STATUS OF C-BAND ACCELERATOR MODULE IN THE KEKB INJECTOR LINAC

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Abstract

For future energy upgrade of the KEKB injector linac, we have been developping a C-band accelerator module which can yield twice higher acceleration field gradient (42 MV/m) than the present S-band modules. This paper reports on a development of the sixth prototype accelerating section and recent performance of the C-band module which recorded an average field gradient of 45 MV/m.

INTRODUCTION

The KEKB injector linac[1] supplies 8.0-GeV electrons and 3.5-GeV positrons to the storage rings. It is composed of 56 accelerator modules, each has a 40-MW S-band klystron, a SLED-type RF-pulse compressor and four 2m-long accelerating sections. A module gives typically 160 MeV energy gain to the beams with a 21-MV/m accelerating field. While electrons for positron production are accelerated up to 4.0 GeV to irradiate a target and the generated positrons are accelerated up to 3.5 GeV for injection, electrons for injection are accelerated up to 8.0 GeV in the entire linac.

Design studies and R & D for the SuperKEKB[2] have been performed since 2001, aiming more than ten times luminosity upgrade of the KEKB. One of the most significant changes in the machine parameters was an exchange of the beam energies of electrons and positrons against the electron-cloud instability. This requires an upgrade of the injector linac to increase the positron acceleration energy from 3.5 to 8 GeV. A simple upgrade scheme to achieve this is to double the acceleration field in the modules for positron acceleration. In the preliminary design consideration for the upgrade, it was suggested that accelerator modules operated in C-band RF (5712 MHz) which was precisely twice of the present S-band frequency (2856 MHz), could give twice higher acceleration field (42 MV/m) with the same amount of peak RF power and the operation was compatible with other S-band modules.

We designed a C-band module which had the same energy gain of an S-band module and a half size in length along the beam-line. It is comprised of a 40-MW C-band klystron, a SLED-type RF-pulse compressor using TE038-mode and two 2m-long accelerating sections. Actually, two 2m-long sections were replaced by two pairs of 1m-long sections connected by wave-guides for convenience in fabrication and in RF measurements. Constant gradient characteristic of the 2m-long section was retained in the pair as a whole. So far, we have developed six prototype sections as shown in Table 1. Details of the previous five sections are described in the references [3],[4] and the prototype No.6 is described in the next section. Hereafter the prototypes are denoted as P5 and P6 for simplicity.

C-BAND ACCELERATING SECTION PROTOTYPE NO. 6

The RF characteristic design of the P6 accelerating section is basically identical to that of the P5[4]. Since the P5 was fabricated at KEK and the P6 was at Mitsubishi Heavy Industries, Nagoya Aerospace Systems (MHI), there are several differences in their fabrication methods. Details of the P6 fabrication is described below in comparison with the P5.

An inner surface of the coupler of the P5 was electropolished (EP) to reduce surface roughness. Ambiguity of the depth of the removed surface by EP gave an error in the resonant frequency of the coupler. It required a frequency tuning by machining a curved edge of beam hole in the coupler. For this tuning, a core part around the beam hole was fabricated as a plunger and was welded to the coupler in the last stage of the fabrication (Fig.1). Since RF contact between the plunger and the coupler body was achieved only by their touched surfaces in a small area, a coupling property sensitive to the contact was sometimes unstable. For P6, the core part around the beam hole and the coupler body were fabricated as one piece (Fig.2). Thus the RF contact was intrinsically stable. The inner surface of the P6 coupler was finished by a milling machine for the coupler iris and by a ultra-precision lathe inside the coupler cavity. The resonant frequency and the coupling property were optimized by iterative RF measurements and machinings of the iris and the coupler cell diameter, further frequency tuning was not necessary. Though the surface roughness of the P6 coupler might be slightly worse than the electropolished surface of the P5, we assumed it would not be critical to RF breakdown frequency.

Regular accelerating cavity cells of the P5 and the P6 were assembled as a stack of disks and spacers. Though both of them were united by copper electroforming which forms copper layer outside of them, the processes were slightly different. For the P5, it was performed in low growth rate of the layer to make less stress to the cells and the resulted frequency shift was negligible ($<$ 100 kHz). The couplers were also united to the regular cells in this electroforming process. During the process, the regular cells and the end part of the couplers were exposed to

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Table 1: Accelerating section prototype specifications

