DAΦNE MAGNET POWER SUPPLY SYSTEM

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Abstract

The e^+-e^-, 1020 MeV at center of mass, Particle Accelerator Complex DAΦNE, consists of a linear accelerator (Linac), a damping ring (D.A.), nearly 180 m of transfer lines (T.L.) and two storage rings (S.R.), that intersect each other in two points (I.P.), for Φ particle production. The D.A., T.L. and S.R. magnets are powered by means of 462 power supplies, rating from 100 W to 1 MW. The very different output currents, from 10 A to 2300 A, and output voltages, from 8 V to 1300 V, imposed many different technical solution realized by the world industry (Danfysik - Denmark, Hazemeyer - France, Inverpower - Canada, OCEM - Italy). This paper describes the Power Supply System giving also a description of the different typologies, their characteristics and control systems. The paper reports also the power supply performances and gives information on their installation and first year operation period.

1 INTRODUCTION

The Φ-factory DAΦNE [1] is an accelerator complex, shown in Fig. 1, that consists of:

- e^+-e^- Linac
- ≈ 180 m of transfer lines
- e^+-e^- Accumulator/Damping Ring
- two pseudo-elliptic storage rings

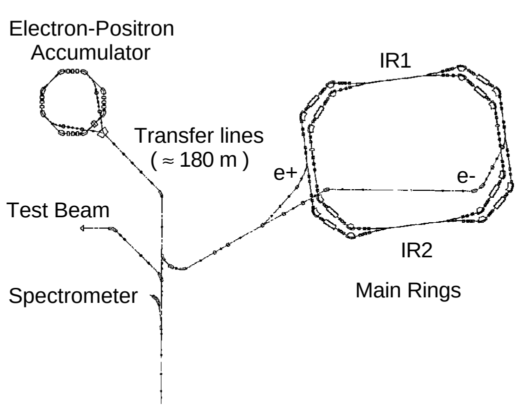

Figure 1: Layout of DAΦNE accelerators and transfer lines.

Electrons and positrons beams are generated and accelerated up to the nominal energy of 510 MeV along the Linac. Then they are transferred, stored and phase space damped in the D.A., with an injection rate of 50 Hz. The beams are then transferred and injected in the S.R. with an injection rate of 1 Hz. The overall injection time should be ≤ 10 minutes, including the time necessary to switch the Linac and the T.L. from positron to electron mode.

The expected S.R. beam life time is ≈ 2 hours.

The Linac, and the related Power Supply System, was assigned on the base of a “turn key” contract and is not described in this paper.

2 THE DAΦNE CONVERTERS

2.1 Transfer Line Converters

The same T.L. is used to transfer the beams from the Linac to the D.A. and from the D.A. to the S.R. This requirement implies that:

- three special magnets have to be powered by pulsed power supplies
- the power supplies powering dc magnets must reverse their current.

The first pulsed converter powers a bending magnet that deflects the incoming beam, from the Linac, toward an energy spectrometer. The second one deflects the beam toward the D.A. during the beam injection and must reverse the magnetic field in the magnet during the damped beam extraction. The third one, normally at zero current during the injection into the D.A., must be switched on during the injection into the S.R. Detailed information on these power supplies may be found in [2].

All the other magnets are powered by means of dc power supplies.

The T.L. have 109 magnets in total that are powered by 140 converters. Table 1 summarizes their characteristics.

Table 1: T.L. Power Supply characteristics

Power Supply for	N.	I_{max} (A)	V_{max} (V)
dc Dipoles	21	100 ÷ 700	25 ÷ 80
Pulsed Dipoles	3	650	1300
Quadrupoles	46	100	25
Injection Septa	8	2300	8 ÷ 50
H/V Steering	62	±10	±15

To decrease the number of different power supplies, they have been grouped in 7 types listed in Table 2. The converters for the pulsed magnets are not included in Table 2.

Table 2: T.L. Power Supply Types

Type n.	I_{out} (A)	V_{out} (V)	Power (kW)	N.
1	700	70	49	3
2	280	40	11.2	9
3	120	110	13.2	11
4	100	25	2.5	46
5	2300	8	18.4	4
6	2300	50	115	4
7	±10	±15	0.15	62

The specified characteristics are listed below:

Three phase, 50 Hz mains voltage	V 380±10 %
Ambient Temperature	°C 0÷40
Current Setting & Control Range	0÷100 % f.s.
Normal Operating Range	70÷100 % f.s.
Current Setting Resolution	$<\pm 1 * 10^{-4}$
Current Readout Resolution	$<\pm 1 * 10^{-4}$
Current Reproducibility	$<\pm 5 * 10^{-4}$
Residual Current Ripple (peak to peak)	$<\pm 1 * 10^{-4}$
Long Term Current Stability (8 hours)	$<\pm 1 * 10^{-4}$

They apply to all the power supplies, except for the H/V Steering power supplies where the Current Setting Resolution, Current Readout Resolution, Residual Current Ripple and Current Stability were relaxed to $<\pm 5*10^{-4}$.

