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Specifications for the supply of 17 power supplies of the CNAO LEBT O3 line, including a 12-month warranty

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1. INTRODUCTION

The CNAO (National Center for Oncological Hadrontherapy, www.fondazionecnao.it), based in Pavia, is an innovative and technologically advanced structure, established by the Ministry of Health with the aim of treating patients suffering from solid radio resistant tumors through the use of protons and carbon ions, particles called hadrons (hence “hadrontherapy”).
CNAO is one of the 6 centers in the world where, with a single machine called "synchrotron", both carbon ions and protons destined for therapeutic use are accelerated, and it is the only center in Italy for carbon ion therapy.
Clinical, radiobiological and translational research activities are carried out in the experimental room, in the dedicated areas and in the laboratories. Research is accompanied by training activities aimed at doctors and university students.
The know-how developed by CNAO makes it an important reference center for technology transfer in the development of similar technologies abroad.
CNAO is the lead research body of the INSPIRIT project, conducted in partnership with INFN and PMI Hifuture, (PROJECT ID 1161908 CUP E18I19000180007) funded by the Lombardy Region under the POR FESR 2014-2020 Call Hub Research and Innovation. The project has among its objectives the realization of a third innovative source capable of producing new ionic species both for clinical (helium, oxygen) and for experimental purposes (iron, lithium). The beams generated by the third source will be directed to the experimental room to be made available for clinical and industrial research activities.
The synchrotron has a linear accelerator (LINAC) for protons and carbon ions, which accelerates the particles up to an energy of 7 MeV / u. An injection line (LEBT and MEBT) transports them to the synchrotron ring where they are injected, accelerated and extracted with an energy between 60 and 250 MeV for protons and 120 and 400 MeV/u for carbon ions. An extraction line (HEBT) guides the beam to the treatment rooms, where the patients are placed.

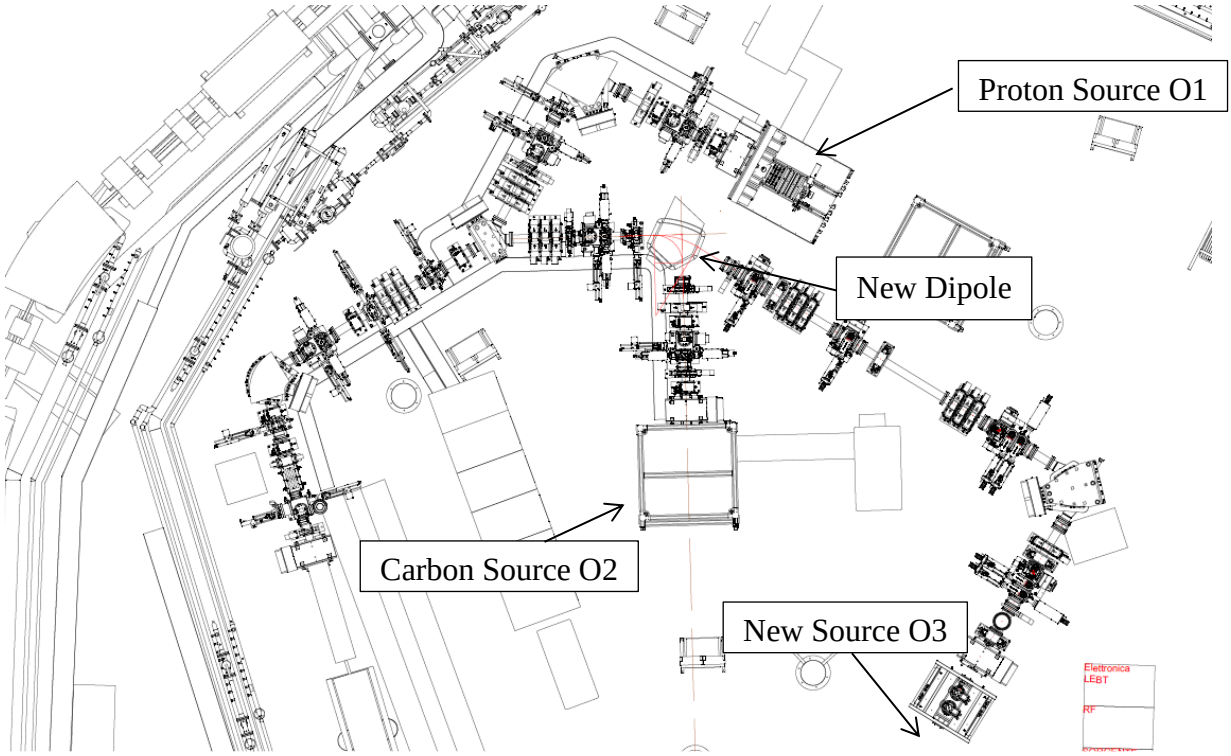

Figure 1 - Layout of the CNAO LEBT line with the new ion source installed

2. OBJECT OF THE ORDER

2.1 This document describes the specifications for the supply of 17 power supplies, including a 12 month warranty, intended to drive the magnets of the new low energy beam transfer line (LEBT) which will be used to connect the third CNAO ion source to the existing accelerator. The warranty period will start at the time of the acceptance, with a positive outcome, of the items at CNAO; the acceptance will be completed within 2 months from the delivery.
The magnets to be driven are:

- One solenoid
- Four steerers for both planes (H&V)
- Seven quadrupoles
- One 90 ° dipole

2.2 For the steerers, each winding will be driven independently by a dedicated power converter. The total number of power supplies required is therefore 17. The power supplies will work in DC: they will receive a setpoint and maintain the corresponding current level for an arbitrarily long time interval. Sometimes, they will be required to change value or to rich the maximum and minimum currents for resetting the hysteresis cycle of the magnet.

