SETUP AND PERFORMANCE OF A CAPACITIVE 300kJ PULSED POWER SUPPLY SYSTEM FOR ETC-GUN INVESTIGATIONS

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Abstract

Due to the electrical power supply requirements of electrothermal chemical guns in terms of pulse duration and shape as well as voltage, current and power magnitudes sophisticated pulsed power supply systems are necessary. Two capacitive 300 kJ pulsed power supply systems have been designed, setup, tested and installed in Sweden by TZN under contract on FMV in order to support the Swedish ETC-Gun programme.

Each capacitor bank consists of four 75 kJ units. Triggered vacuum switches, crowbar diode circuits and adjustable inductors with six inductance values are connected to each high voltage discharge capacitor. The design of the capacitors enables an operation at either 11 kV or 22 kV at full energy. A load bypass switch as well as overvoltage varistors are installed in the output terminal of each system. Computer control systems with consequent fibre optic signal transmissions provide a reliable and safe operation of the systems.

Each unit can be charged to a different voltage during the charging process. Simultaneous and sequential firing of the units is provided. Both systems are installed in a 20 feet ISO container each providing the entire infrastructure. The computer control system is designed to operate both systems together in order to double the features of the systems. After giving the specifications the design and the technical solutions are described. A number of test results is presented which demonstrate the performance complexity of the system.

Introduction

Basic ETC-Gun investigations need a highly flexible pulsed power supply (PPS) system which can generate different current pulse shapes to optimize the gun behaviour. For the Swedish FMV Defence Material Administration two identical 300 kJ PPS Systems were constructed and delivered in 1996. Each of the two PPS systems is fitted into a 20 feet ISO container which can be easily transported.

Each PPS System is controlled via a computer control systems (CCS) which allows a save operation. Furthermore it is possible to operate both PPS systems together and control them with the CCS. The PPS system consists of four independent capacitive discharge units with a pulse forming inductance. The units can be discharged in series or in sequence. For each unit it is possible to use different capacitances, capacitor voltage levels, charge voltage levels and inductivities. Therefore the entire system has high flexibility which is necessary for basic investigations.

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Electrical Setup

The PPS systems for FMV are multi-mode 300 kJ turn-key systems. The 300 kJ system can be separated into four independent capacitor discharge systems which are connected in parallel, each storing 75 kJ when charged to the maximum voltage.

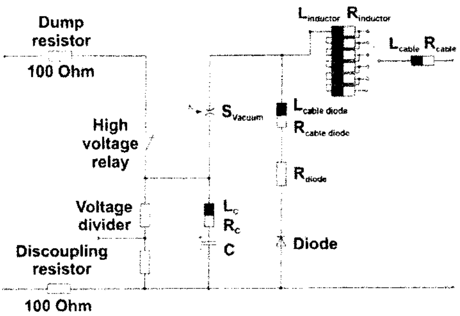

Figure 1: Capacitor discharge system

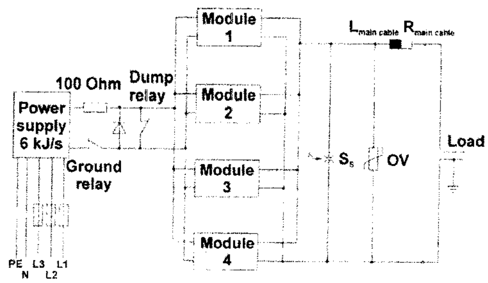

Figure 2: Four 75 kJ discharge systems

Figure 1 shows the circuit diagram of one capacitor discharge system schematically. It consists of an adaptable 325/1300 µF capacitor C with its internal inductivity L_C and its internal resistance R_C, an output vacuum switch S_{vacuum}, a crowbar diode "Diode" combined with a damping resistor R_{diode} and an adaptable pulse shaping inductor with variable inductivity $L_{inductor}$ (six values). The principle contributors to the resistance of each capacitor discharge system are the resistance of the inductor $R_{inductor}$, the resistance of the cabels R_{cable} and, if the crowbar switch is switched on, the 50-mΩ dump resistor R_{diode} mounted in the diode stack. The damping resistor R_{diode} is necessary to protect the diode against too large action i^2dt. Also the inductivity of all connection cables L_{cable} influences the behaviour of the capacitive discharge unit.

