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STATUS OF THE KLYSTRONS FOR THE EUROPEAN XFEL AFTER COMMISSIONING AND FIRST USER OPERATION PHASE

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Abstract

At present 26 RF stations for the European XFEL are in operation. Each of the RF stations consists of a HV modulator located on the DESY campus, up to 1600 m long 10 kV HV cables that connect the modulators and the HV pulse transformers located in the underground tunnel, the horizontal multi-beam klystron (MBK), and an air filled waveguide distribution system (WG) between the klystron and the cavities input couplers. The klystrons can produce RF power up to 10 MW, 1.5 ms RF pulse length and 10 Hz repetition rate. Two RF stations of the injector have already achieved about 30,000 hours of operation, RF stations of the XFEL bunch compressor area have operated up to 20,000 hours and the klystrons in the XFEL main linac already have about 18,000 hours of operation. To increase the lifetime of the klystrons we are using a fast protection system (KLM) that is in routine operation since 2018 in addition to the common interlock system. In this article we will give a summary of the present klystrons operation status including the number of HV and RF arcs in the klystrons and in the WG system and operation statistics for the high power RF part of machine.

INTRODUCTION

The European X-ray Free-Electron Laser (XFEL) [1] can be operated up to energy of 17.5 GeV (July 2018). Currently up to 300 coherent laser pulses per second with duration of less than 100 fs and with photon energy up to 19.1keV are delivered to the experiments. In future the number of pulses will increase to the design value of 27000 per second. For the production of these laser pulses, electrons have to be accelerated using a 2 km long accelerator based on superconducting radio frequency (RF) technology. For the XFEL project for a source of RF power of 26 RF stations were chosen the series horizontal MBKs made by two companies: MBK TH1802 from “Thales” [2, 3] and MBK E3736H from “Toshiba” [4, 5]. Both types of MBKs were equipped with CMs [6, 7] and 3 m long HV cables, and then they were tested on DESY MBK test stands [8]. The test was done with full RF power of 10 MW, full RF pulse length of 1.5 mS and with repetition rate of 10 Hz. Big advantages of using CM and HV cable connection between MBK and HV transformer are that we don’t have to work with the oil during MBK installation in the tunnel and that MBK and WGS can be easy connected together. CM has monitors for the measurement of klystron voltage and cathode current. Figure 1 shows the one of 24 RF stations in the XFEL tunnel.

Figure 1: XFEL tunnel view.

Since 2013 the commissioning of the first RF station for XFEL injector has been started. In 2015 the second RF station started operation for the first cold AC module and since 2016 the commissioning of the main part of linac has been started.

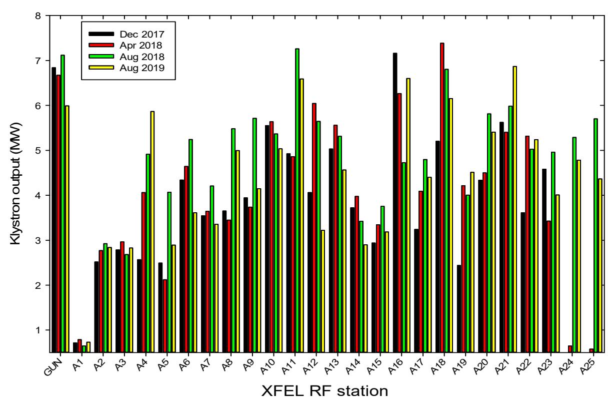

Figure 2: Output power for each of MBK.

In beginning of 2018 the commissioning of last two RF stations was done and in July 2018 the XFEL reached the design energy of 17.5 GeV. Figure 2 shows the output RF power for each of RF station. The average power from one MBK is 4.87 MW, but for several of RF stations the level of output power are more than 7 MW. Figure 3 shows the high voltage level for each of RF stations. In average the high voltage is 104.5 kV. For the moment we don’t have any limitation for XFEL operation from RF stations, the level of RF power from each of RF stations are determinates by XFEL longitudinal beam dynamics and bunch compression system.

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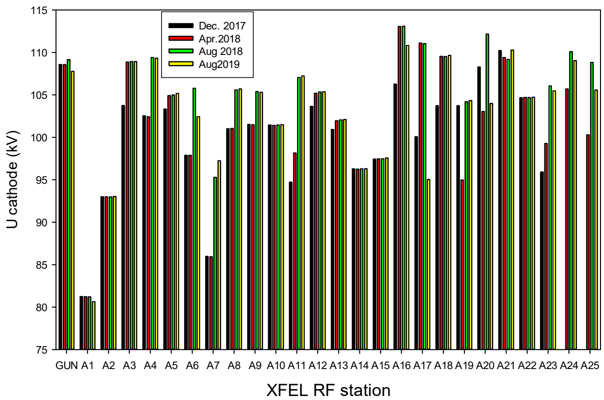

Figure 3: Cathode voltage for each of RF stations.

