Status of the High Current Proton Accelerator for the TRASCO Program

Paolo Pierini
INFN Milano - LASA
on behalf of the TRASCO_ACC group

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a INFN Milano LASA http://wwwlasa.infn.it
b INFN-LNL http://www.lnl.infn.it
c INFN-LNS http://www.lns.infn.it
d INFN Genova http://www.ge.infn.it
e INFN Bari http://www.ba.infn.it
f University and INFN, Napoli http://www.na.infn.it
The TRASCO Program

TRASCO: conceptual study and the prototyping of components for an accelerator driven system for nuclear waste transmutation, and involves research agencies and Italian companies

- TRASCO/ACC
  - Accelerator studies: lead by INFN
- TRASCO/SS
  - Subcritical reactor studies: lead by ENEA

TRASCO/ACC (1998-2004, in three funding stages) is devoted to:

- Conceptual design of a high current superconducting proton linac
  - I=30 mA, E = 1 GeV
- Construction and R&D activities on key items:
  - an 80 kV, 35 mA proton source (INFN - LNS)
  - a 5 MeV, 30 mA, CW RFQ (INFN - LNL)
  - SC cavity prototypes for low $\beta$ cavities (<100 MeV) (INFN - LNL)
  - SC cavity prototypes for $\beta = 0.47$ elliptical cavities (INFN - MI)
  - SC cavity prototypes for $\beta = 0.85$ sputtered cavities (INFN - GE)
  - engineering of elliptical SC linac components (cryomodules, etc.) (INFN - MI)
The Reference Linac Design

### 3 section linac:
- 85/100 - 200 MeV, $\beta = 0.47$
- 200 - 500 MeV, $\beta = 0.65$
- 500 – 1000/2000 MeV, $\beta = 0.85$

#### Five(six) cell elliptical cavities

#### Quadrupole doublet focusing: multi-cavity cryostats between doublets
- 704.4 MHz

#### Baseline design:
- Reentrant cavities (352 MHz)

#### Alternative design:
- Spoke, $\lambda/2$, $\lambda/4$, ladder

#### High Energy SC Linac

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<tr>
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<th>RFQ</th>
<th>ISCL</th>
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<td>Microwave RF Source</td>
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<td>High transmission 95%</td>
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### Beam Dynamics

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Five(six) cell elliptical cavities

Quadrupole doublet focusing: multi-cavity cryostats between doublets
- 704.4 MHz
TRIPS: TRAsco Intense Proton Source

High intensity (tens mA) proton sources exist
- Chalk River, Los Alamos, CEA-Saclay

ADS asks for high reliability and availability
Additional efforts are required for:
- Voltage and current stability
- Control of the low beam emittance

Design in 1999, source in LNS in May 2000

Achievements:
- First beam of 20 mA @ 60 kV in Jan 2001
- 80 kV, 55 mA operation in Aug 2001

Off-resonance microwave discharge source
(2.45 GHz), based on SILHI (CEA/Saclay)

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<tr>
<th>TRIPS Goals</th>
<th>Achieved</th>
</tr>
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<tbody>
<tr>
<td>Proton Beam current</td>
<td>55 mA (~90% p.f.)</td>
</tr>
<tr>
<td>Beam emittance</td>
<td>To be measured</td>
</tr>
<tr>
<td>Operating voltage</td>
<td>80 kV</td>
</tr>
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Reported at EPAC2000, PAC2001
Studies on SILHI extraction system lead to:

- Pentode configuration with new geometry
- Lowered voltage: from 95 kV to 80 kV
Layout of the Source and LEBT

Studies on SILHI extraction system lead to:
- Pentode configuration with new geometry
- Lowered voltage: from 95 kV to 80 kV

Matching transformer (impedance match)
4-step binomial transformer for waveguide to plasma impedance matching
A rms emittance below $0.2 \pi \text{ mm mmrad}$ has been calculated with beam dynamics simulations, crosschecking different codes.

- Emittance unit from CEA is being shipped to Catania for measurements.

