STATUS OF THE HIGH CURRENT PROTON ACCELERATOR FOR THE TRASCO PROGRAM

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Abstract

TRASCO (acronym for TRAsmutazione di SCOrie) is a joint INFN/ENEA program, started in 1998, aiming at the design and the technological investigation of the main components of an accelerator driven system (ADS) for nuclear waste transmutation. The proposed 30 mA proton linac (TRASCO-AC) consists of: an 80 kV ECR source; an RFQ up to 5 MeV; a superconducting linac with independently-phased cavities up to 80-100 MeV; and finally a 3 section superconducting linac with elliptical multi-cell cavities up to 1 GeV. Several key components of the proposed linac have been built and tested. The main achievements and the activities planned for TRASCO_AC are briefly outlined.

1 INTRODUCTION

The disposal of radioactive waste resulting from industrial nuclear energy production represents a problem that is not yet fully solved, especially in terms of environmental and social acceptability. The deep geological repository of nuclear waste seems to be the only possible final solution, however, there is the need to drastically reduce the volumes and the radio toxicity of the high level waste to be stored and the necessary time to reach the radioactivity level of the natural ores originally used for the fuel production, in order not to leave the long term problem to future generations. By using partitioning and transmutation technologies the most hazardous materials – i.e. plutonium, minor actinides (MA) and some long-lived fission products (FP) – could be separated (partitioning) from the nuclear wastes and, then, converted to shorter-lived elements in specially designed nuclear reactors (transmutation). Transuranic elements would be transmuted by fission and FP by neutron capture and beta decay.

Accelerator driven systems (ADS) - sub-critical reactors coupled to an intense spallation neutron source driven by a high power proton accelerator - are generally believed to be particularly suited for the transmutation of nuclear waste and have become a major R&D topic in Europe [1].

Important ADS activities are also going on or are being planned outside Europe e.g., in Japan (the JAERI/KEK Joint Project), in USA (the AAA project) and in Korea (the KOMAC Project). In all cases, the programs are relevant both in terms of R&D resources and in terms of planned test facilities realization.

2 THE TRASCO PROGRAM

Starting from 1996, a growing interest on the ADS concepts has taken place in Italy and has given origin to several studies. The basic R&D program TRASCO has been funded by the Ministry of the University, Scientific and Technological Research, and has been followed by an industrial program, in which major Italian research institutions and industries are involved [2]. TRASCO aims to study the physics and to develop the technologies needed to design an Accelerator Driven System (ADS) for nuclear waste transmutation.

The TRASCO program consists of two main parts, regarding, respectively, the accelerator and the sub-critical system. The first part falls under the competencies of INFN and the second under those of ENEA, which are the two institutions jointly responsible of the TRASCO activities, which include also Italian industrial partners.

The program covers all the main subsystems of an ADS (accelerator, window/target, sub-critical reactor). However, due to the limited available financial resources, all the efforts are concentrated on starting a few significant and qualified experimental activities, in view of the goal of a future participation in an International project dedicated to the study and construction of an ADS prototype, like, for example, the PDS-XADS program of the 5th framework programme of the European Commission.

2.1 The reference accelerator parameters

The TRASCO accelerator program [2] is focussed on the conceptual design and the realization of prototypical components for a 30 MW (1 GeV, 30 mA) CW proton linear accelerator, which is the candidate for an industrial size transmuter with a thermal power in the range of 1500 MW.

The coupling of the accelerator with the subcritical system leads to rather tight requirements on the accelerator reliability and availability. This reliability issue therefore is at the base of the linac design, leading to conservative choices on all components with respect to the "state of the art" technologies, and to an appropriate amount of redundancy in the system, in order to increase the tolerance to component faults and to achieve beam delivery to the target in the presence of faulty components, in the time between regularly scheduled maintenance periods.

