THE 100 MHZ RF SYSTEM FOR THE MAX IV STORAGE RINGS

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Abstract

The construction of the MAX IV facility has started and user operation is scheduled to commence 2015. The facility is comprised of two storage rings optimized for different wavelength ranges, and a linac-based short pulse facility. In this paper the RF systems for the two storage rings are described. The radio frequency (RF) systems will be based on either tetrode or solid state amplifiers working at 100 MHz. Circulators will be used to give isolation between cavity and power amplifier. The main cavities are of normal conducting, entire copper, capacity loaded type, where the present cavities at MAX-lab has served as prototypes. For the MAX IV ring operation it is essential to elongate bunches, in order to minimize the influence of intra beam scattering on beam transverse emittances. For this, 3rd harmonic passive (Landau-) cavities (LC) are employed. These are of similar type as the main cavities, mainly because the capacity loaded type has the advantage of pushing higher order modes to relatively high frequencies compared to pill-box cavities. Digital low level RF systems will be used, bearing in mind the possibility of post mortem analysis.

INTRODUCTION

When deciding what kind of RF system should be used for the MAX IV facility rings [1], many aspects were taken into account, and not only physical. Cost, ease of operation, modularity, electric power consumption beside physical properties like higher order mode spectrum, beam stability and bunch elongation properties from Higher Harmonic Cavities (HHC), were considered. In favour of a 100 MHz normal conducting (NC) system, similar to the one existing at the present MAX-lab facility [2], was cost and power consumption aspects, as well as the possibility to achieve an rms bunch length in the order of 6 cm together with a HHC system. This, together with the increased synchrotron tune spread, suppresses many beam instabilities [3], and allows for a small impact from intra beam scattering, that would otherwise deteriorate the small emittance that the 7-bend achromat lattice [4, 5] allows for. Furthermore, it is favourable that the HOM spectrum is pushed to comparatively high frequencies, in the foreseen capacity-loaded cavities.

CHOSEN CONFIGURATION

The 3 Gev ring requirements have driven the RF-system design, even though side-views had to be taken to fulfil, concerning modularity, the needs for the 1.5 GeV ring. In the early design stage it was assumed that the total losses due to synchrotron radiation (SR), could amount to 1.0 MeV in the 3 GeV ring. It was also a design goal to reach 4.5 % RF energy acceptance in this ring. For the low energy ring, the radiation losses are assumed to be only 13 keV, and the goal RF energy acceptance is 4.0 %. Table 1 shows the ring parameters.

Table 1: Storage Rings Parameters

Energy	1.5 GeV	3.0 GeV
RF	99.931 MHz	99.931 MHz
Circumference	96 m	528 m
Harmonic number	32	176
Current	500 mA	500 mA
HHC freq./RF	3	3
Mom. compaction	$3.04\text{x}10^{-3}$	$3.07\text{x}10^{-4}$
Bare lattice losses	117 keV	360 keV

3 GeV Ring

With a design current of 500mA an RF configuration as shown in Table 2 (rightmost column), could be decided.

Table 2: RF Configuration 3.0 GeV Ring

Operation Phase	Commissioning	Final
Energy loss	360 keV	1000 keV
Current	200 mA	500 mA
Total SR power	72 kW	500 kW
Main RF configuration		
Total RF voltage	1.0 MV	1.8 MV
Number of cavities	4	6
Cavity voltage	250 kV	300 kV
Cavity R_{sh} ($=V^2/P$)	3.2 Mohm	3.2 Mohm
Total Cu losses	78 kW	169 kW
Coupling (beta)	1.9	4.0
Nr of RF stations	4	6
Minimum RF station power (w. LC losses)	39 kW	114 kW
Landau cavity (LC) configuration		
Total LC voltage	308 kV	487 kV
Number of LC	3	3
LC R_{sh} ($=V^2/P$)	5 Mohm	5 Mohm
Total LC Cu losses	6.3 kW	16 kW

