TOWARDS A MODULATOR FOR THE XFEL RF STATIONS: TEST RESULTS OF THE PROTOTYPE FROM THOMSON MULTIMEDIA

H. Leich, S. Choroba, H. J. Eckoldt, U. Gensch, T. Grevsmühl, M. Grimberg, L. Jachmann, W. Köhler, M. Penno, R. Wenndorff

Abstract

The X-ray free-electron laser European XFEL [1] will generate extremely intense, ultra-short pulses of laser light in the X-ray range and open up highly promising research opportunities for almost all the natural sciences. In the LINAC of the XFEL electrons get accelerated by superconducting cavities. The RF-power required by these cavities is generated at 27 RF-stations. An important part of a RF-station is the HV-pulse modulator, which has to supply 12kV pulses at up to 1.8kA for max. 1.7ms pulse duration and up to 30Hz pulse repetition rate. This pulse is conducted by means of a special HV pulse cable to a pulse transformer, which converts it to typical 120kV/140A. This pulse drives a klystron which feeds the cavities of the LINAC with RF-power.

Although experience exists from the test facilities FLASH (DESY, Hamburg site) and PITZ (DESY, Zeuthen site) a dedicated modulator test facility has been constructed for testing and investigating the modulator prototypes in a real setup similar to that of the future RF-station at XFEL. The result of these tests will influence the final design of the XFEL modulators and the process of modulator procurement for XFEL.

THE XFEL MODULATOR SPECIFICATION

The technical specification [2] for the future XFEL modulator was completed in February 2006 and an invitation to tender was sent out to five companies (Europe and USA) in May 2006. Finally two companies were selected and contracted in January 2007.

Table 1: XFEL Modulator Key Parameters

HV pulse Repetition Rate	1 - 30Hz
HV pulse duration	max. 1,7 ms
Output Voltage.	2 - 12kV
Output Current:	up to 2kA
Average Power	< 380 kW
HV pulse rise/fall time	< 70 µs
Pulse flatness variation	< +/-0.3%
Energy deposit in klystron in case of gun arc	< 20J

Modulators of the bouncer type are well known from the operation of FLASH and PITZ. They are able to fulfill the requirements.

An entire different modulator architecture is the so-called pulse step modulator, which uses several switching modules in series to generate the full output voltage.

WHY A SPECIAL TEST FACILITY IS NEEDED?

The XFEL modulator is a complex system. Testing such a device in a complete RF-system setup is desirable but not possible at the manufacturer's site. To perform precision measurements special test equipment is needed. Furthermore, sophisticated tests have to be done to investigate special technical details (pulse cable, cable compensation network optimization, EMI and others). Long term testing is another important issue. Also, it is necessary to integrate the modulator control into the existing slow control environment (DOOCS). Finally, the results of the test phase will improve (optimize) the specification for the final design of the XFEL modulators.

During the testing process it has to be verified if the modulator prototypes comply with the specification. This covers the specification parameters itself but also inspections of the amplitude/phase stability of the RF-power, drift of the parameters, pulse to pulse variation, pulse transmission over the pulse cable and optimization of the cable compensation network. Furthermore meantime to failure and meantime to repair characteristics have to be verified. The energy efficiency and the EMI behaviour are other topics of interest.

THE MODULATOR TEST FACILITY

The existing klystron hall for PITZ at DESY, Zeuthen site, has been extended to accommodate the Modulator Test Facility (MTF). The construction was finished in July 2006. Since then, all the necessary components like pulse transformers, klystrons, low level RF, pulse cables, water cooling system, main power transformer, the control and interlock hard- and software have been installed.

Figure 1: The new Modulator Test Hall.

Since the test hall was designed to be capable of testing two modulators in parallel the test facility incorporates two complete RF stations. But due to the amount of space required to install the pulse cable only one system is equipped with a long pulse cable.

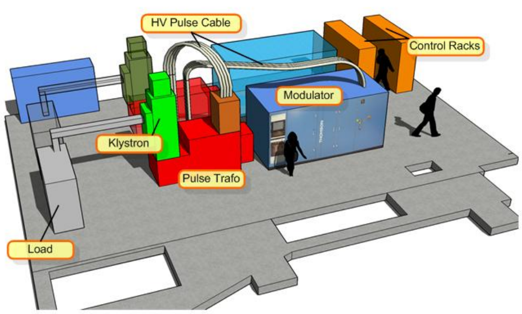

Figure 2: Layout of the MTF test setup.

TEST OF THE FIRST PROTOTYPE

The first prototype was designed and manufactured by Thomson Multimedia, Switzerland [3]. It is a pulse step modulator. In July 2008 the factory acceptance test has been completed successfully at the manufacturer's site and then the device was shipped to the DESY, Zeuthen site.

Figure 3: The Thomson modulator in the MTF hall.

