IEEE Transactions on Nuclear Science, Vol. NS-30, No. 4, August 1983

WIDE-BANDWIDTH TEST FIXTURE FOR ELECTROMAGNETIC BEAM SENSORS*

J. D. Gilpatrick,† B. A. Sherwood, J. Hahn, and D. D. Chamberlin,† AT-4, MS H821
Los Alamos National Laboratory, Los Alamos, NM 87545

Summary

The Fusion Materials Irradiation Test (FMIT) accelerator[1] will provide an intense deuteron beam at 35 MeV ($\beta \simeq 0.19$). The beam, following a stripping reaction on a lithium target, will supply the neutron flux required for studying materials that may be used in a fusion environment. The diagnostic measurement instrumentation, which will characterize the accelerator beam, must be noninterceptive because of the beam's power density. Instrumentation also must be fully functional for start up of the FMIT accelerator.

To this end, a test facility was needed to examine signals from diagnostic probes that sense electromagnetic fields emanating from the charged particle beam. The test facility also will help evaluate the probes' corresponding measurement systems before final assembly into the beamline. Three types of test facility were proposed: (1) a low-energy electron accelerator, (2) a large "electron-gun assembly," and (3) a coaxial structure that produces electromagnetic fields similar to that of the proposed FMIT accelerator. The third type was chosen because the design and fabrication could be done at Los Alamos and Types (1) and (2) would be more costly.

The coaxial structure can carry the impulse currents required but cannot model the FMIT accelerator charged-particle bunch velocities accurately. However, one may introduce a highly resistive dielectric material into the coaxial test fixture so that its electromagnetic-wave velocities match those of the accelerator's particle-bunch velocities.

This paper describes the design and some experimental results of the coaxial test fixture.

Test-Fixture Design

To validate the coaxial test fixture as an electromagnetic field model for the accelerator beam, several assumptions were required. The electric and magnetic fields of the coaxial line should be similar to those of the beam. If the beam is thought of simply as a line current, one could then supply this line with a fast current pulse capable of producing a field similar to that of the charged-particle bunch. With the proper dielectric material in the coaxial test fixture, the velocity of the test-fixture fields matches that of the accelerator's particle bunch and therefore produces similar longitudinal and transverse electromagnetic fields. Because the cross-sectional fields of both the beam and the coaxial line are dependent on the transverse location of charge with respect to the longitudinal axis, the proposed accelerator beam and the coaxial test fixture were equated by considering the FWHM beam width and the beam pipe as a coaxial structure.

With these assumptions in mind, the design was straightforward. Probes must fit in both the FMIT accelerator and test fixture; therefore, the test fixture's first design parameter was the outer coaxial cylinder's inside diameter. Because of cost considerations, manufactured tubing with a 4.815-in. i.d. was chosen. (The actual beam pipe has a 4.625-in. i.d.)

Electromagnetic probes assembled into the fixture will be used in a section of the accelerator where the beam is expected to occupy 50 to 55% of the cross-sectional beam pipe area. Therefore, a characteristic "beam impedance" may be calculated by substituting the FWHM beam diameter and the beam pipe diameter into the characteristic coaxial impedance formula. The beam impedance and the characteristic coaxial test-fixture impedance were calculated to be 101 to 106 Ω.

Most electronic test equipment has 50-Ω input and output impedances. The test fixture must be able to transform 50 Ω to 106 Ω then back to 50 Ω, with minimum signal loss. To achieve this, a tapered[2] impedance transformer was designed so the test fixture would have a low VSWR and a wide bandwidth.

The time-varying signals expected from the diagnostic probes in the FMIT accelerator will have a broad spectrum. The lowest spectral component is that of the proposed 80-MHz beam bunch period and the highest spectral component (1000 MHz) may be the frequency corresponding to the expected FMIT bunch width (∿1 ns). Therefore, the test fixture was designed with a 80- to 1000-MHz *minimum* bandwidth.

