STUDY of HIGH ORDER MODES for the LNLS RF CAVITY

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Abstract

The LNLS received from DESY a 500 MHz RF cavity which could be used for the 1.15 GeV synchrotron light accelerator under construction. A complete program of measurements of the cavity has been made, including HOM frequency, Q, shunt impedance and coupling factor and these have been compared with numerical simulations of the cavity using URMEL-T and MAFIA codes. Dangerous HOM have been identified and several HOM suppressors constructed.

I. INTRODUCTION

In order to replace the electron's energy lost per turn in the LNLS storage ring[1], a 500 MHz RF cavity will be used, with a total RF power of 55 kW at the input coupler (produced by a 62 kW CW Klystron), which should allow the storage of up to 400 mA of beam current[2]. One of the limiting factors in achieving this goal is the possible multibunch instabilities produced by the beam excitation of HOM in the cavity. The DESY cavity is shown in figure 1. It is a three-cell copper pillbox set, coupled through circular iris, with a fundamental π mode at 499.665 MHz. It has 3 independent plungers, one for each cell, used for tuning and balancing of the fields. It also has 6 separate ports that provide sufficient room for damping antennae.

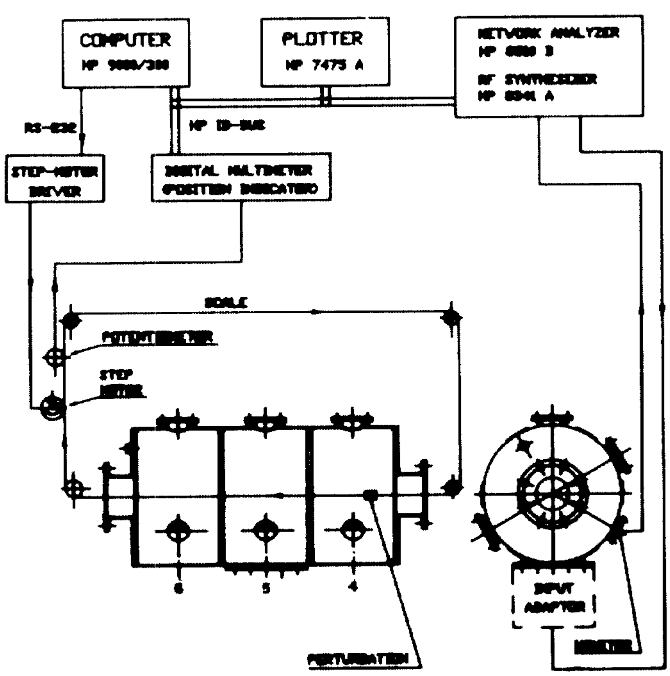


Fig. 1

II. THE CAVITY HOM

A study of the properties of the HOM was performed using URMEL-T[3] code to simulate a three-cell cavity with a geometry similar to the real one. Multibunch instabilities threshold are dominated by the higher longitudinal monopole and transverse dipole modes. Thus, special interest was placed on determining the frequency spectrum, Q value and effective shunt impedance of these modes. A grid of about 6000 mesh points was used for 1/2 of the cavity. Up to 2500 Mhz, a total number of 50 longitudinal and 75 transverse modes were obtained. Some results are shown in table 1.

LONGITUDINAL MODES				
Frequency (MHz)		$R_{sh(eff.)}$	R/Q (Ω)	
Theory	Measured	(MΩ)	Theory	Measured
495.7	495.8	.0684	14.5	-
497.4	497.7	0.002	0.047	-
499.2	499.5	19.8	448.0	441
728.7	729.6	1.70	45.6	35.5
731.1	731.4	4.8	132.4	133
733.4	734	0.922	24.8	-
1138.7	1139	0.0058	0.0824	0.0046
1143.9	1142	0.003	0.412	-
1174.0	1170	0.890	18.8	-
1176.5	1176	1.092	23.0	17
1265.0	1249	0.511	9.56	8.4
1278.2	1280	1.23	23.8	26.9
1560.6	1563.6	0.062	1.08	3.1
1570.8	1572.7	0.335	5.95	2.43
1582.2	1584.7	2.24	40.5	49.9
TRANSVERSE MODES				
Frequency (MHz)		R_t	R_t/Q (Ω/m)	
Theory	Measured	(MΩ/m)	Theory	Measured
634.5	628	0.154	3.51	-
640.6	640	2.69	58.1	-
646.2	-	0.992	18.7	-
766.5	767.9	8.80	187	140
773.6	773.8	32.9	646	4.5
779.6	781	16.1	289	180
904.0	905	75.9	2150	-
919.1	918	11.4	300	-
934.2	935	3.79	90.0	-
1062	1063	0.56	10.6	-
1089	1089	1.67	28.6	-
1111	1113	1.79	28.4	14
1191	1193	0.98	12.2	-
1200	1201	1.0	12.1	-
1208	1209	1.45	15.8	-

