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RFQ1 DIAGNOSTIC DEVICES†

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Abstract

The diagnostic devices in use on RFQ1 will be described. They consist of a double-slit emittance-measuring unit, a 45° deflection energy-analysis magnet, parametric current transformers, optical beam sensors, beam-stop current monitors, and an x-ray end-point analyzer. All of these devices are able to operate up to the full output current of RFQ1 (75 mA cw at 0.6 MeV).

Introduction

The RFQ1 accelerator system is a test bed for a wide range of high-power RFQ accelerator experiments. It is built to accelerate up to 75 mA of protons to 600 keV at 100% duty factor. It comprises a 50 keV injector, a 60° bending magnet for ion species selection, and a 600 keV 267 MHz RFQ.[1] This paper describes the diagnostic devices used to measure the beam at the output of the ion source, and at the input and output of the RFQ.

RFQ1 Diagnostic Devices

The diagnostic devices on RFQ1 are the following:

1. Emittance-measuring Unit (EMU),
2. Beam-stop Current Monitors,
3. Parametric Current Transformer (Bergoz meter),
4. Energy-analysis Magnet,
5. Optical Beam Sensors (Reticons), and
6. X-ray End-point Apparatus.

Emittance-measuring Unit

The Emittance-measuring Unit (EMU) is used to measure the output beam quality of the RFQ. The beam strikes a water-cooled beam stop containing a slit. This slit lets a slice of the beam through to a second slit Faraday cup assembly, so that the beam can be analyzed as a function of position and angle. Two beam stops have been built, one with the swirl tubes vertical to allow a vertical slit for (X,X') emittance measurements, and the second with the swirl tubes horizontal to allow a horizontal slit for (Y,Y') emittance measurements. The Faraday cup can be rotated to place its slit in the appropriate direction.

The primary slit is 0.127 mm wide by 50.8 mm high and can be scanned horizontally and vertically over a total range of 100 mm. The slit on the Faraday cup is 0.152 mm wide and the Faraday cup assembly may be scanned over a total range of 75 mm with respect to the main slit.

The main slit has water-cooled swirl tubes and is capable of absorbing the full output beam of RFQ1. It is not necessary to cool the second slit and Faraday cup assembly, because of the low fraction of the beam that is transmitted to it.

The positioning motors are controlled by an IBM PC and the Faraday cup current is read by a Kiethley low-current amplifier and recorded in the PC. A computer program allows a complete beam scan to be done automatically.

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A number of problems originally limited the usefulness of the system but these are being resolved. The system was originally very slow, being limited by the speed of an autoranging pico-ammeter used to read the Faraday cup current. Replacing the meter with a current amplifier allowed a continuous scan, rather than moving the cup to a discrete position and remaining there while the reading was determined. A related problem was that position was determined by counting pulses sent to the stepping motors, but this became unreliable as motor speed was increased. The motor controllers were in a separate unit and had unnecessary limitations, so the motors were replaced by new ones, with the position controlled directly by the PC. The position is now read by a linear potentiometer position indicator.

Measurements can be made either of horizontal emittance (X,X') or of vertical emittance (Y,Y'), although switching from one to the other requires that the unit be opened to replace the primary beam stop.

Recent (X,X') measurements transformed back to a waist are shown in Figs. 1 and 2.

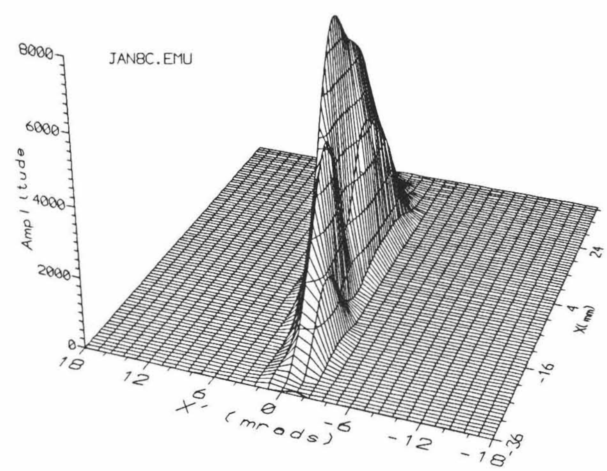

Fig. 1. RFQ1 EMU contour plot.

