COMPUTER-AIDED STUDIES OF THE ALS 500 MHz STORAGE RING CAVITY

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ABSTRACT

The design of the ALS storage ring 500 MHz cavity has been modeled with Mafia and Urmel codes(1,2). The effects of the holes cut for the drive port, the higher order mode damping port, the probe port and tuner plunger were modeled with the Mafia codes. The frequency dependence on the shape and spacing of the nose cones and the general shape of the cavity were modeled with Urmel codes.

INTRODUCTION

The primary reason to model the ALS storage ring 500 MHz cavity with the Mafia and Urmel codes is to look at the physical dimensions to make sure that it can be tuned to the operating frequency. Since Urmel and Urmel-t codes could not accommodate a solid cylindrical tuner protruded into the cavity or a single hole cut on the wall of the cavity along one of the three axes, Mafia codes were used to study those effects.

Since the cavity resonant frequency is very sensitive to the nose cone dimensions, their shape and size were modeled with the Urmel codes to obtain some guidelines for the nose cone trimming required to obtain the final operating frequency. The frequency deviation caused by the holes cut for the higher order mode-damping port, the monitor probe port and the drive port must also be taken into account.

The Daresbury SRS storage ring cavity was also modeled with Urmel codes. The results of the calculations were compared to those of the operating SRS cavity in order to gain confidence on the ALS cavity calculations.

SHUNT IMPEDANCE AND RF POWER REQUIREMENT

The shunt impedance of a RF cavity used in particle acceleration is defined differently from that commonly used in engineering. The shunt impedance of such a cavity is modified by a transit time factor. The transit time factor is important when the time for particles to cross the gap is comparable to the half period oscillation of the RF signal which is used for accelerating particles. The ratio of the momentum gain for a particle in a gap with nonzero width to an ideal thin gap is defined as the transit time factor, T, which is approximately equal to the expression given below(3)

$$T = \sin(\omega \Delta t/2)/(\omega \Delta t/2)$$

where Δt = particle transit time crossing the gap
ω = frequency of RF signal

Since the axial electric field is time varying, an electron traversing the gap at a phase angle, θ, would see an effective voltage(4,9)

$$Ve \simeq Vp\, T \sin\theta$$

where Ve = effective voltage for acceleration
Vp = peak voltage across the gap

For θ = 90 degree.

$$Vp = Ve/T$$

The power, Pa, required to provide the peak voltage, Vp, across the gap is given by

$$Pa = Vp^2/(2Z)$$

it follows that

$$Pa = Ve^2/(2ZT^2)$$

where Z is the cavity shunt impedance and ZT^2 (often designated as Rs) is defined as the transit time corrected shunt impedance of the cavity. Both Mafia, Urmel and Urmel-t codes provide calculations of this quantity, Rs. The transit time corrected cavity shunt impedance, Rs, and the cavity shunt impedance relate to each other as $Rs = ZT^2$. Some have defined the entire quantity, $2ZT^2$, as the shunt impedance. In which case the quoted shunt impedance would be twice that of the calculated ones. However this does not affect the power calculation if one keeps all the parameters in proper perspective.

The total cavity RF power, Pt, required is:

$$Pt = Pa + Pb$$

where Pb = power supplied to the beam

A more detailed description on cavity power can be found in(5).

THE 500 MHz STORAGE RING CAVITY

Figure 1 shows the dimensions of the right half of the 500 MHz Storage Ring Cavity which is a single cell re-entrant type resonator. The beam entering and exiting tubes of the final cavity will have different taper configurations for eliminating synchrotron radiation interference with the operation of the cavity. However for simplicity the beam tubes of the computer model will assume a uniform diameter of 7 cm. Figure 2 shows the cross section of the model cavity. Also shown in this figure are the drive port, the Higher Order Mode (HOM) port, the probe port and the tuner port. The nose cones of the cavity should be made longer than the final dimension so they can be trimmed back to produce the desired final frequency. The nose cone spacing as a function of resonant frequency was one of the subjects of computer studies.

FREQUENCY CHANGE DUE TO PORT HOLES AND TUNER

The frequency change due to port holes was modeled using the Mafia codes. Two versions of Mafia codes were used. The first one was a version with 200 thousand mesh points installed in the LBL VAX computers. The second one was a version with 1 million mesh points installed in the National Magnetic Fusion Energy Computer Center (NMFECC) in LLNL. The logistics and economic factors of the computer runs were the main reasons for using two different machines.

