JOINT INSTITUTE FOR NUCLEAR RESEARCH

Veksler and Baldin laboratory of High Energy Physics

FINAL REPORT ON THE
START PROGRAMME

Investigation of the methods for measuring the tension of the

signal wire in straw trackers

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Annotation

In this work, modern methods for measuring the tension of the anode wire used in detectors based on thin-walled drift tubes are discussed. The relevance of the topic is determined by the need to improve the accuracy and reliability of detectors in various fields, including particle physics and radiation safety.

Content

Introduction

The development of wire detector technology is always associated with increasing demands for the accuracy of coordinate measurements. In this context, the tension of the anode wire is an important parameter that significantly contributes to the accuracy of coordinate determination. Tension is related to electrical stability and determines corrections to the position of the wires caused by electrostatic forces and gravitational forces. Thus, the magnitude of the wire tension and its stability over time are crucial quality criteria for the production of high-precision wire detectors.

This paper describes a device developed for monitoring the tension of wires in the assembly area of drift tubes.

1. Detectors based on thin-walled drift tubes (straw detectors)

Detectors based on thin-walled tubes (straw detectors) are most commonly composed of chambers made from two rows of thin-walled drift tubes – straws, as shown in Figure 1, filled with a gas mixture of argon (Ar) and carbon dioxide (CO_2) in proportions of 80/20 or 70/30.
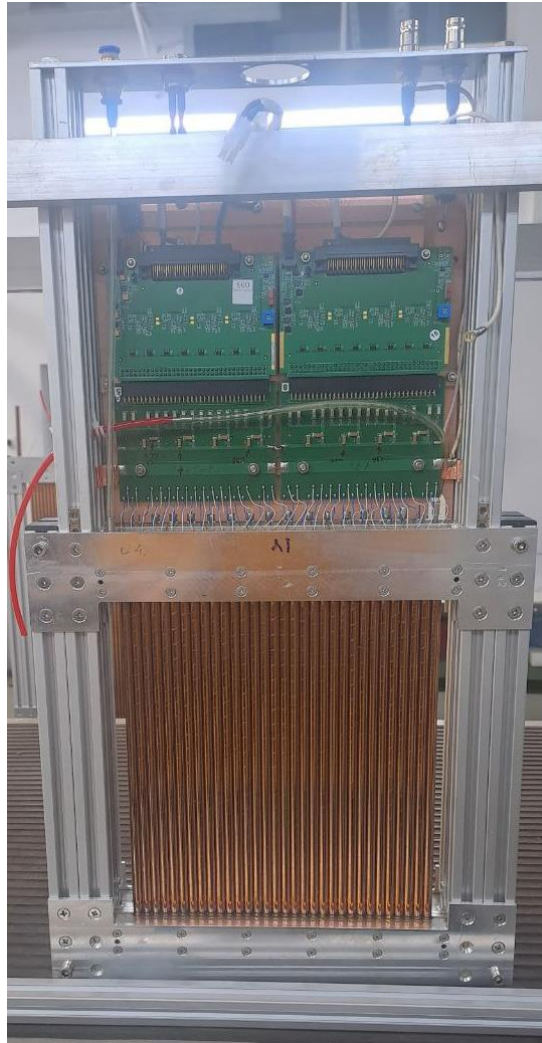

Figure 1 shows a chamber with 64 straw tubes and an active area of 20x20 cm^2

Straw detectors are used for: detecting elementary particles in accelerator experiments, monitoring radiation dose in radiotherapy, ensuring the safety of procedures, and studying cosmic rays.

2. Thin-walled drift tubes (straw tubes)

2.1 Design

The assembled thin-walled drift tube (straw) consists of a precision polymer (polyimide) tube, the inner surface of which is conductive and serves as the cathode, with an anode wire installed along the axis of the tube, the ends of which are secured. To fix the anodes, capillary metal tubes are often used, which are mounted in plastic end caps. The assembled tube is schematically shown in Figure 2.

