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COMPARISON OF SIX ACCELERATING CAVITIES WITH RESPECT TO COLLECTIVE EFFECTS

by

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Abstract

Accelerating Cavities are commonly optimized with respect to shunt impedance in order to minimize rf power for a given accelerating gradient. However, in many large storage rings accelerating cavities cause serious collective effects that limit the maximum charge per bunch to a value well below the fundamental beam-beam limit. Thus the luminosity is limited by parasitic effects that have not been taken into account (so far) for the design of the rf system.

In order to optimize the over-all effect of an accelerating system computional means are necessary for the evaluation of the parasitic effects such as higher order decelerating and deflecting modes and transient wake forces inside a bunch. Now that these computer codes are available it is possible to investigate the existing cavities as well as the systems under development with a much broader view.

In this paper we compare six different accelerating structures of which four are presently installed at PETRA and two are being developed at DESY.

It is found that the "Single-Mode-Cavity" causes three times less parasitic forces per accelerating gradient as the recently installed 7-cell 500 MHz cavities in PETRA.

1. Introduction

Presently there are four different cavity structures being used in PETRA:

A : five cell 500 MHz cavity with 12 cm beam hole (first PETRA cavity) /1/

B : seven cell 500 MHz cavity with 8 cm beam hole (new PETRA cavity) /2/

C : six cell 1 GHz bunch lengthening cavity, 12 cm beam hole /3/

D : modified seven cell bunch lengthening cavity, 1 GHz, 9 cm beam hole /4/

and two cavities being developed at DESY:

E : nine cell superconducting cavity of elliptical-elliptical shape /5/

F : "Single-Mode Cavity" /6/ which has no decelerating mode besides the fundamental one.

The shapes of these six cavities are shown in figure 1.
The aim of this note is to summarize the characteristics of all these cavities with respect to collective effects.

The two major collective effects to be considered are:

- multi-turn instabilities due to resonant higher modes in the cavities excited by the beam

- single passage effects due to wake fields excited by the beam during the passage of a cavity (e.g. head tail turbulence, bunch lengthening and synchro-betatron resonances)

A comparison of all cavities is presented for these effects.

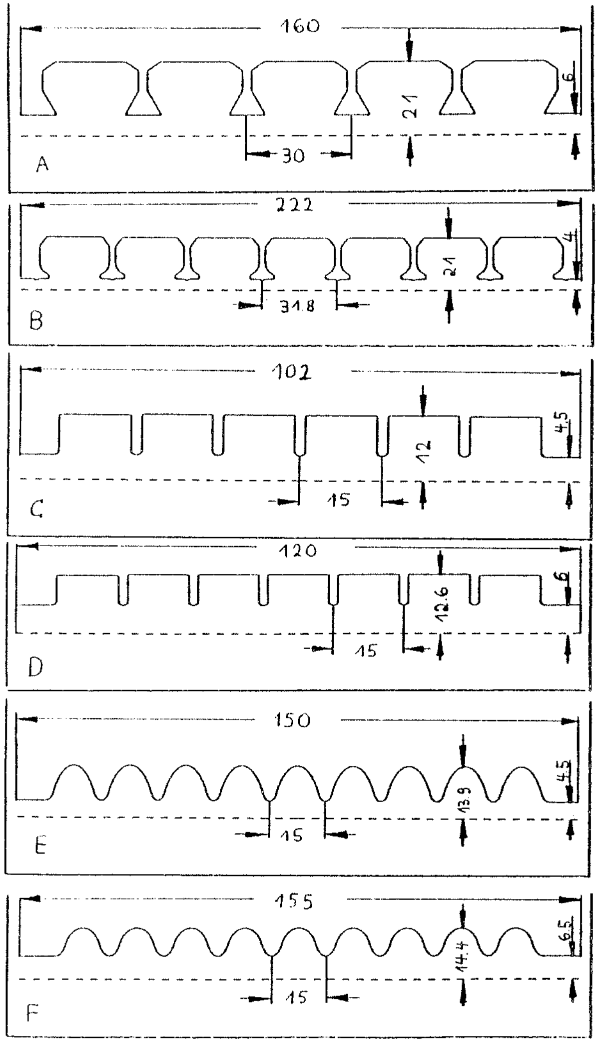


Figure 1: Shape of the six cavities being compared with major dimensions given in cm

2. Comparison of mode structure

The mode characteristics are described by the usual "R/Q" which is defined as

$$\frac{R}{Q} = k \cdot \frac{2}{\omega} = \frac{\left|\int_{-\infty}^{+\infty} \underline{E}_z(r_0,\varphi_0,z=ct)\, e^{i\omega t} c\,dt\right|^2}{\omega\, \varepsilon_0 \int |\underline{E}_z(r,\varphi,z)|^2 dV}$$

For monopole modes without azimuthal variation of the fields this quantity is independent of the path of integration. However, for all deflecting modes with azimuthally inhomogenious fields the quantity varies like the square of the offset of the path of integration if the field variation goes like cos φ (dipoles) /7/. Higher order azimuthal modes are of no practical importance in storage rings and thus ignored in the following. In order to obtain a quantity which is independent of the path of integration we defined for deflecting dipole modes the quantity (which is calculated in URMEL /8/):

$$\frac{R'}{Q} = \frac{R}{Q}\,\frac{1}{(kr)^2}\,, \quad k = \omega/c,\ r = \text{offset of path of integration}$$

With these definitions we have typical quantities that define the coupling between a mode and the beam.

