Development of a portable and fast wire tension measurement system for MWPC construction *

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Abstract: In a multi-wire proportional chamber detector (MWPC), the anode and signal wires must maintain suitable tension, which is very important for the detector's stable and accurate performance. As a result, wire tension control and measurement is essential in MWPC construction. A high pressure ^{3}He MWPC detector is to be used as the thermal neutron detector of the multi-functional reflectometer at China Spallation Neutron Source, and in the construction of the detector, we have developed a wire tension measurement system. This system is accurate, portable and time-saving. With it, the wire tension on an anode wire plane has been tested. The measurement results show that the wire tension control techniques used in detector manufacture are reliable.

Keywords: MWPC, wire tension, tension measurement, CSNS

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1 Introduction

The China Spallation Neutron Source (CSNS) is currently under construction, and three neutron scattering instruments are being built at the same time. Of these, the multi-functional reflectometer employs a high pressure ^{3}He gas multi-wire proportional chamber (MWPC) as its neutron detector [1]. This detector is designed using an 8 atm $^3He/C_3H_8$(80/20) mixture as working gas and gold-plated tungsten as anode and signal wires. The sensitive area of the detector is designed to be 200 mm×200 mm, and the neutron space resolution is expected to be less than 2 mm. The counting rate can reach $10^7/\mathrm{cm}^2\mathrm{s}$ [2]. Due to the influence of electrostatic force and gravity, the anode and signal wires will have some position offset. As a result the performance of the detector, including magnification, position resolution, etc, will be affected [3]. To ensure the wires' position deviation is as small as possible, it is very important to keep the wires at proper tension, so we have to measure and control the wire tension in the detector construction. The principle of the wire tension measurement is based on the relationship between the tension and its vibration inherent frequency, which is shown as formula (1):

$$T = 1\times 10^{-6}\cdot \rho(2Lf_0)^2, \tag{1}$$

where T(N) is the wire tension, f_0(Hz) is the wire vibration fundamental frequency, ρ(mg/m) is the linear mass density, and L(m) is the wire length.

Based on this principle, a lot of equipment has been designed in the past. In general these can be sorted into two classes. In the first class, different periodic driving forces are input to a wire to make the wire resonate, then by determining the resonance frequency the wire's inherent frequency can be measured. Because of the driving force generator and resonance determination module required, this type of equipment is complicated and the measurement is time consuming [4–10]. In the other class, a short-time driving force is used to make the wire vibrate, and then the signal of the vibration is measured to analyse the wire inherent frequency [11−15]. In this type of equipment, the wire inherent frequency is measured directly, so the measurement is quicker and

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more accurate, but a powerful signal processing system is needed.

In this paper, we present a simple, quick and accurate equipment by using the wire vibration method to measure the wire tension in MWPC construction.

2 Description of tension measurement system

According to Faraday's law, when a wire with current (I) is placed in a magnetic field (B), it will experience a force (F), and the force is equal to $I\cdot L\times B$. When a wire is vibrating in a magnetic field with velocity v, electric potential is induced along the wire. The potential is equal to $L\cdot v\times B$. Based on this principle, we designed a simply equipped wire tension measurement system. Two electromagnets are used to generate an adjustable magnetic field, and the wire which will be measured is placed between them. A mono-stable trigger mode is used to produce narrow pulses, then the pulses are amplified by a power amplifier and used to stimulate the wire to vibrate in the magnetic field. To make sure the wire generates the largest vibration, the pulse widths are controlled to about one fourth of the expected wire inherent vibration period. Then the vibration signal, which is an attenuated sine wave in theory, is amplified by a operational amplifier module. Finally, the vibration signal is recorded and analyzed by a digital oscilloscope or a computer controlled data acquisition board, and the vibration frequency is measured. A schematic drawing of the system is shown in Fig. 1.

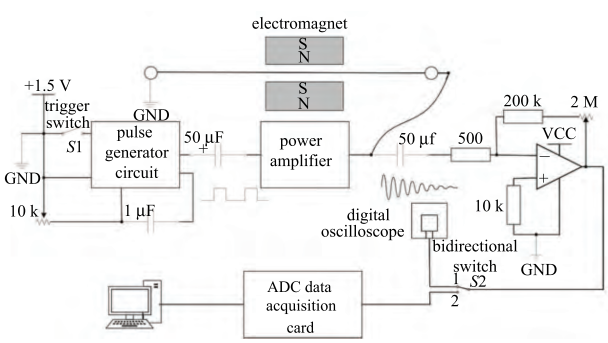


Fig. 1. Schematic block diagram of the wire tension measurement system.

