Commissioning of the Hard Tube Pulser Experiment at DESY

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Abstract

The development of adequate modulators for high peak power klystrons is one of the focus points for linear collider R & D programs. For the DESY/THD S-band linear collider study 150MW rf-pulse power at 50Hz repetition rate and $3\mu s$ pulse duration is required [1]. Instead of the conventional method of discharging a pulse forming network through a transformer to the klystron, a hard-tube pulser (HTP), which switches the high voltage directly from a storage capacitor to the klystron, offers a simpler design and a better pulse quality. A 25MW rf-power test version of a hard-tube pulser has been built up at DESY. Circuitry and the results of the commissioning of the switch tube are reported.

1 TEST SETUP

A test setup of a HTP capable of powering a 25MW-klystron (Thomson-CSF, TV 2002 DoD, 3GHz) has been built up at DESY.

1.1 Circuitry

Figure 1 shows the circuitry of the HTP test setup. The modulator is designed to produce a high voltage of up to 250kV at a current of 250A. The pulse duration is $3\mu s$ at a repetition rate of 50Hz. The rise time of the pulse is mainly determined by the klystron cathode/filament transformer stray capacitance. Assuming a capacitance of 100pF one calculates a 10%-90% rise time of 175ns. During the pulse the voltage at the storage capacitor only drops by 6%, which can be estimated by $\Delta U=U(1-\exp(\tau/RC))$, where R is the resistance of the klystron of 1000Ω, τ the pulse duration of $3\mu s$ and C the storage capacitance of 50nF. Due to its tetrode characteristics the switch tube delivers a nearly constant current to the klystron. According to the relatively low storage capacitance of 50nF the stored energy can be hold relatively small. At U=-300kV it is only 2.25kJ. This limits the danger of damaging the switch tube by arcing. In this case most of the stored energy goes into the current limiting resistor of 30Ω. Assuming an arc resistance of $100m\Omega$ only 7.5J are dissipated in the tube, which should be safe. The charging resistor of $240k\Omega$ decouples the power supply (and the mains) from the rest of the HTP. It limits the charging current to 75mA peak and reduces voltage ripple caused by the the power supply.

1.2 Hardware

Our power supply is capable of delivering a high voltage of U=-300kV at an average current of 50mA. It is an air insulated power supply consisting of lumped elements. In order to give the ability to change parameters of the HTP as fast as possible, charging resistor and storage capacitors are under air as well. We also have additional high voltage capacitors and resistors, which allow us to change parameters of the HTP to longer pulses or lower voltage drop during the pulse. Via a HV-cable the HV is fed into an oil tank (diameter 1.6m, length 3.5m) containing about $6m^3$ oil.

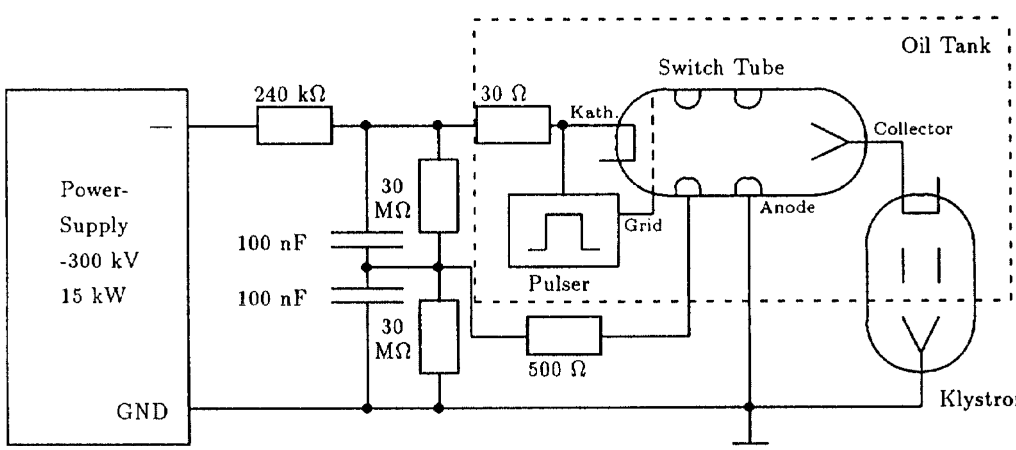

Figure 1: Circuitry of the Hard Tube Pulser

The current limiting resistor, switch tube and klystron kathode are housed in this tank. Also the filament transformers, diagnostic elements and the grid pulser are inside the tank. All these components are accessible through flanges. A lot of feed throughs, electrical and optical, serve for diagnostics and the control of the HTP. An oil circulating systems is needed for cooling, especially the electrodes of the switch tube. The whole system is sited in concrete shielding ($8.5 \cdot 6.5m^2$, 4m high) to protect people from HV and x-rays. It is driven and controlled from a separate control room.

Figure 2 shows the interior of the oil tank.

