HIGH FIELD PERFORMANCE IN REDUCED CROSS-SECTIONAL X-BAND WAVEGUIDES MADE OF DIFFERENT MATERIALS

Kazue Yokoyama#, Yasuo Higashi, Toshiyasu Higo, Noboru Kudoh
Accelerator Laboratory, High Energy Accelerator Research Organization (KEK),
1-1 Oho, Tsukuba, Ibaraki 305-0801, Japan

Abstract

RF breakdown is one of the major issues in the development of accelerating structures operated at high fields since the acceleration field is limited due to the metal surface damage [1, 2, 3]. RF breakdown studies are presently being carried out at Nextef (New X-band Test Facility at KEK) [4]. To study the characteristics of different materials on high-field RF breakdown we designed a reduced cross-sectional waveguide that has a field of approximately 200 MV/m at an RF power of 100 MW [5]. These type of waveguides are made of different materials such as copper (OFC), stainless steel, and molybdenum. This paper presents the first high-power test conducted on one of the copper waveguides.

NARROW WAVEGUIDE

Design and Fabrication

The waveguide was designed to obtain a group velocity of around 0.3*c* and a field gradient of approximately 200 MV/m at an RF power of 100 MW at the centre. The geometry of the waveguide was transformed from the X-band rectangular waveguide (WR90) as follows. The height and the width were reduced from 10.16 mm to 1 mm and from 22.86 mm (λ_g ~ 32.15 mm) to 14 mm (λ_g ~ 76.59 mm), respectively. The setup consists of a rectangular waveguide, a wavelength converter that reduces the width to 14 mm, a cosine taper (~ 1 λ_g) that transform the height to 1 mm, and a central flat part of 1 mm height. This geometry was designed to be matched by the HFSS calculation, as shown in Fig. 1. Some residual mismatch (which cannot be easily taken out) at the cosine taper was canceled by adjusting the length of the central flat part. This mismatch compensation leads to the resonant behavior shown in the three peaks in the figure.

A copper waveguide was constructed from of 4 parts, as shown in Fig. 2. After annealing in a hydrogen furnace, the waveguide was processed by milling and wire electrical discharge machining (WEDM) at the KEK mechanical engineering centre. For the E-plane where the electric field is applied, the surface was finished by the milling. The parts were chemically polished in an acid solution by 10 μm. The parts were bonded by brazing in a hydrogen furnace. The relevant parameters of the waveguide are shown in Table 1.

Confirmation of filed

The VSWR (voltage standing wave ratio) of the first prototype Cu-001 was 1.14 at a frequency of 11.424 GHz, whereas that of Cu-002 and Cu-003 was approximately 1.4. To confirm the field distribution, a bead pull measurement was performed, as shown in Fig. 3. Figure 4 shows the measured reflection coefficient along the central axis of the waveguide in the longitudinal direction. Here, an offset of 0.2, which was speculated to arise due to some other reflection source, was subtracted. This profile reveals that the waveguide has three peaks, but they are asymmetric, unlike the result of the simulation. This asymmetricity might be due to the fabrication error of the waveguide since the VSWR of Cu-004 was improved.

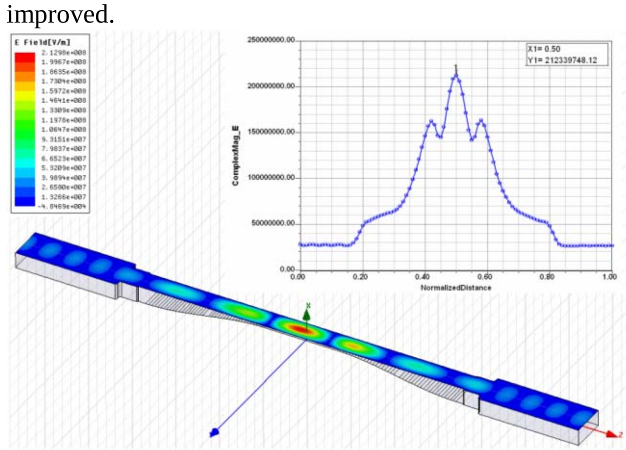

Figure 1: Electric field in a narrow waveguide at an input power of 100 MW by the HFSS calculation.

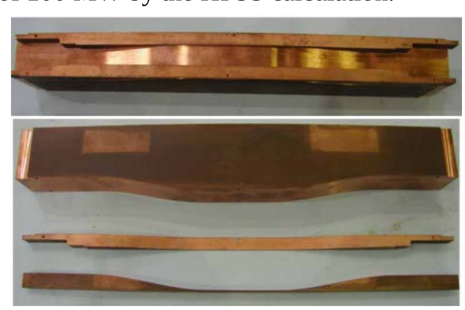

Figure 2: Parts of a copper waveguide. The upper figure shows a set obtained after assembling the 3 parts that are shown in the bottom image.

