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Three-Axis Electron-Beam Test Facility

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Summary

An electron beam test facility, which consists of a precision multidimensional manipulator built into an ultra-high-vacuum bell jar, has been designed, fabricated, and operated at Lewis Research Center. The position within the bell jar of a Faraday cup, which samples current in the electron beam under test, is controlled by the manipulator. Three orthogonal axes of motion are controlled by stepping motors driven by digital indexers, and the positions are displayed on electronic totalizers. In the two transverse directions, the limits of travel are approximately ±2.5 centimeters from the center with a precision of 2.54 micrometers (0.0001 in.); in the axial direction, approximately 15.0 centimeters of travel are permitted with an accuracy of 12.7 micrometers (0.0005 in.). In addition, two manually operated motions are provided, the pitch and yaw of the Faraday cup with respect to the electron beam can be adjusted to within a few degrees. The current is sensed by pulse transformers, and the data are processed by a dual channel box car averager with a digital output.

The beam tester can be operated manually or it can be programmed for automated operation. In the automated mode, the beam tester is controlled by a microcomputer (installed at the test site) which communicates with a minicomputer at the central computing facility. The data are recorded and later processed by computer to obtain the desired graphical presentations.

Introduction

Microwave amplifier tubes are devices that convert the kinetic energy of an electron beam to the potential energy of an electromagnetic wave. The principal applications of microwave tubes today are in high power telecommunications, television transmission, military radars, and microwave heating. For proper operation, the electron gun that produces the electron beam must be designed so that at the point where the beam is launched into the tube the beam diameter is at a minimum and the flow of electrons is approximately parallel to the tube axis. This must be done with great precision if a tube of high efficiency and long life is to be obtained.

While electron gun theory is sufficiently advanced that approximate designs can be obtained analytically, measurements are usually required at least to verify or refine a new design. For applications where the highest quality is required, as, for example, when building tubes for communication satellites, every electron gun will be tested before installation on a tube.

The principal reasons for building the electron beam tester were to provide NASA with the capability of verifying electron gun data submitted by its contractors, to test electron guns built in connection with NASA internal research programs, and to provide a research facility for the high resolution examination of electron beams.

The resolution capability of the beam tester was achieved by employing the novel approach of placing most of the moving parts within the vacuum envelope. In this way only rotary motion need be transmitted through vacuum feedthroughs, and this can be done with much greater precision than the conventional method of transmitting linear motion through a bellows working against atmospheric pressure. All moving parts within the beam tester are either gold-plated or burnished with molybdenum disulfide to combat vacuum friction.

The description of the beam tester presented in this report is complete up to this time. However, as the beam tester is a research facility as well as a test facility, it will continue to undergo modification throughout its useful life to accommodate NASA research interests.

Mechanical Description

The three-axis electron-beam tester is built into a 30.5-centimeter-diameter stainless-steel bell jar which is mounted on a standard ultra-high-vacuum pumping station. Rough pumping is achieved with two absorption pumps of 100 liter per second capacity. The bank of ion pumps and the titanium sublimation pump that provide the ultra-high-vacuum pumping capability are separated from the bell jar by a poppet valve. During electron gun testing the bell jar pressure is typically below 1.3×10^{-6} pascal (1.0×10^{-8} torr). The roughing line is instrumented with a thermocouple gauge, and the bell jar pressure is measured with a standard ionization gauge and an ultra-high-vacuum ionization gauge. A residual gas analyzer is also mounted on the bell jar to identify the gases present during testing.

The beam tester mechanism is shown in figure 1 mounted on a test stand prior to installation in the bell jar. The mechanism is built into a 30.5-centimeter Wheeler flange, which becomes the top of the bell jar when the beam tester is fully assembled. Electron guns to be tested are mounted on a 15-centimeter (6-in.) bakeable stainless-steel flange, which is mounted on a port at the center of the bell jar in line with the axis of the carriage.

The Faraday cup is mounted on a carriage driven by three lead screws in the three orthogonal Cartesian axes. The Faraday cup consists of a removable tantalum aperture plate, a ring electrode that can be used to collect electrons with large initial dispersion or to apply a secondary emission suppression bias, and a collecting cup with an aspect ratio of 5:1. The pinhole in the aperture plate (0.0254 cm thick) was obtained by laser drilling and is a slightly oblong hole approximately 33 by 41 micrometers.

