Proceedings of the Tenth International Conference on Cyclotrons and their Applications, East Lansing, Michigan, USA

THE ELECTROLYTIC TANK FACILITY AT THE NAC

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Summary

The construction and development of the electrolytic tank facility at the NAC is discussed. The measurement of the potential fields is controlled by a mini-computer via a parallel CAMAC branch. The data collected by the mini-computer are transferred to a mainframe computer using magnetic tapes. Potentials can be measured on a square mesh 1 m x 1 m with 0.1 mm resolution, to sufficient accuracy to enable off median plane orbit calculations, on a 3:1 scale model of the injector cyclotron at the NAC. The software is briefly discussed and illustrative results are given.

1. Introduction

The quality of the beam delivered by the k=8 injector cyclotron at the NAC[1] will primarily be determined by the geometry of the electrodes in the central region and the position of the ion source. Because of the complexity of the structures in this region, we decided on building an electrolytic tank to measure the necessary potential fields using various scale models. Measurements in the electrolytic tank are restricted to a two-dimensional grid in the median plane, defined by the electrolyte level in the tank. These data are then processed according to the expression

$$E_z = -z(\partial^2V/\partial x^2 + \partial^2V/\partial y^2) \qquad (1)$$

to find the axial component of the rf field. Initially we specified that the potential fields in the median plane should be measured to 1% accuracy, as this accuracy was felt to be high enough for the prediction of ion orbits. However, this requirement masked far more stringent demands on the accuracy of the measurements, inherent in our method of calculating the axial component of the electric field E_z from equation (1), i.e. from approximating second derivatives of the potential field by second differences of the measured values. If the second derivative values are to be meaningful, the second differences of the measured fields must vary smoothly with displacement, i.e. the "scatter" of the measured field values must be small. We found that if the E_z-values were to be "reasonable", we had to measure the potential to a precision of 1 in 10 000 or better. For this reason also, it is important that the top surface of the model is manufactured, and aligned in the tank, within a tolerance of 0.1 mm.

2. Mechanical hardware

The tank itself is made of fibre-glass and measures 1.2 m x 1.2 m x 0.5 m. It has perspex windows on the four side walls so that the probe and model can be viewed from the side for alignment purposes. The probe positioning mechanism is based on a commercially available high-accuracy coordinatograph (an instrument commonly used in survey applications). This instrument consists of a set of parallel rails on which is supported a third transverse movable rail with a movable carriage on it. We were able to modify this instrument very easily to take two stepper motors for positioning the carriage and movable arm. A probe has been mounted on the carriage for the potential measurements. Fig. 1 shows the positioning mechanism schematically. In order to prevent mechanical coupling, the tank and positioning mechanism are mounted on separate stands. The only contact between the two components is via the probe tip immersed in the electrolyte. The most critical requirement imposed on the construction of the models, is on the flatness of the top surface, i.e. all electrode surfaces coinciding with the median plane should be flat to within 0.1 mm, and should be installed parallel and level to within 0.1 mm.

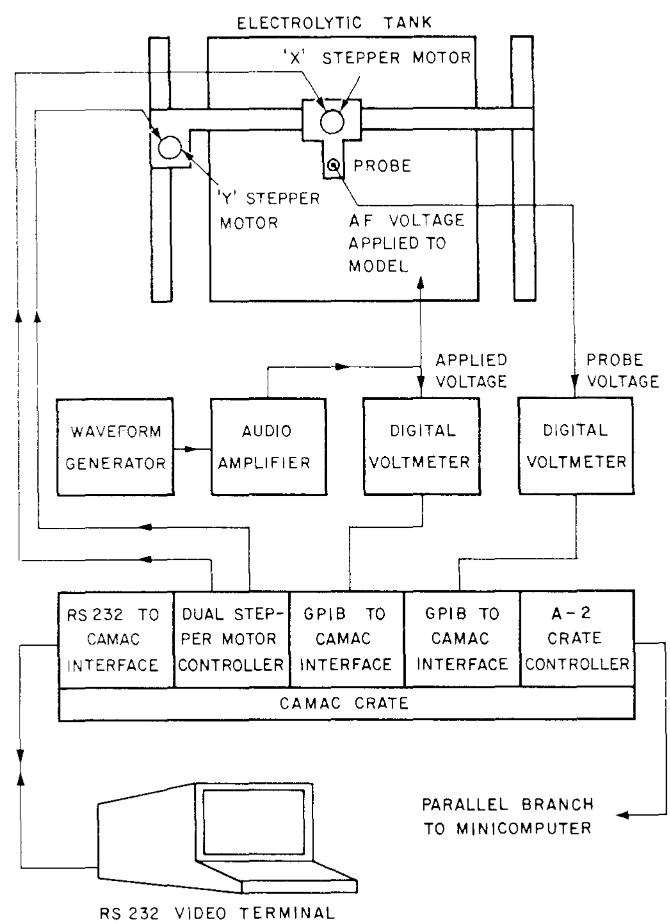

Fig. 1 Schematic layout of the probe positioning equipment, and diagram of the electronic control and measuring hardware.

