive evaluation score was: $C = B \circ S^T = 0.234$

Coal mine tunnel drill chuck is composed of 16 major parts, and slip is used as its main easily damaged parts. It was calculated by the standard of slip parts failure rate and the comprehensive evaluation score, The results showed that sixteen parts failure rate in slip for reference were 5%, the obtained gripper reliability was 82.93%,

$$R = \prod_{i=1}^{16} R_i = \prod_{i=1}^{16} e^{-\lambda_i} = e^{-\sum_{i=1}^{16} \lambda_i} = e^{-16\lambda C} = 0.8293.$$

V. CONCLUSION

According to the slip reliability index to estimate the reliability of the chuck index and the holder of reliability index to estimate the reliability of the machine, which provided a method for reliability prediction of the machine. At the system design stage lack of reliability data, using fuzzy forecast method is the key to set up to predict the connection between the unit and the known unit reliability, though only in ideal situation provided approximate estimate values, it can provide for the designer with the reliability of the effective information

feedback, which has important reference value and provides a new idea for improving the drilling machine reliability.

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