Review Article

Application of Traction Power Supply for Metro Rail Transit Based on Electromagnetic Sensing Technology

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With the gradual acceleration of modernization, metro projects have been opened for the development and construction of urban areas. How to ensure the smooth operation of subway project in public service has become the focus of urban public safety service research. In view of this content, this paper studies the subway field of urban rail transit operation and improves the public safety of urban rail transit operation. Firstly, the factors affecting the track traction power supply are analyzed, the anti-interference technology of ring array electromagnetic sensor is added, and the research scheme is formulated according to the track potential research standard to ensure the operation of the power supply system. Then, the electromagnetic sensor traction algorithm is used to detect the subway track power supply signal, and the working characteristics and advantages of single electromagnetic induction and double electromagnetic induction are analyzed. The experimental results show that compared with the traditional electromagnetic sensor power supply signal detection algorithm, the content of this paper can judge whether the power supply is normal according to electromagnetic induction, detect whether the subway traffic deviates from the track traction coordinates, and understand the size of the deviation from the track. It improves the efficiency of traction power supply detection, stabilizes the running track of subway traffic, and is conducive to the protection and development of urban public safety.

1. Introduction

With the rapid development of urbanization, the increase and expansion of scale are inevitable. The field of urban public security is facing many new problems and challenges [1]. How to control urban population management, improve social harmony governance scheme, innovate urban public security system, and enhance people's living standards are all problems that the country needs to face in the process of promoting urban construction [2, 3]. Among them, in the process of strengthening social governance, the field of urban public safety is a very important link [4]. Due to the combination of urban problems and security problems, the whole public link has become very complex, especially in the face of the rapid expansion of urban scale and the growth of population base [5]. At present, many provinces and cities in developed regions have made a lot of investment and energy investment in transportation hubs. With the intensive growth of population, the traffic environment is becoming

more and more complex and bad. Expanding new modes of transportation is the main problem we cannot avoid. Subway track construction and development is a project content conforming to the social process. Most medium-sized cities have invested and studied subway construction projects [6].

Ensuring the stability and optimization of power supply system is an important support for subway construction and operation. In the metro power supply detection, most systems adopt relatively safe rigid catenary, which has the advantage of increasing the power supply safety in the traction process of metro rail transit. Therefore, it is vigorously applied and popularized in the field of metro power supply [7, 8]. However, in practice, the power supply link and operation technology of metro system are not very developed. A variety of environmental factors and facility factors lead to power supply contact failure, which affects the operation safety of metro rail transit and urban public safety [9]. Therefore, in addition to providing reliable contact equipment for the operation of metro system, we also need to

focus on the power supply detection mode, so as to finally improve the development of metro rail transit and urban public safety in China [10]. At present, most countries use sensor technology to support the research on the traction power supply system of metro rail transit. Common sensor technology includes multisensor technology, current sensor technology, and electromagnetic sensor technology [11, 12]. Through the understanding of the above technologies, we believe that electromagnetic sensor technology and equipment can better analyze the actual situation of rail transit power supply. The change of magnetic field is detected by electromagnetic sensor, and the interference factors and deviation of subway car body can also be detected and analyzed [13].

Based on the traction environment of metro rail transit in the field of urban public safety, this paper studies and analyzes the application of electromagnetic sensor technology in power supply detection mode. The innovative contributions include (1) the factors affecting track traction power supply are analyzed, and the anti-interference technology of ring array electromagnetic sensor is added. The error frequency in power detection is basically reduced. (2) The electromagnetic sensor traction algorithm is used to detect the subway track power supply signal, so as to improve the high sensitivity feedback efficiency and anti-interference performance under the power detection mode. (3) Further safe and effective application of electromagnetic technology to rail transit high-tech development.

This paper is mainly divided into three parts. The first part is about the development status of electromagnetic sensor technology in various countries. The second part is to use the subway track potential test to analyze whether the power supply system mode is normal and use the sensitive electromagnetic sensor to test the current noise to judge whether the power supply is normal and using electromagnetic sensor technology to improve the signal detection ability of upper position on electromagnetic track. Finally, the electromagnetic sensing measurement technology based on ring array improves the anti-interference performance of power supply system. The third part analyzes the detection results of electromagnetic sensor technology on traction power supply mode and the anti-interference performance of electromagnetic sensor to improve power supply environment.

