ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-THPAK077

# FEASIBILITY OF NON-METAL VACUUM CHAMBER FOR STORAGE RINGS*

T.-Y. Lee†, Pohang Accelerator Laboratory, [37673] Pohang, Korea


*Abstract*

This paper studies if the vacuum chamber of an electron storage ring can be made of dielectric non-meta materials such as ceramics or glass. The purpose of this study is to substantially reduce the broadband impedance of the vacuum chamber and consequently mitigate single bunch instabilities. This theoretical study examines how these materials can reduce the impedance and proposes how to resolve technical problems to occur.


## INTRODUCTION

The vacuum chamber for particle accelerators has usually been made of metal such as stainless steel or aluminium because of several reasons. Above all, metal is a perfect material for maintaining high vacuum and is strong enough to resist the consequential vacuum pressure. In general, metal has high melting point and high electric conductivity that is helpful in to minimizing resistive energy loss of the electron beam passing through the vacuum chamber.

On the other hand, there are materials such as ceramics, glass and others that are capable of achieving high vacuum but is dielectric. Actually, such insulating materials as ceramics have been used for accelerator devices or vacuum chamber parts, such as windows for RF cavities, kickers, beam current monitors, where it is necessary to suppress eddy currents induced on conducting walls by rapidly changing magnetic fields or electromagnetic fields are desired to penetrate into the chamber wall [1]. Sometimes, in these cases, thin metal coating is applied to the inside wall of the insulating chamber to prevent accumulation of static charges.

As the high conductivity of metal chamber is the source of image current, it is the source of the (broadband) impedance coming from sudden changes of cross sections, which may cause beam instability. Therefore, one is tempted to imagine that using such dielectric materials for the whole accelerator chamber (except a few parts) may help in reducing the total (broadband) impedance substantially and so weakening single bunch instabilities. This is why this paper explores possibility of non-metal vacuum chamber with the aim to construct an (geometric) impedance-free accelerator. Actually, there was an attempt to use ceramics to build a low impedance linear collider [2].

However, there are problems to be resolved. First, the impedance of a dielectric material has high frequency resonance peaks with very high impedance values, approximately when an odd multiple of a quarter wavelength in the dielectric equals the wall thickness [1]. This was considered to invalidate the hope that ceramic walls may be used to reduce transverse instabilities [1]. However, this paper shows that variation of wall thickness over the ring circumference invalidates the resonance condition. Second, certain elements of an accelerator, such as RF cavity system, magnets, insertion devices and flanges, should definitely be made of metal. Such metal systems generate impedances (particularly, the RF system mainly generates narrow band impedance) and so need to be handled in such a way as to give insignificant contribution to the total broadband impedance. Below, this paper suggests how these devices and parts can contribute only to the resistive-wall impedance but not to the geometric broadband impedance.

* Work supported by Basic Science Research Program through the National Research Foundation of Korea (NRF-2016R1D1A1B03933884).
† email address: tylee@postech.ac.kr

## IMPEDANCE OF DIELECTRIC VACUUM CHAMBER: CERAMICS

The ceramic chamber wall impedance is calculated and explained well in ref. [1]. At a low frequency, the impedance is negligibly low. However, in the high frequency region, there are resonances of the penetrating fields, approximately when an odd multiple of a quarter wavelength equals the dielectric wall thickness $t$ [1]:

$$(2\mathrm{p}+1)\frac{\lambda}{4\sqrt{\beta^2\varepsilon'-1}} = t, \tag{1}$$

where p is an integer, $\lambda$ is the wavelength, and $\beta c$ is the electron velocity. And, $\varepsilon'$ is the complex permittivity defined as $\varepsilon' = \varepsilon_r(1 + i\tan\delta_E) + i\sigma/\omega\varepsilon_0$ where $\varepsilon_r$ is the relative permittivity, $\sigma$ is the conductivity and $\tan\delta_E$ is the electric loss tangent.