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3. Tests and Development

In order to determine the accuracy and repeatability of results, a parallel-plate model consisting of two chrome-plated glass plates was used. The equipotential contours for this model are equidistant and linear in the middle region of the model, and therefore provide a quick and direct verification. We investigated various configurations using different probes, (viz. tungsten, platinum, and platinum grey), different immersion depths of the probe, and different submerged depths and separations of the plates. A potential difference of 18.5 V was applied to the electrodes during these tests.

Initially we used a bridge-balancing method to determine the probe potential. For these measurements we used filtered tap water as electrolyte, since the conductivity of the electrolyte is largely irrelevant when using a null method. The resolution of the bridge measuring system was 10 mV. The results obtained showed generally good repeatability with acceptable accuracy for orbit calculations restricted to the median plane. However, spurious peaks observed in the middle voltage ranges implied that the extrapolation of the data out of the median plane would have inherent errors of up to 20%. To improve the accuracy, the bridge measurement system was replaced by two digital voltmeters (DVM's) to measure the voltage applied to the model, and the voltage on the probe. In this case the conductivity of the electrolyte has to be taken into account, and we added diluted sulphuric acid to increase the conductivity, resulting in a lower noise level on the measurements. Fig. 2 shows comparative runs for the two measurement systems. Both curves are plotted using the second differences of the probe potential as a function of probe position, measured on a line perpendicular to the plate surface. The average voltage gain per 2 mm step was 135.9 mV and the standard deviation for the 42 measured points was 0.78 mV in the second case. As a result of the change, the maximum error at any measured point improved from 6% to about 1%.

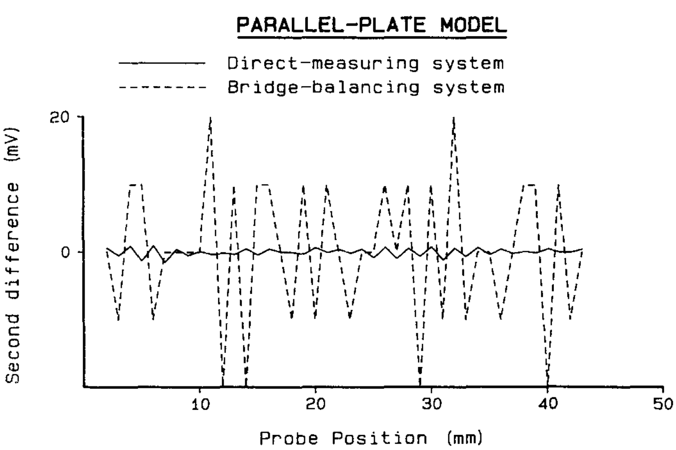

Fig. 2 Comparison of the "bridge-balancing" and "direct-measuring" systems. The second differences of the probe potential are displayed as a function of probe position.

Further reduction of the noise level was obtained by replacing the initially used belt drive system by a direct-coupling shaft between the stepper motors and the pinion driving gears. Fig. 3 shows the reduction of the scatter as a result of this change. Both curves are plotted using the second differences of the probe potential as a function of probe position, and it can be seen that the direct-drive system shows an approximate twofold improvement.

Finally, the repeatability of the system was checked and found to have a variation of less than 1 mV for measurements of the same equipotential taken 13 hours apart during a continuous run. These results are illustrated in fig. 4.

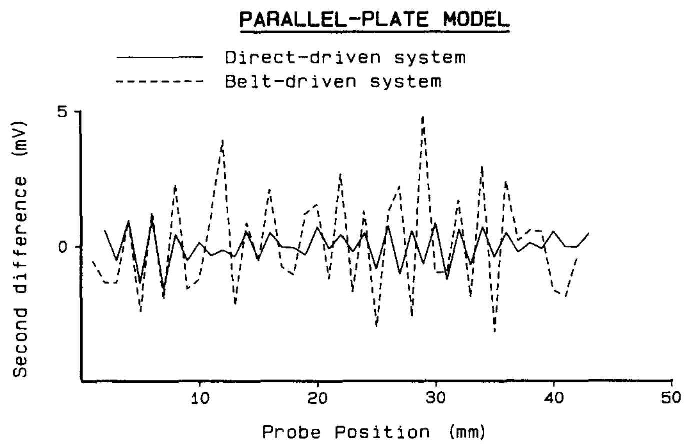

Fig. 3 Comparison of the "belt-driven" and "direct-driven" systems. The second differences of the probe potential are displayed as a function of probe position.

