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THE VSR DEMO MODULE DESIGN – A SPACEFRAME-BASED MODULE FOR CAVITIES WITH WARM WAVEGUIDE HOM ABSORBERS

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Abstract

The VSR (Variable pulse length Storage Ring) demo module is a prototype for the superconducting upgrade of HZB's BESSY II. The module, shown in Fig. 1, houses two 1.5 GHz superconducting cavities operated at 1.8K in continuous wave (CW) mode. Each cavity has five water cooled Waveguide HOM Absorbers with high thermal load (450 W), which requires them to be water cooled. This setup introduces several design challenges, concerning space restriction, the interconnection of warm and cold parts and the alignment. In order to provide support and steady alignment an innovative space frame was designed. The transition from cold to warm over the partially superconducting waveguides made a more complex design for shielding and cooling system necessary. With the design close to completion, we are now entering the purchase phase.

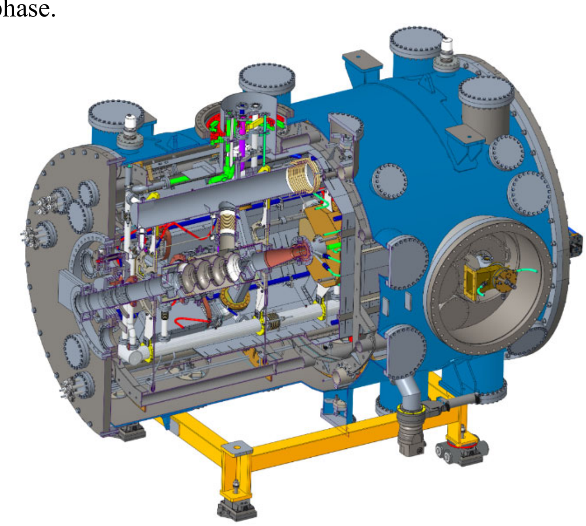

Figure 1: VSR DEMO module.

VSR DEMO PROJECT

Bunch length manipulation is mandatory in modern storage ring light sources and CW SRF provides the required high voltage in a compact system to reach this goal [1]. One possible technique as proposed in [1] is to combine higher harmonic SRF cavities (3 and 3.5 harm.) with the fundamental frequency of the BESSY II storage ring (500 MHz). This corresponds to a setup of 1.5 GHz-Cavities and 1.75 GHz-Cavities.

VSR DEMO seeks to develop and demonstrate the required SRF technology to achieve this by means of "offline" testing at HZB SupraLab facilities of a setup comprising two 1.5 GHz SRF cavities.

If successful, the two-cavity module would be ready for commissioning in the storage ring of BESSY II. This will represent the final step towards validating the proposed technology.

In perspective the module is prepared to accommodate also one or two 1.75 GHz or a subsequent module with four cavities (2x 1.5 GHz cavities 2x 1.75 GHz cavities) as presented in [2] offering the beam flexible dynamics could be built.

VSR DEMO MODULE DESIGN

The VSR module design is defined by some boundary conditions and demands originated from the SRF setup.

Space Restriction

The VSR DEMO module should be able to be installed in the storage ring of BESSY II and at HZB SupraLab. This means there are space restriction.

At Supralab there is main constrain is the ceiling height therefore the module's support structure is lowered and the Multi-transfer-line (MTL) which supplies the Module with Helium does not come from above like at the BESSY II site but from the right side.

At the Bessy II the module should be integrated in the storage ring this means that the possible straight also has space restrictions in axial direction and radial direction. While the axial restriction is relaxed for the two cavities module the radial restrictions are still strictly defined by the distance between beam and radiation protection wall. This also means that the module is only good accessible from the front.

Waveguide and HOMs

Due to the beam-cavity interaction high HOM power is expected. To damp this high loads in an axial space saving way the cavities are equipped with water cooled waveguides HOM absorbers (s. Fig. 2) [3].

Due to the high field strength leaping into the Waveguide the lower part of the waveguide (outside of the helium bath) must kept superconducting. Since the HOM loads are water cooled quite long Waveguides are required to deal with temperature gradient with acceptable headloads. Due to radial space restrains, warm HOM absorbers are on the same radial plane like the cold part of the waveguide. As a

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result, it is not possible to build the module with radial temperature layer, as it would be preferred for cryogenic modules. This has implication to the shield design.