The stepping motors which drive the carriage in the three Cartesian axes are located on top of the flange (fig. 2); their motion is transmitted through rotary feedthroughs to the gear trains and lead screw drives

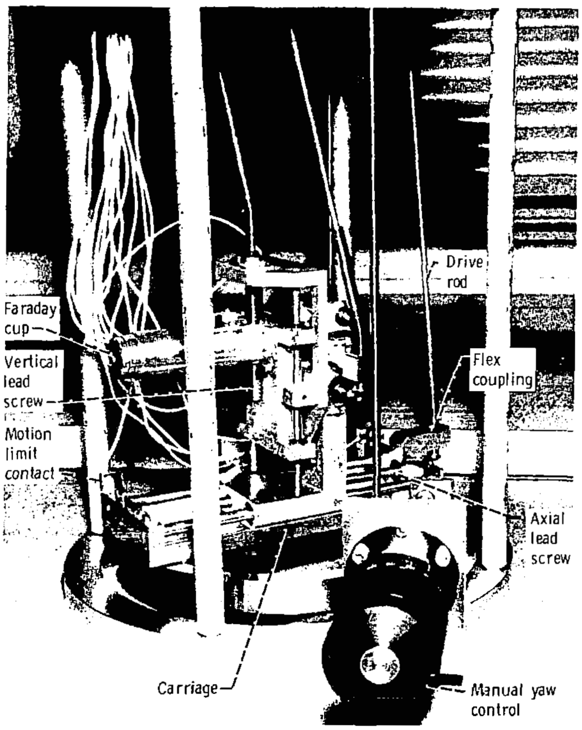

Figure 1. - Beam tester mechanism details.

inside the bell jar. This permits very precise positioning of the Faraday cup since the controls need not work against the force of atmospheric pressure that would be required if linear motion feedthroughs were used. All moving parts and bearing surfaces inside the vacuum system are either gold-plated or burnished with molybdenum disulfide. In the two transverse directions of motion the limits of travel are approximately ±2.5 centimeters from the center with an accuracy of 2.54 micrometers (0.0001 in.) per step. In the axial direction the carriage can move approximately 15.0 centimeters with a precision of 12.7 micrometers (0.0005 in.) per step.

The motion of the Faraday cup is monitored by a shaft encoder on each axis that drives an electronic totalizer. Position information can be read directly by the operator and transmitted to the computer. However, this position information is related to an arbitrary zero setting. To obtain accurate axial position data, the fixture shown in figure 3 is used. The micrometer depth gauge can be calibrated with respect to the reference surface. Then, when the fixture is bolted to the mounting flange on the side of the bell jar, the position of the Faraday cup can be measured with respect to the mounting flange with an accuracy of 25.4 micrometers (0.001 in.). The micrometer depth gauge is electrically isolated from the mounting bracket so that contact with the face of the Faraday cup can be determined electrically.

The telescope mounted on the fixture shown in figure 4 can be bolted to the mounting flange and used as a guide to adjust the axis of the beam tester travel to a line perpendicular to the plane of the mounting flange. The electron beam itself is also a useful guide in aligning the axis of the carriage travel with the electron beam.

A crude indication of the Faraday cup position is provided by electrical contacts which actuate an indicator lamp for each of the two transverse directions when the carriage is in the approximate center of its range of travel. Adjustable electrical contacts, in place at the limits of travel of each of the motor-driven axes, actuate circuits which electronically disable the indexer in the event of an errant command to exceed the limits of travel.

In addition to the three electronically controlled orthogonal axes, two manually operated controls, one of which is shown in figure 1, permit adjustments of a few degrees of the pitch and yaw of the Faraday cup relative to the electron beam.

The beam tester is designed to be baked at up to 150° C, however, a bakeout of the entire system has not been necessary to achieve adequate vacuum for tests that have been conducted to date. In some cases the electron gun under test is baked at up to 400° C

