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A Method for Determining Drift Cell Wire Tensions Using Conventional Front-end Electronics

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We describe a technique to determine drift cell wire tensions that uses conventional chamber amplifiers and data acquisition electronics. The mechanical resonance of the wire is excited by a swept AC high voltage applied to the wire or cathode, and modulation of pulses picked up by the amplifier is detected. The method is practical for *in situ* determination of wire tensions in large completed drift cell detector systems.

1. Introduction

The tension of wires in wire drift chambers governs electrostatic stability, and may be important for determining wire position with long wires. Wire supports at one or more places along the length of the wire improve electrostatic stability and reduce wire sag due to gravity. However, supports impose additional mechanical locating requirements that may be costly to achieve in precision systems, and introduce small regions of chamber inefficiency.

The central barrel muon detector of the Solenoid Detector at the SSC was to be built with single wire drift tubes up to 9 meters long, with no wire supports. With that application in mind, we developed a method to determine wire tensions using conventional front-end electronics, in order to observe changes in tension due to wire creep or crimp slippage over time, or changes during final chamber installation.

A rich variety of schemes has been used over the years to measure the mechanical resonance frequency of wires to determine wire tensions [1]. In general, these schemes require specialized electronics, magnetic fields, or access to the chamber volume, and are not readily adaptable to completed detector systems. As with techniques demonstrated in the past [2], the method presented here uses a high voltage AC electric field to mechanically excite the wire. Simultaneously, short pulses are applied to the sense wire, cathode, or field shaping electrode, and are detected and amplified by the conventional preamplifier. A slight amplitude modulation of the detected pulses occurs at resonance because of the change in capacitive coupling between the moving sense wire and the other chamber electrodes.

The short pulses, typically 20 ns, are applied to an electric field element in the chamber—sense wire, cathode, or field-shaping electrode. The amplitude of the input pulses are adjusted to give a linear response from the preamplifier. The repetition rate of the pulses is arbitrary if it is high compared to the resonance frequency. Otherwise, the pulses should be phase-locked to the AC driving frequency to avoid aliasing.

Following amplifying and shaping, the next step in many data acquisition systems is digitization. Digitization may entail direct analog to digital conversion (ADC), or discrimination and level detection, as with time to digital conversion (TDC). The modulation of the pulses may be detected in either type of system. In a TDC system, the input pulse amplitude or discriminator level is adjusted so that the output pulse modulation envelope overlaps the discriminator threshold. Depending on chamber design and noise level in the amplifier system, the modulation envelope may be wider or narrower than the discriminator threshold or the ADC step size. Amplitude and phase shift information may be analyzed after digitization and data acquisition.

2. Method

The experimental setup is shown in Figure 1. A pulse generator triggered by a very stable function generator provides the input and gate pulses. The sine reference output of a digital signal processing lock-in amplifier (Stanford Research Systems Model SR850) generates a low voltage, swept AC signal. The amplitude is increased to 50 volts peak-to-peak by a laboratory audio frequency amplifier, then stepped up to approximately 1 kV by a small 2.3 VA transformer. The transformer output is biased by positive HV from a Droege-type NIM

supply to increase the electrostatic force on the wire, which varies as V^2 . The pulses are injected and picked up through high voltage capacitors. Two different preamplifier circuits were tested: one based on the LeCroy TRA1000 chip, the other is a Fermilab beam chamber amplifier circuit built around the Fujitsu MB43458 chip. Results for the two amplifiers were very similar—data shown were taken with the Fujitsu amplifier. The radio frequency environment in our laboratory is quite noisy, and no comprehensive steps were taken to eliminate RF noise in the drift tube system. A properly shielded and grounded full detector system should provide an improved signal to noise ratio.

For ADC readout, the preamp pulses are fed directly to a 10 bit CAMAC ADC. For non-linear readout, the pulses are sent to a NIM discriminator, and the discriminator output digitized by the ADC, for convenience, with levels distinguished in software. A third approach, useful in the laboratory, is to pass the discriminator output through a low pass RC filter into the lock-in amplifier input. Traces of the amplitude and phase shift response appear on the CRT display as the frequency is swept. The traces may be transferred to computer via GPIB. The lock-in amplifier requires no software, and a very high pulse repetition rate is possible, and clean resonance curves can be acquired in a short time. All of the signal processing in the lock-in is digital, so, in principle the full lock-in detection scheme can be implemented in software. The lock-in amplifier was an invaluable tool during our investigation.

The phase relationship of the pulse to the AC excitation signal may be measured or fixed several ways. The low voltage sine reference signal may be split, attenuated, offset and read by the ADC. If only two data points per period are sufficient, and the frequency span is small, the TTL zero crossing-signal provided by the lock-in amplifier may trigger a delay generator which will gate pulses at the maximum and minimum voltage of the AC cycle. Alternatively, a computed swept signal may be produced by an arbitrary function generator (LeCroy Model 9109), with the AFG clock output used as a trigger. There may be a phase shift between the AC signal source and the HV signal at the electrode, and this should be measured with a HV probe. When acquiring data via CAMAC, the repetition rate is kept to 1 kHz or lower to allow the CAMAC bus and the 386 PC system to keep up. Software makes adjustments as the frequency is swept to acquire the same number of points per frequency bin.

