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INVESTIGATION OF CRYOMODULES FOR THE MAINZ ENERGY-RECOVERING SUPERCONDUCTING ACCELERATOR MESA*

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Abstract

For the multiturn accelerator MESA it is planned to employ superconducting technology for the main linac, which is supposed to provide an energy gain of 50 MeV per turn. As continuous wave operation is mandatory for the experiments, it is important to minimise the cryogenic losses, hence to find cavities and the corresponding cryomodule meeting the framework conditions for the accelerator. The findings and the current status will be reported.

INTRODUCTION

The Mainz Energy-Recovering Superconducting Accelerator [1] is a small facility under construction at the Institut für Kernphysik at the JGU Mainz, which is scheduled to be in operation by end of 2017. It is designed to accelerate electrons to a maximum energy of 155 MeV at a current of 150 µA in external beam mode or up to 10 mA at 105 MeV in energy-recovering mode. More details about the footprint, lattice and beam dynamics can be found in [2], a schematic drawing of the current lattice is given in Fig. 1 After injecting the continuous wave beam with an energy of 5 MeV in the superconducting main linac, the beam achieves an energy gain of 50 MeV per turn. These operation parameters result in a total beam current of $I = 40$ mA for the energy-recovering mode (two beams ramp up in energy, two ramp down).

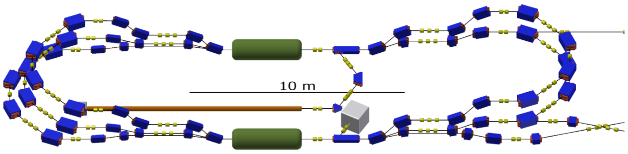

Figure 1: Overview of the current MESA lattice.

CONSIDERATIONS

As it is well known, high beam currents can induce higher order modes (HOMs) in the accelerating structures, and as the structures of choice are superconducting, the quality factor of the HOMs can be very high, and may perturb the beam in the following passes, which eventually leads to beam breakup (BBU). Details about threshold currents are discussed elsewhere [3, 4].

The beam current threshold for recirculating linacs is given by [5]

$$I_{\text{th}} = \frac{2c^2}{e\omega \left(\frac{R}{Q}\right) Q} \frac{1}{\sum_j^N \sum_{\text{i<j}} M^{\text{ij}} \frac{1}{p_i} \sin\left(\omega T^{\text{ij}}\right)} \qquad (1)$$

with c as speed of light, e is the elementary charge, $\left(\frac{R}{Q}\right) Q$ the shunt impedance of the investigated higher order mode, N the total number of passes, M^{ij} the significant matrix element from pass i to j, p_i the momentum of the particles in pass i, ω the frequency of the higher order mode and T^{ij} the time of circulation from pass i to j. With assuming the matrix elements M^{ij} in the order of 10 m, and using the $R/Q \times Q$ given in e.g. [4], the maximum current before beam breakup occurs remains at ≈ 600 µA for a cryomodule with two TESLA-type cavities installed. This easily fulfils the requirements for the external beam experiment (150 µA). Nevertheless, with further optimisation and more precise calculation of the required matrix elements, it is expected to achieve ERL operation with $I = 1$ mA, being the goal for Phase I operation of MESA.

Thus the scope of this paper is to present the advantages and challenges which arise from the choice of a certain type of cryomodule. As - to our knowledge - no cryomodule to date is in operation with $I = 10$ mA of (multiturn) beam current, cryomodule types that are in operation or close to finalisation are examined regarding compatibility and possible beam currents.

ELBE-TYPE CRYOMODULE

Two ELBE cryomodules [6], one is shown in Fig. 2 are in operation at Helmholtz-Zentrum Dresden-Rossendorf (HZDR) for about a decade. They contain 2 TESLA-type superconducting 1.3 GHz cavities. These are equipped with the TESLA Higher Order Mode coupler [7], which usually limit the accelerating field of the TESLA cavities in cw operation to about $E_{\text{acc}} = 10$ MV/m due to thermal instabilities [8]. This is close to the required field of $E_{\text{acc}} = 12.5$ MV/m and thus operation will be close to or at the limit. The company Research Instruments GmbH [9] offers the turn-key fabrication of these cryomodules and has already manufactured several of them.

In order to maintain the reliability of the operation of MESA, minor design changes are requested to be applied to the cryomodule. These include the replacement of the higher order mode feedthroughs with sapphire windows for better thermal conductivity [10]. For the compensation of microphonics, the FNAL/INFN-type blade tuner [11] with

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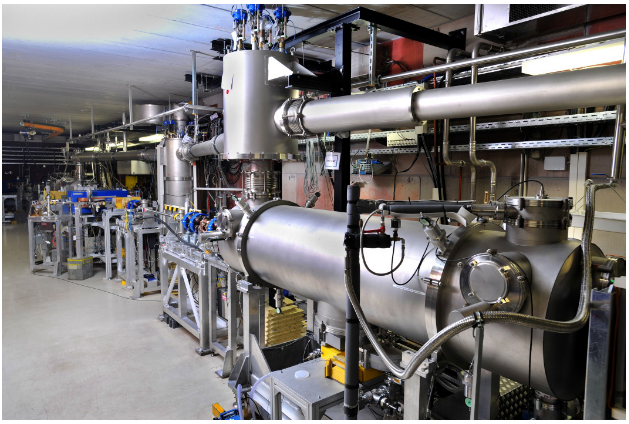

Figure 2: ELBE cryomodule (©Frank Bierstedt).

piezo elements may be installed, thus a modification of the helium vessel is needed. Furthermore there is an option to use a more powerful fundamental power coupler.