2. Related Works

In recent years, China has made important breakthroughs in geological survey, oil resources, metal minerals, and other fields [14]. The technology of electromagnetic sensor equipment is gradually widely used, but the main production equipment of inductive electromagnetic sensors such as audio electromagnetic and transient electromagnetic are still in foreign countries [15, 16]. With the national attention, China has gradually caught up with the foreign standard level in the research and production of inductive electromagnetic sensors [17]. A series of high-tech research contents have been carried out for electromagnetic sensor technology. In the actual use environment,

due to the interference of magnetic field, we will be subject to fluctuations and uncontrollable decline in accuracy when receiving the feedback effect of electromagnetic sensor [18]. This requires electromagnetic sensor technology to maintain high sensitivity and accuracy in the detection process. In the traction power supply detection mode of metro rail transit, we can use electromagnetic sensors to detect and analyze its current noise and know whether the power supply system operates normally. According to the current measurement requirements of power system, sensor magnetic array is the best way to combine electromagnetic sensor and magnetic core. It can solve the problems of space interference and environmental multifactor interference. Therefore, electromagnetic sensor technology can be widely used in various fault detection and anti-interference facilities and equipment [19, 20].

Sensor technology developed earlier. In the use of electromagnetic sensors, they are mainly aimed at the field of automation and military machinery [21]. Due to the rapid replacement of mechanical equipment, the working conditions of military aircraft and other engines are severe, which are prone to defects and wear. Researchers have improved the traditional sensor technology into electromagnetic sensor technology to detect the damage of complex structures of equipment. The wear detection is processed by the combination of electromagnetic sensor and digital locking detection [22].

Researchers collect and study the signal transmission and speed of the motor according to the electromagnetic sensor and spiral rotation signal equipment [23]. They can convert the speed signal into frequency pulse signal to realize current voltage conversion. The signal measurement and feedback based on the electromagnetic sensor is mainly used in the hull power supply control system, with the advantages of accuracy and real time.

The sensor research field is applied to the monitoring system, and the research technology also covers from infrared sensor to indoor transmission electromagnetic sensor [24]. The electromagnetic sensor can detect and analyze according to the circuit change and aging, which improves the safety guarantee of residents' life.

China's corresponding national call for scientific and technological innovation, explore energy security and strengthen technical deployment in the deep-sea field. The application of electromagnetic sensor technology in marine controllable power supply system provides a research and development basis for the exploratory process of deep sea [25]. Mainly according to the electromagnetic time-frequency acquisition principle, combined with the sensor, the acquisition performance is analyzed. Based on the above development status of electromagnetic sensor technology in various countries, this paper puts forward the research on the detection mode of traction power supply of metro rail transit. The electromagnetic sensor is used to analyze the current noise signal and test the subway track potential. Finally, the influence of interference factors of power supply system is improved. This research can improve the safety of metro rail transit and realize the control of urban public safety.

3. Research on Detection and Improvement of Traction Power Supply of Metro Rail Transit Based on Electromagnetic Sensor in the Field of Urban Public Safety

3.1. Research on Traction Power Supply Detection Mode of Metro Rail Transit Based on Electromagnetic Sensor. All electrical equipment in the power system must operate under the condition of not exceeding their allowable voltage, current, and frequency, not only in normal operation but also in accident. Therefore, the security of power system represents the ability of power system to maintain continuous power supply in case of accident in a short time, which belongs to the problem to be considered in the real-time operation of power system. Reliability refers to the probability index that the power system continuously supplies power to users for a long time, which belongs to the scope of power system planning and design. Stability refers to the state that the power system can continue to supply power to the load normally after being disturbed, that is, it has the ability to withstand disturbances. It is generally divided into power angle stability, frequency stability, and voltage stability.

