ISBN: 978-3-95450-168-7 doi:10.18429/JACoW-IPAC2015-TUPJE008

Content from this work may be used under the terms of the CC BY 3.0 licence (© 2015). Any distribution of this work must maintain attribution to the author(s), title of the work, publisher, and DOI.

RELOCATION AND IMPROVEMENT STATUS OF THE SCSS TEST ACCELERATOR TO PROVIDE DUAL FEL DRIVERS AT SACLA *

Yuji Otake #, on behalf of the members of XFEL research and development division,
RIKEN, Koto 1-1-1, Sayo-cho, Sayo-gun, Hyogo 679-5148, JAPAN

Abstract

To increase user experiment chances at SACLA, equipping a new beamline and an additional linac as a further FEL driver is effective. For these reasons, the SCSS test accelerator as the prototype of SACLA is reused, because of terminating its role. SCSS with an electron beam energy of 250 MeV generated an extreme ultraviolet laser with 50~60 nm. We relocated SCSS into the SACLA undulator hall and improved its performance. Three newly designed C-band acceleration-structures for the relocated SCSS accelerator with an acceleration gradient of 46 MeV/m at maximum boost an electron beam energy of up to 500 MeV. By FEL simulation, the EUV-FEL with 10~40 nm and 100 μJ are expected by the increased electron energy and 2 undulators with 5 m long each. By taking opportunity of the relocation, performance improvements of instruments, such as an inverter charger for the pulse-forming network (PFN) of a klystron modulator, were also done. The relocation work of the linac with several instrument developments finished in the summer of 2014 and rf conditioning for the units almost finished in the spring of 2015.

INTRODUCTION

Free-electron lasers (FEL) [1] generate fruitful science results [2] and already become important instruments for science. They have attractive features, such as wide wavelength tenability up to an X-ray region, compared with ordinal laser devices. However they are usually expensive, because of a single user machine being not like ring photon sources. In order to increase experiment chances for users, we had plans for constructing another new beamline BL-2, as well as the existing X-ray beamline BL-3, and an additional linac to drive a FEL in the existing beamline BL-1 of SACLA [3]. Light generated by this linac with a 450~500 MeV electron beam and the BL-1 covers lower wavelengths from 10 nm to 40 nm. This wavelength will be extended up to several nm by a future extension plan to increase a beam energy up to 1.4 GeV by adding 9 C-band acceleration units and 2 undulators. In order to realize the linac for the BL-1, we already had a very suitable machine that is the SCSS test accelerator. The roll of the test accelerator to check feasibility of the X-ray free-electron laser (XFEL) already terminated at that point. Therefore, we decided relocation of the test accelerator from the original place to the SACLA undulator hall. However, space for the relocation is not so wide. Furthermore we want to cover further shorter wavelength of the laser for the experiment users. For these reasons, a higher electron-beam energy by high-gradient acceleration was planned for the relocated test accelerator. We developed a 2π/3 mode qusi-constant gradient (CG) accelerating structure with a highly acceleration gradient of 45 ~ 47 MV/m, which is about 10 % bigger than the present SACLA's case. [4]

By taking opportunity of the relocation, performance improvements of instruments, such as an inverter charger for the pulse-forming network (PFN) of a klystron modulator at SACLA, were also done [4], since the performance, such as a trouble rate, of the inverter was not then perfect for us. Furthermore, individual device controllers using programmable logic controllers (PLC) and a low-level rf (LLRF) system for SCSS was different to those of SACLA. They should fit to the present control system for SACLA, because of easily building and easy maintenance. The rf phase and amplitude stability of the LLRF system for the test accelerator, as which temporal drift is over several pico-second, was not sufficient. Hence, we changed the controller and LLRF system from SCSS's one to the standard instruments for SACLA. [5] The permanent magnet-cell arrangement of the SCSS's undulator was different from that of SACLA. The magnetic period of the undulator was adjusted from 15 mm (K=1.5 at the maximum) to 18 mm (K=2.1 at the maximum). [5] Machine construction for this relocation now proceeds and almost finished. In this paper, the construction status of the relocated SCSS test accelerator, which is under high-power rf conditioning, and improvement status of the above-mentioned accelerator instruments are described.