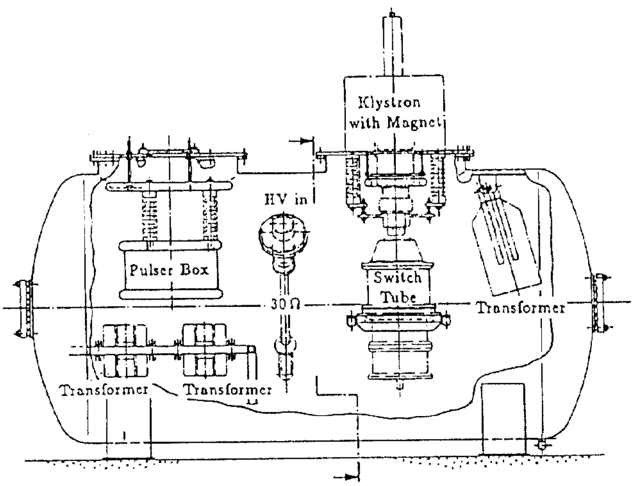

Figure 2: Sketch of the Modulator Tank

2 FIRST TESTS

First tests of the system began in spring 93. The whole system, consisting of the power supply, the switch tube, the klystron, the grid pulser, the control system, the cooling system and the interlock system came into operation without major problems. However, as the switch tube was an unconditioned tube, it had to undergo several procedures such as highpotting and heater aging.

Figure 3 shows typical pulse forms of the hard tube pulser.

The pulse forms were recorded at a power supply voltage of 81kV, a bias voltage of 1200V and a grid pulse voltage of 2800V.

Channel 1 shows the klystron voltage (17.66kV/div). The flat top voltage is 71.7kV, the risetime (10-90%) is about 400ns, the ripple on the flat top is below 1%. Due to the very long fall time of the grid drive pulse, the fall time of the klystron voltage is above $5\mu s$. For the next test run this was improved by adding a tail biter to the grid pulser circuitry.

Channel 2 shows the klystron current (10A/div).

Channel 3 shows the current from the switch tube anode to ground (2A/div). The spike at the beginning of the

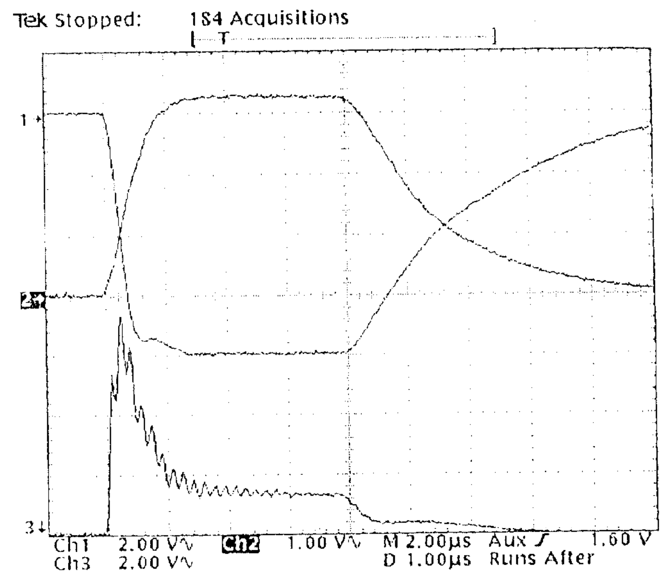

Figure 3: Typical Pulse forms of the HTP.
Chan.1: Klystron Voltage, 17.66kV/div
Chan.2: Klystron Current, 10A/div
Chan.3: Anode Current, 2A/div
Timebase: $1\mu s$/div

pulse is caused by secondary electrons, emitted from the collector. The first electrons coming from the cathode are accelerated by the full power supply voltage when they reach the collector. The secondary electrons created by these high energy electrons are emitted towards the anode. By leaving the collector they lower its potential. This effect limits the risetime of the klystron voltage and could be minimized by an improved collector design.

The timebase for all channels is $1\mu s$/div.

2.1 *Saturation*

Figure 4 shows pulse forms that were taken under the same conditions as those in figure 3, but at an increased grid pulse voltage. The pulse forms were recorded at a power supply voltage of 81kV, a bias voltage of 1200V and a grid pulse voltage of 2920V.

Channel 1 shows the klystron voltage. Here the flat top voltage is 77.7kV.

Channel 3 shows the current from the switch tube anode to ground (2A/div). The timebase for all channels is $1\mu s$/div. At the end of the pulse there is a slight increase in the anode to ground current. At this point the cathode voltage, which is decreasing during the pulse due to the small storage capacitor, has reached the level of the collector voltage. Some of the electrons, that were emitted from the cathode, do not reach the collector and turn back to the anode, causing the increased ground current. The collector voltage decreases, the switch tube is driven into saturation. To avoid saturation, the anode to ground current has to be monitored carefully.

