WAKE FIELDS DUE TO WALL ROUGHNESS FOR REALISTIC SURFACES*

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Abstract

Wake fields due to the wall roughness of the vacuum chamber can catch up to the bunch causing energy spread and emittance growth. Several theoretical models were developed in the past which showed rather different importance of this effect. Some models suggest that the wall roughness effect can be minimized if the vacuum chamber surface is characterized by a large aspect ratio of the surface roughness (characteristic length to the height of the surface bumps). To explore these effects several surfaces were measured and direct numerical simulations were performed for such realistic surfaces. The studies were done both for the long bunches to provide estimates of this effect for parameters of the eRHIC project, as well as for very short bunches to explore parameter space of the wall roughness experiment proposed at BNL's ATF.

INTRODUCTION

This work was originally motivated by beam dynamics studies for the eRHIC project [1-3], which is a proposed upgrade of the Relativistic Heavy Ion Collider (RHIC). The present eRHIC design is based on the multi-pass electron beam transport in existing tunnel of RHIC. As a result of a high peak current and a very long beam transport, consideration of various collective beam dynamics effects becomes important [2, 3]. Contribution of Wall Roughness (WR) to the coupling impedance (wake potential) can become significant, especially when the size of the vacuum chamber is small and length of the electron bunch is short.

Some models indicate that the wall roughness effects can be minimized if the vacuum chamber surface is characterized by a large aspect ratio of the surface roughness (characteristic length to the height of surface bumps). We attempted to explore these effects for realistic surfaces by means of the direct numerical simulations. Several surfaces were measured, including extruded aluminium surfaces, for which such roughness aspect ratio is expected to be very large. The measured surface data was then used as an input parameter in electrodynamics code NOVO [4] to simulate the wake field.

Studies were done both for long bunches (for the eRHIC parameters [2-3]) with bunch length longer than typical correlation length of the rough surface and for short bunches with bunch length much smaller than the correlation length of the surface roughness. In this paper, only results for the case of short bunches are presented, as

an illustrative example of our studies.

WALL ROUGHNESS

An effect of the wall roughness was first estimated based on the impedance of small protrusions of different configurations and orientations in Ref. [5]. Such an "inductive" model can lead to a very strict requirement on the surface polishing. The longitudinal wake potential in this model scales as h/b, where h is the height of the protrusion and b is the radius of the beam pipe.

Another model for the wall roughness was introduced in Refs. [6-7]. In this model the presence of roughness is equivalent to a pipe with a thin dielectric layer or periodic corrugation on the smooth wall surface. This model is typically referred to as the "dielectric" or "resonator" model. In the "resonator" model the coupling impedance also has a resistive part. A detailed comparison of the "resonator" and "inductive" models was given in [7]. The "resonator" model becomes invalid when the correlation length (or period of corrugation) is significantly larger than the height of the protrusion. This happens to be the case for realistic wall surfaces [8] and especially for the surfaces produced with extrusions.

The length of the protrusions along the surface (referred to as the "correlation length" l_c) was taken into account in the model developed in Refs. [8-9], which reduced the coupling impedance significantly for typical surfaces with large correlation length, resulting in the wake potential scaling as $h\cdot h/(b\cdot l_c)$. Comparison of such model with the "inductive" model was given in Ref. [10].

In the eRHIC design, we relied on a significant reduction of wall roughness effects due to the large aspect ratio of the wall roughness by choosing extruded aluminium vacuum chambers. Measurements of several surfaces were performed to allow systematic study of wake field dependences on the height and length of the roughness. In addition, rather than using measured surface data in approximate models for the estimates, we attempted to study wake fields directly, using numerical simulations with the code NOVO [4].

MEASURED SURFACES

In this paper, we limit our discussion to three measured surfaces: 1) "surface-1": sample of an extruded aluminium surface from the NSLS-II vacuum chamber; 2) "surface-2": rough aluminium surface without extrusions; 3) "surface-3": extruded aluminium surface from the superconducting undulator provided by ANL [11].

NUMERICAL SIMULATIONS

Numerical calculation of wake fields due to real surface roughness is extremely demanding task. For this purpose, we used computer code NOVO which was specifically developed to handle calculation of wakes for very short bunches in very long accelerator structures. For solving Maxwell's equations in time domain, the NOVO code uses finite-difference method with improved characteristic of the dispersion curve in the region of minimum critical wavelength [4]. This code was used before to study effects of wall roughness for artificially created surfaces [6-7]. Here we performed simulations of wake fields with real measured surface data.

