DESIGN OF THE PROTOTYPICAL CRYOMODULE FOR THE EUROTRANS SUPERCONDUCTING LINAC FOR NUCLEAR WASTE TRANSMUTATION

S. Barbanotti, N. Panzeri, P. Pierini, INFN Milano, Segrate, Italy
J.L. Biarrotte, P. Blache, C. Commeaux, P. Duthil, E. Rampnoux, IPNO, Orsay, France
M. Souli, GANIL, Caen, France

Abstract

One task of the accelerator workpackage of the EUROTRANS program for the design of a nuclear waste transmutation system is dedicated to the engineering and realization of a prototype cryomodule of the high energy section of the linac, equipped with elliptical superconducting niobium cavities. We review here the present status of the design and the planned program that foresees the experimental characterization of the fully equipped cavity and RF system under its nominal operating conditions.

INTRODUCTION

The EUROTRANS program objective is to develop an advanced design for an experimental facility demonstrating the technical feasibility of Transmutation in an Accelerator Driven System (XT-ADS) and a generic conceptual design of a modular European Facility for Industrial Transmutation (EFIT). Its objective is to provide also an experimental evaluation of the reliability figures for the main modular components of the accelerator configuration. One of the tasks in the accelerator working package of the Eurotrans project is dedicated to building and testing a full prototypical cryomodule of the high energy section of the superconducting proton linac.

A cryomodule is the basic building block of the superconducting accelerator section and has the main role to provide to the cavities both a mechanical support and their cryogenic environment for operation. The XT-ADS linac, which main parameters have been briefly reviewed in Reference [1], on the basis of the high availability/reliability requirements and maintenance considerations, needs a cryomodule designed for easy disconnection both from the beam line and the cryogenic fluids distribution plant [2]. The aim of the work here briefly presented is to deliver an operational prototype cryomodule, which can be extensively tested (without beam, but at high RF power levels as in its realistic operating condition), to assess its main reliability characteristics.

The test cryomodule will be a prototypical module of the beta 0.5 section containing one single elliptical multi-cell superconducting niobium cavity with all its auxiliary equipments.

Besides the development of the bare superconducting cavities, it is important to prototype each auxiliary system needed for the cavity operation in a real environment (frequency tuner, power coupler, RF source, power supply, RF control system, cryogenic system, cryostat…), and relative procedures of assembly and alignment.

The development of the cryomodule relies heavily on prior R&D results, existing infrastructures and investments of INFN, CNRS and CEA. INFN will make available its two beta 0.47 (geometrical length) TRASCO [3] cavities equipped with the cold tuning system [4], which have outperformed the EUROTRANS specifications during vertical tests [5]. CNRS will contribute with clean room for cryomodule assembly, cryogenic infrastructure for test at 2 K, manpower for the cold box study and integration, assembly and tests. CEA will contribute with the cavities chemical treatments.

The final installation and testing of the cryomodule will be done at the Supratech infrastructure under preparation at IPN/Orsay, where the following hardware and facilities will be available:

- A 350 MHz and a 700 MHz high power RF sources.
- A clean room for cryomodule assembly (85 m^2 clean room, with 45 m^2 of class 10/100).
- Ultra-pure water production system and HPR facility.
- An Helium liquefier.
- A cavity chemistry facility.

LAYOUT OF THE MODULE

The actual layout of the module is shown in figure 1. The vessel of the module for a single cavity has a diameter of about 1.4 meters (similar to the SNS vessel) and a length of about 1.5 meters.

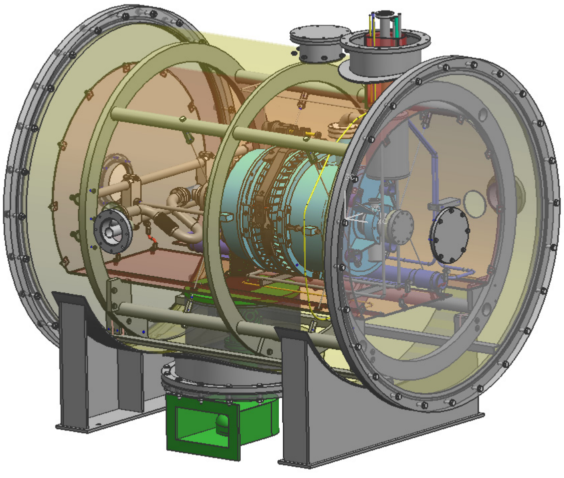

Figure 1: Module layout.

