A LONG-PULSE MODULATOR FOR THE TESLA TEST FACILITY (TTF)

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Abstract

TESLA will be a TeV-Energy Superconducting Linear Accelerator where superconducting (sc) 9-cell Niob-cavities with field gradients of more than 25MV/m will be the key elements. For the TESLA Test Facility (TTF) "long-pulse"-klystron modulators must generate 1.6 ms output pulses with an output power up to 20 MW which is flat to within 1% during 1.5 ms. The main goal of the development at PPT is to optimize the existing modulator design towards a reliable and cost-effective design to allow for a industrial series production of pulse modulators for sc-accelerator operation.

Based on the first design of Fermilab [1] the main features of the redesigned new pulse modulator sub-assemblies are: 1) a compact 300-kW/12-kV switched mode power supply; 2) a volume optimized 1.4-mF storage capacitor bank using high energy capacitors with self-healing segmented PP-foil technology; 3) a rugged , compact solid-state switch stack with seven 4.5-kV IGCT`s, integrated gate units and a current turn-off capability up to 4 kA; 4) a solid-state crowbar switch assembly based on light-triggered high current thyristors replacing the ignitron tubes.

INTRODUCTION

The TESLA cavities will be used in the linac cryo-modules of the TTF2-Free Electron Laser (FEL) project, further for the 35-GeV-linac, driving the European X-ray FEL at DESY and the planned electron-positron linear collider TESLA. One important characteristic number of sc-cavities is the 'quality factor' Q. Q_{sc}-values > 10^{10} exceed the Q-values of conventional normal conducting cavities by more than 10^5. This high Q_{sc}-values increase the filling time of cavities; the TESLA-cavities with an operating frequency of 1.3 GHz need a filling time of more than 0.5 ms. With a required rf-flattop of up to 1.0ms the TESLA rf-source must generate ms-pulse lengths.

In the TTF-project different accelerator subsystems are under test. For the rf-generation different types of 1.3-GHz-klystron tubes are in operation: A 5-MW conventional single beam klystron TH2104, a special developed 10-MW multibeam klystron TH1801 from THALES and at the end of 2004 alternative multibeam klystrons from CPI and Toshiba.

Tab. 1 shows some features of the THALES-klystron.

Table 1: Technical data of "Long-pulse" klystrons

Klystron		TH2104	TH1801
		max	max
Klystronperveance	$AV^{-1.5}$	2,0E-06	3,4E-06
Number of beams		1	**7**
Cathode Voltage	kV	130	120
Anode Current	A	92	140
Impedance	kOhm	1,41	0,86
Input Power	MW	11,96	16,80
Efficiency (min)	**%**	42	60
Output Power	MW	5,0	10,1

TTF MODULATOR

HV-Power Supply

To operate the TTF-klystron modulators the HVPS´s must be able to deliver an electrical peak power up to17 MW with a dc-output voltage up to 12 kV. The load is a 1.4-mF capacitor bank with a storage energy up to 100 kJ - which must deliver periodically current pulses up to 1700 A and pulse lengths up to 1.6 ms. The maximum droop of the the capacitor voltage is about 16 % which must be recharged by the HVPS. The pulse repetition rate may vary in steps from 0.1 to 10 Hz. This operation modus requires a rms-power of about 300 kW. To run large numbers of modulators this units mustbe operated in "constant-power-mode" in order to minimize the generation of low-frequency disturbances on the mains. An essential HVPS-part to achieve this constant power mode is a fast intelligent regulating system which has been developed at DESY.

Pulse Generator

The pulse generator is a solid-state-switched capacitor discharge which will be droop-compensated by an appropriate L-C-ringing circuit (bouncer) [1]. The main components of the pulse generator are: The storage capacitor bank, the crowbar switch, the solid-state high power switch, the droop-compensating bouncer circuit, the undershoot circuit and the backup switch.

PPT tries to reduce the construction efforts and to minimize costs focussing on components widely used in industrial applications.

The main redesigned sub-assemblies of the new, improved pulse generator are:

A volume optimized storage capacitor bank using self-healing Polypropylen capacitors; a rugged, compact12-kV IGCT-switch stack with a 4-kA current turn-off capability and a 100-kA solid-state crowbar switch with light-triggered thyristors.

