A Beamline Design and Data Acquisition with the 20-MeV, 20-ps Electron Beam for the Higher-Order Mode Studies of the APS SR-RF Cavities*

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ABSTRACT

A beamline has been designed and assembled to use the ANL Chemistry Division 20-MeV electron linac for the testing of higher-order mode excitation and damping in RF cavities. The beamline consists of two sections (a beam collimating section with a 1.5"-OD vacuum line, and a cavity test section with a 3"-OD vacuum line), separated by two double aluminum foil windows. The beam diagnostics consist of a stripline beam position monitor, integrating current transformers, fluorescent screens, and a Faraday cup. EPICS (Experimental Physics and Industrial Control System) is used for beamline control, monitoring, and data acquisition. Also described is the diagnostic system used for beam image capture and analysis using EPICS-controlled hardware and PV-WAVE software. The RF cavity measurement will be described in a separate paper [1].

I. INTRODUCTION

The 20-MeV linac beam at the Argonne Chemistry Division was used to measure the RF properties of the single-cell cavity and WR 2300 waveguide system. The primary reason for building this test facility is to measure those HOMs near and above the cutoff frequency of the beampipe. These modes cannot be easily calculated well because of strong geometric effects. Bench measurements cannot be easily related to beam-induced effects. The 20-MeV chemistry electron beam is good for testing because of the similarities of pulse shape and charge to those of the APS storage ring bunch. Comparison of the linac beam and the APS storage ring bunch parameters are given in Table 1.

Table 1 Main Beam Parameters for the APS-SR System and the Chemistry Linac.

	7-GeV APS Storage Ring			20-MeV Linac
Mode	single	Nominal	Maximum	single to 60 Hz
# of bunch	1	20	60	
average current	5 mA	100	300	>1.5 μA
peak current	700 A			> 625 A
bunch length (FWHM)	27.5 ps	50	72.5	25 - 40 ps
total # of particles	1.2X1011	2.3x1012	6.9X1012	>1.5X1011
total charge	18.5 nC			1 - 20 nC
natural emittance	8.2×10^{-3} mm-mrad			10 mm-mrad

Higher-order modes (HOMs) of the SR single cell cavity are studied by sending the beam on-axis and off-axis of the cavities, and the HOM dampers can be tested.

II. BEAMLINE SYSTEM

The Argonne Chemistry linac is an L band (1.3 GHz) traveling wave accelerating structure [2]. The linac beamline exits through an *Al* foil window (5"'), followed by a beam collimator (2' long, and 3/16" diameter). After tuning the linac for an optimized beam condition, the collimator is removed to provide a maximum beam current through the cavity section.

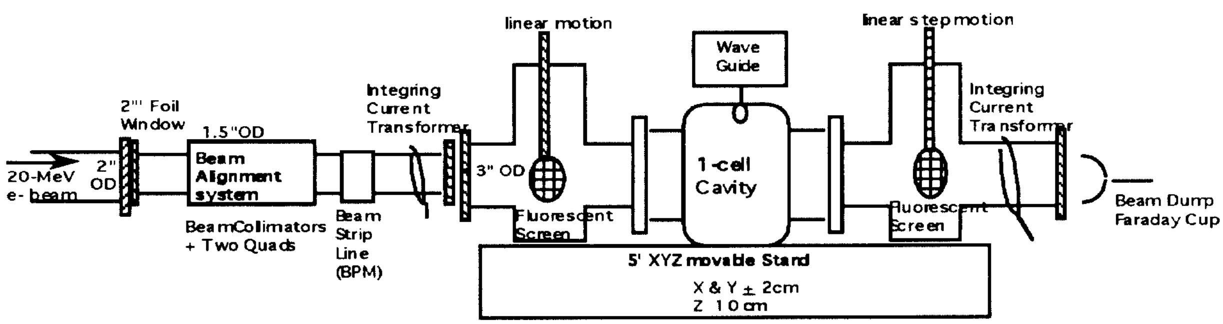

Fig. 1 Schematics of the Beamline to Test HOMs of the APS/SR RF Cavity

Our beamline consists of two sections (a beam collimating section with a 1.5"-OD vacuum line, and a cavity test section with a 3"-OD vacuum line, separated by two double *Al* foil

*Work supported by U.S.Department of Energy, Office of Basic Sciences, under Contract W-31-109-ENG-38.

0-7803-1203-1/93$03.00 © 1993 IEEE

windows as shown in Fig. 1. The collimating section consists of a water-cooled collimator (3/4" long and 1/8" diameter) and 2"' Al foil window to get a small size beam (3 mm diameter). The energy loss and the beam divergence angle through the double 2"' Al foil windows were calculated to be 30 keV and 1.8 degree, respectively [3]. The double Al foil window system was adopted to prevent the beamline from possible vacuum break, using a differential pressure between the two foil windows.

