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LARGE-APERTURE TRAVELLING-WAVE ACCELERATOR STRUCTURE FOR POSITRON CAPTURE OF SuperKEKB INJECTOR LINAC

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Abstract

Comparing to the previous KEKB, the four-times higher charge of 4 nC per bunch is required for the injector linac of SuperKEKB. Not only a flux concentrator will be introduced but also the physical aperture of the downstream six 2m-long accelerator structures was increased as large as 30mm in diameter. We call these structures as LAS, “Large Aperture S-band” structure. The resultant higher RF group velocity of about 3% makes the acceleration gradient lower. In the nominal acceleration system, a 40MW klystron with SLED feeds four 2m-long accelerator structures producing 20MV/m acceleration field. The acceleration gradient higher than 14 MV/m is required for the very first two LAS structures to suppress the satellite bunches. This gradient is obtained by feeding only two LAS structures. Initially, ten LAS structures were installed and the RF processing has partly started. In the present paper, we firstly describe the acceleration system design and then present the processing characteristics through the RF processing without beam and with beam.

INTRODUCTION

The high luminosity of the SuperKEKB main ring demands the high injection rate of the low-emittance positrons. To this end, the high yield of the positrons from the driving electrons hitting the Tungsten-Copper target and captured into the damping ring is one of the most important features of the linac upgrade [1]. The positrons are collected by a 5-10T flux concentrator followed by the RF accelerator capture system immersed in a 5kG solenoid magnetic field. In the early design stage, the large aperture capture system was proposed based on the L-band system. Since it cited the frequency of 1.3GHz, 5/11 times linac acceleration frequency (2856MHz), the injection loss was suppressed accompanying the reduction of the S-band satellite bunches. The feasibility of the L-band accelerator structure was performed [2] but the cost based on the L-band system was found very high.

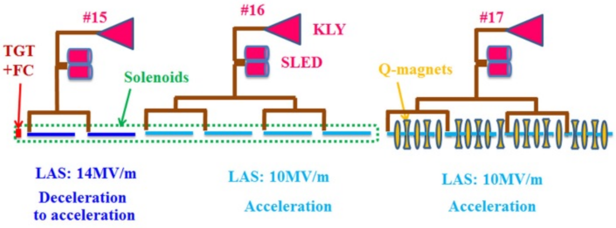

Figure 1: Capture system schematic.

Meanwhile, we found that the satellite is suppressed even using S-band accelerators but in the acceleration gradient higher than 14 MV/m [3]. To realize the big transverse acceptance, this S-band accelerator structure should be large in its beam aperture. In the present paper, we summarize the capture system with focusing on this Large-Aperture S-band accelerator Structure, called LAS.

CAPTURE RF SYSTEM

System Schematic

The system starts with a target immediately followed by a FC. Then 10 capture RF accelerators (LAS) are set. The first RF unit #15 composed of two LAS’s, while the second unit (#16) four LAS’s. The first LAS, just after the FC, in unit #15 is set at the decelerating phase for the positrons. Both #15 and #16 are immersed in a solenoid field of 5kG. The third unit (#17) is composed of four LAS’s with a Q-magnet focusing system. The whole system is schematically shown in Figure 1 and the actual setup is shown in Figure 2.

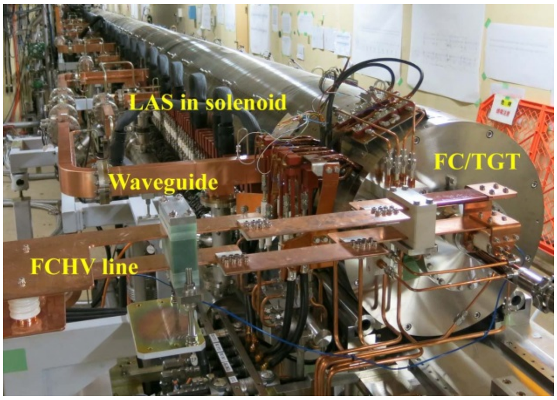

Figure 2: Positron production system.

