HIGH POWER TEST OF A KANTHAL-COATED L-BAND LOSSY CAVITY

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Abstract

We have been developing a Kanthal (Al-Cr-Fe)-coated collinear load as a possible candidates for the L-band accelerating structure of SuperKEKB positron capture system. We understand that the Kanthal-coated cell should be studied in high power to confirm the feasibility at our design field of 10 MV/m level. To this end, we have made a high power test cavity. The cavity consists of 3 cells, one of which was composed of Kanthal-coated disks to lower the intrinsic Q value from 20000 to the order of 1000. The cavity reached 10 MV/m level after 30 hour operation but showed frequent vacuum activity which prevent the stable long pulse operation of 1.5–2 μs. In this paper, the cavity production and the experimental result in high power are reported.

INTRODUCTION

In order to achieve the 5 times higher capture efficiency in SuperKEKB comparing to that of KEKB, the upgrade of the positron production and capture section is required. The system consists of a Tungsten conversion target with a flux concentrator followed by accelerating structures surrounded by solenoid magnets. For the upgrade of SuperKEKB linac, two possible system layouts for the positron capture section are considered. One of them consists of two L-band accelerating structures with the collinear loads followed by four 2-m long large aperture S-band accelerating structures (LAS), while the other is made up from six LAS's. Especially for the former case, the output coupler part of the accelerating structure is preferred to be replaced by the collinear load to compose the system with compact magnets and to minimize the dip in the solenoid field. The load consists of 5 Kanthal-coated cells. For both cases, the reduction of satellite bunches is one of the important features of the capture section, because it causes the beam loss in the damping ring after injection [1]. If the L-band frequency (1298 MHz, which is 5/11 of S-band linac frequency) is adopted, the coprime frequency relation effectively reduces the satellites. In the latter case, a preliminary simulation study indicates that the accelerating field higher than 14 MV/m in the first accelerating structure is required. From cost consideration, we adopted the latter (6 LAS's) system for the first stage of the SuperKEKB. However we keep the possibility to adopt the former case after beam commissioning. In both cases, the positron beam loss and the production of satellite bunches are caused between the 1st and the 2nd accelerating structures. Therefore, it is also better to shorten the gap. The present study of the collinear load gives us the important information for the application to LAS. Considering the above ideas, we have been continuing the development of the collinear load even after the choice to choose the LAS system for the initial commissioning.

The design of the load and the properties of Kanthal were reported in previous works [2, 3]. The high power evaluation of Kanthal-coated cell at S-band is reported [4]. However, there is no precise information of properties of the Kanthal-coated load especially in a high power RF field at the frequency of L-band, except for the existence of L-band linac based on Kanthal-coated cell [5], we designed a Kanthal-coated standing wave cavity and performed the high power test. In this paper, we report design of the load and the test results

LOSSY CAVITY

Although the collinear load is connected to the travelling wave (TW) L-band accelerating structure [6], we adopted standing wave cavity for high RF power test to save cost.

Design of the Cavity

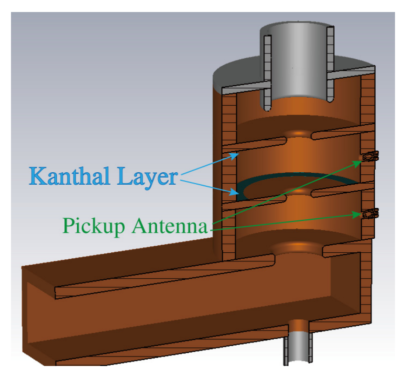

Figure 1: The cross section of the lossy cavity.

A schematic of the cavity is shown in Fig. 1, where it consists of the input wave guide connected to the matching cell, the load cell and the detuning cell which supress $\pi/2$ mode. Disks in the load cell are coated with 0.1 mm thick Kanthal layer.

The coating area, the radiuses of irises and the cylinders were optimized by using CST [7]. The load cell was designed so that the cells has the same Q-value as the 1st cell of the TW collinear load cells, the Q=1300. The field is also designed to be in the similar valance to the last regular cell in TW case. The reflection coefficient lower than -20 dB is realized.

Because the surface resistance of Kanthal layer is influenced by its microstructure, which depend on spraying techniques [2], the electric conductivity σ and the permeability μ are not well known. We have chosen the μ=2.58 [8] and the σ=22000 S/m to realize the same

Q-value reduction ratio. Then, the coating area is determined from r=71 to 87.5 mm.