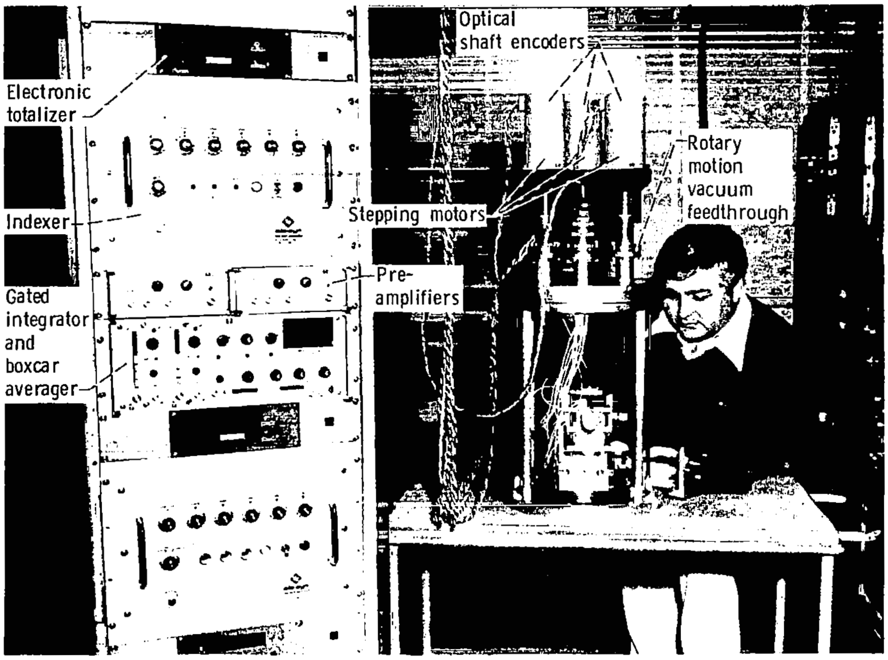

Figure 2. - Beam tester mechanism showing stepping motor location and controls.

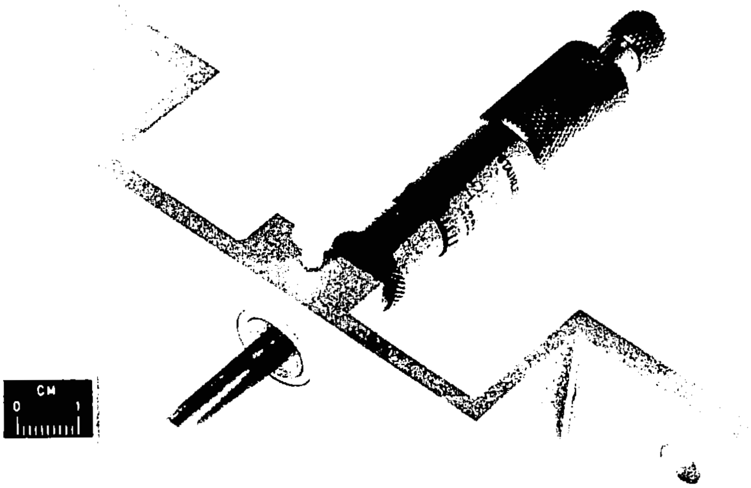

Figure 3. - Micrometer depth gauge.

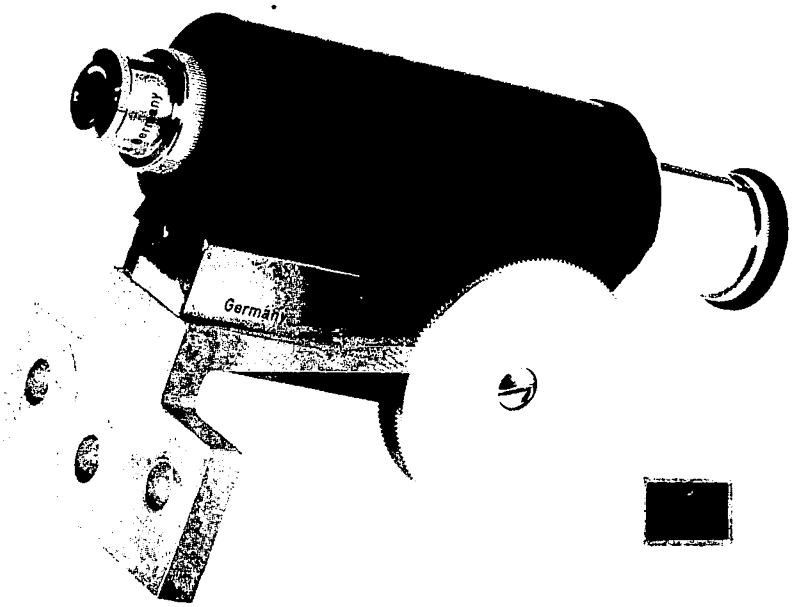

Figure 4. - Microscope electron beam alignment guide.

by a heating tape wrapped around the arm of the bell jar.

