THE C-BAND (5712-MHz) LINAC FOR THE SPRING-8 COMPACT SASE SOURCE (SCSS)

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Abstract

The SPring-8 Compact SASE Source (SCSS) is a high peak-brilliance, soft X-ray free electron laser project [1]. It is a linac-based dedicated source machine for Self-Amplified Spontaneous Emission (SASE) Free-Electron Laser (FEL). We will use a high-gradient C-band (5712-MHz) main linac to generate a beam with energy up to 1-GeV followed by an in-vacuum short-period undulator to enables us to contain the entire SCSS within a 100-m whole machine length. First light is expected to be generated in the VUV region in 2005; the next target is for 3.6-nm radiation in the water-window.

1 INTRODUCTION

The SCSS 1-GeV main linac will use high gradient acceleration to achieve a total active machine length of 40-m. Thus, we will use high gradient acceleration of more than 35-MV/m on a beam charge of 1-nC per bunch. The normalized beam emittance at the end of linac has to be kept to only 2-πmm·mrad, this is two-orders of magnitude lower than the emittance from the usual electron linacs such as the injectors for KEKB and SPring-8.

It is very clear that the pre-injector is of paramount important in providing such a very low emittance beam, and in particular the requirements are especially sever for the electron gun. It is very well known that from the low emittance beam point of view, a dc-gun has a big advantage over any other method; because the electrons from the cathode are accelerated only by a static DC scalar potential. Thus the beam can be designed to be uniform over all locations on the cathode and also in time.

From previous experimental results, we have chosen a dc-gun with a –500 kV drive voltage pulse to obtain the required 2-πmm·mrad emittance [2]. As this paper mainly discusses the high power rf system for main linac, we will not discuss the electron gun further.

This linac is intended to be for a production source of soft X-rays, and not to be for accelerator R&D. Therefore, the design and hardware should satisfy the following demands: (1) High reliability, (2) Simplicity, (3) Reduced construction cost, (4) Reasonable power efficiency and (5) Operational ease.

We first chose 5712-MHz in the C-band as the optimum frequency. This is twice the 2856-MHz (S-band) commonly used in more conventional electron linear accelerators. From the energy efficiency point of view, a higher frequency is desirable because the rf power transferred to the beam in the accelerating structure is increased, since the shunt impedance increases at higher frequencies ($r \propto f^{1/2}$). However, as frequencies go up, the allowable tolerances in the fabrication of the accelerating structure become ever more stringent, and mass production can become problematical. Additionally, the peak output power from the klystron generally declines as the frequency goes up. We conclude that the advantage in choosing a C-band frequency is that we can obtain a high accelerating gradient as required for this accelerator while still using existing fabrication technology [2].

This C-band scheme was first proposed by T. Shintake in 1992 for the e^+e^- linear collider project in Japan (JLC) [2] (C.M. energy of 500-GeV to 1-TeV). Starting in 1996, we began the overall design of the C-band rf system, and developed all the requisite high power devices such as the wave-guide components [2], sexless vacuum flanges [2], 50-MW class pulsed klystrons [2], their 100-MW class modulator power supply charged by a H. V. inverter [2], a low level rf

