# COMPARISON OF RF CAVITY DESIGNS FOR 3RD GENERATION LIGHT SOURCES

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*Abstract*

Investigations have been made to assess the suitability of various normal-conducting RF cavity geometries, to determine which best meets the requirements of the proposed new 3rd generation light source DIAMOND. This paper presents comparative results between the nose-coned and bell-shaped cavities in terms of their higher order mode (HOM) spectra and beam impedance characteristics.

## 1 INTRODUCTION

The RF cavity necessary to achieve the required specification of the DIAMOND synchrotron radiation source[1] can have a number of closed geometry configurations, the three most common are;

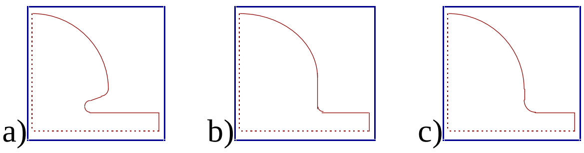


Figure 1: a) nose-coned b) pill-box and c) bell-shaped

The HOM spectra and their relative electro-magnetic (e-m) field strengths will be investigated for the nose-coned and bell-shaped geometry and an indication of their relative merits and short-falls will be highlighted. Previously it has often been assumed that the bell-shaped cavity has better HOM properties than the nose-coned cavity i.e. they have the least number of HOM's whose relative strengths are minimal out of all three cavity geometry designs. Work published at LBL[2] and LSB[3] confirm this as a false premise.

## 2 DIAMOND RF SYSTEM CHARACTERISTICS

The design specifications of the new RF cavity must conform to the requirements of the new machine whilst also adhering to the availability of suitable power sources. It has been calculated that 6 RF cavities, operating at 499.71MHz, each with a minimum shunt impedance ($R_s$) of 3.5MΩ, could provide the necessary accelerating voltage of 5.1MV to achieve the requirements for DIAMOND. Another requirement of the RF cavity is that all other HOM impedances are minimised whilst maximising the fundamental shunt impedance. The 2D computer simulation code URMEL-T[4] was used to investigate geometry options as a function of longitudinal and transverse HOM characteristics.

## 3 CAVITY GEOMETRY OPTIMISATION

### *3.1 Nose-coned (or Re-entrant) Cavity*

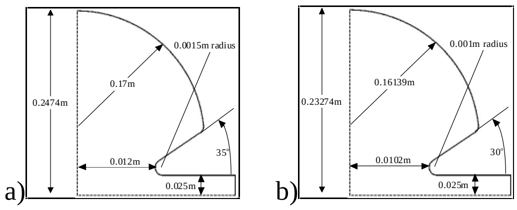


Figure 2: a) Initial and b) Final 500MHz Geometry

To develop an RF cavity which would provide the necessary characteristics to satisfy the criteria for the new machine requires a good starting point for cavity geometry parameterisation. For the nose-coned cavity, the PEP-II cavity geometry was chosen as the initial starting point, as this cavity possesses a reasonably high fundamental shunt impedance whilst also minimising HOM content.

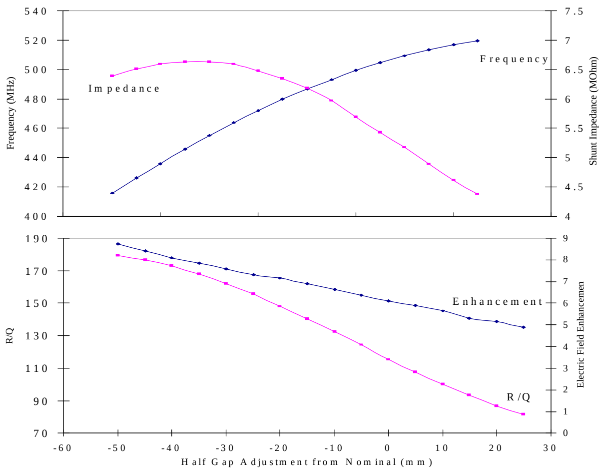


Figure 3: Cavity Half Gap Parameterisations

The PEP-II cavity, however operates at 476MHz and utilises a larger beam pipe radius than that required for DIAMOND and would therefore require substantial alteration to achieve the required 499.71MHz operating frequency. Figure 2a shows the initial 500MHz geometry that was developed from the PEP-II cavity geometry.

Parameterisations were made of this cavity's main outer radius, nose-cone radius, accelerating half gap and nose-cone angle. It is clear that optimisation of shunt impedance will be a compromise between reducing the cavity main radius and reduction of the cavity half gap (see Figure 3), whilst also reducing the nose-cone radius. The optimum geometry that was arrived at is shown in Figure 2b. The improvement of fundamental accelerating mode properties of this cavity geometry, over that of Figure 2a are shown in Table 1.

