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SRF TESTING FOR MAINZ ENERGY-RECOVERING SUPERCONDUCTING ACCELERATOR MESA*

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Abstract

The two superconducting radio frequency acceleration cryomodules for the new multiturn ERL 'Mainz Energy Recovering Superconducting Accelerator' MESA at Johannes Gutenberg-Universität Mainz have been fabricated and are currently under testing at the Helmholtz Institut Mainz. These modules are based on the ELBE modules of the Helmholtz Center Dresden-Rossendorf but are modified to suit the high current and energy-recovering operation at MESA. The energy gain per module per turn should be 25 MeV, provided by two TESLA cavities, which were vertically tested at DESY, Hamburg, Germany. These tests showed an excellent performance of the quench limit and quality factor for three out of the four cavities. The fourth cavity has a lower but still acceptable quench limit and quality factor. In order to validate the performance of the fully assembled cryomodules after delivery to Mainz a test stand has been set up at the Helmholtz Institut Mainz. The test stand is described in detail and the status of the module testing is reported.

INTRODUCTION

For the Mainz Energy-Recovering Superconducting Accelerator MESA, which is currently under construction at Johannes Gutenberg Universtität Mainz, two ELBE/Rossendorf-type cryomodules [1] were ordered from the industry.

Each cryomodules contains two TESLA cavities to accelerate electrons at $f_0 = 1.3\,\mathrm{GHz}$. An acceleration gradient $E_{\mathrm{Acc}} = 12.5\,\mathrm{MV\,m^{-1}}$ with $Q_0 > 1 \times 10^{10}$ each is required for the energy-recovering CW operation at MESA. A beam current of 1 mA has to be accelerated and deccelerated two times. Because of CW operation and a duty cycle of 100 %, there will be two bunches in each cell of the cavity while operating in ERL mode.

To suit the needs of MESA, modifications were made [2]. Especially the cooling of the HOM-coupler was optimized as well as the tuner was changed from ELBE tuner to Saclay tuner. The Sacaly tuner includes a piezo element which can regulate the resonant frequency of the cavities faster, whereas the ELBE tuner was only designed as lever tuner.

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CAVITY CHARACTERISTICS

To characterise the cavity parameters for MESA specifications were made. To verify the compliance of the cavities during production, a vertical test of all four cavities was made at DESY. The final test of the specifications in the cryomodule is done at the Helmholtz Institut Mainz.

Specifications

The vendor guaranteed parameter for the energy gain per cryomodule and the static and dynamic losses. Those can be found in Table 1. The dynamic losses at $\Delta E = 25\,\mathrm{MV} = 2 \cdot 12.5\,\mathrm{MV\,m^{-1}}$ correspond to a $Q_0 = 1.25 \times 10^{10}$ for each cavity.

Table 1: Specifications of the Cryomodule (CM) Performance at 2 K

Variable	Specification
energy gain per CM	> 25 MV
static losses	<15 W
dynamic losses @25 MV (CW)	<25 W
$\propto Q_0$ @12.5 $\mathrm{MV\,m^{-1}}$	>1.25×10^{10}

Vertical Test at DESY

To check the gradients and Q_0 of each cavity a vertical test was made at DESY. The test results were already discussed in [3], but will be shown briefly to compare the results of the site acceptance tests (SAT) with. As shown in Fig. 1, all cavities are within specification at 2 K.

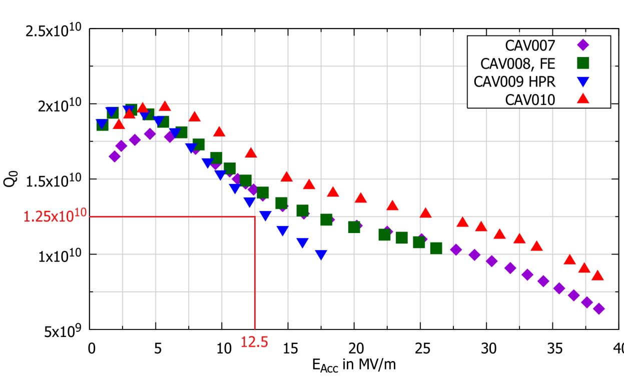

Figure 1: Vertical tests at 2 K at DESY. The MESA specifications are indicated in red. CAV008 shows field emission above 26 $\mathrm{MV\,m^{-1}}$ and CAV009 shows a rather low quench limit. All cavities are within specification.

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Two out of four cavities have shown a excellent behaviour (CAV007 and CAV010). The third cavity (CAV008) had also acceptable rf performances but has light field emission above 26 MV m^{-1}. The fourth cavity (CAV009) fulfilled the specification after a second high pressure rinsing. The quench limit is at 16 MV m^{-1}, which is still acceptable for MESA purposes. After the results of the vertical test, the cavity composition in the cryomodules was finalized. The cryomodule 1 consists of CAV007 and CAV008, while cryomodule 2 consists of CAV009 and CAV010.

