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A Laser Based Instrument for MWPC Wire Tension Measurement

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Abstract

A fast and simple method for the measurement of the mechanical tension of wires of Multi Wires Proportional Chambers (MWPCs) is described. The system is based on commercial components and does not require any electrical connection to the wires or electric or magnetic field. It has been developed for the quality control of MWPCs of the Muon Detector of the LHCb experiment in construction at CERN. The system allows a measurement of the wire tension with a precision better than 0.5% within $\sim 3-4$ seconds per wire

Key words: MWPC, wire tension, quality control
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1 Introduction

The LHCb Muon System [1–3] is made of 1368 Multi Wire Proportional Chambers (MWPC) with anode wire or cathode pad readout to provide spatial $x-y$ information. Almost all chambers [1] have four sensitive layers, consisting of 5 mm thick gas volumes, with the wire plane placed symmetrically in the middle of the volume, with a 2 mm pitch. The wires have a diameter of 30μm and are made of gold–plated tungsten . According to the chamber size, the number of wires in a layer varies from 200 to 760 and the wire length varies from 20 to 46 cm. To ensure chamber stability, the mechanical tension of the wires must be must in the range $50\,\mathrm{g} < \mathrm{T} < 90\,\mathrm{g}$, and must therefore be measured for all the wires. To deal with the huge number of wires, an automatic method that can perform a fast and precise measurement of the tension has been developed. Various methods to measure the wire tension have been developed in the past years [4–9]. They are generally based on an electromechanical excitation of the wires obtained, for example by injecting a current pulse through the wire surrounded by a magnetic field [4] or on electrostatic excitation through capacitive coupling [8]. In both cases it is necessary to electrically connect the wires to an external circuit, that is a somehow hazardous and time consuming operation. Moreover in some cases the tension is obtained by finding a resonance condition by scanning through several excitation frequencies [7] which is again unpractical when a large number of wires has to be measured. In this paper we describe an alternative method where the wire fundamental frequency is excited by a very short mechanical hit and the induced vibration is detected by a laser–based optical system.

2 Description of the system

A wire of length l fixed at the two ends and stretched with a mechanical tension T vibrates with a fundamental frequency f_0 which is related to the fundamental frequency of the oscillating wire by the equation:

$$T = 4\mu l^2 {f_0}^2 \tag{1}$$

where μ is the wire linear mass density.

The setup that has been developed, based on the above principle, is sketched in Fig.1.

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[1] In a small subset there are only two layers

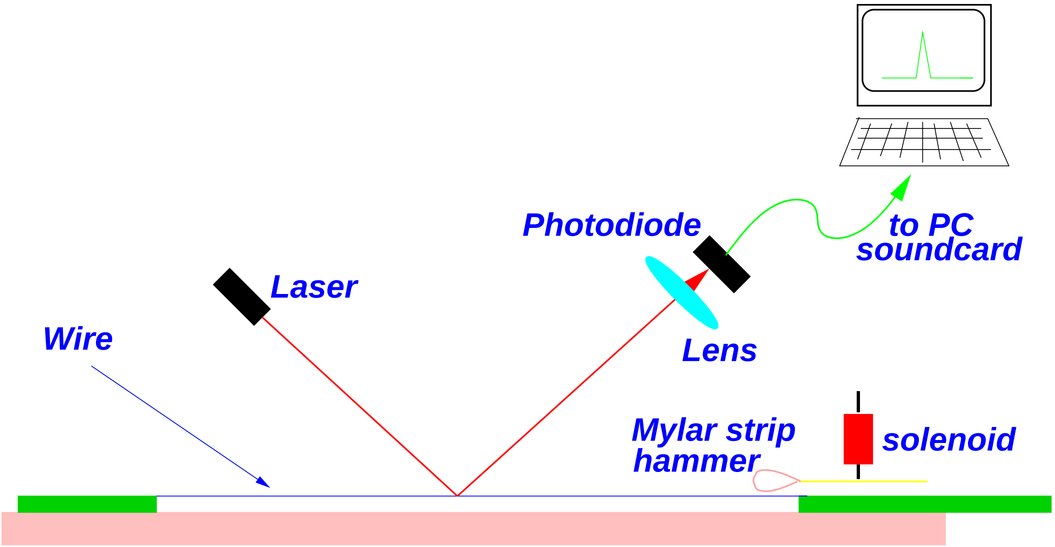

Fig. 1. Schematic description of the setup.

The light beam from a commercial 3 mW, 635 nm laser diode [2] is directed onto the wire, parallel to the wire length. The light reflected by the gold–plated wire surface forms a ring image on a plane perpendicular to the wire itself. The light is collected by a photodiode [3] having a sensitive area of $3.6 \times 3.6\,\mathrm{mm}^2$ and a spectral response in the range 350-1100 nm. The wire vibration is detected through the corresponding light intensity modulation on the photodiode active area. Due to the available lever arm, a wire displacement of a few diameters can be easily detected. To increase the amount of collected light, a lens focusing the reflected light on the photodiode surface is used. In order to reject the light reflected from the cathode surface underneath the wire, the photodiode is placed out of the laser–wire plane, at an angle of about 30°. The signal from the photodiode is amplified by an Hi-Fi audio preamplifier and then sent to a standard PC's soundcard, where it is digitized in a 16 bit format, with a sampling frequency of 11 kHz. The wire fundamental frequency is then found by applying a standard Fast Fourier Transform (FFT) algorithm to the recorded signal and a subsequent peak search algorithm.

