HIGH GRADIENT STUDY AT KEK ON X-BAND ACCELERATOR STRUCTURE FOR LINEAR COLLIDER

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Abstract

This paper describes the high-field studies on accelerator structures conducted at the X-band Test Facility, XTF, which was commissioned at KEK in 2004. A 60cm-long structure built at KEK has been processed in 2004-2005, with an accumulated operation time with the RF turned on of ~1000 hours. The RF breakdown rate of this structure at 65MV/m with 400nsec flat pulses was initially measured to be ~once per 0.2×10^6 pulses, and decreased to ~once per 0.7×10^6 pulses with the processing. This latter breakdown rate satisfies the stability requirement for use of such accelerator structures at the linear collider. The high-power performance of two more 60cm structures will be measured in 2005. These studies are expected to provide benchmark performance data of accelerator structures in both high-gradient and medium-gradient operations, such as those envisaged in applications to compact X-band accelerators.

INTRODUCTION

The R&D of accelerator structures for X-band main linacs of linear colliders (LC) has been conducted at KEK since early 1990s [1]. Many of the studies have been done in collaboration with Stanford Linear Accelerator Center (SLAC) [2]. The techniques for suppressing the wake-field was established by 2000. The focus of research has subsequently shifted on establishment of the high-field performance, aiming at low breakdown rate and long-term stability.

More than 30 structures were tested at Next Linear Collider Test Accelerator (NLCTA) at SLAC [3]. The cells made of oxygen free copper for many of these structures were fabricated by KEK for assembly at SLAC. By Spring-Summer of 2004, those structures showed a high-field performance satisfying the LC specifications.

This development was paralleled by KEK efforts to establish the Japanese domestic technology base for building X-band accelerator structures on its own. For testing the accelerator structures and other key RF components made in Japan, KEK launched in 2003 the program to build an X-band RF test facility called XTF.

In the latest configuration of XTF the combined RF power of ~100MW is produced by a pair of PPM klystrons. Delivered through an 8m-long circular waveguide, this power can produce up to 80MV/m of accelerating gradient in an LC accelerator structure.

This paper describes the processes of the first high-field testing of a test accelerator structure, KX01, which was conducted in 2004-05.

KX01 - TEST STRUCTURE

Structure design

The model, KX01, which was the first accelerator structure tested at XTF, is a 60cm-long travelling-wave structure with a $5\pi/6$ phase-advance design. Its basic parameters, concerning the structure main body, are identical to those with H60VG3A18, one of the NLC/GLC high-gradient test structure series that is detailed in [4]. However, the input and output couplers of KX01 employ the waveguide coupler design, with a matching cell inserted between each of the couplers and the main body [5].

Structure fabrication

The flow of the fabrication of KX01 and preparation towards the high-gradient test are enumerated as follows:

1. Cell fabrication with diamond turning.
2. Chemical etching of ~0.5μm (or less).
3. Diffusion bonding and brazing in a hydrogen furnace.
4. Vacuum baking at 500degC for two weeks.
5. Coupler matching and bead pull for field measurement.
6. In-situ bake at 200degC for a week.

Tuning and field measurement

The coupler matching was tuned to be VSWR<1.2 for the input side and VSWR<1.3 for the output side. The flatness of the accelerating field within the accelerator structure was generally good, as shown in the beed-pull data of Fig.1 A field enhancement (~15%) at cell #52 (cell upstream of the matching cell of output coupler) was left as is, since the matching cell was not equipped with a tuning measures.

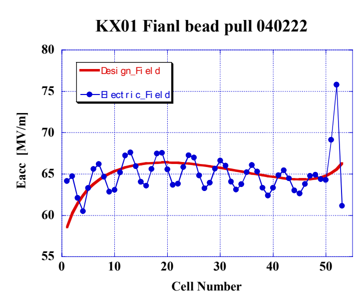

Figure 1: Measured field of KX01.

TEST FACILITY

Hardware setup

XTF was founded at KEK with the aim of high field evaluation of various X-band RF components for linear collider. The output power from two klystrons are combined with a 3dB hybrid, and transported through a 8m-long, low-loss TE_{01} circular waveguide which was built by SLAC. The power is then brought into a TE_{10} WR90 rectangular waveguide, and split into two arms for feeding the input coupler of the accelerator structure (Fig. 2). By adjusting the thickness of the gasket to insert, the left-right phase difference of the two arms is tuned to within a few degrees.