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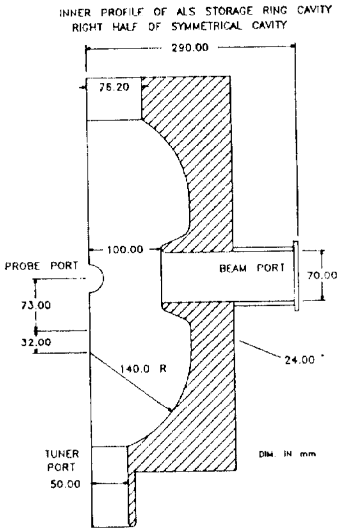


Fig. 1 Right half of the ALS storage ring cavity

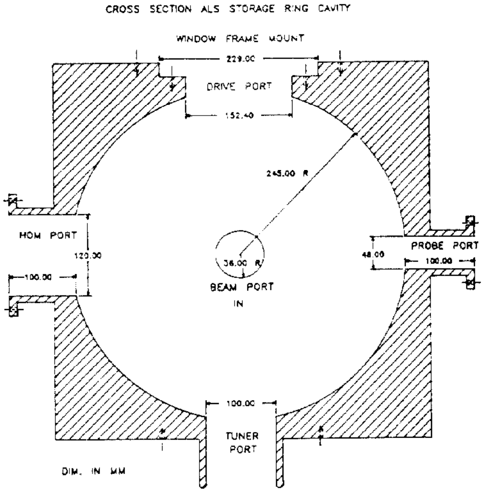


Fig. 2 Cross section of the ALS storage ring cavity

It is noteworthy to mention here that using the Mafia codes on a problem with 150 thousand mesh points requires many hours of calculation time even for Cray 2 computers.

Figure 3 shows the storage ring cavity created by the Mafia Mesh Generator with 147 thousand mesh points. The figure shows the model with all three ports, the beam tubes and the tuner inside the cavity. The cavity in normal operation will be tuned to the resonant frequency with 1 cm of tuner.

The first run was made on a cavity model with two beam tubes only. The second run was made on the same cavity model with the drive port, the HOM port and the probe port added but without the tuner. The third and fourth runs were made with ± 1 cm of tuner extended into the cavity. The fifth, sixth and seventh runs were made with 3 cm, 4 cm and 7 cm of the tuner extended into the cavity respectively.

The shunt impedances, resonant frequencies and the Q's of mode 1 of the seven different calculations are listed in Table 1. The values of all these parameters were derived from the Postprocessor outputs of the Mafia codes.

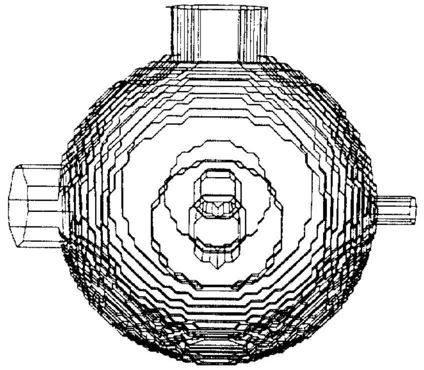


Fig. 3 The 3D mesh of the ALS storage ring cavity generated by the Mafia Mesh Generator

The resonant frequency of the cavity was lowered by 3.656 MHz after the drive port, the HOM port and the probe port had been added to the cavity with the two beam tubes. The full 7 cm tuner when fully extended into the cavity raised the resonant frequency of the cavity by 5.99 MHz. The rate of frequency change of the tuner is approximately 1 MHz/cm. Both the Q and the Rs/Q becomes lower with more of the tuner extending into the cavity. More information on this subject can be found in[6].

From Table 1 the resonant frequency of the cavity with 2 beam tubes, three ports holes and a 1 cm tuner is 3.32 MHz lower than that of a cavity with two beam tubes only. Urmel was used to generate a symmetrical cavity (with two beam tubes only) having a resonant frequency of 502.930 MHz. Subtracting 3.32 MHz from 502.930 MHz the resonant frequency then becomes 499.610 MHz; the target frequency is 499.654 MHz. From this model the gap spacing of the final cavity should be in the vicinity of 22 cm. The transit time corrected shunt impedance calculated by Urmel is 5.26 MΩ compared to 4.75 MΩ calculated by Mafia. The discrepancy of 0.6 MΩ between the Mafia and Urmel calculations is probably due to the difference in spatial resolution between the two and three dimensional models. The shunt impedance of the Daresbury DRS cavity as calculated by Urmel is 4.36 MΩ. The beam tube diameter of the SRS cavity is 5 cm larger than that of the ALS cavity; this accounts for the difference of 1 MΩ in shunt impedance between the two cavities. If $2Z1^2$ is used to define the shunt impedance, all shunt impedance values herein would be doubled.

