Title
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THE LBL EBIS TEST-STAND*

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I. Introduction

An EBIS program was initiated at Lawrence Berkeley Laboratory in late 1979, as described in the companion paper "The LBL EBIS Program." This first stage, construction of an EBIS research and development "test-stand" will be described, along with results of the bare beam experiments.

II. Design

The test stand has been designed to make use of equipment already available at the laboratory. This includes large, water-cooled magnets and a 360 kW motor generator to drive them, along with a test bed for support.

A principal goal of the design [illegible] adequate alignment of the electron gun, drift tube structure, and magnetic field. Since the degree of

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alignment needed for the production of high charge states in anomalously short times (1) is not precisely known, it was decided to aim for less than 0.1 mm misalignment.

Ultrahigh vacuum linear motion manipulators (2) are used to align the electron gun. Figure 1 shows the manipulators which allow for independent motion transverse and parallel to the axis. These alignments can be performed while the system is under vacuum and operating, so they are easily optimized.

In a similar manner, eight ultrahigh vacuum manipulators are provided for drift tube alignment, as shown in figure 1. These were made at LBL since commercial manipulators were magnetically permeable and would have distorted the solenoidal field. The electron current intercepted by the drift tubes can be monitored during operation and minimized through proper positioning. Additionally, a four part split drift tube (3) will be used to aid in centering the structure.

A significant portion of the design effort has been directed to obtaining a straight solenoidal field. The magnets used in the test stand, consisting of three, 16 inch diameter water cooled copper coils, do not provide a field of adequate straightness. To allow the use of these coils (which were on hand), a "magnetic homogenizer" was constructed. (4) The homogenizer consists of a series of annular discs made of soft iron, as shown in figure 2.

These discs were precisely machined to ± 25 μm, and fixed with a non-permeable structure so as to form a parallel and coaxial assembly straight to within ± 25 μm. The discs form a magnetic equipotential, and therefore decouple the solenoidal field inside the annuli from the exact position of the coils. A detailed design desciption is provided elsewhere. (4) The design provides for a straight field with a maximum error in coil location of 0.7 cm, much greater than the actual error in the coils.

The homogenizer provides several other significant advantages. By decoupling the field inside the annuli from the region outside the homogenizer, the experiment is protected from stray fields due to iron located near the experiment. In an operational environment this could otherwise be a significant problem. Another advantage is ease of field alignment. Small changes in the direction and location of the magnetic axis can be performed by moving the homogenizer. This is a significant advantage since the homogenizer is much lighter and easier to move precisely than are the coils.

III. Experimental Results

Since the drift tube structure is presently being installed, the experiments to date have concentrated on magnetic field and electron beam measurements.

The field qualtiy has been measured, using the technique of Nishihara and Terada (5). The resolution of our magnetic (Hall effect) probe assembly is such that a deviation from straightness of approximately 10^{-4} radians, or an axial field line deflection of approximately 0.01mm in a length of 10 cm can be measured. Some results of these measurements are shown in figure 3. The projection in the transverse plane of a field line near the axis is shown for various axial postions given by the labeled points. The upper diagram shows the field with the homogenizer in place. A constant vector has been subtracted from these trajectories, eliminating any misalignment of the axis of the probe assembly from the solenoidal axis, and therefore premitting a clearer comparison. With the homogenizer, the field line is straight to ± 40 μm over an axial distance of 60 cm.

Further verification of the straightness of the axis is shown in the lower diagram. An electron gun is located outside one end of the solenoid, and a tungsten sheet 25 μm thick is moved along the axis. A telescope is used to measure the location in the transverse plane of the spot on the tungsten heated by the (pulsed) electron beam. Upon removing the constant vector, the lower diagram shows the beam trajectory to be straight within ±50 μm (the limit of resolution) over an axial distance of 55 cm.

The field axis was adjusted to achieve these results by slight shifting of the homogenizer. Through judicious adjustment of the tilt and transverse position of the homogenizer, a field line passing through the center of both polepieces and normal to the first polepiece is obtained.