The beam focusing is provided by two quadruple magnets (length = 8 cm, bore radius a = 2.5 cm, focal length f = 30 cm). To confine beam inside the beam pipe, a solenoid coil (L_S = 7 mH, Q = 23.7, and R = 1.7 Ω) is used. The beam diagnostics used in the first section include a beam stripline and an integrating current transformer.

The second section of the beamline includes the RF cavity, two fluorescent screens, an integrating current transformer, and the beam dump.

The second section is movable with respect to the first section by ± 2 cm in the X and Y directions and 10 cm along the beamline to have a beam off-center of the cavity. To align the beamline, many three-point adjustment mounts were used and a He-Ne laser beam was used to check the alignment. The vacuum was about 1 x 10^{-4} Torr.

III. BEAM DIAGNOSTICS SYSTEM

The beam diagnostics consist of an APS/linac beam position monitor (Stripline-type) (BPM), two integrating current transformers (ICT), two fluorescent screens (FS), and a Faraday cup (FC).

The BSL or BPM consists of four equal-length electrodes ($\ell = \lambda/4$, λ = 10.5 cm) [4]. The monitor provides a triggering signal for the rest of the diagnostics in the beamline.

Two ICTs measure total beam current: one upstream of the cavity and the other downstream of the cavity. The ICT, manufactured by Bergoz, is based on toroids and responds with a fast pulse signal as short as ten picoseconds. The ICTs are mounted through the vacuum ceramic break and confined in a Cu housing to avoid disrupting the return current. In-house high speed beam signal processing electronics provides a DC level output proportional to the peak current or the total charge for the digitizer input. The calibration is done with a short electronic pulse (FWHM = 140 picoseconds) using the wire method. More detailed description of the 'Gate' electronics and their measurements can be found in the reference [5].

A fluorescent screen monitors relative beam position and spot size of an electron beam. A chromium doped alumina (Al_2O_3:Cr) ceramic screen inserted into the beamline is monitored by a video camera. The fluorescent screen housing is mounted to the air-actuator to insert and retract from the beamline. The resulting image is captured using a frame grabber and stored into memory. The camera was shielded to prevent possible noise due to radiation. Reconstruction and analysis of the stored image are performed using PV-WAVE [6].

The beam dump serves as a Faraday cup with a 50 Ω termination. Even though the FC does not respond as fast as ICT, it certainly gives a signal that is proportional to the total beam current at the end of the beamline. To reduce the secondary electron emission, and the radiation outside the beam dump due to the high energy beam, the FC is well shielded with lead.

IV. CONTROL & DATA ANALYSIS

The EPICS (Experimental Physics and Industrial Control System) control system is used for control and data collection. The hardware configuration is shown in Figure 2. The operator interface (OPI) is a SUN workstation running the UNIX operating system.

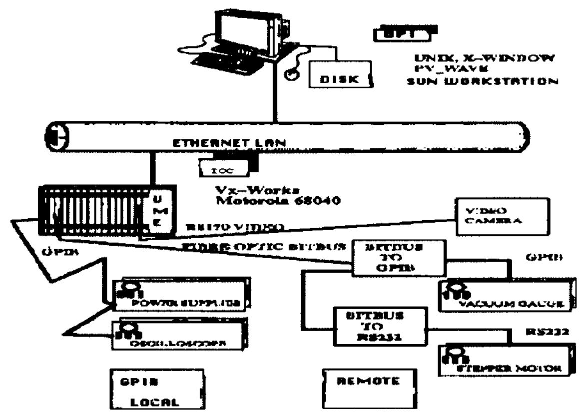

Fig. 2 System Control and Data Analysis, using VME-based with SUN Workstation

Control panels displayed on the SUN and configured with the EPICS Motif Edit Display Manager (MEDM) tools are used to control a frame grabber system, a stepping motor positioner for the fluorescent screen, the power supplies for the vertical and horizontal focusing quadrupole magnets, and a sampling oscilloscope. Monitors for the sampling scope waveform and the vacuum readings are also displayed on operator control panels.

The SUN workstation communicates with a VME based Input/Output Controller (IOC) through an Ethernet LAN. The VME crate contains a Motorola MVE167 single board computer and through VME communication modules is responsible for direct instrument control. For instrumentation close to the VME crate (i.e., sampling oscilloscope and quadruple power supplies) direct GPIB communication is used. For instrumentation remote from the VME crate, a fiber optic BITBUS communication link is used. The BITBUS protocol signal is converted to a GPIB protocol for interfacing to the vacuum gauge, and to an RS232 protocol for interfacing to the stepper motor positioner. These protocol converters were developed at Argonne for the Argonne APS control system. The IOC runs the Vx-Works real-time kernel and the EPICS IOC-CORE software.

The frame grabber is used to capture images of the beam from a camera. The camera views a fluorescent screen placed at an angle of 45 degrees with respect to the camera. The frame grabber is a VME based MaxVideo 10 system with DigiMax frame grabber and RoiStore video memory. The captured image data is stored in a disk file for off-line analysis.