Table 1: Optimised Cavity Improvements

| Geometry | Frequency (MHz) | $R_s$ (MΩ) | $R_s/Q$ (Ω) | Field Enhancement |
|---|---|---|---|---|
| Figure: 2a | 499.6788 | 5.7 | 115 | 6.1 |
| Figure: 2b | 499.62 | 6.4 | 149 | 5.8 |

## *3.2 Bell-shaped (or Re-entrant) Cavity*

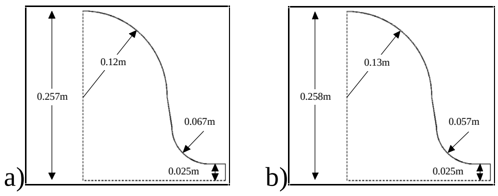


Figure 4: a) Initial and b) Final 500MHz Geometry

To investigate the HOM and shunt impedance characteristics of a bell-shaped cavity geometry, the SPring-8 RF cavity[5] was used as a suitable starting point. It's resonant frequency of 508.58MHz being very close to the DIAMOND operating RF frequency. A 500MHz initial cavity model was developed from the SPring-8 geometry by reducing the beam pipe radius to 0.025m, whilst also increasing the minor radius from 0.04m to 0.067m (see Figure 4a). Similar parameterisations were made of this geometry by variation of both the major and minor radii, keeping the beam pipe radius fixed. It was found that adjustment of the cavity major radius had the effect of increasing the overall cavity inductance (L), and when compared to the analytic solution of shunt impedance from simple tuned circuit theory, confirms that as the main radius increases the shunt impedance also increases. The constraints made on the nose-coned cavity geometry on its field enhancement do not present the same limitations for this cavity design, as this geometry already has the advantage of low field enhancement as the ratio of peak/effective field strengths are much lower with this open configuration. This advantage raises the power threshold for field emission and reduces the susceptibility to multipactor. Increasing the major radius to 0.13m gives slightly higher shunt impedance, whilst reducing the minor radius has the effect of also increasing the shunt impedance. Figure 4b shows the optimum cavity geometry achieved. The cavity geometry is not that much different from the initial geometry of Figure 4a, the overall height being virtually identical. The improvement of fundamental accelerating mode properties of this cavity geometry, over that of Figure 4a are marginal and are shown in Table 2.

Table 2: Optimised Cavity Improvements

| Geometry | Frequency (MHz) | $R_s$ (MΩ) | $R_s/Q$ (Ω) | Field Enhancement |
|---|---|---|---|---|
| Figure: 4a | 502 | 3.9 | 83 | 2.48 |
| Figure: 4b | 501 | 4.0 | 82.5 | 2.56 |

# 4 COUPLED-BUNCH INSTABILITIES (CBI)

The HOM content of each of these cavity designs will inevitably allow growth of CBI. The two optimised cavity geometries have been assessed for longitudinal and transverse HOM properties and a comparison made in terms of their HOM growth rates.

## *3.2 Longitudinal CBI*

The HOM content of the bell-shaped cavity can be seen (in Figure 5) to contain not only more HOM's below beam pipe cut-off, but also the relative strengths of these modes, when normalised with the fundamental mode, are greater. To perform a simplistic determination of whether these modes will cause instability and at what threshold current, should the mode coincide with a beam harmonic, the growth rate of the HOM can be determined[6].

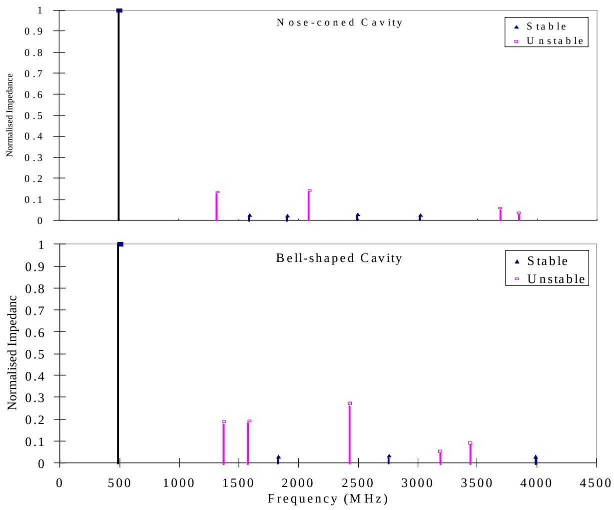


Figure 5: Comparison of Longitudinal HOM Content

It can then be determined whether the growth rate of the mode will be greater than the damping rate of the machine, for DIAMOND the radiation damping rate is $1320s^{-1}$. If the mode growth rate is larger than the damping rate of the machine, the mode will be unstable (U) causing (most likely) dipole synchrotron oscillations of the electron beam at the HOM frequency. Should the mode have a smaller growth rate, then the natural radiation damping of the machine at 3GeV, will damp the mode (D).

