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High-voltage pulse power supply system for klystron in transverse deflecting system of free-electron laser XFEL

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High-voltage pulse power supply system for klystron in transverse deflecting system of free-electron laser XFEL

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Abstract. The high-voltage pulse power supply system has been built as a part of the transverse deflecting system TDS BC1 designed for electron beam diagnostics in the linear accelerator of the X-Ray Free Electron Laser XFEL. The TDS BC1 includes deflecting structure, solid-state modulator, RF generator with THALES TV2002DOD klystron and pulse transformer, the waveguide system and other engineering subsystems. The results of building and testing of the system are considered. The system was successfully tested on a test stand at DESY with the klystron in diode mode as a load at full design parameters: U=260 kV, I=265 A, τ=6 µs.

1. Introduction

Three transverse deflecting systems TDS INJ, TDS BC1 and TDS BC2 have been built within the project of the X-Ray Free Electron Laser XFEL [1].

These systems are to be located on the XFEL electron accelerator axis in the Injector (INJ), after the Bunch Compressor 1 (BC1) and after the Bunch Compressor 2 (BC2), where the electron energy is 130 MeV, 600 MeV and 2.5 GeV respectively. The TDS INJ and the TDS BC2 are installed already in the XFEL linac and operates successfully now. The deflecting structure, the waveguide system and the klystron THALES TV2002DOD of the TDS BC1 are ready for installation in the XFEL linac tunnel. High-voltage pulse power supply system of the TDS BC1 passes the last test before installation in the tunnel. The results of this test are presented in this paper.

The high-voltage pulse power supply system is designed to provide high-voltage pulse power for the klystron, as well as filament power, solenoid power, water cooling and control. Therefore, it includes modulator, filament power supply system, three solenoid power supplies, water cooling distribution system, power supply distribution system, and control system.

3D design of the transverse deflecting system TDS BC1 is shown in figure 1. The deflecting structure as well as connected waveguide system, waveguide load and two ion pumps are fixed on the girder provided with the alignment units installed on the concrete pillars. Two concrete slabs are installed under the girder on the special frame of the TDS BC1 for radiation shielding of the electronic equipment under the slabs. So the modulator and the RF generator are to be located in the space of ~1.6x1.0x1.4 m^3 between concrete pillars under the slabs. Some control and power supply equipment are to be located in a special cabinet in a neighboring space between the pillars.

2. Main parameters

Main parameters of the high-voltage pulse power supply system are presented in table 1.

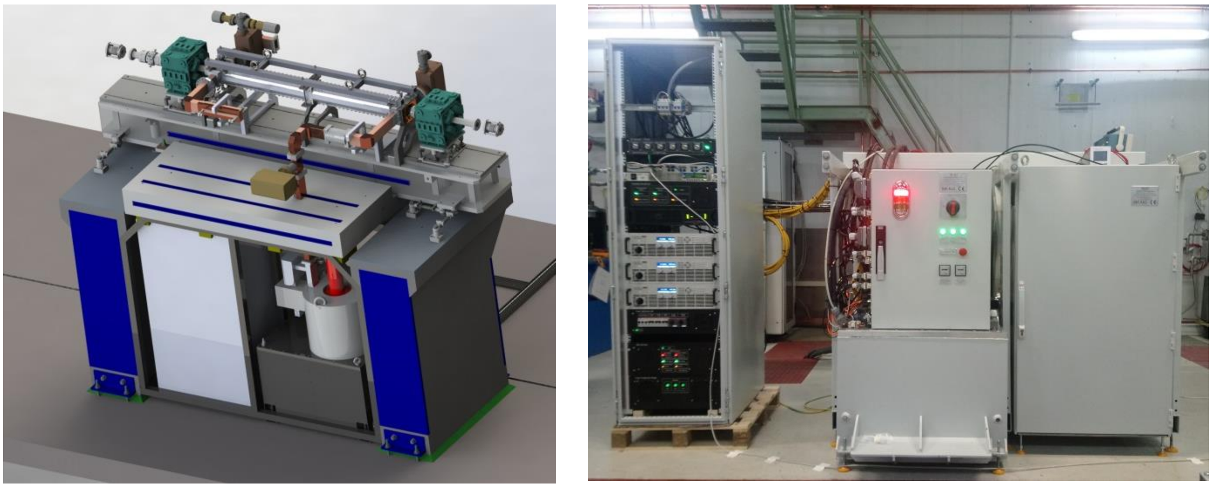

Figure 1. 3D design of the transverse deflecting system TDS BC1 (left) and the system at the DESY test stand (right).

Table 1. Main parameters of the high-voltage pulse power supply system.

Parameter	Designation	Unit	Value
Klystron cathode voltage	U_2	kV	260
Peak klystron cathode current	I_2	A	265
Voltage fluctuation (pulse-to-pulse, rms)	dU_2/U_2	%	0.16
Long-term instability (peak-to-peak)	$\delta U_2/U_2$	%	1
Voltage unflatness (peak-to-peak)	$\Delta U_2/U_2$	%	0.6
Pulse flat-top length	τ	μs	0.1-3.1
Pulse repetition rate	F	Hz	10
Filament voltage	U_f	V	34
Filament current	I_f	A	23

The modulator is provided with a fast interlock, switching OFF the high voltage within the pulse and limiting the current in case of break-down in the klystron.

