Analysis of Subway Braking Performance Based on Fuzzy Comprehensive Evaluation Method

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Abstract. In the process of subway operation, the braking system is a complex system, and its state detection is for high data accuracy and state positioning accuracy According to the structure of the braking system and the principle of the braking method, the basic braking performance parameters of the system are analyzed, combined with the abnormal state of the subway brake cylinder pressure data, the braking process is divided into two stages: brake cylinder pressure establishment and peak stability. And define the six characteristic parameters of 90% brake cylinder pressure establishment time, special slope period time, stable pressure value, stable pressure standard deviation, maximum value and minimum value. Aiming at the braking process performance, a data mining theory is proposed, and software based on the fuzzy comprehensive evaluation method is written to analyze the deterioration of the braking performance of subway vehicles. The actual on-board data is used as an example to verify the reliability of the theory.

Keywords: Subway · Braking performance · Fuzzy comprehensive evaluation

1 Introduction

Urban rail transit has outstanding benefits such as large capacity, fast speed, punctuality, high economy, low environmental pollution, safety, and low energy consumption. Therefore, it has become an inevitable choice for large cities to deal with traffic congestion. As the urbanization of China continues to deepen, it is believed that more and more small and medium-sized cities will also start the era of urban rail transit [1]. For a long time in the future, China's urban rail transit will be in its golden period of development, so there is a huge market for research on urban rail transit train-related technologies. At present, for the entire braking system, the engineering has proposed an analysis method for the performance of the system, but the analysis method for the performance of the subway vehicle braking system is still relatively rough [2]. However, with the degradation of the system performance during the service time of the train and the occurrence of failures, the state of the brake system of the train changes with time and environmental changes, which in turn affects the execution of the brake command by the brake system [3]. These

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reflect the changes in the performance indicators of the braking system in the dynamic working state, as well as the description of the changes in the working state of the vehicle braking system. Since no clear and systematic analysis and evaluation methods are given, there is an urgent need to study the analysis of braking performance [4] (Fig. 1).

Fig. 1. Schematic diagram of subway model

2 Selection of Braking Characteristic Parameters

During the operation of subway vehicles, the brake cylinder pressure reflects the final output of the BECU and BCU, and then the brake cylinder pressure enters the basic braking device to brake the vehicle. Regarding the braking system as a black box, following the black box theory, the impact of internal changes in the braking system will affect the final output, which in turn affects the performance of the entire vehicle. Based on the data mining of the output data, the brake cylinder pressure is selected as the core observation time series data without considering the specific internal abnormality generation mechanism.

According to the simulation analysis of the abnormal characteristics of the brake cylinder pressure data in the previous section, in the actual operation of the vehicle, for example, the braking process at the initial braking speed of 80 km/h needs to cover a variety of different time series data sampling rates and large amounts of data analysis. To characterize the normal or abnormal state of the data, it is necessary to reduce the data volume of the brake cylinder pressure without losing the data characteristics. Therefore, it is necessary to extract the characteristic value of the brake cylinder pressure data to represent the complete braking process with fewer parameters.

This article divides a complete braking process into two major stages: brake cylinder pressure establishment and brake cylinder pressure stabilization. A total of six characteristic parameters are named after A, C, D, E, F, which characterize the change process of brake cylinder pressure. As shown in Table 1 below.

Table 1. Characteristic parameter table

Stage	Parameter item	Characteristic value name
Rising phase	A	90%T

(*continued*)

Table 1. (*continued*)

Stage	Parameter item	Characteristic value name
	B	Special slope time period
Stage two	C	Stable value
	D	Standard deviation
	E	Important maximum
	F	Important minimum