To reduce the gravitational and electrostatic displacement of the anode from the axis of the tube in long straws, supporting anode spacers are installed, one for every 80–100 cm of anode length. The design of the spacers can vary. For example, Figure 2 shows the spacer of the COMPASS straw tracker, which has minimal dimensions in terms of its length and the amount of its own material: 15 mg and 25 mg for straws with diameters of 6 mm and approximately 10 mm, respectively. In this experiment, polycarbonate spacers were used, glued to the wire at precisely defined positions with high-viscosity adhesive ARALDITE-2013.
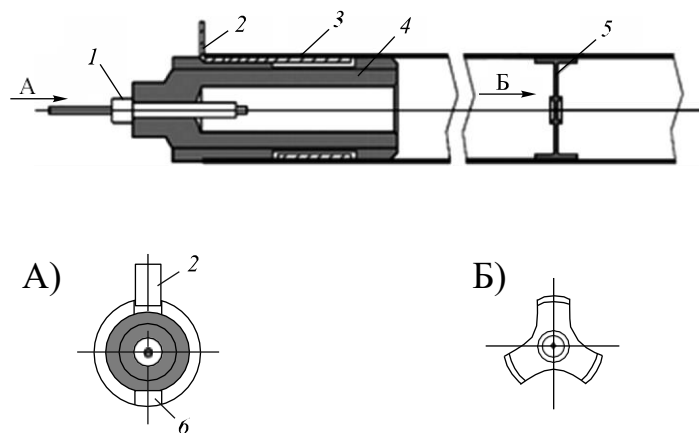

Figure 2. Diagram of the straw with inserted elements: 4 — end cap; 5 — spacer; 1 — crimp pin for securing the anode wire; 2 — ring spring for grounding the straw's cathode; 6 — gas channel. А — top view of the end cap; Б — top view of the spacer.

2.2. Requirements for the accuracy of design elements and materials used

The accuracy of all elements and technological assembly procedures of the straw must ensure high coaxiality of the tube with the anode along its entire length and positioning accuracy of the anodes no worse than 100 microns. The requirements for the materials used in the straw are: high radiation resistance, absence of outgassing, and undesirable impurities. Research conducted in the laboratories of Dubna on various materials has shown good properties of polycarbonate, which is widely used for manufacturing precision plastic components.

2.3. Principle of operation of straw tubes

The straw is a cylindrical tube with a conductive inner layer — cathode and a thin coaxial to it wire — anode. The magnitude of the electric field along the radius of the straw varies inversely with the distance r_i and is defined by the expression:

$$E(r_i) = \frac{V}{r_i \, ln(R \, / \, r)}$$

where V — voltage between the electrodes of the straw; r_i — radial distance from the anode; r — radius of the wire; R — radius of the tube.

The strong electric field near the surface of the anode reaches values exceeding 10^5 V/cm at several radii from it. Primary ionization electrons in a strong electric field, as a result of inelastic collisions with gas atoms, create an electron avalanche at the surface of the anode. The secondary ionization produced by them provides gas gain G, sufficient for registering induced anode and cathode signals.

Depending on how the anode wire is considered — as a source of current or voltage — the signal recorded by the amplifier is described by the following expressions:

$$I(t) = q \frac{d}{dt} F(t) \, , \quad \Delta V(t) = \frac{q}{C} F(t)$$

were

$$F(t) = \frac{\ln\left(1 + {}^{t}/t_0\right)}{\ln\left(1 + {}^{t_{max}}/t_0\right)}$$

q — positive charge of the avalanche; C — capacitance between the anode and cathode; constants: t_0 has a value of approximately 1 ns and t_{max} (the time for positive ions to reach the cathode) — few microseconds.