To verify the specifications, a SRF test stand was built at the Helmholtz Institute Mainz (HIM).

TEST STAND FOR SRF CAVITIES

The Teststand for SRF cavity tests is located at Helmholtz-Institute Mainz. It was already described in [2]. It is designed to test superconducting (s. c.) and normal conducting (s. c.) cavities and it will be used to test CH-cavities for a CW operating LINAC for superheavy element research at GSI [4] in the near future. A deeper discussion of the parameter of the test stand, will be found in [5].

RF Generation and Control

To drive the cavities, a 15 kW solid state power amplifier (SSPA) was installed. Designed as the prototype for rf generation for MESAs normalconducting and superconducting cavities, it was tested on its own, as well as with n. c. and s. c. cavities. A detailed report on the characterisation of the SSPA can be found in [6].

With the SSPA and the given coupling, the cavities can be driven up to 25 MV m^{-1}to 30 MV m^{-1} (see Fig. 2). But

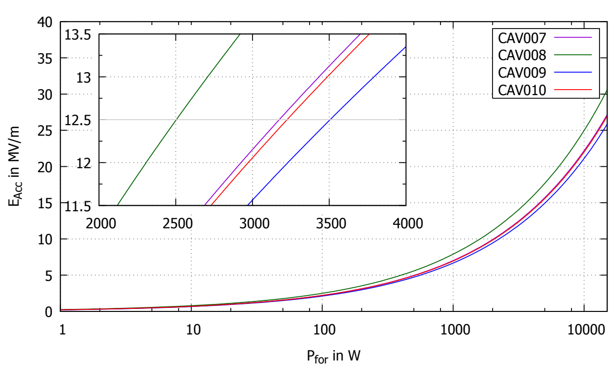

Figure 2: Acceleration gradient per forwarded power. The solid state amplifier is limited to15 kW. Therefore only the quench limit of CAV008 and CAV009 can be reached.

because of the terms of the approval for operation given by the department for radiation protection of the federal state rhineland platinate the measurements were limited to 12.5 MV m^{-1}. A recent adjustment of these terms allows now gradients up to 25 MV m^{-1}. Data with higher gradients than 12.5 MV m^{-1} will be published soon.

As frequency control, a Phase Locked Loop (PLL) was successfully installed and tested [7]. In Fig. 3 the layout of the PLL can be found.

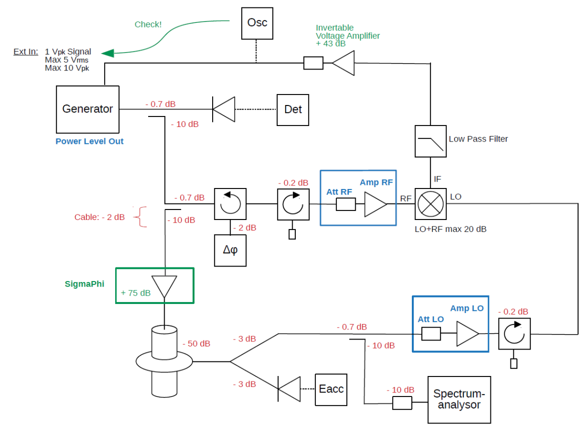

Figure 3: Layout of the Phase Locked Loop (PLL).

Currently a μTCA based low level rf (LLRF) control is installed at the test stand [8]. Because of interferences of both systems, instabilities of the acceleration gradient were induced. Therefore the measurement of the last measured cavity (cryomodule 1, CAV008) suffer from a systematic overestimation which only allow to fix a lower limit which is nevertheless satisfactory.

Cryogenics

The cryogenic installation at the test stand allow operation of the cryomodules at 4 K to 1.8 K. A controlled cool down of the cavities was implemented as shown in Fig. 4. Therefore liquid helium is mixed with warmer helium gas. The temperature of the mixture was always adjusted not to fall below the temperature of the cavity by more than 30 K.

A detailed discussion on cryogenics will be found in [5].

Vacuum

For pumping the beam vacuum of the cryomodule, a particle free pumping stage based on the DESY layout [9] was designed and ordered at Pfeiffer Vacuum GmbH. A mass flow controller allows a pumping speed reduction to $\Delta p_{\text{Cavity}} < 1$ mbar s^{-1} until p_{Cavity} 1 mbar before the turbomolecular pump starts. For a pump down of the cryomodule 20 h are needed. The vaccum inside the module is around 1×10^{-9} mbar after cool down and while testing.