(1) A
90 % pressure build-up time of brake cylinder. The time required for the brake cylinder to start charging until the brake cylinder pressure rises to the specified pressure (90% of the target pressure) is the main indicator describing the response performance of the brake control system. The brake cylinder pressure rise time is an important performance parameter, which includes the time from when the driver's brake handle is pulled to when the air pressure of the brake cylinder rises to the start of the basic brake, which reflects idling stopping distance.
(2) B
The build-up time of brake cylinder pressure in special section. Because the subway vehicle brakes under actual working conditions, there is a small interval of braking, so the build-up of brake cylinder pressure may have been eliminated when the peak braking command is not fully reached, and the 90% brake cylinder pressure build-up time at this time is meaningless. At the same time, in the charging time of the brake cylinder pressure, the first 2 s basically belong to the action phase of the brake system. The brake cylinder pressure data at this time represents a series of actions of the brake system, and the latter part is basically the process of continuing to inflate to the target pressure. Therefore, it is set to select 50 kPa–70 kPa as the special slope section.
(3) C
Stable value. When the brake cylinder pressure is established, the brake cylinder pressure is based on the actual output pressure value of the target pressure. There is a certain difference between the actual output value of the vehicle engineering and the target set value. At this stage, due to the dynamic characteristics of the system, the actual brake cylinder pressure is real-time. Commonly used data processing methods are to take the arithmetic average of the data, geometric average, etc. During a complete braking, if the output value of the brake cylinder pressure of the vehicle is abnormally high or too low, the average value may be affected by the abnormal data. Therefore, a single value in the data segment is selected as the stable value of the brake cylinder pressure in the stable phase, that is, the most frequent data value in the stable phase is selected as the normal actual output value.
(4) D
Standard deviation. In mathematics, it can also be used as the mean square error, which is the square root of the arithmetic mean of the square of the deviation from the mean, expressed as σ. The standard deviation is the arithmetic square root of the variance. Assuming that there is a set of real number data columns: $X_1,X_2,X_3,\ldots,X_n$, the arithmetic

mean value of which is μ, the standard deviation formula is as follows.

$$\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - \mu)^2} \tag{1}$$

The standard deviation can reflect the discrete level of a data set. It is the most frequently used judgment that can quantify the discrete degree of a set of data, and it is also the main indicator of accuracy. Regarding the brake cylinder pressure in the stable phase, the normal state is a constant value, but the actual output results usually produce certain fluctuations. Using the standard deviation can express the degree of fluctuation of the brake cylinder pressure value, so as to monitor the stability of the system output.
(5) E
The maximum value of the stable phase. When the brake cylinder pressure is unstable and abnormal output is present, it is necessary to monitor the actual maximum output pressure. Too high brake contact surface pressure will cause the wheels to lock, which will affect the braking performance.
(6) F
The minimum value of the stable phase. When an abnormality occurs in the brake system, such as relay valve air leakage, brake cylinder air leakage, etc..Due to continuous air leakage, the brake cylinder pressure continues to drop after the brake cylinder pressure rises to the target pressure. It is necessary to pass the minimum value of the stable phase to monitor possible abnormalities.

Therefore, the feature parameter extraction table is obtained as shown in Table 2. below.

Table 2. Analysis table of six characteristic parameters

Stage	Number	Name	Meaning
Stage one	A	90%T	90% target pressure build-up time
	B	Special slope time period	Specific ascent speed
Stage two	C	Stable value	Stable stage value
	D	Standard deviation	Volatility
	E	Important maximum	Brake cylinder pressure overshoot
	F	Important minimum	Insufficient brake cylinder pressure

The graphical data of brake cylinder pressure is shown in Fig. 2 below.

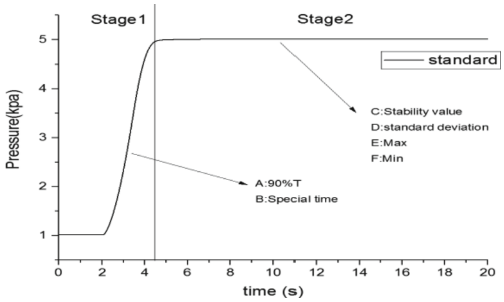

Fig. 2. The distribution of parameters on the brake cylinder pressure curve

3 Fuzzy Comprehensive Evaluation and Analysis Method Based on Characteristic Parameters

In order to analyze the train's health status from multiple angles, it is necessary to filter and analyze the indicators that characterize the train's health status. As far as the train brake system is concerned, the range of features is diverse, such as the operating time of a solenoid valve, the strategy and efficiency of the air compressor's charging and exhausting air, the degree of airtightness of the cylinder, the operating frequency of the large and small brakes, etc.. However, the first thing to consider when analyzing streaming data should be whether these variables and features exist for detection by existing sensors, and whether sensor data can be obtained through simpler streaming data acquisition channels, otherwise, just talking about multiple variables is not reasonable for realization and engineering.

