

DEVELOPMENT OF L-BAND POSITRON CAPTURE ACCELERATOR SYSTEM IN KEKB INJECTOR LINAC

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Abstract

In order to improve the positron beam intensity needed for SuperKEKB project, it was decided to replace the present S-band structures in the positron capture section by a new L-band (1298 MHz) accelerator system. A 2m long TW structure of 12 MV/m gradient is now under design process while a 40 MW klystron will be delivered in summer. After the klystron testing, a single L-band accelerator unit will be constructed for the structure study. The study is scheduled in next spring to operate the structure under solenoid magnetic focusing field.

NEW POSITRON SYSTEM

A new upgrade phase of KEK positron/electron Linac will start soon in order to fit our next project, SuperKEKB, in which we reconfigure the present KEKB accelerator complex into the ultimate luminosity frontier machine of the high energy electron (e-) and positron (e+) collider for B meson physics [1]. The life times of the stored beams in the collider rings are to be very short (typically several hundreds sec) since the beams are extremely squeezed at the interaction point. Thus KEK e+/e- Linac, the injector for SuperKEKB, should provide intense e- and e+ beams to compensate the rapidly exhausting beams in the rings. The Linac beams should have small emittances enough to be injected efficiently into the rings. To fulfill these requirements, we will employ a new RF Gun system for the e- beam while for the e+ beam we will prepare a new capture section to enhance its intensity and a damping ring to improve its emittance [2]. In the present paper the new capture section based on L-band RF is described.

Table 1: Positron Beam Specifications

	Present	SuperKEKB
Charge/bunch at the target (nC)	1	4
Bunch / RF pulse	2	2
Emittance normalized (m^{-1})	2.1×10^{-3}	10×10^{-6}
Rep rate (pps)	50	50
Energy(GeV)	3.5	4

In the present injector Linac, the positrons are generated at the tungsten target located at sector 2 of Linac (with

4GeV primary e- beam of 10nC per bunch), collected and accelerated in the capture cavities downstream of the target to form an e+ bunch of 1nC. As shown in Table 1, we need to intensify the e+ beam by factor four. We expect the introduction of a stronger focusing magnet at the target can give us factor two and another factor two can be earned by enlarging the acceptance for positrons. A natural solution to do this is use of lower frequency capture cavities which have larger aperture and longer wavelength instead of the present S-band cavities. To be specific, we will use L-band cavities, whose frequency is 1298MHz.

The reason of choosing this particular frequency is a little intricated. Note that Linac uses three frequencies: 114MHz for SHB1, 571MHz for SHB2 and 2856MHz for the main linac respectively. These frequencies are from a single frequency $f_0=10.385\text{MHz}$ (The harmonic numbers are 11, $55=11 \times 5$ and $275=11 \times 5 \times 5$ respectively.) The frequency of accelerating cavities in the collider rings is 508.9MHz (49th harmonic of f_0). In principle, the multi-bunch acceleration and injection are possible if these bunches are separated by $96.3\text{ns} = 1/f_0$, and actually this is true for the positron beam in present Linac, where the e+beam consists of two bunches separated by the timing above.

These basic relations will be kept in SuperKEKB accelerator system also. In order to fit the capture cavities in this framework, one can choose the frequency of 1298MHz, 125th ($=5 \times 5 \times 5$) harmonic of f_0 . Thanks to these rational relations, the 2-bunch operation is still valid. Note that this frequency is very close to 1300MHz, which is the most popular frequency in L-band. We may share the established technologies or even purchase various devices which are commercially available.

PROPOSED L-BAND SYSTEM

In Fig. 1, the whole layout of the capture section at the current design stage is shown, in which at least two S-band units will be replaced into L-band. The first unit consists of two 2m long L-band accelerating structures followed by another L-band unit which contains four structures. The final configuration of the positron capture section number will be determined based on the detail study of the beam dynamics downstream of the target which is currently ongoing.