Calorimetric Measurement of Q_0

Because of the strongly over coupled cavities, the CW measurement of unloaded Q is based on calorimetric measurement. Therefore two approaches to measure the heat via the amount of evaporated helium were done: Via a helium flow rate and pressure rise. During measurement all inlet valves into the helium vessel are closed for creating stable helium conditions. The helium flow rate per gradient is measured over a period of 5 min and can be compared with a series of heater measurements for flow calibration.

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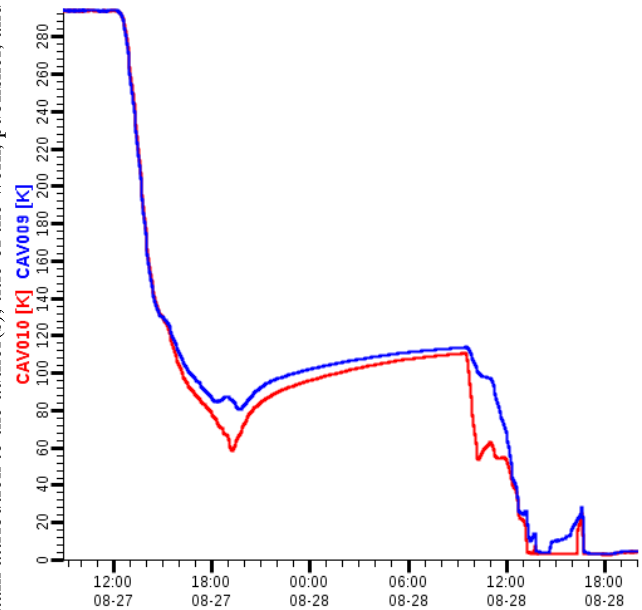

Figure 4: Cooldown of cryomodule 2 to 1.8 K in 30 h. To cool down the cavities down to 4 K a intermediate temperature of the helium is used.

The static loss can be calculated by the calibration measurements. For pressure rise measurement, the exhaust valves are also closed and the pressure rise inside of the closed volume is measured and compared to heater measurements for calibration. A description of this technique was given in [10]. The measurement time is 30 s but can be adapted to the pressure rise. Both measurements follow the Eq. 1.

$$P_{\text{Diss}} = \left(\frac{x_{\text{RF}} - x_{\text{static}}}{x_{\text{heater}} - x_{\text{static}}} \right) P_{\text{Heater}} \tag{1}$$

where x can be $\frac{dp}{dt}$ for pressure rise or ϕ for flow rate measurements.

In the following discussion of the measurements, data collected with both methods are merged together.

SITE ACCEPTANCE TEST OF THE MESA CRYOMODULES

The cryomodule 2 was measured from November 2018 to January 2019. The measurement of CM1 was from January to May 2019. Both modules were shipped under nitrogen atmosphere.

Cryomodule 1

In Fig. 5 and Fig. 6 the Q_0 vs E_{Acc} data can be found. The module tests of CAV007 are in compliance with the vertical test results as shown in Fig. 5.

The measurements of CAV008 in Fig. 6 implies a higher Q_0 in module test than in vertical test on the first glance. A detailed revision of the test set-up showed a unwanted interferance of the µTCA test set-up with the PLL, which was installed after the tests of CAV007.

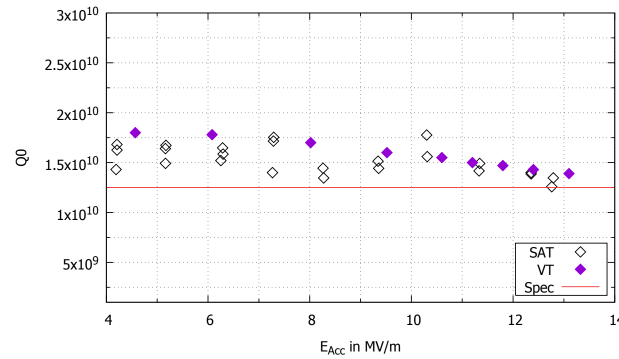

Figure 5: CAV007: Unloaded Q at module test (SAT) in comparison to the vertial test (VT) results. Both measurements are compliant.

The scattering of the data at fields > 10 MV m^{-1} is lower for both cavities if compared to low fields and shows a similar slope than the vertical test data. This is due to the fact that the x_{RF} and x_{Heater}-values in Eq. 1 can be determined with higher relative accuracy if the losses are large. To optimize the accuracy, the measuring time will be adjusted. For CAV008, due to the mentioned problems after the expansion of the LLRF-system, another systematic error occurred. As shown in Fig. 6, the measured values are clearly not realistic. However, based on our experience with the cryogenics and regarding the losses measured at the relevant fields we are safe to assume that CAV008 surpasses the specifications. New measurements are currently performed.