Electron beam measurements have formed the bulk of the experimental effort up to this point. Injection into a cyclotron requires a high pulse repetition rate, which implies a short ion confinement time. This means that the test stand must demonstrate achievement of a high energy electron density at least one order of magnitude larger than the bare beam density, as was achieved at Orsay.(1) The working assumption (to be verified) at LBL is that beam collapse due to space charge neutralization can account for this increase in density.

A simple computer code (6) which calculates the envelope of the electron beam has been used to help model this collapse. The code predicts that low magnetic field at the electron gun cathode, and good matching of the beam to the magnetic field are needed to achieve collapse. Low cathode field is provided by making use of the hysteresis in the iron shield around the gun. By properly cycling the main magnetic field, the residual field at the cathode can be made less than 0.2 Gauss, more than adequate for beam collapse. Matching of the beam to the field is needed to avoid "scalloping" of the beam envelope. While these ripples die out after a short distance, the added beam diameter does not. Since this additional beam diameter represents added transverse energy of some of the beam electrons, they do not collapse along with the laminar electrons. It is therefore desirable, if the code predictions are correct, to keep the scalloping of the beam, due to mismatch of the beam-field matching, much less than the beam diameter.

The electron beam has been examined using a multiwire probe. This consists of fourteen, 25 μm diameter tungsten wires with a center to center spacing of 76 μm. A PDP 11/34 computer is used to provide a graph of the current to each wire, and to calculate the Abel inversion of the signal,(7) thereby determining the current density as a function of radius. A typical profile of the beam is shown in Figure 4. Figure 4a shows the raw data, the current received by each wire, while figure 4b shows the Abel inverted current density as a function of radius. Cylindrical symmetry is assumed in obtaining the Abel inverison, and this assumption has been verified by looking at the beam with both horizontal and vertical wires.

The beam current density, averaged over the full width half maximum, has been used as a measure of beam quality. Figure 5 shows the variation in current density, measured 20 cm from the polepiece, as a function of cathode voltage (V_k) and magnetic field. An optimal gun voltage of about 2.5- 3 kV is evident from these graphs. To see if this optimum corresponded to a less scalloped beam, the probe was scanned along the axis near the polepiece. Figure 6 shows the scan of current to the probe for a beam voltage of 2.5 kV and a field of

3 kG. Note that the profiles vary little from one axial (Z) positon to the next. An axial probe scan for the non-optimal case of 4 kV is shown in Figure 7. A clear broadening of the current to each chord (leading to a hollow current density profile) is evident. While the existence of scalloping is not clear from this data, a correspondence between high current density measured at 20 cm and a constant (with respect to Z), peaked profile near the gun has been established.

IV. Future Directions

The drift tube structure, ion optics, and electronic control systems are presently (May, 1981) being installed on the test stand. Ions will first be produced from the background gas, the pressure of which will be raised to the 10^{-9}-10^{-7} Torr range of nitrogen. Confinement time and charge state production will be examined to learn about pressure inside the the drift tubes and electron beam density.

The next step involves the gas injection system. Commercial getters,(8) which produce atomic vapor of alkali metals, will be used as the gas source. This should eliminate the need for cryopumping since any atoms not ionized will stick to the drift tube surface. It will also aid in pumping, since the atoms desposited will getter background gas. If these commercial units prove successful, units will be designed for other metals.

After reliable, reproducible high density operation has been achieved, repetition rate and duty cycle will be examined. Sensitivity of the system to such parameters as field straightness, gun alignment, and drift tube alignment will be investigated. Further diagnostics will be employed to verify the mechanism of high density operation. Finally, sensitivity to the focal length and degree of aberration of the electron gun will be examined. Investigation of these various parameters should enable the construction of a full scale EBIS with optimal performance.