As shown in Fig. 1, two solenoidal electromagnets with 22 mm diameter magnetic poles, which are operated with a 30 V DC power supply, are placed in the same direction about 10 mm apart. When the power supply voltage is set to 30 V, the magnetic field between the magnets along the wire direction is shown in Fig. 2. If the current in a wire is 1 A, the force applied to the wire is about 3.24×10^{-3} N. The mono-stable trigger, which is connected to a 1 μF capacitor and a 10 kΩ variable resistor and operated with 5 V DC power, can generate a TTL pulse with a maximum width of 4 ms. This is calculated by the formula $\tau=K\cdot R\cdot C$ ($K=0.4$, which is from the mono-stable trigger chip product manual). It makes the system adapt to measure wires with inherent vibration frequency no less than 62.5 Hz. The power amplifier in the system has a 3 A rated current and can amplify the TTL pulse to 15 V level. In the operational amplifier module, a 500 Ω resistor is connected at the input terminal and a 2 MΩ potentiometer is used as the feedback resistor, so the voltage amplification factor can get up to 4000. For flexibility, we design two options to analyze vibration signals. One method uses a digital oscilloscope to record the signal and do Fourier transforms, and the other uses a 12-bit ADC data acquisition board to converts the analog signals to digital signals and transmit them to a computer, then a LabVIEW program is used to display and analyze the signals. To suppress direct current interference, 50 μF capacitors are used for the different function modules.

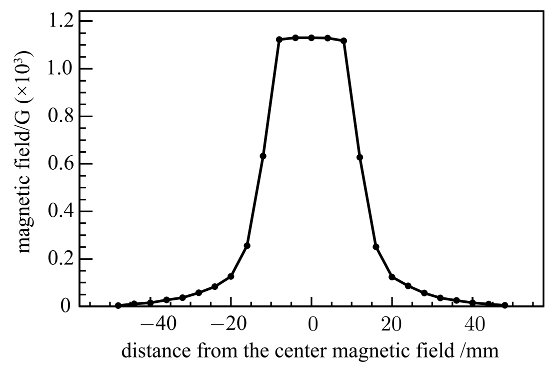


Fig. 2. The magnetic field distribution between two magnets along the measured wire.

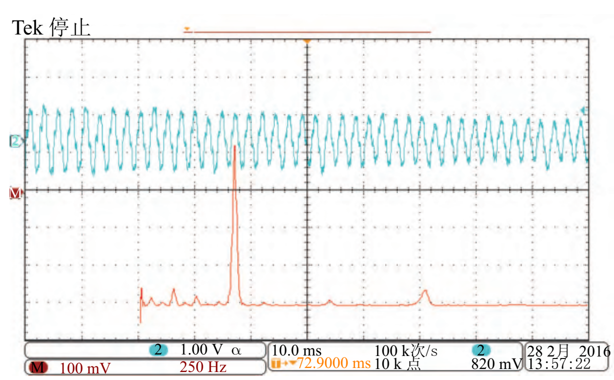


Fig. 3. (color online)The upper waveform is a wire vibration signal and the lower one is the corresponding spectrum of the Fourier transform analyzed by a digital oscilloscope.

A vibration signal captured by oscilloscope and its frequency spectrum are shown in Fig. 3. In this picture, the wire's diameter, length and applied tension are 25 μm, 240 mm and 40 g respectively, and the operating voltage of the electromagnets is set at 30 V. The highest peak at about 420 Hz on the frequency spectrum is the fundamental harmonic, while the peaks at about 1260 Hz are the third harmonic of the wire. Because of this, measuring a wire's frequency with the system takes only a few seconds. At the same time, this system records a half first harmonic signal [10].

For flexibility, an ADC data acquisition board and a LabVIEW computer program were designed as an alternative to a digital oscilloscope. The data acquisition board has a sample rate of 80 kHz and can convert ±8 V analog signals into digital ones. With a USB2.0 connector digital signals in the board are transmitted to a personal computer. Using a LabVIEW signal analysis program, the measurement digital accuracy can reach 1 Hz, which is of the same order of the measurement error. By only taking a low-voltage power supply and a personal computer, the system can be used in any location where it is needed. Fig. 4 shows the front panel and the flow diagram respectively of its corresponding graphical program in the LabVIEW platform.

