SC CAVITY SYSTEM FOR ERL INJECTOR AT KEK

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Abstract

Development of a Superconducting Cavity Injector Cryomodule for the compact ERL (cERL) is being continued at KEK since 2006. Design of a cryomodule containing three 2-cell 1.3-GHz cavities is almost completed and will be ordered soon. Status of R&D and design details are reported.

SC CAVITY SYSTEM FOR COMPACT ERL INJECTOR AT KEK

An injector for cERL is required to accelerate a CW electron beam of 100mA to 10MeV [1]. In this application, critical hardware components are not cavities but RF input couplers and HOM dampers. Several combinations of number of cavity and cells per cavity were examined, and a three 2-cell cavity system was chosen for cERL. Each cavity is drove by two input couplers to reduce required power handling capacity and also to compensate coupler kick. HOM coupler scheme was chosen for HOM damping, and 4 or 5 HOM couplers are put on beam pipes of each cavity. Because of simplicity cavities are cooled by jacket scheme. Figure 1 is the drawings of the cyomodule system for the injector part. Basic parameters of the cavity are summarized in Table 1.

Table 1: Basic Cavity Parameters

Frequency	1.3	GHz
Number of cell	2	
R / Q	205	Ω
Operating Gradient	14.5	MV / m
Number of Input Coupler	2	
Coupler Power	167	kW
Coupler Coupling Q	3.3 x 10^5	
Number of HOM coupler	4 or 5	
Operating Temperature	2	k

Cavity

Two fully equipped proto-type 2-cell cavities (#01 and #02) were fabricated in 2007 and 2008. The cavities are shown in Figure 2 and 3. They have a TESLA-like cell shape and larger beam pipe aperture of 88 mm. The 1st vertical test of proto-type 2-cell cavity #01 with regular HOM pick-up antennae was carried out in April 2009 at STF (Superconducting rf Test Facility) in KEK. The vertical test of proto-type 2-cell cavity #02 will be done December 2009.

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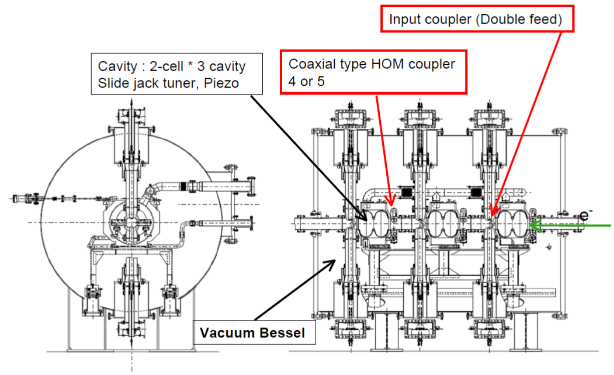


Figure 1: Cryomodule system for injector part.

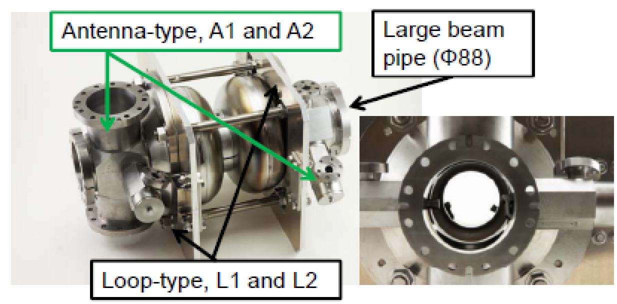


Figure 2: Proto-type 2-cell cavity #01 (Four HOM couplers).

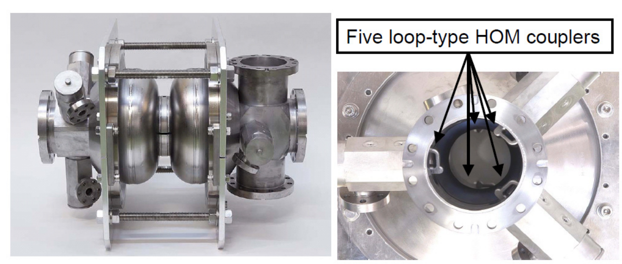


Figure 3: Proto-type 2-cell cavity #02 (Five loop type HOM couplers).