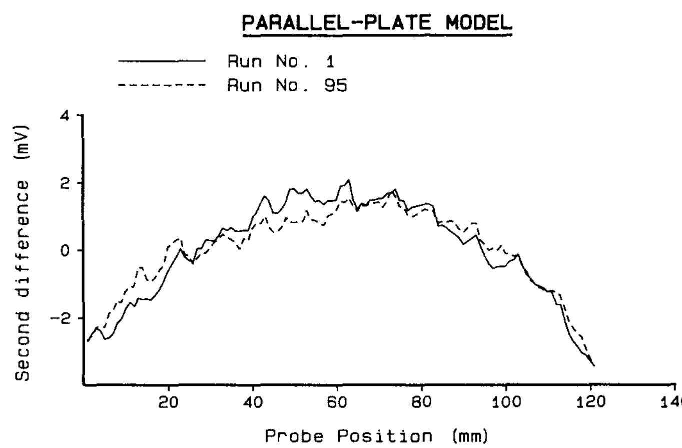

Fig. 4 REPEATABILITY TEST : Comparison of the second differences of two measurements of the same equipotential taken 13 hours apart, showing a variation of less than 1 mV over the entire range.

4. Mini-Computer Control and Data-Acquisition

As the electrolytic tank facility was intended to be a general purpose instrument for accurate measurement of fields on models, the data-acquisition and control requirements for the facility were as follows:

i) Convenient storage of the large amounts of data resulting from the measurements, and transfer of these data to our mainframe computer in as painless a manner as possible;

ii) Flexibility in the control of the tank hardware and the specification of how the data is to be acquired.

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Furthermore, in order to cut development time, we wanted to make use of off-the-shelf components for interfacing the tank hardware to a computer, and a high-level language for coding the tank control and data-acquisition program. The necessary facilities existed on the NAC Control System mini-computers, as they not only provided an easy way of storing and transferring data to the mainframe, but also had a CAMAC interfacing network linked to them. The task of interfacing the electrolytic tank to one of the mini-computers by way of a Parallel Branch and a CAMAC crate at the tank was therefore a fairly trivial task.

Fig. 1 is a schematic of the electrolytic tank facility as it now exists. A waveform generator and an audio amplifier provide the audio-frequency voltage which is applied to the model. The two stepper motors which position the probe are driven by a dual-channel CAMAC stepper motor controller. There is no feedback of the probe position: the system relies solely on counting the stepper motor steps to determine the probe position, a method which has proved to be very reliable. The probe and applied AC voltages are measured by two DVM's which are linked to CAMAC by two GPIB CAMAC modules. In addition there is a video-terminal with which the operator controls the experiment, and which is linked to the control computer by an RS-232 CAMAC module.

From the point of view of the interfacing electronics, several precautions needed to be taken to achieve the measurement precision of 1 in 10000. Firstly, the probe voltage needed to be measured with an instrument which could attain an accuracy of at least 1 in 10000. In the earlier version of the facility we had used a bridge balancing arrangement to measure the probe voltage, but this did not give the required resolution. We now use a DVM which has a claimed accuracy of $5\frac{1}{2}$ decimal digits. Secondly, the probe voltage needed to be compensated for drift in the applied voltage. We do this by measuring the applied voltage with a second DVM whenever a probe voltage measurement takes place, and by 'normalizing' the applied voltage to a value taken at the beginning of a run. If the normalization is to be completely accurate, the measurement of probe and applied voltages must take place simultaneously. We are not able to do this as our CAMAC system does not allow simultaneous triggering. Therefore, in order to trigger the DVM's as close together as possible, each DVM is interfaced to CAMAC via its own GPIB module, and the DVM's triggered by successive CAMAC commands separated by a 350 micro-second interval, compared with the DVM integration time of 200 milli-seconds. Furthermore, measurements are delayed by about half a second to allow vibrations to die down after movement of the probe. Backlash also is taken up by always approaching any point to be measured by at least three grid steps from smaller X and Y values.

