HARD TUBE PULSER FOR 150 MW KLYSTRON

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INTODUCTION

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 3mks pulse duration is required. Two different modulator schemes were investigated. One is the conventional line type pulser, using a pulse forming network and a step up transformer, the other one is a Hard Tube Pulser, using a DC power source at the full klystron voltage and a switch tube. The main advantages of a Hard Tube Pulser are short rise and fall times of the HV pulse, resulting in high efficiency and simpler design.

A 25MW RF power test version of a Hard Tube Pulser has been built up and tested at DESY. Fig. 1 shows the basic circuitry of a Hard Tube Pulser.

A high voltage power supply is used to charge a capacitor (or some other storage element) to the full operating voltage of the klystron. This storage element is connected to the switch tube, a vacuum tube with a gridded gun, that is able to switch the full operating voltage of the klystron. If the grid is driven to a positive potential with respect to the cathode, electrons are emitted from the cathode, go through a hole in the grounded anode and hit the collector, driving it negative to almost the cathode potential. The collector of the switch tube is connected to the cathode of the klystron, supplying it with a HV pulse of the length of the switch tube grid pulse. During the pulse the storage element is discharged to about 90% of its initial voltage, and between the pulses it is charged again.

As long as the cathode voltage of the switch tube does not change by more than 10% during the pulse, the switch tube delivers a constant current, resulting in a constant klystron cathode voltage.

In order to evaluate the advantages and disadvantages of a Hard Tube Pulser, a test setup with a 150kV switch tube was set up at DESY [1][2], a study about a 600kV switch tube pulser was written at INP, Novosibirsk [3], and a study about a 560kV switch tube was written by CPI, Palo Alto [4]. In addition to the tests theoretical investigations were carried out about a Hard Tube Pulser for a klystron delivering 150MW RF power. The results of these studies are presented. Finally the efficiencies of a Hard Tube Pulser and a line type pulser for a 150MW klystron are compared.

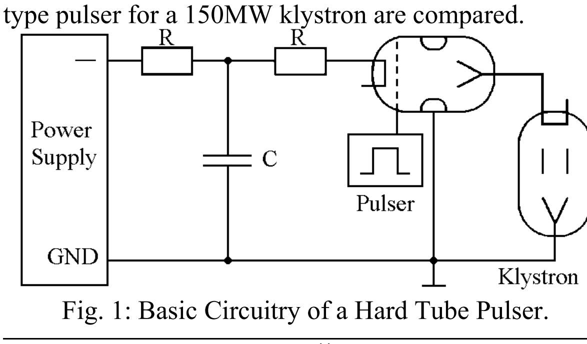

Fig. 1: Basic Circuitry of a Hard Tube Pulser.

PROPOSAL FOR A 600 KV HARD TUBE PULSER

Fig. 2 shows the circuitry of a Hard Tube Pulser, as proposed in [3].

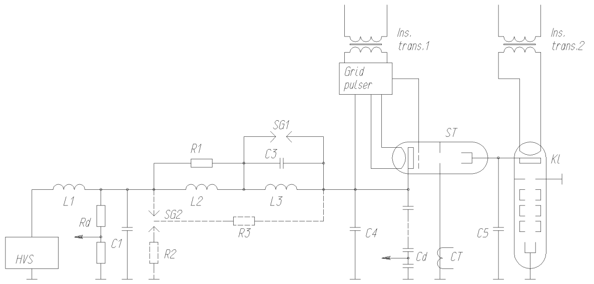

Fig. 2: Circuit of a 600 kV Hard Tube Pulser. *HVS* - high voltage source; *Kl* – klystron; *ST* – switch tube; *CT* – current transformer; *Rd* – resistive divider; *Cd* – pulse divider; *L1* – protection choke; *C1*, *C3*, *L2*, *L3*, *R1* – elements of PFN; *C4*, *C5* – spurious capacitance; *R2*, *R3* – limiting resistors; *SG1*, *SG*2, *SG3* – protection spark gaps.