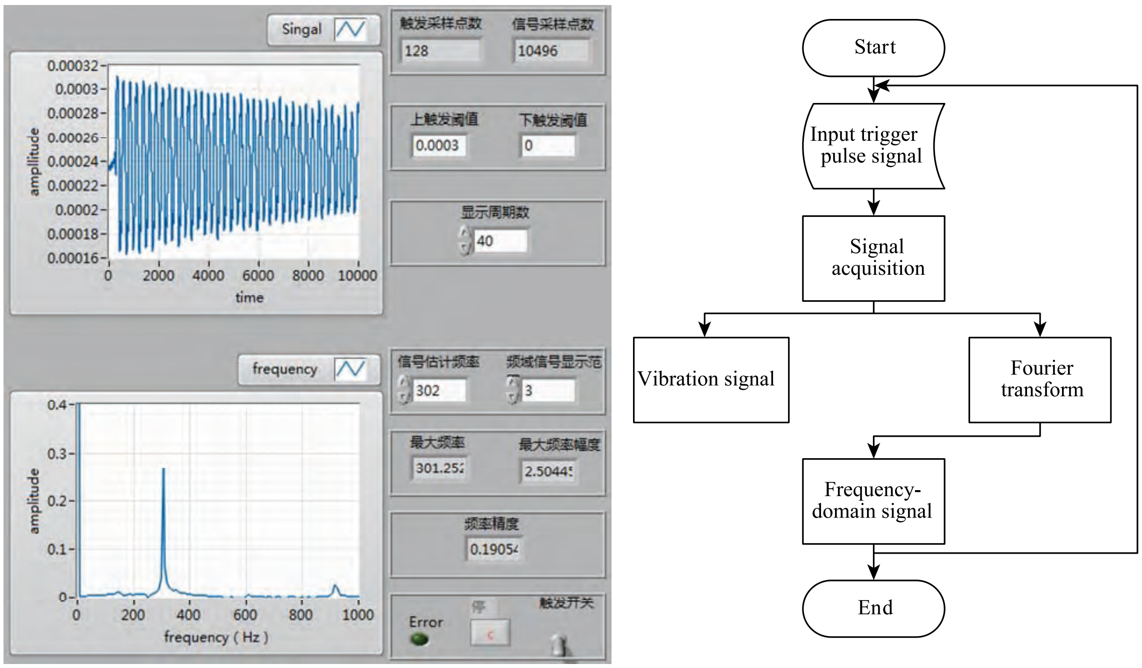


Fig. 4. (color online) The LabVIEW program of the wire tension measurement system (left: front panel, right: flow diagram of the graphical program).

3 Performance of the measurement system

3.1 Accuracy of the system

To test the accuracy of the wire tension measurement system, we measured 240 mm long and 25 μm diameter wires with 20, 30, 40...130 g tension 40 times respectively. The linear mass density is ρ=9.3±0.8 mg/m, which is provided by the wire's supplier. Figure 5 is the measured frequency results of a 20 g tension wire, and the measured frequencies of wires with other tension values have similar distributions. The measured average frequencies and their standard deviations are listed in Table 1, where they are marked as "measured frequency". In the measurement, the electromagnet voltage was set to 25 V. Based on formula (1), we calculated the inherent frequency of every wire, and the results are also shown in

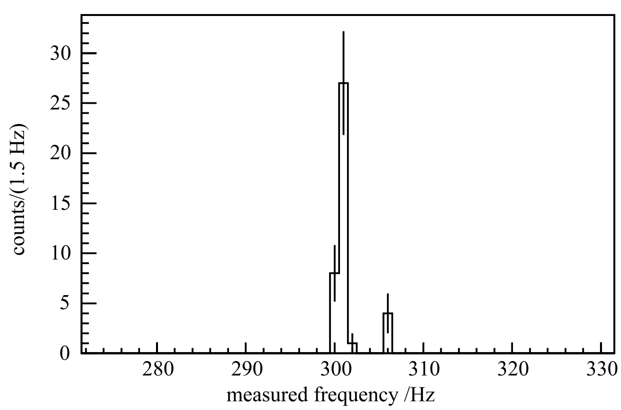


Fig. 5. The distribution of repeated measurements of a single wire with 20 g tension.

