THE PULSED POWER CONVERTERS OF THE BEAM TRANSFER LINES AT DAPHNE / INFN-LNF

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Abstract

DAPHNE, the phi-factory 510 MeV electron/positron ($e^{\pm}$) collider at LNF (Laboratori Nazionali di Frascati), consists of a full energy linac, an accumulator ring (AR) and two storage rings (SRs). The transfer line (TL) conveys the beams from the linac to the AR and thence to the SRs. The TL includes three pulsed magnets. One of them is excited by a special ± 650 A, 55 kW power supply with resonant fast current polarity inversion within 30 ms. The other two are fed by capacitor discharge power supplies, providing half-sine current pulses of ± 650 A / 30 ms and ± 230 A peak / 20 ms duration. The TL operation and the pulsed magnets are briefly described. The design and topology of the power supplies are presented. Some current and voltage waveforms illustrate the functioning of this already installed and fully operational equipment.

1 INTRODUCTION

The accelerator complex DAPHNE [1], includes:

- a high current e^- linac and an e^+ converter,
- a linear accelerator for e^- and e^+,
- a spectrometer line and a test beam area,
- a 510 MeV e^- and e^+ accumulator,
- two 510 MeV storage rings,
- beam transfer lines from the linac to the accumulator and to the storage rings (Fig.1).

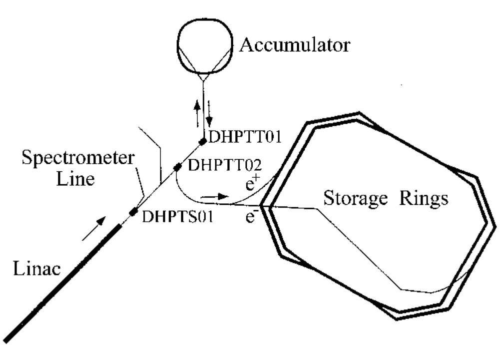

Figure 1: Beam transfer lines with three pulsed magnets.

2 BEAM OPERATION

The 510 MeV electrons are injected into the accumulator ring at 50 Hz pace during 0.3 to 0.8 s. Once per second the e^- beam is mono-turn extracted from the AR and transferred to the e^- storage ring via the same beam line. The e^- injection and transfer processes take about 10 minutes. Then the production of positrons, acceleration to 510 MeV and injection into the AR starts. The same sequence of operations as for electrons takes place, with TL magnet currents of inverse polarity, to feed the e^+ storage ring [2]. The e^- and e^+ beams are kept circulating in the SRs during at least two hours before a new injection begins. The e^- beam injection and extraction sequence, and the magnet current are schematically illustrated in Fig. 2.

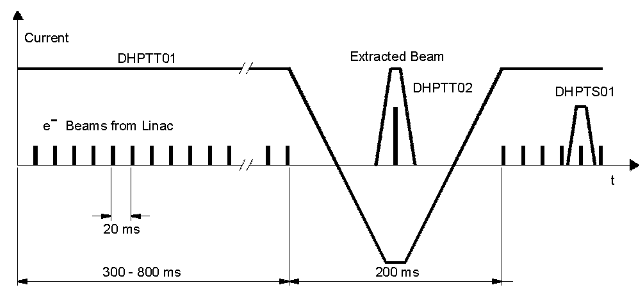

Figure 2: AR beam injection and extraction schemes.

3 PULSED MAGNETS

Three transfer line magnets are pulsed:

a) The 6° magnet DHPTS01 for the spectrometer line.
b) The two curved identical 45° magnets, DHPTT01 to bend beams towards and from the AR and DHPTT02 to deflect beams to the SRs.

Their C-type yokes are laminated. Non-oriented annealed silicon steel, with sheet thickness of 0.35 mm, is used. The Cu windings of the magnets are water cooled. To limit eddy currents and losses, the curved elliptical vacuum chamber is made of 0.3 mm thick AISI304L stainless steel, reinforced by transverse ribs. The magnet characteristics are listed in Table 1. The position of the magnets in the TL is shown in Fig.1 and their current during e^- operation is plotted in Fig. 2.

