SUMMARY OF THE TEST AND INSTALLATION OF 10MW MBKS FOR THE XFEL PROJECT

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Abstract

For the European XFEL project, horizontal multi-beam klystrons (MBK) which produce RF power up to 10 MW, at an RF frequency of 1.3 GHz, 1.5 ms pulse length and 10 Hz repetition rate, were chosen as RF power sources. All MBKs have been manufactured by two companies, 22 tubes from Thales Electron Devices and 7 tubes from Toshiba Electron Tubes & Devices. In this article we will give a summary of the tube testing, conditioning and installation in the underground linear accelerator tunnel.

INTRODUCTION

After the successful test of three horizontal MBK prototypes [1 and 2] in 2008-2011, two companies started klystron delivery for the European XFEL project in 2012. At present all ordered klystrons are manufactured, 26 klystrons are required for first installation. The main parameters of the MBKs are given in Table 1.

Table 1: Main Parameters of the L-band MBK for XFEL

Parameters	Design	Test
Central frequency (MH	1300	1300
RF pulse length (ms)	1.5	1.5
Efficiency (%)	> 63	63-68
Average RF power (kW	150	155
Output power (MW)	10	9.9-10.5
Bandwidth (MHz)	3	>3

After delivery each klystron was connected to a connection module (CM) [3, 4 and 5], which consists of an oil tank, filament transformer and diagnostics, and afterwards tested on one of the MBK test stands at DESY [6, 7, and 8]. The average time of testing for each MBK was about 320 hours with the exception of several tubes, which needed more time for conditioning and retest. The tubes were tested up to full RF power and full RF pulse length with a repetition rate of 10 Hz. Figure 1 shows one of the klystrons with the CM (grey) and HV cable between the CM and the HV pulse transformer (red) inside the XFEL injector underground building. Two coaxial cables of the same type with an additional screen and ferromagnetic cores were used at the test stands for the test of all klystrons for more than 13000 hours.

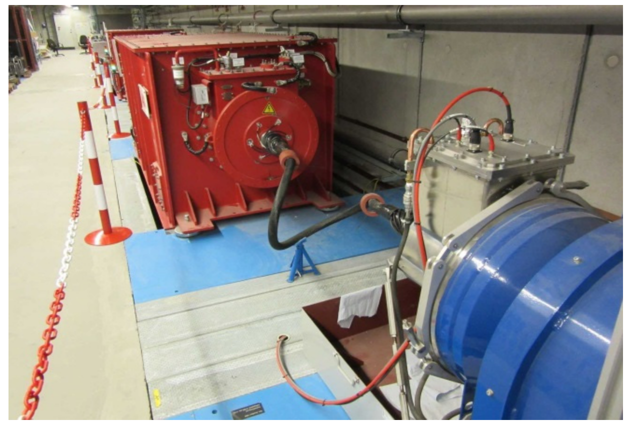

Figure 1: Connection between HV transformer and MBK.

The cables did not show any sign of degradation or increased level of partial discharge in the HV cables itself or the connectors.

MBK TEST AND INSTALLATION

At the start of the XFEL klystron design DESY demanded a mechanical design and interfaces allowing for fast replacement of the klystrons in the accelerator.

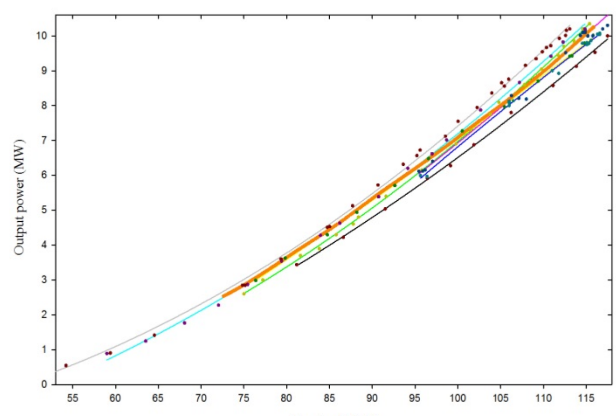

Figure 2: Saturated power of the Toshiba E3736H.