The type of construction material and the material's surface roughness also affect the test fixture's high-frequency capabilities. Hard-drawn copper and aluminum were chosen for their machinable properties and their high conductivity. Copper and aluminum have respective skin depths[2] of 83 and 105.3 microinches at 1000-MHz; therefore, an overall surface roughness of 63 microinches was chosen. Finally, all test fixture components were interconnected with either a silver solder, a tungsten inert gas (TIG) braze, or an O-ring leak-tight connection that will allow future use of liquid or powdered dielectric materials.

Essentially, the Assembly A form of the test fixture consists of two sets of three coaxial components, shown in Fig. 1: an N-connector to a 3.125-in. 50-Ω adapter, a 3.125- to 4.815-in. 50-Ω adapter, and a 50- to 106-Ω impedance transformer. The N-to-3.125-in. adapter was purchased from Phelps Dodge[3] to reduce the fixture's design and fabrication costs. The 3.125- to 4.815-in. adapter was designed to maintain the 50-Ω impedance over its full length. The impedance transformer or coaxial taper[2] spans 1.5 wavelengths at 1 GHz (≃17.72 in.). The VSWR for this section should be 1.1 or less for frequencies below 1 GHz.

Figure 2 shows the test fixture (Assembly B) with the box containing a single capacitive pickup[4]

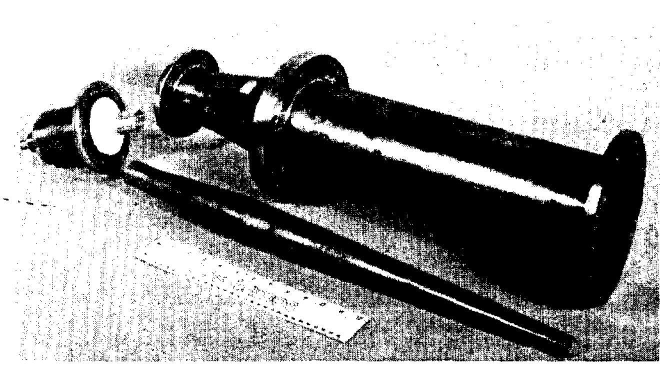

Fig. 1. A set of three coaxial components used in the Assembly A form of the test fixture.

*Work supported by the US Department of Energy.
†Westinghouse-Hanford employee working at Los Alamos.

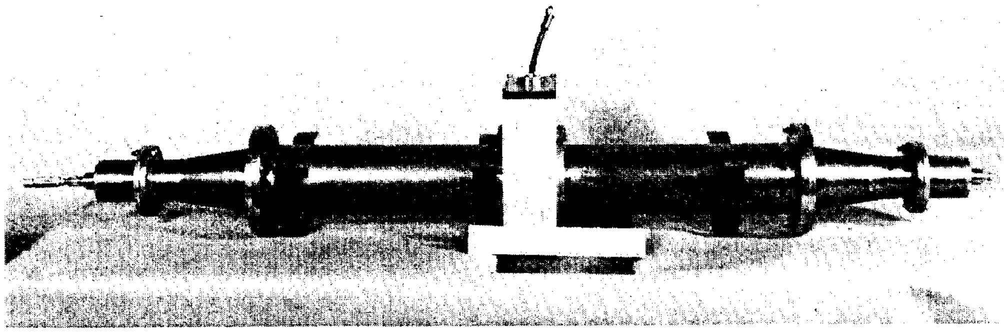

Fig. 2. Assembly B is composed of the Assembly-A components with a capacitive pickup probe and box inserted into the center of the test fixture.

probe and with air the dielectric material. The probe, the first to be assembled into the text fixture, will be used for the time-of-flight energy measurement in the FMIT accelerator. The capacitive pickup senses the electric fields from a beam bunch passing through its two concentric rings. The resultant bipolar, time-varying signals of two probes, separated by a known distance on the beamline, trigger their respective discriminators. The interval between these two discriminated events then will be timed to calculate the velocity and energy of a particular particle beam bunch.

Teflon rf beads or supports maintain the concentricity of the two coaxial cylinders in both assemblies. The inner coaxial cylinder passing through an rf bead is undercut so that the rf reflections are minimized while maintaining a constant characteristic impedance.