The data shown in Fig. 1 was obtained using a 3-aperture source operating at 45 mA. The EMU was 1 m from the RFQ and the data was collected using 12 primary slit positions and approximately 250 secondary slit positions. Some processing of the data is needed to allow the plotting program to work correctly. The analysis program can derive an rms emittance as shown in Fig. 2. Development work is continuing on the most suitable way to display the results.

Beam-stop Current Measuring Devices

Most of the beam-intercepting surfaces in RFQ1 are isolated from ground, so that the beam current falling on them can be measured. Surfaces and beam stops monitored are:

1. Entrance port solenoid,
2. Entrance port solenoid beam plate,

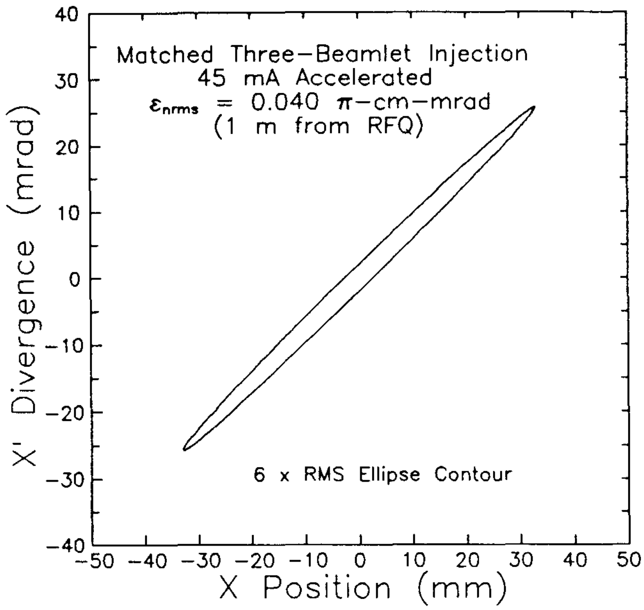

Fig. 2. RFQ1 rms emittance.

3. Straight-through beam stop,
4. H_2H_3 beam stop,
5. Fractional-energy beam stop,
6. Exit port beam plate,
7. Plunging beam stop,
8. Collimator top,
9. Collimator bottom,
10. Collimator left,
11. Collimator right, and
12. Main beam stop.

These devices are grounded with 1, 10, or 100 ohm resistors and typically will have a voltage of between 0 and 100 mV. Intercepted currents are accurate to about 10%. Errors are due mainly to secondary emission, so some inconsistencies are present, but they do provide a useful guide for adjustments of the system. These signals are monitored by the Taurus data logging system and numbers 1, 7, and 12 are also displayed on a digital panel meter.

Parametric Current Transformer

Bergoz DC beam-current monitors of the type developed at CERN by K. Unser[2] were used. These devices are non-intercepting and have a current range of -250 mA to +250 mA, with a frequency range of dc to 20 kHz. Absolute accuracy is about ± 0.1%.

Each monitor has two main toroidal cores with a primary ac signal that drives the cores to saturation in both directions. Two secondary coils are wired in opposition so that in the balanced condition no output signal results. The beam current passes through the toroid and unbalances the saturation so that a second harmonic component appears in the secondary windings. A feedback circuit adjusts the current in a single-turn feedback line to restore the balance, and this current is equal to the beam current.

The toroids have magnetic shields, but still are sensitive to stray magnetic fields, such as from the bending magnet. A zero offset is established after all magnets have been turned on. The device reads current flowing through the aperture of the toroid, so although a metal beam tube may be used, it must have an insulating break to prevent ground currents from flowing on the tube wall.

Electrons from secondary emissions can influence the measurements, so the monitors must be located away from surfaces that may intercept beam.

Two of these units are installed- -one at the entrance to the RFQ and the other at the exit. They are connected to the Taurus data logging system.