LEBT for beam analysis and characterization:

- Solenoid (focussing)
- Beam alignment monitor
- 2 current transformers for beam current measurements
- 10 kW beam stop

Reliability tests have been performed:

- at 65 kV/15 mA: 24 h with no beam interruptions
- Tests at 80 kV are underway (improving)

A new control system for automatic restart procedures after discharge is being implemented.
The low energy linac is split in two components:

- **A normal conducting CW Radio Frequency Quadrupole (RFQ):** from 80 keV to 5 MeV
  - \textbf{RFQ} design: 3 resonantly coupled segments. Modulation:
    - Radial match in the structure
    - Shaper
    - Gentle buncher (from dc to 352.2 MHz bunches)
    - Accelerator (boosts up to 5 MeV, longest portion)

- **A superconducting linac (ISCL):** from 5 MeV to 100 MeV
  - Reentrant cavities for highest availability (allowing beam on with 1 cavity off)
  - $\lambda/4$, $\lambda/2$ cavities
  - Spoke cavities
RFQ Design

Different optimization procedure for TRASCO RFQ w.r.t. LEDA
- Limit to 1 RF source (1.3 MW CERN-LEP klystron)
- Lower design current of 30 mA (transmission of 96%)
- Peak surface electric field is 33 MV/m, 1.8 Kilpatrick limit
- Simplified engineering/manufacturing choices

Substantial heat dissipation in the structure ~ 600 kW total

Three resonantly coupled segments

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</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Final Energy</td>
</tr>
<tr>
<td>Length</td>
</tr>
<tr>
<td>RF Power</td>
</tr>
<tr>
<td></td>
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<tr>
<td>Peak Field</td>
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Poster THPLE083: Field tuning of the TRASCO RFQ
RFQ Design

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Copper dominated
- Not space charge limited
- Not beam loading limited
- 150 kW to beam
- 600 kW to copper

Peak Field | 1.8 Kilpatrick

Poster THPLE083: Field tuning of the TRASCO RFQ
RFQ: fabrication tests

A 3 m Al model of the structure has been built and measured at LNL, and achieved the necessary field stabilization.

A 220 mm part of the structure has been built to test the full fabrication procedures:

- Brazing
- Water channels by long (1 m) drilling

Full structure is under fabrication.
Superconducting low energy linac

**Single or two-gap structure linac**
- Moderate energy gain/cavity
- Solid state RF amplifiers
- $8 \beta \lambda$ focussing lattice

**Various options, are being considered**
- Reentrant cavities
- Spoke cavities
- $\lambda/4$ cavities
- ladder

Quarter Wave resonator (QWR) 2 gap structure of the ALPI linac in INFN-LNL

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**Poster TUPLE121:** A 2.5 kW, Low Cost 352 MHz Solid State RF Amplifier for CW and Pulsed Operation

**Poster THPDO022:**
RF testing of the TRASCO SC Reentrant Cavity for High Intensity Proton Beams

Reentrant cavity single gap structure. He Vessel integrated in the cavity
The high energy linac

Conceptual design of the 3 section linac

Development and test of prototype cavities
- At 352 MHz with the LEP II sputtering technology
- At 704 MHz, bulk niobium, for the lowest $\beta$

Design and engineering of cavity components and ancillaries
- Cryomodule, tuner system, piezo damping, ...

RF Test infrastructure

Designed with high current beam dynamics criteria to avoid emittance growth (smooth, tune resonances, ...)

<table>
<thead>
<tr>
<th>Section $\beta$</th>
<th>0.47</th>
<th>0.65</th>
<th>0.85</th>
</tr>
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<tbody>
<tr>
<td># cells/cavity</td>
<td>5</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>Length</td>
<td>50 m</td>
<td>93 m</td>
<td>102 m</td>
</tr>
<tr>
<td>Initial/Final Energy</td>
<td>100 MeV</td>
<td>190 MeV</td>
<td>480 MeV</td>
</tr>
<tr>
<td></td>
<td>190 MeV</td>
<td>480 MeV</td>
<td>1 GeV</td>
</tr>
<tr>
<td>Doublet period</td>
<td>4.2 m</td>
<td>5.8 m</td>
<td>8.5 m</td>
</tr>
<tr>
<td># periods</td>
<td>12</td>
<td>16</td>
<td>12</td>
</tr>
<tr>
<td># cavities in section</td>
<td>24</td>
<td>48</td>
<td>48</td>
</tr>
<tr>
<td>Max. Eacc (MV/m)</td>
<td>8.5 MV/m</td>
<td>10.2 MV/m</td>
<td>12.3 MV/m</td>
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Conceptual design: cavity design

- **Parametric tool** for the analysis of the cavity shape on the electromagnetic (and mechanical) parameters
- **Inner cell tuning** is performed through the diameter, all the characteristic cell parameters stay constant: R, r, α, d, L, Riris
- **End cell tuning** is performed through the wall angle inclination, α, or distance, d. R, L and Riris are set independently
- **End groups** for a 4 die cavity can be tuned using the end cell diameter (and a,d,R,L, Riris are set independently)