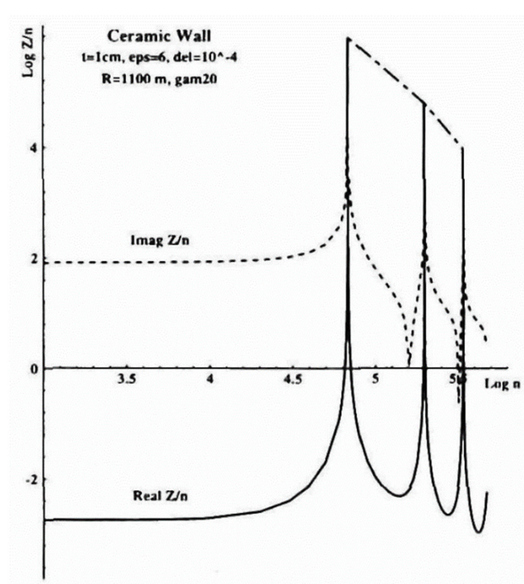


Figure 1: Computed ceramic wall impedance Z/$n$ versus $n$ in the logarithmic scale in both axes. (Courtesy of Zotter and Kheifets [1]).

ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-THPAK077

The longitudinal impedance of the ceramic wall is shown in Fig. 1 as a function of $n = \omega/\omega_0$, in the logarithmic scale, where $\omega_0$ is the revolution frequency of electrons circulating the ring. The transversal impedance of the ceramic wall also shows similar behaviour. Results of this section apply equally well to other dielectric materials including glass.

### *Thin Metallization*

Figure 2 below shows that 100 Å level thin metallization raises real part of the ceramic wall longitudinal impedance slightly in the region of low frequency but reduces it substantially (several orders of magnitude) in the high frequency region of resonance peaks. This is because thin metallization prevents penetration of the high frequency electromagnetic fields and so suppresses the resonance peaks substantially as shown in the figure.

Note that thin metallization plays another role of preventing accumulation of static charges on the ceramic chamber wall.

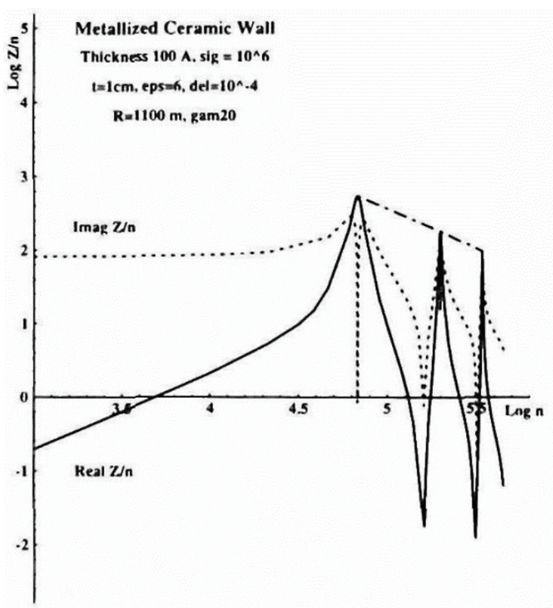


Figure 2: Computed ceramic wall impedance Z/$n$ versus $n$ in the logarithmic scale, in both axes, with thin metallization (Courtesy of Zotter and Kheifets [1]).

### *Variation of Wall Thickness*

Equation 1 cannot hold if the wall thickness $t$ varies from $t_{min}$ to $t_{max}$ over the ring circumference, because there is no fixed wavelength. Then, there would not be resonance picks of the impedances. Variation may be irregular (random) or regular like a saw tooth shape. Then, over the whole frequency range, the dielectric impedance would be very small and the dielectric vacuum chamber would contribute virtually none to the longitudinally and transversal impedances.

### *Possible Absence of Single Bunch Instabilities*

If the dielectric vacuum chamber contributes virtually none to the longitudinal and transversal broad impedances, this means that the chamber contributes virtually none to the longitudinal and transversal single bunch instabilities including the head-tail instability. Sextupole magnets may not be necessary at all to correct chromaticity, if the vacuum chamber is fully made of dielectric materials. However, a few chamber parts such as flanges and position monitors may be difficult to be replaced by dielectric materials. Of course, narrow band impedances arising from the RF cavity or insertion devices would still exist and so multi-bunch instabilities would still exist.

## TECHNICAL DIFFICULTIES

In addition to the above issues about physical principles, there are also a few technical issues.