The capacitor is charged via a dump resistor of 100 Ω and a high voltage relay. During the charging and discharging the capacitor is separated from the ground by a discoupling resistor of 100 Ω. The voltage at the capacitor is registrated using an ohmic voltage divider in parallel to the capacitor. Figure 2 shows the combination of the four 75 kJ capacitive discharge systems which are connected in parallel, the charging device and the load. Before and after each shot the dump relay is closed, to ground the capacitors of the units. The four units can be fired parallel or sequentially to the load. To protect the load against overvoltages and to prevent too long tails of the load current if necessary a 35 kV overvoltage protector OV and a bypass switch S_S are connected in parallel to the electric load. The load is connected with the 300 kJ PPS system via main cables which have the inductivity $L_{main\ cable}$ and the resistance $R_{main\ cable}$. The capacitors are individually charged at postive polarity by a high voltage DC charging power supply (6 kJ/s). An engineering drawing for the plan view of one 300 kJ assembly is shown in Figure 3. The frame includes the following major components of the PPS system:

- four 75 kJ energy storage capacitors
- four diode stacks as crowbar switch for each capacitor
- four output switches with trigger devices
- four variable pulse shaping inductors
- charger with charge dump panel for safety discharge of four capacitors
- three overvoltage protectors and vacuum bypass switch.

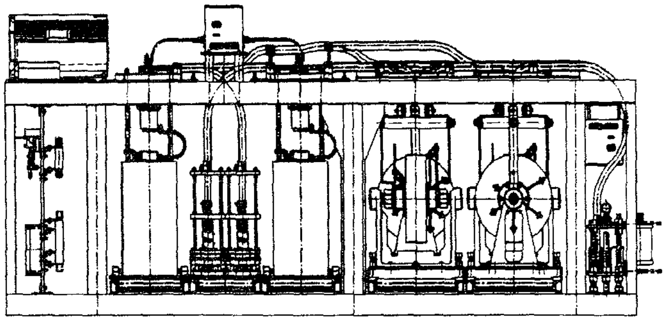

Figure 3: Assembly of one PPS

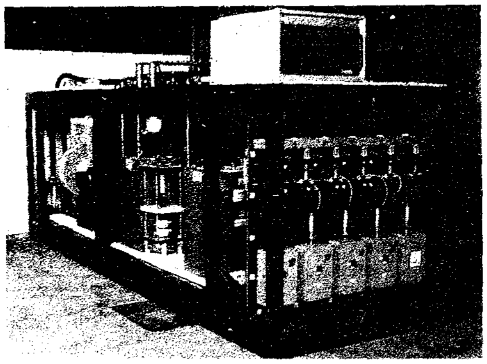

Figure 4: Photography of the PPS

Figure 4 shows a photography of the PPS-system which is mounted inside the 20 feet ISO container.

Components and Subsystems

The major components of the 300 kJ PPS system and their main specifications are described as follows :

1. Energy storage capacitors
   Figure 5 shows the design of the 75 kJ capacitors which can be used as a 1300 μF / 11 kV capacitor or a 325 μF / 22 kV capacitor. Therefore the capacitor consists of two independent 650 μF capacitors inside the case which can be connected via three high voltage terminal bushings (1,2,3) and one ground connection (4) in series (325 μF) or in parallel (1300 μF) operation mode. The normal duty lifetime for 10 % voltage reversal is 5000 shot survival.

2. Crowbar diodes
   The crowbar diodes are mounted into a diode stack which is shown in Figure 6. The stack consists of two high power avalanche diodes and two 100 Ωm protection resistors in parallel connection.
   The specification of the crowbar diode stack is given in Table I.