3. Equipment composition and block diagram

Structurally, the high-voltage pulse power supply system includes modulator, RF generator and control and power supply cabinet. The block diagram of the modulator and the RF generator is shown in figure 2.

The modulator includes 4 modules. Each module is based on the Arkadyev generator scheme with IGBT transistor as a switch and includes 11 voltage levels. Each voltage level includes two parallel IGBTs and 5 capacitors of 2100 μF common capacity. Output parameters of the module are 11kV@1.45kA. Max voltage and current values of the IGBT are 1.7kV@1.6kA. Thus, the IGBT transistor operates with 70% voltage reserve and 120% current reserve. Four modules are connected in two series pairs, as this is shown in figure 2. The modulator power supply charges the capacitors of the modules to the voltage of 1 kV in parallel between pulses. Then, inside the pulse, the control module switches the IGBTs so that the capacitors are connected in series, forming a voltage of 11 kV at the output of each module. Thus, the output voltage of the modulator at two outputs is U_m=±22 kV. This voltage is passed to the primary winding of the pulse transformer.

The voltage and the current at each output of the modulator are monitored via current&voltage sensors. The modulator is provided with the filament and bias power supplies.

The modulator is shown in figure 3.

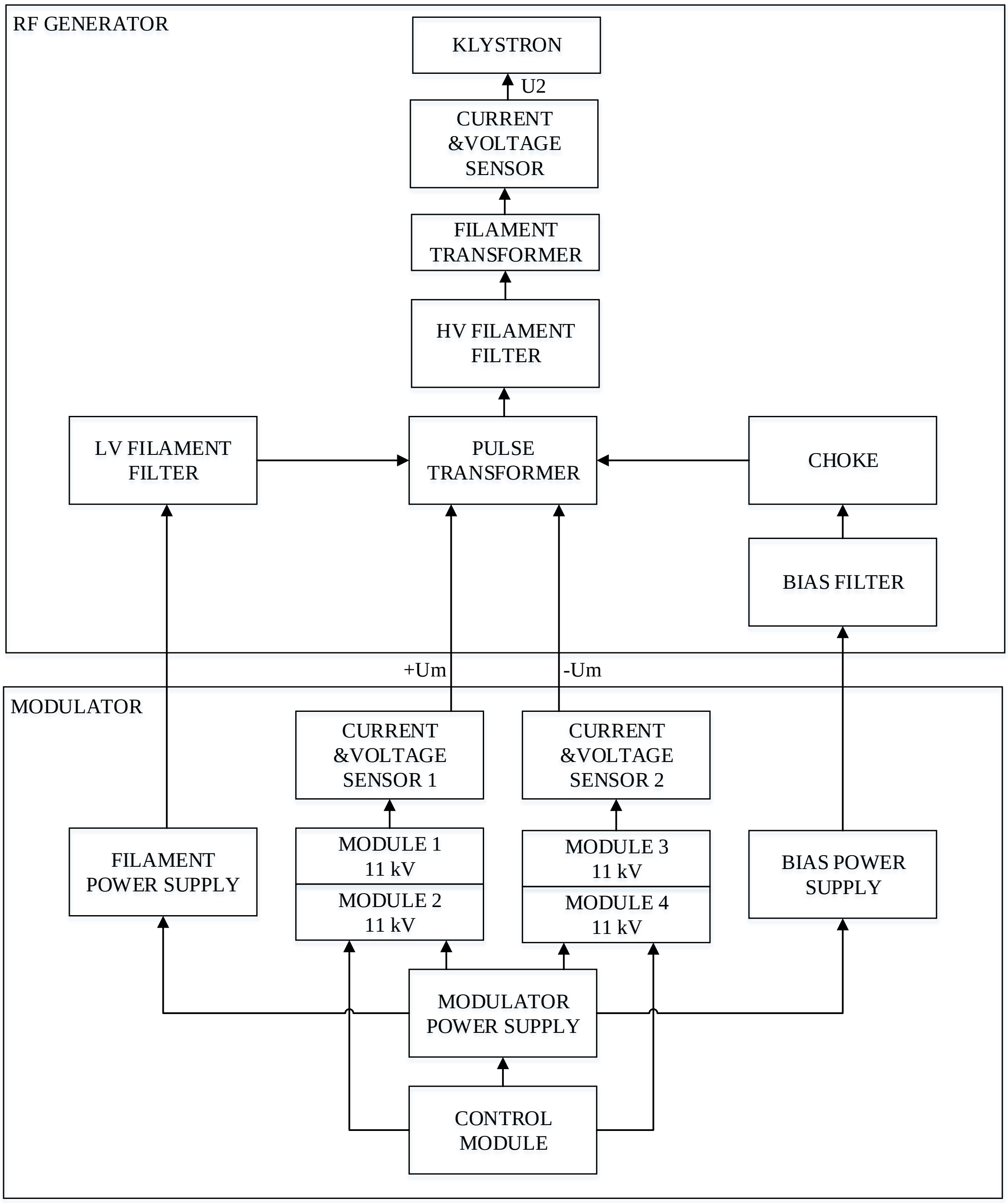

Figure 2. Block diagram of the modulator and the RF generator.