Table 1: Pulsed magnet characteristics

	DHPTT01 DHPTT02	DHPTS01
Nom. Magnetic field (T)	± 1.2	± 0.444
Nom./Max. current (A)	576 / 650	117 / 230
Resistance at 60°C (mΩ)	91	63
Inductance (mH)	17	11
Vertical gap (mm)	25	25
Lamination (mm)	0.35	0.35
Number of turns	48	48

4 PULSED POWER CONVERTERS

4.1 Operational requirements [3]

During e^- (e^+) injection into the AR (see Fig.2), magnet DHPTT01 must have d.c. current and DHPTT02 have zero field. Before e^- (e^+) extraction from the AR to the SRs, DHPTT01 must reverse its current and DHPTT02 attain its nominal field within 100 ms. After the extraction of accumulated e^- (e^+) DHPTT01 must again reverse its current within 100 ms, to restore the initial field and allow pursuing e^- (e^+) injection, while DHPTT02 must be de-excited.

Magnet DHPTS01 can be powered on request within 10 ms to deflect the particles to the spectrometer line for beam quality monitoring.

4.2 Performance specifications

Control of the power converters by the central computer is via an RS-485 interface. Current setting and acquisition occurs via 16 bit DAC/ADC modules.

The DHPTT01 converter (Table 2) operates in d.c. mode with separate positive and negative current set-points, which can differ by 20 %. A TTL pulse starts current inversion and selects the new set-point; the next TTL will revert to initial current and polarity.

The converters DHPTT02 and DHPTS01 (Table 3) receive the current reference, the polarity and a TTL trigger signal.

Table 2: DHPTT01 power converter

Max. rep. frequency at 650 A (Hz)	2
Current polarity reversal	yes
Total polarity reversal time (ms)	< 100
Max. current (A)	650
Current stability $\Delta I/In$	$\pm 5 \times 10^{-4}$
Load R/L (mΩ / mH)	95 / 17
Cooling medium	air / water

Table 3: DHPTT02 and DHPTS01 power converter

	DHPTT02	DHPTS01
Max. rep. frequency (Hz)	2	1
Current polarity selection	yes	yes
Maximum charging time (s)	0.45	0.9
Voltage stabilizing time (ms)	40	40
Max. current (A)	650	230
Current stability $\Delta I/In$	$\pm 5 \times 10^{-4}$	$\pm 5 \times 10^{-4}$
Current pulse duration (ms)	≤ 30	≤ 20
Storage capacitor (mF)	5	3
Capacitor voltage (V)	≤ 1300	≤ 500
Voltage recovery ratio (%)	80	90
Load R/L (mΩ / mH)	95 / 17	69 / 11
Cooling medium	air	air

4.3 Circuit layout and mode of operation

4.3.1 DHPTT01 power converter

DHPTT01 is a d.c. converter rated 80 V/±650 A (see Fig. 3), capable of fast magnet current inversion. The a.c. mains feeds a rectifier via an EMI LC-filter and a soft charge circuit. A iron-core choke L_o (1.6 mH/120 A) and an electrolytic capacitor bank C_o=10 mF form the 540 V d.c. link. This feeds two Double Resonant Converters (DRCs) in parallel. A DRC consists of a IGBT full H-bridge and a double resonant Ls-Cs (100 kHz) and Lp//Cp (20 kHz) circuit. Each DRC drives four ferrite-core transformers (N2/N1=3/15), for voltage step-down and insulation, with primaries in series and secondaries connected to diode rectifiers. The (2x4) rectifiers are connected in parallel. A capacitor Cu across each rectifier smoothes the voltage and provides for circulation of a.c. current components.

