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Thought on the RF Power Source and RF Distribution System for High Beta Elliptical Cavities

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1 ESS klystron Gallery

A conceptual layout of the rf source and distribution system for high beta elliptical cavities is shown in fig. 1. This layout is based on the following principles:

- Maximize availability and power efficiency.
- Separate water and electricity.
- Optimize floor space.
- Insulate high voltage parts in oil.
- Minimize volume of oil.
- Minimize radiation.
- Lean concept. (Modular design and quick replacement of components)
- Best practice of cooling and heat recycling.
- One cavity per rf power source.

1.1 Floorspace

One important concern is the average cavity to cavity distance. The reference baseline in [1] contains 112 high beta elliptical cavities over a length of 196 m. I.e., each power source in the klystron gallery can take up 1.5 m along the linac, including access. According to Montessinos [2] this type of power source and distribution system takes up 29 m^2 floorspace each. I.e, 20 m width is needed.

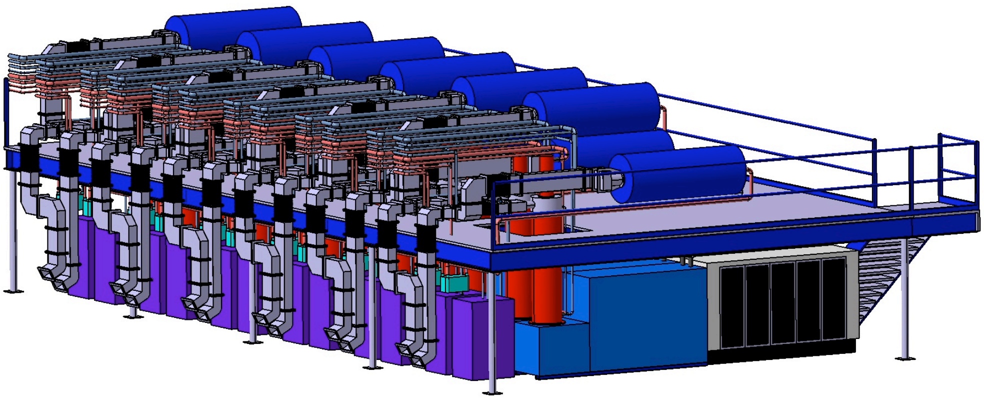

Figure 1: A conceptual layout of the rf source and distribution system for high beta elliptical cavities at ESS.

1.2 Overhead crane

An overhead crane will speed up installation in the klystron gallery and facilitate fast replacement of parts. The cost for the overhead crane depends on the width it needs to cover and therefore floor space under the crane has to be optimized.

1.3 Entresol Plane

The entresol plane reduces the required floor space and facilitates for assembly and maintenance of the rf distribution system. Floor sections can be lifted so that parts beneath can be accessed from the overhead crane.

The entresol plane could also include additional X-Ray shielding, if needed. The entresol plane could also protect the klystron modulators and other electrical components in the case of a water leak.

1.4 Additional shielding of neutrons

By continuing the concrete ducts from the accelerator up to the same level as the entresol plane, (not shown in the layout) additional screening of neutrons is given.

1.5 Klystron

The klystron is mounted in a separate oil tank separate and connected to the klystron modulator through a short (< 2 m) high voltage cable. The layout of the klystron is vertical for the following reasons:

- Easier to take out and install a klystron if needed.
- Less floor space.
- Better temperature gradient for water cooling.
- Reduces the risk of oil leaks.
- Proven concept, as the layout at Oak ridge is vertical.

The disadvantage with a vertical klystron is the need for a high ceiling. In the present layout the klystrons needs to be lifted above the entresol level during installation and replacement.

1.6 Klystron modulator

Klystron modulators are voluminous and expensive pieces of equipment with lots of power stored inside during operation. Electrical safety and prevention of fire and oil contamination are therefore very important.

The large number of components inside the klystron modulators and experiences from other facilities indicates that maintainability and availability issues of modulators can be expected also for ESS. Therefore, careful analysis of MTBF an MTTR of all components should be carried out.