Comparing different cavities we could just list here all the modes but this would be a list of some hundred modes and not be very informative. Instead of the complete list we use the following characteristics:

- the sum of all decelerating R/Q except the fundamental mode up to the cut off frequency of the beam pipe (only modes with $R/Q \geq 5\Omega$)
- the sum of all R/Q' of the decelerating deflecting dipole modes up to cut off frequency (only modes with $R'/Q \geq 5\Omega$)
- the maximum R/Q for both decelerating and deflecting modes
- the ratio of parasitic R/Q to the fundamental R/Q

	normal-conduct. 5-cell PETRA cavity	normal-conduct. 7-cell PETRA cavity	normal-conduct. harmonic 7-cell cavity	normal-conduct. harmonic 6-cell cavity	super-conduct. DESY 9-cell cavity	single-mode cavity 9-cell "SMC"-type
frequency f / MHz	500	500	1000	1000	1000	1000
beam hole diameter	12 cm	8 cm	12 cm	9 cm	9 cm	13 cm
fundamen. R/Q	462 Ohm	766 Ohm	282 Ohm	335 Ohm	510 Ohm	307 Ohm
sum of all parasitic R/Q's for monopoles	225 Ohm in 9 modes	483 Ohm in 24 modes	159 Ohm in 5 modes	171 Ohm in 4 modes	139 Ohm in 3 modes	35 Ohm in 2 modes
sum of all parasitic R'/Q's for dipoles	248 Ohm in 8 modes	422 Ohm in 12 modes	96 Ohm in 7 modes	157 Ohm in 8 modes	182 Ohm in 6 modes	86 Ohm in 3 modes
maximum R/Q of monopoles	71 Ohm	121 Ohm	61 Ohm	74 Ohm	113 Ohm	28 Ohm
maximum R'/Q of dipoles	118 Ohm	92 Ohm	24 Ohm	38 Ohm	92 Ohm	44 Ohm
ratio of sum over parasitic R/Q's and fundam. R/Q (monopoles)	0.49	0.63	0.56	0.51	0.27	0.11
ratio of sum over parasitic R'/Q's and fundam. R/Q (dipoles)	0.54	0.55	0.34	0.47	0.36	0.28

Table 1 : Comparison of mode characteristics

3. Comparison the wake field effects

The influence of wake fields on the beam is subject to complicated beam dynamics and can be solved for only by means of big computer tracking codes presently being developed at various laboratories. In order to have handy parameters indicating the wake field effects we define two "goal functions" giving basically the ratio of the over all energy loss in a bunch and the shunt impedance of a cavity (g_0) and the ratio of the average deflecting force inside a bunch to the shunt impedance (g_1).

These are functions of the bunch length (Gaussian shape) and defined as /9/:

$$g_0 = \frac{1}{k_0}\left(\frac{\int_{-\infty}^{\infty} w_{\parallel}(s)\,\rho(s)ds}{\left(\int_{-\infty}^{\infty} \rho(s)ds\right)^2} - k_{fund}\right)$$

$$g_1 = \frac{\int_{-\infty}^{\infty} w_{\perp}(s)\rho(s)ds}{k_0\left(\int \rho(s)ds\right)^2} \;;$$

with:

ρ = line charge density

$w_{\parallel}$ = longitudinal wake potential

$w_{\perp}$ = deflecting wake potential

$\frac{R}{Q}$, ω_0 = fundamental mode parameter

λ = wave length of fundamental mode

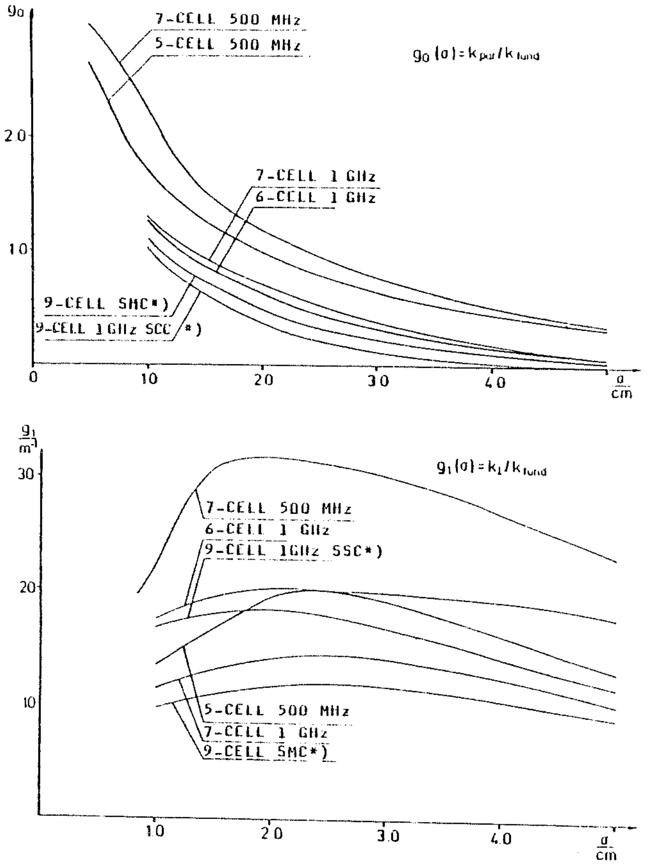
$$k_0 = \frac{R}{Q} \cdot \frac{2}{\omega}$$