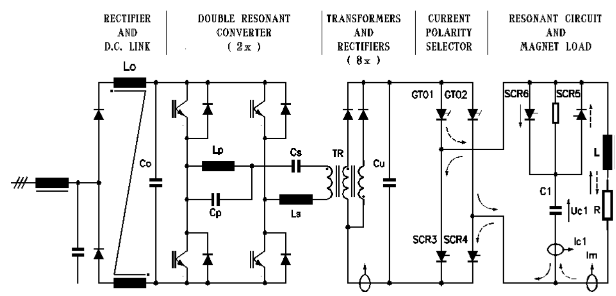

Figure 3: Circuit layout of DHPTT01 power converter.

Two cascaded regulation loops drive the DRCs, and control the magnet current and voltage. The DRCs act as d.c. current sources feeding an H-bridge, composed of two Gate-Turn-Off (GTO1-GTO2) and two normal thyristors (SCR3-SCR4), for current polarity selection.

During fast current inversion the energy stored in the magnet is first transferred into a capacitor C_1=7 mF, connected in parallel to the output via thyristors (SCR5-SCR6), and then returned to the magnet. Figure 4 illustrates the operation of the DHPTT01 converter.

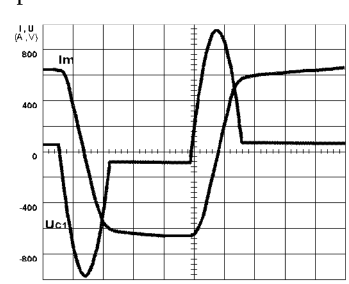

Figure 4: Waveforms of DHPTT01 converter.

Assuming magnet d.c. current in plus-polarity (GTO1 and SCR4 on), when an external TTL signal requests a current reversal the regulation and the DRC gate drives are inhibited. As GTO1 is switched off while SCR5 is turned on, the magnet current flows into the auxiliary capacitor C_1 instead of through the polarity selector GTO1-SCR4. The voltage of C_1, rises sine-like from the d.c. load voltage level, while the magnet current decreases cosine-like to zero. When C_1 has reached its maximum voltage (≤ 1000 V and depending on the actual d.c. current and on circuit damping), SCR6 turns on and the capacitor C_1 discharges back into the magnet, making the current rise sine-like in opposite direction up to about 80-90 % of the previous d.c. value. This first two-step resonant part of current reversal takes 30 ms.

Finally, for regulation, the DRCs are enabled again, GTO2 and SCR3 are turned on while SCR5 and SCR6 are both off, and the magnet current reaches within about 60 ms. the new set-point for d.c. current of minus polarity. So the total polarity reversal time is < 100 ms.

A subsequent external TTL trigger repeats the current reversal sequence: GTO2-SCR3 off → SCR6 on → SCR5 on → GTO1-SCR4 on → SCR5 and SCR6 off.

LEM-type sensors monitor the d.c. link current and voltage, the output of the DRCs and the current of C_1. The magnet current, whose precision is ± $1x10^{-4}$, is monitored by means of a FOELDI-type DCCT.

The DHPTT01 converter occupies two 0.6 m and 0.8 m wide, 0.8 m deep and 2 m high adjacent racks.

4.3.2 DHPTT02 power converter

The power circuit of DHPTT02 (see Fig. 5) includes a rectifier, a choke L_o (8 mH/20 A) and a capacitor bank C_o (2.2 mF) to form the 540 V d.c. link. This feeds a IGBT full H-Bridge DRC. Four transformers (N2/N1=13/14), with primaries in parallel and secondaries connected to diode rectifiers in series, provide for voltage step-up and insulation.

