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TITLE PERFORMANCE OF RF BEAM MONITOR ON THE NBS-LOS ALAMOS
RACETRACK MICROTRON

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A prototype rf beam-position, current, and phase monitor has been used on the 100-keV injector beamline of the racetrack microtron (RTM) where performance was measured with the chopped and bunched beam. This monitor works with both a pulsed beam and a cw beam. The pulsed beam consists of beam pulses with a FWHM of 40 ns. The rf beam monitor was tested with beam currents from ~50 to 600 μ A. The rf beam monitor will be described and its performance will be reported.

Diagram illustrating the exploded view of the beam position monitor assembly. The components shown include:

- BEAM-POSITION CAVITY
- TWO-TWO CAVITY
- RF PROBES

Probes in the cavities couple some of this beam-excited rf power out of the cavities. This rf power can be amplified, if necessary, and then analyzed by a double-balanced mixer (DBM) as shown in Fig. 2. The voltage out of the intermediate frequency (IF) port of the DBM depends on the relative phase of the rf input to the rf reference and on the amplitude of the rf input. If the relative phase of the rf input to the rf reference is approximately $\pm 90^\circ$, the voltage out of the IF port of the DBM will be proportional

The DBM also can be used as a phase detector. If the relative phase between the reference rf source and the rf from the cavity is adjusted for a null on the IF port, small changes in phase of the rf result in a change in the voltage at the IF port that is proportional to the product of the phase change of the beam and the current of the beam in the cavity. The phase change then can be determined from this voltage, or the phase of the reference rf can be changed a known amount to null the voltage on the IF port again.

The beam monitor cavities are made out of stainless steel and are heavily loaded by coupling probes to lower the Q, resulting in a bandwidth of ~ 20 MHz, which is large enough to make the cavities insensitive to temperature changes and allows them to respond to changes in the beam in ~ 20 ns. This fast response is necessary because the beam then can be pulsed with a FWHM of 40 ns to resolve the current, position, and

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phase of the beam each time it passes through the linac in the RTM. It takes ~100 ns for one round trip or pass through the RTM. The 40-ns beam pulse will pass through the monitor, every 100 ns, fifteen times. Each of the four outputs (current, phase, vertical position, and horizontal position) from the beam monitor will consist of a train of 15 pulses, with each pulse representing the current, phase, or position of the beam on that pass through the beam monitor. On the injector line, the beam only passes through the beam monitor once. In this case, the monitor measures the parameters of a cw beam as well as the pulsed beam. With a cw beam, a beam monitor on the linac axis of the RTM can only measure an average value of the phases and positions of all 15 passes. The beam monitor measures the sum of the currents of each pass with the cw beam. However, the 40-ns beam pulse can be superimposed on a cw beam and, as long as the electronics in the beam monitor are not saturated, the beam-position, phase, and current information for each pass can still be extracted.

The effective shunt impedance of the cavities was measured with the cw beam. The effective shunt impedance for the TM_{010} cavity used to measure current and phase was 1000 Ω . For the position-monitor cavity, the shunt impedance is proportional to the displacement from the axis. The effective shunt impedance of the position-monitor cavity is 5 Ω/mm^2 . The measurements of the effective shunt impedances include all losses, even those caused by the mismatch in impedance of the probes and coaxial cables. The effective shunt impedance also is reduced by loading the cavity for the wide bandwidth. With these values of the effective shunt impedance (Z^2), the rf power (P) out of the cavities can be calculated for an arbitrary beam current (I) and displacement from the axis (X). For the TM_{010} cavity $P = I^2 \cdot Z^2$, and for the position-monitor cavity, $P = (IX)^2 \cdot Z^2$.

RF Electronics

For a beam current of 600 μA , the total beam through a monitor cavity on the linac axis of the microtron is 9 mA, which is the maximum current for which the beam monitor will be used in the RTM and will give the maximum power of 81 mW out of the TM_{010} cavity. This power is split in a 90° hybrid coupler with each output, ~40 mW, going to a DBM, one for phase detection and one for amplitude detection. The rf input to the DBM must be restricted to less than 10 mW to prevent destruction of the DBM. Therefore, the rf from the TM_{010} cavity must be attenuated by 6 dB.