Test Results

Any transverse discontinuity in the test fixture will increase its VSWR and, in turn, decrease its bandwidth. To ensure that few discontinuities existed, a surge impedance test was performed. The test used a high-resolution time-domain reflectometer[5] (TDR) capable of resolving impedance discontinuities within 0.2 in. along the longitudinal axis. The Tektronix 7S12 TDR with the S-52 pulsing head and S-6 sampling head has a 45-ps system rise time, with a corresponding frequency well above the test fixture's designed bandwidth. Therefore, the surge impedance test also allowed verification of the impedance transformer mechanical design.

The trace in Fig. 3 has been smoothed to show the overall impedance characteristics of the test fixture (Assembly A). The TDR's smoothing filter distorts the transient peaks; thus, Fig. 4 shows Assembly B's TDR trace without this smoothing function. Figure 4 also shows the large discontinuity reflections from the probe and box in the left half of the trace. Table I summarizes reflection coefficient, VSWR, and impedance data from the TDR measurements of the test fixture. As can be seen from Figs. 3 and 4 and Table I, the Teflon supports and 3.125- to 4.815-in. adapter have a lower VSWR than the purchased Phelps Dodge adapter.

Lower frequency VSWR measurements were acquired by connecting an 80-MHz oscillator and directional power meter to the inputs of 50-Ω terminated test-fixture Assemblies A and B. Table II summarizes this data. Because Assembly A actually is two sets of the components pictured in Fig. 1 plus a Teflon support, one may use the data of both Tables I and II to estimate the overall VSWR at 80 MHz of the impedance transformer. The calculated VSWR of the impedance transformer is 1.03, which is well below the designed VSWR of 1.1.

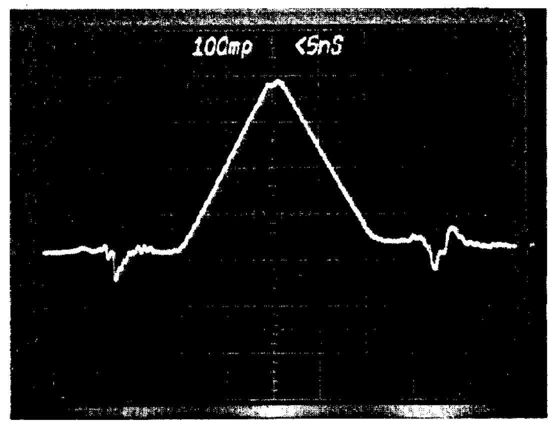

Fig. 3. The TDR trace of Assembly A shows the high-frequency reflection coefficient change with respect to the z-axis, which correlates to an impedance transformation of 50 to 106 Ω.

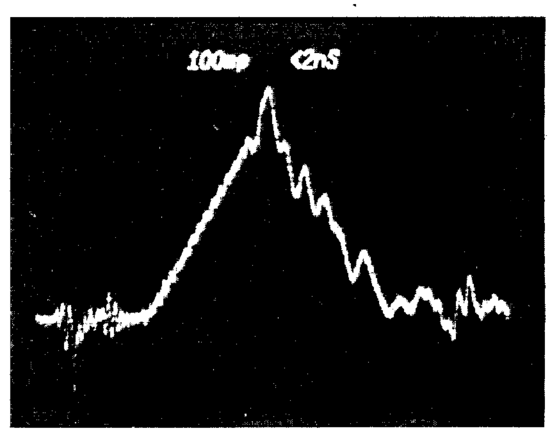

Fig. 4. The TDR trace of Assembly B shows the reflection introduced into the test fixture from the Phelps Dodge connector and the capacitive pickup and box.

TABLE I

TDR COMPONENT VSWR MEASUREMENTS

Component	Fixture Assembly	Reflection Coefficient	VSWR	Impedance (Ω)
Teflon bead or support	A	0.02	1.04	-
Phelps Dodge 3.125-in. adapter	A, B	0.15 0.5	1.35 1.1	-
The 3.125- to 4.805-in. adapter	A, B	∿0	1.0	-
Impedance transformer	A, B	0.36	2.13	50 to 106

TABLE II

LOW FREQUENCY VSWR MEASUREMENTS

Components	Fixture Assembly	Reflection Coefficient	VSWR
All	A	0.414	2.414
All	B	0.458	2.688

The frequency-response curves, shown in Figs. 5 and 6, are for Assemblies A and B with an air dielectric inside the fixture. Both Assemblies A and B display the $TE_{11}{}^2$ mode being excited within the coaxial line at 660 MHz. It also is believed that the low-power spectra ∿740 MHz in Fig. 6 display the $TE_{31}{}^2$ or TM_{11} mode, which consumes power within the capacitive pickup box. The key point is that even with a large capacitive pickup box in the test fixture, the frequency response between 80 and 1000 MHz is flat within ±3 dBm.