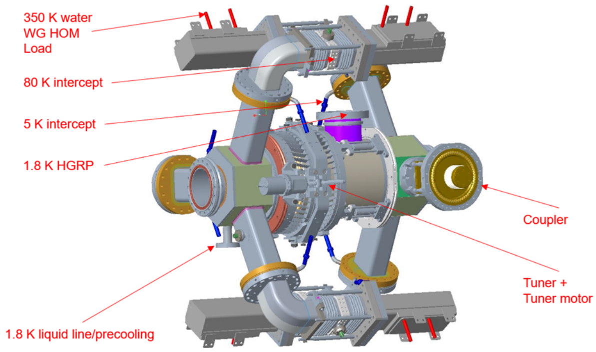

Figure 2: 1.5 GHz cavity.

Alignment

The couplers of the VSR DEMO module define fix points that should move only minimal during cool down. Like the couplers, the waveguides connect the colds side which is subject to thermal shrinkage with the warm remaining side. The waveguides are equipped with bellows but due its rectangular shape these have a preferred direction. Combined with the fact that the beampipe bellow need shielding and therefore have only a limited lateral compensation capability the holding structure has to provide minimal radial and axial movement. This leads to the spaceframe.

SPACEFRAME

Wheel Section

The spaceframe as holding structure was chosen to guaranty minimal displacement during cooldown (s. Alignment). The titanium rods are arranged in 120° angles to compensate the thermal shrinkage of each other. In order to keep the forces and stresses low, they are equipped with springs on the warm side bearing. The springs are also serve for preloading the rods, to minimalize moment in warm and compensate for (unsymmetrical) gravity (s. Fig. 3).

The titanium rods also provide thermal decoupling of the cold structures and warm structures. The support structure is divided in warm and cold. Down to the 80 K level components are supported from the warm side. Everything below are supported from the cold support which are decoupled by the titanium rods.

The spaceframe is designed in a modular fashion. Each cavity its own (wheel) section. This section is in principle interchangeable, so that perspectival a 1.75 GHz cavity could be integrated as well.

The wheel section provides support for HOM loads, magnetics shield and coupler in the final module, but also during assembly. This is from importance since the five Waveguide HOM absorbers and the coupler need support from the very beginning of the assembly.

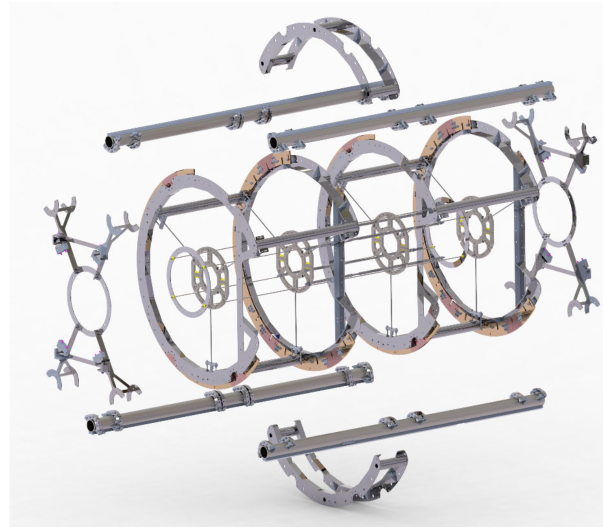

Figure 3: Spaceframe overview.

The wheel section can be turned on the attached rails (orange and red s. Fig. 4) allow a controlled turning so that the waveguides and the cold coupler part can be assembled horizontally with only two turns of 60°. To keep the movement during assembly to a minimum is from utmost importance in order to keep the cavity as free as possible from particles maybe trapped in the attached components.

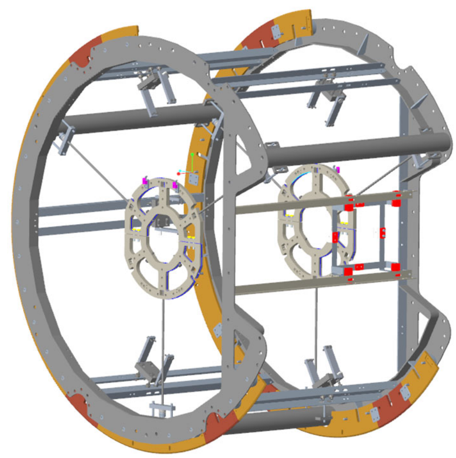

Figure 4: Spaceframe - wheel section.

Axial Fixture

Besides the discussed radial support an axial support is also required. Since the couplers require minimal movement, the support on the coupler side of the cavity serves as fixed bearing (s. Fig. 5). The two fixed bearings are connected with four invar rods. They get cold but due to the very low thermal expanse coefficient of invar, the displacement is minimal.