Between the target and the first strucuture, there is a strong magnet to focus the positrons generated at the target. The structures of first two units are the travelling wave type immersed in the soelnoidal focussing magnetic field ($\sim 4\text{ kG}$).

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The target position is moved upstream from the present position in order to have a sufficient energy margin for e+ beam to 1.1GeV, which is the injection energy of the damping ring which will be located in the middle of Linac.

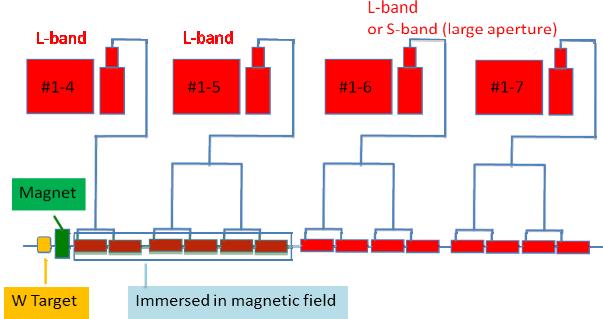


Figure 1: Layout of new positron capture section.

RF Distribution System

We adopted WR650 waveguide for the high power transmission ($a=165\text{mm}$, $b= 82.6\text{mm}$). Note that the typical peak power to be handled in the L-band system is a few tens MW with a few micro seconds pulse width. The whole waveguides to transmit the high power is kept in vacuum.

One concern is that the weights of the waveguide system components: one needs to use waveguides strong enough to sustain ambient atmospheric pressure. Suppose we use copper waveguides with 10mm thickness, their unit weight is about 50 kg/m. Cares should be paid in this respect since the weight of those components give some impact on their support system as well as the actual work for construction. We may use Aluminium alloy for some of the waveguides once we convince ourselves that they work fine under vacuum condition. We will do the gas emission test for a sample Al alloy waveguide.

There are some vacuum flanges commercially available for WR650. Among these, we will adopt MO Flange [3], MOF-650. The MO flanges are unisex. We have confirmed MOF-650 made from SS to be usable in our system.

Most of the RF components necessary for our project such as directional couplers, vacuum ports, dummy loads, or 3dB hybrids, are commercially available. We have ordered those components.

Accelerating Structure

The electric design work of the structure has been done [4]. The design parameters are listed in Table 2. It is a disk loaded 2m-long constant gradient travelling wave structure of 28 cells operated with $2\pi/3$ mode. The coupler dimensions were determined by Kyhl method. The whole structure will be made from OFC class1. To allow the insertion of solenoid magnet after the completion of the structure, the maximum transverse dimensions of the structure are specified to be within 350mm in diameter around the beam axis.

Table 2: Accelerating Structure Design Parameters

Frequency	1298 MHz
Input power	15 MW
Gradient	12 MV/m
$2a$	39.4 ~ 35.0 mm
t	10 mm
vg/c	0.61-0.39 %
Filling time	1.32 μs
Attenuation	0.261
Q	~20000
Length	2 m

Klystron

There is no commercial klystron to meet perfectly with our required specifications. We ordered to construct a new L-band klystron based on a 40 MW S-band klystron (2856 MHz) in such a way that we share its gun design while the RF circuits are newly designed. This brings us advantages not only to save the design effort of the klystron but we need not to modify the modulator which supplies the pulsed power to the klystron. The whole length of the L-band klystron will be slightly increased to fit the lower operating frequency. One needs to optimize the solenoidal focussing field and a new magnet will be prepared. The klystron was delivered in the end of August 2010 (See Table 3 for Klystron design parameter).

Table 3: Klystron

Frequency	1298 MHz
Output power	40 MW
Pulse width	4 μs
Rep rate	50 pps
Gain	>50 dB
Efficiency	>40 %
Cathode Voltage	350 kV
Pervance	2 μP

LLRF

It is simply supposed that LLRF for our L-band system should be as stable as S-band system and it can be. There is no further requirement on LLRF in our system. However, in order to handle the L-band RF signals in a more sophisticated way, we have a plan to introduce a compact LLRF unit based on IQ modulator/demodulator

with an FPGA controller instead of our traditional I_oA module. See Fig.2. This new unit handles the RF signal for a driver amplifier (600 W solid-state amplifier) as well as the monitor signals from the klystron output for the interlock (VSWR) and feedback.