The stability and reliability of power supply system are the basis for the normal operation of metro rail transit system. The analysis and detection of power supply environment are also an important link to monitor the normal operation of metro. In order to study the power supply detection mode, the electromagnetic sensor needs to have high sensitivity and real-time reliability. Firstly, the inductive electromagnetic sensor is used to test and analyze the current noise, mainly from the bottom noise and sensitivity performance, combined with the actual comparison to test whether the electromagnetic sensor can meet the requirements of metro track traction power supply detection task. In this paper, the electromagnetic sensor is designed by coil induction. The basic components include high conduction magnetic core, multi-induction coil group, calibration coil, and current bottom noise amplifier. At present, the current noise analysis of electromagnetic sensor is usually based on the sensor design principle and the numerical simulation of induction coil noise, so as to obtain the noise index and analyze whether the power supply link is normal. However, this method cannot represent the bottom noise of the whole sensor, the actual noise index is small, and cannot make accurate judgment. Therefore, this paper improves the original sensor to be a highly sensitive inductive electromagnetic sensor, and its bottom noise has a uniform power spectrum in sound domain and frequency domain. In order to study the influence of current white noise signal operation on noise, the mean variance is used for signal power detection, respectively. The signal and power spectrum are shown in Figure 1.

It can be seen from Figure 1 that the influence of signal value, energy, and power value is very high, so we need to carry out differential operation and summation. The calculation formula is as follows:

$$\begin{aligned} \text{sub}_{(t)} &= f_{1(t)} - f_{2(t)}, \\ \text{add}_{(t)} &= f_{1(t)} + f_{2(t)}. \end{aligned} \quad (1)$$

FIGURE 1: Signal and power spectrum.

$f_{1(t)}$ and $f_{2(t)}$ form the contrast variables of signal values, respectively. After difference operation and summation, the energy value also changes accordingly. In order to get the influence of interference analog signal on noise signal, we need to add sinusoidal signal for differential sum operation. The signal and power spectrum after adding sinusoidal signal are shown in Figure 2.

As can be seen from Figure 2, the same signal value can be offset by using the signal difference technology. The signal value after differential calculation is equal to the sum of the previous signal values. If the electromagnetic sensor with equal frequency characteristics is adopted, the interference of environmental factors can be solved by differential technology, so as to obtain the bottom noise of power supply current. In this paper, the synchronous test is carried out from the same track position, and the actual mapping data and prediction data of the electromagnetic sensor probe are obtained through data acquisition and processing, as shown in Figure 3.

As can be seen from Figure 3, the power efficiency of the electromagnetic sensor before differential calculation is between 0.0005 and 100 Hz, and the range is relatively stable. The actual measured data can basically agree with the predicted data. The difference signal also decreases obviously in this frequency band, which shows that this method can be applied to the bottom noise acquisition process of electromagnetic sensor. Before the electromagnetic sensor traction algorithm, it is necessary to analyze the current noise detection combined with the track potential. DC traction mechanism is the main mode of metro track power supply. The traction mechanism converts electric energy into power supply basis and supplies power through feeder grid. The current generally flows back to the power supply station through the rail to form a completed current loop. Due to

FIGURE 2: Signal and power spectrum after adding sinusoidal signal.

FIGURE 3: Comparison between actual mapping data and predicted data of electromagnetic sensor probe.

the mixing of miscellaneous electricity, if there is a problem with the power supply mode, we cannot know according to the potential difference, so it will lead to instability such as potential frequency modulation. In urban public safety, if passengers cannot detect whether the power supply mode is normal when taking the subway, there will be step voltage and other personal hazards. The factors affecting the subway track potential include the maximum voltage during traffic operation and the leakage of stray current. The most frequent problem of power supply mode is in the return structure area. Based on the above situation, we need to use electromagnetic sensor magnetic field response to obtain the operation of power supply mode. First, learn about the setting of electromagnetic sensor, as shown in Figure 4.

As can be seen from Figure 4, since the electromagnetic track is close to the ground, the corresponding height is set to establish the coordinate axis. The sensor coil should be

FIGURE 4: Internal setting of electromagnetic sensor.

in a vertical parallel position. If the subway rail transit supplies power normally, the corresponding magnetic field will be generated and the induced electromotive force will be generated. We can obtain whether the traction power supply of metro rail transit is normal according to the reflection of magnetic field. The relationship between coil induction and coordinates is as follows:

$$E = C \frac{h}{x^2 + h^2}. \quad (2)$$

In the formula, C is the standard coefficient, that is, the induced electromotive force.