RF Parameters

To realize the upgrade in a smooth and cost-effective manner, we kept the original RF unit comprising of a 40MW klystron followed by a SLED feeding four 2m S-band structures. To realize the higher gradient at the upstream side of the system, the first RF unit drives two LAS’s, while the following two units drive the original number, four per each. The relevant system parameters are summarized in the Table 1. The beam loading is as small as 1% level and the table shows the unloaded parameters. The klystron power of 40MW is required with non-SLEDed operation. Once SLED operation is realized, much lower power from the klystron is enough, such as

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15 MW level. If the slower phase flip speed is required as shown in Figure 3 for such a reason as escaping from the discharge due to the first spike of SLED pulse, more power is needed from the klystron. The available klystron power is much higher so that we can expect higher gradient, resulting in the higher positron yield.

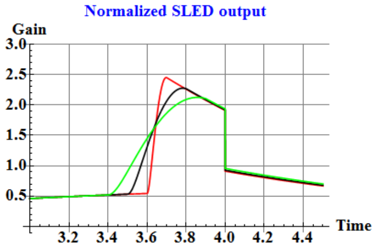

Figure 3: SLED output with 0.1, 0.3 and 0.5 μs flip.

Table 1: Capture RF System with LAS

Unit #	15 / 16	17
Focusing magnet	Solenoid	Q-mag
Focusing field [kG or T/m]	5	4 ~ 12
Number of LAS	2 / 4	4
KLY power non-SLED [MW]	40	40
Non-SLED Gradient [MV/m]	9.8 / 6.9	6.9
SLED Gradient [MV/m]	14 / 10	10
KLY power needed for SLEDed gradient [MW]	14.5 / 14.8	14.8
SLEDed Gradient at KLY maximum power [MV/m]	23.2 / 16.4	16.4

Vacuum System

The relevant vacuum system parameters are summarized in the Table 2. Each unit 15 and 16 is evacuated through a vacuum manifold made of stainless-steel pipe with 140mm in diameter running parallel and 500 mm off from the beam line. Each manifold is equipped with an ion pump (IP) and a non-evaporation getter (NEG). The input coupler and output coupler are evacuated from this manifold via multi-hole-type wave guide pumping port.

The evacuation from the flux concentrator (FC) side is only through the beam pipe so that the conductance is small. This beam pipe is connected by NW40 quick clamp so that we can quickly separate the FC system from the LAS in case of any trouble. This configuration makes the two vacuum systems, FC and LAS, somewhat isolated but not fully. Due to the limited space, no gate valve is installed from FC to the end of the solenoid system. This configuration makes the conditioning of these area complicated by being mutually perturbed through gas burst or electron bombardment due to RF breakdowns.

Table 2: System Evacuation Parameters

Item	Geometry	Value
FC evacuation	IP	75 L/s x 2
FC-LAS conduct.	ϕ40mm x L150mm	6.5 L/s
LAS volume	ϕ85mm x 2m	0.012 m^3
LAS inner surface	ϕ85mm x 59 cells	1.0 m^2
LAS coupler-manifold	Two irises + Waveguide-holes	20 L/s
Manifold evacuation	IP+ NEG	500 L/s + 1000 L/s

LAS DESIGN

There are three nominal requirements for the structure design. (1) In order to increase the transverse acceptance of the positrons, the S-band accelerator structure is designed to have as larger beam hole as possible, while keeping the reasonable acceleration performance [3]. (2) We keep the possibility to replace (in future) the S-band accelerator structure by the L-band one so that the total length is close to the L-band one [4]. (3) The solenoid inner diameter set at 200mm for the collinear-load-type L-band body to pass [4] requires the output coupler to be smaller than the diameter.

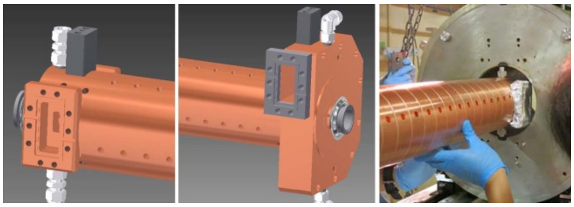

Figure 4: LAS output end (left), input end (center) and insertion of LAS into solenoid (right).

