800 MeV LINEAR ACCELERATOR DEVELOPMENT FOR HLS UPGRADE*

K. Jin, S. C. Zhang, G. R. Huang, D. C. Jia, Y. L. Hong
National Synchrotron Radiation Laboratory, NSRL USTC,
P.O. Box 6022, Hefei Anhui 230029, China

Abstract

Hefei Light Source (HLS) was mainly composed of an 800 MeV electron storage ring and a 200 MeV constant-impedance Linac functioning as its injector in NSRL Phase Ⅰ. A new Linac has been developed successfully in view of the Full Energy Injection and the Top-up Injection scheme will be adopted in the HLS upgrade. In this paper, an 800MeV linear accelerating system construction, the constant-gradient structure with the symmetry couplers will be described in detail. The microwave system, the manufacture technology, the RF measurement, the high power testing and the accelerating system operation with beam currents are presented.

INTRODUCTION

In order to ensure the low-emittance focusing parameters steady operation in the HLS Storage Ring, it's necessary to increase the injector energy to 800MeV. After realize Full Energy Injection, each system of Storage Ring can keep single operation state, the light source stability will be improved eminently. A new Linac is developed in view of the Full Energy Injection and the Top-up Injection scheme will be adopted in the HLS upgrade. An 800MeV Linac layout is shown in Fig.1.

The LINAC is a traveling-wave type, operating at 2856MHz and utilizes 8 klystron amplifiers. It consists of pre-bunch, fundamental mode bunch and 16 three-meter long constant-gradient accelerating sections. The total length of the LINAC is about 71.5 meters. The project has been developed successfully. In this paper, the main parameters of the 800MeV linear accelerating system are presented. Specially, the microwave system layout and the constant-gradient accelerating structure with the symmetry couplers design, fabrication, RF measurement and the high power test will be described in detail.

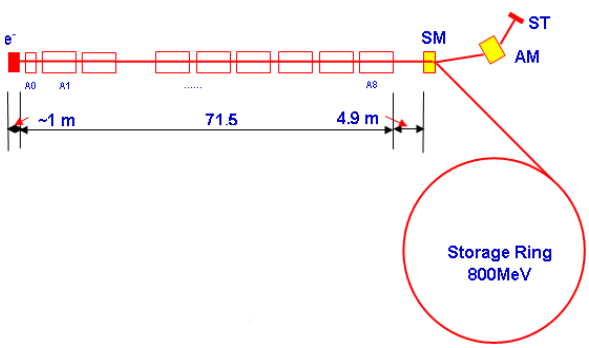

Figure1: HLS 800 MeV Linac and the electron storage ring layout

THE MAIN PARAMETERS OF THE LINAC

The electron gun is thermal emission electron gun, which can produce up to 1.5A (Max.) with 100kV injection energy in 1ns pulse beams. The beam current at the end of the LINAC is supposed to be 1.0A. And there is a switch magnet at the end of the LINAC, by which the electron beams can be switched to the storage ring, the nuclear experiment hall, the energy analysis magnet or the beam dump according to what is needed. Table 1 lists the main parameters of the LINAC.

Table 1: The main parameters of the HLS LINAC

Parameters	HLS Linac
Electron energy	800 MeV
Beam pulse charge	1 nC
Beam pulse width	~10 ps
Energy spread	0.5 %
Beam normalization emittance	<60 mm·mrad
Electron gun voltage	-100kV
Repetition rate	1～10 Hz
RF frequency	2856 MHz
RF power per klystron	50 MWx6，80 MWx2
Number of klystron	8
Temperature of cooling water	42℃
Vacuum (with beam)	$<1\times10^{-6}$ Pa

800 MeV LINAC DEVELOPMENT

HLS accelerating system consists of a pre-buncher, a buncher and eight units of constant-gradient accelerating structures (6m accelerator unit). Total length is about 73meter. The electron beam energy can be achieved to 800MeV~1GeV. In general, seven such as units is in operation condition and another one is in standby state so that to assure storage-ring stability running (Fig.2).