Another very important part of mechanical design is the protection of all sensitive parts of the klystron during transportation and installation in an underground tunnel. Since 2012 when the test of the first series MBKs at DESY site was started no problems occurred during transportation and installation.

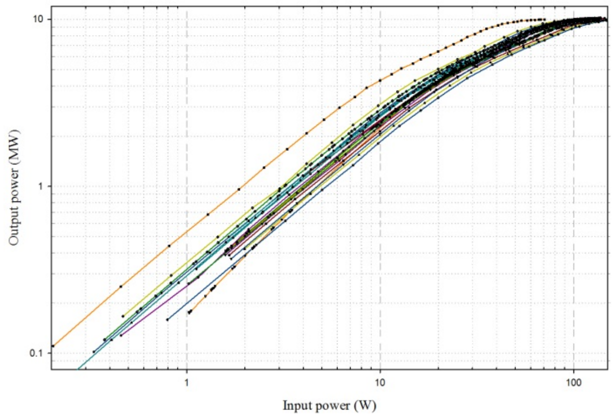

Figure 3: Gain curves of the Thales TH1802.

About three hours are required to exchange a klystron in the accelerator tunnel. During the high power tests all klystron parameters were recorded, e.g. voltage, current, RF power, bandwidth, gain, phase response, efficiency and more [7, 8 and 9]. The measured data were taken not only for acceptance test but will be used also later for feedback optimisation and beam loading compensation in the accelerating modules. Figure 2 shows the maximum output power as function of cathode voltage for the Toshiba klystrons E3736H. Figure 3 and Fig. 4 show the gain curves for the Thales TH1802 and Toshiba E3736H for the maximum operating voltage.

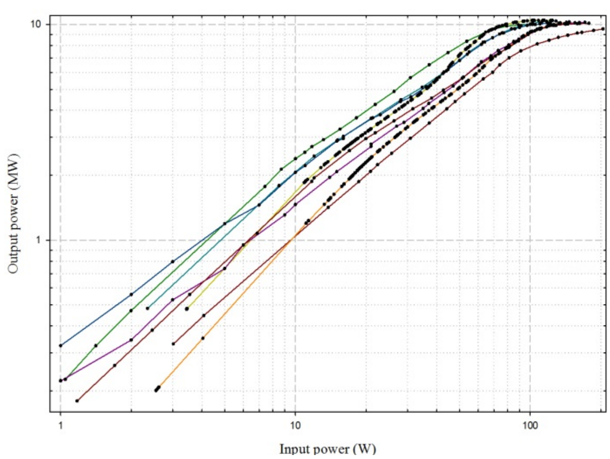

Figure 4: Gain curves of the Toshiba E37367H.

Figure 5 shows the distribution of required maximum RF power for the 26 XFEL RF stations. The level of average power for all the 24 RF stations in the main linac is about 6.5 MW. The power of the RF station used for the RF gun is about 9 MW and the power for the RF station for the first accelerating module in the injector is 1.3 MW. Figure. 6 shows one RF station inside the XFEL tunnel.

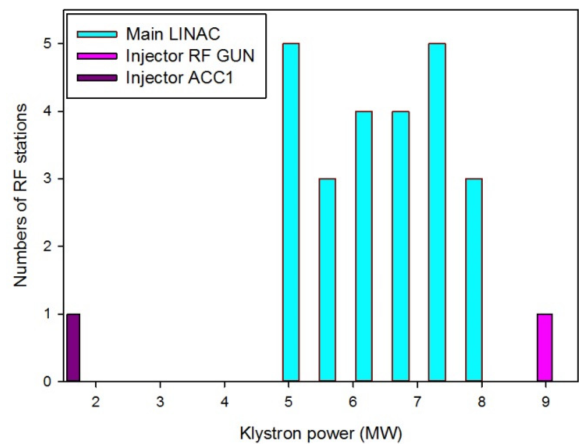

Figure 5: Klystron output power for the XFEL RF stations.