Input Coupler

RF input coupler is the most critical component in the high power application of the superconducting cavity. The most powerful CW coupler under operation is the KEK-B couplers, which has a coaxial disk type window developed for TRISTAN SC cavities [2]. We made scaled models to 1.3 GHz, as shown in Figure 4. Impedance of coaxial parts is 41 Ω, and the outer diameter is 82 mm.

Couplers will be assembled to cavity in the clean room before installation to a cryostat. Then thermal intercept becomes difficult, and requires the 5 K and 80 K anchors at outer conductors. Inner conductors and the windows are cooled by water. High power test at room temperature is scheduled in November 2009.

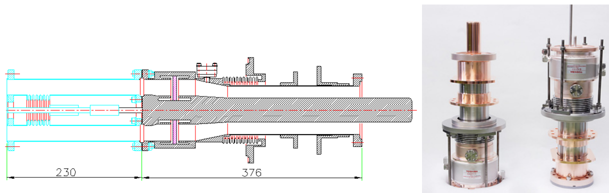


Figure 4: Proto-type input coupler for injector cavity

HOM Coupler

We decided to use HOM couplers instead of beam pipe HOM absorbers to damp HOMs, because absorbers are not well established in cold and they need extra drift space. TESLA HOM couplers are considered as the best choice, but it is well known that thermal instability appears above 10 MV/m in the CW operation. It is also well know that heating happens at pick-up antennae of HOM couplers, but it is not yet understood why niobium antenna becomes normal conducting. One may expect that if the current density at antennae is reduced then the threshold of gradient increases. TESLA style HOM couplers are modified to add the second stub and a boss to reduce the load of the accelerating mode. Two type HOM couplers are designed for CW operation, one is loop-type coupler and two is antenna-type coupler as can be seen in Figure 5. Figure 6 shows the distribution of H-field of the modified HOM couplers. Table 2 is calculation result of current density of HOM pick-up probe tip at each gradient. The current density of probe tip is reduced by a half to 2000 A/m at 15 MV/m [3, 4].

Table 2: Calculation result of current density of HOM pick-up probe tip at each gradient.

Model	Eacc: Current of heating of probe 4000 A/m		
	15 MV/m	20 MV/m	25 MV/m
Antenna	1340 A/m	1800 A/m	2250 A/m
Loop	2080 A/m	2780 A/m	3350 A/m
STF BL (TESLA like)	4250 A/m Heating	5600 A/m	7200 A/m

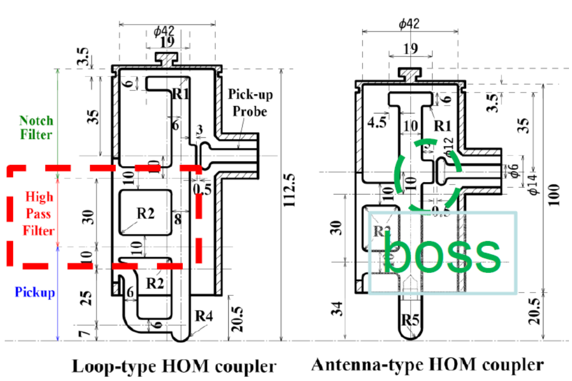
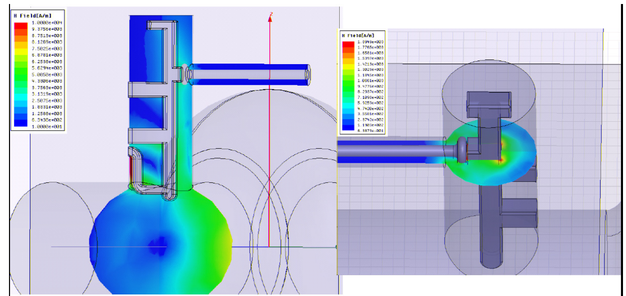


Figure 5: Two stub HOM couplers



H-field distribution at 1.3 GHz (acceleration load)

Figure 6: H-field distribution of HOM couplers

Frequency Tuner System

We will use Slide Jack tuners [5, 6] which are used in STF cavities. This tuner system has one piezo in series with a slide jack tuner. Stroke of the tuner is listed in Table 3.