$$k_{fund} = \begin{cases} k_0 . \exp\left(-\frac{\omega_0^2 \sigma^2}{c^2}\right) & \text{(Power)} \\ k_0 . \exp\left(-\frac{\omega_0^2 \sigma^2}{c^2}\right) & \text{(Voltage)} \end{cases}$$

Figure 2 shows the g functions as functions of bunch length for the six cavities calculated with TBCI /10/.

Figure 3 shows the same functions with a different argument, i.e. λ/σ instead of σ in centimeter.

These second curves are frequency independent and take into account that the bunch length shrinks with increasing the frequency. The second set may be used when two different rf systems are in use in one ring (as it is the case in PETRA) whereas the first set may be used to compare different rf systems for a storage ring without double rf system.



*) SCC Superconducting Cavity
SMC Single Mode Cavity

Fig. 2: a) ratio of parasitic mode loss to fundamental loss parameter as function of bunch length
b) ratio of transverse kick parameter to fundamental loss parameter as function of bunch length

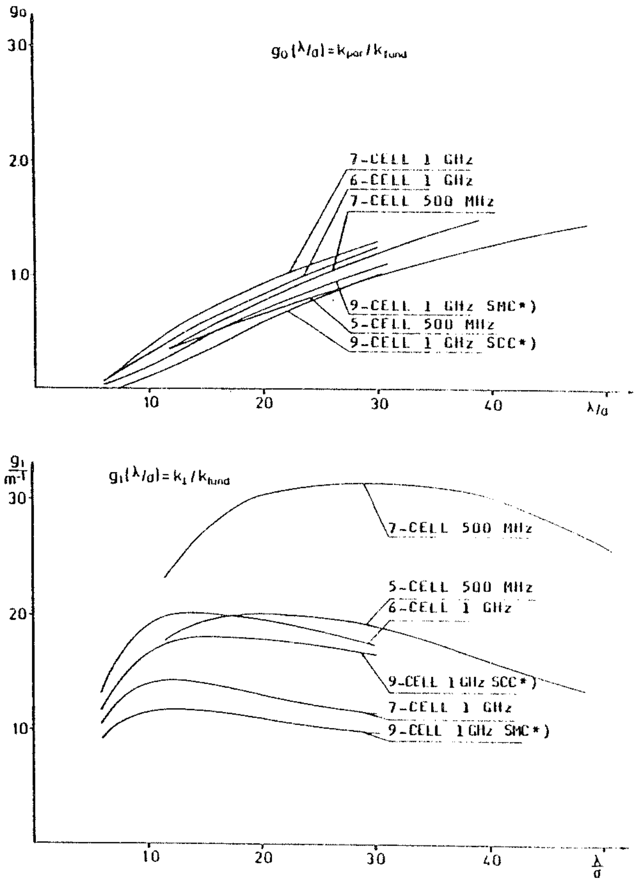


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Fig. 3: a) ratio of parasitic mode loss to fundamental loss parameter as function of λ/σ
b) ratio of transverse kick parameter to fundamental loss parameter as function of λ/σ

Note: λ is the fundamental mode wavelength.
$g_{o/1}$ (λ/σ) takes into account that increases with frequency, i.e. these curves are frequency independent.

4. Summary

Comparing the mode characteristics of these six cavities shows no significant difference between the four normal-conducting cavities. The two superconducting ones are much better having fewer higher order modes that could cause multi turn collective effects. The weakest collective effect is due to the "Single-Mode-Cavity" which has decelerating parasitic modes only inside the passband of the fundamental mode and has roughly five times less higher order mode losses as the normal conducting cavities.

Comparing the wake field effects we find that the seven cell 500 MHz cavity is significantly worse than all the others (due to the small beam hole diameter of 8 cm).

On the average we find that the transverse deflecting force on a bunched beam is roughly three times less in a "Single-Mode Cavity" than in standart cavities.

5. References

/1/ H. Gerke et al., DESY PET-77-08, 1977
/2/ DESY drawing - # 0805018/0.0000/3.5
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