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IN-SITU CHARACTERIZATION OF NORMAL CONDUCTING RF CAVITIES IN SOLARIS LIGHT SOURCE STORAGE RING

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Abstract

The SOLARIS 1.5 GeV storage ring is equipped with two 100 MHz active cavities and two 3rd harmonic passive cavities. They are in operation since 2015. For control of their respective working points, knowledge about cavity voltage and higher order mode (HOM) frequency spectrum is mandatory. After their installation in the storage ring and connection of the RF feeder to a high power isolator and a transmitter, the influence of the external elements on the quality factor and the HOM spectrum should be verified with respect to simulations of a simplified model of a stand-alone cavity. This paper will present results of in-situ cavity measurements to qualify the HOM placement and their quality factor. HOM measurements have been performed in the range 100 MHz to 1.3 GHz for active cavities and 300 MHz to 1.5 GHz for 3rd harmonic cavities at three different temperatures under ultra-high vacuum conditions for each cavity separately. The measurement and analysis methodology will also be presented.

RF CAVITIES

Solaris, the first Polish synchrotron light source, was installed in Krakow in spring 2015. The storage ring is a twin brother of MAXIV 1.5 GeV storage ring installed in Lund [1]. All RF cavities are installed in one straight section.

The RF cavities at Solaris are of the type called capacity-loaded resonance cavities. They are made of OFHC copper and have axial symmetry like pillbox cavities, but not flat end walls. The 100 MHz active cavities have an inner tube with a capacitance plate going into the cavity from one side. The 3rd harmonic passive cavities have such tubes from both sides. The electrons are accelerated in the gap between the plates by the electric field along the symmetry axis. Introduction of the tubes with capacitance plates gives possibility to decrease cavity radius. In parallel, the first HOM frequency is moved upward and the fractional bandwidth of the cavity is increased [2, 3].

Each 100 MHz active cavity is fed from a 60 kW continuous wave (CW) solid-state amplifier (SSA) through a high power isolator using 6 1/8 inch rigid coax line. The electromagnetic wave is *B*-field coupled from the coax line to the cavity using a power coupler loop. The field in the 3rd harmonic passive cavities is induced from the beam.

All RF cavities are operating at room temperature and they are water cooled. Each cavity has its own water temperature stabilization unit, which allows to stabilize cavity temperature with ±0.1 °C in the range from 25 °C to 55 °C [4].

Each cavity is equipped with its own mechanical tuner mechanism for resonance frequency adjustment. It is done by an elastic deformation of end walls. The tuning range is ±500 kHz. Additionally, the 3rd harmonic cavities have a plunger which, when inserted fully into cavity provides additional +500 kHz detuning.

Both capabilities, the operating temperature regulation and the mechanical tuning, provide in combination a way for movement of the HOM placement in frequency domain, while keeping the fundamental frequency fixed.

HOM CHARACTERIZATION

The theoretical details can be found in [2]. The main assumptions are presented below.

The theoretical HOM characterization was done using COMSOL Multiphysics with the simplified cavity geometries shown in Fig. 1. That model does not contain all vacuum ports of the cavity but provides sufficient approximation of the cavity shape.

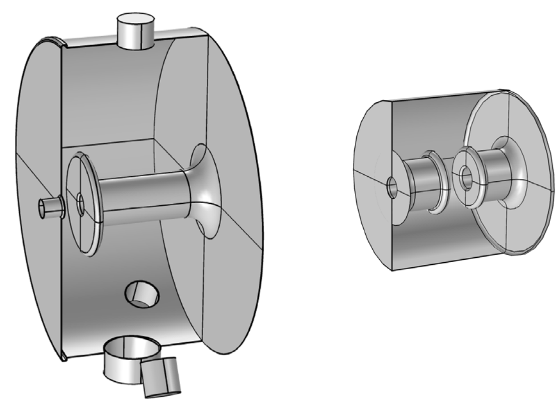

Figure 1: Internal shape of the 100 MHz cavity, extended with ports for power and HOM couplers (left) [2] and of the 3rd harmonic cavity (right) [5].

The simulations gave a theoretical placement of HOM peak frequencies f_0, their quality factor Q and shunt resistance R_{sh}. However for determination of the quality factor from measurement the approach based on full width at half maximum (FWHM) was used:

$$Q = \frac{f_0}{\Delta f} = \frac{f_0}{f_+ - f_-}, \qquad (1)$$

where f_+, f_- frequencies at both sides of the peak at -3dB.

