

Broadband Impedance of Azimuthally Symmetric Devices in RHIC*

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Abstract

The interaction between the beam and its environment leads to beam instabilities, and is characterized by coupling impedance. The longitudinal coupling impedance of some RHIC devices with azimuthal symmetry such as bellows, pipe transition, gate valve and collimator have been calculated numerically using the time domain code TBCI [1]. The objective is to keep the broadband impedance below a threshold so that it satisfies the microwave stability criteria [2]; and make sure there is no contribution to narrowband impedance from any of these structures.

I. DETERMINING COUPLING IMPEDANCE

Let $W(t)$ is the wakepotential of a δ -function charge. The coupling impedance is given by [3]

$$Z(\omega) = - \int_{-\infty}^{\infty} dt W(t) e^{-i\omega t}$$

The broadband impedance has been calculated in time domain, as the excited wakefields decay in a short time. The calculations are done for a Gaussian charge distribution traversing a cavity with $\beta = 1$, perfectly conducting walls and monopole mode ($m=0$). The wakepotential is obtained as a function of distance behind the leading charge. The impedance is given by the Fourier Transform of the wakepotential divided by the Fourier Transform of the charge distribution.

II. IMPEDANCE OF RHIC DEVICES

In RHIC, there is transition in pipe radius from 3.5 cm in the cold region to 6 cm in the warm region. The cutoff frequency of the 3.5 cm pipe is 3.3 GHz and that of the 6 cm pipe is 1.9 GHz. There are bellows in the cold and the warm regions and gate valves in the warm region. The results of numerical calculations, for pipe transitions, gate valves, bellows and a circular collimator are given below. The σ of the Gaussian pulse is 5 mm for the bellows and collimator, and 4 cm for the pipe transition and gate valve. $\sigma = 10\Delta z$ for all the calculations. The collimator calculation was also verified for $\sigma = 20\Delta z$. The results are valid upto a frequency of $c/(2\sigma)$

A. Pipe Transition

The pipe changes radius from 3.5 cm to 6 cm over a length of 5 cm. Figure 1 gives a plot of the wakepotential and impedance. The impedance has resistive and inductive components at low frequencies. The inductance is 1.24×10^{-9} henry. The resistance is 31 ohm. There is a sharp jump near 1.9 GHz, the TM_{01} mode of the 6 cm pipe. Above 1.9 GHz higher order modes of the 6 cm pipe give broad impedance as energy is radiated into the pipe.

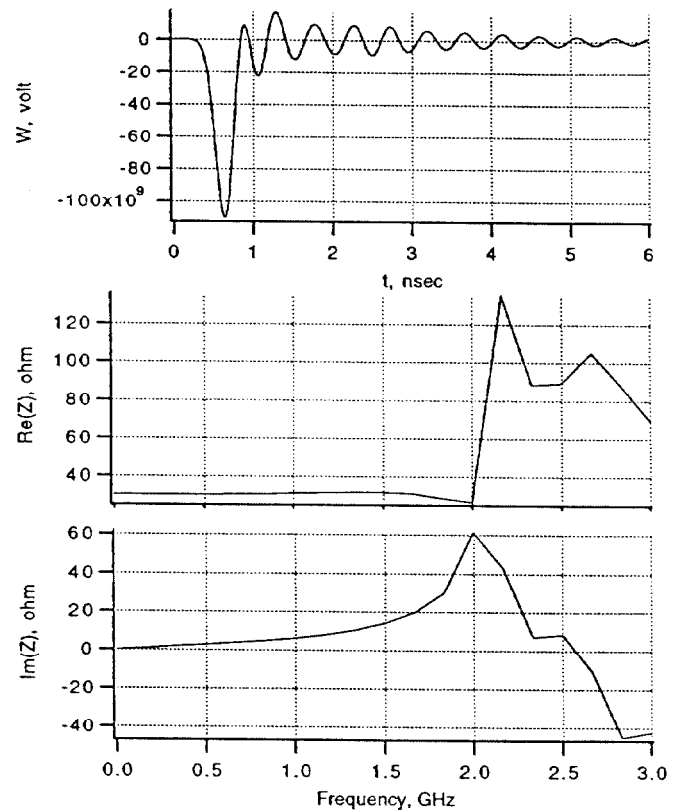


Figure 1. Pipe Transition, Wakepotential and impedance

B. Gate Valve

The gate valve is a rectangular cavity and is approximated by a cylindrical cavity of the same volume. The pipe radius is 6 cm, cavity radius is 9.9 cm and the length of the cavity is 4.2 cm. Figure 2 gives a plot of the wakepotential and impedance. It shows one resonance below cutoff at 1.38 GHz with infinite R and Q, as perfectly conducting walls are assumed. The Q will be finite when the finite conductivity of

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steel is taken into account. The calculation was verified in frequency domain with Superfish, giving a mode at 1.37 GHz. The gate valves will be shielded, in order to avoid coupled bunch instabilities.