### *3.3 Transverse CBI*

Similar characterisations can be made for the transverse acting dipole modes. Figure 6: shows the transverse HOM content for the two cavity geometries.

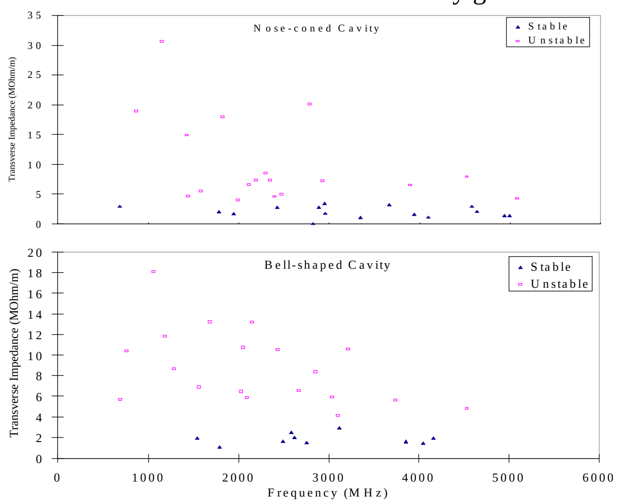


Figure 6: Comparison of Transverse HOM Content

The transverse coupled bunch oscillations are driven by wake fields due to the electron beam interaction with broadband impedance structures, such as RF cavities, or the resistive wall of the vacuum chamber. The growth rate and hence whether the mode will become unstable can also be determined[6]. In order to reduce the damping rate of all transverse acting dipole HOM's, it would improve matters if the cavity was located in the low $\beta_x$ and/or $\beta_y$ sections of the machine. For the purposes of these characterisations, a pessimistic approach for transverse mode growth rates is adopted, using horizontal $\beta_x$ = 15 of the high beta DIAMOND straights. To determine whether a particular HOM will be stable, requires the addition of the radiation and Landau damping rates to predict a growth rate threshold for the transverse HOM's. For DIAMOND, the Landau damping rate is assumed to be $1000s^{-1}$, giving a total machine damping rate of $2320s^{-1}$. If the growth rate of the HOM is greater than the total damping rate of the machine, then it will be potentially unstable, and vice-versa.

The number of transverse HOM's for both cavities are comparable, however, more of the modes are damped in the nose-coned cavity, resulting in more, potentially unstable HOM's in the bell-shaped geometry. The magnitude of the impedance of these modes are greater however, for the nose-coned cavity. Therefore, regardless of which geometry is used, some form of action will need to be undertaken to minimise the effect of these potentially dangerous resonances.

## 5 PRACTICAL SHUNT IMPEDANCE

From the results presented here, it shows that the maximum fundamental mode shunt impedance obtainable for the nose-coned geometry is 37% higher than the maximum achievable for the bell-shaped cavity. The URMEL-T shunt impedance figures that are quoted do not however account for the addition of pumping, input coupler and tuning ports, which will reduce the maximum achievable shunt impedance on the actual cavity. Work done on the PEP-II cavity suggests that approximately 70% of the URMEL-T predicted shunt impedance is obtained in the real cavity. This would reduce the nose-coned cavity to ~4.5MΩ and the bell-shaped cavity to 2.8MΩ. The requirements for DIAMOND could easily be met using 6 nose-coned cavities (providing the cavity could sustain ~0.85MV), but would require 8 bell-shaped cavities to achieve the necessary impedance for efficient operation.

## 6 CONCLUSIONS

Both cavity geometries have a number of HOM resonances, which should they coincide with a beam harmonic could cause longitudinal or transverse instabilities in the electron beam trajectory. For the longitudinal case, not only does the nose-coned cavity have fewer HOM's but the relative strengths are also much weaker. Couple this with ~35% improvement in fundamental mode shunt impedance and there is no obvious advantage. Transversely, although there are fewer unstable modes in the nose-coned cavity, the cumulative contribution of the transverse impedance is ~15% greater. Preliminary investigations have shown that increasing the cavity beam-pipe radius not only reduces the propagating cut-off frequency for both the longitudinal and transverse modes, but also significantly reduces the transverse mode impedances. The fundamental accelerating mode shunt impedance also reduces as a consequence and therefore a compromise needs to be achieved.

## REFERENCES

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