Table 3: Stroke of tuner system

	Type	Stroke	Δf
Mechanical Tuner	Slide Jack	1 mm	1.3 MHz
Fine Tuner	Piezo	4 μm	2.6 kHz

MEASUREMENT OF THE PROTO-TYPE 2-CELL CAVITY #01

The result of the low level rf measurement and the vertical test with the proto-type 2-cell cavity #01 (ERL 2-cell #01) is described in this section. The ERL 2-cell #01 cavity has four HOM couplers (equipped two loop type HOM couplers and two antenna type HOM couplers) to measure gradient when occur a heating of HOM pick-up probe tip at each models. The procedure of cavity test are shown as following,

(a) Inspection of inner surface of cavity at "As received",
(b) Measurement of the accelerating mode and HOMs,
(c) Measurement of the Qin by using dummy couplers,
(d) CP process (20 μm) at Nomura plating company,
(e) Anneal process,
(f) Inspection after anneal process,
(g) Final EP process (100 μm), H_2O_2 rinsing, hot bath rinsing, HPR, assembly and mild baking at STF,
(h) HOM coupler tuning for accelerating mode in vertical test stand,
(i) Vertical test with regular HOM pick-up probe (probe material is Niobium.) and T-mapping (temperature mapping),
(j) Inspection after vertical test with T-map results.

Figure 7 is EBW (Electron Beam Welding) seams at equator and iris part inspected by Kyoto camera system [7] at "As received". The EBW seam of this cavity was uniform around one lap, and iris part was also uniform around one lap.

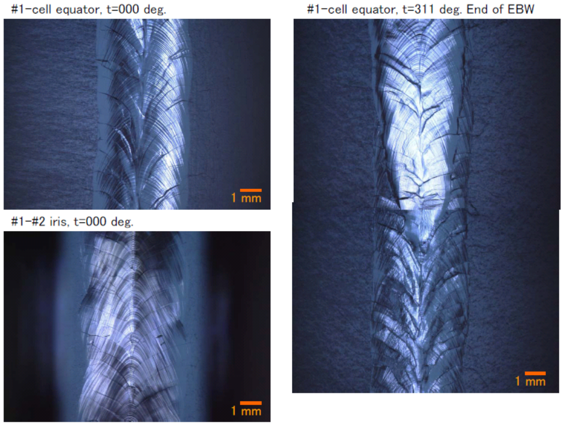


Figure 7: EBW seam of proto-type 2-cell cavity #01 at "As received".

Low Level RF Measurement

The frequency and field flatness of accelerating mode at "As received" were 1299.369 MHz and 99.8 % at room temperature. Therefore, rf measurements were done without pre-tuning. Figure 8 shows the field distribution of TM_{010} passband.

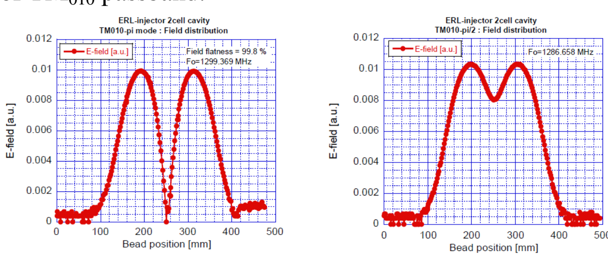


Figure 8: Field distribution of TM_{010} passband.

The target of Q_{in} value with one coupler is $3.3x10^5$ when location of coupler tip is 34 mm from beam axis. This target was calculated by HFSS. Figure 9 is the setup of Q_{in} measurement. Measured Q_{in} value by dummy input couplers was $5.0x10^5$ at room temperature. Result of calculation value and measured Q_{in} value at each location is shown in Figure 10. To achieve the target value, the location of the coupler tip needs to change 30mm from beam axis.

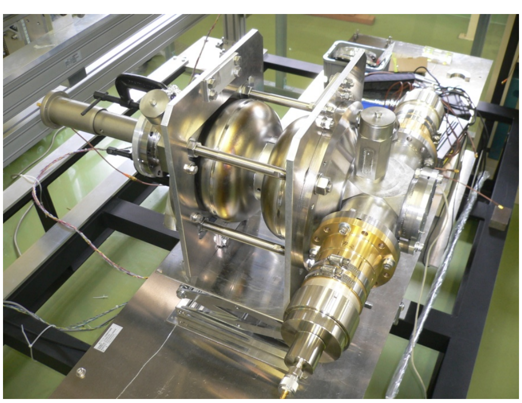


Figure 9: Setup of Q_{in} measurement.