3 Choice of the wire excitation method

Several wire excitation methods has been tested during the development phase: electromechanical, pneumatic, and mechanical. The electromechanical excitation, obtained by injecting a sinusoidal current signal into the wire in a mag-

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[2] Model RS 213-3584. The laser diode package includes a focusing lens with a focus range 30 mm$-\infty$ and can provide a beam size of $20 \times 60 \mu\mathrm{m}^2$, matching well the wire diameter of 30μm .

[3] Model THORLABS DET110.

netic field, was used only to test the optical imaging of wire vibrations, as it requires unpractical electrical connections to the wires. A direct mechanical excitation was then attempted: *a)* by directing a burst of compressed gas towards the wire; *b)* by hitting the wire itself with a piano–like hammer made of an elastic Mylar strip moved by a commercial push–type DC–pulsed latching solenoid (see Fig.1). The hammer excitation gives by far the largest signal amplitude, yielding output signals large enough to make the system essentially insensitive to parasitic vibrations or artificial light background ($f = 100\,\mathrm{Hz}$). A typical signal and its FFT is shown in Fig.2, where a high narrow peak corresponding to f_0 is clearly visible with essentially no background.

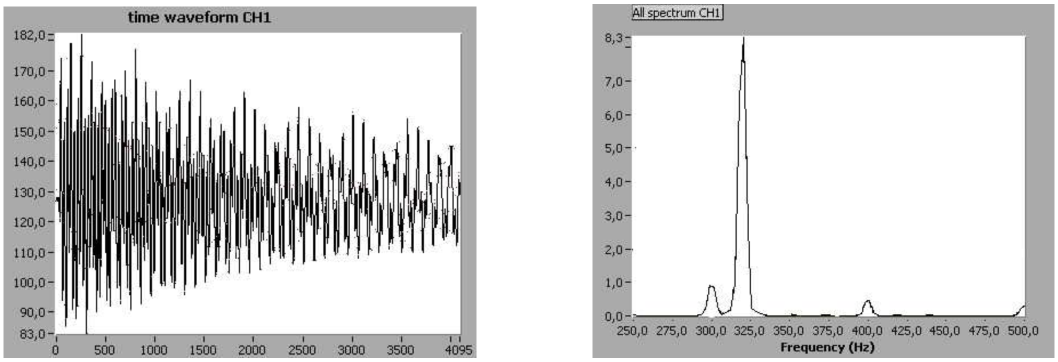
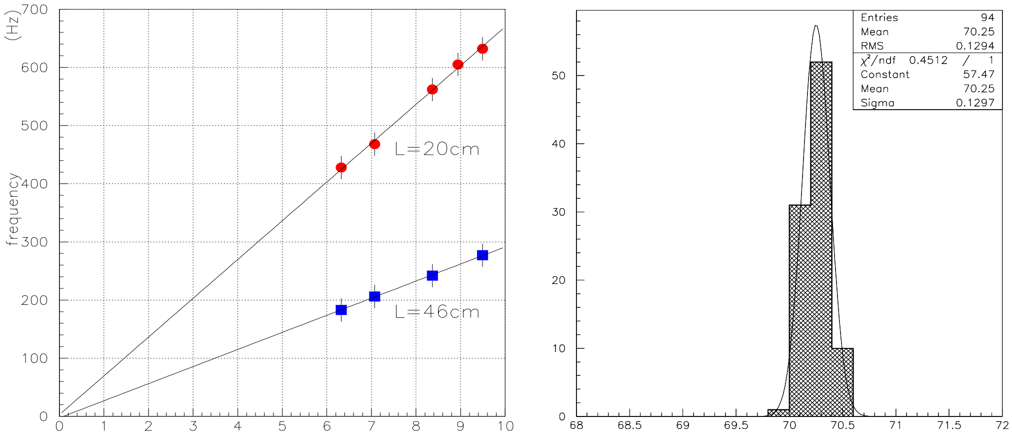


Fig. 2. Output signal of the photodiode obtained with the mechanical excitation method. Left) recorded output waveform; right) FFT spectrum of the same waveform. The highest peak corresponds to the wire fundamental frequency while the smaller ones correspond to the artificial light background.

4 Calibration and results

The system has been checked for linearity and reproducibility by a calibration procedure. Two sets of measurements were taken by stretching two wires of different length (20 cm and 46 cm, to cover the whole range of length of the wires in the LHCb muon system) with a set of calibrated weights. The results of the calibration are shown in Fig. 3(a) where the measured frequencies are fit with Eq. 1.