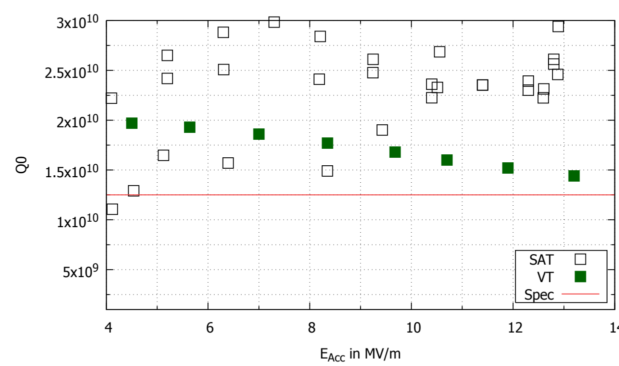

Figure 6: CAV008: Scattering of Q values because of interference of the LLRF system. New measurements will be done soon.

Static losses of the cryomodule 1 are calculated with $P_{\text{Static}} = 9.0(23)$ W and within the specification.

Cryomodule 2

The measurement of the cavities of cryomodule 2 revealed a severe problem with radiation.

The tests of CAV009 (Fig. 7) and CAV010 (Fig. 8) showed radiation of 2 mSv h^{-1} at 2 MV m^{-1} up to 15 mSv h^{-1} at 10 MV m^{-1}. Because of radiation limits and limited forward power, tests over 10 MV m^{-1} were not possible.

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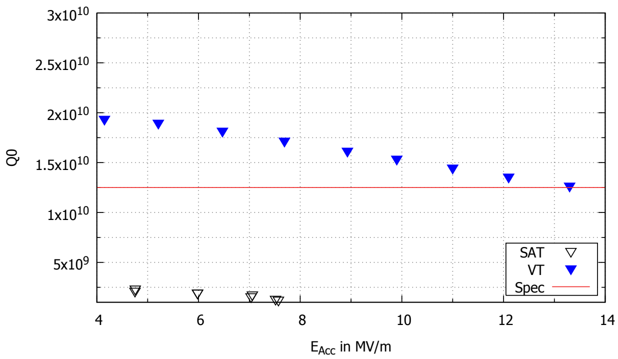

Figure 7: CAV009: Radiation and a low Q_0 was detected. A loose valve disk could have produced particles which caused field emission.

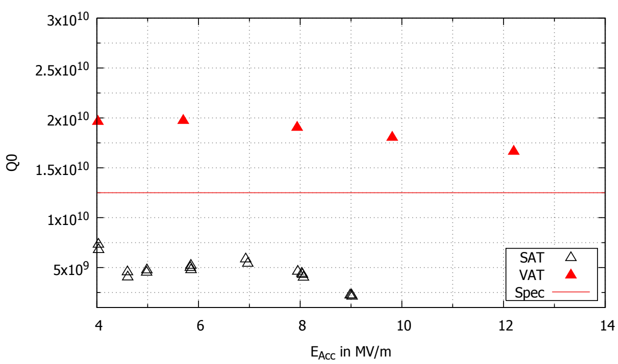

Figure 8: CAV010: Similar behaviour to CAV009, but with a slightly increased Q_0, because CAV010 is farther away from the particle source.

To treat the radiation, a pulsed processing was tried, but a processing effect was not observed.

Tests to identify single field emitter with a matrix of dosimeter on the outside of the vacuum vessel showed scattered radiation rather than single field emitter.

The hypothesis for this unexpected behaviour can be found in a not correctly closed valve between cavity string and a blind flange. It was found at visual inspection after delivery, that the valve of the cryomodule was in an indifferent state. After applying pressured air, it closed. Because of the vibrations of the transport from the vendor to JGU Mainz, a unwanted movement of the valve disk produced particles. Those particles could spread through the nitrogen atmosphere all over both cavities and act as field emitter in the tests. A indicator fot this hypothesis is the slightly higher Q_0 values in CAV010. It is the cavity farther away from the cavity.

Static losses of the cryomodule 2 are calculated with $P_{\text{Static}} = 5.61(35)$ W. Because of the opening of the module for the refurbishment of the cavities the static losses have to be remeasured also.

CONCLUSION

Both cryomodules are fabricated and tested at 2 K. Cryomodule 1 was accepted. The cavities CAV007 and CAV008 showed a good behaviour compared to the vertical test results, despite the fact that the measurement of CAV008 has a high uncertainty due to problems with the RF control. Cryomodule 2 showed radiation in both cavities at low fields and was rejected. As a particle source, a loose valve disk was detected. Because of the shipping under nitrogen atmosphere, the particle were spread all over the cavities and produced a diffuse radiation. The cryomodule 2 was send back to the vendor and CAV009 and CAV010 are under refurbishment and will be tested within the year again. A shipment under vacuum could reduce the risk of distributing paricles all over the cavities.

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