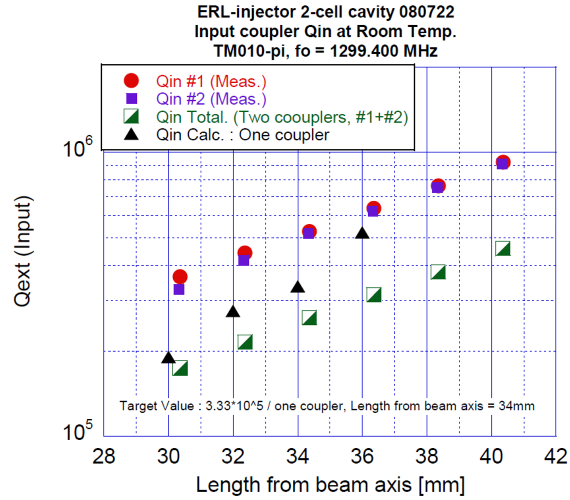


Figure 10: Result of measured Q_{in} value at each location.

Measured Q_L value and frequency of major HOMs at 4.2 K summarised in Table 4. Performance of HOM Qext at each HOM couplers shows Figure 11. Qext of TE_{111} and TM_{110} was obtained strong dumping, but TM_{011} was weaker due to antenna-type HOM coupler does not work for TM_{011} mode.

The injector cryomodule system does not have the BPM (Beam position monitor) in vacuum bessel. To measure the beam position in cryomodule, dipole mode is useful mode to use a cavity BPM. The polarize angle of doublet of TM_{110} passband was measured by bead perturbation method. The material of bead is ceramics ball (diameter is 6 mm.) to detect only E-field, where scan position is 30mm off-center from beam axis. The distribution of polarize angle and field distribution is shown in Figure 12. The angle between X-dipole and Y-dipole of TM_{110} passband was about 90 degree.

Table 4: Summary of measured Q_L value of major HOMs at 4.2 K

Mode	Frequency	R/Q (Calc.)	Measured Q_L
TE_{111}	1.557 GHz 1.563 GHz	0.59 Ω/cm^2	750 350
	1.578 GHz 1.589 GHz	1.8 Ω/cm^2	440 300
TM_{110}	1.629 GHz 1.639 GHz	4.0 Ω/cm^2	1260 1190
	1.784 GHz 1.801 GHz	1.9 Ω/cm^2	850 5130
TM_{011}	2.281 GHz	64 Ω	6000
	2.309 GHz	12 Ω	5040
TM_{020}	2.67 GHz	0.4 Ω	-
	2.69 GHz	31 Ω	-

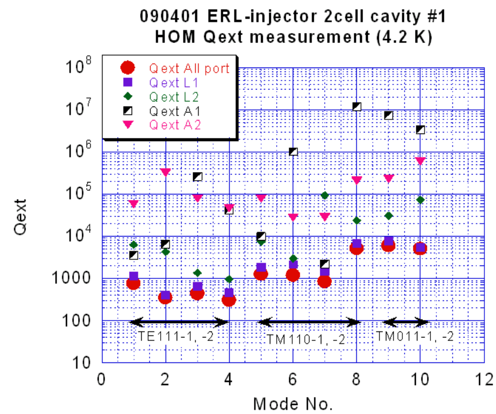


Figure 11: Measured Q_{ext} of each HOM couplers at 4.2 K.

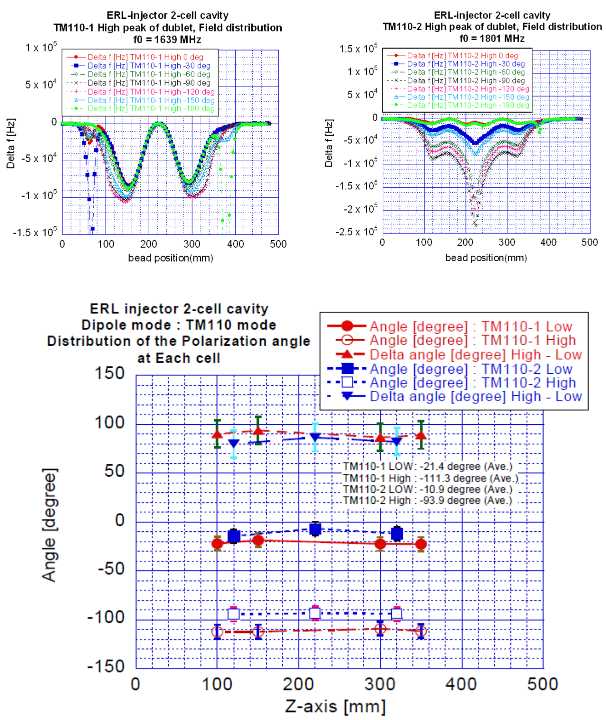


Figure 12: Result of polarize angle of TM_{110} mode and the field distribution of each location.