CONSTRUCUTION AND INSTRUMENT IMPROVEMENTS STATUS

Accelerator Feature and Construction

In accordance with the plan to realize the linac mentioned above, the relocation of the SCSS test accelerator was started in 2013. The relocated accelerator is settled in the upstream of the BL-1 in the undulator hall, as shown in Fig. 1. Figure 2 depicts machine configurations before and after the relocation.

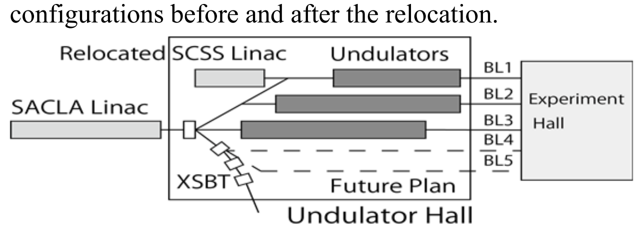

Figure 1: Place to install the relocated SCSS test accelerator (LINAC) in the undulator hall of SACLA.

#otaek@pring8.or.jp

ISBN: 978-3-95450-168-7 doi:10.18429/JACoW-IPAC2015-TUPJE008

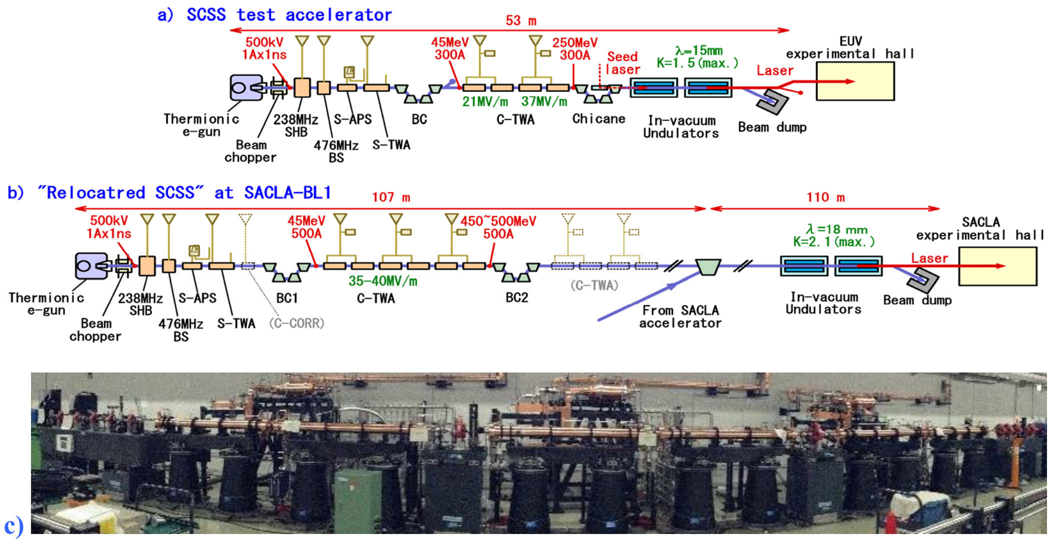

Figure 2: Machine configurations of a) the SCSS test accelerator, b) the relocated SCSS machine and c) installed machine situation in the SACLA undulator hall [5].

Table 1: Comparison of the Machine Parameters Between SCSS and the Relocated SCSS

	SCSS	Relocated SCSS
Operation period	2005 ~ 2013	2015 ~
Linac & electron beam		
Length	30 m	60 m
Energy	250 MeV	450~500 MeV
Bunch charge	~0.3 nC	~0.3 nC
Peak current	~300 A	~500 A
Repetition	60 pps (max.)	60 pps (max.)
Undulators		
Length	5 m	5 m
Permanent magnet periodic length	15 mm	18 mm
K parameter	1.5 (max.)	2.1 (max.)
Photon beam		
Wavelength	50-60 nm	10-40 nm
Pulse energy	10-30μJ/pulse	100 μJ/pulse

