TECHNICAL CONSIDERATIONS OF THE TPS LINAC

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Abstract

The technical considerations of the TPS (Taiwan Photon Source) linac will be presented in this report. A 150 MeV turn-key linac is chosen in this case in order to provide the ease of injection into the booster in which the electron energy will be raised up to 3 GeV. This linac will be similar to that equipping at recently commissioned synchrotron light sources. The major beam parameters are derived from the booster and storage ring injection requirements. The beam diagnostics arrangement for linac commissioning purpose will be briefly described.

INTRODUCTION

The TPS accelerator complex is designed to fill 400 mA into the storage ring within 5 minutes. Consequently, a minimum beam accumulation capability of 100 mA per minute is required. In order to accomplish this goal, the linac capability in delivering electrons with required beam quality needs to be specified for a commercial available turn-key system. Along with the development of the beam parameters for the turn-key linac, the empirical overall beam transfer efficiency, from linac exit to beam accumulation in the storage ring, has beam assumed. The assumed transfer efficiency was based on the operation experience of the existing 1.5 GeV light source – TLS (Taiwan Light Source) [1]. The performance specifications of the linac are outlined in the following section.

A number of 3 GHz turn-key linac system have been successfully installed and commissioned in many synchrotron light sources, e.g., SLS [2], Diamond [3], ASP [4], Soleil [5], and ALBA [6]. This indicates that a turn-key linac system is capable of fulfilling the operation requirements of a synchrotron light source. We have explored the feasibility of taking similar approach for the TPS linac construction plan. The conclusion is briefly described in this report.

The 150 MeV linac will be procured as a single turn-key system, subject to a performance specification. The scope of this contract is to design, manufacture, install and commission in the NSRRC jobsite an electron linear accelerator (linac). It must be capable of operating continuously and reliably at energy of at least 150 MeV. It must have good beam properties and stability, as described in the following sections, and it must be capable of multi-bunch, single bunch and top-up operational modes.

OPERATION MODES

There are two types of operation modes of TPS linac, multi-bunch mode (MBM) and single-bunch mode (SBM).

Both operation modes are designed to meet the needs of potential users in the future.

Multi-bunch mode operation

For MBM operation, the linac will deliver a long beam pulse. The MBM will deliver a chopped beam at 500 MHz (chopped at gun level) with pulse length from 200 to 1000 ns at a repetition rate of 1 to 5 Hz. The total charge in a 1000 ns train is ≧ 5 nC. For top-up injection in MBM, the linac should be capable of reproducibly providing single MB trains at the rate of few mHz (10 to 300 seconds) or sequences of MB trains (with 1 to 5 Hz for 1 to 10 seconds) at the rate of few mHz (1 to 5 minutes). The beam parameters for MBM operation are listed in Table 1. In this MBM operation, the rise/down time of the macro-pulse will be as small as possible, e.g. smaller than 2 ns to ensure a clean filling pattern.

Table 1. Beam parameters of MBM operation

Parameter	Specification
Bunch train length (μs)	**0.2 to 1**
Charge in bunch train (nC)	**≥ 5**
Energy (MeV)	**≥ 150**
Pulse to pulse energy variation (%)	**≤ 0.25**
Relative energy spread (%)	**≤ 0.5 (rms)**
Normalised emittance (1σ) (πmm mrad)	**≤ 50 (both planes)**
Repetition rate (Hz)	**1 to 5, adjustable**
Pulse to pulse time jitter (ps)	**≤ 100**

Table 2. Beam parameters of SBM operation

Parameter	Specification
Pulse FWHM (ns)	**< 1 ns**
Charge in single bunch (nC)	**≥ 1.5**
Energy (MeV)	**≥ 150**
Pulse to pulse energy variation (%)	**≤ 0.25**
Relative energy spread (%)	**≤ 0.5 (rms)**
Normalised emittance (1σ) (πmm mrad)	**≤ 50 (both planes)**
Single bunch purity (%)	**better than 1**
Repetition rate (Hz)	**1 to 5, adjustable**
Pulse to pulse time jitter (ps)	**≤ 100**

Single-bunch mode operation

For SBM operation, the linac will deliver a short pulse of < 1 ns at a repetition rate of 1 to 5 Hz. Each pulse is bunched in a few S-band micro-bunches that will be injected into a single 500 MHz rf bucket of the booster. To ensure good single bunch purity, a sub-harmonic buncher at 500 MHz will be used. The total charge in a

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single bunch is ≧ 1.5 nC. The beam parameters for SBM operation are listed in Table 2.

