HIGHER ORDER MODES IN THE SRS 500 MHz ACCELERATING CAVITIES

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Abstract

As an important part of the beam instability studies on the SRS the higher order modes in the accelerating cavities have been investigated. A two dimensional model of the cavity has been used to determine higher order modes up to 4 GHz using the URMEL-T[1] code. The lower frequency modes (with larger impedances) were then investigated on a three dimensional model using the MAFIA[2] codes. These predictions have helped in locating and exciting the strongest modes in tests on a spare SRS cavity, and perturbation techniques have been used to identify and measure these modes.

Comparisons between computed results and perturbation measurements are made and also comparisons with results from other laboratories using similar cavities.

Introduction

The SRS utilises four 500 MHz accelerating cavities with re-entrant nose cones, aperture coupled to the feeder waveguide. A pair of waveguide low pass absorptive filters are placed in each feeder arm in order to damp any higher order modes which are coupled into the waveguide. Computations using the URMEL-T and MAFIA codes, based on models of an isolated cavity are not expected to give accurate results for this configuration since many modes are expected to be coupled into the waveguide.

Two-dimensional Model

The results of the URMEL-T computations for monopole TM and dipole modes up to the respective cut-off frequencies of the beam pipes (1912 MHz for monopole TM modes and 1464 MHz for dipole TE modes) are shown in table 1. Figure 1 shows the cavity cross section without azimuthal ports used for the two dimensional model. Fourteen modes are found, of which there are three strong dipole modes and two strong monopole modes (excluding the accelerating mode). Worst case growth times for these modes are estimated to be 30μs for the 819 MHz monopole mode and 65 μs for the 1060 MHz dipole mode in the horizontal plane. Note that the impedances of the longitudinal modes are given in linac-ohms in table 1. Perturbation measurements[3] on similar cavities have shown a similar mode distribution with measured impedances within 15% of the computed values.

Table 1

f_{res} (MHz)	Q	R/Q (linac-Ω or Ωm^{-1})	R (Mlinac-Ω or $M\Omega m^{-1}$)	Mode
501.7	44600	186.0	8.30	Monopole
712.1	46200	13.9	0.64	Dipole
799.0	56000	256.0	14.3	Dipole
819.0	39700	66.4	2.63	Monopole
1060.0	43000	536.0	23.0	Dipole
1078.0	43700	0.002	0.0001	Monopole
1204.0	47400	0.07	0.003	Dipole
1228.0	85800	0.85	0.07	Dipole
1274.0	40700	115.0	4.68	Dipole
1341.0	76500	11.3	0.86	Monopole
1398.0	44100	6.63	0.29	Monopole
1692.0	50500	6.66	0.34	Monopole
1767.0	70000	4.04	0.28	Monopole
1882.0	75500	0.30	0.02	Monopole

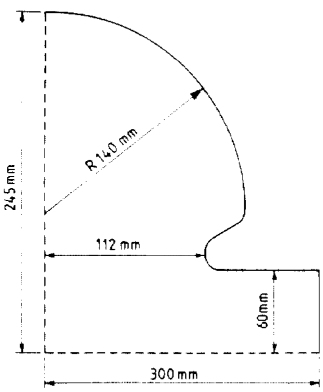

Fig. 1. Two dimensional URMEL-T model.

The modes above cut-off frequencies are not found to give large impedances, and due to propagation along the beam pipes causing damping in the real cavity they have not been further investigated, although they have been used to estimate the equivalent broad band impedance of the cavities to be Z/n = 0.33 Ω[4]. The frequencies of the stronger modes correlate with signals which have been observed on a beam pick-up at various stages of operation of the SRS.

Three-dimensional Model

The three-dimensional model used in MAFIA includes the coupling aperture, a pumping port and a probe port, which destroy the cylindrical symmetry of the cavity. The longitudinal symmetry is maintained, however, and the half cavity model is shown in figure 2. Eighty modes needed to be calculated to obtain a reasonable accuracy for the strong modes identified by URMEL-T, and since the degeneracy of the dipole modes is now split we find nine strong modes in the cavity. These modes are given in table 2.

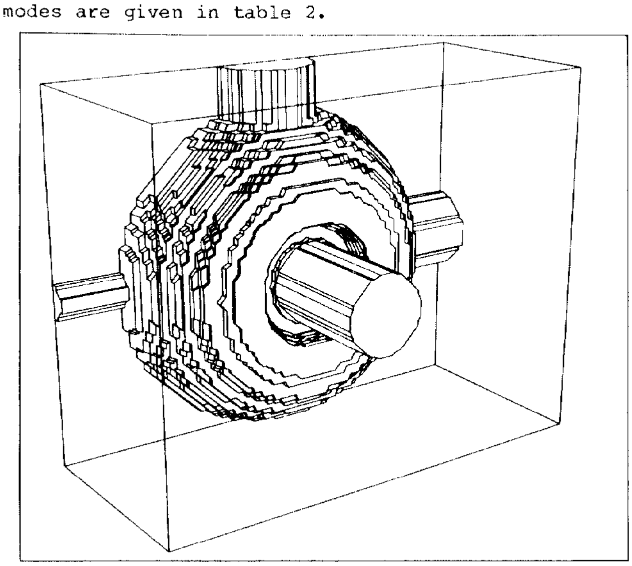

Fig. 2. Three-dimensional MAFIA model, half cavity.