An excellent agreement is observed between the measurements and the theory, for the whole range of MWPCs wire lengths and a reasonably large range of tensions. The experimental error can be estimated by repeating the measurement on the same wire. As shown in Fig.3(b) a measurement error σ_T/T of about 0.2% is obtained.
The final setup, used for routine automatic tests, is shown in Fig. 4. The laser–photodiode–hammer system has been mounted on a motor controlled support (see fig. 4) which automatically moves over each wire and performs the tension measurement.



(a) (b)

Fig. 3. (a) Calibration curves (Frequency vs. square root of Tension) for two wire lengths: $L = 46\,\text{cm}$ (squares) and $L = 20\,\text{cm}$ (circles). The solid lines are the results of a fit with Eq. 1. (b) Distribution of measurements on a single wire.

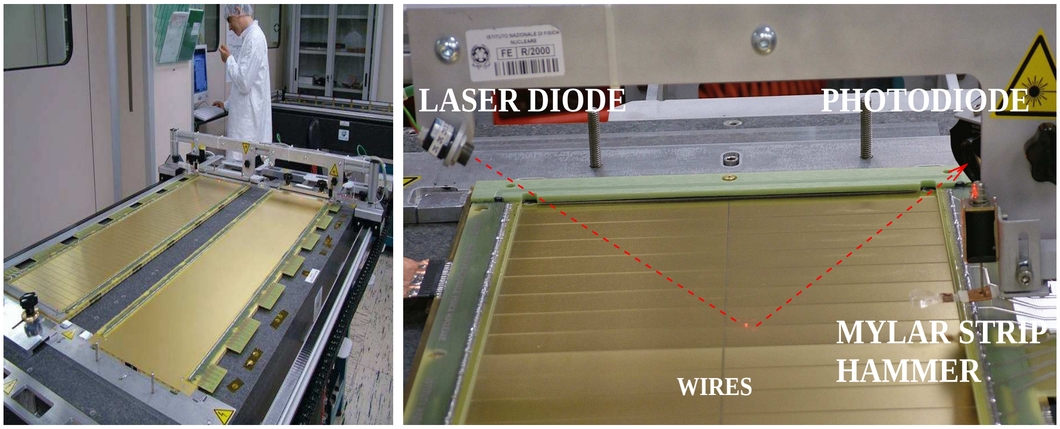


Fig. 4. The setup implemented for LHCb chamber measurements. Left: table with motor controlled bridge. Right: detail of the laser-photodetector system.

Due to the tolerance in the wire positioning (up to 100μm), a scan of each wire was implemented (from -400μm to $+400\mu$m with respect to the expected position) in order to get a reliable and stable measurement over all the wires of the chamber under test. This implies that the measuring time, in principle very low, becomes about $3 - 4$ seconds per wire, allowing the measurements of the 760 wires of the largest MWPCs within 40–50 minutes. An example of the results of the measurements performed on the LHCb MWPCs is shown in Fig. 5. In the top plot, the solid line (at $T = 50\,\text{g}$) shows the minimum wire tension acceptable for the LHCb chambers while the dashed line (at $T = 90\,\text{g}$) indicates the safety level before the wire elastic limit[4] The measurements are made on chambers with 612 wires 26.5 *cm* long. The spread of the measured

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[4] The elastic limit of the wire used in LHCb MWPCs is 140 g .

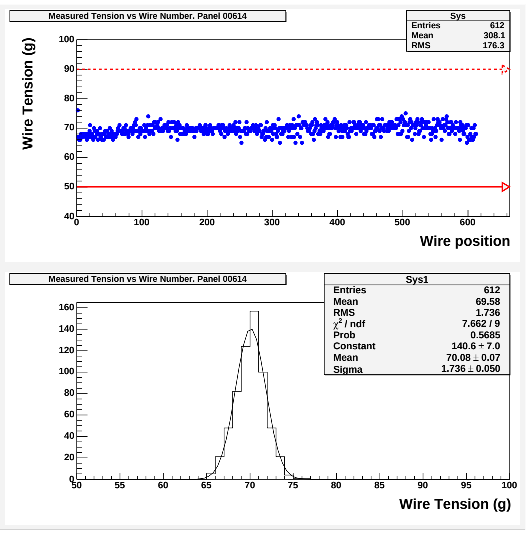

Fig. 5. Example of wire tension distribution as measured with the system described in the text. The solid and the dashed lines indicate the acceptance interval set for the LHCb wire chambers.

values ($\sigma_T/T \sim 2\%$) is due to the wire–by–wire variation of the tension introduced by the wiring system, while the measurement error is about one order of magnitude smaller.

5 Conclusions

A fast and reliable method to measure the mechanical tension of multiwire proportional chambers wires has been described. The system is based on commercial components and does not require any electrical connection to the wires or any magnetic or electric field. The measurements performed on the LHCb MWPCs show that this method is linear and reproducible over the desired range of wire lengths and tensions, with an accuracy of about 0.2%. The method is being extensively exploited for the quality control of the LHCb MWPCs, showing excellent robustness and reliability.

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