ELECTRON-BEAM DIRECT DRIVE FOR RF ACCELERATOR CAVITIES[1]

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INTRODUCTION

This paper describes a Program to Demonstrate Electron-Beam Direct Drive for Radio Frequency (RF) Linear Accelerators at the Westinghouse R & D Center.The experimental program was undertaken using an existing electron beam facility at the Westinghouse R&D Center to demonstrate the potential of the Direct Drive RF Cavities for High Power Beams concept discussed by Humphries[2] as part of a program to develop a viable alternate concept for driving RF linear accelerators.

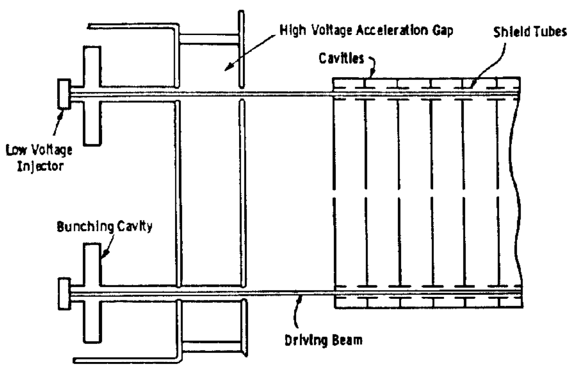

FIGURE 1. Schematic view of the main components of a direct-drive accelerator.

The direct-drive accelerator concept utilizes resonant cavities as an intermediary to couple energy between driving relativistic electron beams and a light-ion or electron load beam. The process transfers power from electron beams at high current and low voltage to particle beams at high voltage and low current as illustrated in Figure 1. The Figure shows a scheme with one stage of acceleration of the drive beams after bunching. In the proof of principle experiment reported here the drive beam is bunched after acceleration. The RF cavity acts as a resonant transformer. High power can be achieved with multiple drive beams. A variety of cavity geometries have been identified to couple beam energy to RF cavities, including the shielded beam tube cavity shown in Figure 2. The shield tubes reduce the interaction of the drive beams with the transverse magnetic field and also permit phase matching between electron drive beams and an ion beam.

1. *funded in part by the Air Force Weapons Laboratory (AFWL) under contract # 29601-85-C-008.*
2. *S. Humphries, Jr. "Direct Drive RF Cavities," Proc. Beams 83 Conf., San Francisco, 1983.*

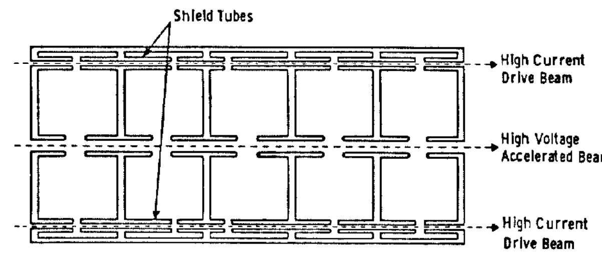

FIGURE 2. TM_{010} mode cylindrical cavity; phase corrected direct coupling between beams.

FACILITY DESIGN

The experimental facility consists of an e-beam gun, the beam transport system, the beam diagnostics, the RF power system, the RF cavities and the RF diagnostics. The system transports the electron beam at a power density of 2 MW/cm^2, a total distance of 5.5 m from the cathode bolt to the beam dump. After a 90 deg. bend the beam is reshaped and sized with two magnetic quadrupole lens, followed by a solenoid, the first lens in the periodic transport system of the beam line. The e-beam will now travel through two pill box RF cavity resonators. Figure 3 is a schematic illustration of the experiment. Figure 4. shows the experimental facility. The vacuum chamber in Figure 4. is part of an old e-beam facility and the new facility starts at solenoid No. 2. The first cavity bunches the beam and the second cavity is driven by the beam. The RF cavities were designed for a resonant frequency of 412-MHz. This frequency was chosen because it is a common value for light ion accelerators and is in the range of the Westinghouse SPS-40 solid state RF amplifier, chosen to drive the buncher cavity. The one item, in Figure 3., not yet installed is the probe beam sensor which is replaced with copper plugs. Only the last solenoid, #5 of the periodic transport line, can be seen in the photo.

The beam transport was modeled using ITAP (Ion Trajectory Analysis Program). ITAP is a three dimensional charged particle transport code for use in ion and electron beam lens design. A matrix technique is used to describe the transport transfer functions for solenoids, sector magnets, and quadrupoles between beam object and image.ITAP utilizes an iterative bisection method to calculate the optimal lens configuration to produce a desired image size or divergence from a given set of object conditions. The output includes the necessary electrode excitations, thicknesses, and gap spacings to design hardware. The completed system transports

