Influence of Beam Pipe Waist on Higher Order Mode Shunt Impedances

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1. Introduction

Intense bunches of charged particles, passing the cavities of accelerator structures excite higher order eigenmodes (HOM's) in the resonator. These higher order eigenmodes can cause multibunch instabilities and beam breakup. Eigenmodes, located in one cavity, may also excite eigenmodes in the neighbouring cavity. Such a beam relevant mode was found by measurements at TESLA Test Facility at a frequency of 2.585 GHz [1]. As basic idea to suppress HOM coupling from one cavity to the next due to resonator disturbances the insertion of an additional waist in the beam pipe between neighbouring 9 cell cavities has been discussed [2]. This waist was placed at the position of the bellows, as shown below in figure 1, because this is the only position, where an additional waist may technically be realized.

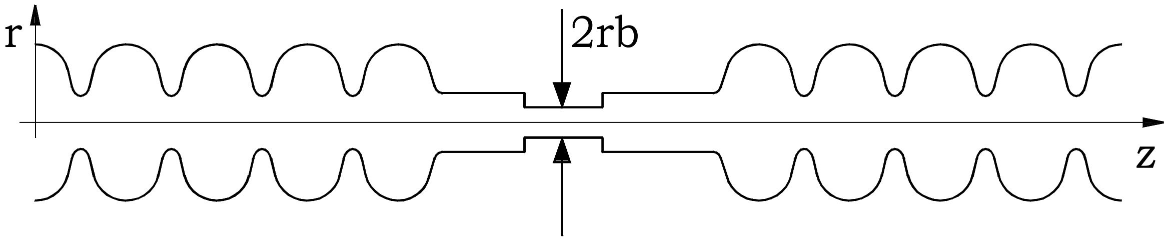


Figure 1. Waist with radius rb in the beam pipe between neighbouring cavities

In our simulations the radius of the waist was reduced from initially 39 mm, i.e. the radius of the beam pipe, to 30 mm within 1 mm steps.

2. Eigenmode Calculation

Monopole and dipole modes of the TESLA 9 cell cavities were calculated, using MAFIA code [3], to investigate the influence of decreasing beam pipe cross section on frequencies, shunt impedances and field distribution. Calculations were performed in rz – geometry, assuming axial symmetry. A special procedure was applied to set up the grid which is used by MAFIA. For every radial line this procedure calculates the z – coordinates of all intersections with the cavity shape and places z – lines at these positions.

This avoids steps in the material shape and reduces the number of mesh lines needed for a good approximation of the geometry [4].
The shunt impedances of both the monopole and the dipole modes were calculated according to

$$R_s = \frac{\left(\int E_z \, dz\right)^2 / rn^2}{\omega \, U} \qquad (1)$$

with E_z the z – component of the electrical field, ω the frequency of the mode, U the stored energy of the electrical field in the whole volume and rn = 5 mm the radial distance of the integration path from the symmetry axis. The integration in z-direction was performed over the whole length of the two half nine cell cavities, connected by the beam pipe, as shown in figure 1.

2.1. Dipole Modes

Figure 2 below shows the influence of the additional waist on frequencies of some dipole modes in the 2.58 GHz range.