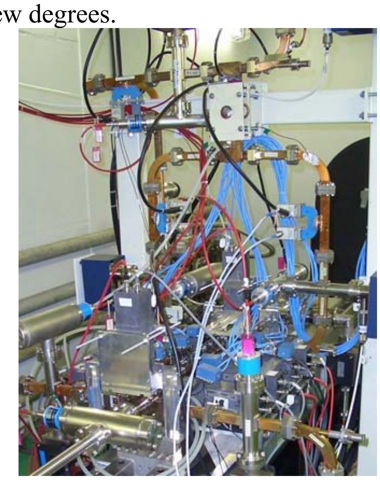

Figure 2: Setup around accelerator structure.

Breakdown detection

To monitor the reflected and transmitted RF signals, directional couplers with crystal detectors attached are introduced at various spots on the WR90 waveguide. Ten X-ray monitors, each consisting of a plastic scintillator and a photo-multiplier, are set, facing the structure. Acoustic sensors are installed on each individual cells of the accelerator structure as well as the waveguide for detecting the acoustic emission due to breakdowns.

RF interlocks are set to stop the next pulse in case of an excessive power reflection toward the klystrons. Pressure levels at various positions within the waveguide are monitored with cold cathode gauges and the interlock level is set at 10^{-4} Pa.

The RF pulse shapes for every pulse (towards the structure, reflection from the structure and transmitted through structure) are recorded with flash ADC (500MHz) CAMAC modules. The pulses are compared to those of the previous pulse. If any of the pulses changes by more than the interlock level preset in the software, the pulse is identified as a breakdown event. Typical setup parameters are listed in Table 1.

The acoustic sensors (64 units in total) [6] were distributed as needed, at the locations of interest. Their signals are recorded for each breakdown pulse and two preceding it for offline studies.

The magnitude and timing of the X-ray signals are also recorded. The X-ray monitor is found to be very sensitive to the structure breakdown and use as one of the sources for interlocking the system. A good correlation between the RF and X-ray signals are observed.

Table 1: Typical interlock level in fast ADC.

Pulse	Reflection	Transmission
Value	Peak	Integral
Level	> 200%	< 95%

Processing history

The history, up to the end of April 2005, of KX01 processing is shown in Fig. 3. The total number of pulses accumulated is about 180×10^6. The pulse width and the repetition rate were 400ns and 50Hz, respectively, throughout this period. Prior to this, a processing with 10×10^6 pulses at a pulse length shorter than 400nsec was applied. In addition, a few tens of hours were devoted to study behaviours with longer pulses. Dark currents were measured to be several μA initially. It became below the detection limit (1 μA) after a processing for 1000 hours.

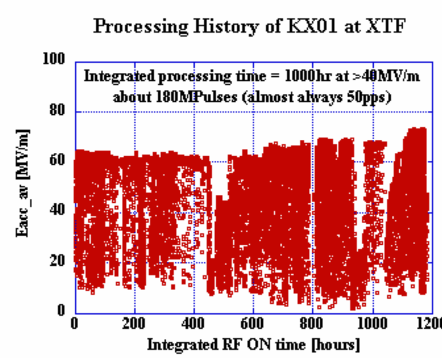

Figure 3: Power versus RF ON period for KX01 processing.

HIGH GRADIENT PERFORMANCE

Breakdown rate

The RF breakdown rates of the structure at the accelerator fields between 50 and 68 MV/m were measured at various stages of the processing. The result is summarized in Fig. 4.

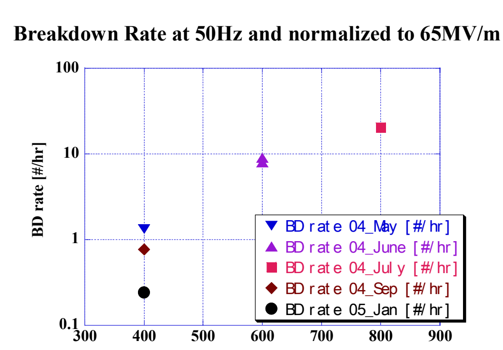

Figure 4: Breakdown rate normalized at 65MV/m with flat pulse shape.