When the electromagnetic induction scheme is established, we can advance from single induction distribution to double inductance mode. Judge the position and operation of the subway car according to the change of the two inductances. The difference of electromotive force between

two inductors is

$$\Delta E = \frac{h}{x^2 + h^2} - \frac{h}{(x - L)^2 + h^2}. \quad (3)$$

The offset calculation formula of inductance electromotive force difference control is as follows:

$$e = \frac{((h/(x^2 + h^2)) - (h/((x - L)^2 + h^2)))}{((h/(x^2 + h^2)) + (h/((x - L)^2 + h^2)))}. \quad (4)$$

According to the above formula, we can get the induced electromotive force function diagram and its difference and sum value comparison diagram, as shown in Figure 5.

As can be seen from Figure 5, the difference can be realized that the center of the double inductor is located in the center and presents a monotonic function. This disadvantage is that the interval size is limited. If the vehicle track operation section changes sharply, it is likely to form error data. Therefore, the sum value calculation is carried out to solve it. The sum value image shows that this interval is almost a linear monotone interval, which can eliminate the signal processing error. According to the above research, we can use electromagnetic sensors for current detection and power supply potential judgment in the traction power supply detection of metro rail transit. It adds reliability guarantee for subway traffic safety in urban public safety.

3.2. Research on Improving Interference Detection of Traction Power Supply of Metro Rail Transit Based on Ring Array Electromagnetic Sensor. Facing the demand of traction power supply detection of metro rail transit, electromagnetic sensor array can solve the problem of spatial interference energy. With the reduction of research cost of sensors such as tunnel magnetoresistance (TMR), it is possible to form a variety of arrays. Compared with the traditional sensor equipment, the ring electromagnetic sensor array can have a centerless structure and there is no saturation problem. It greatly improves the performance of the whole power supply measurement process and can also be applied to power supply detection and protection equipment. The basic way of ring array detection is to use multiple TMR sensors to measure the change of magnetic field according to the ampere current path law. A closed current loop is added near the electromagnetic sensor to effectively resist interference and noise, so as to increase the accuracy of power supply detection.

According to the distance between the TMR sensor and the current carrier, the magnetic field range is sensed, so as to calculate whether the measured current is normal. Assuming that the conductor passes through the center of the ring array through a primary current and is vertical, the output signal of each single electromagnetic sensor is expressed as

$$V_{\text{tmr}} = K_s (H \cdot \hat{s}) = k_s \frac{I \times r}{2\pi r^2} \cdot \hat{s}. \quad (5)$$

FIGURE 5: Induced electromotive force function diagram and its difference, sum value comparison diagram.

In the formula, K_s represents the sensitivity of the sensor after calibration, H is the magnetic field intensity variable generated by the carrier, and I is the measured current variable. The average output value of multiple sensors in the array is calculated as follows:

$$V_{\text{mean}} = \frac{1}{N} \sum_{n=1}^N V_{\text{tmr}}^{(n)}. \quad (6)$$

N in the formula is the total number of sensors. If the carrier does not pass through the center of the ring array, the output value will have different ranges. The measured current value can be calculated according to the sensitivity:

$$I_{\text{cal}} = \frac{2\pi r V_{\text{mean}}}{k_s}. \quad (7)$$

In the ring TMR array, the measurement error needs to be calculated, and the interference factor is the adjacent conductor magnetic field. Set the current variable and center distance in 3D coordinates. Define the angle between the variable and the x -axis, that is, the position of the first electromagnetic sensor. The corresponding variable expression is

$$a^{(n)} = \frac{2\pi n}{N} + a_0 (n = 0, 1, \dots, N-1). \quad (8)$$

The distance relationship between the sensor and the measured current can be obtained from the basic principle of the ring array, that is,

$$V_{\text{mean}} = \frac{K_s}{2\pi} \left(\frac{I_0}{r_0} + \frac{I_1}{N} \right) \sum_{n=1}^N \frac{r_0 - d_{\text{cross}} \cos a^{(n)}}{r^2 + d_{\text{cross}}^2 - 2r_0 d_{\text{cross}} \cos a^{(n)}}. \quad (9)$$

Then, calculate the measurement error caused by

interference:

$$\varepsilon_{\text{cross}} = \frac{I_{\text{cal,cross}} - I_0}{I_0} = \frac{I_1}{I_0} \Delta_{\text{cross}}, \quad (10)$$

$$\Delta_{\text{cross}} = \frac{r_0}{N} = \sum_{n=0}^{N-1} \frac{r_0 - d_{\text{cross}} \cos a^{(n)}}{r_0^2 + d_{\text{cross}}^2 - 2r_0 d_{\text{cross}} \cos a^{(n)}}. \quad (11)$$