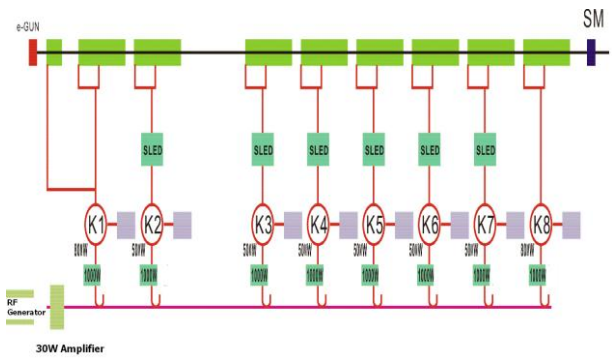

Figure2: 800 MeV electron Linac energy, phase and microwave System Layout

ISBN 978-3-95450-142-7

The Microwave System Layout

According to 800 MeV electron Linac layout, the microwave system consists of the rf driving, high power klystrons and waveguides components. RF generator with fine stability outputs power about 7dbm and is amplified to 30W. After that the power is transmitted to eight solid state amplifiers（1kW）for drive klystrons via RF cable with constant temperature and the direction couplers along the line distributed. The phase shift-attenuation unit (IΦCA) is installed at between the each amplifier and klystron for insulate, attenuation and phase tuning. Thereby the klystron regular operation is ensured effectively. The each waveguide section is used to transmit RF power from the klystron to an accelerator unite. Moreover, various interlocks are provided, either to protect personnel or to prevent equipment from damage.

Table 2: The performance of the LINAC RF system

Parameters	HLS Linac
Work frequency	2856 MHz
Frequency tuning range	±100 kHz
Frequency stability	$<10^{-6}$/day
Output power of solid state amplifier	>1000 W
Peak rf output power of klystron	50，80 MW
VSWR of each waveguide section	<1.2
Power decay of each waveguide section	0.7~0.8 dB
Vacuum of waveguide system	$<1\times10^{-6}$ Pa

The Bunching System

The bunching system work frequency is 2856 MHZ, including pre-buncher and fundamental mode buncher. The beam from the gun is focused initially in the pre-buncher, then electron beam get into buncher to further complete beam phase bunching process, and further increase the beam energy.

- Pre-buncher is a cylindrical reentrant resonator working at TM_{010} mode. Its resonance frequency is 2856 MHz, Q (~ 500) and the shunt impedance Rs/Q = 220. In order to optimize bunching effect, pre-buncher voltage is optimized to 15kV and the distance between pre-buncher and buncher is optimized to 35 cm.
- The fundamental mode buncher is constant gradient disk load accelerating structure. It totally has 45 cavities; the first five cavity is vary phase velocity period structure. The phase velocities are 0.70, 0.88, 0.95, 0.98, 0.99, the others are relativistic accelerating section. Solenoids are used to focus in the transverse direction. The length of fundamental mode buncher is 1.63 m, the accelerating gradient is about 8.2 MV/m, and beam energy is about 13.1 MeV after bunching section.

Accelerating Section

The constant-gradient structure can produce higher energies than an optimized constant-impedance structure when both are operating at the breakdown limit of electric field strength. Considering such structure reduces ration of maximum to average field strengths and increases some advantages [1], the constant-gradient structure was thus adopted for the HLS Linac upgrade.

The cavity type of constant-gradient disk-loaded structure was selected in HLS accelerating section. Operating frequency of 2856MHz, phase shit per cavity of 2π/3, i.e. cavity length of 34.989mm and disk thickness of 5.8mm is set. The optimum cell geometer and its EM performance, calculated with MAFIA-Code [2], are listed in Table 3. The curves of field strength and energy vs. axial distance z are shown in fig.3. Here the power range is 32.0 Mw to 10.1Mw in such accelerator section, the field strength Ez of 20.7Mv/m is acquired and the energy gain is about 62MeV. The manufacture technology, the RF measurement and tuning of the constant-gradient accelerating structure with the symmetry couplers has been described in detail [3].

In order to realize Full Energy Injection, one klystron of 80Mw provides power to a pre-buncher and a buncher as well as to a 6m accelerator unit which is constructed by two 3m standard sections. Another one of 80Mw and six klystrons of 50Mw with SLED technology will provide power to each 6m accelerator unit individually. The average accelerating gradient of 20Mv/m can be obtained in such away. The electron beam energy can be achieved to 800MeV~1GeV. In general seven 6m accelerator units are in operation condition and the other one is in standby state so that to assure storage-ring stability running.