Table 1. The calculated and measured frequencies and the errors of some wires.

tension/g	20	30	40	50	60	70
calculated frequency/Hz	302±14	370±17	428±20	478±22	524±24	566±26
measured frequency/Hz	301.5±1.7	371.4±1.3	426.3±1.1	480.5±0.6	522.4±2.5	561.5±1.2
tension/g	80	90	100	110	120	130
calculated frequency/Hz	605±28	642±30	676±31	709±33	741±34	771±36
measured frequency/Hz	601.8±1.3	645.9±1.2	670.5±1.7	700.8±0.8	735.6±1.2	764.9±1.8

Table 1. In Table 1, the calculation error is from linear density uncertainty of the wires. As shown in Table 1, the measured results are very close to the calculated values. We draw the results in Fig. 6 and fit the results with a line. As shown in the figure, the measurement system can measure different wire tensions perfectly.

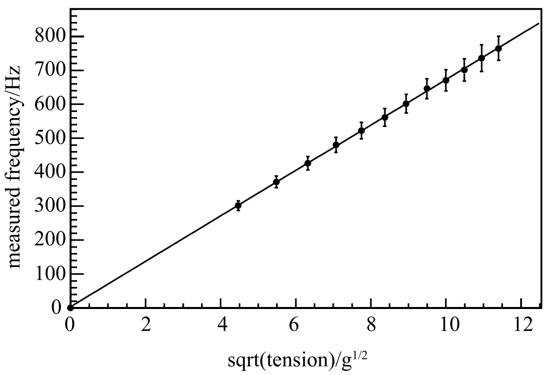


Fig. 6. The measured frequencies vs. the wire tension. The X axis is the wire tension's square root and the Y axis is the measured wire vibration frequency.

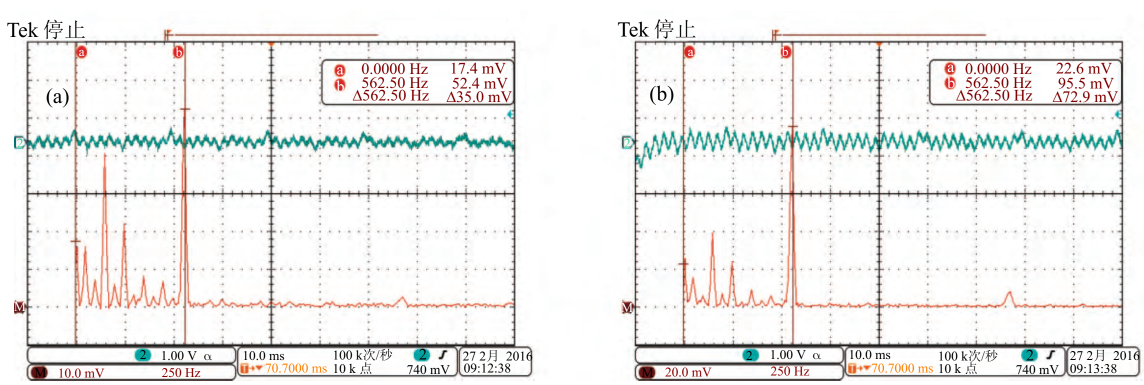
3.2 Signal-to-noise ratio vs. magnetic intensity

As shown in Ref. [11], by enhancing magnetic field intensity, we can increase the amplitudes of wire vibration signals and signal-to-noise ratio. So we set the electromagnet voltages at different values to check the system performance. Figure 7 (a)−(d) shows the vibration signals and their frequency waveforms for wire with 25 μm diameter, 240 mm length and 80 g tension when the electromagnet voltage is set at 10, 15, 20 and 30 V. As expected, the signal amplitude and the signal-to-noise ratio increased obviously with the magnetic field enhancement. Figure 8 shows the signal amplitudes and measured frequencies with different magnetic intensities. Figure 9 shows the measurement errors. Obviously, to get better results, the system should set the magnetic field as strong as possible.

The effect of trigger pulse width on the wire vibration signal was also tested. As expected, it is similar to that of magnetic intensity. The dependence of the vibration signal amplitude on the trigger pulse amplitude is shown in Fig. 10.