The electric field strengths of 0 and π mode are shown in Fig. 2. In the case of π-mode, the maximum field in the load cell is about 80% of the matching cell, which is close to the TW collinear load case. In the Table 1 are listed the maximum fields on axis (E_z) and on surface (E_{surf}^{max}), in the SW cavity at 2 MW RF input power and the TW accelerating field and the surface field (E_{surf}^{max}).

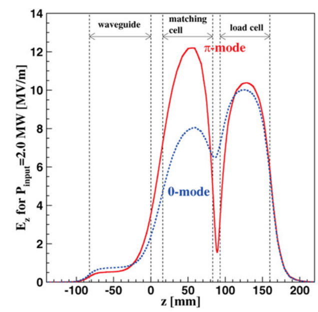

Figure 2: The electric field distribution on axis for 2 MW RF power. Red line and blue dashed line represent π and 0 modes, respectively.

Table 1: Accelerating and Maximum Surface Field in Each Cell

	E_z / E_{surf}^{max} [MV/m]
TW last regular cell	10/20
TW 1st load cell	8/16
Matching cell	12/21 for P_{in}=2 MW
Load cell	10/19 for P_{in}=2 MW

Low Power Measurement

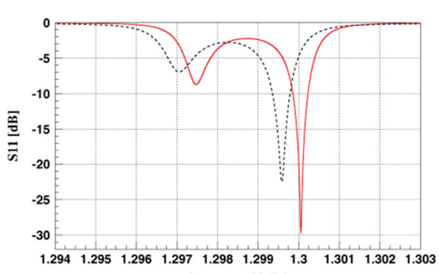

Figure 3: Reflection as a function of frequency. Red line represents simulation result and blue experimental data measured in the atmosphere.

The S-parameter was measured using a network analyser. Figure 3 shows the reflection coefficient of the cavity. The resonance frequency of π-mode is approximately 0.5 MHz lower than that of designed one. This error partly due to the ~0.2 MHz drop by air with humidity and 0.3 MHz unkown, probably machining error. The waveguide to cavity coupling was almost 1 (critically matched). The field balance between the two cells is also measured by using bead pull method. The field balance $E_{load}/E_{matching}$ was about 0.74, almost the same as designed.

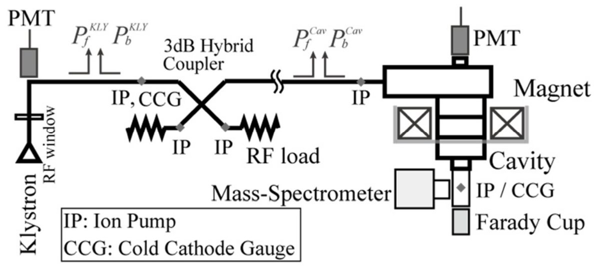

Figure 4: High power test configuration.

HIGH POWER RF TEST

Experimental Setup

The high power test setup is shown in Fig. 4. Forward and backward pulses at the klystron [3] exit and in front of the cavity were monitored by directional couplers. About 40% of the klystron power was transmitted to the cavity. The signal from the pickup antenna and the pressure measured at each ion pump and CCG are also monitored. All readouts of the pressure were used for the interlock system. The typical threshold of the interlock is set $2x10^{-4}$ Pa.

In the positron capture section, the accelerating structure with the collinear load is confined in the 0.4 T solenoid field. To make the present test system close to this condition, the cavity was inserted in an existing large solenoid magnet which gave a magnetic field of 0.09 T at the current of 200 A, limited by the power supply.

Two photomultiplier tubes were set to view the waveguide at just after the klystron and at the top of the cavity. These were used to catch the light emission due to any discharge or field emission. A faraday cup was connected to the detuning cell to measure the dark current. A quadrupole mass-spectrometer was connected to the vacuum port attached to the detuning cell.

RF Signals

The 2.2 μs RF pulse signals transmitted to the cavity and the pickup antenna from the cells are shown in Fig. 5. This long pulse test was performed at the very low input power due to the frequent vacuum jumps at higher power. The reflection in the steady state was less than -20 dB, making most of the input power absorbed in the cavity. The ratio of the pickup signals, load/matching, was 0.73, which was consistent with the field balance measured by the bead pull method.