Storage Capacitor Bank

The original storage capacitor bank designed by Fermilab was based on fifty-six 12-kV-capacitors of 25µF. These dc-filter capacitors are built in aluminum foil technology with paper dielectrics. This technology needs special protection against catastrophic discharge of capacitor bank members into one subunit in case of a capacitor failure. The controlled self-healing technology with segmented, metallized polypropylen films has been evolved for the use in high voltage/high energy capacitors and further improved by the use of internal "fuse gates". No catastrophic failure with an internal high energy discharge will occur even without any external protection circuit. The new technology combines two benefits: First, a controlled self-healing behaviour and second, a superior energy density due to impregnation. The result is a very compact capacitor with stored energies of about 100kJ within a volume of less than $0.75m^3$.

Table 2: Comparison of different capacitor banks

Company			GE	AVX
Type			TTF1/3	TTF
Capacitance	C	uF	25	488
Cap bank no			56	3
Rated dc voltage	Vdc	kV	12	12
Storage energy	Wc	kJ	1,8	33,6
Total cap-bank				
Capacitance	CF	uF	1400	1464
Storage energy	Wc	kJ	100,8	100,8
Fault current	If	kA	120	150
Lifetime (min)		h	90.000	139.000
Weight (total)		kg	2.184	585

Solid State On-/Off- Switch

A characteristic feature of the "long-pulse", high power klystron modulator is the use of a solid state on-/off-switch. This switch assembly must be able to sustain dc-voltages up to 12 kV and to switch off currents up to 1700 A during normal operation and at least 3000 A under fault conditions. The first three generators built at Fermilab used a series combination of six GTO's and later twelve 1600V high-current IGBT-modules.

In the new TTF-generators built at PPT a new IGCT-switch assembly in a rugged, compact stack arrangement is used. An Integrated Gate Commutated Thyristor (IGCT)-switch is a solid state switch derived from former GTO-switch topology. The IGCT-wafer is packed in a new, extreme low-inductive ceramic housing with a ring electrode as gate terminal.

This gate geometry allows for direct coupling of the power switch to the gate driver board.

Due to the low inductance of the integrated gate circuit the IGCT shows a nearly instantaneous turn-off behaviour. There is no dv/dt-limitation. To give the main switch a high immunity and safety against fast powerful pulse-spikes a compact R-C-D-snubber network and a high power varistor stack are parallel to the IGCT-stack. Integrated low-inductive gate driving units and a common trigger distribution box using optical fibre technique are further parts of the compact main switch. The trigger box includes a trigger signal logic which inhibits different malfunctions.

Table 3: High voltage, high current ON/OFF switches

		TTF1	TTF2/3	TTF4/6
Single Switch type		GTO	IGBT*	IGCT
VDRM / VCES*	kV	4,5	1,6*	4,5
ITSM	kA	16	8	25
ITCM	kA	3	2,4 @ 1ms	4
tgq @ dIGQ/dt	us	20	<1,5	< 4
Manufacturer		GEC	EUPEC	ABB
Main switch members		6	12	7
Forw. Blocking voltage	kV	36	24	31,5
Losses per switch	W	< 80	< 200	< 90
Switch volume		moderate	great	moderate
Switch construction		simple	complexe	simple

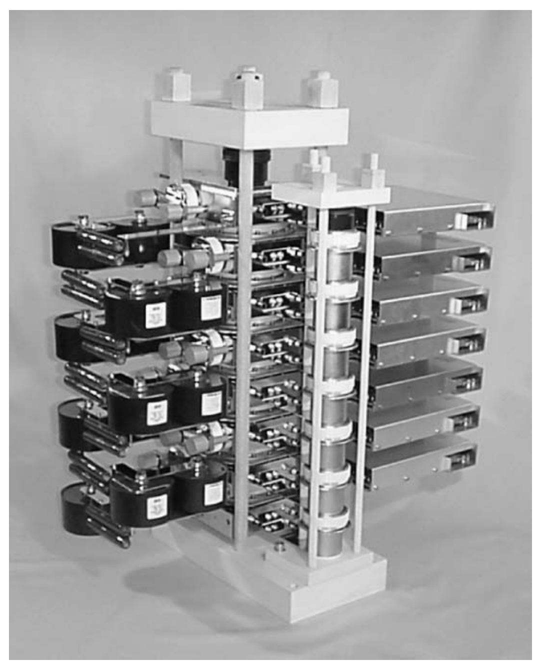


Figure 1: 12-kV IGCT-stack with integrated gate units, R-C-D snubber and MOV-stack.