Table1: Relevant parameters of waveguides.

	Cu-001	Cu-002	Cu-003	Cu-004
material	OFC	OFC	OFC	OFC
anneal	500 °C	500 °C, H_2	500 °C	500 °C
processing	milling, WEDM	milling, WEDM	milling, WEDM	milling
cleaning	-	CP	CP	CP
bonding	Cu/Au/Ni brazing	Cu/Au/Ni brazing	Cu/Au/Ni brazing	Cu/Au brazing
VSWR	1.14	1.44	1.4	1.1
status	prototype	tested	-	to test

Kazue.Yokoyama@kek.jp

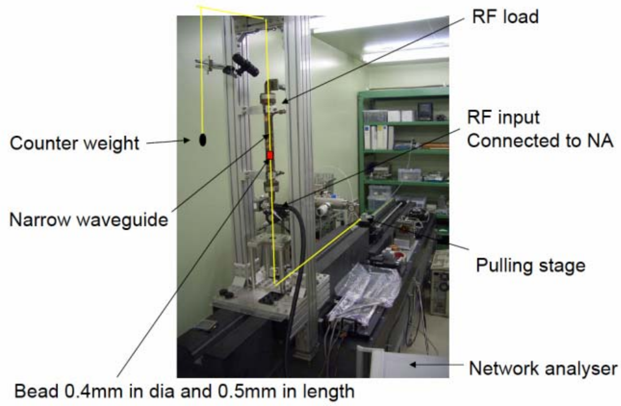

Figure 3: Setup for bead pull measurement.

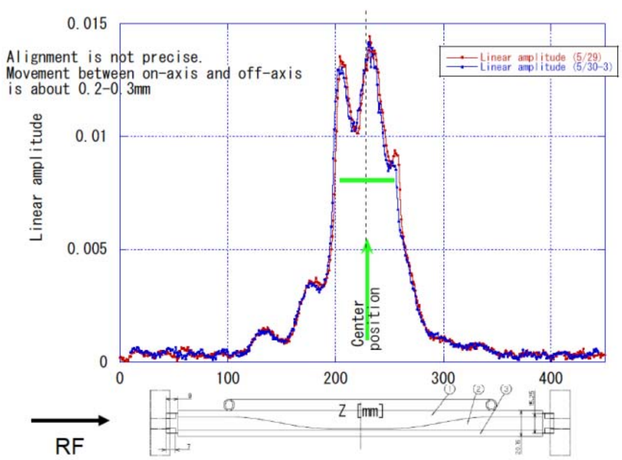

Figure 4: Bead pull measurement along the centre of the E-plane.

HIGH-POWER TEST

Setup

The first high-power test was done at XTF (previous X-band Test Facility at KEK). Cu-002 had been tested for a month. The RF processing time was up to approximately 240 h. The setup for the high-power test is shown in Fig. 5. During processing, transmitted and reflected RF waveforms are observed for the breakdown events. In order to acquire more information about the RF breakdown, photomultipliers (PMTs), acoustic sensors, and a camera to observe visible light are placed along the waveguide, as shown in Fig. 5.

RF Processing and Breakdown

During processing, the RF pulse went from 50 ns to 400 ns feeding up to 40 MW of power at a repetition rate of 50 pps. We have observed RF breakdowns by bursts of X-rays, flashes of visible lights and acoustic signals at the breakdown events. Figure 6 shows an example of the waveforms at a breakdown event. Frequent breakdowns are observed at a level of approximately 100 MV/m, as shown in Fig. 7. The maximum electric field is approximately attained at around 140 MV/m at a pulse width of 50 ns. Figure 8 shows the plot of RF power times the square root of the pulse width and accumulated number of breakdown events during processing. The processing was terminated due to the XTF schedule. Therefore, we could not confirm whether the saturation point was attained or not from the result. The location of the breakdown was evaluated from the signals of the PMTs and acoustic sensors. The results are shown in Figs. 9 (a) and (b). This result indicates that breakdown occurs frequently around the center of the waveguide and its upstream.

