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FERRITE INSERTION AT RECYCLER FLYING-WIRE SYSTEM

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Abstract

Ferrite rods are installed inside the flying-wire cavity of the Recycler Ring and at entrance and exit beam pipes in order to absorb high-frequency electromagnetic waves excited by the beam. However, these rods may also deteriorate the vacuum pressure of the ring. An investigation is made to analyze the necessity of the ferrite rods at the entrance and exit beam pipes.

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1 INTRODUCTION

Flying wire systems are being installed in the Recycler Ring. Ferrite material will be placed inside each cavity housing the flying wire mechanism and also at the beam pipes joining the cavity on both sides. The function of the ferrite is to damp higher-frequency modes excited by the beam that can travel along the beam pipe and deteriorate beam signals sampled by various monitors. These ferrite rods are exposed to the vacuum and may deteriorate the vacuum. We were asked to examine whether the ferrite rods at the entrance and exit beam pipes of the flying-wire cavity, as depicted in Fig. 1, can be removed without affecting the performance of the 1.75 GHz Schottky detector.

Figure 1: (color) Photo showing ferrite rods placed at the entrance or exit of the flying-wire cavity. This circular opening will be joined to the usual $3.806'' \times 1.75''$ Recycler Ring beam pipe.

2 EXCITATION ENERGY

The flying cavity can be approximated by a cylindrical cavity of radius $a = 6.75''$ and height $d = 6.625''$, as is sketched in Fig. 2. Because the beam passes through a long distance of $2a$ inside the cavity where electromagnetic waves are excited, the transit-time effect becomes important. For a cavity with conducting walls and no ferrite insertion, the

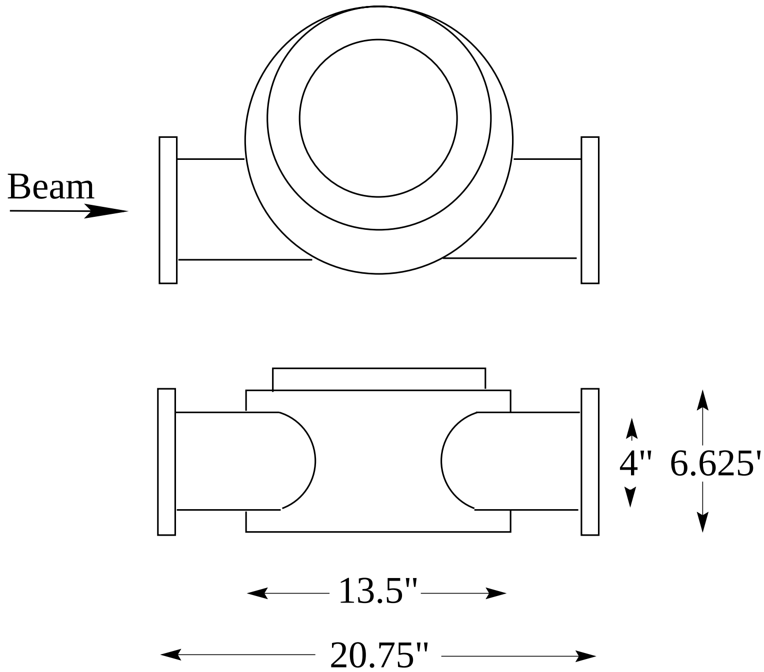

Figure 2: Schematic drawings showing the side view (top) and top view (bottom) of the flying-wire cavity.

amount of excitation energy of the ith mode at frequency ω is

$$\mathcal{E}_i \propto \frac{\omega_i a}{c} \left(\frac{\sin \dfrac{\omega_i a}{c}}{\dfrac{\omega_i a}{c}} \right)^2 , \tag{1}$$

where c is the velocity of light. In above, the last factor is the transit-time factor. The first factor appears because, aside from the transit-time effect, more energy will be excited if the beam particle is in contact with the electromagnetic fields inside the cavity for a longer time. At 1.75 GHz, $\omega_i a/c = 6.29$, and $\sin \omega_i a/c = 0.0052$, showing that the width of the flying-wire cavity is just approximately two-wavelength long at 1.75 GHz. Thus the factor on the right side of Eq. (1) is 7.4×10^{-6}, which is very tiny. This factor will become even smaller for the higher harmonics of the 1.75 GHz. This has been verified recently by Crisp. [1] He placed an antenna at the entrance pipe of the cavity and measured the transmission coefficient S_{21} at a second antenna placed at the exit pipe. We see from Fig. 3 that S_{21} (red curve) exhibits a maximum in the vicinity of 1.75 GHz, showing that waves near such frequency just pass through the flying-wire cavity without much excitation inside the cavity. On the other hand, waves at 2.19 GHz span $\frac{5}{2}$ wavelengths across the cavity and waves at 1.31 GHz span $\frac{3}{2}$ wavelengths across the cavity. They will have most of their energy trapped inside the cavity