PROTECTION SYSTEM FOR RF STATIONS

The protection system for each of RF station consists of three parts and all of them can stop the HV pulse and RF input signal. The first part is a common interlock that collects data from temperature sensors, cooling water flow sensors, levels of currents and voltages in the solenoids coils, reflected RF power levels. It has a connection to the main accelerator protection system and to other external protection systems. The reset of this interlock is possible only by operator or by the main protection system.

The second part of the protection system is a local interlock for the klystron filament and vacuum level in the tube. In dependence on the current in the ion pumps and the cathode heating time, interlock signals sent to the common interlock signals are: filament ready, stop RF, stop HV and stop filament. The interlock resets automatically, when the level of ion pump current returns below the thresholds. An optional part is the KLM (Klystron Lifetime Management System) [7, 8 and 9]. The KLM was developed during klystron test on the klystron test stand. The main task of the KLM is to stop the operation of tube as fast as possible when predicted parameters of the tube are different to the measured parameters. For an M-type cathode used in the XFEL MBK and the maximum cathode current density one can expect a theoretical average lifetime up to 145000 hours. In reality however, the klystron lifetime does not depend only on the type of cathode, but also e.g. on the number of gun arcs, RF breakdown inside the tube, klystron beam losses and the number of filament on and off cycles. The RF part of KLM uses 6 RF signals, two are the forward and reflected RF power from the klystron input cavity, and the four other RF signals are the forward and reflected power of the two klystron output arms. Additional signals like four pulse signals are available from the klystron. Two pulse signals are the klystron cathode voltage and cathode current shapes. These signals are used for the measurement of the saturated klystron power, long term klystron cathode emission and the detection of partial discharge in the HV

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system. The other two pulse signals are the vacuum ion pump current during HV pulse and the sum of the outputs of two light spark detectors installed close to klystron output windows. These signals are connected to the KLM, which controls the klystron RF input. In case of an RF station trip all measured signals are analysed and used to start the right recovery procedure. The partial discharge measurement can be used to make a prediction of the life time for all of the HV components (such as CM, HV cable, HV connectors and pulse transformer). At present the RF part of the KLM is already installed for 10 XFEL RF stations, the pulse part might be installed later.

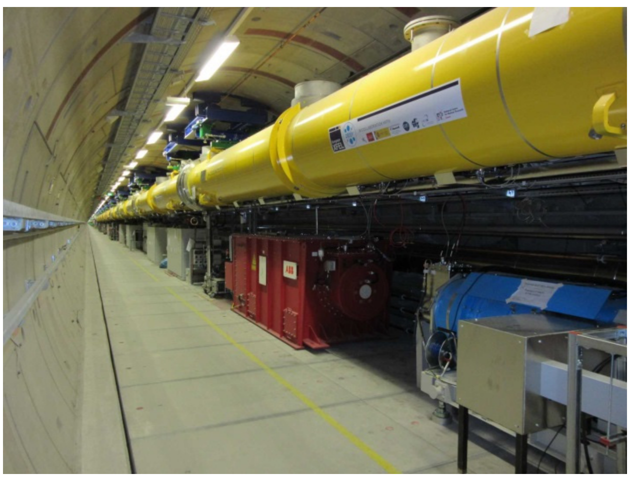

Figure 6: One of the RF stations inside the XFEL tunnel.

For the reliable installation and operation of all klystrons in the underground tunnel correct measurement and interlock signals are important. A special portable electronic create named as “klystron simulator” (KS) was developed which allows the calibration and check of the interlock devices.

CONCLUSION

All of the MBKs for the European XFEL were delivered from two vendors. After six years of testing and conditioning of MBKs for the European XFEL on the DESY test stands, twenty four MBKs are already installed in the main underground XFEL tunnel and two are installed inside the XFEL injector area. During the commissioning of the XFEL injector, one of the RF station operated already more than 9000 hours. Several of the RF stations inside of main underground tunnel are already tested in place and were operated for conditioning of the couplers in the cryogenic modules. We expect the delivery of last two additional MBKs before the end of this year.

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