Although measured surface maps are three dimensional, the NOVO code is a 2-D code. For each numeric simulation, we took a single 1-D slice from the measured surface. Based on such a slice, the code generates azimuthally symmetric protrusions. The net effect of such 2-D simulation is that magnitude of the wake is somewhat over estimated compared to the real structure in 3-D [12]. Therefore, such 2-D simulations can be used for a conservative estimate.

The primary goal of our studies was to study wakes resulting from real surfaces produced with an extrusion technique, and thus very long correlation length. In addition, we studied dependences on the correlation length and height of the surface bumps; as well as different beam distribution from Gaussian to a more uniform bunch profiles. Due to a limited space in this paper, only few results for the case of bunches with a short edge are presented. Shown results are for the bunches with the flat centre region of 0.3 mm and bunch edges of 0.03 mm rms.

EXAMPLES AND RESULTS

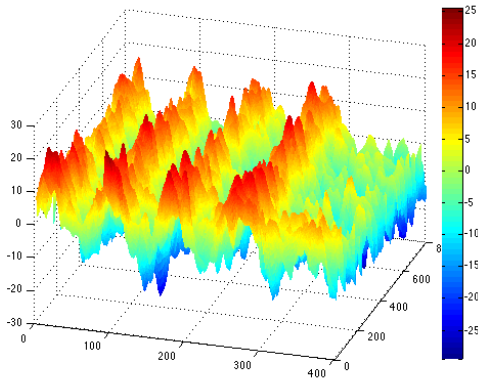Figure 1 shows 3-D measurement of extruded aluminium "surface-1".

Figure 1: Measurement of "surface-1". Extrusions are along mountain ridges (red). Vertical axis in μm; horizontal axes in pixels.

Due to a very large height of the roughness, resulting wake potential for "surface-1" is very large. Figure 2 shows a 1-D slice from the surface in Fig. 1 used in simulations. Figure 3 shows bunch profile and resulting wake potential and loss factor.
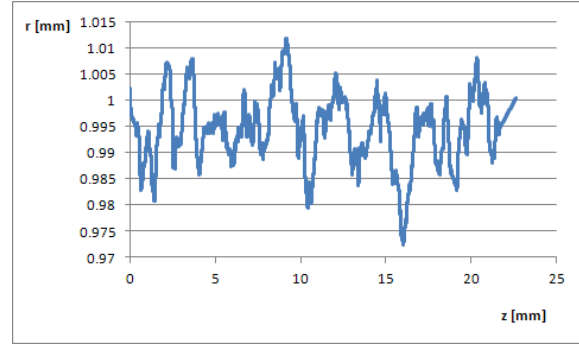

Figure 2: Slice from measured "surface-1" along one of the "mountain ridges" (along extrusion, beam direction z) added to the beam pipe radius r of 1 mm.
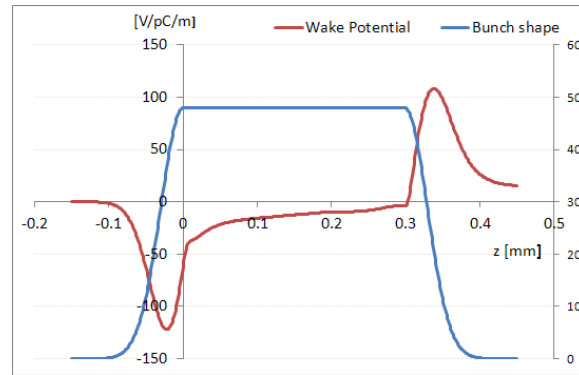

Figure 3: Blue: bunch profile; red: wake potential for "surface-1", r=1mm. Loss factor k=16 V/pC/m.

Simulations using "surface-1" data but with the characteristic length l_c artificially scaled by some factor showed that energy spread scales as $1/l_c$, as suggested in [8-9]. However, we did not observe expected h^2 dependence when the height h of the surface was also scaled by a factor. Instead, observed scaling was more like $h \cdot g/(b \cdot l_c)$, where g an additional surface parameter, for example describing the characteristic distance between the protrusions. Note that for a periodic structure with the depth h, gap size g and period l_c, one gets such $h \cdot g/(b \cdot l_c)$ dependence exactly.
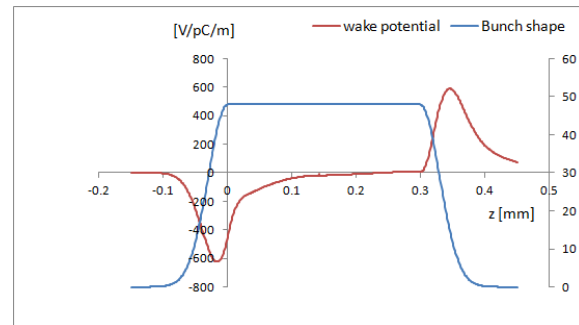

Figure 4: Blue: bunch profile; red: wake potential for "surface-1" with the correlation length 4 times smaller than in Figs. 2-3, r=1mm. Loss factor k=64 V/pC/m.