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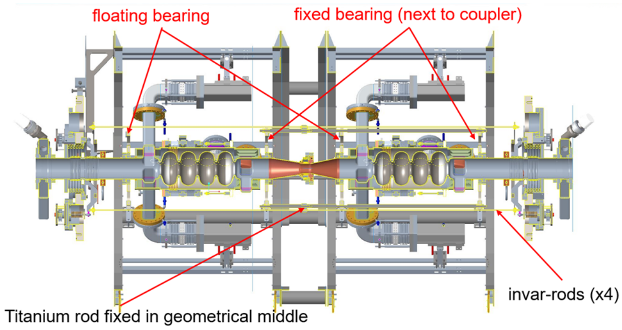

Figure 5: Spaceframe axial fixture.

The connection to the warm side of the module is done by four Titanium rods that are fixed in the geometrical middle of the rods. Therefore, during cool down the thermal shrinkage of the titanium roods compensate get compensated and the invar rod kept centered. To reduce stresses inside the rods and forces on the support structure the rods are equipped like the radial titanium rods with springs.

Since the cavities are shrinking during cool down and have to be tuned during operation, the other side of the cavity support is not connected to the invar rods and serve as lose bearing.

COOLING SYSTEM

For the BESSY II test site an cryo-plant was planned and bought. The feedbox, shown in Fig. 6, contains all valves (including safety valves) and provides the different helium temperature levels. It is placed outside the storage ring and connected by a 10.5 m long multi-transfer-line.

The feedbox provides the VSR Demo Module with

- One 1.8 K circuit
- Two 5 K circuits
- Two 60 K circuits

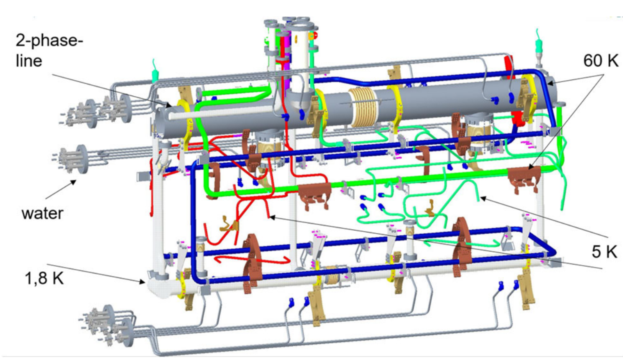

Figure 6: Piping.

The 5 K and 60 K circuits are operated supercritical at 3 bara and 12 bara. The components are all supplied with serial piping. For the 5 K circuit (4.5 to 8 K) temperature critical components like the waveguides are first in line, since they have to maintain superconducting state of the lower part of the waveguide [3]. Besides the intercept of the coupler, all intercepts are directly flown through, to avoid temperature gradient over a copper braids. Copper braids are used for intercepts in the 60 K circuit since the temperature level is less critical and the assembly is easier.

In the 5 K and 60 K circuits all connections are orbital welded except of the connection to the MTL. There have to be detachable connections in order to install and remove the module quickly. This is especially important for the BESSY II site.

1.8 K Circuit

The 1.8 K circuit provides liquid for the 1.8 K and is the only circuit with parallel piping and phase change in the helium jacket.

Since the feedbox has a Joule-Thomson-valve flash gas of (22% for BESSY II) is expected in the forward flow. This makes a phase separator in the module necessary. Due to the space restrains the only possible way is to include this in the two-phase line (s. Fig. 7). The left section of 2-phase-line serves as separator. To avoid spraying of liquid helium in the level sensors pipes there is a baffle installed. This should prevent miss readings of the level sensor.

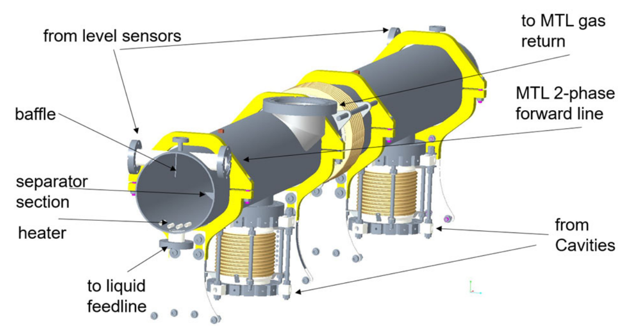

Figure 7: 2-phase-line and separator.

Since the two cavities are in parallel piping the 1.8 K circuit has a liquid feedline. This is primarily for cool down operation. It can be feed directly with (tempered) helium from the precooling line. If the regular inlet over the phase separator is used, the liquid phase flows to the lower feedline and cools down the cavities evenly. To stop liquid helium of spilling in the left cavity there is a small wall welded in the 2-phase line.

Parts like the 2-phase-line or cavities are bigger and will be fabricated separately. Therefore, from an assembly point of view detachable connection are necessary, where CF connection are used. Since the CF flanges are not licensed for these high pressure levels they get an approval for specific use from our notified body.