The mechanical design of the beam tester was the responsibility of Ben T. Ebihara, Joseph W. Pigford, and James Laubenthal of the Engineering Design Division. Fabrication was done by Lyle A. Hoffman, Harry Cole, Paul Simpson, and Leonard Piechowski of the Fabrication Division Machine Shop.

Repeatability and Accuracy of Mechanism

The accuracy with which the Faraday cup can be positioned by the beam tester was tested by measuring its motion relative to a traveling telescope on a micrometer-driven optical translator set up beside the bell jar. With the telescope the movement of the beam tester could be observed through optical viewing ports in the bell jar. The micrometer could be read to 25.4 micrometers (0.001 in.); the telescope had an 80-millimeter 1:1 objective lens and a 10× eyepiece with cross hairs. No discrepancy could be detected in the ability of the beam tester to return the Faraday cup to its starting position after several excursions, demonstrating the repeatability of the beam tester positioning mechanism on each axis.

Unfortunately, this setup was not sufficiently accurate to verify the absolute accuracy of the indicated position. The micrometer was accurate to only 25.4 micrometers (0.001 in.), while the beam tester indicates positions to 2.54 micrometers (0.0001 in.) in the transverse dimensions and to 12.7 micrometers (0.0005 in.) in the axial dimension. Furthermore, there was no way to accurately establish the parallelism of the beam tester axes to the axis of the optical translator. Also, the telescope cross hairs themselves were too thick to be used to resolve a movement of only 2.5 micrometers. What could be done with this measurement was to verify approximately larger scale movements of the beam tester on the two horizontal axes.

The data indicated a discrepancy in each axis between the micrometer and the indicated position of approximately ±0.0025 to 0.005 centimeter for movements of 0.254 to 0.762 centimeter of the Faraday cup. Since the discrepancy in the measurement was not a function of the total travel, it appears that the axes of the beam tester and the optical translator were approximately parallel. The sighting accuracy of the cross hairs on the Faraday cup is of the order of 25 micrometers; for example, in the transverse axis the telescope was sighted on the pinhole aperture which is a somewhat oblong hole 33 by 41 micrometers. Therefore, the discrepancy in the two measurements could nearly be accounted for by this potential error alone. What is established by this measurement is that the indicated motion of the beam tester in the horizontal axes is accurate to within at least approximately 1 percent, which is quite adequate for the function it performs.

Electrical Measurements and Controls

High-voltage direct current is supplied to the beam tester from a power supply capable of delivering up to 20 kilovolts at 400 milliamperes either direct current or pulsed with a rise time of 0.5 microsecond. The pulse width is variable from 2 microseconds to 1 millisecond. The repetition rate can be varied from 200 to 20 000 hertz.

Because no provision is made for cooling the Faraday cup, all tests are conducted with the electron beam pulsed, typically at a duty cycle of less than 1 percent. Currents to the electrodes of the guns under test and to the Faraday cup are detected by using sensing resistors or isolation pulse transformers. When very small currents are being measured, the current collected by the Faraday cup for example, the signal to noise ratio is substantially improved by using a gated integrator and box car averager.

The electrically driven orthogonal axes are powered by stepping motors controlled by electronic indexers. Index commands from 1 to 99999 steps can be generated; the indexers can also run the motors one step at a time or continuously. The position of the Faraday cup on each axis is tracked by a five digit electronic totalizer that is run by an optical encoder. The electronic indexers have an anti-backlash circuit which counteracts any play that may exist in the mechanical system by always approaching a position from the same direction.

A microcomputer, an analog to digital converter, and an electronic data terminal are installed in the room with the beam tester. The analog to digital converter samples the filament heater voltage, cathode voltage, bell jar pressure, Faraday cup temperature, and beam current. The microcomputer is connected by telephone lines to a minicomputer in the Lewis Research Center's central computing facility. In automated operation, a test program describing the motion of the Faraday cup and other test parameters is entered on the electronic data terminal. The beam tester follows this preset three-dimensional matrix, and the Faraday cup current is recorded in the microcomputer at each location. Periodically, the microcomputer interrupts the beam tester motion, samples the output of the analog to digital converter, and records the beam tester position. These data are all transmitted to the minicomputer where they are recorded and the beam tester position is compared to the programmed position. If there is a discrepancy in position, the test is interrupted. The minicomputer is also programmed to compare the output of the analog to digital converter against values for these measured quantities which the operator may enter from the data terminal. At the operator's choice a test may be interruped if the analog outputs are outside their preset tolerances; a warning message is printed out at the terminal in either event. After a test has been interrupted the operator has the choice to continue or abort. If there are no interruptions, the test continues automatically until completion.