5. Software Description

The control program ETANK has to be loaded from one of the mini-computer user terminals. Thereafter all control communication can be handled from the terminal at the tank site via CAMAC (fig. 1). From the program menu one may set up and initialize the CAMAC modules as well as the DVM's. The centre calibration mode allows the origin to be defined and in the options mode various scale factors, sizes and display modes are chosen and stored. One may also position the probe using the keyboard, and store all calibration points (5 maximum) thus measured. At the start of a measuring run, the grid to be measured is defined and the calibration points are then measured before the grid points. A run may be interrupted at any point and resumed after a return to the menu. The measured data are written to a workfile which may be inspected at any stage, and also either stored permanently on disc or purged. Termination of the program can also be done from the workstation.

6. Results

As an example of our results, we discuss the measurements carried out on a 3:1 scale model of the central region of the NAC injector cyclotron SPC1.[1] The electrolyte pH was adjusted to between 3 and 4. A few drops of detergent was added to reduce the surface tension. This reduces the surface vibrations of the water as well as the meniscus effects on the probe tip, thus improving the reliability of the measurements.

Alignment of the model

The model is made with five pillars used as reference points, aiding in the correct alignment of the model in the tank. One pillar represents the centre of the cyclotron, while two each of the remaining four pillars define the X and Y axes corresponding with the X and Y axes of the measuring equipment. The alignment is done by means of positioning the platinum probe tip to coincide with the sharp point of one or other pillar, moving the probe along the X and Y axes to the next pillar and checking to see whether the probe and the new pillar are coincident, if not, the model is then shifted or rotated in the horizontal plane until the correct alignment is obtained.

The top surface of the model represents the median plane and ideally the height of the water above the top of the model must be constant throughout and as low as possible, but sufficient for the probe to be immersed to a depth of ~ 1 mm to overcome meniscus effects, without actually touching the model. To facilitate the vertical alignment, the base plate of the model contains 3 levelling bolts.

Accuracy of the Measurement

The resolution of the digital voltmeters is ± 0.1 mV, and the voltage applied to the electrodes is about 7.5 V. The minimum step size for the probe is 0.1 mm. By using models which are larger than the actual region in the cyclotron, the step size may be increased to diminish any inherent mechanical errors while retaining the same order of resolution.

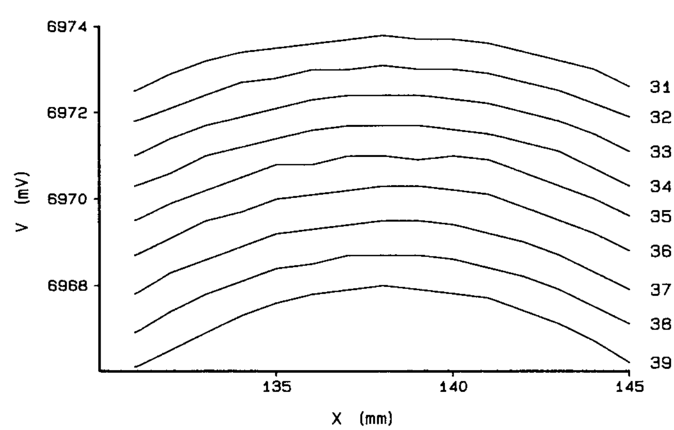

Fig. 5 Cross section of potential contour plot taking successive rows (Y = 31, ... 39) of the rectangular grid between the values X = 131 and X = 145 showing the accuracy achieved (0.3 mV) in a region of the model where the potential shows slight but smooth variations.

A definition of the accuracy of the measurements is difficult owing to the non-linear behaviour of the potential as a result of the complex boundary conditions of the model. However, by choosing a flat region of the model where the potential is expected to remain nearly constant, a clear indication of the accuracy of the measurements can be obtained.

Fig. 5 shows the potential measured over a flat region, centrally situated above the second dee of the model. The maximum error, shown as deviations from the expected smooth curve, is of the order of 0.3 mV, or expressed as a percentage of the maximum measured voltage, it represents an error of 0.0004%. This results in an error of 0.08% for a particle accelerated with a z-displacement of 20 mm when using the extrapolation formula (1) above.

Example of Results

The 3:1 scale model covers the central 167 mm x 167 mm of the injector, and measures 1 m x 1 m. The maximum grid measured covers the central 135 mm x 135 mm of the cyclotron. The probe step sizes are 3 mm and the time taken to measure a full 271 x 271 points grid depends on the display mode selected (26.5 hours with no display, and 40 hours with a display on the monitor of every measurement taken). In fig. 6 an example of a measured field is displayed by means of equipotential contours. Further examples can be found in the reference given.