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The rates are normalized at the nominal gradient of LC, 65MV/m. To obtain the values at this nominal field from the measurements at different fields, we applied the experimental dependence obtained at SLAC [7]

$$BD\,Rate \propto 10^{(E_{acc}-65)/6},$$

where the field E_{acc} is measured in MV/m.

Locations of Breakdowns

In Fig. 5 shows three examples of measured shapes of transmitted and reflected RF pulses during breakdown events, together with signals from acoustic sensors. The red lines correspond to each of the breakdown event (The blue lines are overlaid to show the preceding normal pulse as reference). The locations of breakdowns, as estimated from the RF pulses, are mostly consistent with those obtained from the distributions of the signal amplitudes from acoustic sensors.

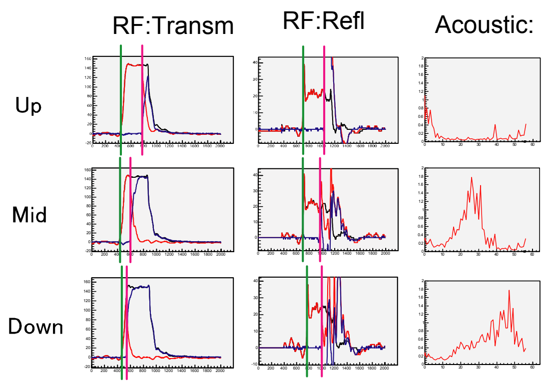

Figure 5: Typical breakdown pulses identified to be located at up, middle and down of the structure.

Fig.6 shows the distribution of the locations of breakdowns along the structure. An increased population near output coupler is seen. This might be caused by the higher field at the end of the structure due to the insufficient tuning as previously discussed with Fig. 1. The timing distribution of breakdowns during the pulses is fairly uniform.

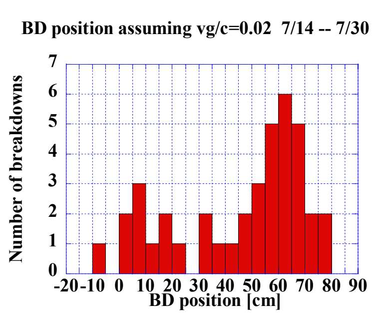

Figure 6: Breakdown position distribution.

Precursors before breakdown?

It was found that almost all breakdowns occur without any noticeable precursor signatures such as changes of the RF pulse shapes before the breakdown event. This is illustrated in Fig. 7, where the crystal output for consecutive 50 pulses is plotted before a breakdown occurred. Huge, abrupt changes in reflection and transmission pulse shape are taking place with the breakdown event.

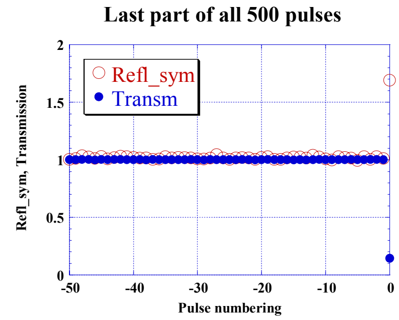

Figure 7: Last 50 pulses out of 500 pulses preceding a breakdown at pulse number "0".

SUMMARY

The results of the studies so far made at XTF at KEK may be summarized as follows:

- XTF has been used for 1000 hours for structure high-field test at KEK.
- Breakdown rate became less than linear collider specification.
- We will study two more structures from general high-field view point in addition to LC views.
- We believe that the X-band technology developed so far for linear collider can be extended to future accelerators and for various applications.
- The activities have been closely related to SLAC linear collider research and we greatly thank them.

However, with the decision by ICFA in the summer of 2004 to adopt the superconducting technologies for the main linacs of the international linear collider (ILC), the X-band efforts in the context of LC R&D will no longer be pursued. In 2005, two more test accelerator structures, which have been in production since 2004, will be tested to collect data for completing the high-gradient studies in the X-band frequency regime. Then some of the XTF components may be relocated within the KEK campus for further basic research in accelerator development.

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