SYSTEM CONFIGURATION

The 150 MeV turn-key linac consists of an electron gun, focusing and bunching system, and three accelerating sections.

Electron gun

A thermionic triode gun generates 1ns (10^{-9}) electron bunch and then the electrons gain energy up to 90~100 keV. In MBM operation, the gun will be driven by the cathode at 500 MHz and directly produce a chopped beam. In SBM operation, the cathode will be pulsed with respect to the grid. The maximum FWHM of the pulse will be less than 1 ns..

Focusing and bunching system

In order to obtain high transfer efficiency of the electrons from gun to linac, the electron bunch has to be prepared by this focusing and bunching system before being injected into the linac. A 500 MHz sub-harmonic pre-buncher is applied to achieve good bunching purity into the booster. The subsequent 3 GHz buncheres will bunch and accelerate the electron close to the speed of light (β ~ 1).

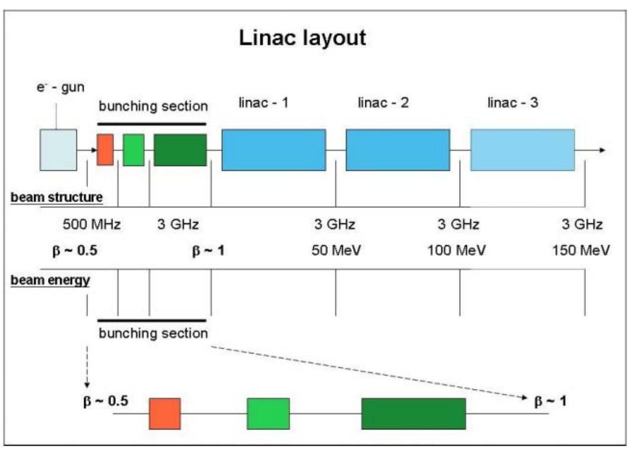

Figure 1: The schematic layout of the TPS-linac bunching structure.

Accelerating sections

Three identical accelerating structures at 3 GHz will be installed and powered to increase the electron beam energy to 150 MeV. Three identical rf stations each capable of providing 35 MW for accelerating structure will be equipped. The rf power distribution from these three rf stations to the bunching section and three accelerating structures should be configured to be able to operate in rescue mode. The rescue mode is defined as whichever one of the rf stations malfunctioned, the rf power distribution can be adjusted and re-configured (via a waveguide switch system) such that the power from the remaining two rf stations can be fed into the bunching section and the three accelerating structures. The switchover time needed for the rf power redistribution arrangement should not take longer than 4 hours before restoring the linac for routine operation.

The schematic layout of the TPS linac concerning the accelerating beam energy together with its corresponding bunch structure is shown in Fig. 1.

GENERAL LAYOUT

The general layout of the proposed 150 MeV linac is shown in Fig. 2. Three accelerating sections and their associated rf power stations are sketched for evaluation purpose in discussing with the civil construction team. A possible diagnostic beamline is also planned in this layout for linac commissioning preparation. The beam dump for radiation safety consideration will also be implemented.

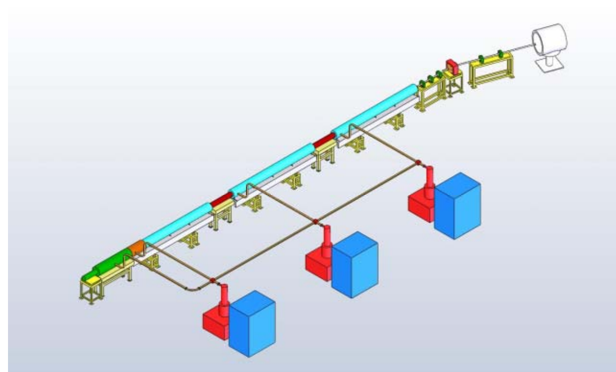

Figure 2: The general layout of the 150 MeV linac.

