# INDIAN PROGRAMME TO DEVELOP HIGH CURRENT PROTON LINAC FOR ADSS

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*Abstract*

India has initiated a programme to develop Accelerator driven Sub-critical System (ADDS) for nuclear power. Under this programme, Centre for Advanced Technology (CAT) is developing a high current Proton Linac whereas Bhabha Atomic Research Center (BARC) is developing the spallation Neutron Source and sub-critical nuclear assemblies particularly with a view to utilizing the large resources of Thorium in India. In the first phase, CAT has taken up development of a 100 MeV, 10 mA Proton Linac. It is also proposed to develop a 1GeV, 100 kW, 25 Hz Rapid Cycling Proton Synchrotron for a Pulsed Spallation Neutron Source. The 100 MeV Proton Linac will be the injector for this synchrotron.

## 1 MOTIVATION FOR ADS IN INDIA

Although the electricity generation in India exceeds 90 GWe today, the average per capita electric energy consumption is only about 780 kWh/year, which is about one third of world average. India's immediate goal in electricity generation is to reach world average in energy consumption by the year 2020. This will require 250 GWe electricity generation. It is planned that 20 GW of this will be nuclear power.

From fig.1, which shows India's energy resources, it is seen that India has very limited resources of uranium but has very large resources of thorium, in fact the largest in the world. Thus to have sustained generation of nuclear power at 20 GWe or more, India has to depend on breeding of Thorium. India has already initiated a programme to develop fast breeder technology and a 40 MW liquid sodium cooled fast breeder test reactor has already been developed. However Accelerator Driven Sub-critical Systems offer several advantages over fast breeder reactors. Hence India has embarked upon a programme to develop an ADS specifically for utilizing thorium. The reactor core design and development of the spallation neutron source is being carried out at the Bhabha Atomic Research Centre, Mumbai, whereas the accelerator is primarily being developed at the Centre for Advanced Technology (CAT), Indore.

## 2 INDIA'S ADS PROGRAMME

Department of Atomic Energy had constituted a committee of experts to prepare a plan for developing Proton Accelerators for ADS in India. This committee has recommended such a programme in two phases. In

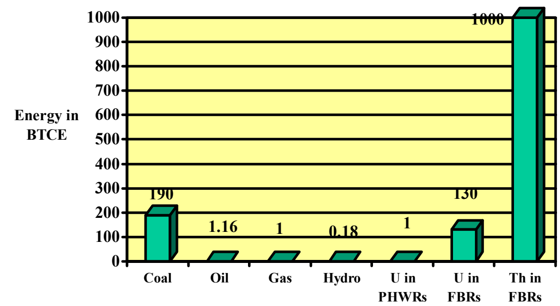


Figure 1. Energy resources in India

the first phase, lasting between 5-7 years, a 100 MeV proton linac of nominal current of 10 mA and a 30-50 MeV / 1-5 mA proton cyclotron would be developed. Simultaneously development of superconducting accelerating structures should be taken up. After completion of the first phase a decision could be taken to follow either the cyclotron route or the Linac route to reach 1 GeV proton energy.

## 3 LINAC DESIGN

The Linac route is being followed at the Centre for Advanced Technology. Fig.2 shows the proposed linac and a 25 Hz Rapid Cycling 1 GeV Synchrotron under development at CAT. With the 1 GeV 25 Hz Synchrotron, this will become a multitask facility including a pulsed spallation neutron source.

Since the linac will be an injector to the 1 GeV Synchrotron, the ion source will be a microwave driven multi-cusp H- source, capable of giving about 25 mA current in 500 μsec pulse or nominally 12 mA current in CW mode.

### *3.1 RFQ*

The RFQ will accelerate the ions to 4.5 MeV energy. The design of RFQ is governed mainly by the requirement of CW operation. The RF frequency of 350 MHz was selected based on two factors, firstly ease of removal of heat from RFQ structures and secondly availability of high power CW sources. The RFQ structure is the standard four integrated vane-cavity structure with Pi Mode Stabilizing Loop (PISL). We are also looking into the possibility of resonantly coupled RFQ structure[1]. In order to reduce the power dissipation per unit length in the RFQ structure, the intervane voltage is kept at 65 KV which is considerably lower than what is used in pulsed RFQs.

Beam dynamics studies have been carried out to optimizing the parameters of RFQ. Similarly, thermal and structural coupled analysis of the RFQ structure has been carried out. Both these are presented by my colleagues as contributed papers in this conference [1][2][3].