	P1	P2	P3	P4	P5	P6
type	D	D	U* (C.I.)	D	U	U
disk iris (mm)	12.5→10.5	12.5→10.5	14.5	12.5→10.5	14.5→12.5	14.5→12.5
shunt imp. (MΩ)	75→85	75→85	65	75→85	65→75	65→75
filling time (ns)	243	243	103	243	135	135
electroforming	fast	slow	slow	fast	slow	fast
fabricated at	MHI	KEK	KEK	MHI	KEK	MHI

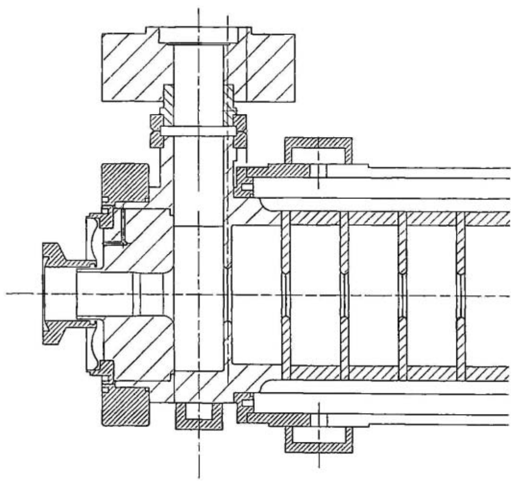

Figure 1: Input coupler of P5 section

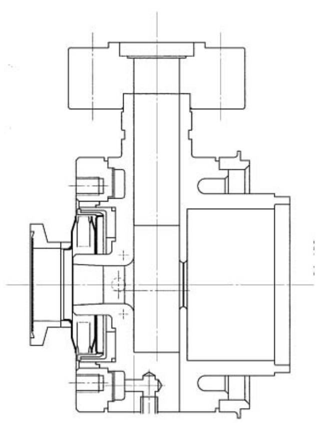

Figure 2: Input coupler of P6 section

copper sulfate solution, but the coupler regions at both ends were covered by waterproof packings. It was because the copper layer could not grow uniformly in angular surface. Existence of the packings made distribution of electric flux line non-uniform and the copper layer growth was slow in the vicinity of the packings. This electroforming process took 20 days to have sufficient layer thickness in the entire structure.

For the P6, only the regular cells were electroformed. It was performed with a similar recipe for the S-band accelerating section fabrication at MHI. The growth rate of the layer was much faster, since it was advantageous for mass production. It took only 4 days. This fast growth inevitably cause a resonant frequency shift (∼ +400 kHz) of the regular cells by a stress inside the copper layer. However, magnitude of this frequency shift was precisely predicted by a careful control of composition of the copper sulfate solution and a preliminary test with a small sample. Resonant frequencies of the cells were tuned before the electroforming considering this frequency shift. Deviations of the final resonant frequencies from the design value were only +10 kHz. After the electroforming, the couplers were united to the regular cells by electron beam welding (EBW). EBW has a merit that only a localized region is heated and influences to the couplers are negligible. On the other hand, the cells for EBW have suffered from resonant frequency shift. It gave slight deformation of the Nodal shift property from straight lines as shown in Fig.3, but degradation of the RF reflection (VSWR) was not significant (Fig.4).

In the last stage of the P6 fabrication, a cooling water jacket was TIG-welded outside the regular cells. TIG welding performed at MHI for the previous prototypes P1, P4 caused a definite frequency shift (∼ -200 kHz) in the regular cells. We suspected that it gave a tension for the structure to contract. For the P6, shape of joint part was modified to be flexible for the tension. It was successful that the frequency shift was negligible (-25 kHz).

The P6 was completed in December of 2006. After two weeks of RF-processing in a test stand, it was installed in the C-band accelerator module in the KEKB linac to replace the P3 section to achieve higher energy gain.

RECENT PERFORMANCE OF THE C-BAND MODULE

With the four accelerating sections (P1, P2, P3 and P4) installed in August of 2005, the C-band accelerator module in the KEKB linac has been operated as a full equipped module. However, as described in Ref.[4], the filling times and the shunt impedances of the four sections were in a makeshift configuration and they were unbalance for the two pairs of the sections. By installations of the P5 in August and of the P6 in December of 2006, the problem was fixed and the design configuration was completed.