Table 1

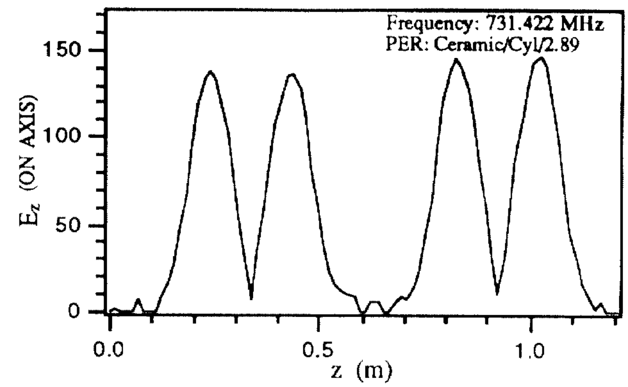
The value of the effective shunt impedance for the longitudinal case is obtained by integrating $E_z e^{jkz}$ along the axis of the cavity. The corresponding transverse impedance for the dipole modes is similarly calculated using the E_z taken at a radius of 3 cm off the axis. MAFIA[4] code was used to check the values of the transverse shunt impedance for some of the modes, resulting in good agreement with the URMEL calculations. A separate important result obtained with the simulation is the distribution of **E** and **B** fields in each cell and especially in the regions where damping antennae could be placed.

III. Measurements of HOM Impedances

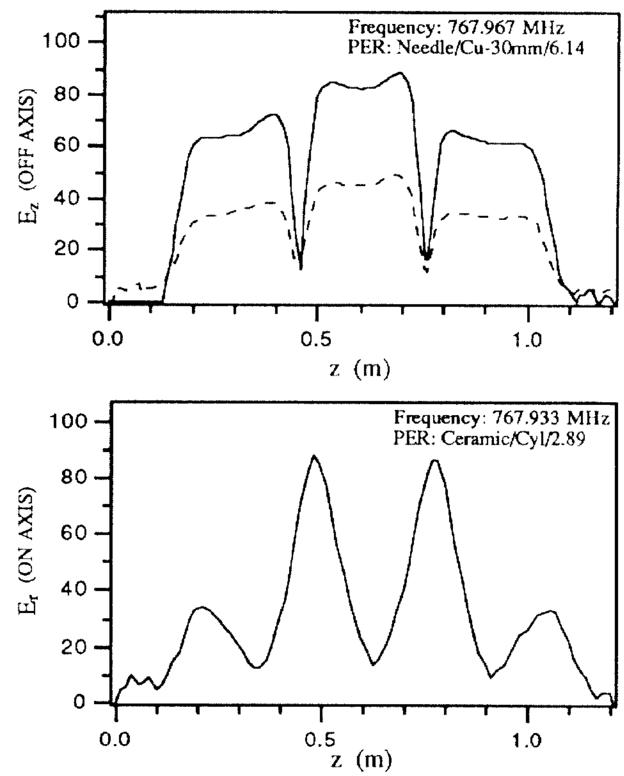
To measure the field distribution of the HOM, the perturbation technique was used[5]. For that purpose, an automatic measuring system was built as shown in figure 1. The system uses a computer-controlled step motor to displace a small object along the cavity. Every 1 cm, a measurement of the shift in the resonant frequency produced by the perturbation is made using a network analyzer. Care is taken to minimize and correct temperature variations during the measuring process, which takes about 2 minutes to be performed.

The experimental set-up allows the use of several types of perturbations, and also permits the displacement to be done along either the cavity axis or lines parallel to the axis, up to a radius of 4 cm. For the TM monopole modes, the E_z field is of interest. In this case, a ceramic cylinder is used and the measurement is done along the cavity axis. A similar procedure is used to map the radial electric field E_r for the dipole modes. Comparison of the measured shape of E_r with the computed values offers a simple and precise method of identification of the modes. Figure 2 shows some measured results using a ceramic cylinder and a needle as a perturbation.

For the transverse dipole modes, the magnitude needed to calculate the shunt impedance is E_z evaluated at a distance r from the axis. Furthermore, since the mode is ϕ dependent, the measurement has to be performed in 2 perpendicular planes. For this purpose, the perturbing object used is a 3 cm copper needle positioned along the cavity. The displacement line can be adjusted at different radii and in the vertical and horizontal planes. The possible contribution of the E_r field to the total frequency shift must be taken into account. In spite of the small value of the transverse form factor of the needle, this contribution can be significant for some modes with high enough E_r field on the cavity axis. For this purpose, a measurement is done with the copper needle along the cavity axis, where E_z is 0, and the result adequately subtracted from the measurements at other radii. For some modes, the cavity monitors have a very small coupling and, in these cases, an antenna located on one of the available ports is used. There is good agreement between calculated and measured values of R/Q for the longitudinal modes. The results for the transverse modes are less reliable and in several cases show differences with respect to the calculated values. Some measured results are listed in table 1.