Table- I RFQ Design Parameters

| | | |
|---|---|---|
| Beam current | 25 | mA |
| Inter vane voltage | 65 | kV |
| Particle | $H^+$ /$H^-$ | |
| Total length | 6.52 | m |
| Modulation Parameter | 1 – 1.915 | |
| Minimum aperture radius | 2.20 | mm |
| Average radius | 3.30 | mm |
| Synchronous phase | -90 – -30° | |
| Transmission efficiency | 96.3 | % |
| Input emitt. | 0.20 | πμm.rad |
| Output emitt. rms(n) | 0.20 | πμm.rad |
| Output emitt. rms(n) | 0.10 | deg.MeV |
| Quality factor | 9000 | |
| Total power loss | 539 | kW |

We are considering two options after RFQ namely DTL up to 20 MeV followed by SDTL up to 100 MeV and SDTL from RFQ to 100 MeV. Beam dynamics study of second option is presented in this conference[2]. Similarly, two options for the operating frequency namely 350 MHz and 700 MHz are being studied.

SDTL offers two main advantages namely easier fabrication hence lower cost and higher shunt impedance. On the other hand, the focusing in SDTL is inferior to DTL resulting in poorer beam quality particularly in the lower energy range.

Since RF and space charge defocusing is stronger at lower energies, smaller number of gaps per tank are desirable at lower energies.

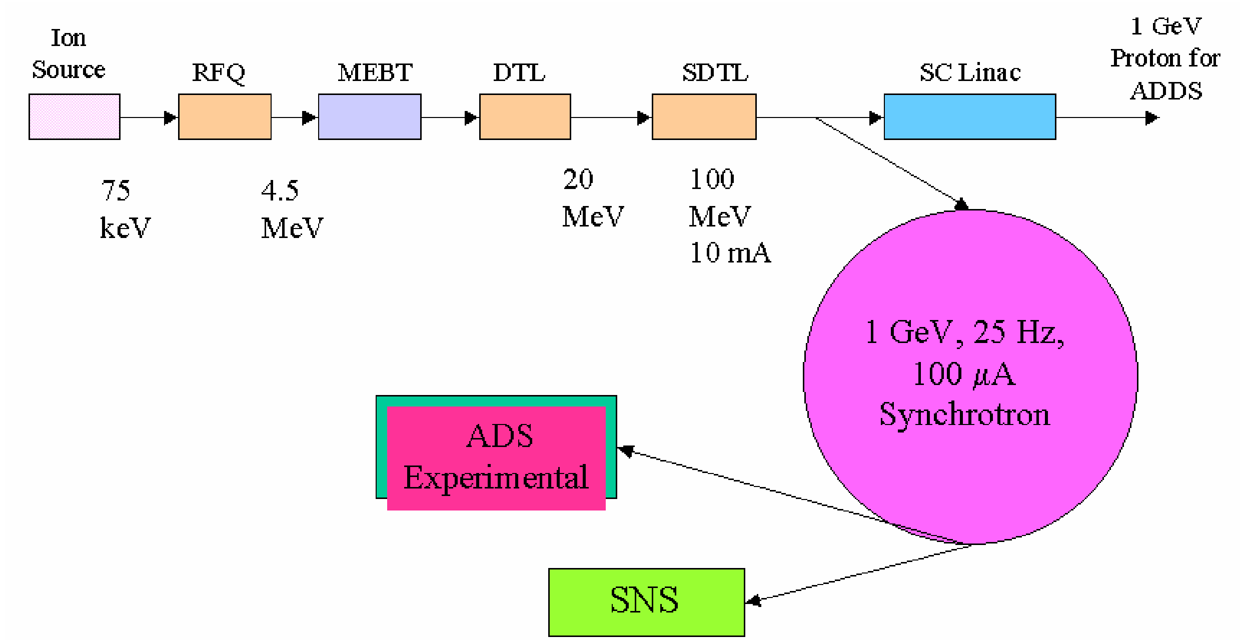


**Figure 2. Proposed Proton Linac and Synchrotron being developed at CAT**

## *3.2 DTL and SDTL*

Design specifications of the 100 MeV linac are given in Table-I. The 1 GeV ADS linac will need 10 mA CW proton beam at injection where as the SNS synchrotron needs 20 mA $H^-$ ion beam. Hence the RFQ, DTL and the SDTL are designed for a current of 25 mA.

Table-I: Design Specifications of the 100 MeV Linac

| | ADSS | SNS | |
|---|---|---|---|
| Input energy | 4.5 | | MeV |
| Output energy | 100 | | MeV |
| Beam current | 10 | 20 | mA |
| Particles | H+ | H- | |
| Operating mode | CW | Pulsed | |
| Pulse duration | – | 500 | μsec |
| Repetition rate | – | 25 | Hz |

### *3.2.1Beam Dynamics studies*

Beam dynamics studies were performed with the help of code PARMILA for DTL and SDTL. The phase space matching in MEBT and the following structures is performed using TRACE3-D.

### *DTL*

The axial field was ramped from 1.8 MV/m to 2.2 MV/m and the synchronous phase $\varphi_s$ is ramped from -60°

to –30° over 120 cells. DTL parameters are listed in Table-II.