TABLE 1

CAVITY SPECIFICS	DOMINANT MODE FREQUENCY (MHz)	Rs/Q (OHMS)	Q	Rs (MOHM)
Beam tubes only dia. 7 cm	510.029	116.30	40,730	4.74
All ports and 0cm tuner	506.373	115.97	41,000	4.75
All ports and -1cm tuner	506.014	115.97	41,130	4.77
All ports and +1cm tuner	506.705	116.05	40,940	4.75
All ports and +3cm tuner	508.388	116.2	40,430	4.70
All ports and +4cm tuner	509.387	115.55	39,980	4.62
All ports and +7cm tuner	512.360	114.90	38,210	4.39

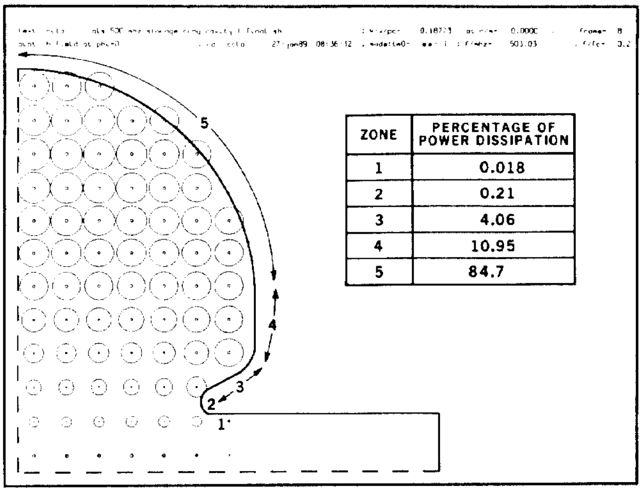
NOSE CONE SPACING EFFECT ON RESONANT FREQUENCY

The moderate number of mesh points in a two dimensional model provide better resolution than a much higher number of mesh points in a three dimensional model which takes a much longer time to run. As long as the model is not set up with any non-symmetrical structures Urmel and Urmel-t codes would yield more economical and accurate frequency calculations. Urmel uses a rectangular mesh and takes a shorter time to run than Urmel-t which uses triangular meshes. Urmel-t allows the treatment of structures with arbitrary dielectric and/or permeable material insertions and calculations of TEO-modes. Detail descriptions of the capabilities of Urmel and Urmel-t can be found in(2).

Urmel was used for this part of the studies. The resonant frequency of the final cavity will be purposely made lower to start with so it can be precisely trimmed to the target frequency by trimming the nose cones. For simplicity the nose cones were made flat to generate this set of data. Rounding the nose cones will affect the resonant frequency to a certain extent. The frequency change as a function of nose cone spacing is 600 KHz per mm.

POWER DISTRIBUTION

The power distribution of the cavity was investigated with Urmel-t by setting the LPOWER switch to true. The distributed power pattern generated was then added across certain designated areas and the power distribution map of the cavity was generated. Figure 4 is a plot of the magnetic field of the dominant mode produced by Urmel-t showing one quarter of the symmetrical cavity. The same figure is also used for power distribution mapping. Five designated zones are indicated in this figure. The percentage of power dissipation in the various zones is listed in the Table in the same figure. The bulk of power is dissipated on the body of the cavity however a significant amount will be dissipated around the nose cones with the highest power density occurring in the vicinity of area 4. Adequate cooling of this part of the cavity is essential. The power dissipation of each ALS storage ring cavity is estimated to be 60 kW using 4.75 MΩ as the shunt impedance (Rs). This does not include the power supplied to the beam.



ZONE	PERCENTAGE OF POWER DISSIPATION
1	0.018
2	0.21
3	4.06
4	10.95
5	84.7

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Fig. 4 Power distribution and magnetic field plots of mode 1

CONCLUSIONS

The ALS storage ring cavity has been modeled with Mafia, Urmel and Urmel-t codes. The results agree with those of the operating SRS cavity fairly well. The shape of the cavity and the nose cones and their spacing have been confirmed with the codes. The power dissipation at various parts of the cavity has also been looked at. The power dissipation map should help in the cavity cooling system design. The Mafia codes require hours of calculation time for a problem with 150 thousand mesh points. Hopefully with the next generation of super computers these powerful tools would cost less to use.

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