ISBN: 978-3-95450-214-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2021-WEPAB045

EUROPEAN XFEL HIGH-POWER RF SYSTEM – THE FIRST 4 YEARS OF OPERATION

M. Bousonville†, S. Choroba, S. Göller, T. Grevsmühl, A. Hauberg, V. Katalev, K. Machau, V. Vogel, B. Yildirim, Deutsches Elektronen-Synchrotron, 22607 Hamburg, Germany

Abstract

In 2016, the installation of the European XFEL was completed and its 26 RF stations started operation in 2017. Each RF station consists of a 10 MW-1.3 GHz-multibeam klystron, a HV pulse modulator and a waveguide system to supply the superconducting cavities and the normal-conducting electron gun with RF power. During commissioning and subsequent operation, the RF stations were closely monitored and causes of failures were investigated. For the optimisation of the RF systems, the various RF station failures were evaluated according to their impact on accelerator operation and the measures to eliminate them were prioritised accordingly. This report describes the operation experience and improvements of the high-power RF stations during the first 4 years of operation.

SYSTEM OVERVIEW

A total of 97 superconducting accelerator modules are powered by the high-power RF system. The high-voltage pulses for the klystrons are generated above ground in a hall and fed to the RF stations via pulse cables up to 2 km long (Fig. 1). Their voltage is 6.3 to 9.2 kV, which is transformed up to 76 to 108 MV with the help of a transformer in the tunnel and then fed to the klystrons. The RF power range from 0.7 to 6.3 MW, depending on the operating mode of the accelerator, and are thus partly higher than specified in the TDR [1]. 24 of the RF stations are installed directly under the accelerator modules in the same tunnel. Each RF station supplies 4 accelerator modules with 8 cavities each. The RF power generated by the klystron is coupled out via two klystron RF windows and then distributed to each of the 32 cavities of 4 accelerator modules (Fig. 2).

As it turned out during the production of the accelerator modules that the quench limits of the cavities are very different, the power distribution over the waveguides was adjusted. Cavities that quench at lower RF powers receive less power, while cavities that can be operated at higher powers receive more. In this way, the gradient per RF station could be significantly increased [2]. Some cavities have been completely removed from operation by detuning. However, the reflected power is not a problem because a circulator is installed in front of each cavity.

Many vital functions of the RF system are monitored by an interlock system, such as:

- Cooling water flow in klystron, pulse transformer, waveguides etc.
- Oil levels in the pulse transformer
- Vacuum in the klystron

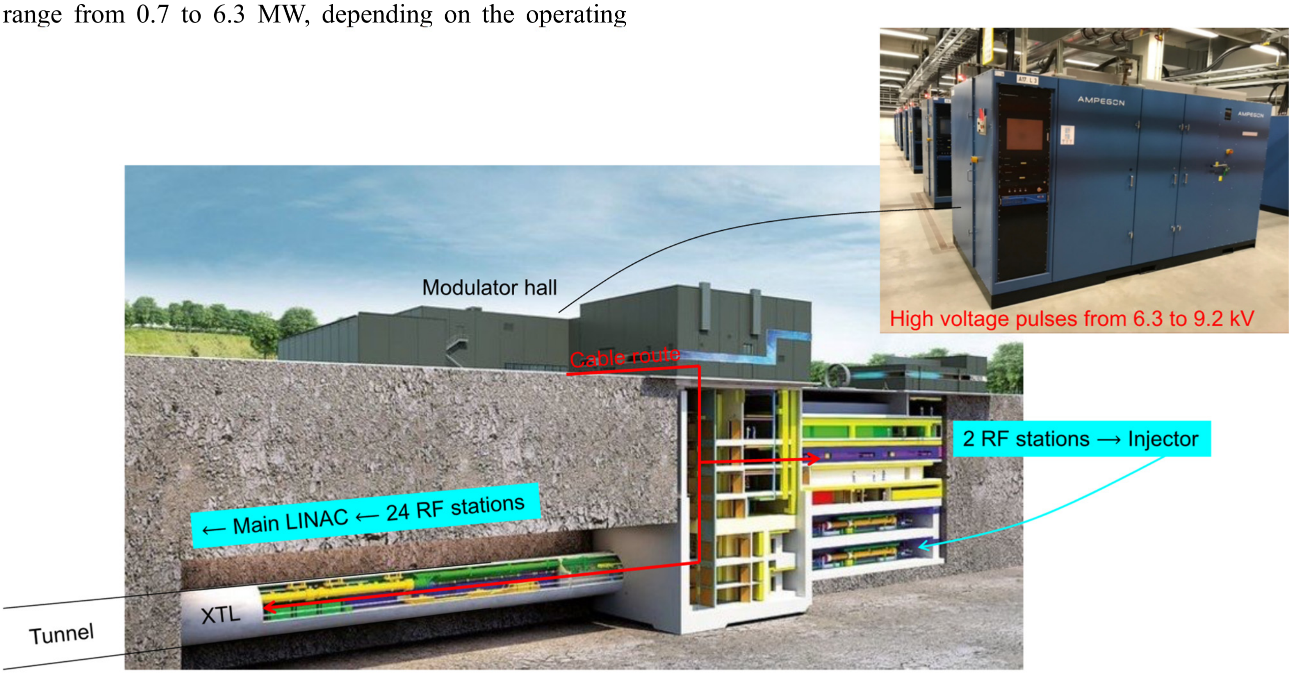

Figure 1: Hall with 26 modulators and cable routes for the high-voltage pulses to the RF stations.