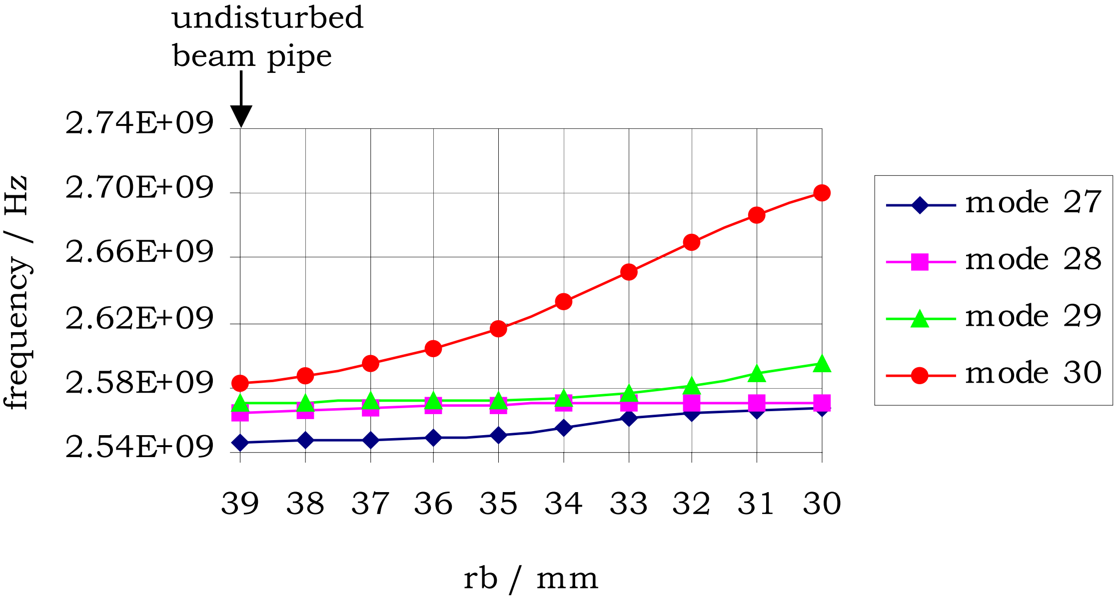


Figure 2. Change of frequencies of dipole modes in the 2.58 GHz range with radius rb

Only the frequency of mode 30, which is localized in the beam pipe, increases significantly on reducing waist rb. The change of frequency with reducing waist radius is about 13 MHz/mm. The shunt impedance of mode 30 decreases significantly for beam pipe radius rb ≤ 35 mm, as can be seen from figure 3. The drop of shunt impedance in the range from rb = 35 mm to rb = 30 mm is approximately 75 %. The increase of the frequency and the decrease of shunt impedance correspondes to the results, found for the behaviour of a pillbox-cavity with attached beam tubes [5].

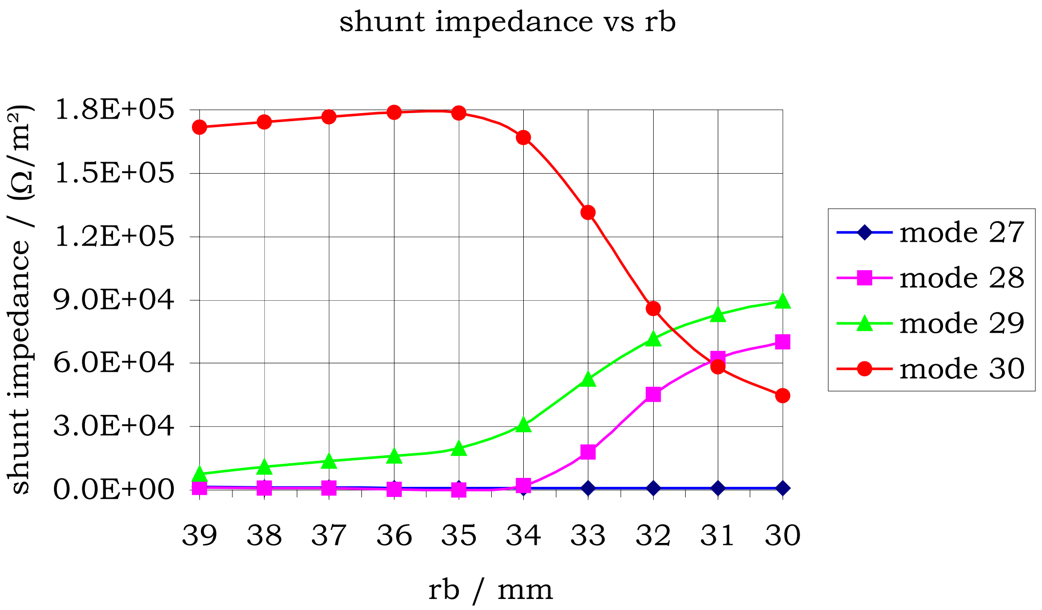


Figure 3. Change of shunt impedances of the dipole modes in the 2.58 GHz range with radius rb