Table 3: Beam RF Parameters 3.0 GeV Ring

Ring Phase	Commissioning	Final
Synch. Freq. w/o LC	0.929 kHz	1.177 kHz
Synch. Phase w/o LC	159 º	146 º
Syn. Phase w LC	157 º	145 º
Main Cavity detuning (Q = 20000)	-6 kHz	-11 kHz
LC detuning (Q = 20000)	70 kHz	110 kHz
Bunch rms length w/o LC (@ σ_E = 0.08 %)	13 mm	10 mm
Bunch rms length w LC (@ σ_E = 0.08 %)	60 mm	56 mm

We also include a plausible configuration, matched for 4.5 % RF energy acceptance, at one stage in the commissioning phase. One could of course think of any combination of beam current and number of IDs that would give a case somewhere between the two cases described in Table 2. It is therefore important to reach stable operation, with Landau cavities engaged, for this whole span. Considering the Robinson instability, difficulties arise when operating with low current but with high SR losses, since it requires the least de-tuning of the Landau cavities (when maintaining the 4.5 % RF acceptance). This is why a comparatively high total LC shunt impedance is chosen. Table 3 shows that, at least for the commissioning scenario considered, the detuning frequencies of the cavities seem in favour for Robinson stable operation. The bunch lengths are calculated self-consistently for an "almost flat" potential well condition.

1.5 GeV Ring

The RF configuration for this ring is shown in Table 4. The exact Landau cavity configuration is still under consideration.

Table 4: RF Configuration 1.5 GeV Ring

Operation Phase	Final
Energy loss	130 keV
Current	500 mA
Total SR power	65 kW
Total RF voltage	560 kV
Number of cavities	2
Cavity voltage	280 kV
Cavity R_{sh} (=V^2/P)	3.2 Mohm
Total Cu losses	49 kW
Coupling (beta)	2.3
Nr of RF stations	2
Min. RF station power	57 kW

RF Stations

Looking at the minimum needed RF power per cavity/station, one can think of using 60 kW transmitters. In the 3 GeV ring each RF station should then consist of two combined transmitters, while in the 1.5 GeV ring an identical single 60 kW transmitter would constitute the RF station. Circulators will be used in both rings to isolate the cavity from the transmitters. The question whether tetrode or solid state amplifiers should be used, is still open.

THE CAVITIES

Main Cavities

The main cavities are almost the same as the cavities [2] used presently at MAX-lab. One half of the cylindrical symmetric profile is seen in Fig. 1.The capacitor gap has been increased to 50 mm since the design gap voltage is raised to 300 kV. This alters some other measures in order to keep the resonant frequency: capacitor plate radius is 130 mm, the cavity inner length is 376 mm, while the cavity inner radius and rod radius still are 410 mm and 60 mm, respectively. The back of the rod is rounded with a radius of 60 mm. Altogether it results in a theoretical shunt impedance of 3.5 MΩ, just as the present cavities. We know that the practical shunt impedance should end at 3.2 MΩ.

The manufacturing has been contracted to Research Instruments GmbH, who will begin with an OFHC prefabricated cylindrical shell in one piece, in contrast to our present cavities made from one bent and welded plate. This weld caused vacuum problems, which we now avoid. Likewise, water cooling of the shell of the cavity is improved in order to decrease the needed tuning compensation at power level changes. Also an improved cooling of the capacitor plate, should keep its temperature at maximum 25 C above water inlet temperature, to avoid excessive out-gassing at full power (28 kW).

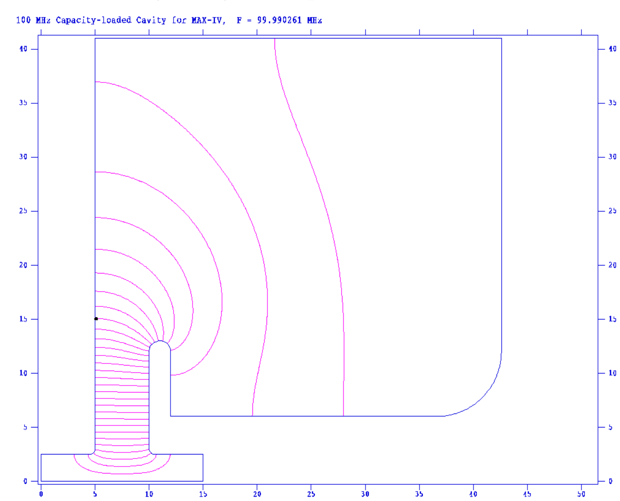

Figure 1: Main cavity profile.