2.3 The installation of the supplied power supplies must be considered excluded from the subject of the contract. This activity will be performed by CNAO staff.

2.4 Table 1 summarizes the electrical characteristics of the magnets. The indicated resistance is that of the magnet only, excluding cables

Table 1 - Electrical characteristics of the magnets

Magnet type	Resistance [mOhm]	Inductance [mH]
Steerer (H = V)	70	4
Quadrupoles	25	1
Dipole a 90°	150	107
Solenoid	252	108

3. COMMON REQUIREMENTS FOR ALL THE POWER SUPPLIES

This section lists the requirements shared by all the power supplies

3.1 The power supplies shall be standard commercially available units. A limited number of customizations are allowed; to be discussed with CNAO and approved by CNAO. No fully custom units are acceptable.

3.2 The power supplies shall be enclosed in a case compatible with installation in a 19 "rack. No ventilation grids are allowed on the side or on top and bottom faces of the case.

3.3 The input voltage can be 230 V (± 10%) only for units with a nominal below 1 kW; otherwise the input voltage shall be 400 V (±10%), three phase. All voltages at 50 Hz.

3.4 Each power supply must be equipped with a general switch that cuts the supply line, shutting down the unit completely.

3.5 A STANDBY state shall be foreseen in which the control electronics is active, but the output stage is off.

3.6 A POWER ON state shall be foreseen in which the output stage is active

.

3.7 A FAULT state shall be foreseen which is triggered when an alarm is activated. In FAULT mode the control electronics is active, but the output stage is off. When the alarm(s) are reset by the user or by the control system the units will enter the STANDBY state.

3.8 Air cooling can be accepted only for units with a nominal power below 1 kW.

3.9 Water cooling shall be compatible with deionized water.

3.10 At least two inputs for external interlocks, compatible with a voltage-free contact, shall be available to stop the operation of the power supplies within 100 ms. The inputs shall react to the contact changing state from closed to open.

3.11 The power supplies must have a LOCAL and a REMOTE working mode: the first will allow the unit to be controlled by means of a local panel and display plus keys or a touch panel; the second requires the unit to be able to receive commands / setpoints and send read-backs / status information over an Ethernet connection. Both commands and data exchanged with the power supplies shall be in ASCII format. The selection of the working mode shall be possible only from the local panel.

3.12 The slope of the ramp used to reach the setpoint shall be selectable by the user, both in LOCAL and in REMOTE mode. The range of allowed ramp speed values shall be such that the full output current excursion will be completed between 4 and 60 seconds.

3.13 Two ways of actuating a new setpoint are required, and shall be selectable in REMOTE mode:

3.13.1 Immediate: the ramp to the new setpoint (with the selected slope) shall start as soon as the value of the setpoint is received.

3.13.2 Triggered: the ramp to the new setpoint (with the selected slope) shall start as soon as an hardware trigger signal is received on a dedicated connector, compatible with both TTL and LVTTL signals. The maximum delay between the trigger signal and the start of the ramp shall be better than 500 microseconds.

3.14 The power supplies shall typically operate in current mode. The possibility of working in voltage mode for testing purposes is also required.

3.15 Parameters of control loop.

3.15.1 The parameters to tune the control loop (both the voltage loop the current loop) shall be accessible by the user, who will calibrate them in the field after the installation of the magnet and the cabling

3.15.2 As an alternative, the loop can be calibrated at the factory for the specific load and may require some fine tuning, for example to account for the real cable length, after the installation is complete.

3.15.3 In both cases there must exists a set of parameters that guarantees that no overshoot is present at the end of the ramp for the fastest allowed ramp speed.

3.15.4 In case of replacement of one power supply with a spare one, the settings shall be applicable by CNAO with no intervention by the Supplier, either by hand or from a file.

3.16 The power supplies shall be auto-protected from overloads and short circuits.

3.17 The power supplies shall operate with an ambient temperature between 0°C and 40°C and a relative humidity between 30% and 80%.

3.18 Long Term Support (LTS): The Supplier will commit to service the power supplies and make spare parts available for at least 10 years from the date of the delivery. In case components are discontinued, the Supplier commits to find compatible replacements or to modify the units to make them compatible with new components.

3.19 After the installation, carried out by CNAO staff, and the final calibration, performed according to the terms indicated in point 3.15 above, the performance of each type of power supply will be tested according to a procedure and an instrumentation set that will be agreed between the Supplier and CNAO. In case the expected performance are not met, the Supplier shall make all the required modifications to match the performance indicated in this Specification.

