The 500 MHz Cavity for the MAX II Synchrotron Light Source.

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Abstract

The MAX laboratory has generously been offered a 500 MHz 3-cell cavity from DESY. The cavity will be used in the new 1.5 GeV third generation synchrotron radiation source MAX II. Technical solutions concerning cooling and tuning of the cavity are given. Measured electromagnetic parameters are presented, both for the fundamental mode and for a number of higher order modes (HOM). Given the boundary conditions for the MAX II operation, different means to avoid dangerous excitation of HOM are contemplated.

1. INTRODUCTION

MAX II [1,2] is a third generation synchrotron radiation source under commissioning at the MAX laboratory in Lund, Sweden. It is optimised for the VUV and soft X-ray spectral region, and its operating energy will be 1.5 GeV. Injection will take place at 0.5 GeV. The design beam current is 200 mA. A 500 MHz 3-cell cavity, generously offered by DESY, will be used in the storage ring. Multibunch instabilities driven by HOM in the cavity might occur, diluting the beam quality such as energy spread and horizontal beam size. Therefore an extensive study of the HOM is currently performed at MAX-lab. However, the main task of the cavity is to provide the power necessary for ramping the electron beam energy, and the power necessary for restoring the energy lost in form of synchrotron radiation. Furthermore, it should provide a high enough RF voltage in order to maintain a sufficiently long Touschek lifetime for the stored beam. The latter requirement is by far the strongest and will demand a peak effective voltage of 800 kV. A large amount of power, almost 35 kW, will then be dissipated in the cavity walls. This power should be carried away by a cooling system, and since we want to have as precise as possible a control over the HOM in the cavity the design of this cooling system is somewhat critical. In fact, the cooling system will be used as a mean to avoid dangerous HOM excitation, by tuning thermally. However, this is a very slow tuning system, hence a conventional tuning system with movable plungers will also be used. The storage ring RF dependent parameters are given in table 1. Radiation losses due to insertion devices are included.

Table 1
RF parameters of storage ring

Energy	1.5	GeV
Beam current	200	mA
RF-frequency	499.800	MHz
Harmonic number	150	
Revolution freq.	3.332	MHz
Peak effective voltage	800	kV
Radiation losses per turn	160	keV
Synchronous phase	78.5	degree
Power to the beam	32	kW

2. THE CAVITY

The DESY cavity consists of three coupled pill-box cells. They are coupled via the circular beam hole of 60 mm radius. Each cell is provided by one movable plunger mechanism and one probe loop. Two additional ports per cell are available for fixed plungers or damping antennas etc. The RF power is fed into the cavity via a circular hole in the mid cell. A ceramic window provides for the UHV compatibility. The input coupling has been adjusted and measured to $\beta = 2$. A transverse cut of the mid cell is shown in fig. 1. The input coupler is attached at the bottom, the movable plunger at the top and the probe loop at the small flange.

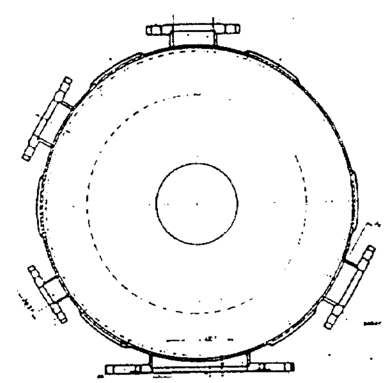

Figure 1. Transverse cut through mid cell of the DESY cavity

3. COOLING SYSTEM

As mentioned above, the cooling system should be able to carry away 35 kW of dissipated power. Besides separate cooling of each plunger, there are six cooling channels on the mantle surface of the DESY cavity, running in parallel with the beam axis. The cross-section area is rather large, 5 square centimetres per channel, which implies a high water flow in order to reach the turbulent regime. This fact led us to design a cooling system for the cavity, separated from the main MAX II cooling system.

A heat exchanger, with a primary circuit dimensioned for 100 l/min, connected to the main cooling system, and a secondary circuit of 240 l/min connected to the cavity, was chosen. It will provide an incoming water temperature in the range 30 to 60 °C, with a thermal stability of ±0.5 °C. This corresponds to a frequency stability of ±4 kHz. The water temperature rice will be only 2 °C for maximum power load, due to the large flow. This is achieved by a regulated valve, by-passing the heat exchanger with the appropriate amount of water. Thus, the water speed through the cavity is kept constant. This is desirable in order to have a good control over the HOM. According to our calculations, the mean bulk temperature will be approximately 20 °C higher than the water temperature.

4. FUNDAMENTAL MODE; TUNING AND RF PARAMETERS

From an analytical treatment of coupled identical resonators [3], it follows that the fundamental pill-box mode TM_{010} will divide into three separate modes of resonant frequencies:

$$f_0 = f_r/\sqrt{1+k} \quad (1)$$

$$f_{\pi/2} = f_r \quad (2)$$

$$f_\pi = f_r/\sqrt{1-k} \quad (3)$$

where f_r is the resonant frequency of a single cell, and k is a coupling factor determined by the geometry of the coupling hole. In our case k is positive, since we have electric field coupling. The π mode is the appropriate one for acceleration. However, in this configuration the field distribution is not equal in each cell. The mid cell will have a factor of $\sqrt{2}$ higher electric fields compared to the outer cells. This is not desirable, regarding the possibility of multipactoring. Furthermore, the shunt impedance is somewhat lower than with equal field distribution. Therefore it is usual to tune the outer cells to a higher resonant frequency f_r',

$$f_r' \approx f_r\,(1+k/2) \quad (4)$$

In this way one obtains the so called flat π mode, with equal field amplitude in all cells.