HOM Measurements

Measurements of the quality factors of the most threatening higher order modes [4] have been carried out in May 2014 at the ELBE cryomodules at T=2 K without beam. The transmission parameter S21 has been measured using the HOM coupler antennas and the rf pickup antenna (see Fig. 3)with a network analyzer connected to the corresponding feedthroughs at the modules. Measurements taken from HOM1 to HOM2 usually showed a passband with the overlapping frequencies which coupled to the corresponding HOM antennas, depending on the polarisation of the mode. Thus a statement about the quality factor of the higher order mode is not possible and only the measurements from one HOM antenna to the pickup are presented.

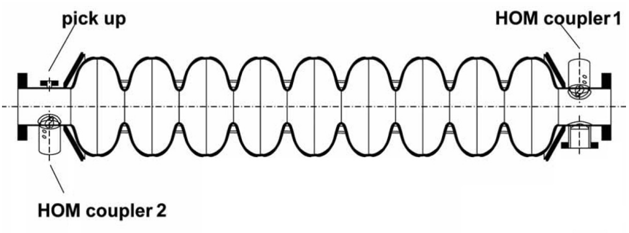

Figure 3: Used antennas for the HOM measurements at the TESLA cavity [12].

As four cavities have been examined, Table 1 shows the variation of the mode frequency as well as the span of the external quality factor for the appropriate mode. "Mode x-y" indicates the $y/9\pi$ dipole mode in the xth passband. The measurement of Q_{ext} showed slightly smaller values than expected [4] except for mode 2-4 in the measurements from HOM1 to the pickup, but there might be major uncertainties which have not been taken into account given by the measurement setup, the production and tuning-process of the cavities. Thus it is expected that exceeding a beam current of 1 mA in ERL mode is possible, depending on the final accelerator lattice.

Table 1: Measurements of the Most Dangerous Dipole HOMs

	f / GHz	Q_{ext} / 10^3
	HOM1→Pickup	
Mode 1-6	1.7038-1.7040	11-23
Mode 1-7	1.7313-1.7320	10-13
Mode 2-4	1.8732-1.8735	28-110
Mode 3-0	2.5738-2.5747	16-81
	HOM2→Pickup	
Mode 1-6	1.7038-1.7041	10-25
Mode 1-7	1.7313-1.7318	9-16
Mode 2-4	1.8735-1.8737	13-42
Mode 3-0	2.5733-2.5738	10-24

ARIEL E-LINAC-TYPE CRYOMODULE

The ARIEL e-linac at TRIUMF [13] is currently under construction. The linac cryomodule also contains 2 1.3 GHz cavities which have a slightly modified cavity shape [14] related to the TESLA design. Main differences are the beam line HOM absorbers and the designed capability of accelerating I = 10 mA single-pass beam current. In contrast to the ELBE cryomodule, these cryomodules have not been set into operation with beam up to now. But an injector cryomodule, similar to the linac module but containing only one cavity has already been cooled down successfully. A sketch of the injector module is shown in Fig. 4.

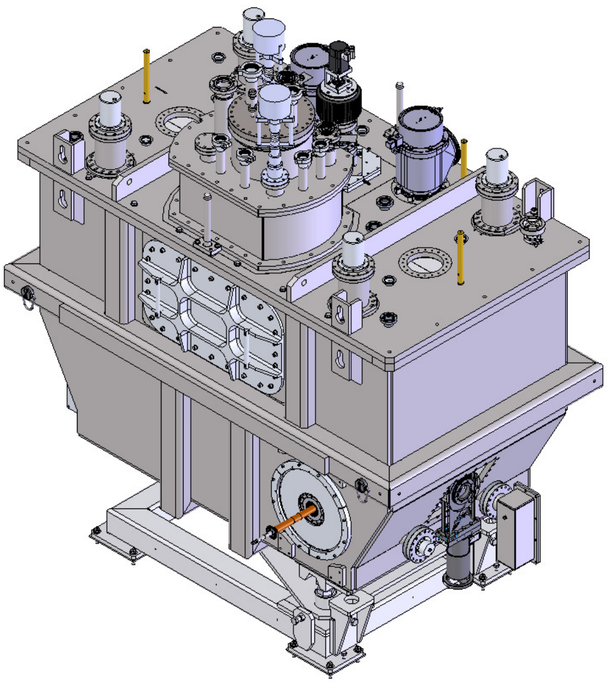

Figure 4: ARIEL e-linac injector cryomodule [15]

OTHER CRYOMODULES

A multitude of other cryomodules exist, which, in particular, offer advantages concerning HOM-stability. Examples are modules which employ the CEBAF- or Cornell style cavities [16, 17]. The most radical approach is of course to design a new cavity in a specific cryomodule, such as foreseen for Berlin-PRO [18] and LHeC [19].

Besides their obvious advantages, these scenarios increase the project risks with respect to cost, timeline and technological complication, in particular if other frequencies than 1300 MHz are considered. In intense discussions with all possible manufacturers we currently try to quantify such risks, in order to find a suitable compromise between risk and gain. A definitive decision will be taken before fall 2014.

CONCLUSION AND OUTLOOK

Several types of SRF accelerator cryomodules have been investigated for application in the MESA accelerator. Existing 1.3 GHz cryomodule designs allow to conduct the experiments foreseen for MESA stage-1; in particular the precision determination of the electroweak mixing angle (P2 experiment [20]). The call for tender is placed and it is expected to accept a bid by August/September 2014.

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