The data analysis program (PV-WAVE) provides background subtraction, compensation for the viewing angle of the fluorescent screen, and calculation of the beam position and full-width half and tenth maximum values. Pseudo color displays are provided for the raw and compensated images. X and Y beam profile displays are also provided.

V. MEASUREMENTS AND RESULTS

The beam emittance was measured with the collimating system of the first section of the beamline. The image of the beam profile was captured with the first FS, while varying the magnetic field of the two quadrupole magnets. A typical image pattern is exhibited in Fig. 3. The top-left photo is a 2-D pattern plot and the bottom-left is a 3-D plot. The top-right is an X-profile and the bottom-right is a Y-profile, respectively. Analyzing the beam image pattern, one can get FWTM versus strength of a focusing magnet as presented in Fig. 4. The measured emittance, ε_x and ε_y, are 9.20 and 3.72 mm mrad, respectively [7].

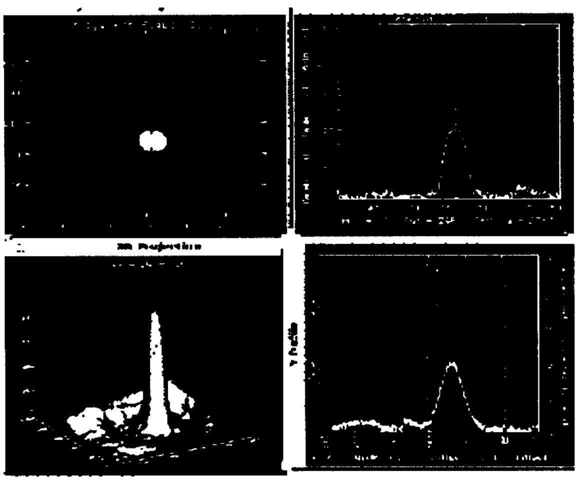

Fig. 3 Typical Beam Profile with the focused beam

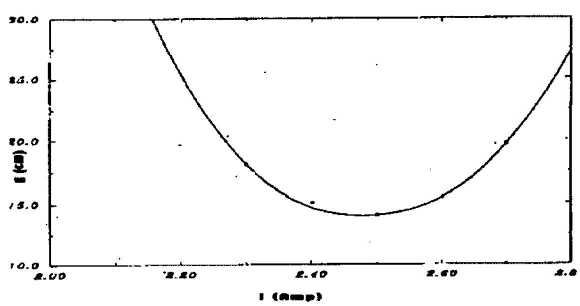

Fig. 4 Beam Profile Width (FWTM) with Various Current in Q2.

The data with ICT is shown in Fig. 5: The left one is the ICT output signal with 100 mV/Div, 20 ns/Div and the right one is a DC output with Gate, 200 ns/Div, 200 mV/Div. The total charge is about 5.0 nC and the sensitivity of both ICTs (one with 1.5" OD and the other with 3" OD) is about same within 5% of each other.

The signals from the BSL and FC are shown in Fig. 6: The bigger signal is from the BSL and the smaller signal is from the FC with 2 ns/Div, 5 V/Div. The total current transmission is about 87% when it ends at the beam dump. The time delay between the two signals signifies the time of flight of the beam between the BSL and the FC, which is about 5.5 ns.

The RF cavity measurement was done with two H-loops and E-probes, and will be discussed in a separate paper [1].

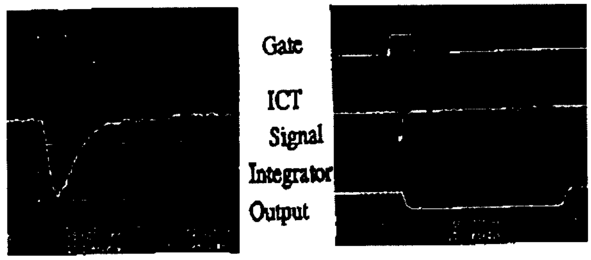

Fig. 5 ICT output signal and its gated DC signal.

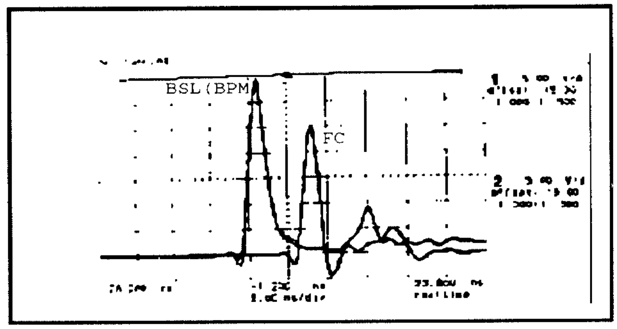

Fig. 6 Signal from BSL and FC, with 2 ns/Div, 5 V/Div.

VI. ACKNOWLEDGMENTS

The authors would like to thank Bill Berg, Don Ficht, Eric Landahl, Ed Wallace, Fred Vong, Bill Wesolowski, and Portia Young for their technical support and allowing their beam diagnostics use.

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