Table 1 shows the parameters of the SCSS test accelerator and relocated one. The relocated SCSS, which is almost the same configuration as the original one, comprises a 500 kV pulsed thermionic electron gun, a 238 MHz sub-harmonic buncher, a 476 MHz booster, an S-band APS cavity, an S-band traveling-wave accelerating structure, the 1st bunch compressor (BC), six C-band accelerating structures, the 2nd BC and 2 undulators. The 1st BC compresses the beam bunch length up to about 180 fs in FWHM (500 A peak), which is shorter than about 300 fs in FWHM (300 A peak) of SCSS. This increased bunch compression ratio compensates degradation of a FEL amplification-gain length along the undulators in the short wave length. The planned 450~500 MeV electron beam with a charge of 0.3 nc drives a 10~40 nm EUV laser with a energy of 100 μJ. In the summer of 2013, we built accelerator components, which are insufficient to construct the linac and moved accelerator comportments, such as injector cavities, from the original place of the test accelerator to the SACLA's undulator hall. Furthermore, the utility system for the linac, such as a water-cooling system and a precision air-conditioner, were constructed. In the summer of 2014, the components including the rf cavities and the undulators described in Fig. 2-b were installed in the hall to perform the relocation construction. Figure 2-c shows the linac after the installation. In the autumn of 2014, high-power rf conditioning started. We almost finished the rf condition to obtain the designed acceleration gradients in the spring of 2015 and will start beam commissioning in the autumn.

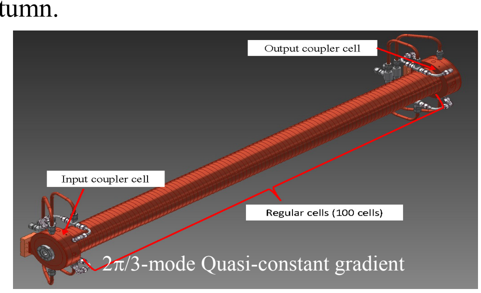

Figure 3: Outlook of the accelerating structure. [6]

Instrument Improvements

The CG accelerating structure with a high acceleration gradient of more than 45~47 MV/m mentioned above, was developed, as shown in Fig. 3. In order to decrease a discharge rate in the highly accelerator gradient, an ellipsoidal cross-sectional shape of the rf coupling iris of the structure was employed. [7] The shape reduces its own surface electric field strength. Figure 4 shows the experiment results of a high-power rf test for the structure. The final acceleration gradient in the structure reached up to 50 MV/m, which is sufficient for our demand. Next is about the inverter charger for the PFN of the klystron

Content from this work may be used under the terms of the CC BY 3.0 licence (© 2015). Any distribution of this work must maintain attribution to the author(s), title of the work, publisher, and DOI.

ISBN: 978-3-95450-168-7 doi:10.18429/JACoW-IPAC2015-TUPJE008

Content from this work may be used under the terms of the CC BY 3.0 licence (© 2015). Any distribution of this work must maintain attribution to the author(s), title of the work, publisher, and DOI.

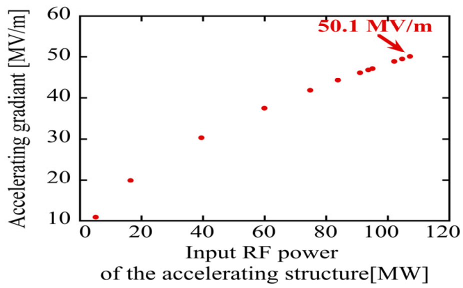

Figure 4: Acceleration gradients of the 2π/3 CG accelerating structure, as a function of its input rf powers. These gradients are calculated by using an averaged shunt impedance of 64 MΩ/m. [4,6]

modulator. The original inverter charger for SACLA has overheat troubles at 60 pps operation on voltage regulation transistors and power rectify diodes in an oil-filled high-voltage tank. To overcome these problems, a new inverter charger was developed. Figure 5 depicts the outlook of the charger. Figure 6 shows voltage output waveforms of the charger at a charging voltage of 50 keV, with which the voltage stability is 5 ppm in rms. A heat load to oil in the tank raises a temperature up to around 50 deg. at 60 pps, which is sufficiently low from about 70 deg. of the SACLA's inverter charger. The voltage jitter of the charger is less than 5 ppm that is comparable or less than the original voltage jitter of SACLA's one. This value is also sufficient for our demand.