PROTECTION SYSTEM AND OPERATING STATISTICS

To make the operation of XFEL more reliable and increase the lifetime of the MBKs, in additional to the common interlock system since middle of 2018 we have started to use a fast protection system (KLM) [9 and 10] that was developed and tested during MBKs initial tests. The fast protection system is based on the comparison of the actual RF shape and the expected RF shape. In the case of a difference exceeding a certain margin, for example, in the case of RF breakdown in a klystron or RF breakdown in a waveguide system (WGS), the KLM faster than 800 ns, switches off the input RF signal. Thus, it does prevent the vacuum level in the klystron to worsen too much or it minimizes the RF overvoltage time at the output windows of the klystron in case of breakdown in WGS. The KLM system includes the partial discharge measurement in all of HV parts of RF station. Especially we were worry about life time of enough new HV components which were developed during MBKs test. To be sure that we don't have any degradation in HV system one of HV cable from RF station A19.L3 after 11000 hours of operation on HV level of 104,5 kV, was sent back to factory. The factory test has confirmed the good state of this cable and HV connectors; the level of partial discharge was the same as just after initial cable test. The test of HV quality of CM will be possible to make only after one of MBK will be for some reason removed from XFEL tunnel because CM and MBK can't be separated without working with open transformer oil in the tunnel. Figure 4 shows the number of events that have happened inside of MBKs since beginning of 2017. The most parts of events are the high voltage breakdowns in the gun area of klystrons, usually this type of breakdowns doesn't show the big increasing of vacuum level in the tubes, in contrast with RF breakdown inside of tube, where the vacuum level in the klystron greatly increases and it can provoke the arc in the gun area or, if vacuum level becomes very big, the main interlock system switched off the filament for this tube. For the filament recovery procedure for our type of MBKs it needs at least one hour. In this case it is very important to switch off the drive signal fast. Since the KLM system for MBKs has been implemented as routine for XFEL operation (08/2018), the number of cases of filament recovery was reduced noticeably.

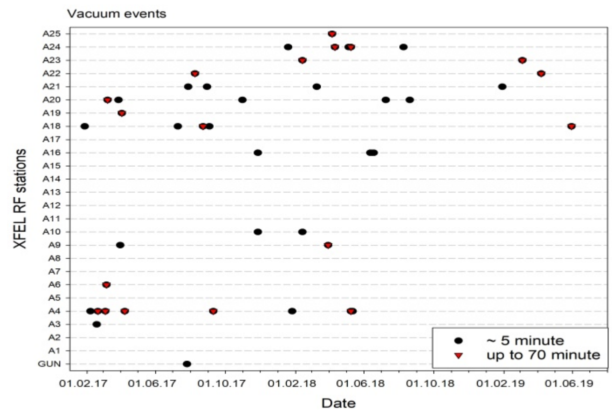

Figure 4: Gun HV arcing and RF breakdowns in XFEL MBKs.

Figure 5 shows the number of events that happened inside MBKs for full 2017 and 2018 years and in comparison the events number for 8 months of 2019, one can see that in the beginning of XFEL operation during the conditioning period the number of events are greater than we have in this year. This is in the good agreement with what was expected. But we also expect that in future the number of events in the klystrons will increase. The good way to reduce the number of events in the future is the reducing the cathode voltage and klystron output power and this is possible using developed in 2010 in DESY the phase modulation procedure [11]. It is the method of changing of the klystron output phase which allows decreasing the required klystron peak power by reducing the reflected power during cavity filling time.

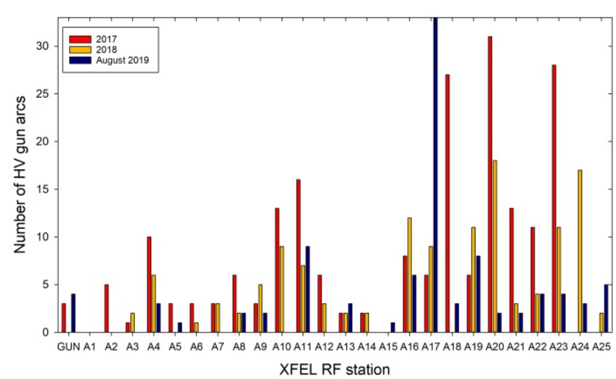

Figure 5: Number of HV arcs in the klystrons guns.