Vertical Test

The 1st vertical test of ERL 2-cell #01was carried out in April 2009. The thermo-sensors attached the cell equator and HOM couplers. Total number of thermo-sensor is 33 (8 sensors per cell equator, and 4 sensors per HOM coupler). The sensor location of HOM feed through (Kyocera-type) is important to detect a heating at HOM pick-up antennae. The setup of thermo sensors in vertical test is shown Figure 13. The cavity gradient reached 30MV/m with small electron loading (Figure 14). The reason of low Q value is due to losses at beam pipe flanges made of stainless steel. During the test, we observed some thermal instability (blue dots in Figure 14), where both Q and gradient decrease slowly. It is well known due to the heating of pick-up antennae of HOM couplers. Heating of one HOM coupler (A2) was detected by thermometer at around 16 MV/m. Other three HOM couplers and cell equator were not observed a heating in processing.

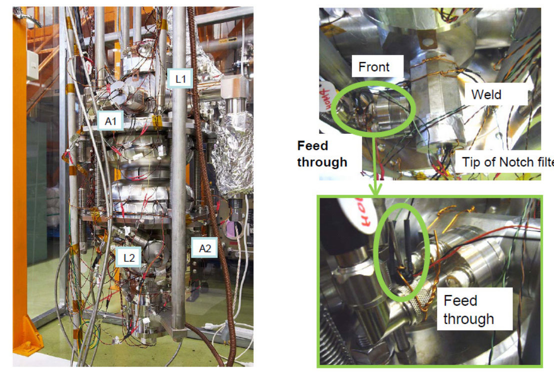


Figure 13: Setup of thermo sensors in vertical test.

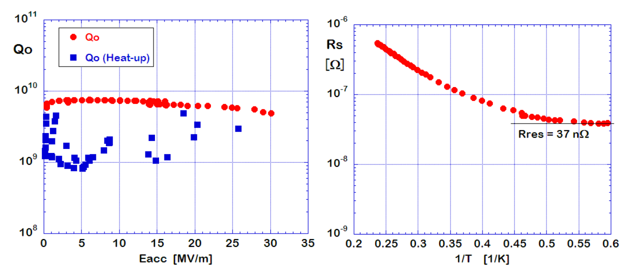


Figure 14: Q_0 – Eacc curve and Rres.

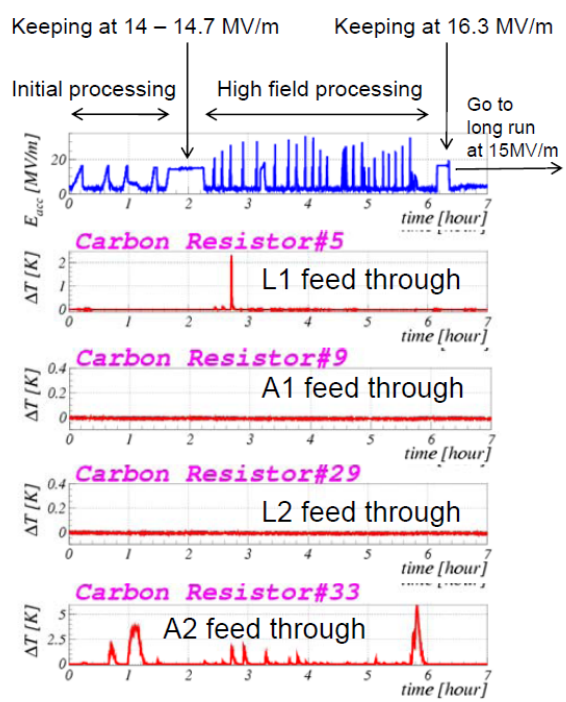


Figure 15: Processing history in vertical test.