CONTROL SYSTEM AND INTERFACE

The linac control system will be provided by the contractor complying with EPICS control environment. It should include necessary software for machine control, start-up, and operation (e.g. medm (edm) GUI pages and start-up SNL programs or other CA start-up scripts), and should be designed and developed to be easily integrated in the NSRRC accelerator EPICS control system.

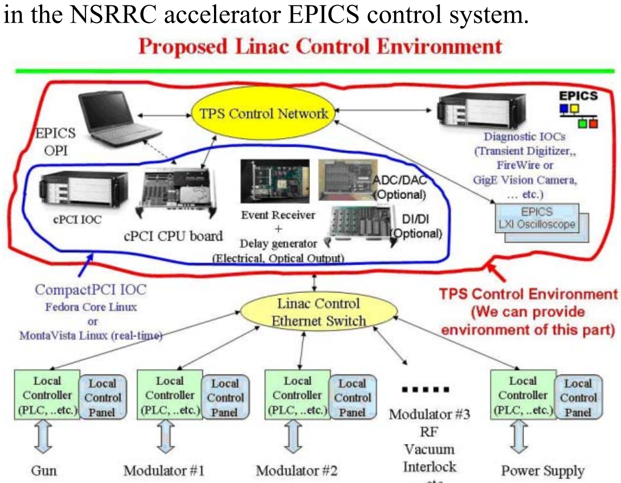

Figure 3: The proposed interface and control environment.

The linac should be designed to be operational under a local console. The linac will be fully operational with the local PC system, as part of the linac system, provided by the contractor.

A sketch of the preliminary proposed interface as well as the integration environment of the NSRRC control system is outlined in Fig. 3

DIAGNOSTIC BEAMLINE

The linac-to-beam-dump (LTD) diagonal beam line, as a branch of the linac-to-booster (LTB) transfer line, will be employed in measuring the beam parameters at the linac exit. As shown in figure-2, the LTD transfer line will be equipped with appropriate elements for beam transport and beam diagnostics purpose, such as dipole, quadrupole, current monitor, screen monitor, energy slits etc. The LTD is separated into two regions, the dispersion free region between the linac and the bending magnet and the dispersion region after the bending magnet. In the dispersion free area, a set of triplet quadrupoles will be arranged and a screen monitor will be installed in front of the bending magnet for beam size display. Tuning of the triplet magnets will be applied for beam size and emittance measurement. In the dispersion region, the beam energy spread will be determined by applying standard measurement technique in association with using bending magnet, energy slits, and beam current monitor [7].

The evolution of the beta function by the transfer matrix M from the linac exit to the screen is:

$$\beta_m = \beta_0 M_{11}^2 - 2\alpha_0 M_{11} M_{12} + \gamma_0 M_{12}^2$$

where

$$\gamma_0 = \left(1 + \alpha_0^2\right) / \beta_0$$

$$M = M\left(s_m \mid s_0\right)$$

The beam size measured at the screen monitor before the bending magnet is:

$$\sigma_m = \sqrt{\varepsilon \beta_m}$$

The transfer matrix M can be determined and adjusted by tuning the triplet quadrupoles. With N sets of the M matrices and beam size measurements, one can determine the α_0, β_0 and ε by using the fitting method statistically. Concerning the energy spread determination, one could also install another screen monitor located at the dispersion region for this purpose. The beam energy spread δ can be calculated by the measured horizontal beam size:

$$\sigma = \sqrt{\varepsilon \beta + D^2 \delta^2}$$

where β and D are the beta and dispersion functions located at the screen.

PROJECT SCHEDULE

The project schedule of the TPS 150 MeV linac is to start the design and fabrication of the turn-key system in 2008. The proposed construction duration is about 2 years. The proposed installation and commissioning time is about 6 months. This turn-key system is expecting to acquire good beam quality and reliable performance as those turn-key linacs in synchrotron light sources highlighted in section 1.

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