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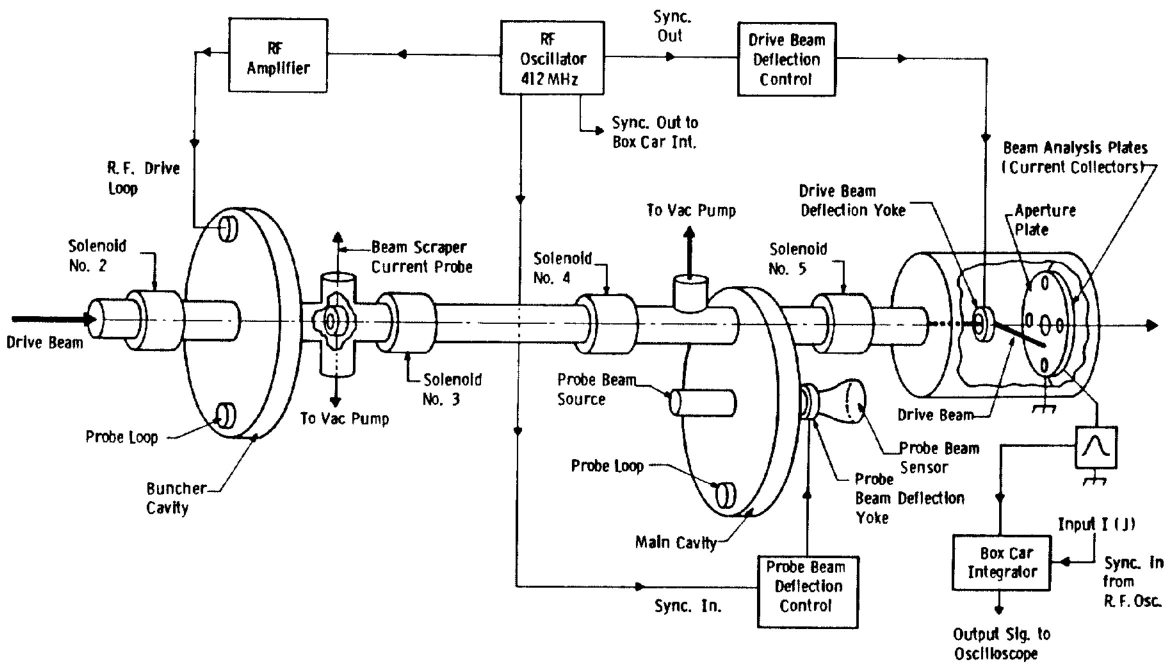


FIGURE 3. Schematic illustration of the dual-beam experimental facility.