V. Conclusion

The present EBIS test stand at LBL has been described, with special emphasis on the unique alignment devices. Experimental measurements of the magnetic field and electron beam have been presented. The next few months will be spent looking at ions produced in the source, with emphasis on obtaining reproducible, reliable, high electron density operation. Subsequently, the sensitivity of the operating conditions to various parameters will be examined to help with the design of the full scale EBIS for the 88 inch cyclotron.

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* This work was supported by the Director, Office of Energy Research, Office of High Energy and Nuclear Physics, Nuclear Physics Division of the U. S. Department of Energy under Contract No. W-7405-ENG-48.

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FIGURE CAPTIONS

Figure 1: Schematic of the EBIS test stand.

Figure 2: Magnetic homogenizer, showing the iron annuli and the non-permeable structure.

Figure 3: Upper - Projection in the transverse plane of the axial field line. The points are positions along the axis, measured in centimeters from the polepiece near the electron gun.

Lower - Projection in the transverse plane of the electron beam trajectory.

Figure 4: Beam Profile Measurements.

4a: Current to each wire chord.

4b: Abel inverted current density versus radius.

Figure 5: Current density as a function of cathode voltage and magnetic field, measured 20 cm from the polepiece.

Figure 6: Current to each wire chord for various axial positions near the polepiece, with $V_k = 2.5$ kV and $B = 3$ kG.

Figure 7: Current to each wire chord for various axial positions near the polepiece, with $V_k = 4$ kV and $B = 3$ kG.

