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A NOVEL METHOD FOR MEASURING BEAM ENERGIES BY TIME-OF-FLIGHT

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In this paper we report on a novel time-of-flight (TOF) technique for the measurement of ion beam energies. This technique was used, along with a more conventional nuclear reaction technique, to measure the calibration function of the Holifield Heavy Ion Research Facility tandem accelerator energy-analyzing magnet. A more complete account of this work will be presented elsewhere.[2]

The technique to be described is based on the use of a variable frequency buncher[3] and two identical capacitive pickup units (CPU) to measure the velocity of ions selected by the energy-analyzing magnet. A sketch of the CPUs is shown in Fig. 1. The CPUs were separated by a distance of 6166.2 ± 0.4 mm and were connected by equal length cables to wide band HP-8447F preamplifiers which in turn were connected to a dual trace oscilloscope. The beam was bunched using the first harmonic element of the double-drift bunching system which is located in the tandem accelerator injection line. This buncher was originally developed to produce suitable bunches from the tandem accelerator for injection into the Oak Ridge Isochronous Cyclotron. For this purpose the buncher produces bunches about one ns wide in a

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frequency range between 4.5 and 14.5 MHz.

For each measurement the buncher frequency was adjusted, as shown in Fig. 2, so that an exact integral number of beam bunches spanned the distance between the two CPUs. In that case, the TOF between the two CPUs is a multiple of the buncher period. This synchronous condition can easily and accurately be determined since the signals from the two CPUs must then be coincident on the dual trace scope. Systematic timing differences between the two CPU circuits were eliminated by reversing the circuits to the CPUs and using the average frequency.

Sixteen measurements of the magnet constant at various levels of magnet excitation using this method are summarized in Fig. 3. These data were obtained over a 54 hour period with injected beam currents ranging between 500 and 1000 nA. Seven different measurements were made with the same injected $^{16}O^-$ beam and unchanged terminal voltage of 9 MV. In particular, ^{16}O 2+, 3+, 4+, 5+, and 6+ beams were used to obtain calibrations for values of $E_0{}^4$ between 28 and 109. Likewise, ^{58}Ni 3+, 4+, 5+, 6+, and 7+ beams were used for a series of measurements at a terminal voltage of 11 MV. These beams gave calibration points for $109 < E_0 < 298$. Two additional ^{58}Ni beams were accelerated with terminal voltages of 15 and 18 MV to better define the calibration curve at higher magnetic excitations. The error bars shown in Fig. 3 are estimates of standard deviations and were taken to be 67% of the frequency change for which one could clearly observe a non-aligned condition between the two traces on the dual scope. These uncertainties are typically 3×10^{-4}. The flight-path-length fractional uncertainty of 0.6×10^{-4} is not a significant source of error in these measurements. We were pleased to note that the five measurements at $E_0 = 109$, made with two different ion species, have a fractional standard deviation of 2.2×10^{-4}.

In summary, we found this method to be simple, fast, accurate, and inexpensive. It appears to be especially well suited for routine energy measurements for a variety of ion species. Its principal disadvantage is the requirement of a buncher whose frequency is variable.

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3. W. T. Milner, IEEE Trans. Nucl. Sci. NS-26, (1979) 1445; N. F. Ziegler, IEEE Trans. Nucl. Sci. NS-26 (1979), 3304.
4. The ion kinetic energy E (MeV) is related to the NMR reading B, the rest mass energy m_0c^2 (MeV), the charge Q (electron units), and the mass M (amu) by $B^2\ K(E_0) = E_0$ where $E_0 = \frac{EM}{Q^2}\left(1 + \frac{E}{2m_0c^2}\right)$.