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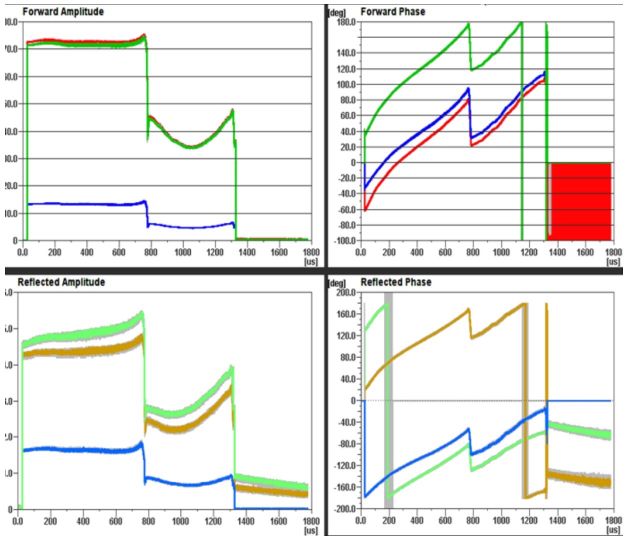

Figure 6: The output RF shapes of MBK in case of using phase modulation.

In case of phase modulation we can get the same gradient in the accelerate cavity but using up to 20% less RF power or, in case of using the same power level, we can reduce cavity filling time. Figure 6 shows RF shapes for amplitude and phase on the klystrons output in case of using phase modulation.

CONCLUSION

In February 2008 the first prototypes of MBK for XFEL had been installed on the MBK test stand DESY. Since August 2012 we have started a test and conditioning of the first one from 27 series MBKs for XFEL. The klystrons were tested together with connection modules (CM) and with different types of HV cables. To increase the lifetime of klystron a special fast protection system (KLM) was designed and tested. In March 2015 we started the installation of MBK to the XFEL tunnel. In July 2018 XFEL reached the design energy of 17.5 GeV. For the moment 26 XFEL RF stations produce 4.87 MW in average, the average cathode voltage is 104.5 kV, RF and HV breakdown rate for the MBK during last 8 months is 0.47 breakdowns per day. For the moment the XFEL operators can get as much RF power from MBKs as it is necessary for current mode of XFEL operation.

REFERENCES

[1] M. Atarelli *et al.* (Eds.), “XFEL: The European X-Ray “Free-Electron Laser: Technical Design Report”, DESY 2006-097, July 2006.

[2] A. Beunas, G. Faillon, “10MW/1.5ms, L band multi beam klystron”, *Proc. Conf. Displays and Vacuum Electronics*, Garmisch-Partenkirchen, Germany, April 29-30, 1998.

[3] V. Vogel *et al.*, “Testing of 10MW Multibeam Klystrons for the European X-Ray FEL at DESY”, in *Proc. PAC07*, Albuquerque, NM, USA, Jun. 2007, paper WEPMN013, pp. 2077-2079.

[4] A. Yano *et al.*, “The Toshiba E3736 Multi-Beam-Klystron”, in *Proc. LINAC'04*, Lübeck, Germany, Aug. 2004, paper THP45, pp. 706-708.

[5] V. Vogel and S. Choroba, “Status of Horizontal MBK for XFEL”, `http://www.xfel.eu/project/meetings/project_meetings/2009`

[6] V. Vogel *et al.*, “Connection Module for the European X-ray FEL 10MW Horizontal Multibeam Klystron”, in *Proc. IPAC'10*, Kyoto, Japan, May 2010, paper THPEB043, pp. 3978-3980.

[7] P. Bak, V. Zabrodin, A. Korepanov and V. Vogel, “Klystron Cathode Heater Power Supply System Based on the High-Voltage Gap Transformer”, in *Proc. PAC'09*, Vancouver, Canada, May 2009, paper TU6RFP016, pp. 1562-1564.

[8] V. Vogel and S. Choroba, “Status of Multi-Beam Klystrons”, presented at 51th ILC DESY General Project Meeting”, Jan. 2007, `https://agenda.linearcollider.org/event/1318`

[9] V. Vogel, “MBK protection”, LLRF Seminar, 2008, `http://ttfinfo.desy.de/LLRFelog/index.jsp`

[10] V. Vogel *et al.*, “Summary of the test and installation of 10 MW MBKS for the XFEL project”, in *Proc. LINAC'16*, East Lansing, MI, USA, Sep. 2016, pp. 506-508, `doi:10.18429/JACoW-LINAC2016-TUPLR017`

[11] V. Ayvazyan *et al.*, “Optimization of felling procedure for TESLA-type cavities for klystron RF power minimization for European XFEL”, in *Proc. IPAC'10*, Kyoto, Japan, May 2010, paper TUPEA039, pp. 1416-1418.