Impact of NEG Coating on the Impedance

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1 Introduction

◊ In the SOLEIL ring, nearly all straight sections shall be equipped with NEG coated Al vessels.

◊ Recently, however, installation of such chamber in ELETTRA apparently associated an anomalous increase of the impedance.

![Vertical impedance evolution graph](image)

*Courtesy E. Karantzoulis (ELETTRA)*

◊ At ELETTRA, this anomalous increase was later confirmed when second such chamber was installed in spring 2003.

⇒ Preliminary studies, made at SOLEIL on the effect of NEG coating on the impedance, including the collaboration with ELETTRA on the analysis of their observations, are reported.
2 Impedance model

◊ One may assume that it is \( Z_{RW} \) (Resistive-Wall) in question.

◊ To evaluate \( Z_{NEG} \), one needs a formula that takes account of a metallic layer on the chamber surface.

Standard formula \[
Z_{\perp}^{RW}(\omega) = \frac{[\text{sgn}(\omega) - i]}{2\pi} \cdot \frac{1}{b^3} \sqrt{\frac{2c\rho}{|\omega|}} \times L
\]

- Assumes a circular chamber with an infinitely thick wall
- Maxwell solutions in regions I and II matched on the boundary.

Matching must now be made on both sides of a metallic layer. We have derived \( Z_{\perp} \) and \( Z_{\parallel} \) using the formalism of A.W. Chao.

◊ Verified that the obtained formulae
  - Reduce to the standard ones when \( \rho_{II} = \rho_{III} \).
  - Are numerically identical to those of Burov and Lebedev (EPAC 2002), derived in a different approach.

⇒ Led us to suppose that these formulae, as well as those of Burov and Lebedev for flat chambers are reliable.
Inapplicability of the standard formula elsewhere (a side aspect).
- In large machines where $\delta_{\text{skin}} > d_{\text{wall}}$.
- Incoherent tune shifts due to asymmetric chambers.

(b = 4 mm, chamber thickness = 1 mm, material = SS)

Critical importance of the different behaviour of $Z_\perp$ at low frequencies in understanding the incoherent tune shift.

(Chao, Heifets and Zotter; PRST 5, Nov02)
3 Properties of the impedance of a coated chamber

◊ In applying the formulae, \( \rho \) of the coated NEG is a priori unknown.
  \[ \Rightarrow \text{Started with } \rho = 25 \times 10^{-8} \, \Omega m, \text{ i.e. the lowest of (Ti, Zr, V) of NEG.} \]

◊ With 1 \( \mu m \) NEG coating on an Al chamber (7 mm radius);
  - \( \text{Im} Z_{\perp} \) increases by roughly a factor of 2
  - Increase of \( \text{Re} Z_{\perp} \) is relatively small.

Behaviour of \( \text{Im} Z_{\perp} \) is in qualitative agreement with the observation in ELETTRA.

◊ Same trend for flat chambers. Amplitudes are scaled
  - Vertically by roughly the form factor \( \pi^2/12 \sim 0.82 \).
  - Horizontally \( \pi^2/24 \sim 0.41 \).
  - Elliptical and rectangular chambers lie in between the 2 extremities.
◊ Variation of $\rho$ at a constant coating thickness $d$ of 1 µm
- A steep increase of $\text{Im} Z_\perp$
- Saturation at a ratio of $\sim 2$ above $\rho \sim 50 \times 10^{-8}$ Ωm.

![Graph showing the variation of $\text{Im} Z_\perp$ at 2 GHz with resistivity for $d = 1$ micron.]

◊ Variation of $d$ at a constant $\rho$ ($43.5 \times 10^{-8}$ Ωm)
⇒ The same trend that the impedance saturates rather rapidly.

![Graph showing the variation of $\text{Im} Z_\perp$ at 2 GHz with coating thickness for $\rho = 43.5 \times 10^{-8}$ Ωm.]

- Saturation at $d > \delta_{\text{skin}}$ (~7 µm in the example).
- $\text{Im} Z_\perp$ converges to that of a chamber made of the coating material.

