RENEWAL OF BESSY II RF SYSTEM SOLID STATE AMPLIFIERS AND HOM DAMPED CAVITIES

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Abstract

The BESSY II storage ring is a synchrotron light source in user operation since 1999. Due to the aging of the cavities and due to the fact that the klystron tubes run out of production a renewal of the BESSY II RF system was necessary. The old hardware has been replaced by solid state amplifiers (SSA) and HOM damped normal conducting (nc) single cell cavities. The parameters of the components, the installation phase and the impact on the beam are presented.

RF PARAMETERS OF BESSY II

BESSY II is a 1.7 GeV synchrotron light source in user operation since 1999. Typical beam current is up to 300 mA. The energy loss per turn is about 290 keV when all insertion devices are in operation. First installation were four 75 kW_{CW} 500 MHz klystron based transmitters at the storage ring and one 40 kW transmitter at the booster synchrotron.

RENEWAL OF CAVITIES

Cavities at BESSY II

The first installation of cavities at BESSY II have been four single cell DORIS type cavities at the storage ring and one three cell DESY type cavity at the booster. All cavities have been old recycled cavities from DESY.

The DORIS type cavities at the storage ring are single cell cavities with pillbox shape and a shunt impedance of 2.9 MΩ.

They are moderately mode damped by three narrow band antennas and three broadband ferrites [1]. The dampers in combination with a bunch-by-bunch feedback system are sufficient to provide stable beam conditions.

Degrading of DORIS Cavities

The DORIS cavities were produced in the 1970´s for installation in the DORIS storage ring at DESY. Due to aging leakages occurred from the water channels to the beam vacuum or to the surrounding air.

In fall 2010 we installed the last spare cavity. There were no drawings of the DORIS cavity available any more. So there was no chance to order any spare cavity of DORIS type.

HOM Damped Single Cell BESSY Type Cavity

There has been a development of a strong HOM damped single cell normal conducting cavity about ten years ago. This was done in a collaboration headed by BESSY. Data and damping characteristics can be seen in [2]. After the first prototype was tested there was a modification developed in cooperation with the RF group of the ESRF.

The major design criteria for the HOM cavity are:

- HOM damping applicable to all existing light sources
- better shunt impedance (3.4 MΩ) than DORIS cavity (2.9 MΩ)
- 80 kW wall losses
- same length of beam pipe as DORIS cavity
- same fundamental power coupler as DORIS cavity
- same tuner as DORIS cavity

Figure 1 shows the cavity in a test stand. Characteristic for the cavity are the three HOM dampers. On the left side is the fundamental mode power coupler, on the right side the tuner.

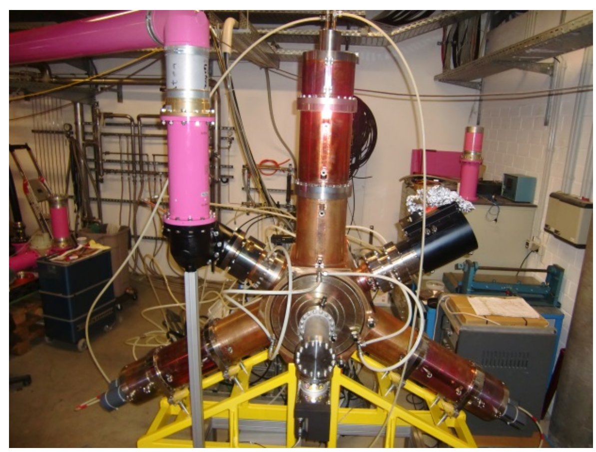

Figure 1: HOM damped cavity in a test stand.

The cavity is already operated in the Metrology Light Source (MLS) at HZB [2], at DELTA [3], at ALBA [4] and it is planned to install the BESSY HOM cavity at DIAMOND as well.

Installation in Storage Ring

The cavities were installed in two steps. In shutdown 2013 the first two BESSY HOM cavities have been installed and in shutdown 2015 the next two cavities.

