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A system to test the effect of materials on electron drift lifetime in liquid argon and the effect of water

R. Andrews, W. Jaskierny, H. Jöstlein, C. Kendziora, S. Pordes *, T. Tope

Particle Physics Division, Fermi National Accelerator Laboratory, Batavia, IL 60510, USA

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ABSTRACT

A materials test system (MTS) has been developed at FNAL to assess the suitability of materials for use in a large liquid argon time projection chamber. During development of the MTS, it was noted that controlling the cryostat pressure with a 'raining' condenser reduced the electron drift lifetime in the liquid argon. The effect of condensing has been investigated using a series of passive materials to filter the condensate. We report the results of these studies and of tests on different candidate materials for detector construction. The inferred reduction of electron drift lifetime by water concentrations in the parts per trillion is of particular interest.

1. Introduction

Liquid argon time projection chambers (LArTPCs) offer an opportunity for novel neutrino physics [1,2]. They can provide bubble-chamber quality event images by drifting ionization electrons created by the passage of charged particles through the liquid to readout planes. Since argon is cheap and plentiful, one can conceive of detectors with multi-kiloton active volumes. A principal challenge for large LArTPCs is the removal of electronegative impurities that capture the ionization electrons. The materials test system (MTS) has been built at FNAL to develop liquid argon purification techniques [3] and to qualify materials for use in a large LArTPC by measuring their effect on the electron drift lifetime. A photograph of the MTS is included in Fig. 1 and a schematic of the MTS cryostat is included in Fig. 2.

2. The materials test system

The materials test system has two major physical components—the argon source, a single-pass system that provides clean argon from commercial argon dewars, and the MTS cryostat in which the electron drift lifetime and other quantities are measured. The components used in the construction of the MTS are listed in Ref. [4]. The supply piping conforms to ASME B31.3 and the cryostat conforms to ASME Section VIII DIV 1.

The MTS controls are automated using a Beckhoff programmable logic controller (PLC). The PLC reads out pressure, liquid level, temperature, and gas analysis instrumentation. Based upon the monitored instrument values, the PLC performs tasks such as opening and closing valves to control cryostat pressure, and sounding alarms that alert operators of undesirable conditions. The PLC communicates with iFIX software run on a Windows PC. The iFIX software allows entry of temperature and pressure set points and other operational parameters, displays real-time instrument values, and archives instrument values for historical viewing. The iFIX graphical user interface is shown in Fig. 3.

Operation of the MTS involves evacuating the cryostat to 10^{-6} Torr filling it with clean argon, inserting a sample material, and monitoring the electron drift lifetime. Upon evaluation, the sample is removed and another sample can be inserted without changing the argon load. The condenser and internal filter are operated as needed.

2.1. Argon source

Commercial argon [5] is passed through a molecular sieve [6] to remove water and then activated copper [7] to remove oxygen and other electronegative impurities before entering the MTS cryostat. The liquid argon is supplied through vacuum-jacketed $\frac{3}{8}$ in. diameter tubing that consists of both stainless steel and copper sections. Small diameter tubing was chosen to limit the system throughput to match the capacity of the cryostat relief valve. The molecular sieve and activated copper filter material are each housed in $2\frac{3}{8}$ in. diameter stainless steel tubing capped with

* Corresponding author.
E-mail address: stephen@fnal.gov (S. Pordes).

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Fig. 1. Photograph of the materials test system (MTS) at FNAL. Commercial argon (left) is passed through two filters (center) before entering the cryostat (right).

ConFlat flanges. All valves in the delivery system are metal seal to atmosphere to prevent the diffusion of oxygen through o-ring or stem packing seals. Piping relief valves with o-ring seals have an argon purge on the exhaust to prevent diffusion of ambient oxygen. This setup provides liquid argon with an electron drift lifetime of many milliseconds [8].

2.2. MTS cryostat

The MTS cryostat is a 250 L vacuum-insulated vessel with a working pressure of up to 35 psig. It is equipped with a liquid nitrogen-powered condenser that allows it to operate as a closed system. The cryostat itself contains the lifetime monitor, an active filter, a set of selectable return paths for the condensed argon, and a mechanism that allows materials to be inserted and removed from the cryostat.

2.2.1. Internal filter

This novel filter sits in the MTS cryostat and contains a combination of molecular sieve and activated copper. It is used to maintain the purity of liquid argon in the cryostat and also to remove impurities introduced during materials testing. A description of filter operation can be found in Ref. [3].

2.2.2. Lifetime monitor

Modeled after the ‘purity’ monitors of the ICARUS Collaboration [8,9], this device allows for the direct measurement of the electron drift lifetime.

2.2.3. Condenser to control cryostat pressure

Argon vapor enters the condenser through a central tube and contacts surfaces cooled with liquid nitrogen. The nitrogen is maintained at 50 psia to prevent argon from freezing on the contact surface. The condensed argon flows down the condenser walls and drips into one of four return paths before entering the bulk liquid. When the condenser is not operating, argon is continuously vented. A closed system is desirable during materials testing so that material-introduced impurities are not removed by venting and their effect on the electron drift lifetime can be observed.

2.2.4. Return paths for condensed argon

A wheel below the condenser allows the selection of a return path for the condensate. There are four paths available: a $1\frac{1}{2}$ in. diameter tube with stainless steel wool enclosed by sintered metal, a similar tube with a disk of sintered glass at the end, a thin spiral tube, and a hole which allows the condensate to fall directly into the bulk liquid. Fig. 4 shows details of this system. Other return paths, described in Section 3.1, were used briefly.

2.2.5. Mechanism for material insertion and removal

An airlock, separated from the cryostat by a large gate valve, sits above the cryostat. The sample material is placed into a cage inside the airlock and prepared for insertion by evacuation or by purging with clean argon gas from the cryostat. The gate valve is then opened and the cage lowered into the cryostat via a rod attached to the top of the cage. Once in the cryostat, the cage is set on a lift platform. The rod is then released from the cage and retracted, allowing the gate valve to be closed. The cage is then lowered further into the cryostat. An RTD attached to the lift platform is used to indicate the temperature of the sample. Material removal involves raising the sample cage, opening the gate valve, attaching the rod to the cage, and raising the cage into the airlock. Once the gate valve is closed, the tested sample can be removed and another sample prepared.

The MTS airlock has the ability to prepare materials for insertion by purging with argon because it may not be possible to evacuate the cryostat of a future large LArTPC. Samples can also be subject to evacuation, but this procedure is not routinely used since evacuation might remove contaminants that would not be removed by purging.

2.2.6. Data acquisition

The data acquisition system for the lifetime monitor consists of a Visual Basic program run on a Tektronix 5054 NV digital oscilloscope. The system is fully automated and takes