⇒ A significant increase of $\text{Im} Z_\perp$ can only be expected when both $\rho$ and $d$ are increased simultaneously. $Z_{\parallel}$ behaves similarly.
4 Effective resistivity of NEG

◊ Is $\rho_{NEG} \approx \rho$ of the constituent elements?
  \[ \{\rho_{Ti}(30\%), \rho_{Zr}(30\%), \rho_{V}(40\%)\} \sim \{40, 44, 25\} \times 10^{-8} \ \Omega m \]
  \[ \Rightarrow \rho_{<\text{elements}>} \sim 35 \times 10^{-8} \ \Omega m. \]

◊ Information from SAES Getters:
  - NEGs once reduced in powder form have poor conductivity, being powder grain covered by an oxide layer.
  - High compression should ideally lower $\rho$ to that of graphite.

◊ V. Ruzinov (CERN) pointed out that NEG on Al and Be have a granular structure, as opposed to very smooth surface on Cu and S.S.

◊ E. Plouviez (ESRF) made a direct measurement of $\rho_{NEG}$ at 14 GHz, with thin NEG films ($\sim 1 \ \mu m$) on a kapton sample.
  \[ \Rightarrow \rho_{NEG} \sim 1600 \times 10^{-8} \ \Omega m \text{ was concluded} \ (\rho_{NEG}/\rho_{<\text{elements}>} \sim 50). \]
  \[ \Rightarrow \delta_{\text{skin}} > 1 \ \mu m \text{ coating even at 14 GHz.} \]

◊ D. Proch et al. (DESY) assume $\rho_{NEG} \sim 350 \times 10^{-8} \ \Omega m$.
  (“RF Losses in CU Surface with TiZrV Coating”, D. Proch and A. Zavadtsev)
5 Some analysis of observations in Elettra

◊ Collaboration is made with ELETTRA (E. Karantzoulis) to identify the observed anomalous detuning.

◊ Try firstly to understand the approximately constant increase of the detuning, every time a low-gap chamber (no coating) is installed.

◊ RW and geometric impedance both seem important because;
  - Detuning is nearly equal for SS and Al chambers
  - Measured horizontal detuning > calculated with $Z_{RW}$ alone

◊ By varying $\rho$ and $d$ of the coating, find that only when $d > \sim 10$ μm and $\rho > \sim 500 \times 10^{-8}$ Ωm, can $\text{Im}(Z_{\text{eff}})_{\text{NEG}}$ explain the observation.

Plot of $\text{Im}(Z_{\perp})_{\text{eff}}$ versus resistivity $\rho$ and thickness $d$. 
6 Impact on SOLEIL

◊ The following 3 cases are compared:
   1) Without NEG coating (Al + SS chambers)
   2) With NEG coating (NEG coated Al + SS chambers)
   3) All chambers made of S.S. (No NEG)

- $b$ and $\rho$ values taken according to realistic configuration of the ring
- Coating thickness $d = 1 \, \mu m$
- $\rho_{NEG} = 50 \times 10^{-8} \, \Omega m$ (a value already in the saturation)
- $\beta$ values according to the nominal optics

$\Rightarrow$ There is \sim 50\% increase due to NEG in both transverse and longitudinal
◊ Increase of ImZ may not a priori be detrimental for instabilities
- RW instabilities should not be sensitive
- Could even be beneficial in the PWD regime
- However, $(I_{th})_{TMCI}$ is expected to decrease proportionally

- Could be harmful in the high current/bunch regime (microwave, post head-tail, …)
- Short range incoherent tune shift may also be affected
7 Conclusion

◊ The NEG coated chamber impedance was estimated with formulae that take into account a metallic layer on the chamber surface.

◊ Found that $\text{Im}(Z)_{\text{eff}}$ increases by $\sim50\%$ with 1 $\mu$m coating, while $\text{Re}(Z)_{\text{eff}}$ remains roughly unchanged.

◊ Fortunately, $\text{Im}(Z)_{\text{eff}}$ saturates rather fast in both $\rho$ and $d$.

◊ The increase of $\text{Im}(Z)_{\text{eff}}$ would have a non-negligible impact of reducing $(I_{\text{th}})_{TMCI}$ on SOLEIL ring.

◊ To explain the anomalous observation in ELETTRA, one has to assume $\rho >> \rho_{\text{elements}}$ and $d >> 1 \mu$m.

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