† michael.bousonville@desy.de

ISBN: 978-3-95450-214-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2021-WEPAB045

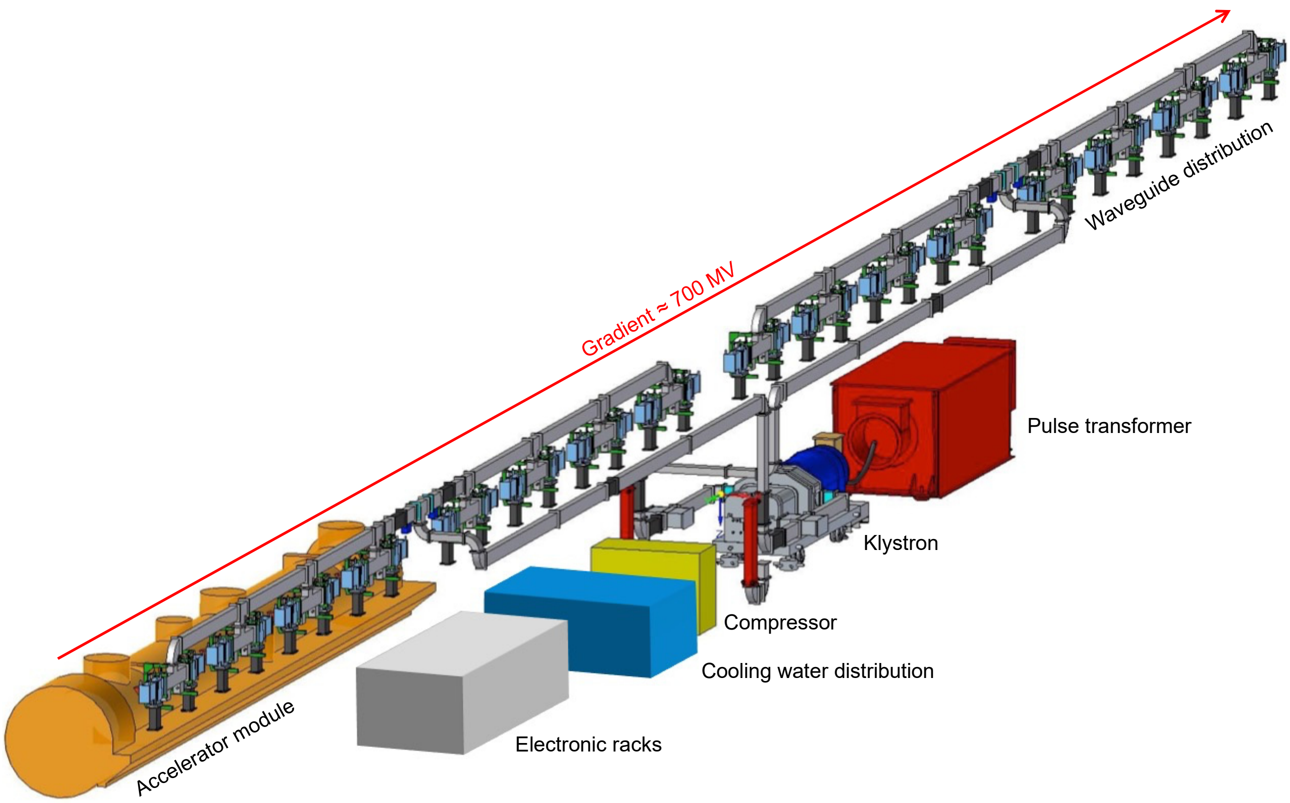

Figure 2: One RF station in the accelerator tunnel.

- Temperatures in the klystron, pulse transformer, and waveguides (harmonic filters and circulators)
- Currents and voltages
- Oil moisture measurement in the pulse transformer
- RF leaks
- RF power.

However, it is not only an interlock system, but also monitors many of the mentioned parameters over time. With the help of software that has been developed, one can quickly get an overview of the operating status of the RF systems and identify errors that occur. The occurring errors are stored continuously in a table and one can easily see which type of error causes how much downtime. Based on this data, the optimisation potential of the RF system was determined.

OPERATION

After a large number of the RF stations had been set up between 2014 and 2016, the superconducting accelerator modules were cooled down from 11 December 2016 on. After the operating temperature of 2 K was reached in January 2017, the commissioning of the RF stations began. The technical problems that arose during the first four years and how they were resolved are described below.

Waveguide Distribution

In 2017, arcing occurred in two waveguide distributions. Using the reflected RF power detected by our interlock system and additional sound sensors, the arcing points could be localised. In each case it was a waveguide phase shifter in which the arcing occurred. These were replaced and since then there have been no more problems with arcing in the waveguide distributions.