3. Results

Tests were made on three types of single wire drift tubes—a 9 meter tube with field-shaping elements of the Solenoid Detector (SDC) design [3], as depicted in Figure 2; a 0.61 meter SDC tube; and 3.66 meter simple, cylindrical tubes 30 mm in diameter. Aligned simple tubes present a particular challenge because the forces and amplitudes of oscillation are small due to the symmetry. In all cases, the drift tubes were strung with 90 micron diameter gold-plated tungsten wire at nominal initial tensions of 9.8 N.

The modulation of the pulse amplitude at resonance in the 9 meter tube is as large as 10%. This is readily visible on an analog oscilloscope. Figure 3 shows the resonance response for the 0.61 meter SDC tube with the preamp output fed directly into the ADC. The ADC was gated at the maximum and minimum voltages of each cycle, and the ADC counts are summed separately. Plotted is the difference in the count sums for each frequency bin. The 10 Hz sweep with 0.1 Hz frequency bins took 16.7 minutes. With discriminated pulses, the sums of the numbers of pulses over threshold were subtracted, and yielded a nearly identical curve.

The algorithm just described is not adequate to detect the slight modulation in the 3.66 meter simple tube in a reasonable amount of time in our noise environment. Integrating the ADC output with the sine function at a 1 kHz pulse repetition rate gave noisy, readable resonance plots, but required many hours of data. So, we used the lock-in amplifier with its narrow detection band algorithm and a 1 MHz pulse rate. Figure 4 shows the amplitude and phase response of the simple tube. The 4 Hz scan took 4 minutes. The detailed shape of the resonance curves is influenced by HV values, pulse amplitudes and phase offsets.

In the absence of perfect symmetry, the electrostatic force on the wire in the simple tube acts to oppose the mechanical restoring force. The resonance frequency f decreases with DC high voltage V approximately as

$$f^2 = f_0^2 \left(1 - \frac{V^2}{V_c^2} \right)$$

where f_0 is the resonance frequency with no applied voltage and V_c is the critical voltage where the wire restoring force becomes zero. V_c is given by

$$V_c = \sqrt{\frac{T}{2\pi\epsilon_0}} \pi \frac{R}{L} \ln \frac{R}{r}$$

where T is the tension, R is the tube radius, L is the tube length, r is the wire radius, and ϵ_0 is the permittivity of free space [4]. Figure 5 plots f^2 versus V^2 for the simple tube, and a linear fit is obtained. Extrapolating the line to $V = 0$, and given the mass per unit length of wire we calculate the tension: $T = 9.328 \pm 0.008$ N. Extrapolating the line all the way to $f = 0$ we obtain $V_c = 29.7 \pm 1.4$ kV. Substituting the calculated tension into the expression for the critical voltage yields $V_c = 30.6$ kV, which is consistent. Note that the critical voltage for this wire diameter is much larger than ordinary operating voltages for most gases and pressures, providing a wide margin of stability. The change in frequency for the six points spans only 0.15 Hz, which is a demonstration of the sensitivity of the method. The resonance frequencies measured by this method are in good agreement with those obtained by two conventional techniques which employ a magnet and currents in the wire. The first conventional method uses the lock-in amplifier to observe the phase change at resonance. The second method uses a self-resonant circuit to excite the wire and a frequency meter to read the result.

4. Discussion

Resistors are generally used in the HV supply of chambers to minimize damage in the event of a spark, and to provide some degree of RF filtering by large RC time constants. Large resistors impede the pulse and excitation signal and must be bypassed during the test with this method of tension analysis. Test voltages can be substantially lower than chamber operating voltages, providing a margin of safety. Resistor bypassing may become a chamber design consideration, although no modification of the readout chain is required. The method should work for a wide variety of drift cell and straw tube designs and may allow routine measurement of the tension of all the wires in large detector systems. No tests were made on multi-wire chambers and they may present a more difficult challenge.

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[1] N.J. Shenhav, Nucl. Instr. and Meth. A324(1993) 551, and references cited therein.

[2] K.B. Burns, B.R. Grummon, T. A. Nunamaker, L.W. Mo, S.C. Wright, Nucl. Instr. and Meth. 106(1973) 171.

[3] Solenoid Detector Collaboration, *Technical Design Report 1 April 1992*, SDC-92-201, SSCL-SR-1215, p. 7-30

[4] For a derivation of an equivalent expression see W. Blum and L. Rolandi, *Particle Detection with Drift Chambers*, (Springer-Verlag, Berlin 1993) p. 121

Figure Captions

Figure 1. Diagram of the experimental setup, with a simple cylindrical drift tube and direct ADC readout.

Figure 2. Cross-section of the SDC muon drift tube. Tube is made of extruded aluminum 9 cm in diameter, with insulated field-shaping electrodes. Illustrated are the electric field lines and isochrones of the active drift region.

Figure 3. Resonance response of 61 cm long SDC drift tube. Wire is held at positive HV; AC and pulse are applied to one field shaping electrode. Frequency bins are 0.1 Hz wide. CAMAC ADC values are read at minima and maxima of the AC high voltage cycle and separately summed. Sums are then subtracted to obtain the difference for each bin.

Figure 4. Lock-in amplifier response for a 3.66 m simple cylindrical tube. Preamplifier output is discriminated, low-pass filtered, and fed to lock-in input. Amplitude and phase response are plotted.

Figure 5. Shift of resonance frequency with DC bias high voltage. The DC HV is summed with the 1 kV peak-to-peak AC excitation signal. Plotted are frequency^2 vs. DC Voltage^2 , with a linear fit.

Figure 1

Figure 2

Figure 3

Figure 4

Figure 5