HIGH-POWER RF CONDITOING

In the autumn of 2014, high-power rf conditioning for the acceleration cavities of the relocated SCSS has been carried out. After installing the linac last summer, rf powers were inputted into the acceleration cavities. An automatic conditioning software process gradually increased the powers and their pulse widths. Figure 7 shows a high-power rf conditioning history, which are the acceleration gradient, pulse width and vacuum level trends of the C-band accelerating structure (CB1-1), as examples. The acceleration gradient of the C-band structures reached our expected acceleration gradient of 46 MV/m after the rf conditioning during 24 days. The present discharge rate of the C-band structure at 46 MV/m is about once a 2~3 hours.

CONCLUSION

Development of accelerator instruments, such as a CG C-band accelerating structure, was well finished. An acceleration gradient of it reached at 50 MV/m in the tests. The heat load in the high-voltage tank of an inverter charger was mitigated. Installation work of the relocated SCSS accelerator using our developed instruments was going well and high-power rf conditioning was proceeded. Acceleration gradients of the C-band structures in the conditioning reached up to the demanded level of 46 MV/m in average. As a result, we will start electron and laser beams commissioning after this summer.

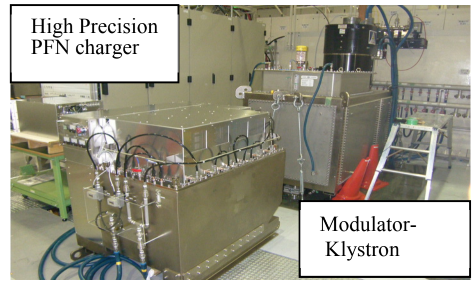

Figure 5: Outlook of the high-precision inverter charger for the PFN of the klystron modulator. [4,8]

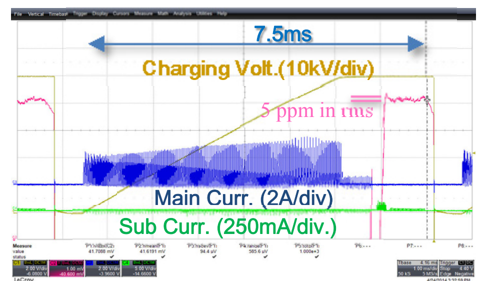

Figure 6: Output wave forms of the high-precision inverter charger. The charging voltage is 50 kV. [8]

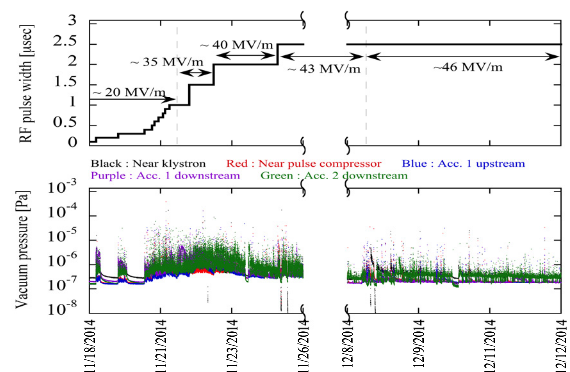

Figure 7: High-power rf conditioning history of the C-band accelerating structures (CB1-1). The rf pulse width and power were increased during 24 days.

REFERENCES

[1] E. L. Saldin, et al., The physics of Free Electron Laser, Springer, 52 (2000).
[2] Jianwei. Miao, et al., Nature **406**, 342 (1999).
[3] T. Ishikawa et al., Nature Photonics, doi:10.1038/nphotonics (2012). T. Ishikawa et al., Nature Photonics, doi:10.1038/nphotonics (2012).
[4] Y. Otake et al., Proc. of Linac2014, 342-344 (2014).
[5] T. Inagaki et al., Proc. of 10th Annual Meeting of PASJ, 259-263 (2013) in Japanese.
[6] N. Shigeoka et al., Proc. of FEL2014, THP063 1-4 (2014).
[7] T. Taniuch et al., Proc. of 6th Annual Meeting of PASJ, 1087-1089 (2009) in Japanese.
[8] C. Kondo et al., Proc. of 11th Annual Meeting of PASJ, 199-204 (2014) in Japanese.