The schematic diagram for obtaining coordinate information about the point of intersection of a particle with the anode wire, determined by measuring the drift time of the ionized electron to the anode wire, is shown in Fig. 3. In this case, the radial coordinate of the electrons closest to the anode cluster is measured, defining the radius of the coaxial surface of the cylinder with electrons that caused the avalanche. To eliminate left-right ambiguity for the tracks of passing particles, the straw chambers contain two layers of straw, offset by their radius. The stereo coordinate of the particle's trajectory point is determined from information from several differently oriented straw chambers intersected by particles. The presence of multiple chambers with different orientations allows for the determination of the spatial coordinates of particles.
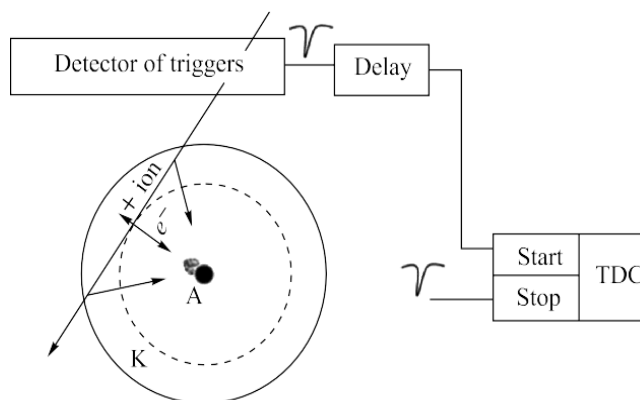

Fig. 3. Diagram for registering the radial coordinate during the passage of a charged particle in a straw tube.

3. Tension test

3.1. Tension test of the wire

Existing methods for measuring the tension of anode wires in various wire detectors are typically based on the relationship between the tension of the wire and the fundamental frequency of its free vibrations:

$$f = \frac{1}{2L}\sqrt{\frac{T}{\tau}}$$

where f is the frequency of oscillation; L, T, and τ are the length, tension, and linear density of the wire.

Usually, forced vibrations of the wire are induced by an external periodic force. The amplitude of the vibrations or their phase is observed as a function of the frequency of the external influence. When this frequency coincides with the natural frequency of the wire, the amplitude of the vibrations approaches its maximum, and the phase shift is equal to $\frac{\pi}{2}$. Various methods are used to excite vibrations: electrostatic (by applying an alternating voltage to the electrodes), electromagnetic (by passing a sound-frequency current through the wire placed in a magnetic field), or mechanical (using a vibrator or sound waves). The vibrations of the wire can, in turn, be registered by changes in the impedance of the wire or by the electromotive force induced in the wire as a result of oscillations in a magnetic field.

Such methods are well-studied, but achieving an accuracy better than 0.5% with them is quite challenging. This is due to the fact that the form of excitation of the vibrations can influence the measurement results. Additionally, significant effects arise from damping, which shifts the maximum of the amplitude response towards lower frequencies.

Based on this, to achieve the set goals, a method was chosen where the main distinction lies in observing not forced, but free vibrations of the wire. The wire is placed in a constant magnetic field, and its vibrations are excited by a series of

current pulses. Then, the application of the exciting pulses is stopped, and the electromotive force induced in the wire due to free damped vibrations in the magnetic field is amplified and digitized. To determine the spectral composition of the vibrations, the obtained data is analyzed using Fourier transformation, after which the fundamental harmonic of these vibrations is identified. The use of free damped vibrations and Fourier analysis allows for virtually complete elimination of the effects of damping and the method of excitation of the vibrations. In this measurement method, the ratio of the amplitudes of harmonics and the width of peaks in the spectrum may vary, but their positions remain unchanged. Moreover, due to the discreteness of the spectrum of free vibrations, this method allows for obtaining accurate results even at extremely low signal amplitudes comparable to the noise induced in the wire.

The preliminary measurement of the wire tension is conducted after it has been secured in the crimp pins of the end sleeves of the strouhal detector, as shown in Fig. 4. The final measurement of the tension is carried out after soldering the signal wire to the pin to eliminate any loosening of the tension after heating the pin or due to mechanical damage, as shown in Fig. 5.