Our approach to the tuning of the acceleration mode, has not been to go fully for the flat π mode. Instead, while tuning in the acceleration mode, we have tried to simultaneously keep track on some dangerous HOM, and not allowing them to come too close to a dangerous frequency that could be excited by the beam. This requires of course a great amount of time and patience, and more work are to be done. At present, we have stopped at a configuration where the fields in the outer cells are 6% lower than in the mid cell. Since our approach is to avoid dangerous resonance frequencies, we desire as high Q values as possible, and therefore all the six free ports have been provided with simple plungers ending almost in the mantle surface. The tuning has then proceeded with hammer strikes on the cavity body. Cavity parameters for the fundamental mode are given in table 2. The first four are measured ones and the additional are calculated.

Table 2
Fundamental mode cavity parameters

Coupling factor	k	1.0	%
Quality factor	Q	38400	
Quality factor (loaded)	Q_L	12700	
Shunt Imp over Q	R/Q	540	Ω
Transit time factor	T	0.67	
Effective shunt impedance	R_{eff}	9.3	MΩ
Power dissip. in cavity	P_{loss}	34	kW
Detuning due to beam loading	Δf	51	kHz

5. HIGHER ORDER MODES; TUNING AND RF PARAMETERS

In principle, each monopole and dipole mode of a pill-box cavity will split in three and six modes, respectively, for a 3-cell cavity. For pill-box cells analytical calculations of the RF parameters would be possible, but the different ports and also manufacturing errors will introduce asymmetries that make such an approach unreliable. Therefore, the RF parameters of interest will be measured. As a first step, and that is where we are at the time of writing, we have identified a number of HOM . During this process the perturbation method, used for measuring R/Q, have been a great help. All monopole modes up to 1.5 GHZ have been identified, and also a number of dipole modes. The aim is to measure the resonance frequencies for all these modes for different plunger positions, and by this map how they move while tuning the acceleration mode. This is necessary since we have to continuously detune the cavity due to the beam decay during a fill, starting around 50 kHz of detuning and then decreasing it. If a dangerous resonance is excited during this detuning we can choose either of two ways to avoid it. The first is to alter the cavity temperature and tune back by moving the plungers. In this way the HOM resonance frequency might shift. The other alternative is to change the relative position between the two outer and the mid plunger. Our hope is that we should be able to avoid exciting the HOM in this way. One advantage in our case is that we have a relatively short ring circumference, which makes the spacing between possible beam frequencies rather large. However, the knowledge of the HOM frequencies is essential. So far the measurement has been performed in air. These results are shown in table 3. In this case the movable plungers were all in line with the inner mantle surface. In the near future the frequencies will be measured with the cavity under vacuum, and for different plunger positions.

Table 3
Measured higher order mode frequencies.

Mode		Frequency [kHz]
	0	496139
TM010	$\pi/2$	498533
	π	499847
	0	632206
TE111 V	$\pi/2$	639984
	π	644504
	0	635659
TE111 H	$\pi/2$	641382
	π	647600
	0	729747
TM011	$\pi/2$	731287
	π	734927
	0	768414
TM110 V	$\pi/2$	775493
	π	781783
	0	765505
TM110 H	$\pi/2$	774724
	π	779188

Mode		Frequency [kHz]
	0	904660
TM111 V	$\pi/2$	918818
	π	935363
	0	905776
TM111 H	$\pi/2$	920471
	π	936366
	0	1136802
TM020	$\pi/2$	1146521
	$\pi/2$	1147561
	π	1150518
TM012		1178176
		1178908
	0	1267730
TM021	$\pi/2$	1280526
	π	1294805
	0	1563526
TM022	$\pi/2$	1574288
	π	1584956

H and V stands for different orientation of the electric field. One can note that the $\pi/2$ mode of TM020 is split in two modes. Further, we could not fully determine the different modes of TM012.

6. CONCLUSIONS

Technical solutions concerning cooling and tuning of the 500 MHz cavity for the MAX II synchrotron radiation source have been investigated. The approach is to try avoiding dangerous excitation of HOM by carefully choosing an appropriate tuning. The short circumference of the MAX II ring helps us in this respect, since we get a rather large spacing of the possible coupled bunch frequencies. However, the knowledge of the HOM frequencies is essential, and further investigations of these are necessary.

7. REFERENCES

[1] Å. Andersson, M. Eriksson, L.-J. Lindgren, P. Röjsel and S. Werin,"The MAX II synchrotron radiation storage ring" NIM, A 343, pp.644-649, 1994

[2] Å. Andersson et.. al., "Design report for the MAX II ring", ISRN LUNTDX/NTMX--7019--SE.

[3] D.E. Nagle,E.A. Knapp and B.C. Knapp, "A coupled resonator model for standing wave accelerator tanks",Rev. Sci. Instr. 38, pp. 1538, 1967.