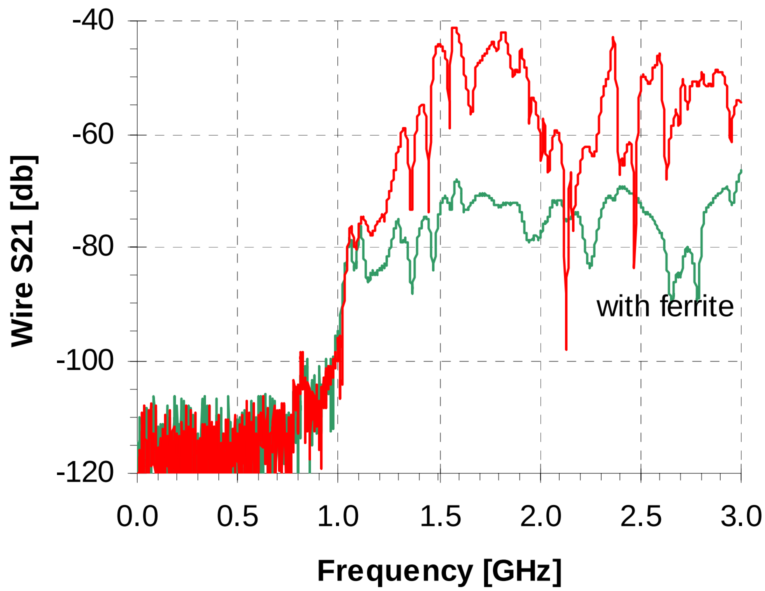

Figure 3: (color) Plot showing S_{21} across the flying-wire cavity measured by Crisp[1] by placing an antenna at the entrance pipe and another antenna at the exit pipe. A transmission peak near 1.75 GHz is clearly seen (upper red curve), indicating that not much excitation takes place inside the flying-wire cavity near this frequency. When ferrite rods are placed at both the entrance and exit pipes, the transmission is reduced by about 30 dB (lower green curve).

because the beam particle moves with the variation of the longitudinal electric fields and strong excitations take place. Actually we do see in Fig. 3 that the transmission coefficient S_{21} exhibits minima near 2.1 GHz and 1.2 GHz.

From the transit-time analysis and the experiment measurement, we can conclude that when a beam passes through the flying-wire cavity, not much excitation near 1.75 GHz will take place. The implies that there will *not be much* extra electromagnetic waves generated near 1.75 GHz.

We do not have enough knowledge of the structure of the the 1.75 GHz Schottky detector. We assume that there must be a resonant box with a narrow gap for the beam particle to pass through. If this gap is of width 5 mm, the factor on the right side of Eq. (1) turns out to be 0.091 which is a factor of 12400 times (5 times less if the gap is 1 mm) larger than the excitation at the flying-wire. Or the contamination of the Schottky signals from the flying-wire cavity amounts to 41 dB.

For this reason, we may say that the excitation at the flying-wire cavity should not affect the 1.75 GHz Schottky detector by very much even if there are no ferrite rods at the entrance and exit pipes of the cavity.

3 CUTOFF FREQUENCY

The beam pipe of the Recycler Ring is elliptical in shape with total width and length equal to $3.806''$ and $1.75''$, or major and minor radii $a = 4.8336$ cm and $b = 2.2225$ cm. Unfortunately, an analytic expression for the cutoff frequency of an elliptical beam pipe is not available. We can, however, make an estimation by assuming a cylindrical pipe of radius $a = 4.8336$ cm. The cutoff frequency is then

$$f_{\rm cutoff} = \frac{2.405c}{2\pi a} = 2.37 \text{ GHz} . \tag{2}$$

Another estimation can be made by assuming a rectangular beam pipe of size $2a \times 2b$, from which we obtain

$$f_{\rm cutoff} = \frac{c}{4a} = 1.55 \text{ GHz} . \tag{3}$$

We believe the cutoff frequency should be close to 2.37 GHz rather than 1.55 GHz. In other words, electromagnetic waves excited in the flying-wire cavity in the vicinity of 1.75 GHz cannot travel along the beam pipe to affect the Schottky detector. However, harmonics of 1.75 GHz are well above cutoff and can travel along the beam pipe.

The measurement of Crisp in Fig. 3 shows very clearly that electromagnetic waves start flowing around 1 GHz, in apparent contradiction to our estimation of the cutoff frequency. Crisp's measurement was made with circular side pipes of diameter $4''$, which has a cutoff frequency of 2.246 GHz according to Eq. (2). The reason that he got a much lower cutoff frequency is due to the fact the $4''$ side pipes used in the measurement had been rather short. To make a credible measurement of the cutoff frequency, one must use a beam pipe that has the length of several wavelengths.