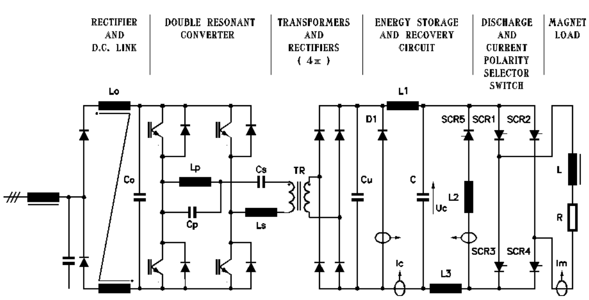

Figure 5: Circuit layout of DHPTT02 power converter.

The DRC is a current source rated 1300 V/7 A d.c., driven by two control loops acting in parallel. Capacitor C=5 mF is charged within 450 ms, via an inductor L_1 (100 mH/27 A), from the voltage recovery level up to the preset voltage Uc at roughly constant current Ic. C is discharged into the magnet and produces a half-sine current pulse of up to ±650 A peak and 30 ms duration. A power diode D1, anti-parallel to the DRC output rectifiers, protects against current surges during capacitor voltage reversal. A thyristor H-bridge (SCR1-SCR4) acts as discharge switch and polarity selector. It is protected by an inductor L_3 (0.5 mH/195 A) against a short circuit of C. Part of the energy stored in C is recovered during discharge via L_3 and L_2 (0.5 mH/165 A) and thyristor SCR5, fired 35 ms after SCR1-SCR4.

The bipolar load current is monitored by a FOELDI-type DCCT. A magnet current precision of ± $1x10^{-4}$ is obtained within a time of 300 μs at the top of the pulse.

Figure 6 illustrates the mode of operation of the DHPTT02 converter, which occupies two 19'' racks.

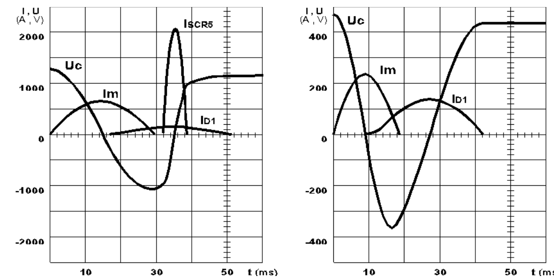

Figure 6: Waveforms of DHPTT02 and DHPTS01.

4.3.3 DHPTS01 power converter

The layout of this power converter is derived from that of DHPTT02 (Fig.5). The DRC is rated 500 V/1.5 A d.c. to charge up a capacitor C=3 mF within 900 ms. The specified half-sine current is ±230 A/20 ms. On the d.c. link the choke L_o is 100 mH/1.6 A and the capacitor C_o is 0.2 mF. The DRC consists of a IGBT half H-bridge and drives one transformer (N2/N1=43/21) only. The capacitor C is charged via L_1 (30 mH/27 A). A thyristor H-bridge (SCR1-SCR4) acts as switch and polarity selector. The protective inductor L_3 is 0.2 mH/25 A. Part of the energy stored in C is recovered during discharge via L_1 and a diode D1 anti-parallel to the DRC output rectifier (without SCR5 and L_2). A current precision of ± $1x10^{-4}$ is obtained within 200 μs at the top of the pulse. Figure 6 illustrates the mode of operation of the DHPTS01 converter, which occupies a 19'' rack.

5 CONCLUSIONS

The DHPTT01 power converter represents a novel solution for fast polarity inversion of d.c. magnet current.

The DHPTT02 and DHPTS01 converters are state of the art pulsed power supplies using DRC current source chargers.

Since the start of DAPHNE operation the three pulsed converters, built by the firm OCEM/Bologna/It, have shown excellent performance and reliability.

6 REFERENCES

[1] G. Vignola, "DAΦNE, the first Φ-Factory", Proceedings of the 5th European Particle Accelerator Conference, Sitges, June 1996, page 22.

[2] G. Vignola, "Performance of DAPHNE". This conference.

[3] C. Sanelli, M. Serio, S. Vescovi, F. Völker, "Specification for Pulsed Power Supplies - DAΦNE Project", October 1993.