Performances seen in High Power Operation

The high power test, with its goal of 4 to 6 MW at the klystron, was started at the pulse width of 500 ns, minimum available from the LLRF system. The input power and the pulse width was increased slowly so that the base pressure did not exceed ~4x10^{-6} Pa and the vacuum trip rate was kept low. The input power reached 6 MW with 500 nsec after 30 hours operation.

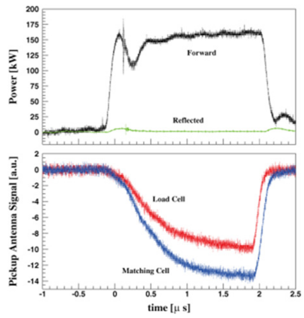

Figure 5: Input/reflected RF power to/from the cavity (upper) and field monitor signal (lower) at pulse width 2.2 μs.

A comparison of the vacuum activity between (a) the beginning of the test and (b) the timing after 220-hour conditioning is shown in Fig. 7. The peak powers were almost the same, but the pulse width at (b) was longer by 250 ns. It is seen that the amount of the out-gassing and the frequency of the spike became small through the RF conditioning. Note that the base pressure of (b) was higher than (a), because the evacuation by IP's in (a) was changed to turbo molecular pumps (TMP) in (b). After the evacuation by TMP's was switched back to that by IP's, we confirmed the base pressure around the cavity was 8x10^{-7} Pa, lower than (a). Also to be noted is that many of the vacuum jumps in (b) were due to other parts than the cavity, such as the klystron window.

The correlation between the vacuum spike and the variation of the reflected pulse just after RF off was observed, though many of the spikes showed no correlation. The dominant residual gases such as H_2O, CO and N_2, CO_2, and H_2 were observed. Note that the partial pressure pattern has not changed much. It is difficult to identify the observed large out-gassing source, due to the high conductance through the L-band wave guide. After the operation for several days, we checked the inner surface of the cavity by using an endoscope, but no damage was observed.

We have measured the dark current by varying the input power and the solenoid coil. We found that the dark current was nearly proportional to the input power, which is significantly different from the Fowler-Northeim field emission theory [9]. It is to be noted that it became narrow maximum (16pA at 2 MW and at 25 Hz) at a specific magnetic field of about 0.4kG, while at other magnetic fields deviated by more than 10% it stayed at the noise level of a few pA. The large PMT signal and base pressure increase were also observed at this magnetic field.

In summary, we observed the following characteristics,

- Cavity reached 10 MV/m level after 30 hours operation.
- Second peak of the reflected pulse varied when the pressure jumped but not always.

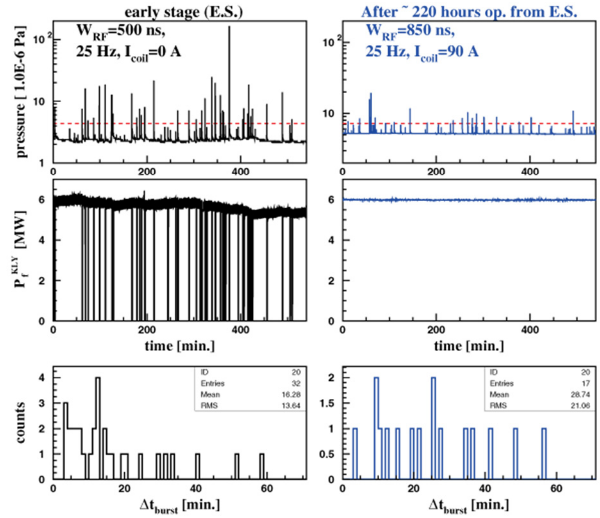

Figure 7: Comparison of vacuum activity between (a) left, early stage and (b) right, after 220 hour additional conditioning. Figures from top to bottom are (up) pressure of the cavity, (middle) the klystron peak power during 9 hours operation and (bottom) time interval between pressure jump exceeding 2x10^{-6} Pa.

- Residual gas consisted of H_2O, CO/N_2, CO_2, and H_2.
- Dark current of a few tens of pA with big jitter was observed.

Discussions

The cavity reached the design gradient after 30 hour operation, though in a shorter pulse. The RF conditioning is still in progress and it is clear that the cavity processing is certainly advancing. The main obstacle is the vacuum burst actually happening sometimes in the cavity but its mechanism is not understood. The dark current, pressure increase and the light emission were observed at the specific solenoid field. Simulations and the experimental setup modification are needed to understand these. If successfully performing these, we will confirm the feasibility of the Kanthal-coated load.

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