3.3 Wire length effect

To test the performance of the system in measuring different sizes of MWPC, we measured some 25 μm diameter wires with 50 g tension, with the length of the wires from 250 mm to 450 mm. In these measurements, the electromagnet voltage was 30 V. Figure 11 shows the results. As displayed, the system can get correct frequencies for different length wires. Wire tension of an MWPC with sensitive area from 200 mm×200 mm to 450 mm×450 mm can be measured by the system correctly.



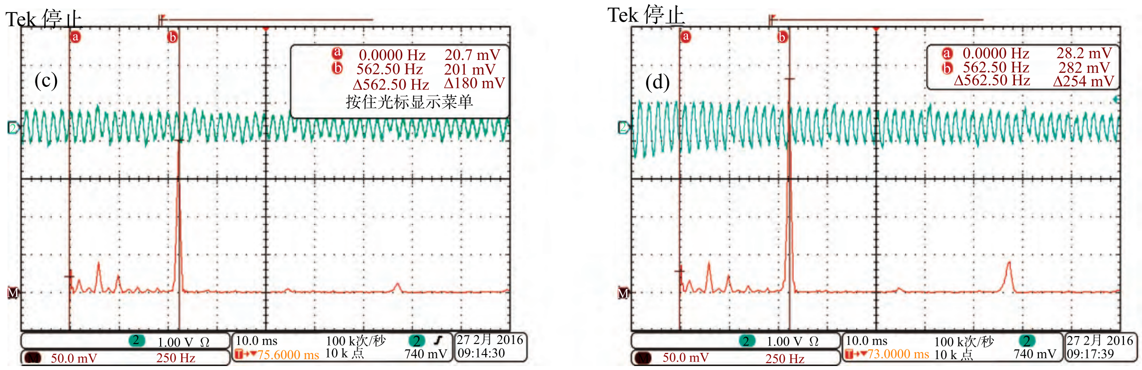


Fig. 7. (color online) (a),(b),(c),(d) are vibration signals and corresponding frequency spectra when the electromagnet voltage is set at 10, 15, 20, and 30 V respectively.

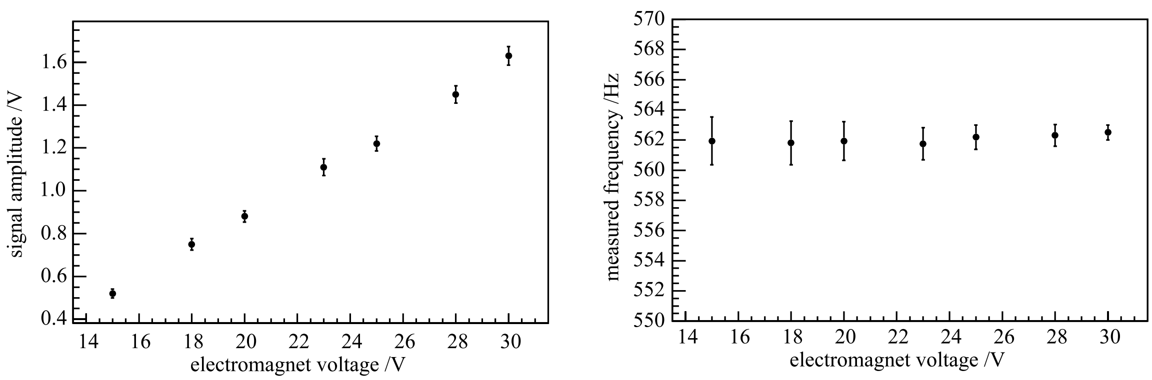


Fig. 8. Signal amplitude and average measured frequency vs. electromagnet voltage.

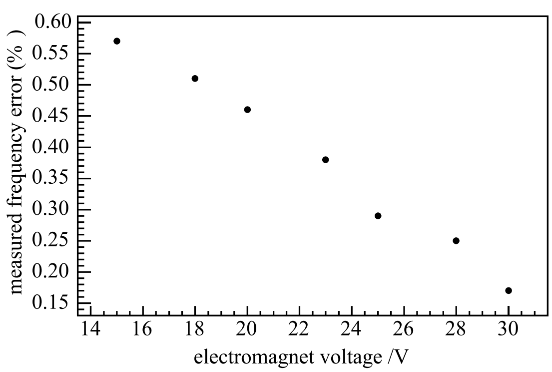


Fig. 9. Frequency error at different electromagnet voltage.