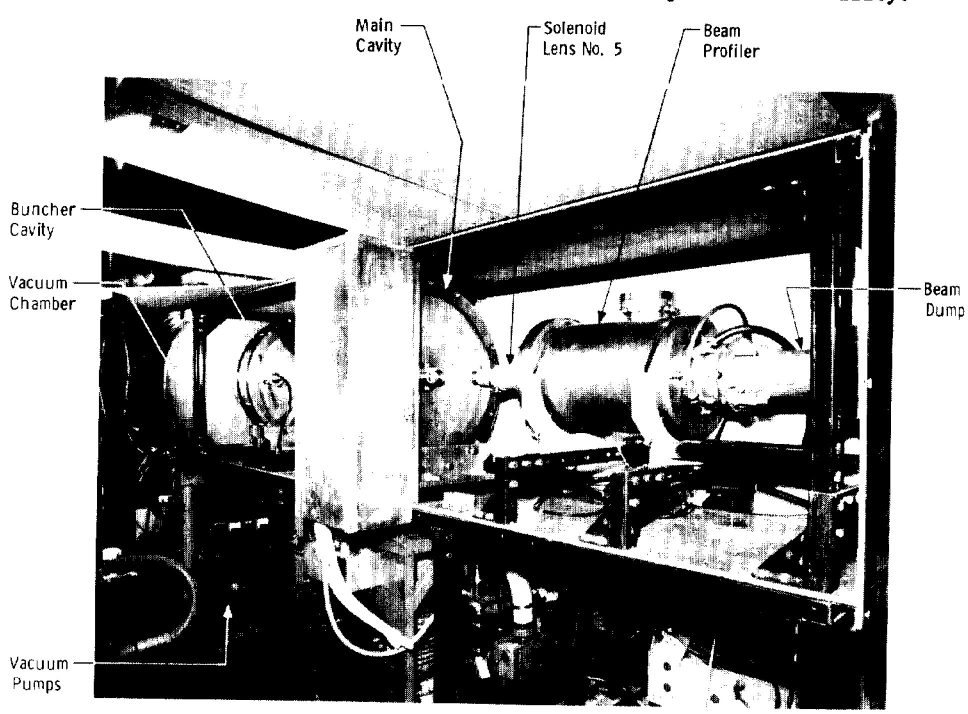


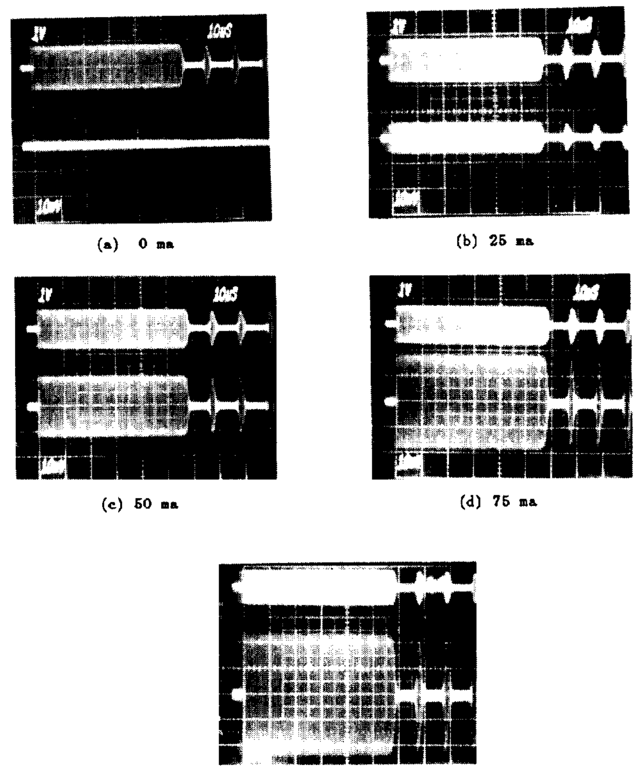
FIGURE 4. Dual-beam experimental facility.

98+% of the initial current beam dump. The drive beam deflection yoke, shown in Figure 4. scans the beam across the analysis plates to determine the beam emittance. . The profiles show a beam with a FWHM of 1.5 mm and an energy spread of less than 1%. The beam has an power density of 1 MW/cm^2. The special cathode ray tube (CRT) to be used as a diagnostic device has been designed, and fabricated, but not installed. This tube will be inserted in the main RF cavity, with the low current CRT electron beam serving as a test load to demonstrate acceleration imparted by the drive beam. Simple analysis of the electromagnetic deflection of the CRT beam, with and without the drive beam operating, will permit determination of the RF voltage at the axial aperture of the main (or load) cavity. The CRT will also be equipped with one pair of electrostatic deflection plates, which can be driven by an RF voltage at the same frequency, and in phase with, the voltage driving the buncher cavity. An analysis of the electrostatic deflection of the CRT beam will be used to determine the phase of B_θ in the load cavity, and hence the radial deflection of drive beam.

EXPERIMENTAL RESULTS

The results described below demonstrate that a cylindrical cavity can be driven in the TM_{010} mode by a modulator electron beam passing through the cavity parallel to the axis near the outer wall of the cavity. The results were obtained with a power of only 100 watts into the buncher cavity. The 24-dB SPS-40 RF power Amplifier was damaged while bringing the Dual Beam system on line and the experiment had to be completed with only the first stage RF driver. The experiment compared the signals from the inductive pickup loops in the buncher cavity and the main cavity as a function of the beam current. Figure 8(a) is an oscillograph trace of the loop current in the buncher cavity and the main cavity with no beam current in the cavities. The five traces in Figure 8 show the field in the main cavity induced by a beam of 0, 25, 50, 75, and 100, with a constant beam energy of 120-keV and a constant bunching factor.

A total of 100 watts should give an optimum bunching distance of 2.5 m, or about 50% of optimum at the main cavity. No attempt has been made to tune the two cavities to the same frequency. However, the field induced in the main cavity is ~2.5% of the field calculated. Assuming a bunching factor of no better than 50%, the induced field should be 90% of the field calculated for a 100-mA beam with a tune error of ~$5X10^{-5}$ and 2.5% for a tune error $\Delta\omega/\omega$ of $3X10^{-4}$. A stepper motor driven tuning plate has been added to the cavity. Cold test show that the necessary control of $\Delta\omega$ can be achieved. The probe loops in each cavity are approximately the same size, and therefore the signal is proportional to the relative field strengths. The traces in Figure 8 show a that all the RF information in the buncher cavity is transferred to the main cavity by the beam. The maximum signal in the main cavity as measured by the traces in Figure 8 is plotted as a function of beam current in Figure 9. The coupled field in the main cavity is a linear function of the beam current. The linear dependence is what the theory predicts for a focused modulated beam, and this is what would be expected with the beam optics of our system. At this point we have demonstrated that the principle works at low power and that the Dual-Beam Facility and its diagnostic system function as planned.



(a) 0 ma (b) 25 ma (c) 50 ma (d) 75 ma (e) 100 ma

FIGURE 5. Cavity field induced by bunched electron beam at constant bunching for 5 values of beam current. Upper traces are bunching field, lower traces are induced field.

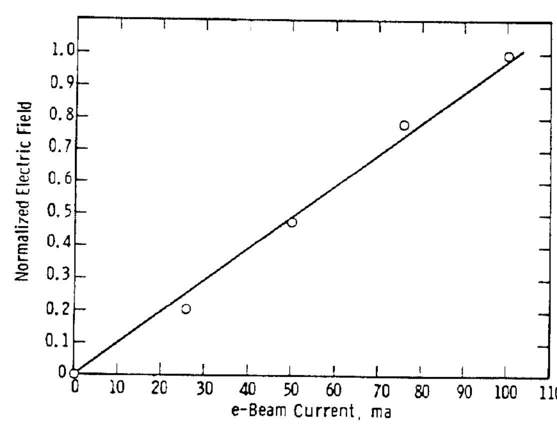


FIGURE 6 Induced field from Figure 8. plotted as a function of beam current.