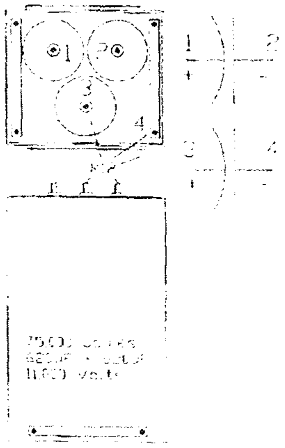

Figure 5 : 75 kJ capacitor

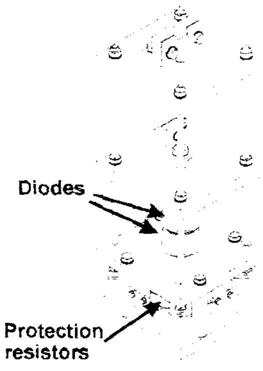

Figure 6: Diode stack

Item	Value and unit of measure
Reverse rep. peak voltage	24 kV
Vdc max.	20 kV (1 min)
Surge current (3 ms)	60 kA
Surge current (0.5 ms)	80 kA
Max. Action integral	5.4 $(kA)^2s$
dI/dt_{max}	300 A/μs
Resistance	800 $\mu\Omega$

Table I

3. High power switch

The high power switch consists of triggered vacuum switch and a trigger generator. The design of the switch is shown in Figure 7 schematically. The main electrical specifications of the switch are summarized in Table II.

Item	Value and unit of measure
Hold-off-voltage	40 kV
Peak current	100 kA
Pulse duration	500 - 2000 μs
dI/dt (I=0) at blocking conditions	100 - 500 A/μs
Charge transfer	100 Cb/pulse
Action integral	1.7 $(kA)^2$s
DV/dt (I=0) at blocking conditions with-out snubber or external damping	17 kV/μs
Number of shots	10000 shots
Delay	< 0.1 μs
Jitter	< 10 ns

Table II

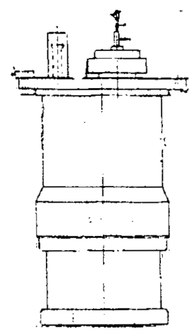

Figure 7: High power switch

4. Pulse shaping inductor

The pulse shaping inductor consists of flat strip windings (pancake type coil) with six terminals at the front side and the high voltage terminal at the back side. Figure 8 shows an isometric drawing of an inductor with the mounting support. The main electrical specifications of the pulse shaping inductor are summarized in Table III.

Serial #	*TBD*	*TBD*	*TBD*	*TBD*
L_A [μH]	*20*	*20*	*20*	*20*
R_A [mΩ]	*1.13*	*1.13*	*1.13*	*1.13*
L_B [μH]	*80*	*80*	*80*	*80*
R_B [mΩ]	*2.38*	*2.38*	*2.38*	*2.38*
L_C [μH]	*170*	*170*	*170*	*170*
R_C [mΩ]	*3.63*	*3.63*	*3.63*	*3.63*
L_D [μH]	*320*	320	320	320.0
R_D [mΩ]	*5.25*	*5.25*	*5.25*	*5.25*
L_E [μH]	*700*	*700*	*700*	*700*
R_E [mΩ]	*8.32*	*8.32*	*8.32*	*8.32*
L_F [μH]	*1240*	*1240*	*1240*	*1240*
R_F [mΩ]	*11.6*	*11.6*	*11.6*	*11.6*

Table III

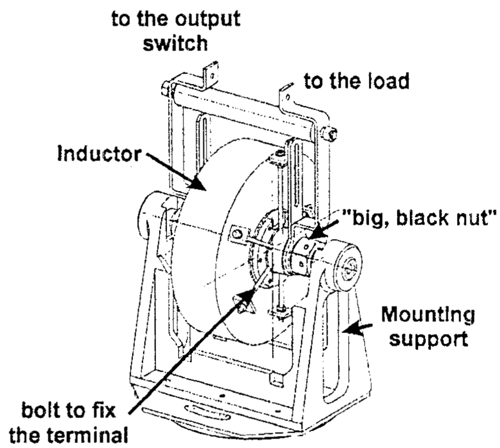

Figure 8: Inductor with mounting support

5. Charge dump panel with a charger

The charger of the PPS system is a remotly controlled high voltage DC charging power supply. It is based on a 50 kHz resonat inverter H-bridge with pulse width moulation control. It has a constant current linear charging profile. It is self protected against overvoltage by open circuits and overtemperatures. The charging power is 6 kJ/s at efficiency of larger than 92%.