Solid State Crowbar Switch

In case of a malfunction of the main IGCT-switch the klystron must be protected by discharging the 100-kJ capacitor bank by a fast, 100-kA crowbar switch. The first modulators used two redundant ignitron switches. In order to avoid the use of mercury filled tubes PPT replaced these conventional crowbar units by light-triggered, high current thyristor stacks.

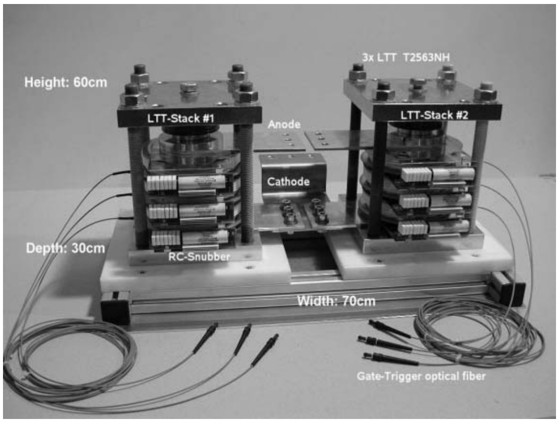


Figure 2: 100kA-crowbar switch unit with light-triggered, high current thyristors.

SUMMARY

The main improvements made in the redesign of the modulator refer to the integration of modern power components like new capacitors, IGCT-switches and LTT crowbar switches. These features are marked in the following schematic (Fig.3).

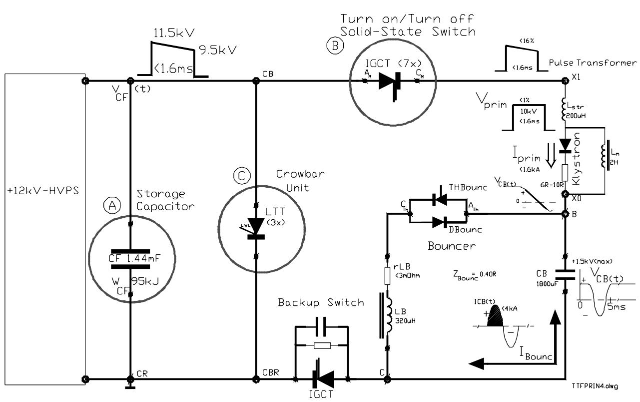
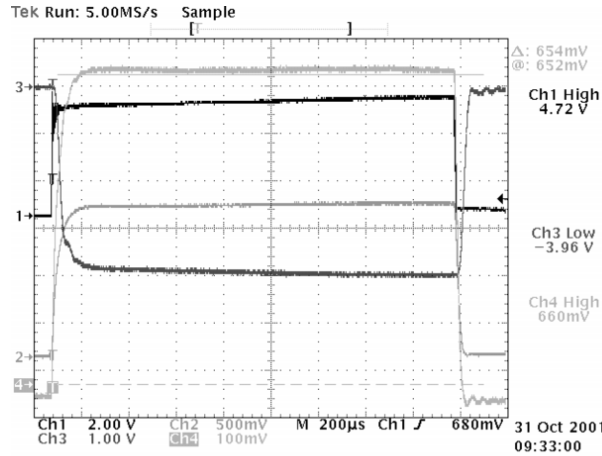


Figure 3: Schematic of the improved TTF modulator.

In the meantime eight TTF-modulators have been built by PPT. Five modulators are running in the laboratories at DESY/Hamburg, DESY/Zeuthen and LAL/Orsay. Typical pulse shapes are shown in Fig. 4.



5MW Klystron TH2104C V_{CF}: 10kV / t_p: 1,7ms

CH1	V_prim	(2kV / 1V)	black
CH2	I_prim	(500A / 1V)	green
CH3	V_Klystron	(27.5kV / 1V)	red
CH4	I_Klystron	(100A / 1V)	blue

Figure 4: Voltage and current pulse shapes of the improved TTF modulator.

The new design has led to a compact arrangement of all modulator parts. Fig.5 shows all main modulator cabinets except the control unit cabinet.
The klystron and the pulse transformer tank assembly are located at the rear side.

Figure 5: HVPS- / Pulser cabinets of the new modulator.

REFERENCES

[1] H.Pfeffer,L.Bartelson, K.Bourkland, D.Wolf, C.Jensen, Q.Kerns, P.Pietro, G.Saewert "A Long Pulse Modulator For Reduzed Size and Cost" 24th IEEE PMS Costa Mesa p48-51,1994