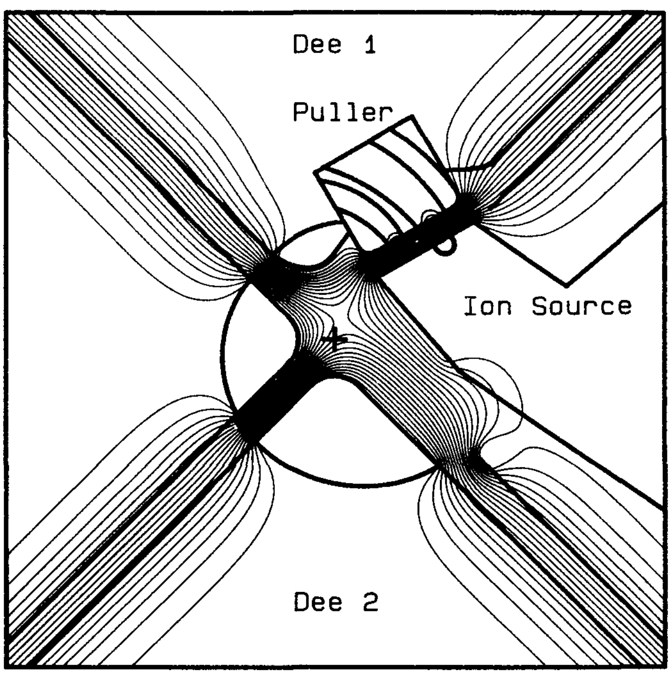

Fig. 6 Measured equipotential contours showing the essentials of the model in outline. The contours have been plotted at 5 % intervals. The central 200 mm x 200 mm of the cyclotron is covered by the area shown in the figure.

Fig. 7 shows isometric representations of the field displayed in fig. 6. The upper part of fig. 7 depicts the situation at the instant when the dees are at a minimum voltage relative to the dummy dees, and the lower part shows the reversed situation half a period later. The viewpoint remains unchanged.

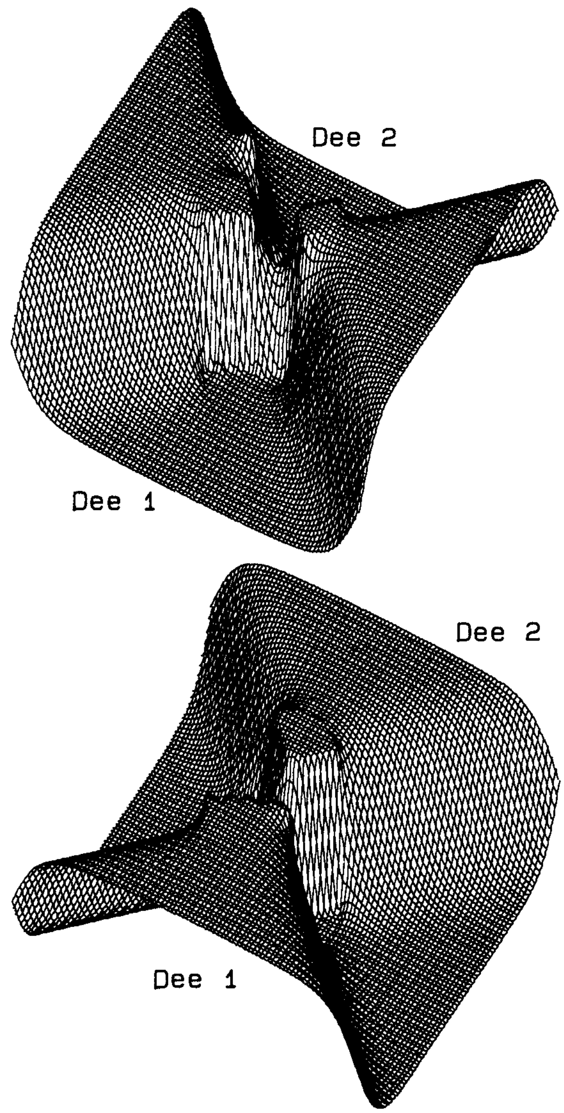

Fig. 7 Isometric representations of the potential field shown in fig. 6. The upper half of the figure displays the field shape at the instant at which the dees are at a minimum potential with respect to the dummy dees, and the lower half shows the reversed situation half a period later.

Reference

1. S.J. Burger et al., On the design of the central region of an 8 MeV injector cyclotron. This conference.

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