Figure 2 shows a CAD drawing of the cavity section. The cavities are grouped in two pairs with a vacuum valve in the middle. The installation of the cavities in the storage ring can be seen in Fig. 3. Due to the high number of water flow meters and many water tubes only the HOM dampers can be seen clearly.

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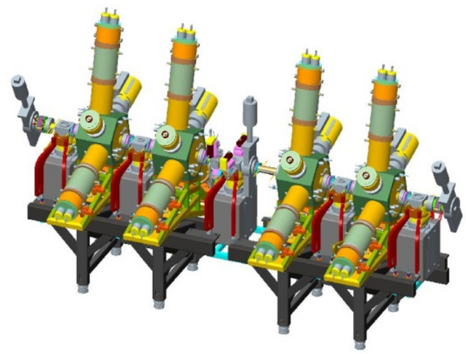

Figure 2: CAD drawing of the cavity section.

Figure 3: BESSY HOM cavities installed at BESSY II

Cavity Performance in the Storage Ring

The longitudinal stability of the beam is increased by using the new cavities.

The simple HOM dampers of the old DORIS cavities lead to longitudinal stable beam up to 250 mA. The installation of the BESSY HOM cavities results in longitudinal stable beam up to 300 mA (current limit by radiation safety). This allows to operate the storage ring without longitudinal bunch-by-bunch feedback.

The higher power capacity and the higher shunt impedance give the option to operate at higher cavity voltage of up to 650 kV per cavity limited by the transmitter power and RF line losses. This is used occasionally for experiments and for short bunch operation in low alpha mode.

RENEWAL OF TRANSMITTERS

In the last years there is a technology change in high power CW RF transmitters. RF transistors get more powerful and solid state transmitters are more and more replacing klystron and IOT based RF transmitters. TV stations started replacements and this technology is now applied at light sources at well.

First light source was SOLEIL developing 354 MHz 190 kW SSA in-house [5]. Same transmitters were implemented at the ESRF [6]. With the installation at BESSY II the HZB is the first light source installing considerable high power SSA at 500 MHz.

Klystron Transmitters at BESSY II

First RF installations at BESSY II were four 75 kW_{CW} 500 MHz klystron based transmitters (Thales & E2V klystrons) at the storage ring.

Three of the five klystrons had operational times (high voltage) of more than 100,000 hours and we only had a few spare klystrons in stock. We expected some of the klystrons to fail in the next years.

Due to general technology changes the companies stopped the production of these klystrons.

For this reason we decided to replace the klystron transmitters by solid state amplifiers.

Solid State Amplifiers

We ordered four 80 kW_{CW} and one 40 kW_{CW} solid state transmitters at the company CRYOELECTRA .

The transmitter is installed in closed cabinets with an air cooling device to have stable temperature conditions. The power supplies are a set of redundant modules for each 8 kW RF section. This 8 kW RF section is a set of 13 RF modules and one driver module mounted on a water cooled panel. 10 RF sections are summed up in a waveguide combiner.

Figure 4 shows one transmitter. The small air cooling unit is on the left, the power supplies rack (black) is next to it. The power combining section is in the center and next to it on both sides are the two racks housing the RF modules. On the right side is the control and interlock section.

Figure 4: 500 MHz 80 kW CW solid state amplifier.

The 40 kW SSA was the first transmitter to be delivered for testing and debugging.

Each transmitter got a burn in time of 3-4 weeks, even though not necessary, to be sure that everything is OK with the SSA.

Exchange of Transmitters

The replacement of the transmitters was a difficult logistic work. It was done within only one year. Several boundary conditions had to be taken into account, as the transmitters were installed at an operating light source.

Therefore most of the work could only be done in shut-shutdown phases.

There was floor space only to install two additional SSA. For the next SSA the old klystron transmitters had to be removed. After removing the old transmitters at the beginning of a shutdown the new SSA installation had to be operable at the end of the same shutdown.