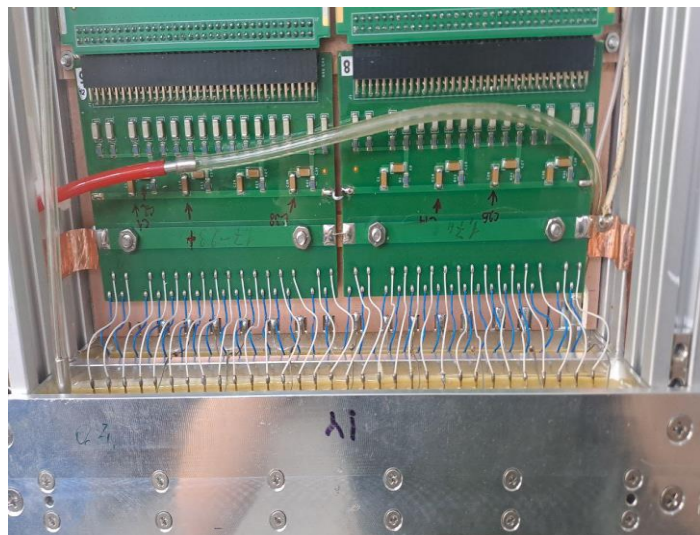Fig. 4. Preliminary tension measurement with a magnet.

Fig. 5. Final tension measurement is conducted after soldering the signal wire to the pin.

Physically, the measurement occurs through a device connected via USB to a PC on one side and connected through wires to the crimp pins of the wire on the other side.

Fig. 6. Device for measuring tension with a USB cable for connecting to a computer.

3.2. Device for checking wire tension

A similar method for measuring the tension of the anode wire was used in a device created in the late 1990s at the Nuclear Problems Laboratory of JINR. The main drawback of that device was that it was based on a DAC-ADC installed on the ISA bus of a personal computer.

Since computers with this bus ceased production in the early 2000s, and old computers gradually became obsolete, the idea arose to create a similar device that could be connected to a computer via USB, allowing the use of any modern computer with a USB port. Below is the block diagram of the device, Fig. 7.

The software of the hardware-software complex is divided into two parts: the software for the STM32 microcontroller located in the device and the user software on the PC. The ModBus RTU communication protocol is used between the microcontroller and the user PC. STM32 acts as a slave device, while the PC is the master.
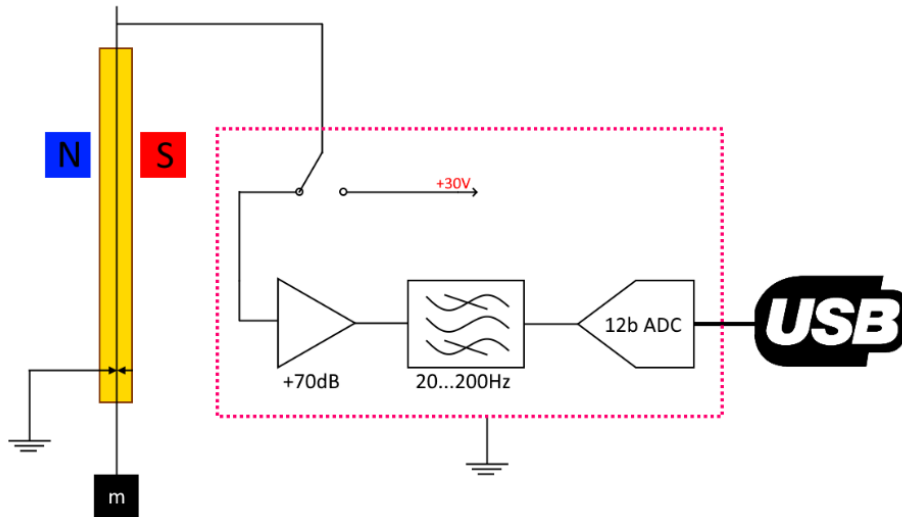
Fig. 7. Block diagram of the tension measurement device.