$\varepsilon_{\text{cross}}$ is the measurement error. It can be known from formulae (10) and (11) that the error is the ratio of the interference current to the measured current. The spatial distance between two currents determines the ratio range. It can also be proved that after the initial array is determined, the error value can decrease with the increase of the number of TMRs, then

$$\lim_{N \rightarrow +\infty} \Delta = 0 (r_0 < d_{\text{cross}}). \quad (12)$$

When the number of TMRs increases, the output of the ring array is closer and closer to the Abe loop principle. That is, the calculation along any path in the magnetic induction intensity is equal to the algebraic sum in the current path multiplied by the permeability. The relationship between the error value and the number of electromagnetic sensors and interference distance is shown in Figure 6.

As can be seen from Figure 6, in order to show the relative relationship between distance and current, it is assumed that there is interference. Most interference currents are the same, and the number of sensors changes from 1.5 to 6. It can be seen that the maximum measurement error occurs when the distance is between 16 and 20. With the increase of distance, the measurement error decreases exponentially and approaches 0. In the carrier measurement error, we also need to consider the eccentricity error of electromagnetic sensor in the influence of noninterference and geomagnetism. The influence of eccentricity error on annular TMR array is shown in Figure 7.

As can be seen from Figure 7, the intersection of the carrier and the annular array is no longer on the center of the circle, a variable d_{unc} is defined as the center offset variable, and the distance between the intersection and the electromagnetic sensor is calculated. The distance of each sensor is different due to the eccentricity of the carrier. Calculate the output current of the ring array, the distance from the carrier to the sensor, and the direction of the sensitive axis according to the Biot-Savart formula:

$$V_{\text{mean,unc}} = \frac{k_s I_{\text{cal}}}{2\pi r_0} = \frac{1}{N} \sum_{n=1}^N V^{(n)}. \quad (13)$$

Finally, the relative measured value of offset error is derived according to the above formula:

$$\varepsilon_{\text{unc}} = \frac{I_{\text{cal,unc}} - I_0}{I_0} = \Delta_{\text{unc}} - 1. \quad (14)$$

Through calculation, we can know that when multiple

FIGURE 6: Relationship between error value and number of electromagnetic sensors and interference distance.

FIGURE 7: Influence of eccentricity error on annular TMR array.

TMR sensors are used, the maximum error caused by eccentricity is uncontrollable. This situation will lead to serious measurement failure. However, with the increase of the number of sensors, the error decreases exponentially. Therefore, in the detection process of traction power supply of metro rail transit, we can apply electromagnetic sensors to optimize the measurement error and anti-interference application. The annular array of electromagnetic sensors has excellent compensation ability for error offset, improves the accuracy of actual measurement, and gives the offset range.

4. Analysis of Research Results of Metro Rail Transit Traction Power Supply Detection and Improvement in the Field of Urban Public Safety Based on Electromagnetic Sensor

4.1. Analysis of Research Results of Traction Power Supply Detection Mode of Metro Rail Transit Based on

FIGURE 8: Sensitivity feedback curve after adding modulated square wave signal.

Electromagnetic Sensor. Firstly, the sensitivity of the induction effect of the electromagnetic sensor is tested. The ratio of the induced voltage to the magnetic field strength and frequency changes with the change of the magnetic field strength. In the high-frequency stage, the effective area of the magnetic core becomes smaller, which reduces the control of the electromagnetic sensor on the sensitivity of the power supply mode. Therefore, in this paper, the excitation coil is used to generate the corresponding magnetic field to realize the production of magnetic field strength within the limited power range. A modulated square wave signal is added to the excitation coil, and the frequency signal is collected at an interval of 0.1 seconds. The sensitivity feedback curve in the power supply system can be obtained by measuring the current output signal corresponding to the sensor, as shown in Figure 8.

As can be seen from Figure 8, when the magnetic field strength is weak and the frequency is low, the corresponding induced voltage is also low. The number of acquisition points generated in the interval seconds of the modulation frequency signal is larger and larger, and the feedback frequency is more and more dense. Experiments show that the electromagnetic sensor has high induction sensitivity in power supply detection mode. It can effectively detect the current direction and whether the output voltage is normal. We use the area with a length of 1.132 km from Hongshan station to Nanjing station for power supply detection. The actual test results are shown in Figure 9.