Performance of the SSA

All SSA transmitters are working without any problems.

The SSA and the klystrons have the same efficiency of slightly above 50%, but the SSAs are operating in class AB mode while the klystrons are operated in class A mode. This leads to a reduction of the average mains power of about 30%.

RF Noise to the Beam

There is one additional advantage of the SSA in comparison to the klystron transmitters. The SSA has significantly less noise as shown in Fig. 5. Red is the noise of a klystron transmitter and blue is the noise of a SSA in beam operation. The plot shows the noise spectrum in the range -70 to -150 dBc over a frequency range of 10 Hz to 100 kHz.

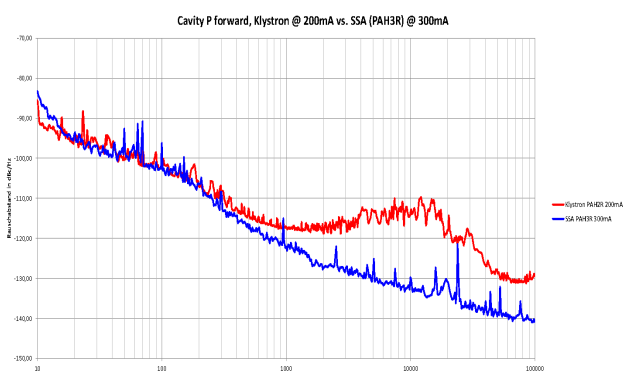

Figure 5: Noise at forward directional coupler at a power RF-line feeding a cavity. Red: 200 mA beam current using one klystron transmitter. Blue: 300 mA beam current using a solid state amplifier.

It is clearly seen that the noise added by the klystron transmitter is significantly higher in the frequency range of 1 kHz to 100 kHz. The synchrotron frequency is typically between 4 and 7 kHz.

Figure 6 and Fig. 7 show the synchrotron frequency while operating the storage ring at low beam current and using only one transmitter. It is clearly seen that the noise is much higher when using the klystron transmitter (Fig. 6) and the noise is lower when using the solid state amplifier (Fig. 7).

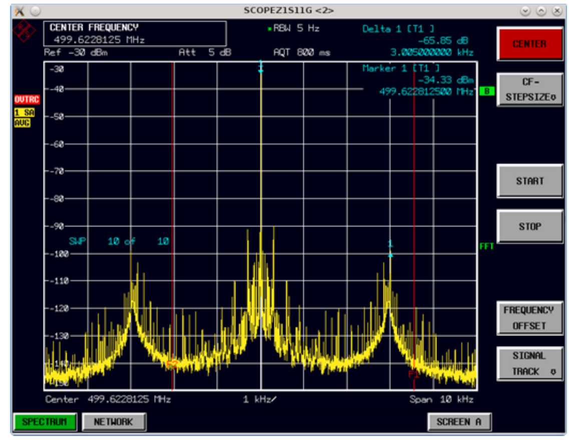

Figure 6: Synchrotron side bands at 3 mA beam current and operation of one single klystron transmitter.

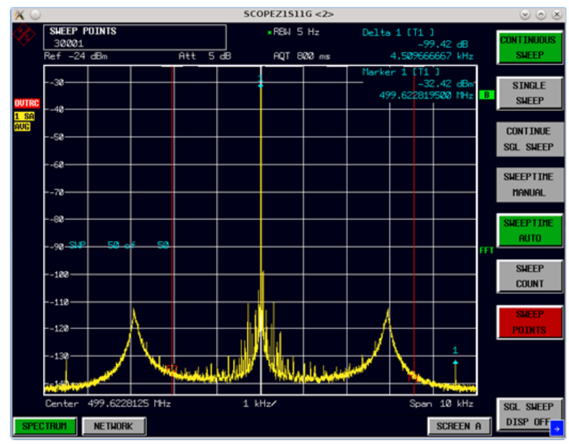

Figure 7: Synchrotron side bands at 3 mA beam current and operation of one single SSA.

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