4 THE FERRITE RODS

Because we do not have complete understanding of the Schottky detector and because we are not certain about the level of signal contamination that the Schottky detector can tolerate, it is difficult to decide whether the ferrite rods at the beam openings of the flying-wire cavity can be removed or not. Instead, let us study the cons and pros of these ferrite rods:

1. We do see that these ferrite rods play an important role in damping electromagnetic waves. In Fig. 3, we see that the transmission peak near 1.75 GHz almost disappears (green curve) when the ferrite rods are installed. The attenuation has been about 30 dB. Thus the ferrite rods do play an important role on damping excitations generated in the flying wire cavity.

2. The ferrite rods will introduce more impedance to the vacuum chamber of the Recycler Ring. The longitudinal impedance, Z/n, measured by Crisp [1] with or without the ferrite rods is depicted in the left plot of Fig. 4. The transverse impedance, Z_t, derived using the Panofsky-like relation for a circular beam pipe of radius $2''$ is depicted in the right plot. We see that the impedances increase with frequency (green curves) when the ferrite rods are present. The impedances, both longitudinal and transverse, are not large up to 1.5 GHz. However, we do not know how large they become at higher frequencies.

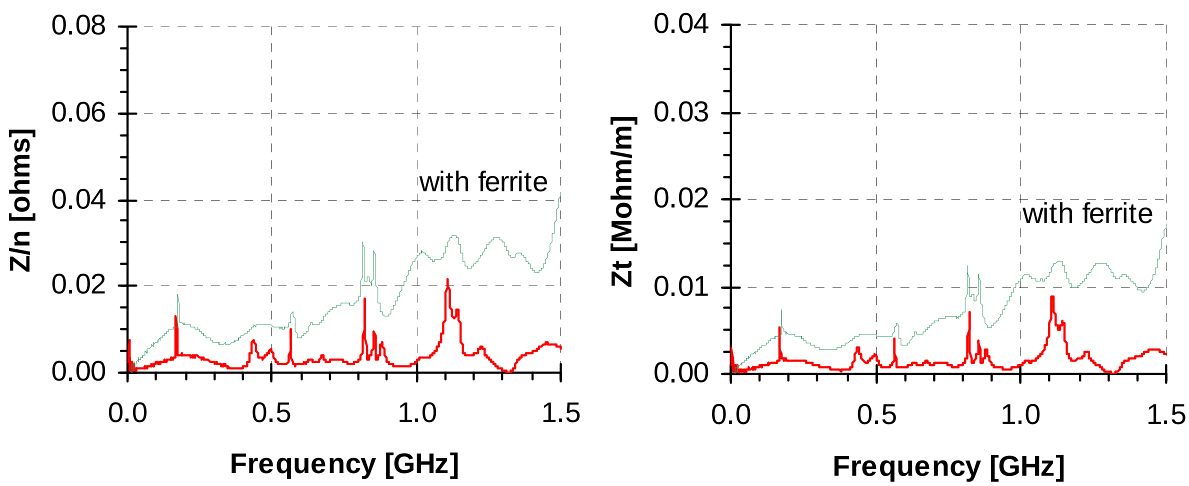

Figure 4: (color) Left: Longitudinal impedance per harmonic, Z/n, measured by Crisp [1] across the flying-wire cavity with (upper green) and without (lower red) the ferrite rods at the entrance and exit. Right: Transverse impedance, Z_t, derived from the longitudinal impedance using the Panofsky-like relation for a circular beam pipe of radius $2''$.

3. In fact, besides the ferrite rods to be installed at the entrance and exit pipes of the flying-wire cavity, there will be other ferrite material exposing to the Recycler vacuum.

The resistive-wall monitor [2] is broadband and has a bandwidth limit up to 23 GHz. It can also be corrupted by spurious electromagnetic energy generated at a large range of frequencies when the beam image current flows across various discontinuities of the vacuum chamber. To reduce this noise, unshielded ferrite or microwave absorber material is placed inside the vacuum chamber up and down-stream of the detector.† Inside the flying-wire cavity, there will also be ferrite rods to absorb electromagnetic waves generated. Therefore, it is unclear why, in the presence of so much unshielded ferrite, the addition of some more ferrite rods at the entrance and exit of the flying-wire cavity will further deteriorate the vacuum severely. One way to understand this is to subject the flying-wire cavity with the entrance and exit openings loaded with ferrite rods to a vacuum test and see whether the designed vacuum can be reached or not. If we can verify the achievement of the required vacuum pressure, there is not much reason to have those ferrite rods removed. Of course, we also need to ensure that these ferrite rods will be securely supported at the entrance and exit pipes so that none of them will fall into the beam.

5 ACKNOWLEDGMENT

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References

[1] Jim Crisp and Brian Fellenz, *Beam Impedance of the Recycler Flying Wire Can*, Fermilab Report TM-2212, 2003.

[2] *Fermilab Recycler Ring Technical Report*, Fermilab Internal Report, November 1996, Rev. 1.2, Section 3.8.

†The original design in Ref. [2] was to place the absorbing material outside a 5″ aperture ceramic sleeve to preserve vacuum specifications without lessening the absorbing properties. However, this shielded design has never been realized.