### *RF Cavity System*

RF cavity system should definitely be made of metals, normal conducting or super conducting. This means that the conducting RF cavity system should be connected to the non-conducting vacuum chamber. Therefore, the image charges generated by the cavity system would not flow to the dielectric chamber but accumulate at the connection part. These charges should be removed in some way, or highly accumulated charge would lead to heat. One of possible methods of removal is to ground the cavity system so that the image charges generated inside the cavity system may flow from the accelerator to the ground. Certainly, proper grounding is important. Note that such a RF cavity system still generates narrow band impedance that may cause multi-bunch instabilities, grounding or not.

### *Magnets and In-Vacuum Insertion Devices*

There are many dipole and quadrupole magnets in an electron storage rings. They are at the outside of vacuum chamber. If the chamber is made of metals, the electromagnetic fields generated by electron bunches cannot penetrate into the chamber wall and see the magnet pole faces. However, if the chamber is made of dielectric materials, the fields penetrate into the chamber wall to see the magnet pole faces and the material for magnets is important. A typical material for magnet is NdFeB the conductivity of which is two orders lower than aluminium but still high enough for image charges to be generated on the magnet pole face. Hence, resistive-wall impedance may occur, although there would still be no geometric impedance. To reduce the resistive-wall impedance, it would be necessary to cover the pole faces with a thin copper sheet. As more image charges would be generated with the cover-sheet, these sheets should also be grounded, sheet by sheet. In conclusion, magnets would contribute to the resistive-wall impedance but not to the chamber broadband impedance.

In a recent low-emittance light source, in-vacuum insertion devices play a central role and many in-vacuum insertion devices are installed there. Again, the insertion device magnet blocks have poor conductivity and may generate high resistive-wall impedance. But, this time, wake field is trapped within the in-vacuum insertion device chamber and the consequential instability would be multi-bunch one [3].

ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-THPAK077

As in normal magnets, a copper sheet should be covered over each magnet block to reduce the resistive-wall impedance and such sheets should also be grounded to direct the image current to the ground. Again, in conclusion, in-vacuum insertion device would contribute to the resistive-wall impedance but not to the chamber broadband impedance

### *Flanges and Beam Position Monitors*

Flanges and beam position monitors are hardly replaceable by dielectric materials. But, each flange or monitor should be grounded to direct the image current to the ground. They would give minor contributions to the chamber broadband impedance.

### *Use of Glass*

While ceramic is often used for the accelerator chamber parts where it is necessary to avoid eddy current as in kickers or fast-cycling accelerators, glass has never been used. Certainly, glass has the disadvantage of being brittle and weak against external impact. However, it has also advantage of easily shaping and being cheap. Like ceramics, glass is capable of maintaining high vacuum and has very high melting points around 1,400 °C-1,600 °C. It is imaginable, for a storage ring, that glass is used for the bending section and ceramic is used for the straight section.

The problem of being weak and brittle may be resolved by strengthening, for example through wrapping the glass vacuum chamber with something like rubber.

## CONCLUSION

The vacuum chamber of a circular accelerator can be made of dielectric materials to have low broadband impedance and mitigate single bunch instabilities. Candidate materials include ceramics and glass. These dielectric materials have very low impedance in the low frequency region but very high resonance peaks, in the high frequency region, which may be suppressed by thin metallization or may not occur at all if the wall thickness varies over the ring circumference.

Certain chamber parts should be made of metals and so generate image charges. To avoid accumulation of image charges, each such part should be grounded. Also, pole faces of all magnets should be covered with copper sheets to avoid high resistive-wall impedance and also grounded to avoid accumulation of image charges.

## REFERENCES

[1] B. W. Zotter and S. A. Kheifets, *Impedances and wakes in high-energy particle accelerators*, Singapore: World Scientific, 1998.

[2] J. Simpson *et al.*, “The Argon Test Facility”, Note 109, ANL/WF, 1989.

[3] T. Nakamura, K. Soutome, M. Takao, M. Masaki, and T. Hara, “Resistive-wall coupled bunch instability driven by in-vacuum insertion devices in the Spring-8 storage ring”, in *Proc. 2001 Particle Accelerator Conf. (PAC 2001)*, Chicago, IL, USA, June 2001, pp. 1969-1971.