Another problem was in the flow monitors for the cooling water of the circulators. Here the hysteresis was so large that some of them switched off safely when the water flow was too low, but did not switch on again after the nominal water flow had been restored. When pressure fluctuations occurred in the cooling water system of the XFEL, e.g. due to power failures, staff had to reset the flow monitors manually. In collaboration with the specialist group for water cooling, a suitable flow monitor with small hysteresis was sought and a manufacturer was found that met the requirements. The flow monitors concerned have since been replaced by this new type.

Klystrons

26 multibeam klystrons are installed in the XFEL [3]. A major problem occurred in one of the 2 klystron types used. Leaks in the solenoid cooling water circuit occurred in 3 klystrons in succession between December 2018 and March 2019. As the cause was not clear at first, the first of these klystrons was replaced. Outside the tunnel, it was then discovered that only one water hose which is not suitable for de-ionised water due to its composition had burst in this type of klystron. In the case of the two subsequent leaks instead of the klystrons only the hoses were replaced at the klystron in the tunnel. As it was only a matter of time before more hoses burst in the other klystrons of this type, all hoses were replaced as a preventive measure in

ISBN: 978-3-95450-214-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2021-WEPAB045

March 2019. Finally, stainless-steel hoses replaced the original plastic hoses.

Replacing a klystron in the XFEL is more complicated than in other accelerator facilities because they are located under the accelerator modules in the tunnel (Fig. 3).


Figure 3: The klystrons are located below the accelerator modules.

Using a crane is not possible and the tunnel transport vehicle designed for the installation phase is very large. It takes 2 days just to get it in and out of the tunnel. Therefore, some measures have been taken to speed up a klystron replacement:

- First of all, a new, much smaller transport vehicle was constructed that can be brought into the tunnel much faster than the one used during the installation phase.
- Spare klystrons have been deposited in the XFEL to shorten the transport time.
- Each spare klystron has all the necessary accessories for the installation.
- The klystron lead shields have been optimised so that they can be dismantled and reassembled as quickly as possible.
- A bag with all the tools needed for klystron replacement is provided.
- The klystrons have been equipped with wheels that allow them to be pushed sideways into the transport path (Fig. 3 on the right).

In this context, it should be mentioned that in the first 4 years of operation, only one of 26 klystrons in operation was used up. This is where the careful initial testing on the test stand pays off. In addition, a lot of time was and is spent on selecting the most stable high-voltage operating points.

Electronics

The electronics are also located in the accelerator tunnel. This means that initially we had to go into the tunnel more often to switch components back on or reset them, which typically caused an hour of downtime. To reduce this downtime, two major optimisations were made here.

During power failures, it happened that circuit breakers tripped. This was investigated and measurements showed that when a complete electronics cabinet was switched on again, inrush currents occurred that were sufficient to trigger the standard circuit breaker (C-type) used. New installed D-type circuit breakers that tolerate 2 times higher and 10 times longer inrush current solved the problem.

The second optimisation was to equip some units with remote-controlled sockets so that power cycles can be carried out without access to the accelerator.

Modulator

There was a very persistent problem here. The modulator electronics consists of 2 boards and a server that communicate with each other via USB interfaces. For reasons that were initially unknown, the communication via the USB interface got lost from time to time, completely unpredictably, sometimes with one modulator, then with another. As a result, the affected modulator stopped operating and could only be restarted by restarting the electronics. This problem was first observed in 2016, but was very rare (MTBF = 104 days). Over time, however, it occurred more frequently. The MTBF shortened to 18 days in 2018 and 2019. In 2020, the probability of occurrence increased by a factor of 10 and became the dominant downtime cause of the high-power RF system (MTBF $\approx$ 2 days). A large number of staff were then deployed to search for the cause, which was finally found in mid-2020. The level of the USB signal with which the components of the modulator electronics communicate was weak, so that bit errors occurred from time to time which led to a communication breakdown. The problem was solved by using USB cables with very low attenuation, so that about 10% more signal level arrives at the USB ports of the modulator electronics. These low attenuation cables were installed in December 2020 and the error has not occurred since.

SUMMARY

In the first 4 years of XFEL operation, the reliability of the high-power RF system was significantly increased. Remarkable is the low klystron consumption so far and the fact that there are hardly any problems with the complex waveguide distributions.

REFERENCES

[1] R. Brinkmann *et al.*, "The European X-Ray Free-Electron Laser Technical design report", DESY, Hamburg, Germany, Rep. DESY 2006-097, July 2007.

[2] S. Choroba, V. Katalev, and E. Apostolov, "Series Production of the RF Power Distribution for the European XFEL", in *Proc. LINAC'16*, East Lansing, MI, USA, Sep. 2016, pp. 1008-1010. doi:10.18429/JACoW-LINAC2016-THPLR067

[3] V. Vogel *et al.*, "Summary of the Test and Installation of 10MW MBKs for the XFEL Project", in *Proc. LINAC'16*, East Lansing, MI, USA, Sep. 2016, pp. 506-508. doi:10.18429/JACoW-LINAC2016-TUPLR017