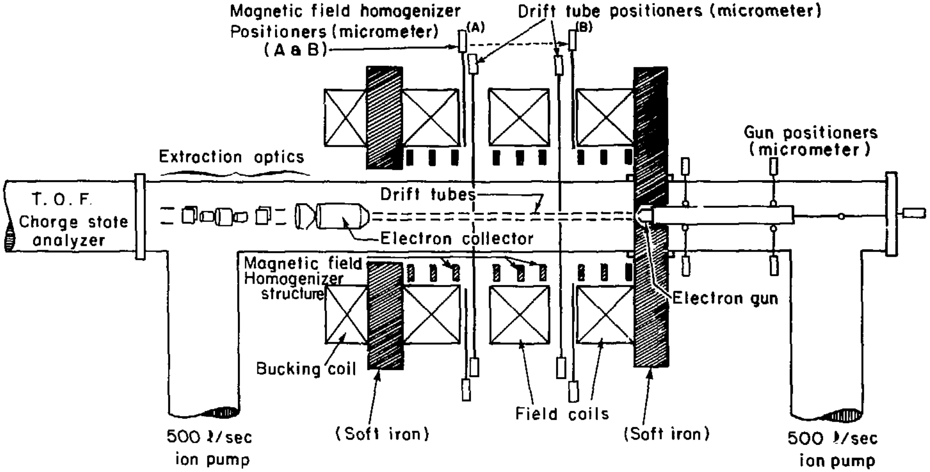

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Figure 1

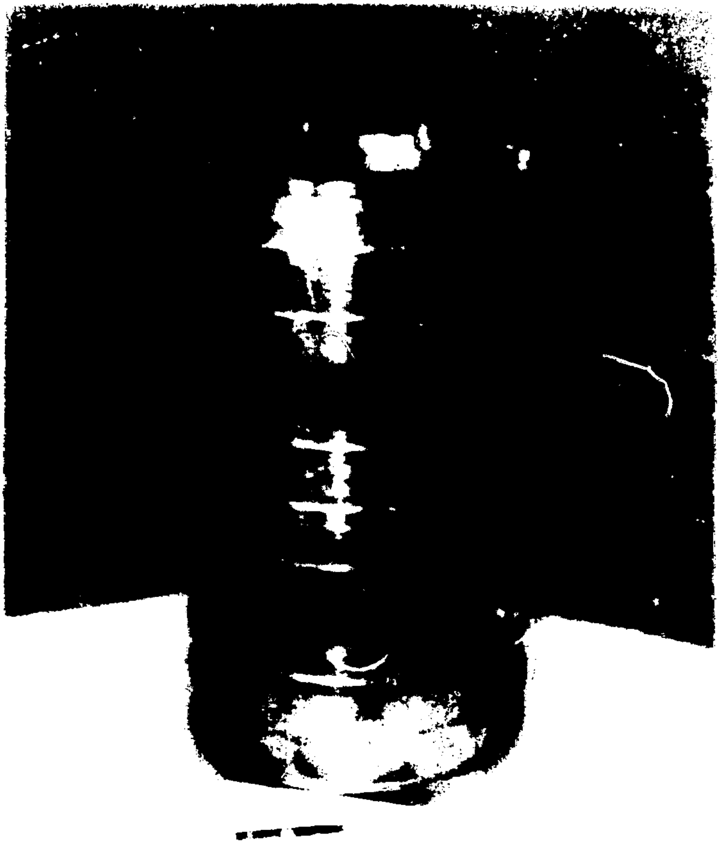

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Figure 2

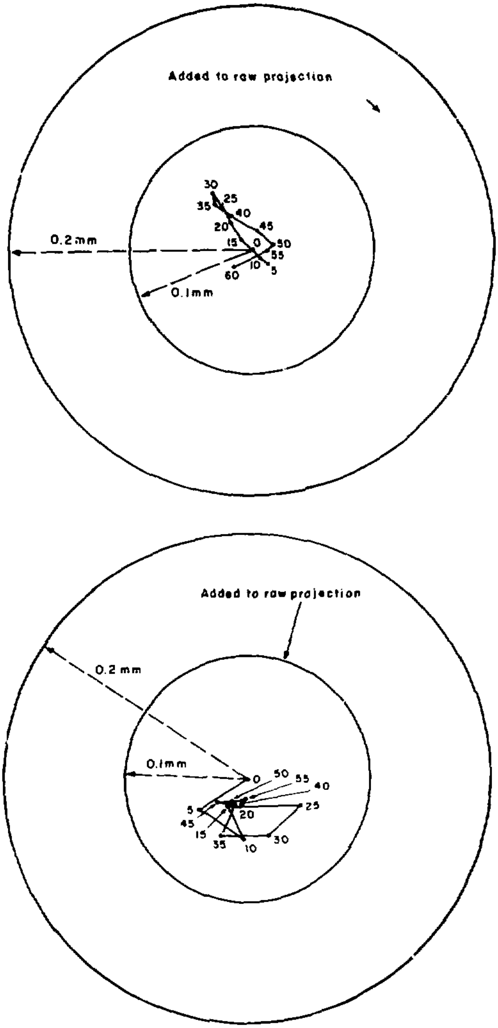
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Figure 3