MAFIA shows the dipole modes to be split into two perpendicular polarizations with a null plane in the longitudinal electric field which is either horizontal or vertical. Thus the dipole modes are identified as

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Table 2

f_{res} (MHz)	Q	R/Q (linac-Ω or Ωm^{-1})	R (Mlinac-Ω or $M\Omega m^{-1}$)	Mode
498.8	40600	195.0	7.9	Monopole
791.5	56200	220.0	12.4	Dipole (V)
797.1	56400	255.0	14.4	Dipole (H)
809.5	33900	68.5	2.3	Monopole
1059.2	43500	566.0	24.6	Dipole (V)
1059.3	43400	568.0	24.6	Dipole (H)
1285.0	53400	69.8	3.7	Dipole (H)
1286.0	53600	70.1	3.8	Dipole (V)
1333.0	69900	11.0	0.8	Monopole

having a transverse impedance either to vertically offset beams or to horizontally offset beams. The computed impedance due to an offset in the null plane is reduced by one or two orders of magnitude compared to the impedance in the perpendicular plane.

The changed geometry is expected to result in a change in R/Q and Q for each mode, and a comparison with the URMEL-T results shows changes of up to 15% in these parameters. The exceptions are the dipole modes at 1285 and 1286 MHz, where the agreement between the two models is not better than 20%. This is probably due to the perturbing effect of the coupling aperture which has a dipole TE cut off frequency of 1153 MHz, and so propagation is possible in the aperture at these frequencies.

Modes of higher order than dipole have not been analysed, although MAFIA shows some of these modes as being perturbed and having an on-axis longitudinal electric field component which will give rise to on axis impedance. MAFIA also finds monopole TE modes which are not found by URMEL-T, however these modes have a weak longitudinal impedance and have not been further investigated.

Perturbation Measurements

Perturbation measurements of the strongest computed modes have been made on a spare cavity with feeder waveguide as shown in figure 3. Measurements were also made on the cavity without filters in the feeder waveguide in order to determine the effectiveness of the filters in damping higher order modes. The cavity

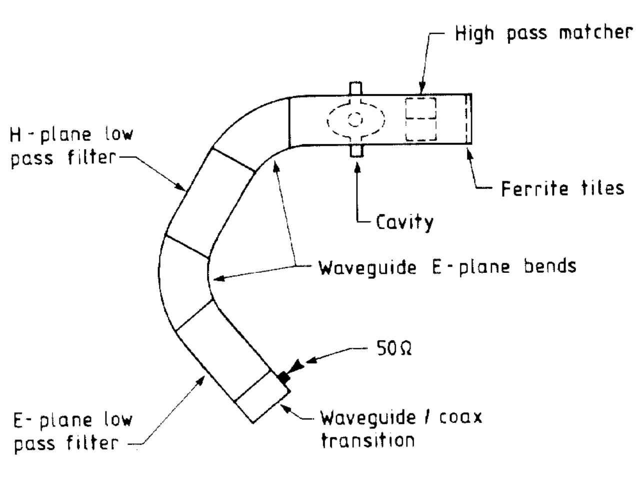

Fig. 3. Experimental arrangement with filter sections in feeder waveguide.

tuner is positioned approximately flush with the cavity wall, giving a fundamental frequency of 499.65 MHz. The matcher is then positioned to give a coupling factor β=1 as seen from the waveguide/coax transition. All measurements were made with the cavity window in place.

A metallic object is pulled through the cavity on a fine nylon thread perturbing the electric field and hence the resonant frequency of a mode. Careful choice of perturbing object shape and positioning of the object minimises perturbation due to magnetic fields. Using a long thin object, which selectively perturbs the electric field along its length, and a spherical object, which perturbs all electric fields within its volume, the modes are identified; perturbation with a bead on axis indicates a monopole or dipole mode, and perturbation with a longitudinal needle on axis indicates a monopole mode.

As the perturbing object is pulled through the cavity, the longitudinal position of the object is determined by connecting one end of the supporting thread to a linear potentiometer. The resonant frequency of the higher order mode is measured by a vector network analyzer (HP8753A), connected to a coupling loop inserted through the probe port on the cavity. The resonant frequency and object position are recorded and data stored on a computer. This allows the longitudinal electric field to be mapped, and the R/Q to be calculated.

Q values were measured from the S_{21} bandwidth of the reflection from the coupling loop, and the coupling factor was measured to obtain the unloaded Q from $Q_0 = Q_1(1 + \beta)$. The Q values of several modes were sensitive to the termination of the pumping port, and for all measurements this port was covered with a metal plate.

Measurements of the accelerating mode at 500 MHz using a bead of radius 3 mm pulled along the cavity axis followed by similar measurements with a needle (actually a syringe needle 25 mm long by 0.5 mm diameter) with its axis parallel to the cavity axis allowed the form factor of the needle to be determined to be 8.5. The needle was then used in measuring the higher order modes.

