THE ANKA RF CAVITIES

M. Bocciai, A. Fabris, C. Pasotti, P. Pittana, M. Svandrlik,
SINCROTRONE TRIESTE, Trieste, Italy
D. Einfeld, F. Perez, S. Voigt, FORSCHUNGSZENTRUM KARLSRUHE, Karlsruhe, Germany

Abstract

Four 500 MHz ELETTRA-type radiofrequency cavities will be installed in the ANKA storage ring, under construction at Karlsruhe. For an overvoltage factor of 3.6 they will provide a total accelerating voltage up to 2.4 MV. With 400 mA of stored current at 2.5 GeV, about 264 kW have to be delivered to the beam. The maximum forward power through the input window is therefore larger than 100 kW. At a high power test performed at DESY it was verified that the input window can stand a power of up to 200 kW. The input coupler is a slightly modified version of the ELETTRA type coupler. An external cage stretching or compressing the axial region of the cavity will provide the required tuning range for the accelerating mode, which is ±150 kHz. Effects of the cavity Higher Order Modes (HOM) will be cured by mode shifting. A measurement set-up for full characterization of the cavities, field measurements included, has been prepared as well as a test stand for automatic RF power conditioning of the cavity. The status of the cavity fabrication is also presented.

1 COMPONENTS TECHNICAL DESCRIPTION

1.1 Storage Ring RF cavity

The resonant cavities for the ANKA Storage Ring are single cell cavities resonating at 500 MHz. They are made out of normal conducting, OFHC copper, purity 99.99%.

The nominal axial length of the cavity is 480 mm. This length can be adjusted for tuning purposes by a few millimetres. The internal diameter of the cavity is 526 mm. The inside profile of the cavity section is made up of quarters of ellipse.

There are seven equatorial ports on the cavity and two polar ports (beam tubes ports). Each port bracket is made of a copper part on the cavity side and a stainless steel part where the flanges are welded.

The beam tubes of the cavity are ended with CF150 flanges (ϕ_{int} 100 mm). The frequency of the fundamental cavity mode is kept tuned to 499.652 MHz by means of a tuning cage that stretches or compresses the axial length of the cavity. The limit for the continuous frequency correction is given by the elastic limit of the copper in the neck region of the cavity. This limit corresponds to a maximum frequency change of ±150 kHz. Larger frequency changes, up to ±2.0 MHz, can be obtained by a plastic deformation of the cavity neck region, which can be done by the tuning system.

The three CF100 ports available in the equatorial region of the cavity shall host the input power coupler (on the cavity top), the HOM Frequency Shifter and the ion vacuum pump (on the cavity bottom).

Water cooling is provided by 36 copper pipes, 10 mm external diameter, brazed on circular channels machined on the cavity body. An improved brazing geometry will increase the cooling efficiency by a factor of two, compared to the cavities operating at ELETTRA. The cooling pipes are arranged in series connection into 12 parallel circuits. Extra cooling is foreseen for the equatorial brackets.

The specified cavity parameters are:

- f_0 499.652 ± 0.150 MHz
- R_{sh} 3.4 MΩ
- Q_0 40000
- $V_{RF,cav}$ 600 kV
- P_w 52.9 kW

The expected HOM's spectrum for the ANKA cavities is shown in table 1. The parameters are an average of the measurements performed on existing ELETTRA-type cavities.

Table 1: Expected HOM's spectrum.

LONGITUDINAL HOM's				
	f_r, MHz	R/Q, Ω	Q	$R_{\|\|}$, kΩ
L1	950	28.9	37000	1070.0
L2	1057	0.7	40200	28.1
L3	1421	5.0	33300	166.5
L4	1514	4.9	27700	135.7
L5	1600	9.0	21000	189.0
L6	1876	0.3	31000	9.3
L7	1947	1.8	51500	92.7
L8	2074	0.1	22600	2.3
L9	2122	7.7	27000	207.9
TRANSVERSE HOM's				
	f_r, MHz	(R/Q)', Ω	Q	$R_{\perp}$, MΩ/m
T1	743	4.7	41400	3.0
T2	746	15.8	41800	10.3
T3	1114	13.0	34100	10.3
T4	1220	0.1	40000	0.1
T5	1242	4.5	24500	2.9
T6	1304	0.3	30700	0.3

1.2 Input Power Coupler

The input power coupler is a modified version of the Elettra couplers. It is a coaxial coupler with inductive coupling to the cavity. The internal profile and the length have been changed in order to meet the ANKA specifications. The coaxial line standard is the 6 1/8", 50 Ω cable.