Design and Fabrication

The relevant parameters of the LAS and the associated fabrication technologies are summarized in Table 3. The largest difference from the original structures, the typical example of type-C [5], is naturally the beam-hole diameter. Due to this choice, the shunt impedance reduced and the group velocity increased, resulting in the less accelerator gradient.

The couplers are designed to be symmetrical to keep the field symmetry not only for the beam emittance preservation but also suppressing the possible high field problem in the coupler. The output coupler is equipped with two irises connected to the wave guide flanges mounted close to the coupler body to be compact. The two irises of the input coupler are connected by the wave guide system circulating the coupler cell, called J-type. This one port connection to outside is preferred for the easy installation/uninstallation process under a high residual radiation.

Table 3: Structure Relevant Parameters

Item	**LAS**	**Type-C**
Frequency MHz	2856	2856
# of regular cells	57	54
Active acc. Length [mm]	2064.40	1959.43
Flange-flange length [mm]	2191.01	2072.45
Beam hole dia. (2a) [mm]	31.9-30.0	24.28-20.3
Group velocity v_g/c [%]	4.2 – 3.5	1.24 (av.)
Shunt impedance [MΩ/m]	46 – 48	57.8 (av.)
Attenuation parameter τ	0.121	0.333
Filling time [ns]	185	507
Maximum E_p / E_{acc}	2.42	2.14
Input coupler iris	J-type Double	Single
Output coupler iris	Double	Single
Cell machining tool	Diamond	Diamond
Coupler fabrication	Brazing	Brazing
Assembly technology	Vacuum brazing	Electro-forming
Cooling passage	Four	Jacket

RF OPERATION

Installation

Installation of LAS was performed typically as shown in Figure 4 (right). We kept the nitrogen flow as much as possible during the exposure to the air in various stages.

Initial-stage Performance

After evacuated down to the low 10^{-6} Pa measured at the pumping ports, we started the high power operation with the short pulse of 200 nsec without SLED and gradually increased the width after reaching the target power level at each width. After reaching 500 nsec, the gas burst became more frequent.

In the initial two months, the most conditioning was devoted to suppressing this pressure burst as shown in Figure 5. We suspect the multipacting in the RF passage circulating the input coupler because the magnetic field of several hundred gauss significantly affected the pressure burst condition. The burst depends on the solenoid magnetic field in addition to the power level.

At the last moment of two month operation for 800 hours, we tasted the SLED operation. From the beginning the significant gas burst was observed. We speculated that the low-power period in a pulse became long in the SLED operation so that the multipacting might be enhanced.

After this initial operation, we checked the inside of the LAS near coupler cells. No darkening or pit-like objects were observed around the input coupler, indicating no evidence of the severe breakdowns or discharges.

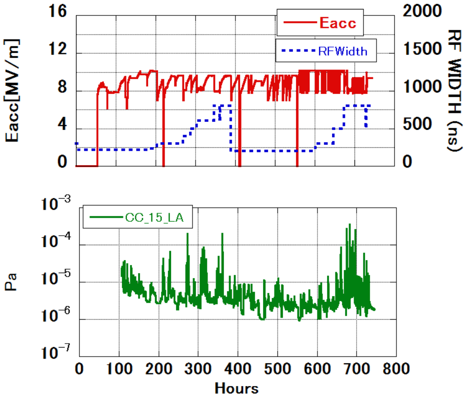

Figure 5: Initial conditioning of unit 15.

CONCLUSION

Since the beam dynamics simulation prefers a higher gradient in LAS section, especially the very beginning one, we should carefully condition the LAS's with SLED on. Since the standing-wave and the travelling-wave modes coexist in the wave guide line circulating the input coupler cell, it may present the parameter range which easily results in the multipacting condition. We hope that the conditioning process will clear this problem out but if it stays heavily, we may need to change the input coupler to be simple double-feed design instead of J-type coupler.

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