Research on ZPW-2000A Track Circuit State Diagnosis Based on Set Pair Analysis

Haoyue Zang¹*, Ruifeng Wang²

¹School of Automation and Electrical Engineering, Lanzhou Jiaotong University, lanzhou, Gansu, 730070, China
²School of Automation and Electrical Engineering, Lanzhou Jiaotong University, lanzhou, Gansu, 730070, China
⁰0218387@stu.lzjtu.edu.cn
*Corresponding author’s e-mail: 1324286006@qq.com

Abstract. For ZPW-2000A the traditional maintenance mode of uninsulated track circuit has some problems such as low efficiency and poor timeliness. This paper analyzes various index parameters that affect the running state of track circuit. Due to the influence of various random uncertain factors, such as the bad operation environment of track circuit equipment, the complex composition of equipment and the variety of fault causes, then the set pair analysis theory is introduced and the influence index is quantified by using the connection number. The degree of uncertainty is represented in mathematical form, and the expression of connection number between index and operation state is described systematically. The comprehensive and accurate state evaluation of track circuit is realized. Finally, an example is given to verify the effectiveness and feasibility of the proposed method.

1. Introduction

ZPW-2000A jointless track circuit is one of the basic equipment of railway signal in China, which is widely used in Section Railway. It is an important equipment to ensure the safe operation of railway system. The working environment of track circuit is bad and the composition of equipment is complex, which leads to the possibility of failure, which affects the driving efficiency at least and endangers the safety of personnel. At present, due to the lack of intelligent analysis and prediction of equipment health status, track circuit adopts the maintenance strategy of fault maintenance and regular maintenance, which is easy to lead to "excessive maintenance" or "insufficient maintenance". Therefore, it is of great significance for the safe operation of railway to grasp the operation status of track circuit timely and accurately.

Experts and scholars at home and abroad have done a lot of research on fault diagnosis and early warning of track circuit. In reference [1], chaos mapping is used to generate initial population, and adaptive genetic operator is used to solve track circuit equipment status and maintenance strategy is studied. In reference [2], the health status of track circuit was evaluated and the residual life of equipment was predicted by stochastic fuzzy theory. In reference [3], the track circuit health status assessment model was established by combining support vector description method and grey prediction method to predict the future trend of track circuit health status.

However, the relationship between various uncertain factors and operation status has not been considered in the current method, and the intuitive quantitative description between the impact index
and the operation state has not been established. In order to establish a comprehensive track circuit operation state health model, this paper selects representative, independent and feasible evaluation indicators, namely equipment operation conditions (operating environment, real-time operation parameters), operation data (maintenance records, operation time) and basic equipment conditions (technical parameters, family quality history), which comprehensively reflect the overall operation status of track circuit from dynamic and static aspects state.

2. track circuit
ZPW-2000A jointless track circuit is composed of indoor and outdoor parts. The environment is complex, and the failure of equipment is usually caused by many reasons. The equipment and even the whole track circuit system from health to failure is a gradual process. Therefore, it is necessary to understand the operation level of track circuit equipment. According to the <ZPW-2000A track circuit technical conditions> regulation: the safety and perfection level of track circuit electronic equipment is divided into 4 levels, namely, health, sub-health, abnormal and fault, and the classification is indicated by $l_1$, $l_2$, $l_3$ and $l_4$ respectively. Table 1 shows the division of operation state and corresponding description.

| Grade | The value range of $\mu$ | Health level | Describe |
|-------|--------------------------|--------------|----------|
| $l_1$ | $0.5 < \mu \leq 1$ | Health       | The state parameter value is rated value, the equipment is very safe, and the possibility of failure is very small. |
| $l_2$ | $0 < \mu \leq 0.5$ | sub-health   | The state parameter value deviates from the rated value, the equipment is not safe, pay attention to monitoring, and the possibility of failure is within the acceptable range. |
| $l_3$ | $-0.5 < \mu \leq 0$ | abnormal     | The state parameter value deviates from the rated value more, the equipment is not safe, the possibility of failure is greater, strengthen the monitoring and troubleshooting. |
| $l_4$ | $-1 \leq \mu \leq -0.5$ | fault        | Equipment failure must be overhauled. |

ZPW-2000A jointless track circuit system for qualitative indicators of the scoring standard reference [5].

3. Set pair analysis
Set pair analysis method (SPA) is a new mathematical theory and system analysis method first proposed by Chinese scholar Zhao Keqin in 1989, which deals with the uncertainty caused by random, fuzzy, intermediary and incomplete information. This paper analyzes the relationship between two different things as a whole, and quantitatively studies the certainty and uncertainty of things from the same, different and reverse aspects by the principle of three parts [4]. The two things with connection are called set pair operators.

Due to its complex and difficult classification, strong uncertainty, qualitative and quantitative comprehensive consideration, the state assessment of track circuit has strong correspondence with the characteristics of set pair analysis, so it can be used as the supporting theory of track circuit state assessment.

The function used to represent the relation number and properties of two set pair operators in the set pair is called the characteristic function, also known as the connection number. Its expression is shown in formula (1).

$$\mu = a + bi + cj$$  \hspace{1cm} (1)
Where: $a$ is the identity of two set pair operators in the same problem background; $b$ is the difference degree; $c$ is the opposite degree. $i$ represents the difference degree coefficient, with the value range of [-1,1]; $j$ represents the opposite degree coefficient, which is generally taken as -1.

4. State evaluation of track circuit based on Set Pair Analysis

4.1 Determine the set of set pairs
The indexes that affect the operation state of track circuit include operation environment, real-time operation parameters, operation time, technical parameters, maintenance records, and family quality history. According to the six indicators, the running state level is described from dynamic and static aspects, and the evaluation index set of track circuit state is established.