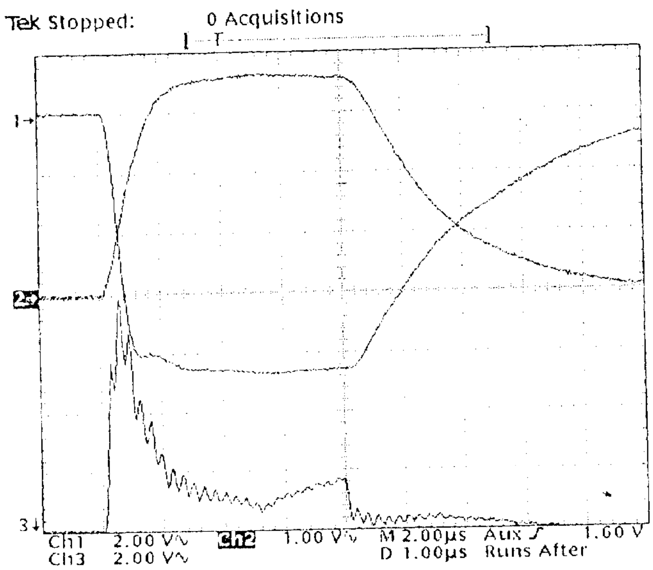

Figure 4: Increased Grid Pulse Voltage, Saturation.
Chan.1: Klystron Voltage, 17.66kV/div
Chan.2: Klystron Current, 10A/div
Chan.3: Anode Current, 2A/div
Timebase: $1\mu s$/div

2.2 *Long Pulse Application*

Figure 5 shows an example for a long pulse application of the hard tube pulser.

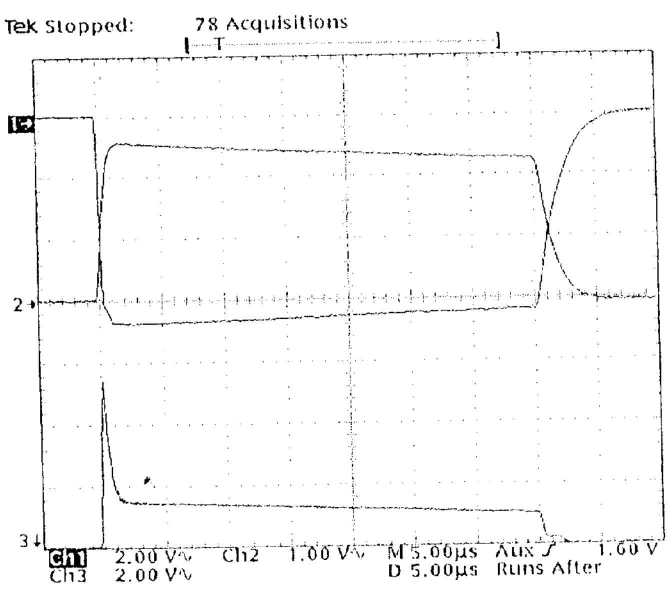

Figure 5: Long Pulse Application.
Chan.1: Klystron Voltage, 17.66kV/div
Chan.2: Klystron Current, 10A/div
Chan.3: Anode Current, 2A/div
Timebase: $5\mu s$/div

The pulse forms were recorded at a power supply voltage of 79kV, a bias voltage of 1200V and a grid pulse voltage of 2420V. The pulse length was increased to $35\mu s$.
Channel 1 shows the klystron voltage. Here the peak voltage is 60.4kV.
Channel 2 shows the klystron current.
Channel 3 shows the current from the switch tube anode to ground (2A/div).
The timebase for all channels is $5\mu s$/div.
Klystron voltage and current show a drop during the pulse, caused by a drop of the storage capacitor voltage during the pulse. The capacitance of the storage capacitor was originally chosen for a pulse duration of $3\mu s$. At $35\mu s$ pulse duration the voltage at the storage capacitor and so the switch tube cathode voltage drops by about 20% of the initial charging voltage. The tube can not compensate for this large voltage drop, the current through the tube decreases and so does the klystron voltage. Since the switch tube cathode voltage drops significantly during the pulse, but has to be kept well above the klystron voltage in order to avoid saturation at the end of the pulse, the switch tube has to be operated with a relatively large voltage drop across the tube at the beginning of the pulse. For long pulse applications a larger storage capacitance, which allows smaller voltage drops, must be chosen. For our application with a pulse duration of $3\mu s$ a storage capacitance of 50nF is absolutely sufficient.

2.3 *Operational limits of the switch tube*

During the commissioning of the Hard Tube Pulser the operating voltage was limited to about 120kV by breakdown in the switch tube. A relatively high gas pressure in the cathode region caused breakdown between grid and cathode. The bias voltage broke down and the subsequently emitted high electron current caused a high voltage breakdown in the tube.
To improve this situation the tube was shipped back to the vendor, the cathode heater package was redesigned and an additional vacuum pump was mounted on the cathode flange. The rebuild of the tube is finished, the tube is back in the modulator tank and ready for a new test.

3 REFERENCES

[1] K. Balewski et.all., Status Report of a 500 GeV S-Band Linear Collider Study, *DESY 91-153,* December 1991