3.20 The supply will include:

3.20.1 The user manual (in English, including the instructions for the maintenance);

3.20.2 The complete schematics (also for internal boards);

3.20.3 All software needed to set up the units and to configure them.

3.21 The performance requirements for each type of power supply are listed in following sections. In case a single unit is not capable of delivering the required voltage and current, more units can be connected in series/parallel combinations. In this case one of them will act as a master and will be responsible to manage the interface with the CNAO Control System.

4. PERFORMANCE REQUIRED FOR THE POWER SUPPLY OF THE SOLENOID

Table 2 lists the performance requirements of the power supply for the solenoid

Table 2

Type output current	Unipolar
Maximum output voltage	60 V
Maximum output current	200 A
Current setting and control range	0.5% ÷ 100% f.s.
Normal Operating Range (NOR)	0.5% ÷ 100% f.s.
Current setting and readout resolution	< ±8.0E-5 f.s.
Reproducibility	< ±4.0E-5 f.s.
Residual current ripple (pk-pk) within the NOR	< ±8.0E-5 f.s.
Linearity error	< ±4.0E-5 f.s.
Stability (8 hours)	< ±8.0E-5 f.s.

5. PERFORMANCE REQUIRED FOR THE POWER SUPPLIES OF STEERERS

Table 3 lists the performance requirements of the power supplies for the steerer magnets. Each magnet drives the coil of just one plane (horizontal or vertical).

Table 3

Type of output current	Bipolar
Maximum output voltage	±10 V
Maximum output current	±10 A
Current setting and control range	-100% ÷ +100% f.s.
Normal Operating Range (NOR)	-100% ÷ +100% f.s.
Current setting and readout resolution	< ±2.0E-4 f.s.
Reproducibility	< ±1.0E-4 f.s.
Residual current ripple (pk-pk) within the NOR	< ±5.0E-5 f.s.
Linearity error	< ±1.0E-4 f.s.
Stability (8 hours)	< ±1.0E-4 f.s.

6. PERFORMANCE REQUIREMENT FOR THE POWER SUPPLIES OF QUADRUPOLES

Table 4 lists the performance requirements of the power supply for the solenoid.

Table 4

Type of output current	Unipolar
Maximum output voltage	20 V
Maximum output current	300 A
Current setting and control range	0.5% ÷ 100% f.s.
Normal Operating Range (NOR)	0.5% ÷ 100% f.s.
Current setting and readout resolution	< ±5.0E-5 f.s.
Reproducibility	< ±2.5E-5 f.s.
Residual current ripple (pk-pk) within the NOR	< ±5.0E-5 f.s.
Linearity error	< ±2.5E-5 f.s.
Stability (8 hours)	< ±5.0E-5 f.s.

7. PERFORMANCE REQUIRED FOR THE POWER SUPPLY OF THE 90° DIPOLE

Table 5 lists the performance required for the 90° dipole power supply

Table 5

Type of output current	Unipolar
Maximum output voltage	35 V
Maximum output current	100 A
Current setting and control range	1% ÷ 100% f.s.
Normal Operating Range (NOR)	1% ÷ 100% f.s.
Current setting and readout resolution	< ±5.0E-5 f.s.
Reproducibility	< ±2.5E-5 f.s.
Residual current ripple (pk-pk) within the NOR	< ±5.0E-5 f.s.
Linearity error	< ±2.5E-5 f.s.
Stability 8 hours)	< ±5.0E-5 f.s.

8. NON-MANDATORY FEATURES

This section lists some requirements that are preferred, but not mandatory.

8.1 Virtual oscilloscope (point assessed as a whole, not individually):

8.1.1 The power supplies should be equipped with a system that allows you to acquire the voltage and current waveforms at the output and show them on a virtual oscilloscope interface, in order to tune the control loop parameters without the of external instrumentation**.**

8.1.2 A minimum sampling frequency of 20 kHz is required**.**

8.1.3 The number of points per acquisition shall be such that a transient at least 5 seconds long can be acquired**.**

8.1.4 Some sort of trigger mechanism should be available to start the acquisition when a certain threshold value of the desired quantity is reached, as in an ordinary oscilloscope**.**

8.2 Arbitrary waveforms generation (point assessed as a whole, not individually)**:**

8.2.1 The power supplies should be equipped with an arbitrary waveform generation function**.**

8.2.2 The sampling frequency of the waveform should be at least 20 kHz.

8.2.3 The number of points that describe the waveform should be such that it can last up to at least 10 seconds.

8.2.4 It should be possible to load the points that describe the waveform into the power supplies through the Ethernet connection

.

8.3 Programmable inputs for external interlocks (point assessed as a whole, not individually):

8.3.1 As specified in 3.10 two inputs for external interlocks shall be present, able to react to the opening of a voltage-free contact; it is preferred that these two inputs are programmable to react to both the opening and the closing of a voltage-free contact.

9. TIME SCHEDULE

The supply must be completed within 5 months of signing the supply contract or sending the purchase order.

10. DELIVERIES

The power supplies shall be delivered, carriage paid, to Fondazione CNAO located in Strada Campeggi n.53 – 27100 Pavia, Italy.