As for the RF source, a C-band klystron (PV-5050K)

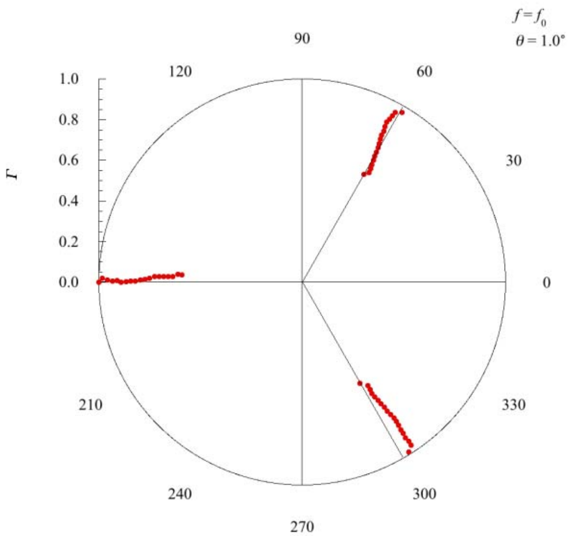

Figure 3: Nodal shift measurement of P6 section

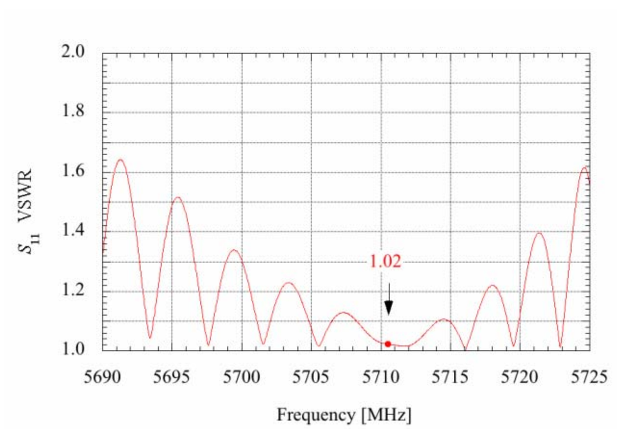

Figure 4: VSWR property of P6 section

fabricated by Mitsubishi Electric Corporation was installed in this accelerator module in August of 2006 and has been operated for ten month as a trial use. It can yield an output power more than 53 MW and the C-band module has been RF-processed by gradually increasing the power up to the maximum 53 MW. Frequency tuning of the cavities of the RF-pulse compressor for compensating the difference of the operating conditions at low and at high powers, improved the input RF power to the accelerating sections more than 10 percent. With this RF power source and the tuned pulse compressor, an energy gain of the C-band module was measured at an energy analyzing station of the linac with 8.0-GeV electron beam of 1-nC charge. An RF phase of the module was changed and a variation of the beam-energy was measured as a change of beam position based on the dispersion of 0.307 m at the station. Since a beam orbit distortion generated by transverse fields in the couplers of the accelerating sections might give systematic errors, it was corrected by steering coils for each measurement in different RF phases. The measured sine-like beam position dependence upon the RF phase was translated into that of the beam energy as shown in Fig.5. With the most probable fit of a sine-curve to the data, the energy gain by the C-band module was estimated to be 172±1 MeV. The error came from a fitting error and a resolution (0.1 mm in r.m.s) of a strip-type beam position monitor which corresponds to an error of 2.6 MeV in the beam energy. It is less than the size of a plot point in Fig.5. This energy gain (172 MeV) corresponds to an average acceleration field gradient of 45 MV/m, assuming effective acceleration lengths of the four sections were all 0.962 m. Klystron trip by RF breakdown is still frequent and occurs typically 25 times a day at the RF power level for this energy gain, but it will be lower at a level for daily operation. Dependence of the frequency upon the energy gain will be studied in the next autumn run.

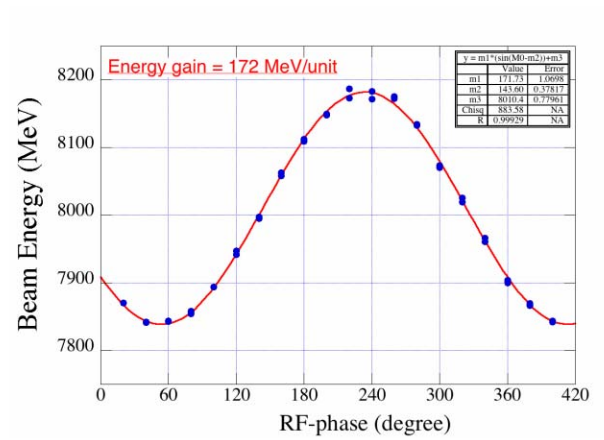

Figure 5: Energy gain measurement of C-band module

SUMMARY

With the latest prototype accelerating section No.6 installed in the C-band accelerator module in the KEKB injector linac, a design configuration of four sections in the module was completed. An energy gain of the module in this configuration was measured to be 172 MeV with a klystron output power of 53 MW. It is corresponding to an average acceleration field of 45MV/m. It exceeds the design energy gain of 160 MeV.

REFERENCES

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