STM32 provides ModBus storage registers that allow the user to set: the number of pulses to be applied to the wire, the pulse frequency, pulse duration, and measurement sampling frequency. The block diagram of the STM32 software operation is presented in Figure 8.

When recording a certain number N in the pulse count register, N pulses are sent to the control output with specified frequency and duration settings. After that, the ADC on the measurement input is switched to continuous measurement mode, and values are read into the input registers through a timer interrupt with a specified sampling frequency, from where they can later be read by the user software. At the end of the measurement, the pulse count register is reset, signaling to the user software that the tension measurement cycle has been completed. After this, information about the wire tension value is displayed on the user monitor (Figure 9).

Figure 8. Block diagram of STM32 software operation.

The computer software operates under Windows OS and provides a user interface for hardware settings, measurement initiation, and calculations.
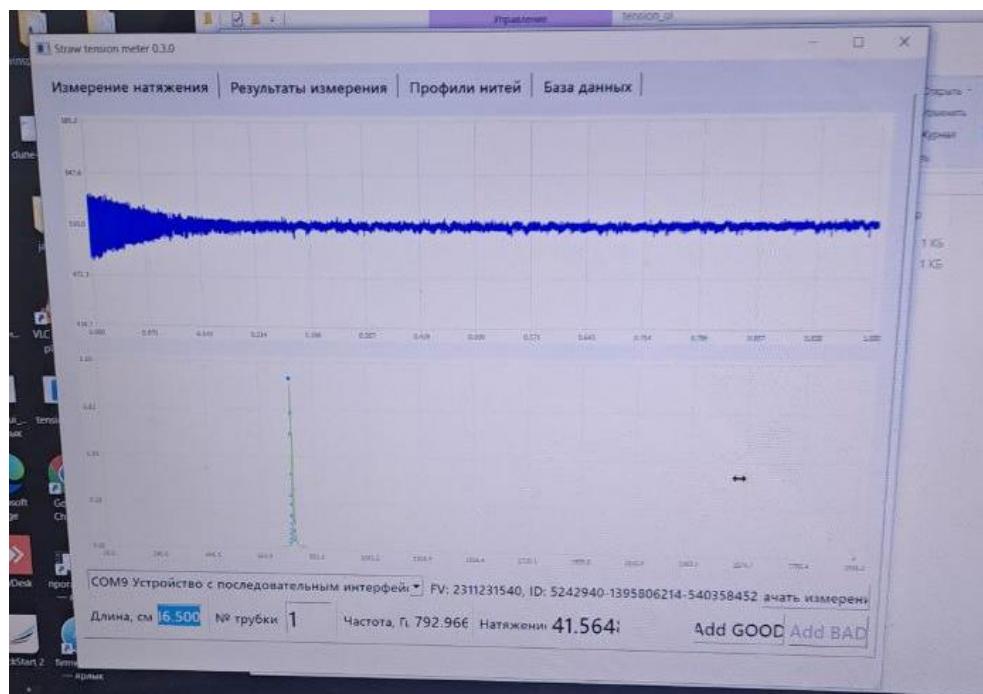

Figure 9. User program interface.

Upon launching the program, it reads information about connected devices from the system and prompts the user to connect to the hardware if it is found in the list of connected devices. In the corresponding input fields within the program window, the desired measurement parameter values can be configured. After that, by pressing the "Start Measurement" button, the values are recorded in the appropriate storage registers on the STM32, and the program waits for the measurement to complete. Once the measurement is finished, the obtained data from the STM32 input registers are read into the program's memory, and their Fourier spectrum is calculated. A simple algorithm is used to estimate the position and parameters of the highest peak on the spectrum. It is assumed that this peak corresponds to the frequency of the wire's oscillation in the string tube. The peak is then approximated using a Lorentzian peak, which describes the physical process of string oscillations. This allows for determining the exact position of the peak and, consequently, the exact frequency of oscillations. From the frequency of oscillations, the tension of the wire is calculated.