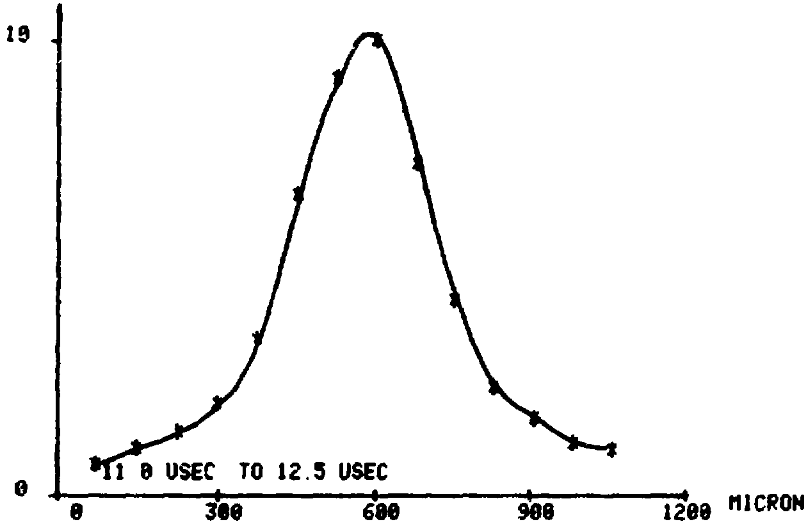

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Figure 4A

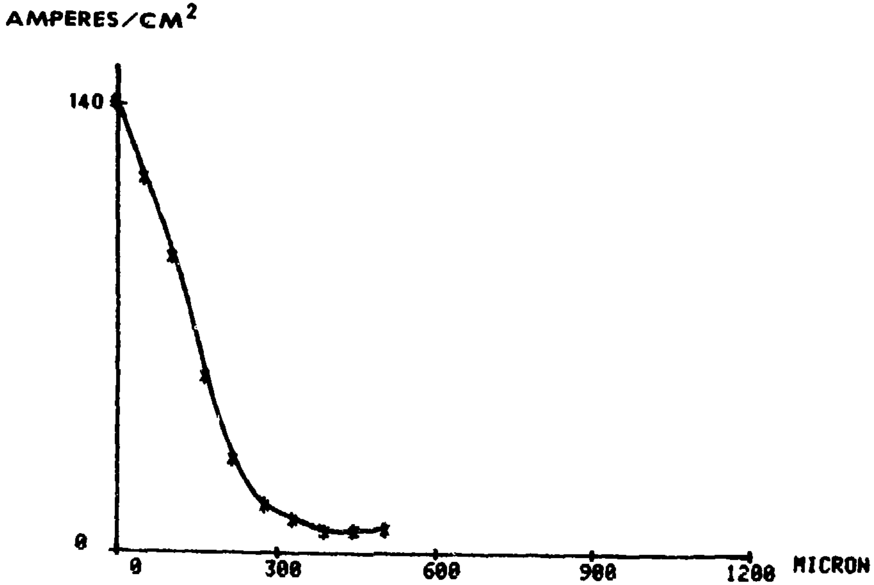

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Figure 4B

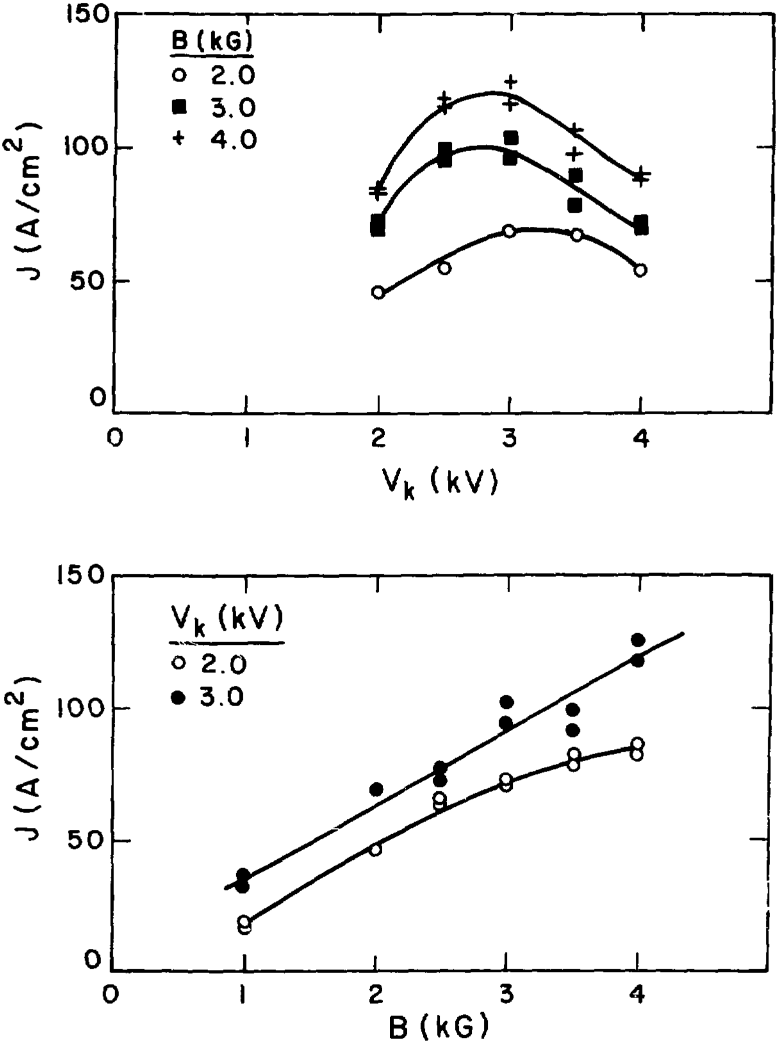