The performance of the modulator (in terms of rise time, droop and ripple) will have a large impact on the efficiency of the power source and beam losses.

At SNS several klystrons are connected to one large modulator for which the output power is matched to the highest cavity gradient. Inevitably, this leads to an elevated power consumption since the gradients vary from cavity to cavity. More important, if one modulator is out of service the accelerator cannot be operated. Therefore, each klystron at ESS will be powered with one single solid state klystron modulator.

2 Alternative solutions

2.1 Mod anode klystrons

The high power rf at JPARC is pulsed by modulating the anode voltage of the klystron. Then the klystron modulators can be replaced by large DC power supplies. This solution proved to be the most cost beneficial alternative for JPARC. However, for ESS it is not an alternative because of reliability and efficiency concerns.

2.2 Alternative power sources

Optimistically, we expect a klystron efficiency of 65% at saturation for the high beta elliptical cavities. Further, if we take into account the approximate 30% margin for LLRF regulation and 90% efficiency of the klystron modulators, then the efficiency of the rf power source is only 40%. (not including losses in the distribution systems and filling time of the cavity which reduces the efficiency further to 30%). Therefore it is well worth to invest efforts to replace klystrons and modulators with alternative power sources, such as solid state amplifiers. However, the serial production of the rf power sources has to start in 2014. Until then, it is not realistic to finalize development of alternative rf power sources, especially not if we take into account for the 95% availability demands.

2.3 Future power upgrades

We should be very careful when considering future power upgrades during the present design of the rf power source, since increasing the peak power of the klystron reduces the efficiency. The power source will be design for the baseline accelerator parameters, with some safety margins. Any future power upgrades will be achieved by either optimizing the usage of the power source or for the distant future by replacing the power source with more modern solutions (solid state amplifiers?)

3 Tests and optimizations needed before start of serial production 2014

3.1 Rf power source and distribution system

ESS will have a minimum of 112 high beta elliptical cavities. The corresponding power source and distribution system needs to be tested and optimized before serial production. These tests and optimizations shall include the following:

1. Test electrical and mechanical interfaces, in particular between the klystron and modulator.

2. Test and optimize assembly and replacement procedures for klystrons and modulators.

3. Test and optimize water cooling system.

4. Test and optimize recycling of surplus heat.

5. Test and optimize LLRF design, including feedforward and feedback loops. This makes it necessary to include the directional couplers to be used in the linac in the tests.

6. Test machine safety sensors and interlocks at the RF power and LLRF subsystems.

7. Test the modulators and estimate MTBF, MTTR and decide on which modulator topology is the preferred one.

8. Test the high efficiency klystrons (i.e 65% efficiency) with 1.5 MW output power. This is important because there is a trade off between stability of the klystron output power and high efficiency.

9. Test linearization methods for the klystron, which may make it possible to increase the efficiency of the rf power source. The development of this concept makes it necessary first to develop a mathematical model of the klystron amplifier, and then to test the developed algorithms. In both cases there is a need to operate the klystron under full power.

10. Test the concept of RF power recapture. As most of the power in the RF pulse is reflected back to the load and thus lost in the beginning of the pulse, when the cavity is empty, there is the possibility to gain total efficiency if this power could be captured and redirected back into the cavity. There are a number of possible solutions, all of which has to be tested at full power with a cavity to judge their respective suitability to include in the final layout of the ESS linac.

11. Test and optimize LLRF compensation of Lorenz detuning by Piezo tuners.

12. Optimize droop compensation of the modulator pulse in combination with LLRF.

References

[1] M. Eshraqi. Beam dynamics and design of the ess linac. In *Proceedings of HB2020, Morsach, Switzerland*, 2010. `http://hb2010.web.psi.ch/proceedings/papers/tuo1b01.pdf`.

[2] E. Montessinos. Spl possible rf power sources. 5th SPL Collaboration Meeting, 2010. `http://indico.cern.ch/contributionDisplay.py?contribId=18&sessionId=5&confId=109664`.