According to table 1, the evaluation set of track circuit operation state level is established, and the track circuit operation state level and index evaluation set are regarded as two set pair operators to construct set pair.

4.2 Calculation of index weight
Different indicators have different influence on the overall operation of track circuit, so objective weight value should be given in the evaluation process. In this paper, the entropy weight method is used to determine the index weight. Unify the dimension and avoid the decimals being eroded by large numbers. Data normalization is performed as shown in formula (2).

$$x' = \frac{x - \min x}{\max x - \min x}$$

The calculation formula of index entropy weight is shown in formula (3).

$$h_{kn} = -\frac{1}{\ln m} \sum_{k=1}^{m} \frac{x_{kn}}{x_{kn}} \ln \frac{x_{kn}}{x_{kn}}$$

$$w_{kn} = 1 - h_{kn}$$

4.3 The construction of connection number.
The state evaluation of track circuit is divided into four levels, that is, quaternion connection number is used to analyze the correlation degree between set pair operators, as shown in equation (4).

$$\mu_m = a_m + b_m i_1 + c_m i_2 + d_m j$$

Among them: $a_m$ is health state degree; $b_m$ is sub-health state degree; $c_m$ is abnormal state degree; and $d_m$ is fault state degree.

The expression of connection number between index and operation state level is shown in equation (5).

$$\mu_m = \begin{cases} 
1 + 0i + 0j + 0k & x \in (S_4, +\infty) \\
\frac{S_1 - x}{S_1 - S_2} + \frac{x - S_2}{S_2 - S_4} i_1 + 0k + 0j & x \in (S_4, S_3) \\
\frac{S_1 - x}{S_1 - S_2} + \frac{x - S_2}{S_2 - S_4} i_1 + 0j & x \in (S_3, S_2) \\
0 + 0i + \frac{S_3 - x}{S_3 - S_4} i_1 + 0j & x \in (S_3, S_1) \\
0 + 0i + 0j + 0k & x \in (0, S_4) 
\end{cases}$$
In the formula, $\mu$ is the overall connection degree under each index; $w_m$ represents the weight of the index, and the evaluation grade where the maximum connection degree is located is the final determined level. The difference coefficient in the connection number is uniformly selected on $[-1,1]$ by the average division method $^4$.

The basic framework of evaluation process of track circuit operation status level based on set pair analysis is shown in formula (1).  

$$
\mu = \sum_{m=1}^{6} w_m \mu_m
$$

(6)

5. Example analysis

There are many track circuit equipment, among which the failure probability of transmitter and receiver is far greater than that of other equipment $^2$. Therefore, this paper selects 24 groups of measured data of transmitters used by Railway Administration for 12 years as an example for verification.

Table 2. measured data 1

| Evaluation index fraction | Evaluation index | fraction |
|--------------------------|-----------------|---------|
| Operating environment    | 94.77           | Real time operation parameters | 86.32 |
| Running time / year      | 91.85           | technical parameter | 93.05 |
| Maintenance record       | 91.96           | Family quality history | 91.85 |

According to formula (3), the weight values of six index parameters can be calculated as follows: $W=[0.178, 0.328, 0.0547, 0.132, 0.2976, 0.0097]$

According to formula (5), the connection number of each index corresponding to different grades is calculated, as shown in Table 3.

Table 3. measured data 1

| Contact degree | $a$ | $b$ | $c$ | $d$ |
|----------------|-----|-----|-----|-----|
| $\mu_1$       | 0.523 | 0.477 | 0   | 0   |
Combined with formula (6), the overall contact number of each index for the running state of track circuit is calculated as follows:

\[ \mu = 0.4766 + 0.372i_1 + 0.1514i_2 + 0j = 0.5501 \]

According to the values of \( \mu \) in Table 1, the transmitter detected at this time is in a healthy state. The remaining 23 groups of data in 2 are verified, and the results are shown in Fig. 2.

In the actual operation, the transmitter has run for 12 years without failure, which shows that the results in this paper are consistent with the actual situation, and with the conclusion of reference [2]. The accuracy and feasibility of the proposed method are verified by the proposed state assessment method.

6. conclusion
In this paper, taking track circuit as an example, SPA is used to quantitatively analyze each index. The system describes the relationship between the running state and the indicators, quantitatively describes the uncertainty of the track circuit index, realizes the overall analysis and local dialectical treatment. The final results show that the method described in this paper is effective and feasible, and it is easy to program, which provides a new theoretical method for on-site operation and maintenance.

Acknowledgments
Thank you for providing a good learning environment and creating a strong learning atmosphere. Thanks for the tutor's guidance and encouragement, as well as the help of peers. Finally, I would like to thank my parents and boyfriend for giving me the greatest comfort in my life.

Fund projects: National Natural Science Foundation of China (61661027)

References
[1] Wang R F, Tao R J. (2018) Research on maintenance strategy optimization of ZPW2000A track circuit based on NSGA2 algorithm. J. Journal of Railway Science and engineering, 15: 2394-2400.
[2] Zhang F X. (2015) Research on ZPW-2000A track circuit health management system.D. Lanzhou: Lanzhou Jiaotong University.
[3] Wang R F, Jia N. (2018) Research on life prediction of ZPW-2000A track circuit equipment based on SVDD and grey prediction J. Journal of measurement science and instrumentation, 9: 373-379.

[4] Zhao Keqin.(2000) Set pair analysis and its preliminary application . Zhejiang science and Technology Press, Hangzhou.