After processing, the material surface was observed by a laser microscope. Figure 10 (a) shows a picture of the waveguide. Many breakdown damages were seen on the E-plane surface. Figures 10 (b) and (c) show the laser microscope view and (d) shows the concavoconvex-view of (c) by laser scanning. Many cone or umbo-shaped protuberances (~ 25 μs height) are detected on the surface. The surface is intensively damaged, and it could also melt due to breakdown.

CONCLUSION

Prototype Cu-002 had been tested at the previous XTF for about a month. On several occasions, we have observed RF breakdowns at around 100 MV/m from a pulse width of 50 ns to 400 ns. The maximum electric field is estimated at approximately 140 MV/m at the shortest pulse width of 50 ns. After processing for 240 h at 50 pps, the temperature related parameter, $P*T^{1/2}$, attained approximately 400 $MW{\cdot}ns^{1/2}$.

Studies on Cu-004 and a stainless-steel waveguide will be performed at Nextef. A high-power test of around 100 MW at 400 ns will be conducted this autumn.

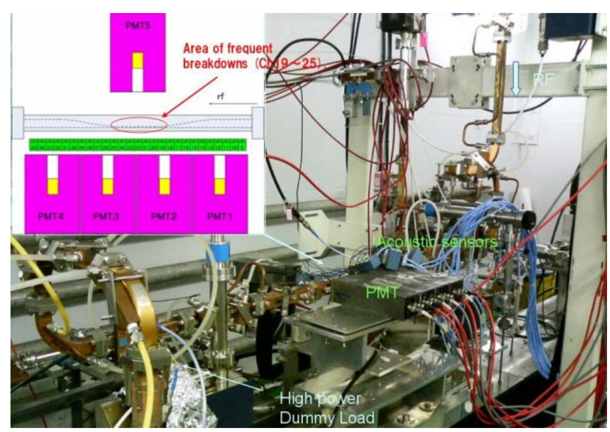

Figure 5: Setup for high-power testing.

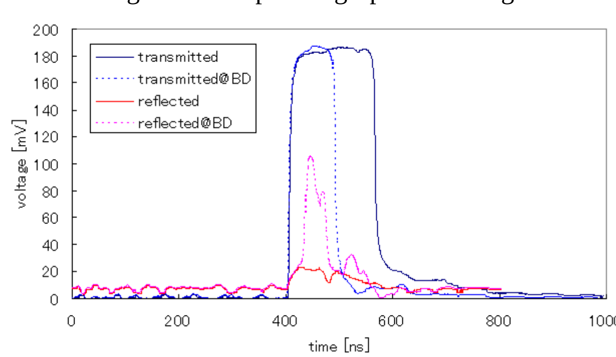

Figure 6: Example of transmitted and reflected RF for normal pulse (solid) and a breakdown (dashed).

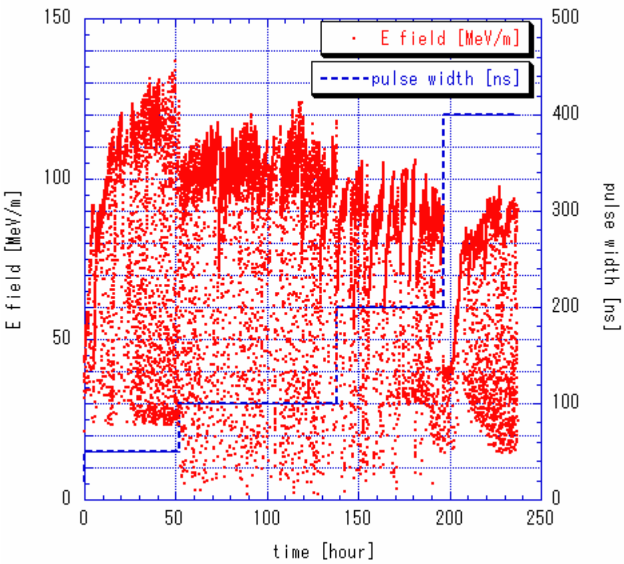

Figure 7: Field and pulse width over processing.

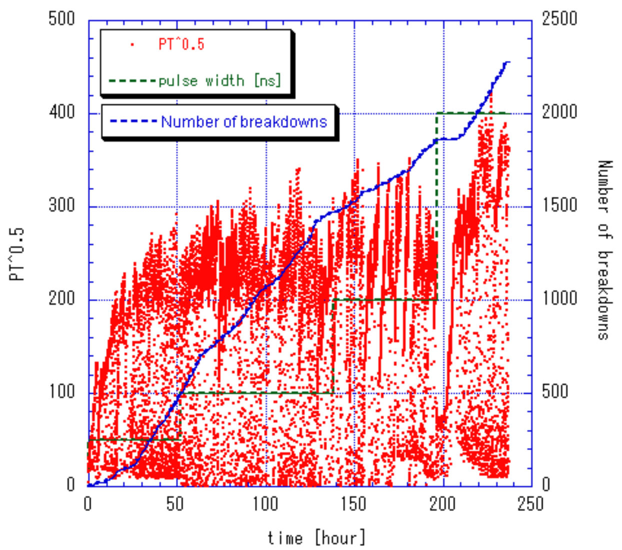

Figure 8: Plot of $P*T^{1/2}$ and the number of breakdown events vs. time with RF on.