The problem of state analysis is that it is difficult to establish a complete model for complex systems to analyze their failure probability, and although the operating parameters of the system and components show degradation with the increase in service time, this degradation is severely non-linear and at the same time ambiguous, without a strict boundary limit. Refined to the rail transit train braking system, due to its importance to ensure safety, there is no full life cycle database like other components. In order to realize the quantitative expression of the above-mentioned qualitative characteristics, rely on these factors to establish a stream data analysis and evaluation system, and choose the fuzzy comprehensive evaluation method.

Fuzzy comprehensive evaluation method is a comprehensive evaluation method based on fuzzy mathematics. It makes full use of the membership degree theory of fuzzy mathematics, and expresses various qualitative evaluations through quantitative evaluation, that is, uses fuzzy mathematics to make an overall evaluation of affairs or objects restricted by multiple factors. The fuzzy theory can be understood through simple examples. Water with a temperature of 0 °C can be regarded as ice water, or a mixture of ice and water, while water with a temperature of 80 °C is obviously hot water, so the properties of water at 40 °C between the two are difficult to give a clear judgment. In the process of changing properties from hot water to ice water, there is only a vague understanding of how to make accurate judgments based on temperature, and it is impossible to clearly give a reasonable judgment boundary. For example, the maximum impulse requirement for the common braking of a subway train is less than 0.75 m/s^3, so if the actual impulse is greater than this value, it is obviously a poor state, which will greatly affect the comfort of the user, and even a strong impact may cause deformation of the coupler. Then if the maximum impulse of a certain service brake is second-order derivation of the speed, the calculated value is 0.72 m/s^3. The braking performance this time is only from the perspective of impulse, which is obviously not ideal, but it does not exceed the data of 0.75 m/s^3.

The naive evaluation index is that the smaller the impulse when the train is braking, the better, and it can meet the needs within a reasonable range. When it exceeds a certain value, although it is still acceptable, it still faintly feels that there is a hidden danger, that is, the driving state of the vehicle has declined.

4 Analysis and Verification of Long-Term Vehicle Operation Status

For the braking performance degradation accompanying the long-term operation of the vehicle, the theoretical method is to conduct periodic consistency tests on the vehicle to observe the state change of the braking performance. In this article, based on the above-mentioned fuzzy comprehensive evaluation and analysis method theory, a set of software that can realize data visualization and data in-depth analysis is developed, and the braking state of the vehicle is analyzed based on the actual on-board data of many months.

4.1 Data Analysis Software Development

The development of data analysis software is based on the database as the carrier and is developed based on the Labview language, which realizes the storage and deletion of on-board data, and at the same time realizes the multi-function view of the data, and can analyze the braking state of the whole vehicle based on multi-day data. The overall structure of the software is shown in Fig. 3.

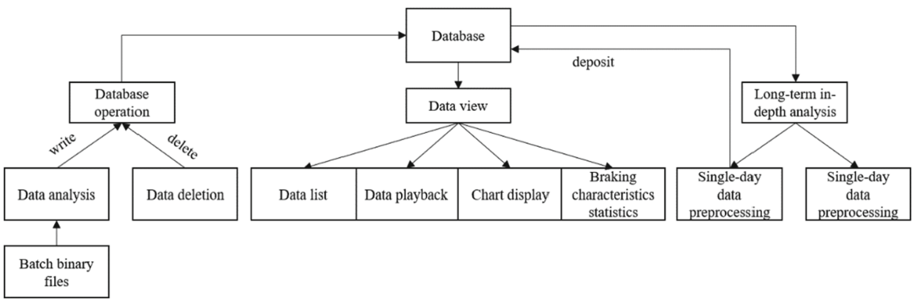

Fig. 3. Data analysis software architecture

The overall layout of the data analysis software is divided into a functional area and a working area. The functional area has database operations, data viewing, and data in-depth analysis. The working area is to implement specific operations on each functional area module. The software interface is shown in Fig. 4.