Water Circuits

The water circuits consist of 10 separate circuits for each HOM-Absorber an extra controllable circuit. This is necessary since the Absorbers should operate with laminar flow only to avoid microphonics.

Safety Concept

Due to space restrains on the possible sites it was not possible to integrate safety valves inside the module. Therefore, they had to be integrated in the feedbox. To discharge the high mass-flows (calculated according to DIN EN ISO 21013-3:2016-12) with an acceptable pressure drop, following measures were taken.

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For the 5 K and 60 K circuit the safety valve for the 5 K and 60 K circuit have a nominal opening pressure of 15 barg. This helps to keep the volume flow smaller and in the case of the 5 K System there is no air condensation. Furthermore, the MTL return pipes are dimensioned accordingly.

For the 1.8 K circuit a phase change and air condensation (in the case of a breached insolation vacuum) is not avoidable, but the return pipe is dimensioned for under pressure operation.

To dimension the safety vales for a higher opening pressure is for the 1.8 K system not a possibility. In the opposite the pressure levels for opening the safety valve already to high (s. Figure 8). The opening pressure is defined by the counter pressure of the guard system. For the cold operations this would be acceptable, but at room temperature RRR Niob especially after heat treatment 800°C, like it is planned for the cavities [3], the Yield Strength is too low. In order to avoid deformation of the cavity in a warm state there are two lower pressure levels implemented (s. Fig. 8).

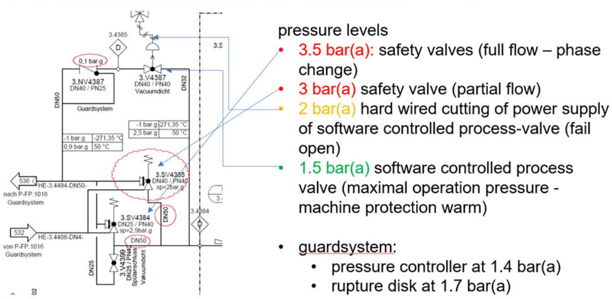

Figure 8: 1.8 K safety concept.

MAGNETIC SHIELD

In the module there are two magnetic shields. One directly around the cavities helium vessel and the second outer magnetic shield around the cavity and tuner (with the motor outside) (s. Fig. 9).

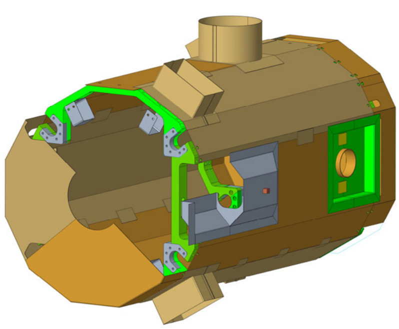

Figure 9: Magnetic shield.

The shield is build form 1 mm Mu-Metal. It is heavily segmented, since it gets assembled after the cavity is already installed. It has a G10 support structure that is supported by the cold holding structure. The segments are carefully bolted to the support structure. the preferred connection between plates is overlapping to avoid mechanical deformation, what would affect the magnetic properties of the Mu-metal.

THERMAL SHIELD

The thermal shield is made by 3 mm aluminum sheets bolted on extruded profiles of aluminum. The basic concept is that every segment (with exception of the pockets for the HOMs) is bolted to a helium cooled profile. Therefore, even with a high segmentation can be allowed without too big thermal gradients. For a better assembly the piping is inside and can be connected to the support frame, before assembling the plates (s. Fig. 10).

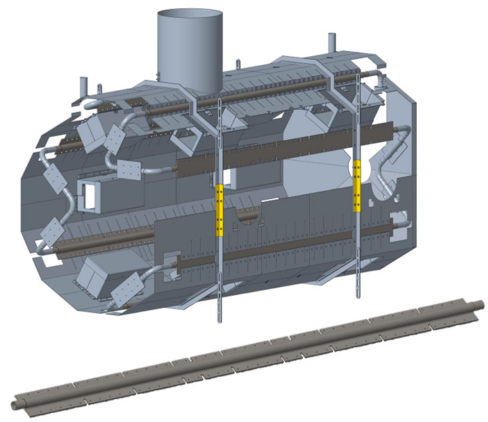

Figure 10: Thermal shield.

All connections with the exception to the piping are planned to be done by orbital welding. In the moment there are studies ongoing to determine a reliable welding process.

CONCLUSION

The design phase of almost all mayor components of the VSR module is close to completion. For the vacuum vessel, the space frame and the tooling (not in this paper) the tender has already been open. The rest of the components should be order in 2021. Delivery is expected during 2022/23. As soon as the components of the coldstring are delivered and tested in 2023 the assembly of the module can begin.

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