Figure 4 below shows the spectra of the shunt impedances of the first 50 dipole modes, left for the undisturbed beam pipe and right for the radius rb = 31 mm of the additional waist. No severe change in the spectra of

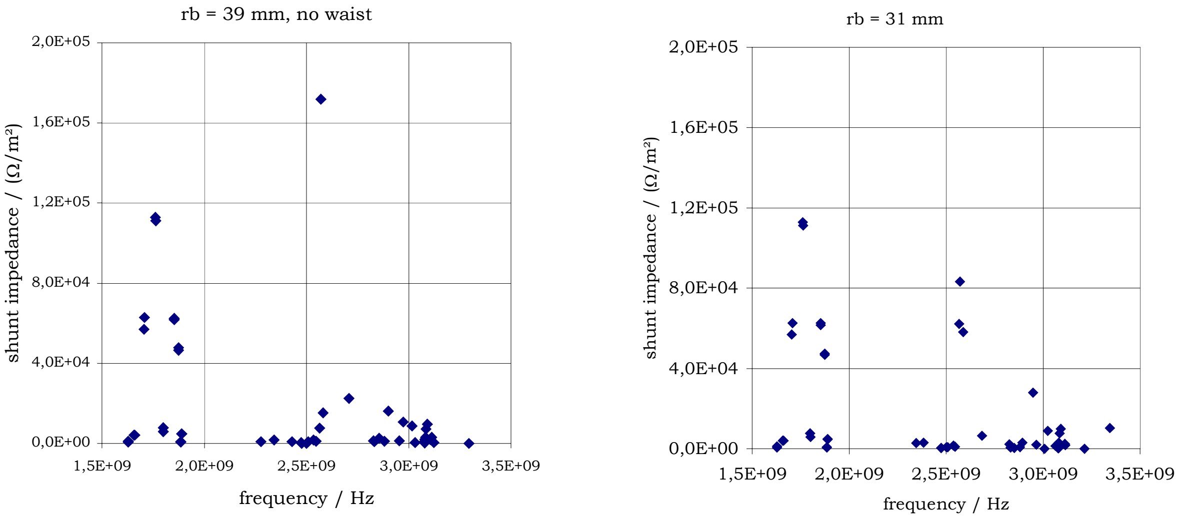


Figure 4. Spectra of shunt impedances of the first 50 dipole modes for the undisturbed beam pipe (rb = 39 mm, left) and for disturbed beam pipe (rb = 31 mm, right)

undisturbed and disturbed beam pipe is to be observed. The maximum value of the shunt impedance decreases by about 50 % with increasing disturbance, the shunt impedance value of of some modes increases with increasing disturbance.

The additional waist in the beam pipe acts strongly on the electrical field distribution of the dipole modes with field intensity in the beam pipe, as can be seen from figure 5. From the field distribution of mode 30 with disturbed beam pipe, compared with the field distribution without disturbance, it can be seen, that the coupling from one cavity to the neighbouring cavity is reduced. An influence of the additional waist in the beam pipe on the field geometry of modes with field inside the cavities was not observed.

rb = 39 mm, undisturbed beam pipe; mode 30, f = 2.5823 GHz

rb = 33 mm, disturbed beam pipe; mode 30, f = 2.6514 GHz

Figure 5. Electrical field distribution of dipole mode in undisturbed beam pipe (top) and with additional waist (bottom)

2.2 Monopole Modes

The influence of the additional waist in the beam pipe on the monopole modes was also investigated. The fundamental mode has no field in the beam pipe, hence it was not influenced by the additional waist.