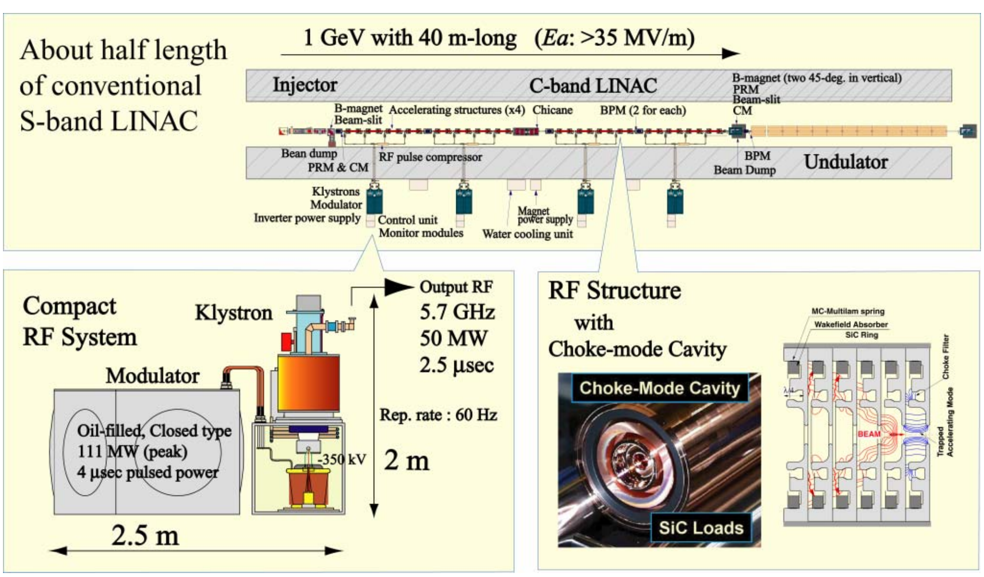

Figure 1: An over-all schematic layout of the C-band linac and 30-m long undulator. The total facility length is less than 100-m. The accelerating gradient of each rf structure is more than 35-MV/m and the beam charge per bunch is 1-nC. The normalized emittance is 2-πmm·mrad at the end of linac.

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compression cavity, and a high power Choke-Mode HOM-free rf structure [2]. Recently, we developed a new capacitive-divider using ceramics, a roller cam type active mover system, which can provide a position repeatability of ±0.1-μm [3] and a very stable support stand using a new high compressive concrete [3].

In the following, we will discuss the details of the technologies for the rf system for the C-band main linac.

2 C-BAND MAIN LINAC

2.1 RF System Description

The SCSS main linac will use four C-band rf system units to generate a beam energy of 1-GeV from a machine only 40 m long. Figure 1 shows the over all-schematic layout of the linac and the design specifications of the new C-band main linac are listed in Table 1.

Table 1: Main parameters of the C-band linac.

Klystron:	8	tubes
Modulator power supply:	8	Sets
RF compressor cavity:	4	Sets
RF structure:	16	structures
Energy (E):	1	GeV
Energy spread (rms, σ_δ):	0.02	%
Charge per bunch (Q):	2	nC
Peak current (I_{pk}):	2	kA
Bunch length (FWHM, Δz):	0.15 (0.5)	mm (psec)
Normalized emittance ($\varepsilon_{nx,y}$):	2	πmm·mrad
Klystron rf output power:	50	MW
rf pulse width:	2.5	μsec
Modulator output voltage:	25	kV
Repetition rate:	60	Pps
rf compressor cavity power multiplication factor:	>3.5	
RF structure length:	1.8	m
Accelerating gradient with beam loading:	>35	MV/m
Wave-guide transmission rf power:	400	MW (max.)

We decided to use the same configurations as in the main linac from the previous JLC linear collider design. The reason being that rf system has been under development since 1996, and is well optimised for high gradient beam acceleration and over-all system reliability. Each unit is mainly composed of two 50-MW klystrons, their modulator power supplies, a pair of the rf compressor cavities, four 1.8-m long Coke-Mode type rf structures and a vacuum-tight high power wave guide system. The output rf power from two 50-MW klystrons is combined with a 3-dB wave-guide hybrid and multiplied by rf compressor cavities to supply a 0.5-μsec pulse of more than 350-MW, which is then fed to four rf accelerating structures. They in turn can generate an accelerating gradient of more than 35-MV/m while being loaded with a beam containing 1-nC per bunch.

Fig. 2: Model-E3746 klystron (TOSHIBA).

2.2 C-band 50-MW Klystron

We have developed three 50-MW class klystrons during the years 1996-1998. They are of the conventional solenoid focus type as shown in Fig. 2 [2]. The newly developed 3-cell travelling-wave output structure provides an output power of 55-MW at 365-kV and with a conversion efficiency from beam to rf power of 45%, which is a very good performance in a high power klystron. Fig. 3 shows the measured characteristics of the klystron, showing the efficiency, and rf output power curves. The 3rd-klystron has already been operating problem free for more than 10,000 hours. From this experimental result, we are confident in its reliability in actual accelerator application.

