

THE HIGH ACCURACY RF PHASE DETECTOR RESEARCH FOR 200 MEV LINAC

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Abstract

The basic configuration of one experimental RF Phase detector and its application in Hefei 200MeV RF Linear accelerator are introduced. The 200MeV linac, which is the injector of Hefei Light Source (HLS), is cascaded by 5 accelerator tubes. The beam energy could be stabilized and controlled accurately by implementing RF Phase detectors of the 5 cascaded accelerator tubes into a phase locked system. The tabletop experiments are given and the RF Phase detector is tuned in the off-line status. The microwave in 2856MHz under CW mode is differentiated accurately by the developed RF phase detector. The measured results are better than prediction. The accuracy of the basic configuration of the RF Phase detector is verified, which establishes foundations for further experiments.

INTRODUCTION

200 MeV electron linac is an injector of HLS (Hefei Synchrotron Radiation Light Source), as shown in Figure 1. The Linac has been running for 17 years. Its typical operation parameters are energy of 200 MeV, Current of 50 mA and energy spread of 0.8%[1]. Its energy shift during the injection period suggest its cure by implementing RF Phase detectors of the 5 cascaded accelerator tubes into a phase locked system.

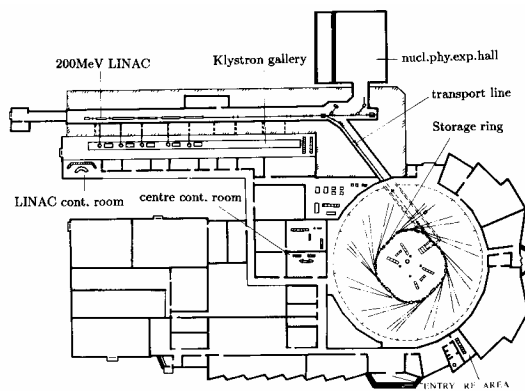


Figure 1: Layout of Hefei SLS.

In Phase-II Project of the National Synchrotron Radiation Laboratory, the old RF drive system of

200MeV Linac[2] is transformed into a high peak power RF solid-state amplifier as illustrated in Fig. 2. The main parameters of the RF power solid-state amplifier are operating frequency of 2856 MHz, peak power of 300W, pulse width (flat top) of 2.0 μ s, RF repetition rate of 300 pps. The new RF drive system consists of a medial power klystron amplifier and a medial power modulator. The RF solid-state amplifier drives the first high peak power klystron to amplify the 300Watt of the solid-state amplifier to a level of 8.5 MW. This power will be fed to the first accelerating tube, buncher and prebuncher. Simultaneously, a level of 15 kW from the first klystron is divided into 5 branches to drive other 5 high power klystrons along the new main drive line.

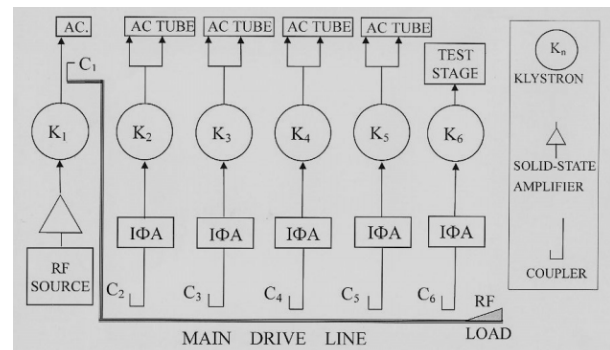


Figure 2: The New RF drive system of 200 MeV LINAC.

Free Electron Laser (FEL) is the only light source with over 20 eV photo energy and GW peak power [3-7], which covers the spectrum from mm wave to x-ray. Linac based FEL requires state-of-the-art performance from the all linear subsystems, especially RF power (within 0.1% shot-to-shot) and phase (less than 1° rms jitter shot-to-shot and 5° rms long-term drift). To satisfy such tight criteria, both low-level and high-power RF systems are under evaluation together with development of a precision on-line phase detector system for FEL [8-12].

The high accuracy RF Phase detector is not only necessary for reliable and stable operation of Linac as injector for storage ring [10-13], but also plays one important role in developing future Free Electron Laser system driven by the 200MeV Linac.

In 2003, National Synchrotron Radiation Laboratory, Univ. of Science and Technology of China was awarded

two grants (Innovative Research fund from Chinese Science Academy and No. 10375061 of Natural Science Foundation of China) to develop high accuracy RF phase detector and to assess its applications for RF Linear accelerator and Free Electron Laser system. These efforts are focused on RF phase detector in 2856MHz, its application to the present 200MeV RF Linear accelerator, and potential system configuration of Free Electron Laser driven by the 200MeV RF Linear accelerator. Until now, the tested resolution of the designed RF phase detector in 2856MHz is better than 0.3 degree. This paper describes the configuration of the high accuracy RF Phase detector as well as the architecture, trade-offs, and progress in the development of these RF phase detectors for RF accelerators and Free Electron Laser.

