Prototype Penning trap of TAMU-TRAP facility

E. Bennett, B. Fenker, M. Mehlman, D. Melconian, J. Patti, and P.D. Shidling

A prototype cylindrical Penning trap has been designed and fabricated to demonstarate the trapping of stable ions from the offline ion source. The dimension of prototype trap is half the dimension of the planned Penning trap for measuring the beta-neutrino correlation parameter, $a_{\beta\nu}$, in T=2 superallowed β-delayed proton decays. More details about the planned Penning trap is discussed in previous annual reports [1,2]. The electrode structure of the trap is both tunable and orthogonalized, which allows for a near quadrupole electric field at the trap center, a feature necessary for performing precision mass measurements.

The TAMUTRAP prototype Penning trap will also be used to perform mass measurements. Penning trap determine the mass 'm' of a trapped ion of charge state 'q' by measuring its cyclotron frequency

$$\omega_c = \frac{q}{m}B,$$

in a magnetic field 'B'. In the trap the ions are confined in three-dimensions by overlaying a quadrupolar potential and a magnetic field. The motion in a Penning trap is not a simple cyclotron motion(ω_c) but a combination of three harmoic eignemotions, an axial oscillation (z) and two circular motion commonly referred to as magnetron (ω_-) and reduced cyclotron (ω_+) motions. The mass of the trapped ions can be determined by performing independent measurements of the eigenfrequencies and a determination of the true cyclotron frequency via the relation :

$$\omega_c = \omega_+ + \omega_-.$$

To measure the cyclotron frequency of a stored ion, it is necessary to drive the ions motion at a sum, or difference, of two eigenfrequencies with an external oscillating electric field (quadrupole radiofrequency (RF) field). At TAMUTRAP, a quadrupolar driving field in the radial plane will be applied. For this purpose one of the electrode is four-fold segmented as indicated in Fig. 1.

Fig. 1 shows the prototype cylindrical Penning trap system of TAMUTRAP facility. The superconducting magnet has a homogeneous (to better than 2 ppm) region at the center, where the trap will be placed. The inner diameter of the trap is 90 mm and a length of about 166 mm, and consists of seven electrodes: a pair of end caps, a pair of end electrodes, a pair of compensation electrodes and one ring electrode. The end caps have a hole of diameter 5 mm for loading and ejecting the ions from the trap. To apply the RF-fields as required for the exciation of the ion motion, the ring electrode is azimuthally divide into four segments. The four-fold segmented ring electrode offers the possibility to excite the trapped ions by a quadrupole RF field. The pair of compensation electrodes are used to compensate for higher-order electric field components. The trap geometry is both tunable and orthogonalized, which allows for a near quadrupole electric field at the trap center. All the trap electrodes are made of oxygen-free high conductivity (OFHC) copper, and are gold-plated to avoid oxidization