Energy Analysis Magnet

The RFQ will transmit beam of all energies, so the presence of an output beam is no guarantee that beam is being accelerated by the RFQ. A 45° magnetic analyzer is used to measure the output beam energy. A typical measurement is shown in Fig. 3. The analyzer has a resolution of about 0.2% but no energy calibration has been done; the energy scale on the figure is based on field maps, giving an uncertainty that could be as great as 10%.

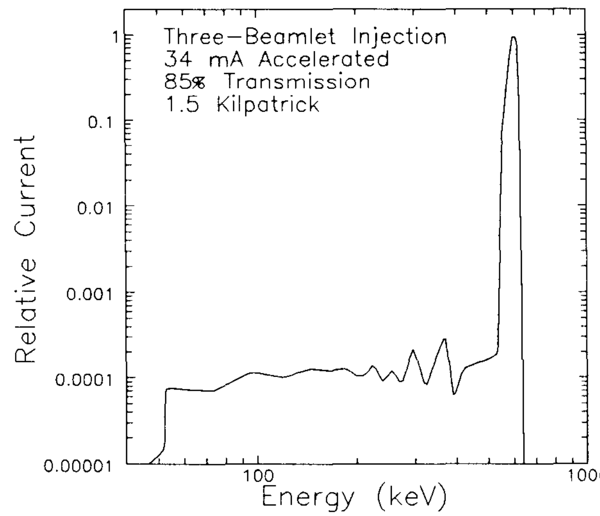

Fig. 3. RFQ1 energy spectrum.

Optical Beam Sensors (Reticons)

Ionization of the residual gas by the beam allows the beam to be observed visually. The light intensity is affected by residual gas composition and pressure. Therefore, optical measurements are not a reliable measure of beam current, but they are a useful measure of beam size and position.

The light intensity depends on the beam energy. It is a maximum in the 50 to 100 keV range, which makes it very suitable for injector diagnostics. For 50 keV protons the intensity is sufficient to give a good signal-to-noise ratio at currents ≥ 5 mA and gas pressures ≥ 10^{-5} torr.

The system uses two Reticon LC1902 line scan cameras to view the beam, one looking at the horizontal profile, the other looking at the vertical profile. The present configuration has a pair of cameras viewing the beam at the exit of solenoid #1. A diagnostics box was built to hold a second pair of cameras in the beam line before the plunging beam stop, but that position is now occupied by one of the Bergoz current monitors. An alternate position for a second pair of cameras is between the end of the dc column and the entrance to solenoid #1.

The present Reticon system has amplifiers optimized for speed as opposed to resolution. As a result, the circuit has poor offset compensation and poor gain stability. Improvements are planned.

In the present installation, the cameras are connected to an IBM PC and each produces a line scan of the beam that is converted to a table of intensity at 256 positions. This can be displayed as linear intensity plots or saved for later analysis.

The results of a scan using the top port on a 3-aperture beam are shown in Fig. 4. An analysis program has been written which decomposes the trace into three components with equal intensity. The peak height and width of the components are estimated manually, and the program adjusts their positions to produce a composite curve that best fits the data.

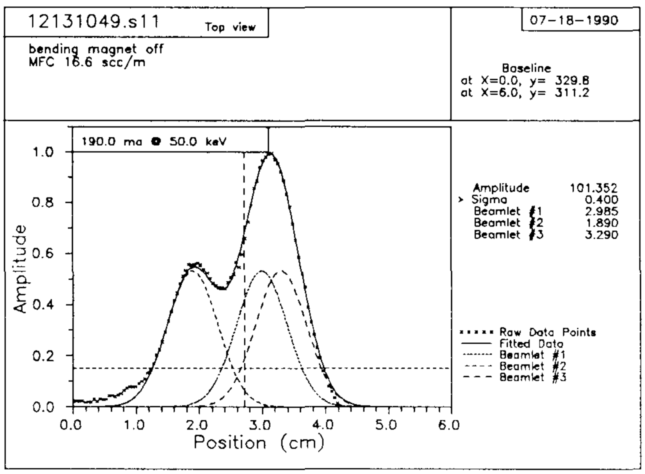

Fig. 4. Three-beamlet top view.