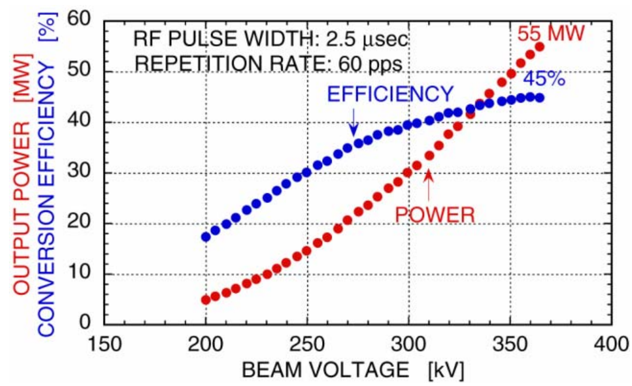

Figure 3: Typical efficiency and rf output power characteristics at saturation as a function of beam voltage.

2.3 Closed Compact Modulator

To improve the insulation and cooling of the high voltage components, we decided to use a sealed cabinet filled with insulation oil [2]. Except for the inverter type PFN charging power supply, all the parts, including the thyratron tube will be enclosed in an oil filled cabinet. The cabinet need only be 1.5-m wide, 1-m high and 1-m deep. A prototype is now under construction by NICHIKON Co. in Japan, and will be tested by the end of this year. A sketch of the modulator and klystron can be seen in Fig. 1; the main specifications of the modulator are listed in Table 2.

We decided to use the usual PFN circuit and thyratron tube (EEV-CX1836) for the switching device at this time. The reason for the thyratron is that from the standpoint of reliability, we find semiconductor switching devices such as IGBTs to be not yet suitable for pulse switching of high currents at high voltages; for example our PFN requires switching 5000-A at 50-kV.

We will use a new inverter type H.V. power supply for charging the PFN. It is very compact, being only 48-cm wide, 42.4-cm high and 68-cm deep. It generates a maximum output voltage of 50-kV and provides an average power of 30-kW (or a peak of 37.5-kJ/sec); this supply can drive a 50-MW klystron at up to a 50-pps repetition rate giving a 350-kV beam voltage after a 1:16 step-up transformer [2]. We obtained an output voltage regulation of within ±0.1% on a test prototype. The H.V. power supply is now being fabricated by TOSHIBA Co. in Japan.

Table 2. Main parameters of the new modulator.

Peak output power:	111	MW
Average output power:	46.7	kW
PFN charging voltage (max.):	50	kV
Peak switching current:	5414	A
H.V. pulse width:	3.5	μsec
Pulse repetition rate:	60	pps
Voltage flatness (top) and repeat-ability:	±< 0.5	%
Timing jitter:	< 5	nsec
PFN impedance:	4.3	Ω
Energy stored in the PFN:	438	Joule
PFN cells:	18	sections
Transformer step-up ratio:	1:16	
Cabinet size (W x H x D):	1.5 x 1 x 1	m
Inverter output voltage:	0 ~ 50	kV
Inverter Average output Current:	1.5	A
Charge rate average (peak):	30 (37.5)	kJ/sec
Output voltage regulation:	<± 0.1	%
Power factor (50-pps, full load):	> 85	%
Power efficiency (full load):	> 85	%

2.3 C-band RF Structure

The C-band Choke-Mode type damped rf structure was developed in 1998, and its performance has been confirmed in the ASSET facility at SLAC [2]. A cut away view of the cavity is shown in Fig. 4. The dark square shapes (top and bottom) in Fig. 4 show where the ring shaped SiC HOM absorbers go in the assembly.