The actual shunt resistance was not measured, because it is not possible in installed cavities. It was estimated knowing that the fraction of R_{sh}/Q is independent from the cavity wall conductivity and only dependents on the actual mode and the geometry [6]:

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$$R_{meas} = \frac{Q_{meas}}{Q_{sim}} R_{sim} \quad (2)$$

Within small absolute temperature variations region the frequency and the Q-values vary approximately linearly with temperature. To analyse the linearity of the frequency shifts, a linear fit from three measured HOM frequencies at three temperature set points was used. It was later subtracted from the measured value at each temperature point to obtain the difference between the fit and the measured values, which is called as the relative spectral offset Δf [5]:

$$f_{fit}(T) = k_{fit} \cdot T + m_{fit} \quad (3)$$

$$\Delta f(T) = f_{measured}(T) - f_{fit}(\mathrm{T}) \quad (4)$$

The same approach can be used to estimate the Q-values. However, for these, it showed out to be more informative to look at a normalized offset instead of the absolute offset: [5]

$$Q_{fit}(T) = k_{fit} \cdot T + m_{fit} \quad (5)$$

$$\frac{\Delta Q(T)}{Q(T)} = \frac{Q_{measured}(T) - Q_{fit}(T)}{Q_{measured}(T)} \quad (6)$$

MEASUREMENT SETUP

Since each cavity is equipped with two pick-up probes there is an ability to perform transmission measurements (S21). The spectrum analyser equipped with tracking generator, type FSV-7 from Rohde & Schwarz has been used. Each HOM with theoretical shunt resistance bigger than 2kΩ was investigated in terms of peak resonance frequency and corresponding quality factor. Such limit of the shunt resistance has been selected to keep the amount of measurements at reasonable level, but still having good information about potentially dangerous modes. In total, 45 HOMs were measured for each 100 MHz cavities and 15 HOMs for 3rd harmonic cavities per every temperature set point. For calculation of the quality factor built-in function of the spectrum analyser was used [7].

Measurements have been performed for arbitrary chosen temperatures 30 °C, 40 °C, 50 °C, which are around the cavity nominal working point of 38 °C. At such temperature range alteration of the materials properties are negligible. All cavities were kept at pressure below 8e-10 mbar.

MEASUREMENT RESULTS

Relative spectra offset for 100 MHz cavities is shown in Fig 2. It is below 100 ppm for the main cavities if taking into account all correctly identified HOM in full frequency span. The small value of the relative offset means that it is close to the linear fit model, which then verifies that this is a proper choice of model. For some modes it was difficult to identify either mode itself or calculate Q from the measurement. The explanation is that for higher frequencies simulated model becomes less and less accurate because of some features, like the pump slots and surface roughness, are not in the model. The main cavities are equipped with strongly coupled loop of the high power coupler (presently β=2), which has an influence on *R/Q* ratio. That ratio is not more constant as assumed in simulations. The power coupler and associated coax rigid line with RF isolator and SSA were not included in the model.

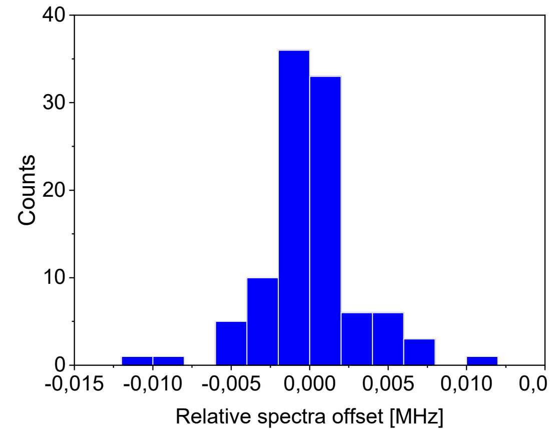

Figure 2: Relative spectral offset for 100 MHz cavity CAV1.

The analysis of the frequency relative spectra offset for 3rd harmonic cavities shows good HOM linearity scaling versus temperature, the offset is below 100 ppm. Also normalized quality factor follows linear fit as shown in Fig 3.

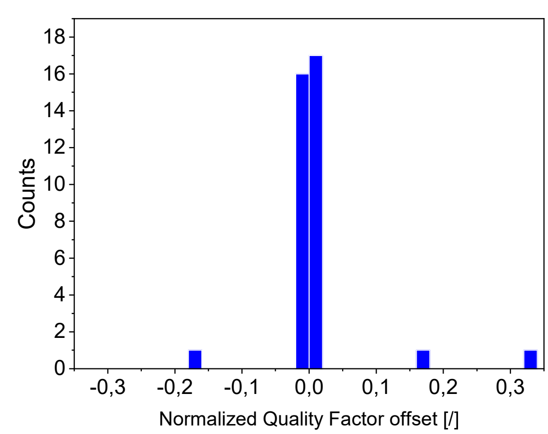

Figure 3: Normalized Quality Factor offset for 3rd harmonic cavity LAN1.