2.2 Accumulator/Damping Ring Converters

The D.A. is a dc machine where the Linac beam is first injected at 50 Hz in one RF bucket, damped, extracted at ≈ 1 Hz and injected into a single DAΦNE bucket.

A total of 22 converters, listed in Table 3, power the D.A. magnets. All the dipoles of the ring are series connected, meanwhile the quadrupoles are grouped in three families and the sextupoles in two families. The steering magnets, combining the horizontal and vertical correction, are individually powered.

Table 3: D.A. Power Supply characteristics

Power supply for	N.	I_{out} (A)	V_{out} (V)
Dipoles	1	750	250
Quadrupoles	3	315	80
Sextupoles	2	336	30
H/V steering	8	±10	±15÷±25

The following characteristics were set more stringent than for T.L. power supplies:

Normal Operating Range	50÷100 % f.s.
Current Setting Resolution	$< 5 * 10^{-5}$
Current Readout Resolution	$< 5 * 10^{-5}$
Current Reproducibility	$<\pm 5 * 10^{-5}$
Residual Current Ripple (peak to peak)	$<\pm 5 * 10^{-5}$
Long Term Current Stability (8 hours)	$<\pm 5 * 10^{-5}$

2.3 Storage Ring Converters

In DAΦNE electrons and positrons circulate in two separated storage rings (see Fig. 1) laying in the same horizontal plane with horizontal crossing in 2 * 10 m long interaction regions (IR1 and IR2), at an angle of 25 mrad. These interaction regions will house the experimental detectors KLOE and FINUDA. In DAΦNE the eight bending dipoles and the central poles of the four wiggler magnets of each ring are series connected and powered by means of ≈ 1 MW, 20 kV input voltage, power supplies. All the other magnets are individually powered by dedicated power supplies. Table 4 summarizes the main characteristics of the power supplies of the S.R.

Table 4: S.R. Power Supply characteristics

Power Supply for	N.	I_{max} (A)	V_{max} (A)
Bending Dipoles	2	750	1250
Dipole Back Legs	16	±10	±20
Wiggler Central Poles	2	750	1250
Wiggler End Poles	8	750	120
Quadrupoles	94	585	45
Sextupoles	32	336	25
Splitter magnets	8	750	80
“C” Steerings	16	±215	±25
“Lambertson” Steerings	16	±215	±6
Rectangular and Square Stee.	64	±10	±20
H/V Steerings	32	±215	±10
Skew Quad. Correctors	16	280	40

The other characteristics are the same of the D.A. power supplies, except for the power supplies of the steering and corrector magnets that are the same of the T.L. steering power supplies.

3 TYPOLOGIES

Many different typologies of power supplies have been adopted according to the power supply output current and power rates and to the specific experience of the builder. A list of the typologies, and related company names, of the DAΦNE converters follow.

- SCR’s Graetz Bridge Converter with Active Filtering [HAZEMEYER, OCEM];
- SCR’s Graetz Bridge Converter with Transistor Output Bank [DANFYSIK];
- Diode’s Graetz Bridge Converter with Transistor Output Bank [DANFYSIK];
- Series Double Resonant Switching Converter [OCEM];
- Zero Voltage Switching (ZVS) Converter [DANFYSIK];
- Hard Switching Converter [INVERPOWER];
- Bipolar Linear Converter [DANFYSIK; HAZEMEYER, INVERPOWER];
- Bipolar Switching Converter with 4 Quadrant Output Chopper [INVERPOWER].

The SCR’s Graetz Bridge scheme has been adopted when high output currents were requested as for the S.R. Bending Dipole and Wiggler magnets. In this case two six-phase bridges in series were used. In other cases, e.g. for the high current T.L. dipole magnets and the S.R. Splitter magnets, the two six-phase bridges are in parallel.

The configuration with SCR’s rectifying bridge and Transistor Bank on the output was chosen to power the D.A. dipole and quadrupole magnets, whereas the variant with diode’s rectifying bridge was employed for the D.A. sextupole magnets.