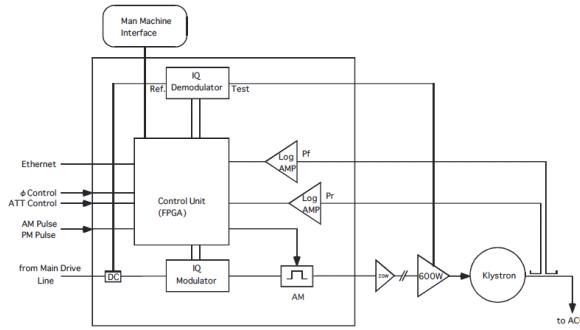


Figure 2: Diagram of a proposed compact LLRF unit for KEKB Injector L-band RF.

Vacuum

Design work on the vacuum system is ongoing. The volume, the surface area and the vacuum conductance are the primary parameters for the design. Those numbers of WR650 waveguide and the accelerator structure are shown in Table 4. From these numbers, we can sketch the L-band vacuum system. For example, the coupler of the accelerating structure is known as the most vulnerable to RF breakdowns therefore it is critical for stable operations to lower the pressure around the coupler as much as possible. If we assume the gas emission rate from the accelerator structure or the waveguides is lower to be some 2×10^{-8} Pa m³/s/m², we need more than 50 l/s evacuation at the coupler area in order to maintain the pressure below 2×10^{-6} Pa.

Table 4: Area, Volume and Conductance

WR650 Waveguide (unit length)	Surface Area	0.50m ²
	Volume	0.014m ³
	Conductance	270 L/s
Accelerator Structure (2m long)	Surface Area	1.9m ²
	Volume	0.05 m ³
	Conductance	3 L/s

The gas emission rates from the surface are the fundamental data for the vacuum design. Since the

surface area per unit length of L-band components is about twice of that of S-band, it is preferable to lower the gas emission from the surface. The rate from Aluminum alloy surface will be available soon and we can actually start to design the detail configuration of the pumps to meet the vacuum requirements.

TEST PLAN

The whole devices and components will be tested before they are assembled to be the L-band capture section of Linac. The test of the klystron will be started soon. We will check its performance and if it is successful, we are going to do the high power testing of RF components such as a dry RF load using the power provided by this klystron.

The accelerating structure will be delivered in January next year 2011. One accelerator unit will be constructed with this structure. The L-band klystron will be moved to the sector 1-4 connected to the modulator and a new transmission line will be constructed to the accelerator structure which will be set in KEKB Linac tunnel. Its high power test will be done in two stages: in the first stage, the test will be done for the structure alone and in the second it is with the focussing magnetic field (the structure will be immersed in the focussing field) to check whether the application of the field induces additional breakdown events in the structure.

CONCLUSION

Most of the specifications of the e+ beam in Linac are considered to be already fixed and work for a new L-band accelerator system for the positron capture section in Linac has started. The klystron power test will be started in this autumn. We expect the key devices such as klystron and accelerating structure will be ready soon. We also expect the RF components needed to form a power transmission line to be ready. Those devices and components will be assembled for the first half RF unit of the accelerator within this JFY2010 and high power testing of the accelerating structure will be done in next year 2011.

REFERENCES

- [1] M. Masuzawa, "Next Generation B-factories", IPAC10, Kyoto, Japan, May23-28, 2010.
- [2] T. Kamitani, "Injector Linac Upgrade for SuperKEKB", MOP011, these proceedings.
- [3] <http://mo-ohtsuka.co.jp/moflange/index.html>
- [4] K.Saito, et. al., "Design of L-band positron capture accelerating structure" in Proc. of the Particle Accelerator Society of Japan, Himeji, Japan, Aug. 2010 (in Japanese).