The influence on the quality factor of connected coax rigid line to the 100 MHz cavity is shown in Fig 4. The strong coupling through power coupler degrades the quality factor of the fundamental mode and the first HOM. As shown in Fig 5 the 3rd harmonic cavities are not affected because there are no any strong coupled probes installed. For both cavities the mismatch of the model and the real measurements is visible at higher frequencies.

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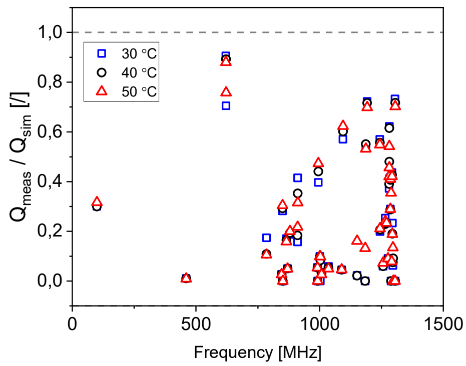

Figure 4: Measured Quality Factor normalized to simulated one for 100 MHz cavity CAV1.

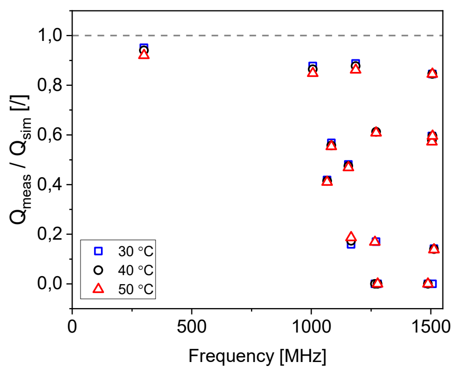

Figure 5: Measured Quality Factor normalized to simulated one for 3rd harmonic cavity LAN1.

The estimation of the shunt resistance from Eq. (2) for the 100 MHz and 3rd harmonic cavities is plotted in Fig 6&7, respectively. Since the quality factor is reduced for modes below 500MHz also the shunt resistance of that modes is damped in 100 MHz cavities. This frequency range corresponds to the good matching of feeding line and the isolator. The modes around 600 MHz are almost not damped because the isolator is getting higher mismatch. Accordingly, the shunt resistance in the 3rd harmonic cavities is not affected at lower frequencies.

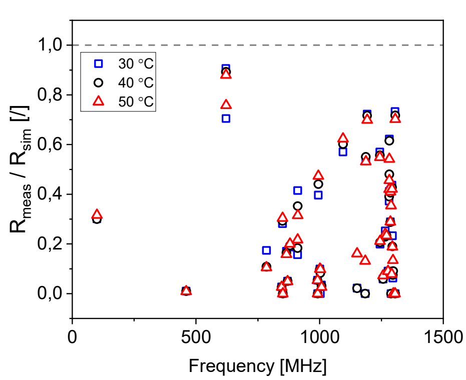

Figure 6: Estimated shunt resistance normalized to simulated one for 100 MHz cavity CAV1.

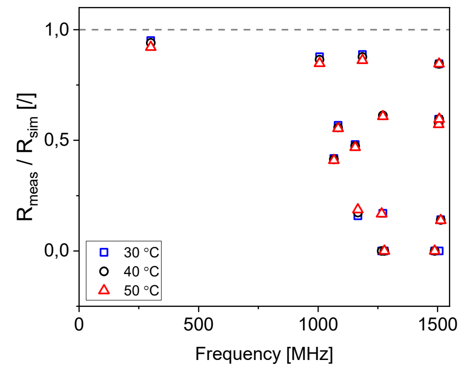

Figure 7: Estimated shunt resistance normalized to simulated one for 3rd harmonic cavity LAN1.

FUTURE WORK

The plunger installed in 3rd harmonic cavities is used for their detuning during injection and ramping (Solaris doesn't have full energy injector), then shall be retracted. Nevertheless some beam losses are observed during plunger movement. There could be two reasons: system is not fully conditioned yet or during tuning spurious HOM are generated. The HOM simulations with plungers included would help in subject investigation.

CONCLUSION

The measurement of the HOM properties when the cavities are installed is crucial to find the influence of the connected devices on the quality factor and the shunt impedance. They change considerably the response of the whole system. The simulations with cavities shape mapped in details is very time consuming or impossible due to computing resources. Additionally it is difficult to make the good simulation model of the components outside the cavity in the whole frequency range. The in-situ measurements are effectively revealing the characteristics of the entire real system.

ACKNOWLEDGEMENT

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