The maximum power out of the position-monitor cavity would occur if all 15 passes were off the axis by 5 mm in the same direction. This is the maximum distance that the beam could get away from the axis because the radius of the accelerator bore is 5 mm. With this worst-case condition, the rf power from the cavity is 10 mW. The rf amplifiers will not be damaged with this much rf power on their input; therefore, no attenuation is needed for their protection. If an amplifier with a gain of 11 dB and maximum output of 8 mW is used, the amplifier would saturate only if the average displacement exceeded 1.4 mm. The average position of the beam should be within 1.4 mm of the center line before a 600 μA beam is accelerated. Therefore, rf amplifiers with a gain of 11 dB will be used to prevent saturation of the beam-position monitors on the linac axis of the microtron. On the injector beamline, the maximum current is only 600 μA , which will allow amplifiers with 31-dB gain to be used in the rf position monitors, and an 11-dB gain amplifier can be used on the TM_{010} cavity.

Because the sensitivity of the position-monitor cavity is proportional to the current through the cavity, the dynamic range of the signals expected from the beam-position monitor is very large. Therefore, the gain of the rf amplifiers used in the system should be selected to provide maximum gain and yet not saturate at the maximum current expected. No dynamic, rf-gain adjusting is planned because such adjustment might cause phase changes that would complicate the use of the rf beam monitors.

Figure 3 shows the measured response of the prototype rf beam-current-monitor setup as shown in Fig. 2. The response is a linear function of beam current within the accuracy of the measurement.

Fig. 3. The measured response of the prototype beam monitor to beam current.

Figure 4 shows the response of the prototype rf beam-position monitor measured with a beam current of 300 μA . This measurement was made with a pulsed beam. However, nearly identical results were obtained with a cw beam. These responses, shown in Figs. 3 and 4, are measured at the output of the DBMs. The final version of the rf beam monitors, shown in Fig. 5, will have video amplifiers with a gain of 10 to drive the long coaxial cables to the oscilloscope used to measure the signals. These amplifiers will reduce the effect of noise picked up on the long cables. In addition, ground currents in the coaxial cables, which would mask the small signals, will be reduced by isolating the electronics from ground at the rf beam position monitors. The electronics will be grounded only through the shields of the coaxial cables. Shields of the cables will be grounded only at the oscilloscope used to view the signals. All the rf cables to the electronics will be connected through inside/outside dc blocks.

Two probes are used for each polarization of the position monitors. The rf from the two probes are connected to a 180° hybrid with equal-length cables. The phase of the rf coupled from a TE_{102} or TE_{201} mode by these probes differs by 180°. This rf power is combined and appears at the difference (Δ) port of the 180° hybrid. Because the rf probes are strongly coupled to the cavity, these probes also pick up some rf power directly from the beam. The rf power picked up on the two probes this way is in phase and will appear at the sum (Σ) port of the 180° hybrid. This rf power could be used to provide the current and phase information if the cables were exactly the right length and

Fig. 4. The measured response of the prototype beam monitor to the position of a 300-μA pulsed beam.

Fig. 5. The rf electronics for the beam monitor will use X10 amplifiers to increase the sensitivity and to drive the long cables to the oscilloscope used to observe the signals. The dc blocks isolate the DBMs and amplifiers from the accelerator ground to prevent a ground loop in the signal cables.

the 180° hybrid was perfectly balanced. However, this is not the case, and a small fraction of the power in the TE₁₀₂ or TE₂₀₁ mode is mixed in with the rf power that comes directly from the beam. This mixing will spoil the usefulness of this technique because the current and phase measured this way would not be independent of position. The 180° hybrids and two probes are still needed for the position information because the direct rf power from the beam must still be subtracted from the rf that appears at the rf probes. If this were not subtracted with the use of the 180° hybrid and two probes, the electrical center of the cavity would not correspond to the physical center of the cavity. The two probes must be coupled as nearly equally as possible to minimize error in position caused by the contribution from the direct pickup of rf power from the beam.

Conclusion

The prototype rf beam monitor performed satisfactorily in tests on the 100-keV chopper/buncher beam-line. The resolution was good but the requirement for some type of ground-loop isolation was demonstrated.

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