2.2 General layout

The following figure illustrates a schematic layout of the TRASCO linac:

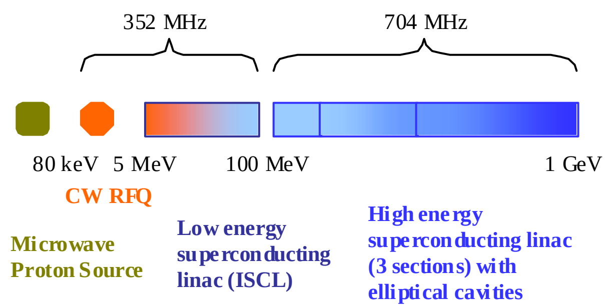

Figure 1: The schematic layout of the TRASCO linac

The linac consists in a microwave discharge proton source, operating at 80 kV, capable of providing 35 mA of CW proton beam, followed by a 352.2 MHz RFQ up to 5 MeV. A 352.2 MHz superconducting linac with independently phased single gap resonators brings the energy to approximately 100 MeV, and the beam is finally brought to the nominal energy of 1 GeV by a three section superconducting linac that uses multicell elliptical cavities at 704.4 MHz.

The main objectives of the TRASCO program are:

- The conceptual design of the whole linac;
- The design and construction of the proton source and of the RFQ pre-accelerator;
- The design, construction and test of prototypes of the superconducting cavities for the low energy and high-energy linac.

In the following sections the status of the design of the components of the TRASCO linac will be presented, followed by the description of the R&D experimental activities.

2.3 TRIPS: The TRASCO Intense Proton Source

High intensity proton sources of several tens of mA already exist – at Chalk River National Laboratory, at Los Alamos National Laboratory (LANL), and at CEA-Saclay – but additional R&D efforts are still necessary for ensuring the availability and reliability required by the ADS system. TRIPS design is based on the principle of microwave discharge, off-resonance, and it is a modified version of the source SILHI operating at CEA/Saclay since several years.

With respect to that source some things have been changed and some new features have been added: the microwave matching system has been modified in a four step maximally flat transformer, a system to move the coils on-line has been implemented (in order to vary the position of the ECR zones in the chamber), but mainly the efforts have been concentrated on the design of a new extraction system with the aim to increase the source availability and reliability, in order to meet the requirement of a driver for an ADS system.

2.4 The RFQ and low energy linac

The TRASCO RFQ has been designed with the constraints of low beam losses (less than 4%), the use of a single LEP type klystron (1.3 MW nominal power) and a Kilpatrick factor of 1.8 (corresponding to a 33 MV/m surface electric field). Table 1 summarizes the main parameters of the TRASCO RFQ.

Table 1: Main parameters of the TRASCO RFQ

TRASCO 352.2 MHz RFQ Parameters	
Beam current	30 mA (96% transmission)
Beam emittance	0.2 π mm mrad transverse
	0.18 π deg MeV longitudinal
Final energy	5 MeV
Length	7.13 m (3 sections)
RF power	150 kW (beam)
	600 kW (structure)
Peak field	1.8 Kilpatrick (33 MV/m)

The RF structure is split in three resonantly coupled segments (similar to the LEDA design). Four coupler ports, one in each quadrant and in two longitudinal positions, will feed the RF power to the structure. The vane tips have a fixed transverse radius of 2.93 mm, and the vane voltage is kept constant along the structure, to reduce power dissipation. A total of 96 tuners will provide the compensation of local frequency errors due to fabrication errors. A cold 3 m aluminium model has been built and has demonstrated the capability of field stabilization. Tests of the fabrication technology have been performed on a 22 cm short model of the structure, and the full RFQ structure is now under fabrication.

For the low energy linac several options have been investigated: a normal conducting DTL, and a few superconducting linac options based on different type of resonators (single gap reentrant cavities, half wave resonators or quarter wave resonators). Another option using spoke cavities is currently under investigation.

The choice of a superconducting linac with independently phased cavities seems the more attractive both in terms of power consumption and in terms of reliability. Due to the limited energy gain at each superconducting cavity it is possible to feed the cavities with solid-state amplifiers (of high reliability) and, furthermore, the tolerance to the loss of one cavity (from the beam dynamics point of view) is high.

2.5 The high energy linac

From the 90 – 100 MeV energy range the technology of superconducting cavities of the elliptical type represent the most efficient and cost effective solution to accelerate the beam to higher energies. By choosing the RF frequency of 704.4 MHz (twice that of the RFQ and low energy linac) it is possible to use the bulk Nb technology for cavity fabrication, taking advantage of the outstanding performances driven by the TESLA/TTF Collaboration. In order to cover the desired energy range (from ~100 MeV to 1 GeV), three different linac sections are sufficient, with cavities corresponding to the normalized particle velocity of 0.47, 0.65 and 0.85, respectively.