Figure 5 shows a similar scan using the side port with a 4-aperture beam.

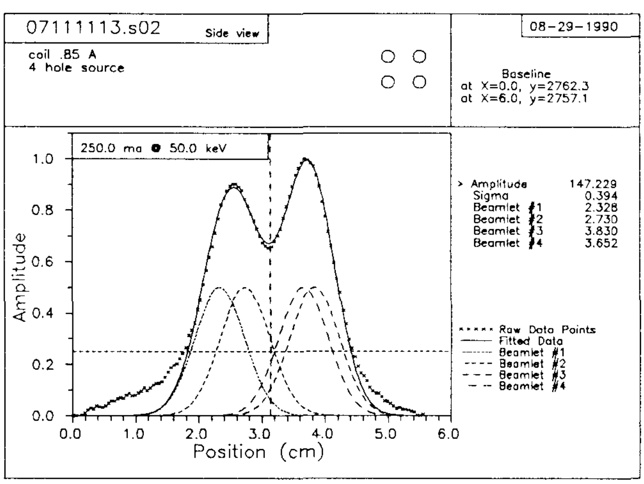

Fig. 5. Four-beamlet side view.

X-ray End-point Apparatus

X-rays are generated by electrons accelerated between surfaces at different potentials in the RFQ. The most energetic of these will occur in the region of the highest electric potential difference, across the intervane gap. This will give rise to Bremsstrahlung radiation, with an end point equal to the peak intervane voltage.

The x-rays are measured with an intrinsic germanium detector located to the side of the RFQ. To limit the counting rate, it is necessary to use an aluminum attenuator and place the detector about 5 meters away from the RFQ. End-point energy can be determined within ± 0.5 kV and the measurement is local enough to be able to detect longitudinal field tilts in the RFQ.

The design intervane voltage is 78 kV, and the spectrometer is calibrated using the 60 keV gamma of Am^{241} and the 122 keV gamma of Co^{57}. Fig. 6 shows a typical spectrum. The resolution is 140 eV/channel and the end point is 78 ± 0.7 kV.

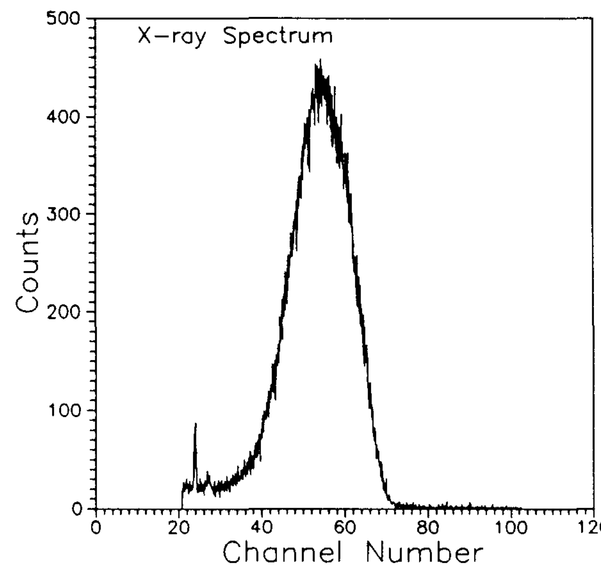

Fig. 6. X-ray spectrum for vane voltage determination.

Conclusions

A number of diagnostic devices have been developed and refined on RFQ1. A companion paper[3] gives results of the measurements made with them.

References

1. G.M. Arbique, B.G. Chidley, G.E. McMichael and J.Y. Sheikh, "CW Operation and Initial Beam Experiments with the RFQ1 Accelerator", Proc. 1988 LINAC conf., Continuous Electron Beam Accelerator Facility report CEBAF-Report-89-001 (1989) 91.

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3. G.M. Arbique, B.G. Chidley, M.S. de Jong, G.E. McMichael and J.Y. Sheikh, "Beam Performance and Measurements on the RFQ1 Accelerator", these proceedings.