As an example, Figure 4 shows wake potential for the "surface-1" with the longitudinal structure of the surface in Fig. 1 compressed by a factor of four.

In further studies, a small-gap extruded aluminium vacuum chamber with a very smooth surface (Fig. 5), without applying possible polishing techniques, was provided by ANL [11]. The calculated wake potential and loss factor for such surface are shown in Fig. 6.
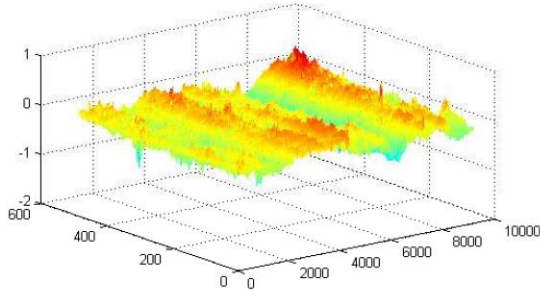

Figure 5: Measured surface for extruded aluminium "surface-3" provided by ANL. Vertical axis in µm; horizontal axes in pixels.
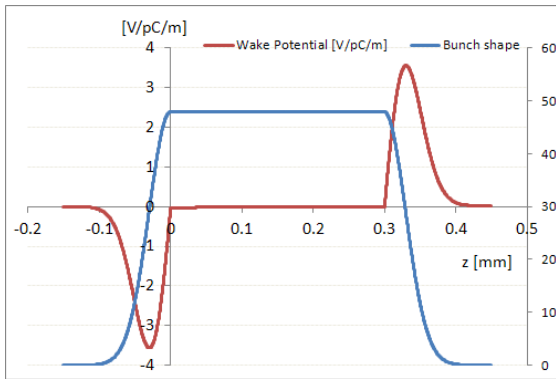

Figure 6: Blue: bunch profile; red: wake potential for "surface-3", r=1mm. Loss factor k=0.05 V/pC/m.
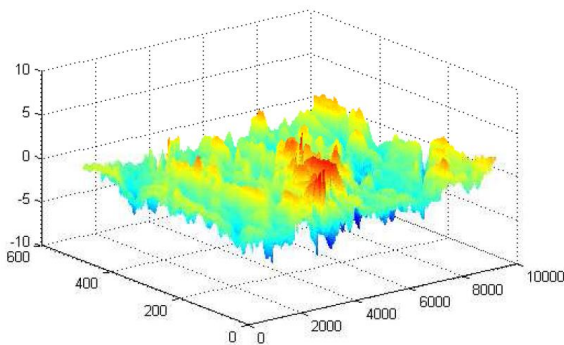

Figure 7: Measurement for aluminium surface without extrusions ("surface-2"). Vertical scale in µm.

We also studied wake potential for several aluminium surfaces without extrusions. Although these surfaces did not have large correlations lengths the height of the roughness bumps was not as large as for "surface-1". As a result, computed wake potential was of the same order as for "surface-1" with extrusions, as shown in Figs. 7-8.
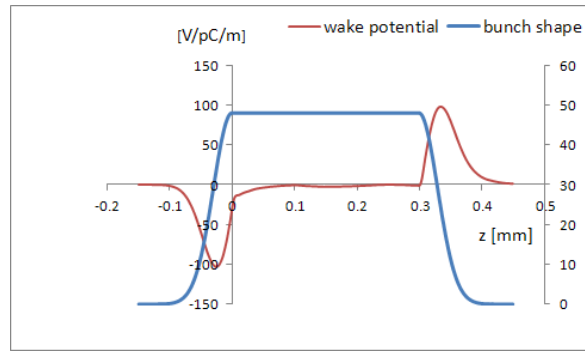

Figure 8: Blue: bunch profile; red: wake potential for "surface-2", r=1mm. Loss factor k=4 V/pC/m.

SUMMARY

In these studies we simulated wake potentials due to a wall roughness using real measured surface data. Some dependences on the correlation length and height of the surface bumps were examined. Several examples from our studies are reported in this paper.

Our simulations confirmed that effect of wall roughness can be strongly suppressed with the smooth extruded surfaces like "surface-3". Simulation of wakes for the eRHIC parameters (not presented in this paper) showed that such a surface would be satisfactory for the eRHIC design.

ACKNOWLEDGMENT

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