The Series Double Resonant Switching configuration, working between a low resonant frequency of 20 kHz and a high resonant frequency of 100 kHz, was adopted up to 13.2 kW output power and with a maximum of 280 A output current for the air cooled converters of the T.L. dipole and quadrupole magnets. In this typology the current is regulated by varying the switching frequency.

A ZVS full IGBT's bridge configuration, phase modulated, was chosen to power all the multipole magnets of the S.R. The IGBT's switching frequency is fixed at 20 kHz and the output current is controlled by comparing the set current with the one measured by a high precision DCCT. DANFYSIK developed this solution for the first time producing a modular, very compact, water cooled converter. Three converters were located in the same rack.

The Hard switching configuration, with a full IGBT's/MOSFET's bridge, was employed to power the Skew Quadrupole Correctors of the S.R.

Also in this case the converters are water cooled.

The classic Bipolar Linear configuration was chosen for the low current steering magnets of the T.L., D.A. and S.R. Dipole Back Leg correcting windings. The same configuration was developed by DANFYSIK for the "C" and "Lambertson" steering magnets of the S.R.

Finally, the Bipolar Switching Converter with a four quadrant MOSFET's chopper on the output typology was adopted by INVERPOWER for the horizontal and vertical steerings of the S.R.

4 CONTROL SYSTEM

4.1 Abstraction Process

The main issue in developing the computer control was to keep simple and uniform the procedures for the power supplies remote management. Even though all the power supplies have a serial interface (RS422/485) and an internal microcontroller, they follow different protocols. Dealing with several communication standards, it has been necessary to define an abstraction of the power supply object characterized by a set of variables for the readbacks relevant to the control and services for acting on the element itself. The abstraction process allows the user to have information on status and analog readouts always presented in a uniform way and to treat any operation always as a single entity, despite the fact that the operation may actually be achieved by a complex sequence of lower level actions.

4.2 Low Level Control and Tests

The debugging of low level drivers has been carried out during the acceptance tests with a portable computer (Macintosh PowerBook 180c) running LabVIEW® [3] which is the same development environment adopted for the DAΦNE Control System[4]. The use of a high level software tool such as LabVIEW allowed to develop "on the spot" a huge amount of VIs (Virtual Instruments) for issuing commands and getting information through the power supplies serial interface. Those VIs have been extensively used during the acceptance tests and then embedded, with no significant modifications, into the Command and Control tasks presently running on the distributed CPUs of the DAΦNE Control System.

5 PERFORMANCES

The performances of the converters in general meet the specification, in terms of Current Setting, Control Range, Normal Operating Range, Current Setting and Readout Resolution, and Current Reproducibility. The specified Long Term Current Stability was achieved and in some cases exceeded by all the converters. However, the specification on the Residual Current Ripple caused some problems, mainly on converters of new production. Accurate setting of the active filtering, where foreseen, was a resolutive tool. A fine regulation of converters that power multipole magnets, together with a relaxation of the specification by a factor less than two, was necessary but, in any case, it was proved not to be harmful to the circulating beams. Particular attention was dedicated to the EMC compatibility and to the harmonic content of the absorbed primary currents, reducing them to acceptable levels by fine tuning of the rectifying bridges of high power converter and appropriate filtering. In particular, all the switching converters were officially tested according to the German VDE 0875N norms (type tests).

6 FIRST YEAR OF OPERATION

First year of operation pointed out few problems mainly related to random failures of some components (breakers, auxiliary transformers, IGBT's, IC's, etc.) without any serious consequence and promptly repaired in collaboration with the builders.

A major problem, still on the table, concerns some IC's that thermally degrade reducing the threshold between logic levels. This causes the internal control logic to detect an "alarm" state even though the PS is working regularly and drives consequently the converter in Standby mode. This problem is under evaluation and near to be solved.

REFERENCES

[1] Performances of DAΦNE - This Conference.

[2] C. Sanelli, S. Vescovi and F. Völker, "The pulsed power converters of the beam transfer lines at DAΦNE" - This Conference.

[3] LabVIEW® is a trademark of National Instrument Corporation. 6504 Bridge Point Parkway Austin, TX 78730-5039.

[4] G. Di Pirro, C. Milardi, A. Stecchi and L. Trasatti, "DANTE: control system for DAΦNE based on Macintosh and LabVIEW", Nuclear Instrument and Methods in Physics Research A 352 (1994) 455-457.