An isometric drawing of the charge dump panel is shown in Figure 9. It is fixed at the front side of the panel. All necessary relays, voltage dividers and resistors are mounted on the panel.

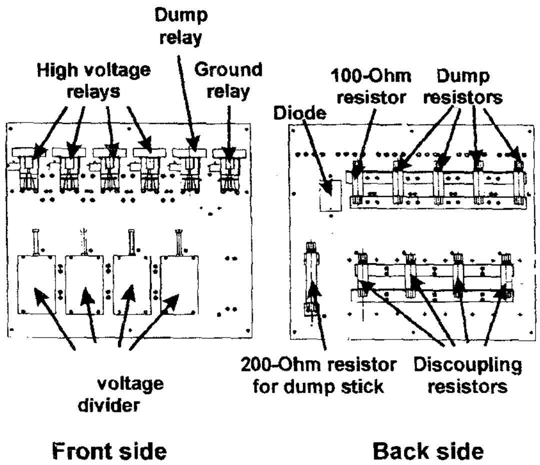

Figure 9: Charge-dump panel

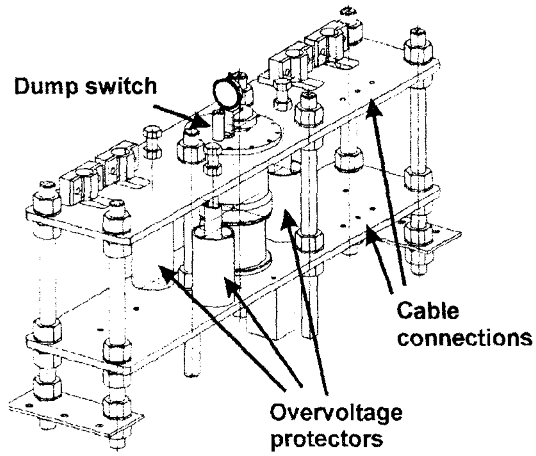

Figure 10: Overvoltage protection and dump load section

6. Overvoltage protection and dump load section
The overvoltage protection part of the 300 kJ PPS system consists of three metal oxide varistors connected in parallel operation. Furthermore a high power switch described in 3. is used as dump switch to the load. An isometric drawing of the overvoltage protection and dump load section is shown in Figure 10.

7. Computer Control System (CCS)
A simplified block diagram of the facility inside the container is shown in Figure 11. The 300 kJ PPS system is controlled via different fiber optical ring bus systems which are connected through the container junction box, system junction box, trigger generators and the high voltage dividers. The entire system is controlled with a control computer outside the container using multitasking technology. The software allows a simple remote handling of the whole system in normal operation mode and in service mode. The charging and discharging are controlled continously by the CCS and the necessary data i.e. Charging voltage of each unit data is stored. The CCS system is designed to drive three 300 kJ PPS systems connected in parallel. It can be easily extended to drive more than three systems.