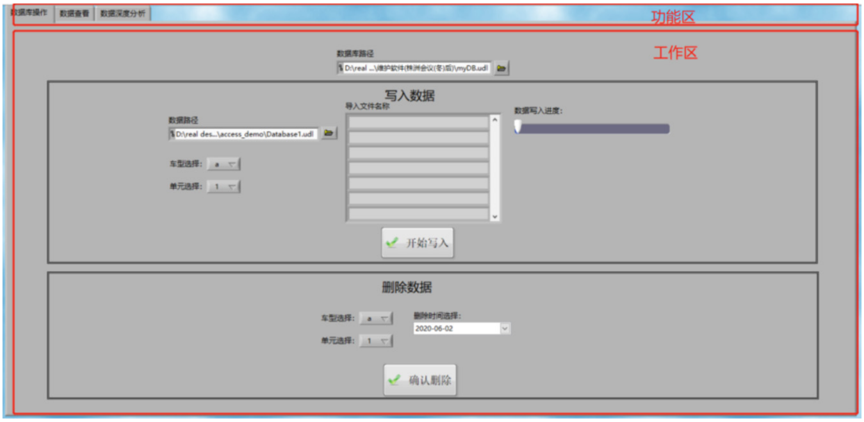

Fig. 4. Introduction to the software interface

4.2 Result Analysis

Use the software to analyze the data to get the scoring of the braking state of the vehicle. The result is shown in Fig. 5. According to the analysis method in this article, when the score is lower, it proves that the consistency of the vehicle is worse, which means that the braking performance of the vehicle has decreased.

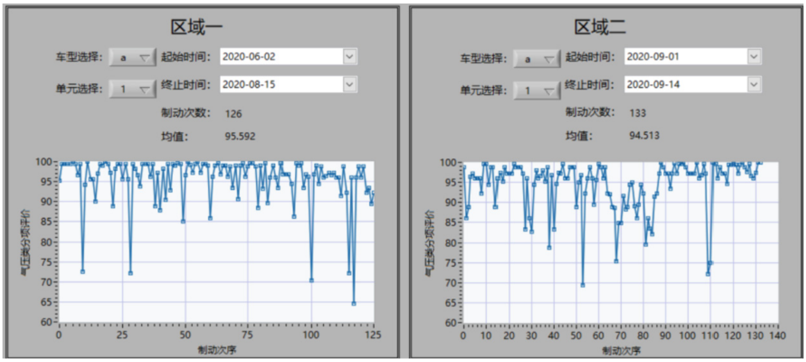

Fig. 5. Analysis of braking performance

As shown in Fig. 5, a total of 126 braking occurred from June to August, and the average braking state score was 95.592. In September, a total of 133 braking occurred, and the average value of the braking state score was 94.513. It can be seen that the braking state of the vehicle has declined over time.

5 Conclusion

First of all, this article introduces the subway brake system, which is the object of subway braking performance, analyzes its braking method and working principle, combines the output parameters of the brake system, and establishes the brake cylinder pressure data as the data analysis carrier. Then combined with the abnormal data characteristics of the brake cylinder pressure data, two major stages and six characteristic parameters of the braking process based on the brake cylinder pressure are established, which are respectively: 90% brake cylinder pressure establishment time, special slope time period, brake cylinder pressure stable value, stable phase standard deviation, maximum value, minimum value. The braking performance analysis method based on the consistency analysis method is proposed, and the braking performance of the vehicle is deeply studied. Through the analysis of data mining methods, and based on the similarity measurement model of sample data, a braking performance degradation analysis method suitable for subway vehicles is established.

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