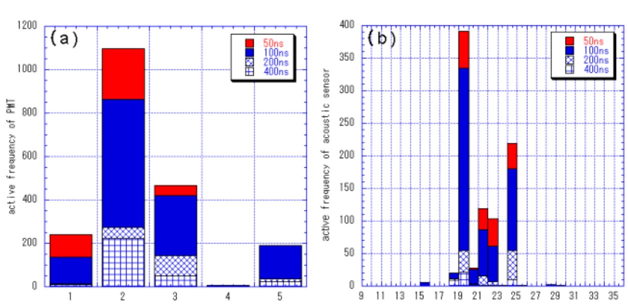

Figure 9: Breakdown location as determined (a) PMTs and (b) acoustic sensors.

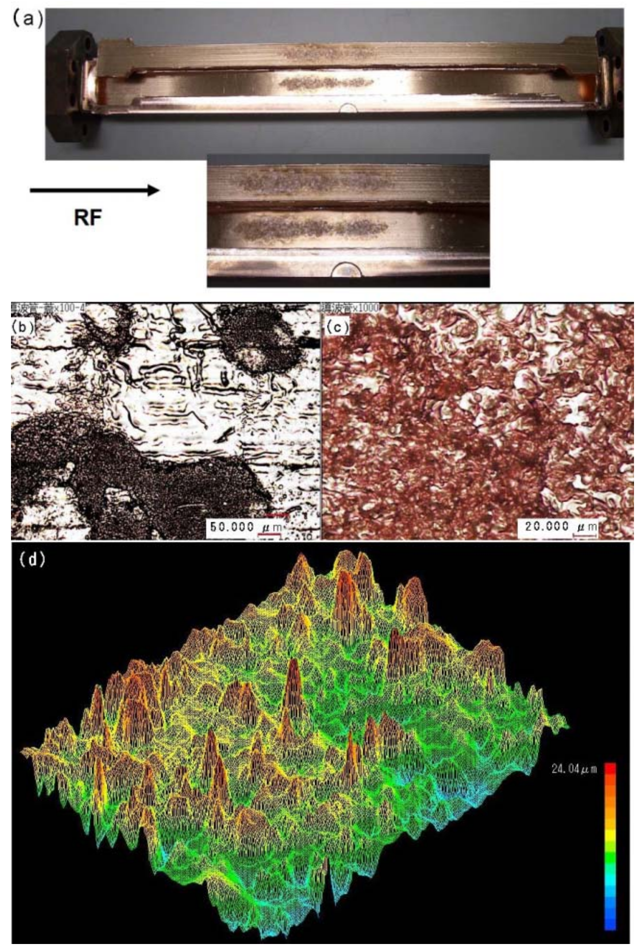

Figure 10: Surface of the copper waveguide after processing. (a) provides an overview of Cu-002 after being split apart, (b) and (c) are examples of the breakdown area with different scales, and (d) provides the concavoconvex-view of laser scanned (c).

REFERENCES

[1] V. A. Dolgashev, S. G. Tantawi, "RF Breakdown in X-band. Waveguides," TUPLE098, EPAC'02, 3-7 June, 2002, Paris,. France, pp. 2139-2141.

[2] Wang, J. W., and G. A. Loew., "Field Emission and RF Breakdown in High-Gradient Room Temperature Linac Structures", SLAC. Stanford, CA, 1997. 1-7.C. Petit-Jean-Genaz and J. Poole, “JACoW, A Service to the Accelerator Community”, EPAC’04, Lucerne, July 2004, p. 249, http://www.jacow.org.

[3] P. Wilson, "A Theory for the Comparative RF Surface Fields at Destructive Breakdown for Various Metals", SLAC-TN-06-003, 2006.

[4] http://www-linac.kek.jp/nextef/

[5] T. Higo, et al., "Normal Conducting High-Gradient Studies at KEK", LINAC2006, 21 - 25 August, 2006, Knoxville, TN, USA, pp. 661-663.