Conclusion

The test fixture has the designed bandwidth and a minimal VSWR that preserves the desired signal

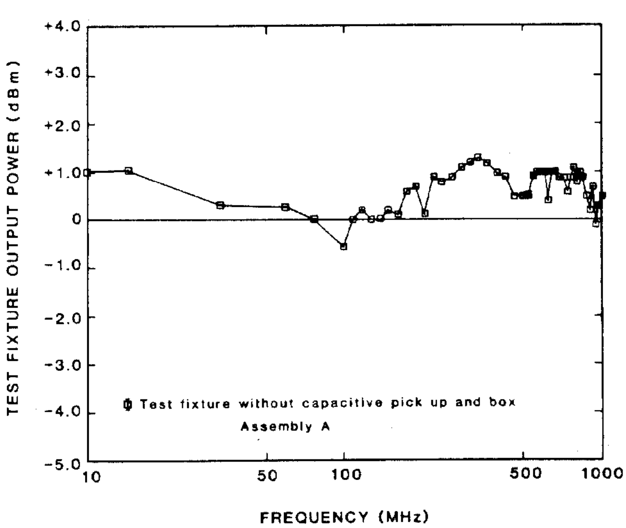

Fig. 5. The frequency response and curve for Assembly A is flat to within ±1 dBm.

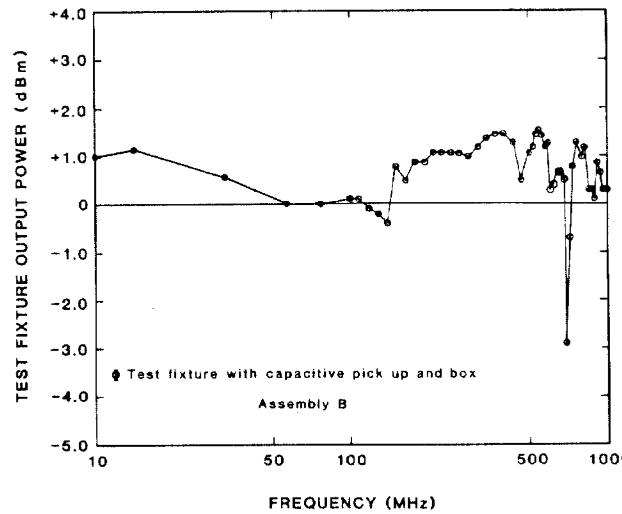

Fig. 6. The frequency-response curve for Assembly B output has a 2.9-dBm power loss, 740 MHz, that can be attributed to the addition of the capacitive pickup and box.

spectra. In the future, the test fixture containing deionized water (ε ≈ 81) or another dielectric material will be used in conjunction with other probe styles to observe lower phase-velocity electromagnetic fields. The expansion of the present test fixture configuration to one that uses more than one probe also will allow the design of prototypic time-of-flight energy-measurement systems.

References

1. D. D. Armstrong, "The FMIT Accelerator," Los Alamos National Laboratory document LAUR-83-717 (1983).

2. Theodore Moreno, Microwave Transmission Design Data (Dover Publications, 1958).

3. Rigid Coaxial Transmission Lines and FM Broadcast Antennas (Published by Phelps Dodge Communications Co., Rt. 79, Marlboro, NJ 07746) Catalog No. 779, p. 5.

4. Beam Diagnostic and High Vacuum Components Specifications (Published by NTG, 6460 Gelnhausen 3 Hailer, West Germany), Vol. 2, p. 46.

5. Supplement to Sampling Systems and Applications, Application 5 (Published by Tektronix, Inc., P.O. Box 500, Beaverton, OR 97077).