The design has been performed on the following reliability-based considerations:

- As a general request, easy and reliable connection interfaces to the cryogenic and RF system and fast and reliable cold mass alignment strategies are needed to guarantee a short mean time to recover in the case of a module exchange in the linac.
- As in the SNS experience, in order not to produce mechanical stresses on the warm ceramic RF window the fundamental power coupler is positioned vertically. Furthermore, in order to avoid the possibility of contamination of the inner cavity surface during the coupler assembly with dust particles, the warm RF window is positioned below the cavity.
- The actual layout simplifies the handling of the subassembly coming out of the clean room. The suspension of the dressed cavity to a room temperature "spaceframe" with tension tie rods does not require any vertical movement of the cavity during assembly. In more details the cavity will be supported by 8 tension rods in a symmetric X pattern to a room temperature "spaceframe" support cage similarly to the SNS concept. The spaceframe acts also as the support for the thermal shield that protects the cold mass at 2 K from the room temperature surfaces of the vacuum vessel, intercepting the thermal radiation at higher temperatures.
- This design allows the connection to the cold box providing the liquid cryogenic circuits at different temperature levels already developed by IPN Orsay and similar to the CM0 coldbox used for the spoke cryomodule. The coldbox will be located above the module, connected on the top of the vacuum vessel.

As a last consideration, it seems important to borrow, as extensively as possible, proven technologies from existing state-of-art cryomodule designs, again with the perspectives of reaching the ADS reliability goals. Most of the technical solutions, and the underlying superconducting RF technology, outlined for the module layout have been derived from the huge experience accumulated by the TESLA Test Facility (TTF) and the Spallation Neutron Source (SNS) experience.

The Dressed Cavity

The module will be equipped with one of the two TRASCO cavities, fully "dressed" with the components required for their operation in a linac cryomodule.

In particular, the cavity will be equipped with a titanium helium reservoir (which provides the low pressure bath liquid He for the operation at 2 K) and with an internal magnetic shield: a layer of a high-permittivity (at low temperatures) material (Cryoperm) that provides the required shielding from the earth magnetic field in order to guarantee low values of surface resistance for RF losses minimization.

A coaxial blade-tuner [4], based on the prototype tested on the TTF linac, provides the slow tuning and fast piezo-assisted actions. The mechanism has been fully engineered and fabricated.

THERMAL DESIGN

One of the main issues driving the technical design of a cryomodule is the heat load budget at low temperatures. This either comes from a static contribution (thermal radiation, heat conduction or convective heat transfer from the room temperature environment) or from the dynamic contribution driven by the presence of the RF fields sustained by the accelerating cavities.

Static Heat Loads

Static losses are handled in the modules by minimizing the heat flows towards the 2 K helium bath and intercepting it at higher temperatures, thus gaining in thermodynamic efficiency. The thermal radiation flowing from surfaces at room temperature is intercepted with a thermal shield fixed at intermediate temperature, and minimized by using multilayer insulating (MLI) blankets (layers of doubly aluminized mylar® sheets separated by a low thermal-conducting spacer material). Direct heat conduction paths from the room temperature environment to the 2 K circuit need to be carefully intercepted at intermediate temperatures. Finally, convective effects are prevented by providing a good insulating vacuum between the cold mass and the external vessel at room temperature.

For the estimation of the static heat load budget and its proper handling, a thermal analysis of each direct path from the room temperature vessel to the cold mass environment has been performed by taking into account the proper temperature-dependent material properties. Estimation based on simplified geometries and tabulated material data has been verified with finite element calculations on the model geometry.

Dynamic Loads:RF Losses

For the TRASCO cavity operation at its design parameters (E_{acc}=8.5 MV/m, Q_0=10^{10}, with L_{active}=0.5 m and R/Q=160 Ω), the estimation of the dynamic loads gives 11.3 W of dissipated power at each cavity. For comparison, in the SNS case, the two cryomodules types (medium beta and high beta) have a nominal RF dynamic load of 10 and 13 W, respectively. Even if the vertical tests performed on the existing structures were able to exceed these limits, for the heat load computations, a conservative value of Q_0=5 10^9 has been assumed.

Heat Load Budget

Table 1 reviews the overall heat load budget on the module. The overall heat load estimates seems to be well within the capacity of the coldbox (~ 50 W).

On the basis of the heat load assessment reported above were calculated the required mass flow for the shield and cavity circuits. For these calculations, it has been assumed that the shield circuit is cooled by nitrogen gas. Even using a conservative estimate for the dynamic heat loads and a 30% overcapacity budget for the coolant mass flow, a total requirement of 1.7 g/s at 2 K is needed for the liquid helium circuit.