After a short commissioning period long term testing started in October 2008 first with a 5 MW klystron. In October 2009 the test setup was rebuild and we started testing the modulator with a 10 MW klystron from Toshiba. To investigate parameters at full output power and at a repetition rate of 30 Hz a new cable compensation network was designed and installed in March 2010 (Fig. 4).

Figure 4: Cable compensation network for 30 Hz operation.

Fig. 5 shows examples of the voltage and current pulses measured at the modulator output and at the cathode of the klystron.

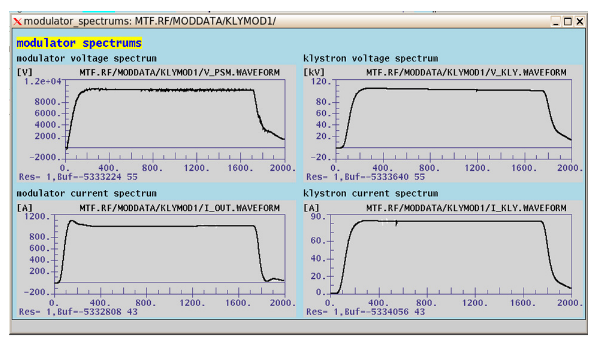

Figure 5: Voltage and current pulses at modulator output and klystron cathode.

The relationship between the pulse repetition rate and the maximum pulse length for a given output power (in this case 280 kW) is plotted in Fig. 6. From the curves an operator can determine the necessary set points for the modulator output voltage.

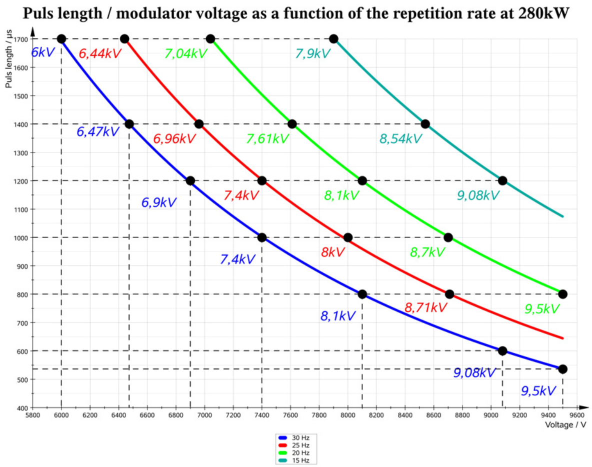

Figure 6: Modulator output characteristics at different repetition rates.

The set points for maximum output power out of the Toshiba klystron have been determined as follows.

Modulator settings

• $U_{modulator}$	9,5 kV
• $I_{modulator}$	1581 A
• HV-Pulslength	1,7 ms
• Repetition Rate	10 Hz

Klystron settings

• Filament Voltage	22 V
• Filament Current	25,6 A
• Cathode Voltage	115 kV
• Cathode Current	131,8 A
• RF-gain	48 dB
• Solenoid Current	50 A

The resulting RF-output power is 4,6 MW / 5,1 MW for the two arms of the klystron output.

TEST RESULTS FOR THOMSON MODULATOR:

- Cumulated run time at end of July, 2010: 3330 hours
- No. of defects/repairs: 1

(one of the switching modules failed to work properly. Since the design of the modulator is strongly modular the modulator continues running after automatic reconfiguration. The defective module has been exchanged during the next shutdown within 1/2 hour.)

- The Thomson Modulator fulfils the specifications at 5 MW and 10 MW klystron output power and up to 30 Hz pulse repetition rate
- The modulator is capable to drive the long HV-pulse cable (625 m in the test set-up)
- One of the benefits of the pulse step design is that the waveform of the output pulses can be controlled by the firmware inside the modulator's control unit.
- Currently a new firmware update is in preparation which provides more freedom when adapting to the needs of the HV-transmission line (pulse cable + cable compensation network)

SUMMARY

At DESY, Zeuthen site, a Modulator Test Facility has been set-up for intensive testing of XFEL modulator prototypes within a complete XFEL like RF environment.

As a result of an international bidding process two companies have been offered contracts to develop and to build a XFEL modulator prototype.

The first prototype was delivered to DESY by Thomson Multimedia, Switzerland, in summer 2008. Systematic testing started in autumn 2008 after a short commissioning phase.

After a testing phase of more than 18 month the Thomson modulator has been certified to be a candidate in the procurement process of components for the XFEL LINAC.

REFERENCES

[1] M. Altarelli et al., "XFEL, The European X-Ray Free Electron Laser, Technical Design Report", DESY 2006-097, July 2007.

[2] "The HV Modulator for the XFEL RF Station. Requirements and Specifications", Revision 2006-05-12, DESY 2006 (DESY internal document)

[3] J. Alex et al, "A new Prototype Modulator for the European XFEL Project in Pulse Step Modulator Technology", TU5PFP101, PAC'09, Vancouver, May 2009