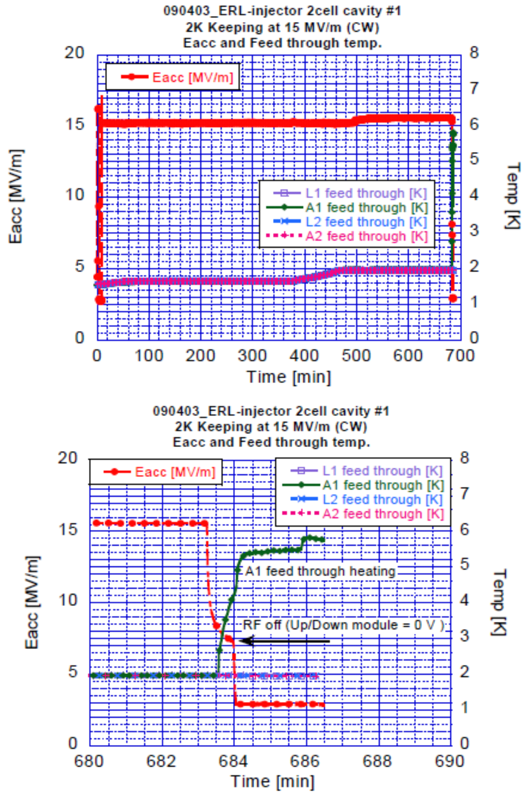


Figure 16: History of the long run operation after high field processing.

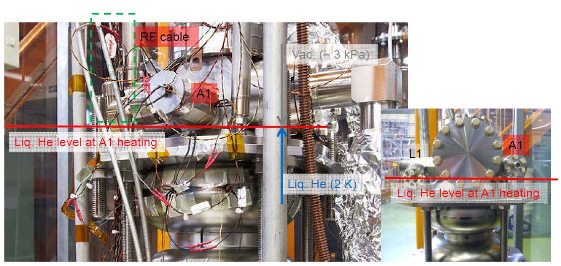


Figure 17: Liq. He level when occurred a heating A1 feed-through.

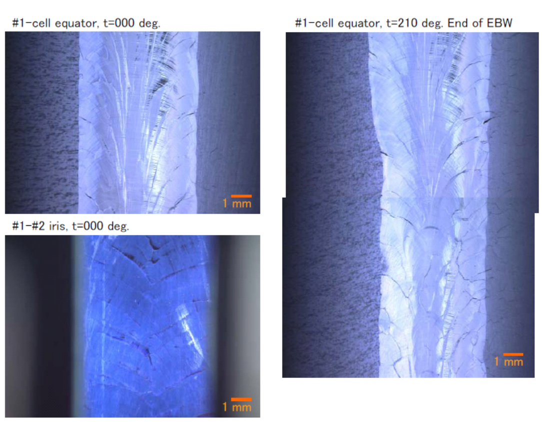


Figure 18: EBW seam of proto-type 2-cell cavity #02 at "As received".

Figure 15 is history of processing and thermo sensor of HOM feed through in vertical test. To make the high filed processing, the field was raised as the highest as possible before the heating happens. After high field processing, the field could be kept 16.3 MV/m at long time, and long run CW operation at 16 MV/m was carried out for 11 hours at ~ 2K, until liq. He was used up (to assume cryomodule test). The history of the long run operation shows in Figure 16.

Finally in this test, the A1 feed through was heating when A1 HOM coupler (and rf cable) was not dipped on liq. He level, then the field and Q_0 value was decreased (Not A2 feed through, beam pipes and cell). Figure 17 is image of He level when occurred a heating A1 feed-through.

SUMMARY AND FUTURE PLAN

Two fully equipped proto-type 2-cell cavities (#01 and #02) and two input couplers were fabricated at 2007 and 2008. The cavity #01 was achieved the operation gradient in vertical test (CW, long run operation). The Max field was achieved over 30 MV/m at short time. The field was limited by one HOM pick-up probe. The 2nd vertical test of #01will be equipped the thermal anchor to obtain a good cooling for HOM pick-up antennae to assume the cryomodule operation.

At present, the initial surface treatment and low power test of proto-type 2-cell cavity #02 was carried out. Figure 18 is improved EBW seam of ERL-2cell #02 at "As received". The first vertical test of this cavity will be done December 2009. The high power test of the input couplers will be done from November 2009.

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