The RF generator includes pulse transformer with primary winding, bias winding and bifilar secondary winding, choke, voltage&current sensor, klystron socket, dielectric frame, 2 high-voltage input sockets, water-oil heat-exchanger, double-wall oil tank with top cover, 2 covers with electrical connectors, cover with oil pump and valves, 3 oil level sensors, high-voltage dried oil, low voltage filament filter, high voltage filament filter, bias filter, bias current interlock unit, oil temperature sensor, klystron, three winding solenoid. The inner view of the pulse transformer oil tank is shown in figure 4.

The control and power supply cabinet includes power distribution unit, modulator power supply, safety earthing unit, personnel interlock unit, filament power supply unit, UPS, ETHERNET switch, control computer, RF controller, three solenoid power supplies.

4. Test of the system

The high-voltage pulse power supply system at the test stand at DESY is shown in figure 1. It includes the modulator (right), the RF generator (middle) and control and power supply cabinet (left). The RF generator includes pulse transformer oil tank, as well as small control cabinet, solenoid and klystron on the top of the tank. The modulator and the RF generator are to be located in the space between the pillars under the deflecting structure. 19” crates of the control and power supply system are installed in the cabinet temporary for the test. Then they will be installed in the special low cabinet in the linac tunnel.

Figure 3. Modulator (left) and 11 kV module (right).

Figure 4. RF generator during assembly.

The system was tested in two steps: a) with an equivalent resistive load connected to the socket in the pulse transformer oil tank instead the klystron first and b) with the klystron then.

The dual equivalent resistive load (shown in figure 5) includes:

- set of resistors connected in series-parallel to operate at full high voltage conditions 260kV&265A instead the klystron cathode-anode circuit,
- set of resistors connected in series-parallel to operate at full filament condition 32V&23A instead the klystron heater at the high voltage ON,
- controlled high voltage discharging circuit to simulate the klystron break-down for the test of the fast interlock,
- stainless steel case of the load,
- oil pumping system to fill the case with the oil from the tank.

Figure 5. The dual equivalent resistive load: top part of the load over the tank cover – on the left, bottom part of the load under the tank cover – on the right.

The measured shape of the voltage and current pulses on the klystron operating in diode mode is shown in figure 6.

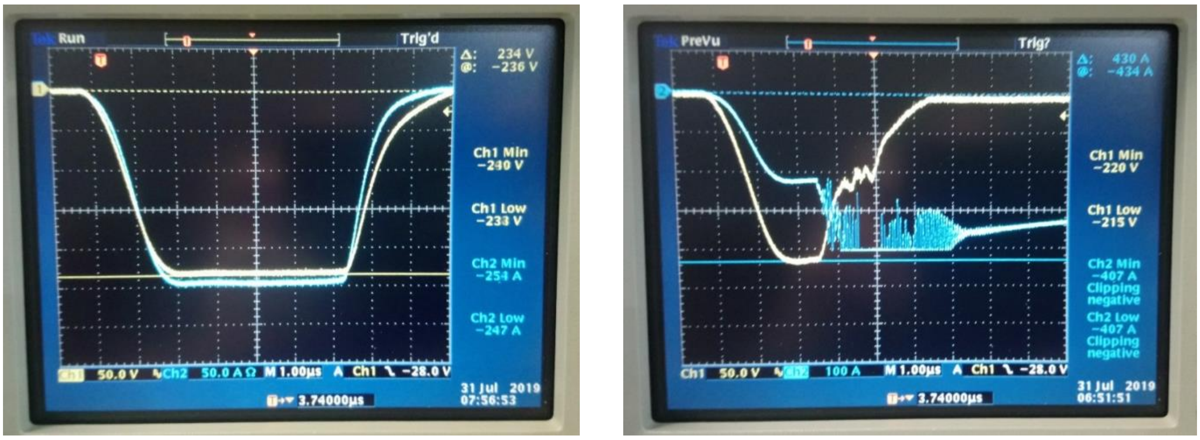

Figure 6. The measured shape of the voltage and current pulses on the klystron: at normal operation – on the left and in the break-down event – on the right.

As a result of the tests, the design shape of the output voltage pulse at the klystron was obtained. The fast interlock disconnects the high voltage circuit for a time of 1.5 μs inside the pulse and limits the klystron current at 400 A level in the breakdown event.

All design parameters of the high-voltage pulse power supply system were obtained during testing. The system is ready for installation at the XFEL linac.

5. References

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[2] Zavadtsev A, Zavadtsev D and Churanov D 2017 Modular compact solid-state modulators for particle Accelerators *Proc. III International Conf. on Laser and Plasma Researches and Technologies* IOP Conf. Series: Journal of Physics: Conf. Series 941(2017) 012095 pp 1-6.

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