A set of multicell cavities for all three linac sections has been designed, taking into account both the optimization of the electromagnetic performances (in terms of peak fields on the surface) and the needed mechanical performances (stability under vacuum load, stiffness for microphonics and Lorentz forces excitation). Conservative values with respect to the state of the art technology of the TTF cavities have been used in terms of maximum peak design electrical and magnetic fields on the surface (set to < 30 MV/m and < 50 mT), in order to increase the reliability of the proposed technology. Table 2 summarizes the main parameters of the section.

Table 2: Main high energy linac parameters

TRASCO 704.4 MHz SC linac			
Section #	1	2	3
Section β_g	0.47	0.65	0.85
Input/Output Energy [MeV]	90 190	190 480	480 1000
Lattice period [m]	4.2	5.8	8.5
# Lattice Periods	14	16	12
# Cells/Cavity	5	5	6
Cavity Eacc [MeV/m]	8.5	10.3	12.3
# Cavities/Cryomodule	2	3	4

2.6 Beam dynamics analysis and simulations

The whole linac has been designed using high current beam dynamics criteria aimed at minimizing the occurrence of beam emittance growth and particle losses. In particular structure and tune resonances, and strong tune depression, have been avoided in the design and a smooth variation of all linac parameters has been guaranteed (focussing structure, fields and phase advances). Also, proper adiabatic matching procedures, described in a contribution to these Proceedings [4], have been employed at the section interfaces. The validity of the design has been assessed by means of multiparticle simulations with standard beam dynamics codes.

3 R&D ON LINAC COMPONENTS

In addition to delivering a conceptual design report for an ADS driver, the TRASCO program foresees the realization of prototypical activities on critical components of each section of the proposed linac. The most representative examples of these activities are described in the following paragraphs.

3.1 TRIPS operation

The TRIPS source has been assembled in LNS-Catania in May 2000, commissioned in January 2001 with a 20 mA beam at 60 kV and finally achieved 55 mA of beam current with 90% of proton fraction during beam tests in August 2001. Preliminary tests of the source reliability resulted in continuous source operation with no beam interruptions for more than 24 h.

3.2 Fabrication of the TRASCO RFQ

The RFQ design has been engineered, in collaboration with the industrial partners of the TRASCO program and the full structure is now in the fabrication stage [4]. Special attention during the design has been dedicated to the analysis of the cooling channels needed to the removal of the substantial heat dissipation in the structure and to the influence on the thermally induced frequency displacements.

3.3 SC cavities for the low energy linac

In the framework of the TRASCO program, a single gap SC re-entrant cavity (at the 352.2 Mhz frequency) has been designed and manufactured. A report of the performances obtained in the tests is reported in a separate contribution to these Proceedings [4]. Furthermore, an experimental program for a solid state RF amplifier in the 15 kW range (the maximum power required for these single gap cavities) has started, in order to benefit from the compactness, reliability and lower costs of solid state technologies with respect to the vacuum tube technology.

3.4 SC cavities for the high energy linac

A total of four β=0.47 single cell cavities have been built and tested with the TRASCO industrial partners, two of which using low grade niobium sheets (RRR>30) and two using high purity sheets (RRR>250). The vertical tests were very successful, and the cavities reached the record accelerating field of 22 MV/m with a $Q>10^{10}$. On the basis of this experience the construction of two complete five cell cavities has been launched. A description of this portion of the experimental program is presented in a contribution to these Proceedings [4].

4 REFERENCES

[1] EU Tech. Working Group on ADS, "A European Roadmap for Developing Accelerator Driven Systems (ADS) for Nuclear Waste Incineration", April 2002, http://www.neutron.kth.se/TWG22/default/index.html.
[2] TRASCO Partners for the accelerator program are: INFN and the Italian companies HITEC, CINEL, Saes Getters, CESI and ZANON.
[3] The TRASCO_AC Group, "Status of the High Current Proton Accelerator for the TRASCO Program", INFN Report INFN/TC-00/23, December 2000, available from http://wwwsis.lnf.infn.it/pub/INFN-TC-00-23.pdf.
[4] Papers TUPLE121, WEPLE109, THPDO022, THPDO023, THPLE083, these Proceedings.