The high voltage power supply, the storage elements, the switch tube and the cathode of the klystron are all in one oil tank. The filament power for switch tube and klystron and the power for the switch tube grid pulser are fed into the tank by insulating transformers. The tank (without the klystron) has a height of 2.25m, a width of 1.75m and a length of 3.75m.

HVS consists of a step-up transformer with a closed core and a full-wave rectifier. The secondary winding of the transformer is divided into coils, which (together with diodes) form sections of the rectifier. Twenty-five sections make a column, providing the preset voltage. A one layer primary winding is conic in shape to decrease the leakage inductance. Rectifier diodes of SEMIKRON HSKE-14000/6300--0.4 type are used for the rectifier. A high voltage choke capable of a short time operation is used here to protect the rectifier elements in a situation of a total voltage breakdown. It inductance is 1 mH. The choke is equipped with a resistive divider providing for a sufficient damping in case of breakdowns. The choke connects the high-voltage electrode of the HVS with the rest of the circuit.

The energy storage unit consists of a storage capacitor *C1* and a simple pulse forming network (*Rl*, *C*3, *L*2, *L*3). High voltage capacitors PERTINOL ROK 200/V at an operating voltage of 210 kV and a capacitance of 75 nF are used as energy capacitors. Three capacitors are connected in series in a special module with admissible dimensions to obtain a specified voltage of 630 kV. PFN elements, excluding the energy storage *C1* are united into one assembly unit. Taking into account the stray capacitance of switch tube and klystron, the elements of the pulse forming network can be optimized reaching a rise time of the klystron voltage of about 500ns and a fall time of about 1 µs.

Function-unit principle is realized in design of pulser box. Low current electronic plates are located in a frame assembled of an aluminium profile, special configuration VME type. The frame is located in a hermetic container with necessary electrical connectors. Other components of the unit are submerged in oil. All components of the unit are placed in a square (but with necessary rounds off) metal container which is at a high potential. The container is installed on a support insulator designed to operate at a high constant voltage. There is a special connector on the wall facing the switch tube. It allows to quickly replace the tube. The unit is powered via an insulating transformer with its primary winding located on the tank wall, and the secondary one located on one of the container walls.

The protective spark gap of ST is located near the ST cathode insulator. It is mounted on the tank wall to be able to feed the gas mixture for blowing. The protective spark gap of modulator is mounted on the tank wall also for the purpose of blowing. Besides, such a design allows to open the inside cavity of the spark gap in order to check and restore the electrodes without draining the oil from the tank. A resistor 12 Ohm absorbing the energy at an action of the spark gap is mounted at the spark gap end.

Fig. 3 shows the calculated waveforms of the klystron cathode voltage and the voltage across the switch tube. Trace shows a blowup of the klystron voltage flat top. The ringing on the pulse is of the order of ±0.6%.

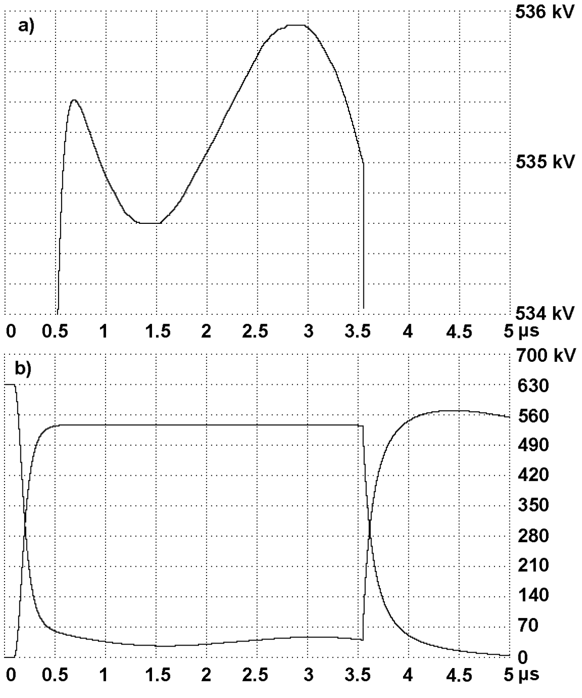

Fig. 3: a) – pulse flat-top on klystron, b) – pulse voltage on klystron and switch rube.