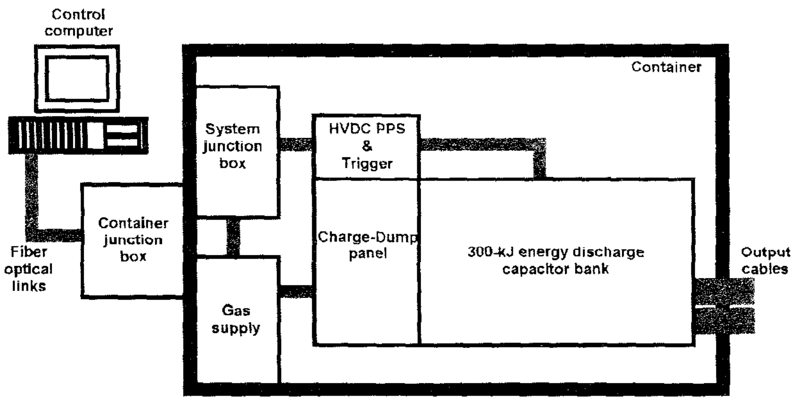

Figure 11: Simplified block diagram of the PPS system

Performance test results

During the acceptance procedure a series of tests were performed to demonstrate the expected specification of each 300 kJ PPS system. Two characteristic experiments are presented which give an overview about the possibilities of the system.

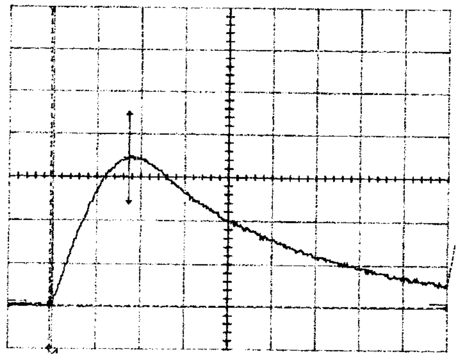

Figure 12: Measured current pulseshape of a simultaneously shot

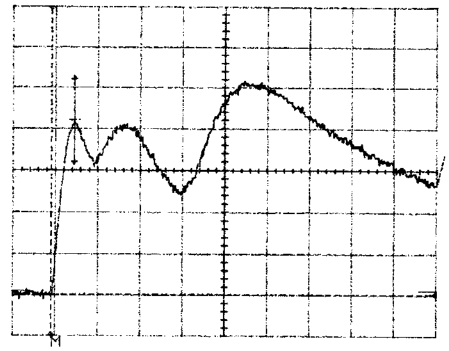

Figure 13: Measured current pulseshape of shot with sequence discharge

Figure 12 shows a measured current pulseshape of a simultaneous short circuit test with the PPS system. Table IV shows the system parameters for this short circuit test. All inductors and capacitors of the PPS system had the same value of inductance L and capacitance C. The units were charged up to the same charging voltage U_{CH} and discharged at the same time t. The maximum current during this discharge test was 240 kA at a time of 200 µs.

System Parameters	Mod. 1	Mod. 2	Mod. 3	Mod. 4
L [μH]	20	20	20	20
C [mF]	1.3	1.3	1.3	1.3
U_{CH} [kV]	11	11	11	11
t [ms]	0	0	0	0

Table IV

System Parameters	Mod. 1	Mod. 2	Mod. 3	Mod. 4
L [μH]	80	320	703	1240
C [µF]	325	325	325	325
U_{CH} [kV]	13	16	19	22
t [ms]	0	0.5	1.5	1.7

Table V

A measured current pulseshape of a sequential discharge test with a dummy load of 50 mΩ is shown in Figure 13. Each Module had a different value of the inductance and charge voltage. Table V shows the system parameters for this test. The three amplitudes of the current pulseshape shown in Figure 13 have values of 21, 20 and 26 kA. These both examples give an impression about the flexiblity of the designed and fabricated PPS system.

Conclusion

The presented 300 kJ PPS system is a highly flexible system that allows to generate different current pulse shapes in a wide range. This PPS system can support fundamental ETC-gun investigations. The PPS consists of four capacitive discharge modules which can be discharged in a sequence. It is possible to charge the modules with different charging voltages. Each of these modules has a 75 kJ capacitor with two capacitance values and an inductor with six inductance values. The capacitors are crowbared via diodes. A triggered vacuum switch is used as an output and dump switch. The system is controlled by a personal computer which is connected with the PPS system via a fibre optical ring bus system. The performance results have shown the large flexibiltity of the PPS system.