The measurement results can be stored within the program itself or exported through Excel or similar applications.

As a result of participating in the START program, I measured the tension of strings for 20 chambers using this method. As an example, the measurement result for a chamber consisting of 32 strings, each 47.5 cm long and with a wire diameter of 30 microns, is presented:

№ wire	wire tension g.
1	93,65304
2	94,25912
3	95,82609
4	97,51018
5	87,05961
6	96,93552
7	91,38319
8	95,04055
9	97,5709
10	91,38139
11	93,52483
12	94,3973
13	98,98287
14	95,08586
15	92,0496
16	94,51923
17	102,8747
18	96,25566
19	102,0308
20	102,3398
21	99,59506
22	101,9565
23	100,4488
24	101,7834
25	100,6214
26	98,60944
27	102,8177
28	102,425
29	107,266
30	105,653
31	106,8154
32	104,5523
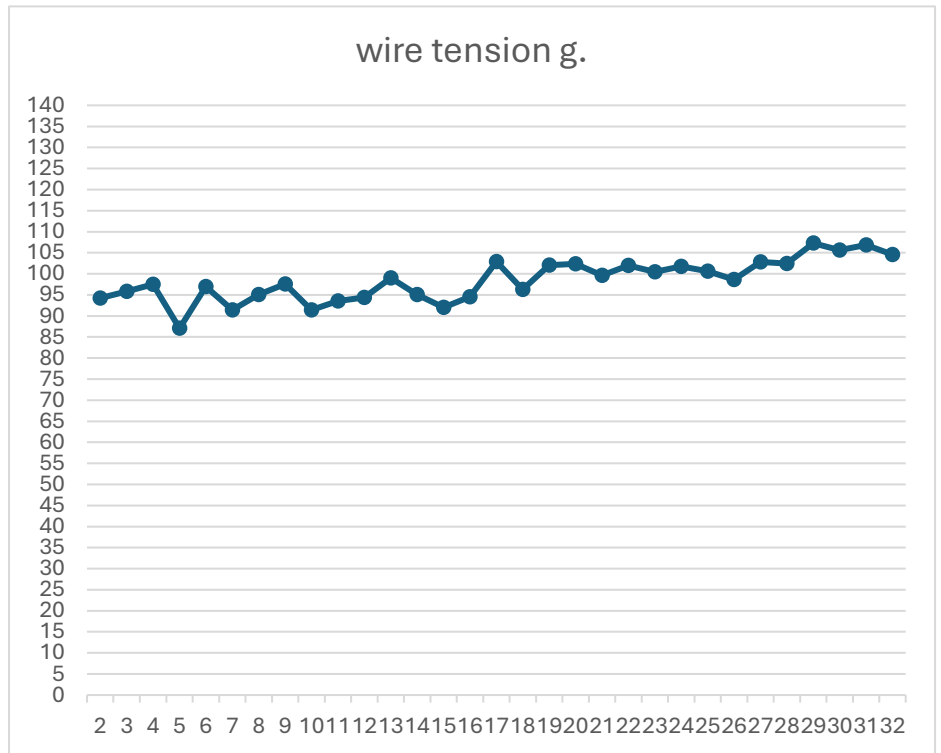
wire tension g.

The tension of the wire with a diameter of 30 microns for these chambers should be within the range of 90 ± 20 grams, as below 70 grams would cause the wire to sag, which could lead to a break, and above 110 grams is dangerous as it approaches the maximum breaking load for this wire. As can be seen from this graph, the string chamber passed the tension test without any issues.

Conclusion

During the summer student program at JINR, I became acquainted with gas coordinate detectors based on thin-walled drift tubes. This is one of the areas of work at the V.I. Veksler and A.M. Baldin Laboratory of High Energy Physics.

I gained knowledge in the fabrication and testing of straw detectors. I conducted a tension check on the anode wires for 20 straw chambers.

References

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