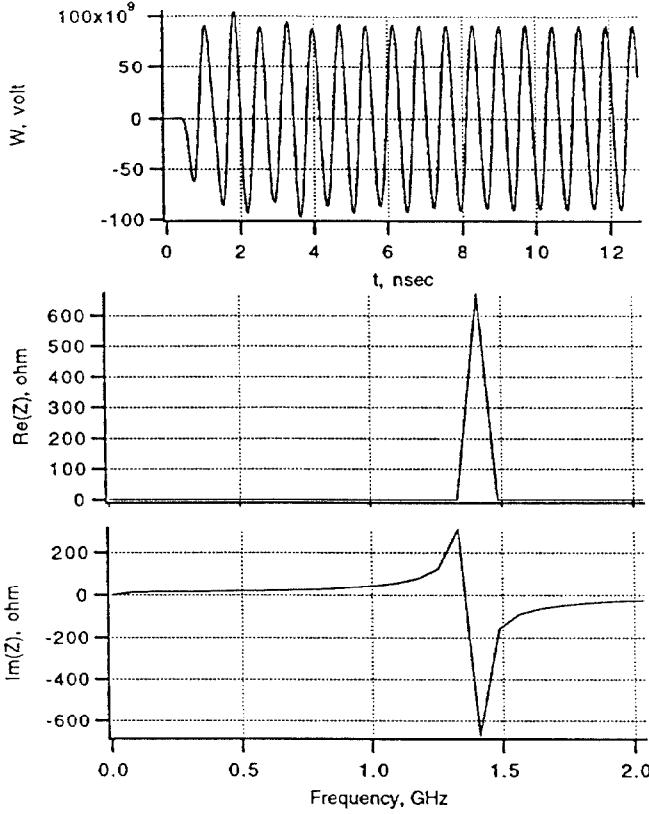


Figure 2. Gate Valve, Wakepotential and Impedance

C. Bellows

The parameters of the bellows are its total length (l), number of corrugations (N) and the depth of the corrugation (Δ). The bellows show a broad resonance at frequency which is a strong function of the depth of the corrugation. The impedance was calculated from the wakepotential and fitted to a resonator response of the form

$$Z(\omega) = \frac{R}{1 + iQ \left[\frac{\omega}{\omega_r} - \frac{\omega_r}{\omega} \right]}$$

where R is the shunt impedance, Q

is the quality factor and ω_r is the resonance frequency.

Figure 3 shows wakepotential and impedance of 3.5 cm bellows with $\Delta = 1$ cm, $l = 15$ cm and $N = 30$. There is a resonance at 4.7 GHz with $R = 850$, $Q = 7$ and $R/Q = 121$. As the depth Δ is decreased to 0.5 cm, the resonance frequency increases to 7 GHz with $R = 360$, $Q = 3.2$ and $R/Q = 112$.

$$\frac{R}{Q} = \sqrt{\frac{L}{C}} \text{ and } f_r = \frac{1}{\sqrt{LC}}, \text{ both } L \text{ and } C \text{ have decreased by a}$$

factor of 1.5 and f_r has increased by a factor of 1.5 keeping R/Q approximately constant.

For the 3.5 cm bellows with $\Delta = 1$ cm, the resonance at 4.7 GHz is above the pipe cutoff of 3.3 GHz. If Δ is increased to say 1.5 cm, there will be resonance and very large impedance around 3 GHz. Therefore Δ should be kept below 1 cm.

The 6 cm bellows with $\Delta = 1$ cm, $l = 15$ cm and $N = 30$ show resonance at 3.6 GHz, with $Q = 2.5$ and $R = 170$. The resonance frequency is above the cutoff frequency. Therefore for the 6 cm bellows as well, Δ should be kept below 1 cm.