SYSTEM DESCRIPTION

In the multi-section RF accelerators employed in high energy RF Linac, the beam is tuned to sit on the top of RF traveling wave to get the best acceleration with RF phase shifter and energy spectrum target. Due to lots of objective reasons such as temperature, pressure and voltage fluctuations, the beam is shifted with RF phase. The process can not be automatically tuned and drawn back by personal computer (PC) to the required phase for absence of “eye”-the phase detector to monitor the RF phase deviation to the beam.

The HLS 800MeV electron storage ring is injected by 200MeV electron Linac and ramping up to 800MeV for synchrotron radiation use. The RF system to drive the 200MeV Linac has no phase detector and feedback system presently, which needs upgrading for more stable and reliable injection to the storage ring as well as FEL investigation based on Linac.

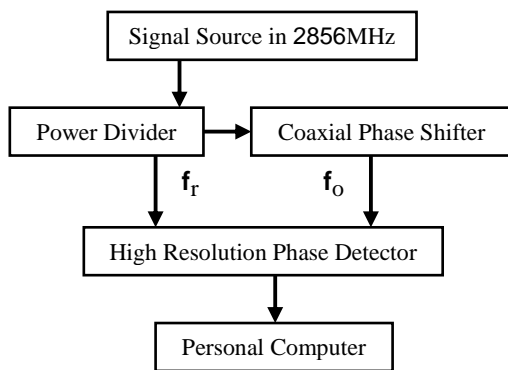


Figure 3: Configuration of Precise Phase Detector.

The configuration of the RF phase detector is illustrated in Fig. 3. The precise coaxial phase shifter is used to simulate all RF phase distortion due to temperature, pressure and voltage fluctuations. The multi-section RF accelerator could then be stabilized by implementing the developed high resolution RF phase detector in 2856MHz with the feedback loop.

The RF upgrade of Hefei 200MeV Linac with the developed RF phase detector is shown in Fig. 4. Successful implementation this RF system in HLS will

benefit not only the storage ring with more stable injection, but also FEL research based on Linac.

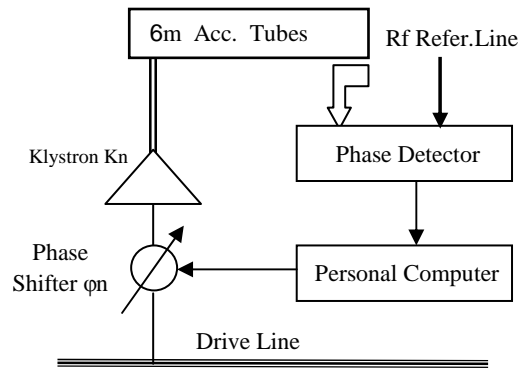


Figure 4: RF upgrade for Hefei 200MeV Linac.

PRIMARY IN-SITU EXPERIMENTS

The precise RF phase detector illustrated in Fig. 3 is tested in Hefei 200MeV RF Linac, as illustrated in Fig. 5. The signals in the downstream of klystron 5 and main drive line are coupled out for measuring. The results are listed in table 1, which states that the resolution of the precise phase detector is better than 0.3 degree.

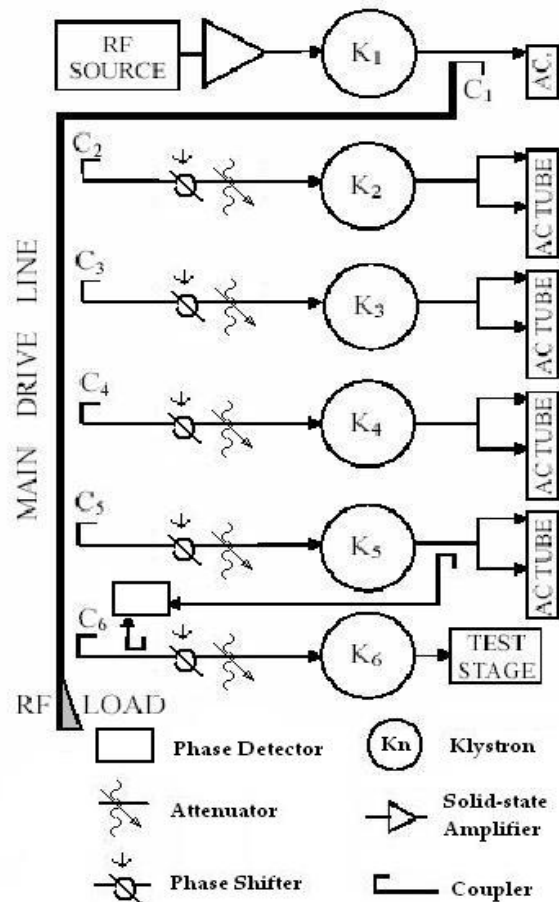


Figure 5: In-situ Experiments of Precise Phase Detector.