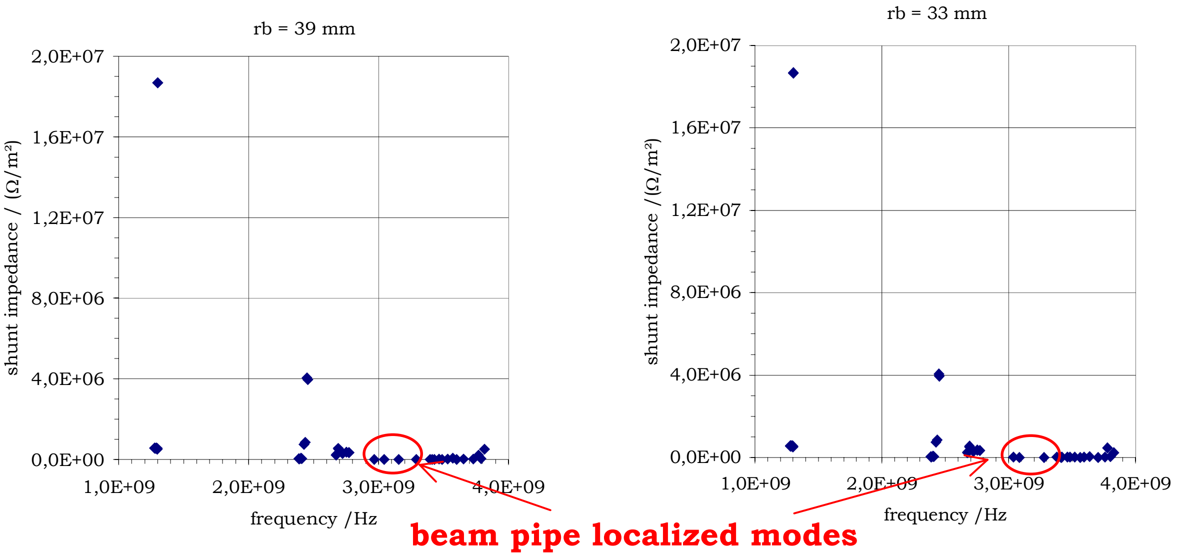
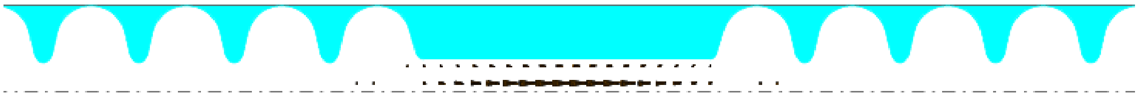


Figure 6. Spectra of shunt impedances of the first 50 monopole modes, calculated using equation (1), for the undisturbed beam pipe (rb = 39 mm, left) and for the beam pipe with additional waist (rb = 33 mm, right)

In the spectra of the monopole modes as shown in figure 6, the indicated modes were found to be beam pipe localized.

As can be seen from figure 6 the beam pipe localized modes have negligible shunt impedances. The frequencies of these modes were shifted towards higher values with decreasing waist radius rb.

rb = 39 mm, undisturbed beam pipe; mode 29, f = 2.968 GHz



rb = 33 mm, disturbed beam pipe; mode 29, f = 3.037 GHz

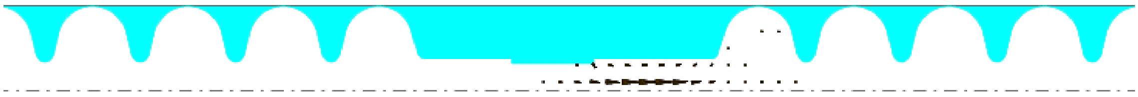


Figure 7. Electrical field distribution of monopole mode in undisturbed beam pipe (top) and with additional waist (bottom)

Figure 7 shows the electrical field distribution of one of the monopole modes, showing a reduced cavity to cavity coupling of the mode.

3. Conclusions

The influence of an additional waist in the beam pipe of TESLA-TTF-structures on frequencies, shunt impedances and field distribution of both dipole and monopole modes was investigated. The frequency of one dipole mode in the 2.585 GHz range increased significantly with decreasing waist radius rb. No severe changes in the spectra of shunt impedances of undisturbed and disturbed beam pipe were to be observed. From the field distribution of the dipole modes it can be seen, that the coupling from one cavity to the neighbouring cavity was reduced by the additional waist. The frequencies of monopole modes with field in the beam pipe were shifted towards higher values with decreasing waist radius rb. From the field distribution of these modes a reduced coupling from one cavity to the neighbouring cavity was observed, too.

References:

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