![Longitudinal eigenmode analysis](image)

**Tool used also for the SNS cavity design**

\[ \beta_g = 0.81 \text{ Cavity for SNS – 4 dies} \]

Effective \( \beta \) that matches the TTF curve = 0.830

- \( \frac{E_g}{E_{acc}} \) = 2.19 (2.14 inner cell)
- \( \frac{B_g}{E_{acc}} \) (mT/(MV/m)) = 4.79 (4.58 inner cell)
- \( \frac{R}{Q} \) (Ω) = 485
- \( G \) (Ω) = 233
- \( k \) [%] = 1.52
- \( Q_{BCS} @ 2 \text{ K} \) = 36.2
- Frequency [MHz] = 805.00
- Field Flatness [%] = 1.1

**Geometrical Parameters**

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<th>End Cell Left</th>
<th>End Group (coupler)</th>
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</tr>
<tr>
<td>( R_{B5} ) [mm]</td>
<td>48.8</td>
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</tr>
<tr>
<td>D [mm]</td>
<td>164.15</td>
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</tr>
<tr>
<td>( d ) [mm]</td>
<td>15.0</td>
<td>13.0</td>
</tr>
<tr>
<td>( r )</td>
<td>1.8</td>
<td>1.6</td>
</tr>
<tr>
<td>R</td>
<td>1.0</td>
<td>1.0</td>
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<td>( \alpha ) [deg]</td>
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Build linac from simple rules, with control of longitudinal & transverse phase advances

Find matched beam solution in all linac

Run non-linear multi-particle simulations for confirmation of design

Poster WPLE109: Adiabatic Matching in Periodic Accelerating Lattices for Superconducting Proton Linacs
352 MHz $\beta=0.85$ prototypes with CERN

352 MHz cavities with CERN (MOU)
- Use LEP II sputtering technology
- Single cell and 5 cell sputtered - $\beta = 0.85$
- Cavity integrated in a LEP type cryostat

All tests reached the design goals, indeed performed as the best LEP batch

But: Bulk niobium is needed at lower $\beta$, and the gradient is moderate w.r.t 704 MHz

Test in a modified LEPII cryomodule (Aug. 2001)
- Powered to 250 kW
- 7 MV/m

TRASCO Specifications
$Q=2 \times 10^9$ @ 5.5 MV/m
**β=0.47 single cell cavities prototypes**

Fabricated with RRR>30 & RRR>250 Niobium at Zanon BCP, HPR and tests at TJNAF (Z104) and Saclay (Z101-Z103)

Max $E_{\text{peak}} = 74$ MV/m  
Max $B_{\text{peak}} = 138$ mT

- **For 1-cell:**
  - $E_p/E_{\text{acc}} = 2.90$
  - $B_p/E_{\text{acc}} = 5.38$ mT/(MV/m)

- **For 5-cell:**
  - $E_p/E_{\text{acc}} = 3.57$
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Two 5 cell cavities are under fabrication

**Poster THPDO023: RF Tests of the Single Cell Prototypes for the TRASCO β=0.47 Cavities**

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**Poster THPDO023: RF Tests of the Single Cell Prototypes for the TRASCO β=0.47 Cavities**
Baseline of the “smooth” linac design

Continuous phase advances at transitions

RFQ

P. Pierini

EPAC 2002, Paris, 3-7 June 2002
Full SC linac from 5 MeV to 1 GeV

Input @ 5 MeV $10^5$ ptcl

Results of non-linear simulations
No particle losses, beams well confined

Output @ 1 GeV
Rms emittances growth (from end of RFQ to full energy) < 2%

Avoided:
- Structure resonances
- Tune resonances
- Big tune depression

Guaranteed:
- Smooth beamline changes
- Good matching procedures
Rms emittances growth (from end of RFQ to full energy) < 2%

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The effort to build a complete ADS system exceeds the capabilities (and the funding availability) of any national program like TRASCO

- TRASCO means to provide significant R&D and prototipical effort along the road to the design of a transmuter system

Already in the FP5 of the European Commission a Program has been funded: "PDS-XADS - Preliminary Design Studies for an eXperimental Accelerator Driven System"

- 25 Partners, from Research Institutions to EU Industries
- 12 M€ Program (50% supported by the Commission)
- Several Working Packages, dealing with various aspects of an ADS
- WP3 is dedicated to the Accelerator

More to come in the FP6 ...