Table 1: The in-situ Measured Phases dated on 27-4-2004

Phase Shifter Position	The Measured Phase/degree	Time
189	-82.0	11:23
170	-56.0	11:27
170	-56.2	11:31
180	-67.7	11:34
180	-65.1	11:35
189	-81.4	11:40
189	-82.6	11:41

SUMMARY

The high accuracy RF Phase detector in 2856MHz is designed, built and tested, which underpins solid foundations for more stable injection for HLS as well as the development of linac based FEL in HLS. It's connected to the PC by Fiber optical cable. The measured phase resolution in 2856MHz is better than 0.3 degree, which could be further enhanced to 0.1 degree in the near future. Primary desktop and in-situ experiments with klystron give us confidence about its application in the phase control system of RF accelerators, where the beam energy and the energy chirp can be accurately controlled. Particularly in photo cathode RF gun, the cavity is excited by combined fundamental and third harmonic RF sources matched with suitable amplitudes and phases of them, the beam emittances are reduced from 0.6 to 0.3 microns or less over the main body of the bunch [18-20]. Therefore, the saturation length of the FEL system can be significant decreased, especially in the process of developing the short wavelength FEL [12-13, 16-17].

REFERENCES

- [1] Y.J.Pei, D.F.Wang, D.H.He, Proc. of the 3rd International Conference on Synchrotron Radiation Instrumentation, Review of Scientific Instruments, Vol. 60, No. 7, 1701 (1989)
- [2] Zhiang Yuan, "Design and Performance of RF Drive system for 200 MeV LINAC", Proc. of the International Conference on Synchrotron Radiation Application, May 9-12, 1989
- [3] C. Limborg, "Design considerations for the LCLS," Nuclear Instruments and Methods in Physics Research A 507 (2003) 378-381
- [4] J. Rossbach, "Demonstration of gain saturation and controlled variation of pulse length at the TESLA test facility FEL," Nuclear Instruments and Methods in Physics Research A 507 (2003) 362-367
- [5] Dinh C. Nguyen and Henry P. Freund, "Possibility of a high-power, high-gain FEL amplifier," Nuclear Instruments and Methods in Physics Research A 507 (2003) 120-124
- [6] Vladimir N. Litvinenko, "New results and prospects for harmonic generation in storage ring FELs," Nuclear Instruments and Methods in Physics Research A 507 (2003) 265-273
- [7] Kui, ZHAO, "FEL Investigation Based on Superconductor Accelerator," in Chinese 973 Programme 2002-2007. Available: <http://www.973.gov.cn> in Chinese, Beijing, Ministry of Chinese Science and Technology.
- [8] T.L. Smith et al, "RF SYSTEM UPGRADES TO THE ADVANCED PHOTON SOURCE LINEAR ACCELERATOR IN SUPPORT OF THE FEL OPERATION," in Proc. of XX Linac 2000 □ Monterey □ California □ August 21-25 □ 2000.
- [9] A. E. Grelick et al, "Phase control & intra-pulse phase compensation of the APS linear accelerator," in Proc. IEEE PAC'95, Dallas, May 1995, pp. 1082-1084, 1996.
- [10] A. E. Grelick et al, "The High-Power S-band Feed Subsystem for the APS Injector Test Stand," in Proc. IEEE PAC'2001, Chicago, May 2001, pp. 1393-1395.
- [11] S. V. Milton, E. Gluskin and N. D. Arnold et al. Exponential Gain and Saturation of a Self-Amplified Spontaneous Emission FEL[J], Science, Vol. 292, 15 JUNE 2001, PP2037-2041.
- [12] S.V. Milton et al, "Observation of Self-Amplified Spontaneous Emission and Exponential Growth at 530 nm," PRL 85(5), pp. 988-991, July 2000.
- [13] C. Pellegrini, "High power femtosecond pulses from an X-ray SASE-FEL," Nuclear Instruments and Methods in Physics Research A 445 (2000) 124-127
- [14] J. Y. Liu, C. Z. Diao and D. H. He et al, "COHERENT HARMONIC GENERATION EXPERIMENT ON HEFEI SYNCHROTRON RADIATION SOURCE," in Proc. IEEE PAC'2003, May 2003, pp. 968-970.
- [15] Dong Sai, Huang Guirong, Jia Dachun, Pei Yuanji, et al, "RF Drive System with High Power Solid-State Amplifier for 200MeV LINAC," in Proc. of Linac 2002 □ Gyeongju □ Korea □ August 19-23 □ 2002.
- [16] L.-H. Yu, M. Babzien, I.Ben-Zvi et al. "High Gain Harmonic Generation FEL", Science, Vol. 289, Aug. 11, 2000, PP932-934.
- [17] Patrick G. O'Shea and Henry P. Freund, "Free-Electron Laser: Status and Application", Science, Vol. 292, 8 JUNE 2001, PP1853-1858.
- [18] D.H. Dowell, M. Ferrario, T. Kimura, J. Lewellen, C. Limborg, P. Raimondi, J.F. Schmerge, L. Serafini, T. Smith and L. Young, "A Two-Frequency RF Photocathode Gun," Tsukuba, Japan, (2003)
- [19] L. Serafini et al, NIM A318 (1992)301-307, T.I. Smith, Proc. Linear Acc. Conf., SLAC PUB-303.
- [20] Robert M. Phillips and Daryl W. Sprehm, "High-Power Klystrons for the Next Linear Collider," Proc. of the IEEE Vol. 87(5), pp. 738-751, May 1999.