The following empirical relation satisfied by the resonance frequency agrees with that in [4].

$$f_r = \frac{1.69}{2\pi} \left(\frac{c}{\Delta} \right) \left(\frac{\Delta}{b} \right)^{0.43}$$

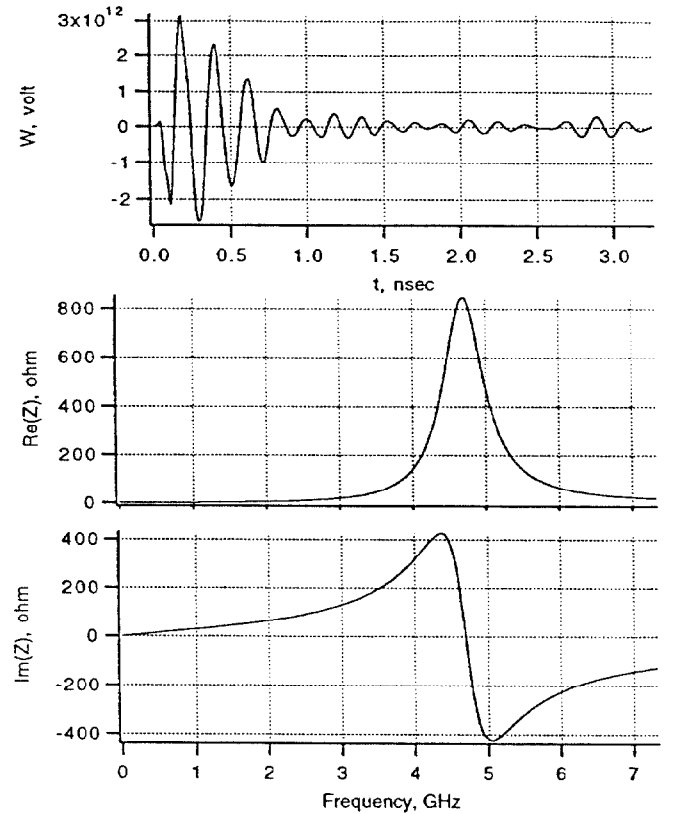


Figure 3. Bellows, Wakepotential and Impedance

D. Collimator

The impedance and wakepotential of a circular collimator with radius 1 cm, length 50 cm and beam pipe radius 3.5 cm was determined. Figure 4 gives a plot of its wakepotential and impedance. The impedance is similar to that of the pipe transition. At low frequencies there is an inductive response, with inductance 8.6×10^{-9} henry. At 3.3 GHz, there is a resonance due to the TM_{01} of the 3.5 cm pipe. Above the 3.3 GHz there is broad impedance due to the higher order modes of the 3.5 cm pipe.

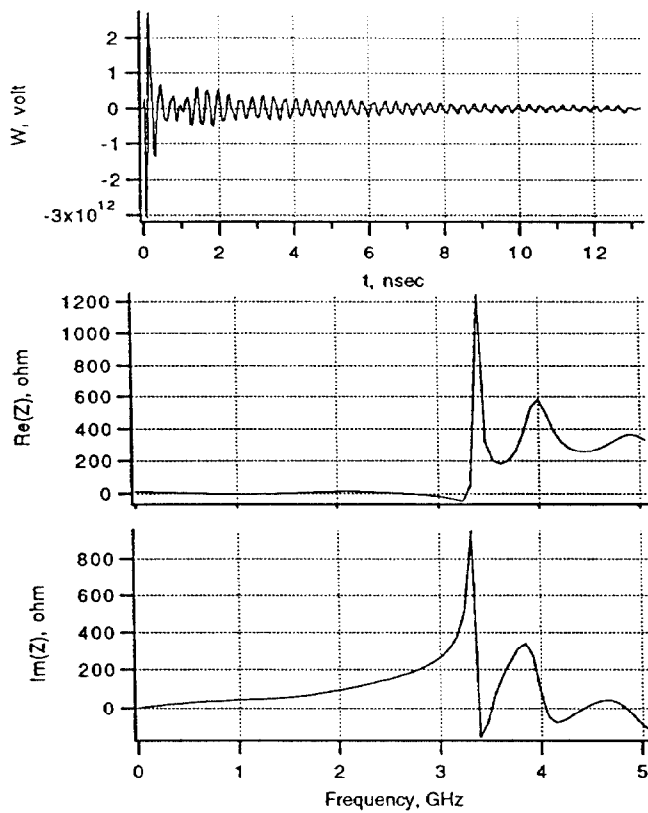


Figure 4. Collimator, Wakepotential and Impedance

III. CONCLUSION

In order to satisfy the microwave stability criteria, the broadband impedance should be below a threshold, upto 3.3 GHz. Of the above mentioned structures, the largest contribution to broadband impedance, comes from the bellows. In addition beam position monitors, wall resistance and injection and extraction kickers also contribute to the broadband impedance. The kickers would also have resonances which have to be determined.

IV. REFERENCES

- [1] T. Weiland, Particle Accelerators 15 (1984), pp.245-292
- [2] A. Hoffman, CERN 77-13.
- [3] A. Chao, SLAC-PUB-2946, June 1982.
- [4] K. Bane, R. Ruth, SSC Impedance Workshop Report SSC-SR-1017, p.10 (1985).