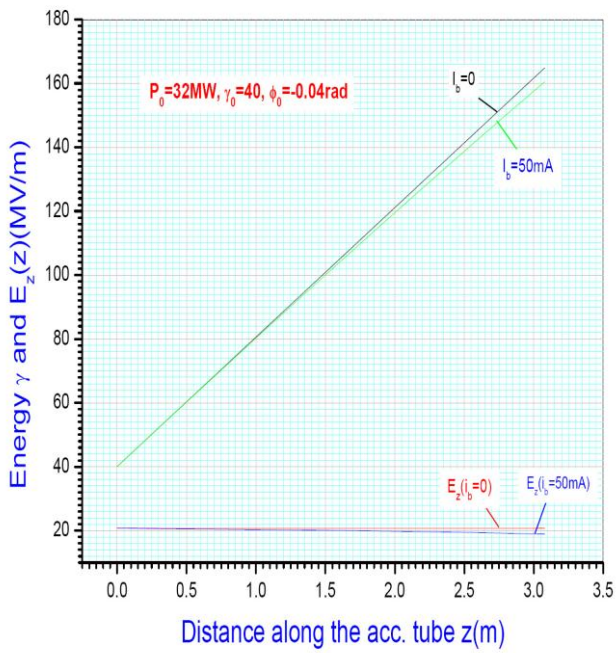

Figure 3: The field strength and energy gain in the 3m accelerating section.

Table 3． Final design and performance of the HLS accelerator structure

Parameters	HLS Linac
Operating frequency (f)	2856 MHz
Phase shit per cavity	2π/3
Iris diameter range of disk-loaded (2a)	25.386-19.260 mm
Cavity diameter range of disk-loaded (2b)	83.118-81.718 mm
Range of shunt impedance (R_s)	55-63 MΩ/m
Normalized group velocity range (Vg/c)	0.0177-0.0063
Attenuation parameters (τ)	0.585 Np
Filling time (t_F)	0.8995μsec
Operating state	42°C, vacuum
No. of standard 3m section	16
No. of cavities in each 3m section	86+2 coupler
Distance between inputs of two consecutive sections	31 λ
No. of 6m accelerator unit	8

CONCLUSION

On the basis of general planning, a buncher and all 16 standard 3m sections has been manufactured successfully in NSRL, and the favorable microwave performance is obtained end of Sep. 2012. During this period, the high-power test of the 3m accelerator section was processed. The pulse length of 1uS, maximum input power to the section is approximately 50Mw peak; Steady operation of pulse length of 5uS, input power of 35MW peak for such section was achieved. All accelerating sections, the waveguide components and cooling system were installed in Aug. 2013 as shown in Fig. 4 and have been operated in a fine status. In current operation, the electron beam energy gain in HLS LINAC is shown in Table 4.

Figure 4: HLS 800MeV electron Linac

Table 4: The beam energy gain in HLS Linac Ⅱ

Equipments	Beam energy gain
e-Gun	100 keV
Pre-Buncher	140 keV
Buncher	15.5 MeV
1# 6m acc. unit	160.0 MeV
2# 6m acc. unit	250.0 MeV
3# 6m acc. unit	340.0 MeV
4# 6m acc. unit	416.0 MeV
5# 6m acc. unit	500.0 MeV
6# 6m acc. unit	590.0 MeV
7# 6m acc. unit	680.0 MeV
8# 6m acc. unit	800.3 MeV

The emittance of 40nm.rad design parameters and the accumulated current of 450mA in every fill are realized in 800MeV HLS Electron Stage Ring. It can be looked at, the machine will formal operate and open to outside in 2015.

ACKNOWLEDGMENT

We would like to thank all the members of the collaboration for their contributions. Special thanks are given to J. Wang, J. F. Gao, Y. Z. Liu, J. Y. Zhang, W. Wei, F. Hu, S. Y. Jiang, X. Y. He and Y. J. Pei, who were heavily involved in the HLS Linac Ⅱ fabrication.

REFERENCES

[1] R.B. Neal et al., Theory and selection of characteristic parameters, The Stanford Two-mile Accelerator, Chapter 6-1.

[2] Mafia, the MAFIA Collaboration, December 1996.

[3] K. Jin, et al., The Linear Accelerating Structure Development for HLS Upgrade, Proceedings of LINAC2012, Tel-Aviv, Israel, p.254

ISBN 978-3-95450-142-7