As can be seen from Figure 9, as the subway depth decreases, the section track resistance is also different. We represent the resistance change in different colors to obtain the current voltage and current. The closer the color to red, the higher the resistance. It can be seen that the power supply is in normal state and the resistance change is basically stable. The high sensitive feedback efficiency of electromagnetic sensor is also reflected in the actual detection, which provides a guarantee for urban public transport safety.

4.2. Analysis of Research Results on Improving the Detection Interference of Metro Rail Transit Traction Power Supply Based on Ring Array Electromagnetic Sensors. Based on the ring TMR array prototype, this paper adopts the full bridge structure design, including high-sensitivity sensing unit. In order to verify the performance of annular array electromag-

FIGURE 9: Diagram of metro car body current surround and power supply detection results.

FIGURE 10: Comparison diagram of eccentricity value, anti-interference actual value, and theoretical value.

netic sensor, we designed an error test system. When the carrier passes through the sensor array, connect the current power supply and DC power supply. The current mode is regulated by a selector switch. We take the collected high-precision resistance as the reference of the measured data. Control the eccentricity of the ring array and compare the actual value and theoretical value of the anti-interference error value, as shown in Figure 10.

As can be seen from Figure 10, the current output is controlled at the same variable, and the distance change of the sensing conductor is adjusted for sampling. It can be seen that the actual test value of the experimental error value is almost the same as the theoretical value, which basically achieves the experimental purpose. It can effectively improve the interference in power supply detection in metro rail transit traction and increase the accuracy and sensitivity of power supply detection mode. In the field of urban public safety, metro rail transit has always been a content that cannot be ignored. If we can effectively improve subway traffic safety, we can further ensure urban public safety.

To sum up, this paper optimizes and improves the interference in the detection of metro traction power supply according to the ring array electromagnetic sensor technology. The error frequency in power detection is basically reduced, improving high sensitivity feedback efficiency and anti-interference performance in power detection mode. The above research results show that electromagnetic sensor technology can improve the safety of metro rail transit and ensure the timeliness and effectiveness of power supply detection. The study meets the needs of urban public safety and should be vigorously carried out and supported.

5. Conclusion

In the process of urbanization, with the growth of population base, the problem of public security is gradually revealed. Facing the complex social environment, how to safely and effectively apply high-tech development has always been an inevitable research content in people's life. Based on the traction environment of metro rail transit in the field of urban public safety, this paper studies and analyzes the application of electromagnetic sensor technology in power supply detection mode. Firstly, the functional gap between electromagnetic sensor and ordinary sensor is analyzed, and the appropriate research direction is found through the development status of various countries. Then, the electromagnetic sensor is mainly used to analyze the power supply mode of current noise detection and judge whether there is voltage fault through the change of potential difference. Analyze whether the power supply mode is normal according to the change of magnetic field and induced electromotive force, and effectively judge the vehicle body section where the fault occurs. Test the sensitivity of the electromagnetic sensor to prove whether it meets the power supply detection requirements. Finally, according to the ring array electromagnetic sensor technology, the interference in the traction power supply detection of metro rail transit is optimized and improved. Basically reduce the error frequency in power supply detection. Improve the high sensitivity feedback efficiency and anti-interference performance in power supply detection mode. The above research results show that electromagnetic sensor technology can improve the safety of metro rail transit and ensure the timeliness and effectiveness of power supply detection. The study meets the needs of urban public safety, so it should be vigorously developed and supported.

Although intelligent electromagnetic flow sensor has many advantages and is widely used in various fields of industrial production, it also has some shortcomings so that it is limited in use. Electromagnetic flow sensor cannot be used to measure gas, vapor, and liquid containing a large amount of gas. This has caused some obstacles in rail transit. Because the insulating lining material of the measuring pipe is limited by temperature, the industrial intelligent electromagnetic flow sensor cannot measure high-temperature and high-pressure fluid. In addition, it is also vulnerable to external electromagnetic interference. Therefore, in the future research, the research will continue to focus on the above problems.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The author declares that there are no conflicts of interest.

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