Following completion of a test the data are transferred from the minicomputer to magnetic tape and fed into the Lewis Research Center central computer where they are processed to obtain the desired graphic displays. Two samples of data processed by the computer are shown in figures 5 and 6. In figure 5 the current density measured across the beam is shown at several axial positions along the beam. The change in beam diameter and in the maximum beam current density as a function of distance from the anode can be seen. In figure 6, a contour plot of the cross section of an electron beam at a single axial position is presented. The contours connect points of equal current density from 95 to 5 percent of the maximum in 10-percent increments.

The microcomputer hardware was designed by Leslie G. Kee and built by Burdell L. Detterman. The programming for the microcomputer was done by Charles W. Mealey, Jr., for the minicomputer by Robert N. Setter, and for the computer generated graphics by Richard B. Canright, Jr. The computer

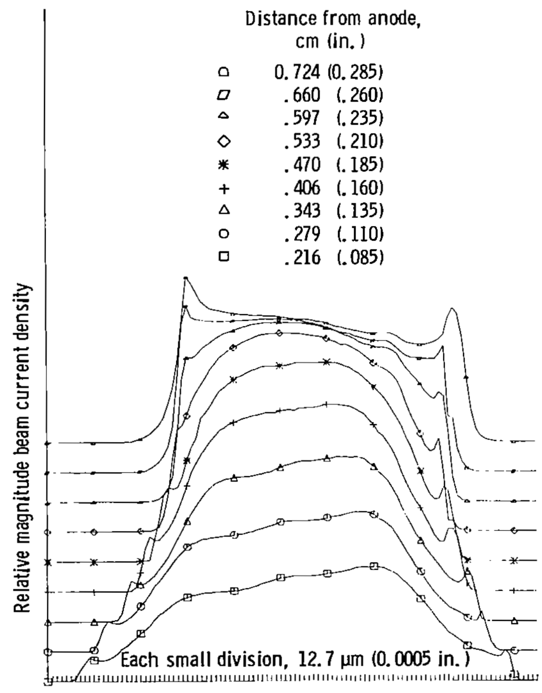

Figure 5. - Cross section of beam current density as function of beam axial position.

Contour label	Contour value (percent of maximum)
A	95.000
B	85.000
C	75.000
D	65.000
E	55.000
F	45.000
G	35.000
H	25.000
I	15.000
J	5.000

Each square, 25.4 by 25.4 μm (0.001 by 0.001 in.)

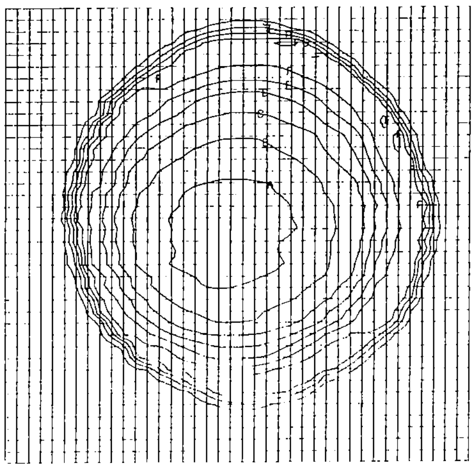

Figure 6. - Current density contour plot of an electron beam at a single axial position.

requirements were determined by Fredric N. Goldberg. The beam tester instrumentation and integration was done by Salvatore A. Campo.

Concluding Remarks

The three axis electron beam test facility provides NASA with the capability of making automated measurements with unprecedented resolution of the current density in electron beams. It is the result of the skillful efforts of many professionals and technicians at the Lewis Research Center where the beam tester was designed, fabricated, installed, and operated.

Lewis Research Center
National Aeronautics and Space Administration
Cleveland, Ohio, December 5, 1980

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15. Supplementary Notes

16. Abstract

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