Table-II Drift Tube Linac

| | | |
|---|---|---|
| Energy | 20 | MeV |
| Beam current | 25 | mA |
| Average E0 | 1.8 – 2.2 | MV/mm |
| Synchronous Phase | -60 - -30 | ° |
| Length | 15.33 | meters |
| Focussing lattice | FODO | |
| Input εtrms(n) | 0.225 | π mm mrad |
| Output εt, rms(n) | 0.235 | π mm mrad |
| Output εzrms(n) | 0.104 | deg.MeV |

### *SDTL*

SDTL design at 700 MHz using 4 gaps/tank initially increasing to 6 gaps/tank later has been optimised for 25 mA beam current. The accelerating gradient $E_0$ is ramped from 1.6 to 3.0 MV/m and synchronous phase from –60 to –30 deg. A detailed thermal – structural analysis has been performed for the 91$^{st}$ SDTL Tank which has maximum power dissipation and is reported in this conference [4]. The temperature plot of the optimised geometry of SDTL drift tube is shown in figure 3.

Another option using 350 MHz SDTL has been studied with accelerating gradient $E_0$ varying from 1.6 to 2.2 MV/m and the synchronous phase φs from -60° to -30°. After studying various schemes with TRACE3D a Triplet lattice was decided for inter tank focusing. The triplet is placed at the centre of the inter tank space which is an integral multiple of βλ. In order to have a symmetric focusing in x and y planes, each triplet is rotated by 90 degrees wrt to the preceding one. The inter tank matching is also performed using TRACE3D. The design parameters of the 100 MeV SDTL are listed in Table-III.

Table-III: Design parameters of the SDTL

| | | |
|---|---|---|
| Frequency | 350 | MHz |
| Energy | 100.43 | MeV |
| Beam current | 25 | mA |
| Number of Tanks | 98 | |
| No. of cells/tank | 3 | |
| DT bore ID | 20 | mm |
| DT OD | 60 – 100 | mm |
| Tank Diameter | 520 – 560 | mm |
| Tank length | 252.98–1099.5 | mm |
| Shunt Imp. (eff.) | 43 – 52 | MΩ/m |
| Beam Power | 2.4 | MW |
| Cavity losses | 4.76 | MW |
| Total RF Power | 7.16 | MW |
| Quad gradient | 40 – 75 | T/m |
| RMS O/P emitt. x | 0.31 | πmm.mrad |
| y | 0.32 | πmm.mrad |
| z | 0.11 | deg.MeV |

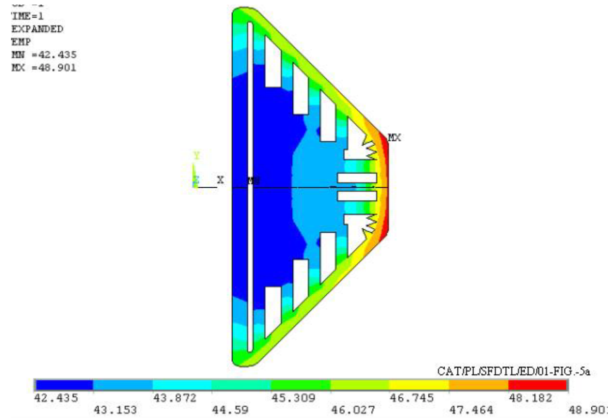


Figure3. Tempearture Plot of optimized drift tube.

## 4. 1 GeV PROTON SYNCHROTRON

A 1 GeV, 100 □A, 25 Hz rapid cycling synchrotron is also being designed for the spallation neutron source and the experimental ADSS facility. A beam power of 100 kW will be available for the proposed facility.

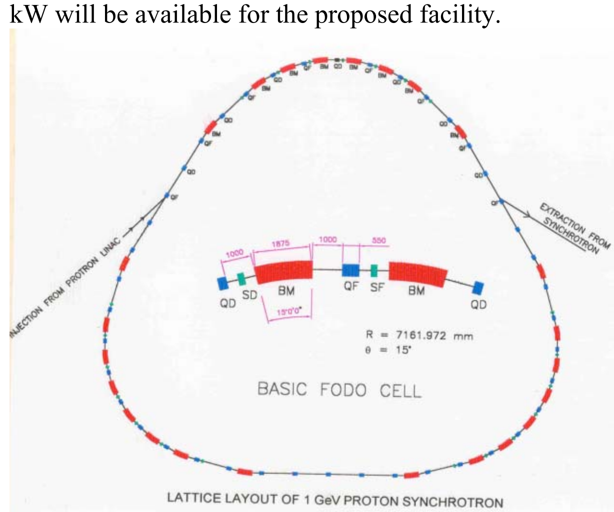


Figure 4. Lattice Layout of 1 Gev Proton Synchrotron

## 5 REFERENCES

[1] S.A. Pande et al. "Design of 4.5 MeV RFQ for Protons/H– Ions", this conference.

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[3] S. C. Joshi et al., "Prototype Engineering Design of 350 MHz 4.5 MeV RFQ Structure for Proposed Proton Linac for Indian ADS Program"; this conference.

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