An alumina ceramic window, brazed on the inner and outer conductor of the coaxial line, provides the vacuum transition. Water cooling is provided to the vacuum side of the coaxial coupler. The alumina window will be air cooled.

The specified input power coupler parameters are:

- β 2.7/3.5
- RF Power 130 kW

1.3 HOM Frequency Shifter (HOMFS)

The HOMFS is used for shifting the resonant frequencies of harmful HOM's of the cavity [1]. This allows to create intervals in the cavity temperature setting range free of interactions between the cavity HOMs and the electron beam. The device is a water cooled OFHC Cu cylinder installed on one of the two CF100 equatorial ports on the bottom side of the cavity. It is moved by a remotely controlled stepper motor, working in closed loop with an encoder.

The specified HOMFS parameters are:

- HOMFS Position Range 40 mm
- Position Resolution 5 µm
- L_0 Max. Frequency Shift 1000 kHz
- L1 Max. Frequency Shift 500 kHz
- L1 shift in temperature ~ 50 °C

1.4 Cavity Cooling Rack

The cooling rack is a cooling station with a heat exchange between two water circuits: the primary water circuit, which is connected to the ANKA water line and the secondary water circuit, which is a closed water circuit connected to the cooling pipes on the cavity.

Scope of this cooling station is to extract the RF power dissipated in the cavity walls. Furthermore the cooling rack allows a tight regulation of the cavity external surface temperature in a wide temperature range, in order to make possible the cure of Coupled Bunch Instabilities via temperature tuning [2], [3].

The secondary water flux is always kept constant in any operating condition. Precise cavity temperature regulation is obtained by regulating the flux of the primary cooling water through a heat exchanger by means of a three ways valve. The temperature on the cavity is measured by a thermocouple. The thermocouple signal is elaborated within the cooling rack by a PID regulator which controls the opening of the three ways valve.

Pre-start up heating of the secondary circuit water is possible thanks to a heating resistances bank.

The specified cavity cooling rack parameters are:

- Water Flow 15 m^3/h
- Input Water Temperature 27.0 - 70.0°C
- Input Water Temperature Stability ± 0.1°C
- Cavity Temperature Range 40.0-70.0 °C
- Cavity Temperature Stability ± 0.05°C
- Maximum Handled Power 62.0 kW
- Nominal Handled Power 52.9 kW

2 TIME SCHEDULE AND FABRICATION STATUS

The first item out of the four pieces series is being produced separately and will first be tested at the Sincrotrone Trieste 60 kW test stand prior to proceed with the manufacturing of the remaining pieces.

The first cavity delivery time is the mid of June 98, together with its tuning system and its HOMFS, while the first input power coupler will be delivered in July 98. The preliminary tests on these components are expected to be terminated within August 98.

The acceptance tests will be performed on each single system and are scheduled every two months starting from November 99. Final delivery of the components should happen before the end of July 99.

3 FACTORY TEST

The factory test for each cavity assembly, including cavity, frequency tuning system, input power coupler, HOMFS, will include the following steps:

- Measurement of the R/Q of the 500 MHz mode
- Identification of the Higher Order Modes
- Measurement of the β of the input power coupler
- Bake-Out at 150 °C and Vacuum Leak Test
- Low RF Power Measurements
- Shunt Impedance Calculation
- High RF power tests

The cavity assembly will have to meet all the required specifications. In particular the vacuum leak rate shall be less than 5 10^{-10} mbar*lit/sec and the residual gas mass spectrum after bake-out will be typical of UHV with H_2 dominant.

The final test will be a high RF power test. The cavity, adjusted to β=1 and tuned to the amplifier radiofrequency (reflection coefficient |ρ|~ 0.0), will have to function for four hours continuously at a cavity wasted power level equal to 52.9 kW cw with no vacuum trips (threshold value $1.0 \cdot 10^{-7}$ mbar). Afterwards the cavity, still adjusted to β=1 but detuned from the amplifier radiofrequency (reflection coefficient |ρ|~ 1.0), will have to function for two hours continuously at a forward power level of 60.0 kW cw with no vacuum trips.

3.1 R/Q Measurements

A field measurement station has been provided both to measure the R/Q of the fundamental mode and to identify the HOM's by using the perturbative method [4]. An automatic acquisition system measures the frequency shift due to the calibrated needle moving along the cavity beam axis. Both frequency and phase measurements are performed by the HP Network Analyzer 8510B. The frequency measurement lasts 25 minutes for bead steps of 2.5 mm (phase measurement 10 minutes). The reproducibility of the R/Q measurement of the L_0 mode is better than ±2.0%. A typical measurement output for this mode is shown in fig. 1.