For dipole modes the needle is offset either radially or vertically, depending on the mode orientation. In order to minimise the effects of non-linear field variation away from the cavity axis and to obtain reasonable sensitivity an offset of 20 to 25 mm was used. The standard conversion formulae were used to obtain the transverse R/Q from the longitudinal R/Q measured off axis. The strength of the perturbation was found to be at least an order of magnitude greater with an offset in one direction than the other, as predicted by MAFIA. The weaker contribution has not been further investigated.

Table 3 gives the measured impedance data for the cavity with waveguide and filters. Q values for those higher order modes measured without waveguide filters are given in table 4.

Two modes at 1063.1 MHz were found to be coupled, these being a monopole symmetric mode and a dipole asymmetric mode. These modes could not be decoupled under a variety of conditions involving various coupling methods and tuner positions. The measured monopole mode impedance is given, and an estimate of the dipole mode impedance. The dipole mode at 790.1 MHz is not seen with the waveguide filters in place. The figures given are for measurements without the filters.

Table 3

f_{res} (MHz)	Q	R/Q (linac-Ω or Ω m^{-1})	R (Mlinac-Ω or MΩ m^{-1})	Mode
499.6	37000	185 4	6.8 0.2	Monopole
790.1	8100	< 60	< 1	Dipole (V)
793.8	21450	306 22	6.6 0.7	Dipole (H)
819.9	21100	74 2	1.56 0.05	Monopole
1061.2	16400	489 24	8.0 0.6	Dipole (V)
1063.1)	3300	(< 500	< 1.6	Dipole (H)
1063.1)		(< 0.10	< 0.01	Monopole
1280.2	24700	54 3	1.3 0.2	Dipole (H)
1281.7	35100	68 6	2.4 ± 0.2	Dipole (V)
1340.4	48800	13.6 ± 0.3	0.66 ± 0.02	Monopole

Table 4

f_{res} (MHz)	Q	ΔQ (Q with filters - Q without filters)	
790.1	8100	(not seen with filters)	
793.8	39500	- 18050	(46%)
819.9	23200	- 2100	(9%)
1061.2	29100	- 12700	(44%)
1063.1) 1063.1)	10100	- 6800	(67%)
1280.2	26400	- 1700	(6%)
1281.7	36600	- 1500	(4%)

All modes measured were also observed at the waveguide/coax transition, indicating coupling of the modes into the waveguide.

Temperature drift during the 1 to 2 minutes of the perturbation run was almost linear, and was corrected for numerically before the R/Q was calculated. The overall experimental accuracy is estimated to be better than 3% for the monopole modes and 5 to 15% for the dipole modes.

Discussion

Correlation between measured and MAFIA computed frequencies and azimuthal field configuration is extremely good, and the modes were found and identified with the help of the computed results. Agreement between measured and computed R/Q and Q values is less good, and the effect of the coupling into the waveguide is seen. A comparison of R/Q values shows variation by up to 30% between MAFIA computed values and measured values, depending on the mode and its ability to couple into the waveguide. An exception is the 790.1 MHz dipole mode which has an R/Q reduced by 67%, as measured without waveguide filters. The R/Q of the accelerating mode is 5% lower than predicted by MAFIA, and this may be attributed to coupling into the waveguide which is enhanced by the ceramic vacuum window which occupies an appreciable fraction of the coupling aperture. This lowers the cut off frequency of the coupling aperture within the ceramic. The window has not been included in the computational models. The measured Q values are not expected to be in agreement with computed values since measurements were performed on a cavity with open beam ports and exposed to the atmosphere (and hence with an unclean surface), also the waveguide and filters can load a resonance reducing its Q value, and stresses in the cavity due to manufacture cause an increase in resistive loss in the cavity.

The Q values of all higher order modes measured are reduced by the action of the waveguide filters. The magnitude of reduction in Q is not as great as would be expected given the filter specification of - 10 dB rejection over the frequencies at which measurements were made. This may be explained by the different waveguide modes launched from the cavity compared to the modes launched by a waveguide/coax transition when making bench measurements of the filters. The filters may be expected to be mode selective.

Perturbation measurements on similar 500 MHz cavities at KEK[3] have identified very similar mode distributions with impedances very similar to those calculated by MAFIA for the SRS cavities. These measurements were performed on a specially made cavity without the feeder (which in this case is coaxial loop and not aperture coupled) and so do not compare with the measurements here reported. The advantage of aperture coupling with respect to damping of higher order modes can be seen.

Conclusions

Computer calculation of the higher order modes in the 500 MHz accelerating cavities has provided useful data on the impedance presented by these modes. Three- dimensional modelling is particularly useful and provides a great deal of information. However, aperture coupled cavities such as those used on the SRS provide broad-band coupling into the waveguide, thus reducing the impedance of many higher order modes.

The use of low pass absorptive filters in the feeder waveguide is seen to further reduce the Q values of many modes, indicating the value of such filters in higher order mode suppression for aperture coupled cavities. Since installation of the filters into the SRS the occurrence of beam pick up signals correlating with known higher order modes in the cavities has been greatly reduced.

References

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