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Figure 5

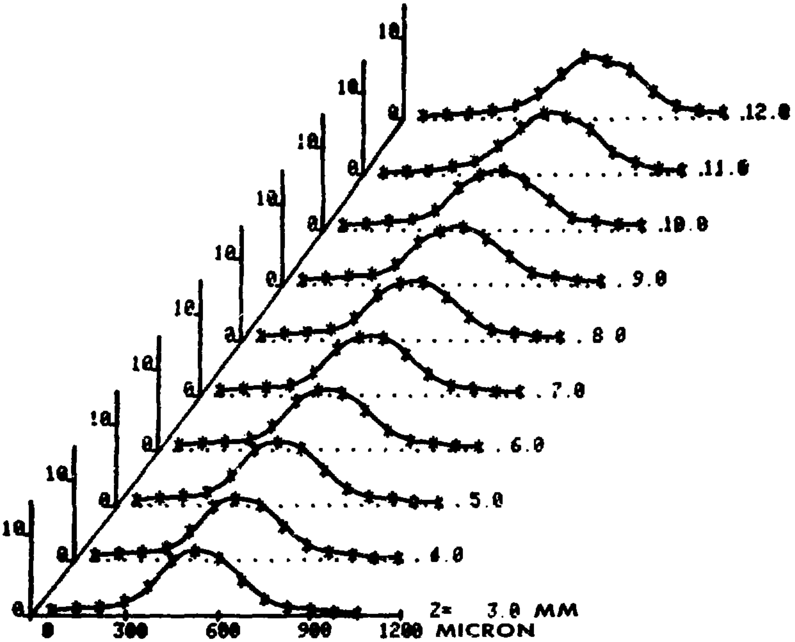

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Figure 6

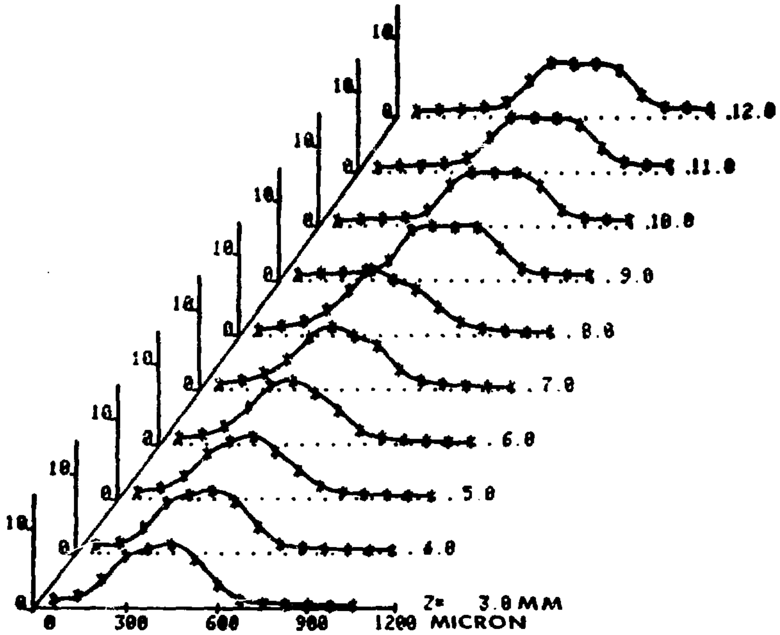

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Figure 7