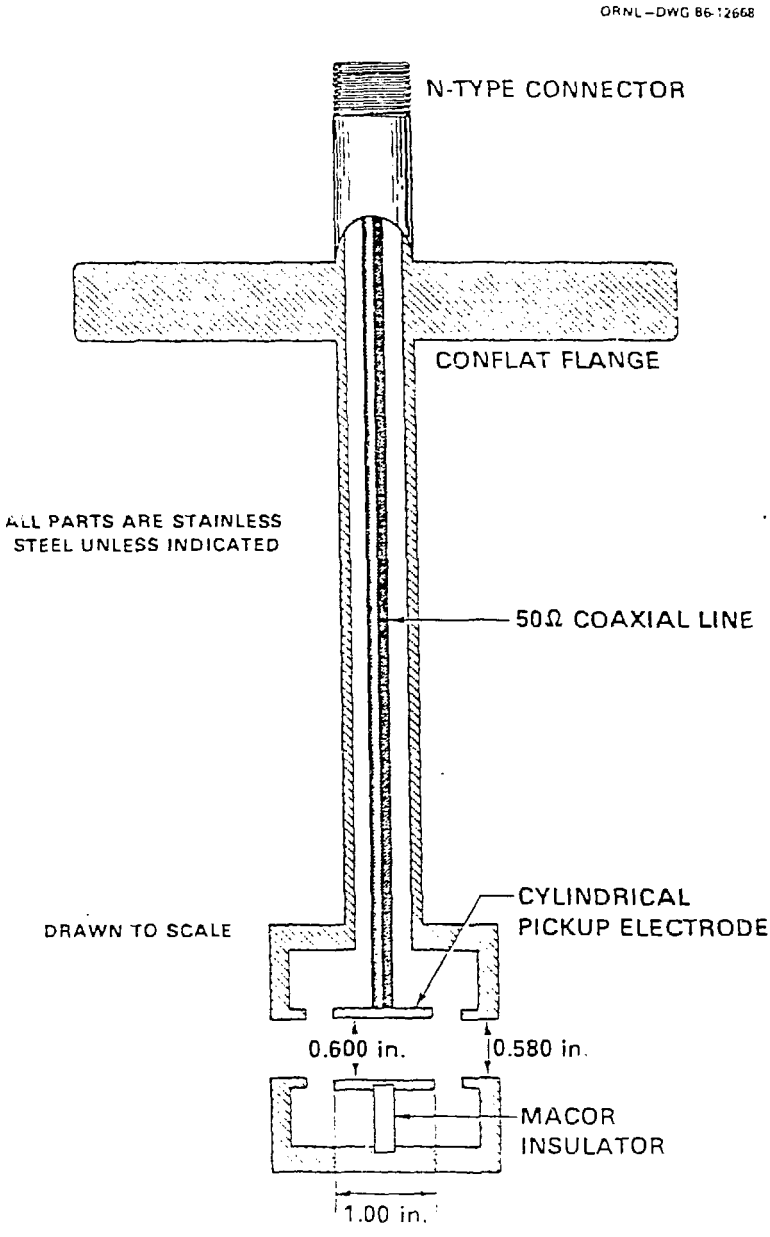

Fig. 1. A section view of the capacitive pickup unit used for measurements described in the text.