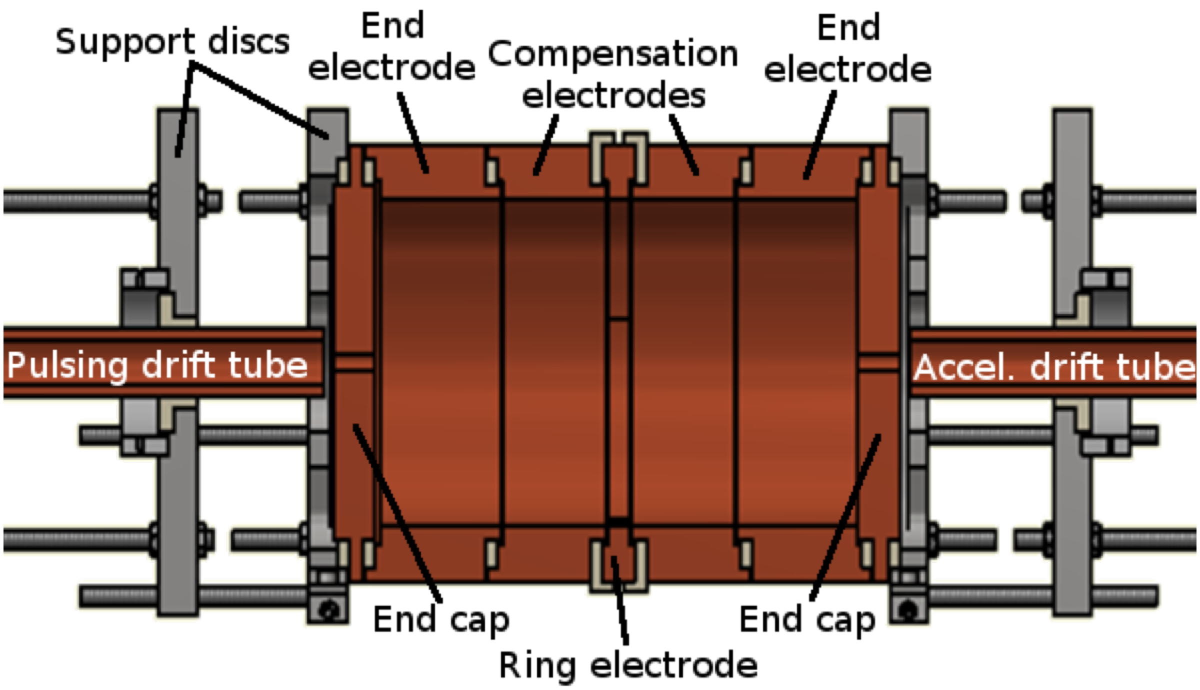

FIG. 1. Prototype cylindrical Penning trap system.

which would distort the electric field. The insulators between the electrodes are made of aluminium oxide (Al_2O_3) and the distance between two electrodes is 0.5 mm. The elements are mounted on 12 mm thick disc (labelled "Support disc" in Fig.1) made of high strength Aluminum (7075 grade). The disc has two titanium wheels at 45^0 from the centre. The wheels are used to rail the Penning trap system into the beampipe tube which is inside the magent bore. The tube is made of 316 L stainless steel with low susceptibility and no magnetic enclosures in order to maintain the high homogeneity of the magnetic field. The alignment of the Penning trap with respect to the magnetic-field axis will be performed by electron gun method and is discussed in other report.

As mentioned earlier, the mass of an ion is determined via its cyclotron frequency. At TAMUTRAP facility, we plan to measure the cyclotron frequency by the time-of-flight ion cyclotron resonance method (TOF-ICR). It is a destructive detection method and can be used for single or a low number of stored ions in the trap. This is of particular advantage for very short-lived radioactive ions where the nuclear decay anyhow limits the storage and observation time in the trap.

The injection optics of TAMUTRAP Penning trap system consists of einzel lens, x-y steerer, and a pulsing drift tube. The ion bunches at energy 2.5 keV are guided using the combination of einzel lens and an x-y steerer into the pulsing drift tube with a length of l = 400 mm and put at a potential of 2.4 kV. While the ion bunches fly through the tube, its voltage is pulsed to the ground potential. This lowers the ion energy from 2.5 keV to about 100 eV for an efficient capture in the cylindrical Penning trap. Einzel lens and x-y steerer are installed outside the magnet where the strength of the magnetic-field is around 200 Gauss. The pulsing drift tube is placed in strong magnetic field. The gap between the pulsing drift tube and the end cap is around 5 mm. The extraction optics consists of a 13 mm inner diameter drift tube with a length of l = 400 mm to accelerate the ion while they are in the strong magnetic field region. Since the magnetic field gradient in this region is small, no radial kinetic energy change occurs. Thus, no significant effect on the time-of-flight spectra will be observed by varying the drift tube potential. After the ion undergoes sequence of excitation in the center of the trap, the ions will be axially released as an ion pulse from the trap through an accelerating drift tube. Their individual time of flight will be recorded by a MCP detector. A DEL MAR Microchannel Plate Detector (MCP-MA series) with two microchannel plates and a single metal anode readout will be installed about 0.8 m from the center of the trap (about 20 cm from the end of the magnet) where the strength of the magnetic field is around 200 Gauss.

The Penning trap system has been assembled and we are currently installing it in the superconducting solenoid. The electronics to apply an external RF field to the segmented ring electrode of the Penning trap has been built and tested up to 6 MHz. All the parts and electronics essential to couple the Penning trap system to the beam line have been fabricated and tested. We expect to demonstrate trapping of stable ions before the end of the summer of 2016.

[1] M.Mehlman *et al.*, Nucl. Instrum. Methods Phys. Res. **A712**, 11 (2010).

[2] R.S. Behling *et al.*, Progress in Research, Cyclotron Institute, Texas A&M University (2011-2012), p. V-40.