PROPOSAL FOR A 560 KV SWITCH TUBE

The design of a 560 kV switch tube has been investigated by CPI (former Varian), Palo Alto. Fig. 4 shows the design of the proposed switch tube, the preliminary specifications of the tube are given in Table 1.

Table 1: Specifications of the Switch.

Cathode voltage, kV	622
Anode voltage, kV	0
Collector voltage, kV	560
Efficiency, %	90
Beam current, A	503
Microperveance, $AV^{3/2}$	1.025
Pulse width, μs	3
Duty cycle	$1.5\ 10^{-4}$

The insulator between cathode and anode is divided into 6 ceramics and 5 intermediate electrodes to keep the maximum hold off voltage between adjacent electrodes below 110 kV. Experience with the switch tube tested at DESY indicated that the voltage hold off capability on the DC side of the switch tube is one of the key problems of these tubes.

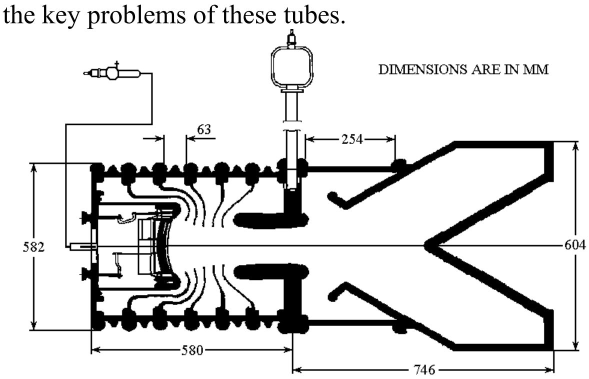

Fig. 4: Design of the proposed switch tube.

The electron beam, emitted from the gridded gun, is electrostaticly focused, passes through the grounded anode, widens up behind the anode and hits the collector. Calculations of electron trajectories show that the collector can be depressed to at least 91 % of the cathode potential without the risk of returning electrons, which might hit the anode and cause breakdown.

With the switch tube investigated at DESY a collector depression of 92 % could be reached.

EFFICIENCY OF A HARD TUBE PULSER

For a prediction of the efficiency of a Hard Tube Pulser, the maximum collector depression of the switch tube is an essential parameter. For further calculations a maximum depression of a well-designed collector of 95% will be used as an upper limit.

Calculations of the losses in all modulator components lead to an average input power (HV supply, electronics and switch tube filament) of 74960 W. The useful power, i.e. the power in the flat top of the switch tube pulse (535 kV, 700 A, 3 μs, 50 Hz), is 56175 W. These numbers lead to a total efficiency of the proposed Hard Tube Pulser (useful power divided by input power) of 75 %. This has to be compared with efficiencies of 50-60 % of existing line type modulators and 70% of proposed line type modulators [5]. Although the power efficiency of a Hard Tube Pulser is of the same order as the efficiency of a well designed line type modulator, the total operating costs of a Hard Tube Pulser will be higher due to the limited lifetime and high price of the switch tube. The lifetime of a switch tube will be of the same order as the lifetime of aklystron (typically given by the cathode lifetime), and the production cost will be at least as high as that of a klystron (big ceramic, many intermediate electrodes). This has to be compared with the lifetime and production costs of thyratrons, which are the only major parts of line type modulators that have to be replaced regularly. It also should be mentioned that replacing a thyratron is a much faster job than replacing a switch tube, because the oil tank has to be drained and taken apart to remove the switch tube.

With the efficiency of a Hard Tube Pulser being not better than the efficiency of a line type modulator, and with the remaining R&D necessary to transfer the proposed Hard Tube Pulser and the proposed switch tube into real hardware, for the required power level a Hard Tube Pulser can not be recommended as an alternative to a line type modulator.

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