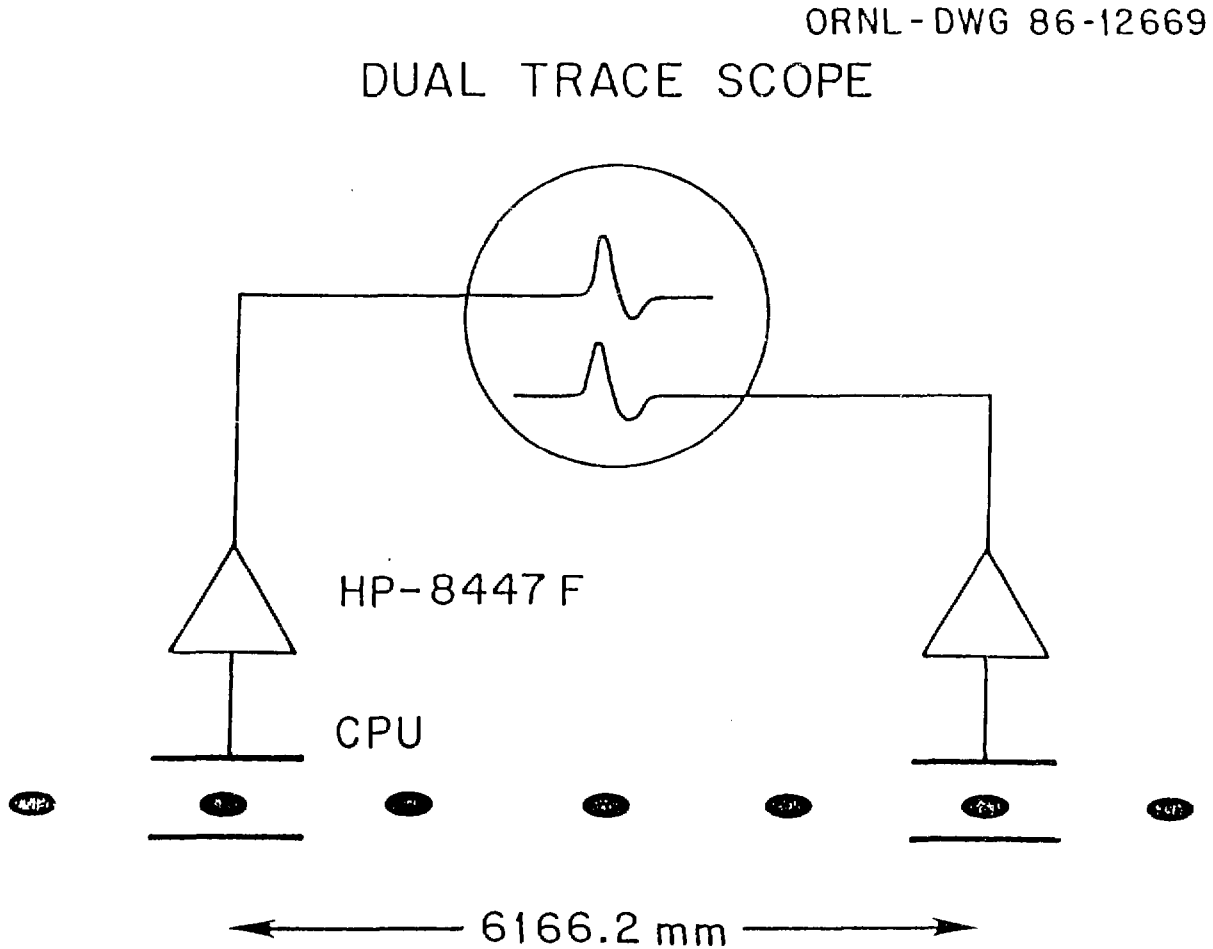

Fig. 2. A schematic view of the apparatus used for the measurements described in the text.

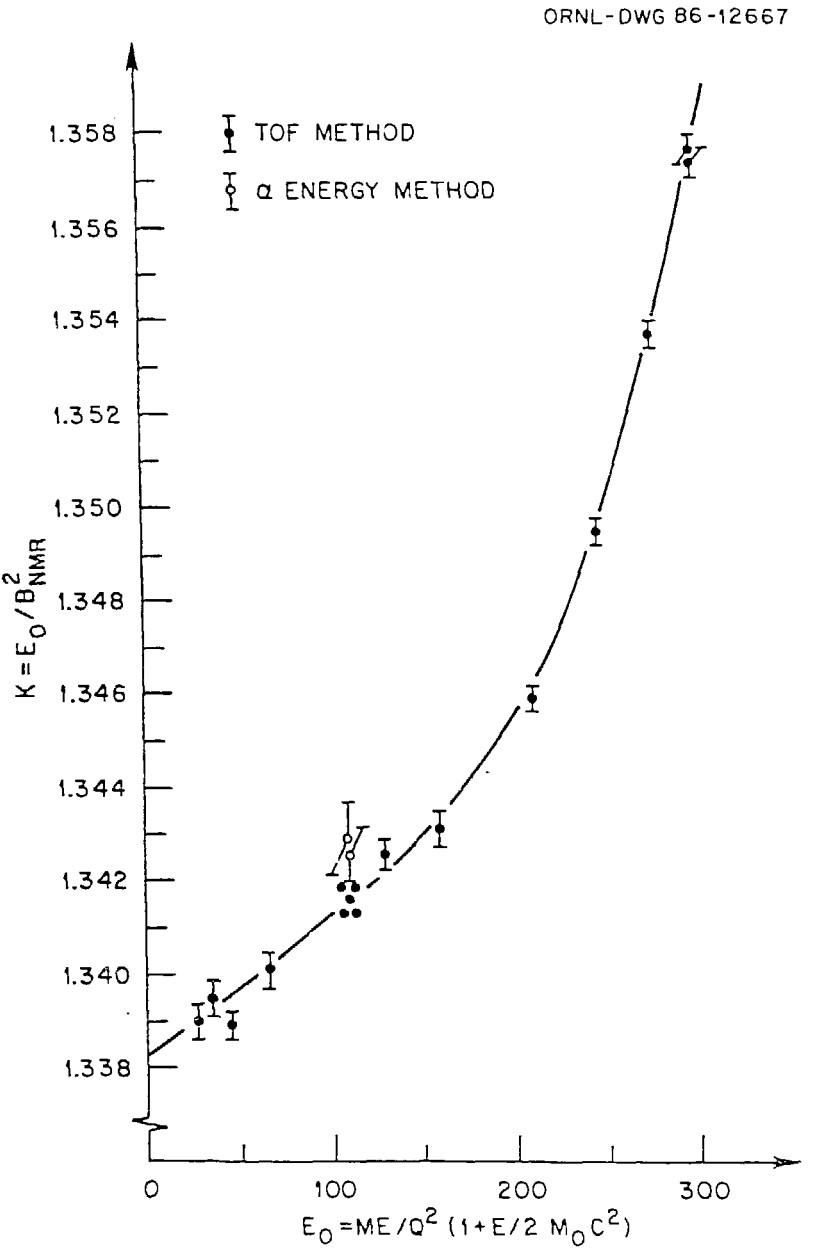

Fig. 3. Measured magnet constant $K(E_0)$ as a function of magnet excitation. The data points with closed circles were measured with the TOF technique described in the text. The data points with open circles were measured with a nuclear reaction technique. The solid line is an analytical fit to these data.