Table 1: Heat load budget on the module

	Circuit 4.3K	Circuit 1.9K		Thermal shield
	(W)	Static (W)	Dynamic (W)	(W)
Transfer line	0.5			
Cold Box	2.0			20.0
Cryomodule		4.0	25.0	50.0
Coupler	1.2	0.0		
Total	**3.7**	**4.0**	**25.0**	**70.0**
	32.7			
Mass flow (g/s)		1.70		0.45

The Cryogenic Cold Box

The cryogenic cold valves box is derived from the IPN Orsay Eurisol design, which has a nominal cooling capacity of 50 W at 2 K. The cold box supplies 3.3 g/s of liquid helium for the cavity cooling, 2.5 g/s of liquid helium at 4.3K and a Joule Thomson valve for the 2K operation (it can produce a maximum flow rate of 2.2 g/s at 1.9K, ~50W).

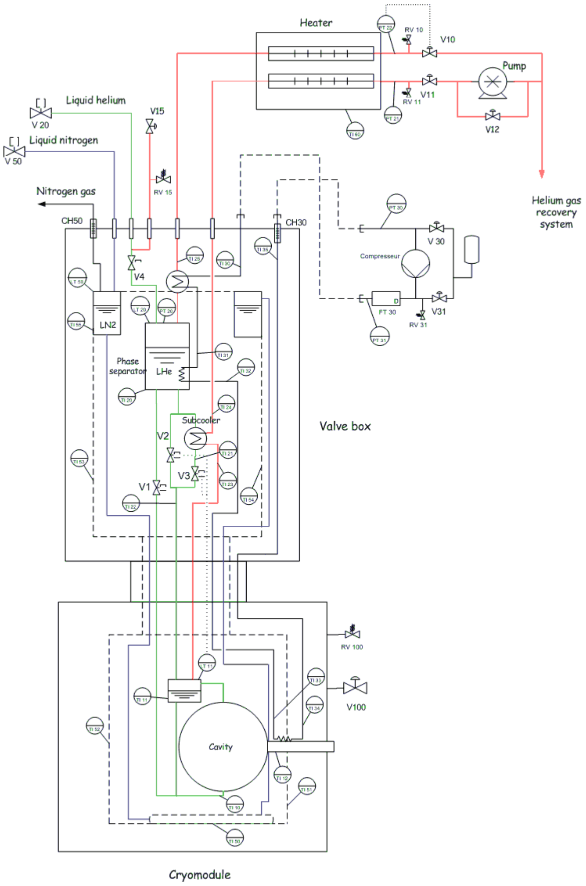

Figure 2: The main cryogenic scheme.

A ~ 20 litre helium buffer is placed inside the valve box to prevent from pressure perturbations on the cavity when feeding liquid helium. A thermal shield, able to evacuate around 60 W at around 80K, made of copper and covered with multi layer insulation, surrounds the cold internal parts of the valve box.

THE COUPLER

The 704.4 MHz power coupler is under development at IPN Orsay and is based on the SNS design, adapted and optimized for the needs of this design (different frequency, more CW power, additional cooling provisions included).

The main characteristics of the coupler are the following:

- capacitive coupling to the cavity
- coaxial geometry of the antenna
- ceramic window geometry: disk with chokes
- doorknob to perform the transition from the coaxial to the waveguide geometry
- capable to transmit up to 80 kW of RF power to the cavity
- inner cooling of the antenna with r.t. water
- window cooling by water @ 300 K
- cooling of the outer conductor between the ceramic and the cavity by supercritical liquid helium @4.5 K.

FUTURE WORK

For the experimental characterization of the fully equipped cavity and RF system the following steps are foreseen:

- finalization of the cryomodule design and production
- production of the coupler system
- cold box design finalization for production.

The cryomodule assembly is expected in summer 2009, while the final tests should take place up to December 2009.

ACKNOWLEDGMENTS

This work is supported by the EURATOM 6th Framework Program of the EC under contract FI6KW-CT-2004-516520.

REFERENCES

[1] J-L. Biarrotte, “Status of the Eurotrans R&D activities for ADS Accelerator Development” Proceedings of the 5th HPPA Workshop, Mol, OECD/NEA, 2007.

[2] P. Pierini, C. Pagani, “Task 1.3.3. Preliminary Report: Specifications of the Prototype Cryomodule”, EUROTRANS report, Deliverable 1.15 of EU contract FI6W-516520, April 2006.

[3] M. Napolitano et al., “Status Of The High Current Proton Accelerator For The TRASCO Program”, in Proceedings of EPAC 2002, Paris, France, p. 251.

[4] P. Pierini et al., “Report on Tuner Design”, CARE-Note-2006-003-HIPPI, available from http://www-dapnia.cea.fr/Documentation/Care/index.php.

[5] A. Bosotti et al., “RF Tests Of The Beta=0.5 Five Cell TRASCO Cavities”, Proceedings of EPAC 2004, Lucerne, Switzerland, p. 1024.