The tuning of the cavity will be by a small deformation of the left endplate. The profile of this endplate is optimized to minimize the imposed stress. For a deformation of ±1.0 mm (equivalent to ±540 kHz), the maximum stress will be kept below 100 MPa. For this reason this endplate will be electron beam welded onto the cavity body, so that the forged copper properties are preserved, and the tuning can be kept in the elastic range.

Higher order mode (HOM) couplers are not foreseen in the first phase, but two ports on the mantle surface will be provided for possible future use. The power coupler, that should stand 120 kW, will be of the well-proven DORIS-type.

Landau Cavities

The third harmonic Landau cavities are also of capacity-loaded type, in order to push up the frequency spectrum of the HOMs. Likewise to the main cavities, a resulting moderate shunt impedance of 5 MΩ is due to this compromise. Inner length and radius of the cavity are 312 mm and 200 mm respectively (see Fig. 2). The water cooling is emphasised on the inner rods, and especially designed to avoid any water to vacuum joint. The maximum Cu temperature raise, compared to the water inlet temperature, should not exceed 20 C, at full power (5 kW).

The tuning of the cavity will be by a small deformation of both endplates. The profile of the endplates is not entirely optimized to minimize the imposed stress, because of manufacturing implications. For a deformation of ±0.25 mm per end plate (equivalent to ±550 kHz), the maximum stress will still be kept below 60 MPa. Both endplates will be electron beam welded onto the cavity shell and centre rods, so that the forged copper properties are preserved, and the tuning can be kept in the elastic range. Two HOM ports will be placed on the mantle surface.

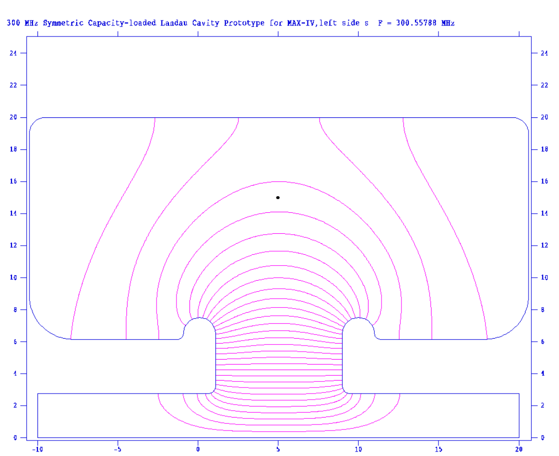

Figure 2: Landau cavity profile.

LOW LEVEL RF SYSTEM

The Low Level Radio Frequency (LLRF) system is an essential part of the RF systems. Its function is to regulate the amplitude and phase of the RF field and resonance frequency of the cavity to compensate for transient beam loading and temperature variations. A digital LLRF (DLLRF) system was chosen due to higher flexibility than an analog system. It is possible not only to easily program and monitor the signals inside the control loops but also to perform other tasks such as fast data logging for post mortem analysis and automatic conditioning

A digital LLRF (DLLRF) system, based on the ALBA LLRF, has been developed using a commercial FPGA board with cPCI format provided by Lyrtech (VHS-ADAC). Each LLRF will control two RF cavities and each cavity will be powered by tetrode or solid state transmitter(s).

The main features of the LLRF firmware are: Amplitude loop (stability <0.5%), phase loop (stability < 0.5º) and tuning loop(stability<±1º), IQ digital demodulation, slow and fast diagnostics for post mortem analysis, fast interlock utilities, automatic conditioning for cavities and automatic start up for operation.

A fast data logger system is integrated in the system. The LLRF will measure 10 RF diagnostics signals per RF plant besides of the loops inputs. A graphical user interface (GUI) to control all modes of the DLLRF and to monitor the status of the RF signals will be integrated into Tango.

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