(a) Monopole mode



(b) Dipole mode

Fig. 2

IV. Multibunch Instabilities

A study of the possible multibunch instabilities was done using ZAP[6] code. Calculated values of Q (unloaded Q) and R/Q were used. For the longitudinal TM modes, measured values of R/Q are in good agreement with the theoretical results. In order to identify the dangerous modes, each frequency was separately studied and the result compared with growth times predicted for groups of 20 modes. More than 150 modes have been considered, which corresponds to all TM monopoles and TM or TE dipoles up to 2500 MHz.

The stability criterion is based on a comparison of the synchrotron or betatron damping time with the calculated multibunch oscillation growth time for a beam energy of 1.15 Gev. Table 2 lists the fastest growing instabilities for the longitudinal and transverse modes, assuming a total of 142 stored bunches in the ring with 1 mA each. Taking into account the estimated radiation damping times for synchrotron (6 ms) and betatron oscillations (12 ms)[1], it is possible to conclude that no instabilities should occur for currents up to 100 mA. For higher stored currents, damping antennae are necessary.

LONGITUDINAL MODES	
Resonant freq.(MHz)	Inst. growth time(ms)
731.0	7.0
733.4	27
1174	3.0
1176	58
1570	33
1669	0.06
1670	50
1853	9.1
TRANSVERSE MODES	
Resonant freq.(MHz)	Inst. growth time(ms)
903.9	15
934.3	2.0
1698	3.0

Table 2

In order to damp the modes that can excite unstable multibunch oscillations, it is necessary to load the cavity by means of antennae. These can be located in one or more of the cavity ports. One of the central ports will be used for vacuum pumping, which leaves a total of 5 ports placed in two planes 60° apart. Loop antennae have to be discarded because they would affect the fundamental mode which has a strong magnetic field at the location of the ports. Measurements of Q for the modes listed in table 3 were made without damping and the results compared with those obtained when using antennae at different ports numbered according to figure 1.

LONGITUDINAL MODES					
Frequency (MHz)		Loaded Q			
		Antenna Location			
Theory	Measured	none	port 4	port 5	port 6
731	731.2	14000	-	10000	-
733.4	734.6	16500	2300	-	2300
1174	1173.8	27000	-	15000	-
1176	1177	32500	-	-	-
1570	1573	18000	18000	18000	18000
1669	1669.5	12500	-	11500	11500
1670	1670.9	7200	7000	7000	-
1853	1856.6	18000	9000	11500	15000
TRANSVERSE MODES					
Frequency (MHz)		Loaded Q			
		Antenna Location			
Theory	Measured	none	port 4	port 5	port 6
903.9	905.4	19000	-	-	-
934.3	936.1	10300	-	-	-
1698	1698.7	6300	-	-	6200

Table 3

Some modes with low E field at the location of the ports can not be damped with dipole antennae. In that case, a resonant filter can be used. Such a relatively narrow band filter is capable of selectively reducing the Q, even at places where the fields of the particular mode are low. Figure 3 illustrates the effect of a resonant absorber, tuned for the 767 MHz longitudinal mode.

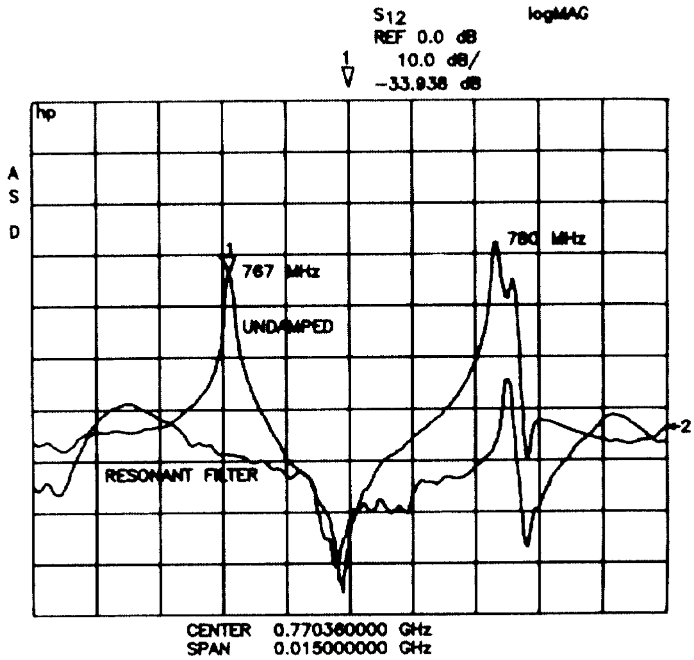


Fig. 3

V. CONCLUSIONS

A complete characterization of the HOM of the RF cavity was performed. Good agreement was found between URMEL-T simulation and experimental results. Measurement of damping of potentially unstable HOM shows that dipolar antennae located at the available ports in the cavity can suppress both longitudinal and transverse unstable modes

ACKNOWLEDGEMENTS

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