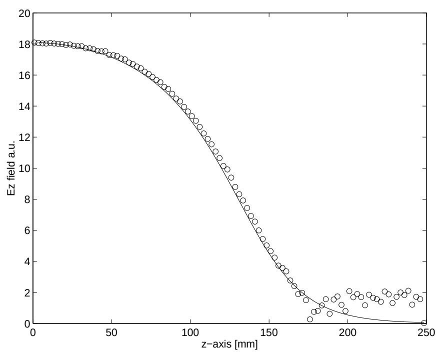

Figure 1: Measurement on a spare ELETTRA cavity.

3.2 Automatic RF Conditioning System

In view of the necessity of conditioning an increasing number of cavities, an automatic RF conditioning system has been developed at ELETTRA under the LabVIEW 4 environment, with standard IEEE488 interface on an Apple Power Macintosh 4400/200 station [5]. The target of the system is to operate both with amplitude modulated 500 MHz RF signals and with CW 500 MHz signals. Furthermore the peak RF power level and/or the length of the modulating pulse shall be automatically changed on the basis of the pressure reading in the cavity. Finally a feedback on the RF frequency will always keep the cavity in tuned conditions (or detuned by a fixed value).

An amplitude feedback reads the cavity voltage and compares it to the DAC setting. The error signal is used to drive a voltage variable attenuator. The main difference between this system and the traditional amplitude loop used in the ELETTRA storage ring is the sample-hold board. This is required to operate also under pulsed RF operation, with a minimum pulse width of 100 μs at 100 Hz repetition rate which are the typical settings at the start of conditioning. The sample-hold board, triggered by the pulse generator, samples the V_{gap} when the pulse is present and holds this value constant for the whole period where the cavity signal is zero. In this way the amplitude loop keeps the pulse amplitude always to the DAC set level within the specified error.

At the beginning of the conditioning procedure an algorithm increases the DAC value by constant time and amplitude steps, which can be defined in the preliminary set-up of the program. Once the maximum desired cavity voltage is reached at 1% duty cycle, the pulse length is increased in a similar way. In both cases when the cavity pressure increases beyond a safety threshold, which is set about half a decade below the vacuum interlock threshold, the DAC value or the pulse length is decreased. The next increase in amplitude or pulse length is regulated by an hystheresis cycle. The operator can select algorithms with different set-ups.

The tuning of the cavity during the conditioning procedure happens via a frequency loop acting on the generator RF frequency. The cavity can be tuned exactly to the RF frequency or an offset can be introduced. The frequency regulation is performed by a PID controller implemented in LabVIEW on the PC. This kind of PID controller requires a continuous input signal for correct operation, thus a sample-hold board, similar to the amplitude sample-hold board, is included in the feedback loop. A frequency change of 1 kHz is typically corrected in few cycles of the program (typically 1 cycle is performed in less than 50 ms). Thus this frequency loop is much faster than the mechanical tuning loop (~1 kHz/sec) and is more suitable to recover large detunings that may be caused by sudden power level changes required by the amplitude algorithm. The option of switching to the mechanical tuning system is however provided.

Among the other features of the program there is the possibility to follow the conditioning progress on the PC video where the relevant data can be plotted as they evolve in time. The same data can also be saved on the hard disk for post-processing.

After a first troubleshooting on a spare ELETTRA cavity, an RF conditioning up to full power has been simulated on the same cavity. The results are satisfactory, in particular for the algorithm which takes under control the pressure level in the cavity. The first test on a fully new cavity will be performed on the first ANKA cavity, starting in July 98.

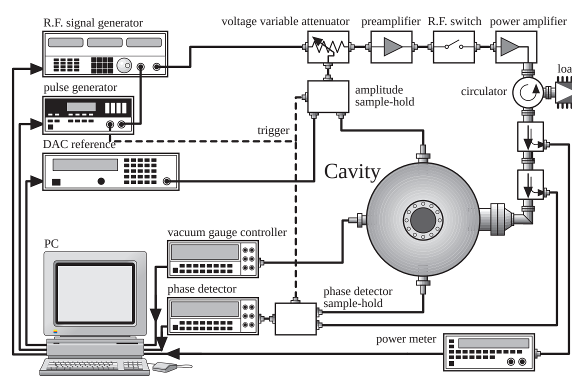

Figure 2: Layout of the automatic conditioning system.

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