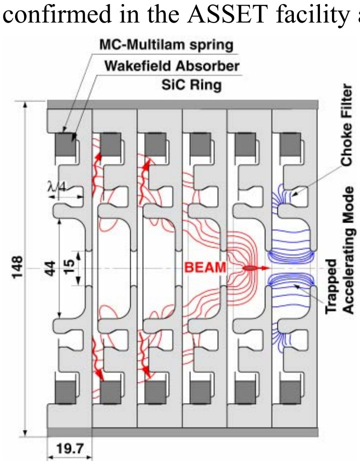

Figure 4: A cut away view of the C-band choke-mode rf structure.

We will use same type of rf structure for the SCSS main linac. One particular advantage is that since all of the parts are completely axially symmetric, they can be machined on a turning lathe, thus this type of cavity has a big advantage in mass production because of its easier machining. The first high power model is being fabricated by MITSUBISHI HEAVY IINDUSTORY Co. in Japan.

Table3: Main parameters of the Choke-mode rf structure.

Frequency:	5712	MHz
Phase shift per cell:	$3\pi/4$	
Electric field distribution on the axis:	Quasi-C.G	
Quality factor (Q, average):	10256	
Attenuation parameter (τ):	0.53	
Filling time (t_F):	290	nsec
Shunt impedance (r, average):	58.5	MΩ/m
Ratio of Es/Ea:	2.2	(max.)
Iris aperture ($2a$) up-stream:	17.330	mm
down-stream:	13.587	mm
Disk thickness (t):	4	mm
Number of cells:	91	
Number of Couplers: (field symmetry & double feed)	2	
RF structure active length:	1.8	m

The main parameters of the rf structure are listed in Table 3. We decided to use a quasi-constant-gradient for the electric field distribution along the structure axis, this minimizes the surface electrical gradients, which strongly contribute to breakdown problems in high gradient operation. Doing this, we have successfully kept Es/Ea to only 2.2 at the maximum. Small amplitude higher trapped modes (HOM) appeared at 20-, and 23-GHz in first model rf structure. To eliminate them, the disk thickness will be changed from 3- to 4-mm. Fig. 5 shows the single bunch wake filed simulation using MAFIA. As can been seen, the wake field amplitudes are damped enough before the arrival of the 2nd bunch, and also there are no higher trapped modes found in the new rf structure.

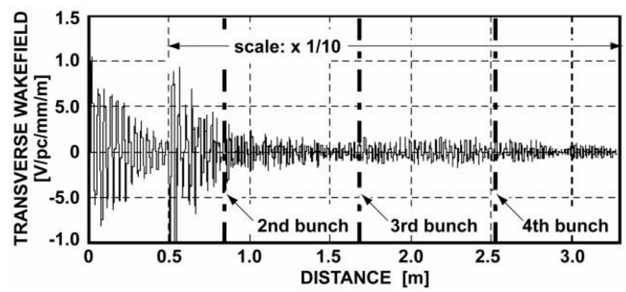

Figure 5: A single wake field simulation of the C-band Choke-mode rf structure.

2.4 C-band RF Compressor Cavity

The first high power model used an invar metal with copper plating for the rf cavity [2, 4]. This keeps the thermal expansion coefficient to only $4x10^{-7}$, which is a value 20 times smaller than for copper material alone. This copper plated invar cavity is thus a big breakthrough for the very high Q cavities needed in the rf compression system. A high power model will be tested by the end of this year (2002) at KEK as shown in Fig. 6.

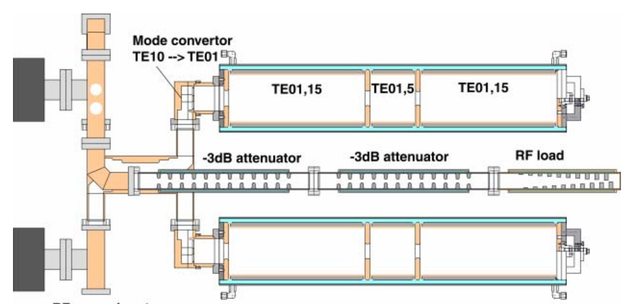

Fig 6: High power test stand for the RF pulse compressor cavity.

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