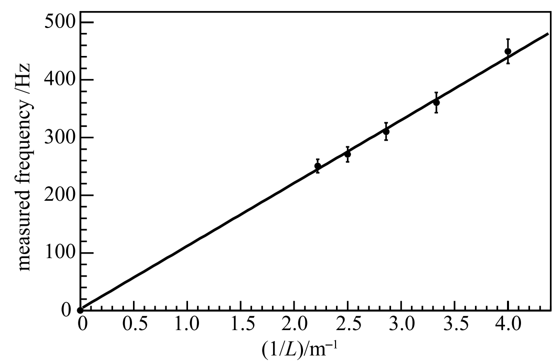


Fig. 11. Average measured frequency vs. reciprocal of wire length.

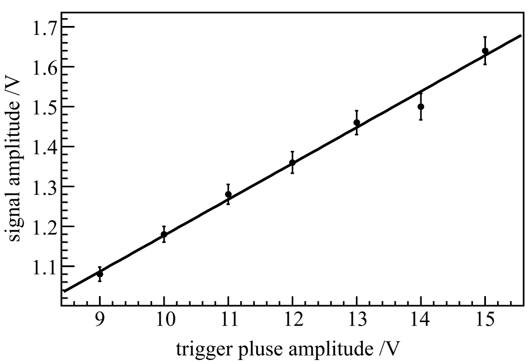


Fig. 10. Trigger pulse amplitude vs. amplitude of the wire signal.

3.4 Wire tension of an anode wire plane

In the MWPC neutron detector of the CSNS multifunctional reflectometer, many 25 μm, 206 mm long wires with 50 g tension are welded on a PCB board, parallel at 2 mm intervals, to make an anode wire plane. To make sure the detector has a steady and uniform amplification factor, the tension deviation is controlled to no larger than 10%. Using the system described above, we measured the tension in the anode wires. The results

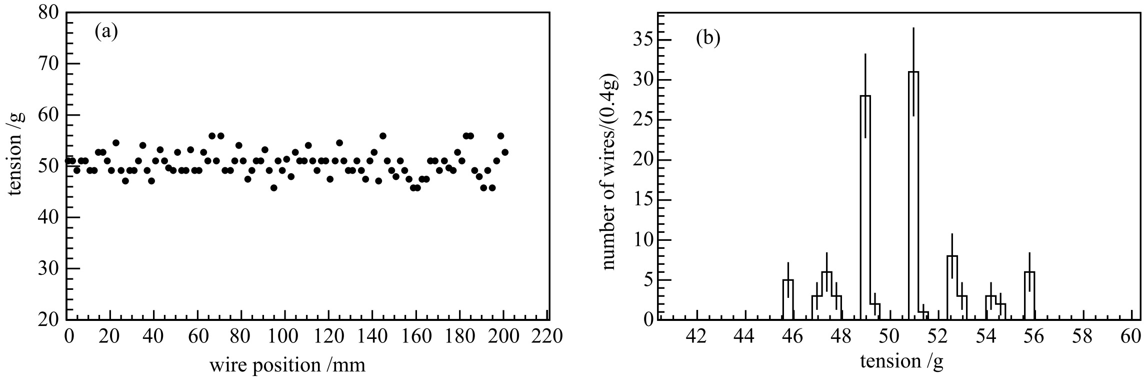


Fig. 12. Measured wire tensions in an anode wire plane. (a) the X axis is the wire positions in millimeters; (b) measured results distribution.

are shown in Fig. 12 and the standard deviation is about 3.5%. This means the wire tension control techniques in the wire plane manufacturing are reliable and accurate.

4 Discussion

For the construction of MWPC neutron detectors at CSNS, we developed a portable, accurate and time-saving wire tension measurement system. With a low-voltage power supply and a digital oscilloscope or a personal computer, the system can measure a wire's tension in a few seconds with an error of about 3 Hz. Compared with the wire's diameter and tension uncertainties, the measurement error is very small and can be neglected. We also used the system to test the tension of all wires in an anode wire plane of a MWPC. The results show that the wire tension control methods in the detector construction are reliable, and they can make the detector work stably in the future.

The design of the system consults the paper A Device for Quick and Reliable Measurement of Wire Tension in Princeton/BaBar TNDC-96-39 by Mark R.Convery. We express our appreciation to the author.

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