

INVESTIGATION OF 9-CELL CAVITY PERFORMANCE PROBLEM BY FACILITIES IN KEK AR EAST 2ND EXPERIMENTAL HALL

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Abstract

In this half of year, our 9-cell cavity performance often suffered from field emission. We investigated our facilities in the KEK AR East 2nd experimental hall. Particle contamination problem was found in our HPR system, cavity assembly and vacuum evacuation procedure. We took cures for these problems. Field emission problem has reduced remarkably after these cures. We will report about these problems and cured results on cavity performance in this paper.

MOTIVATION

We are developing an alternative high gradient cavity for ILC 1TeV energy upgrade, applying Ichiro shape instead of TESLA one. Currently we have achieved the ILC alternative configuration design goal: 40MV/m @ Q₀=8E+9 on the Ichiro 9-cell cavity as seen in Fig.1 right bottom, which was done by KEK/Jlab collaboration. More information is in the reference [1].

However, as seen in Fig.1, since last October 2010, Ichiro 9-cell cavities tested in KEK are limited to the gradient lower than 20MV/m. I9#11 in the 2nd and 3rd tests, which is made of large grain niobium material, was limited by hard quench due to less material removal (60μm by BCP). Centrifugal barrel

polishing, which is our standard procedure prior to EP or BCP, did not take place for this cavity. In the I9#11 3rd VT, rinsing was strengthened around end group by adding steam cleaning and wiping before HPR. The amount of X-ray reduced very much by these methods, that suggests the strengthened end group cleaning is effective to suppress field emission. However, other most cases were limited by field emission.

Our concern is the onset of X-ray. X-ray starts from 10 -15 MV/m at all KEK tests in Fig.1. In the single cell cavity test, we have often observed the X-ray onset around 20MV/m initiated by Multipacting (two point first order) but the 10 - 15MV/m X-ray onset is too low. The I9#7 result shown in Fig.1 right bottom, on which all preparations including EP were done in Jlab. In this case, X-ray onset is around 15MV/m. This onset is lower than that of ILC baseline cavity (TESLA shape) treated and tested in Jlab. The amount of X-ray is also more serious in I9#7 than that of ILC cavity in Jlab.

Our most concerns are 1) why the X-ray onset is so low in our recent test, 2) why the amount of X-ray is so serious in our test. We started to suspect our facility. We have investigated our facility to look for the answer from particle contamination point of view.

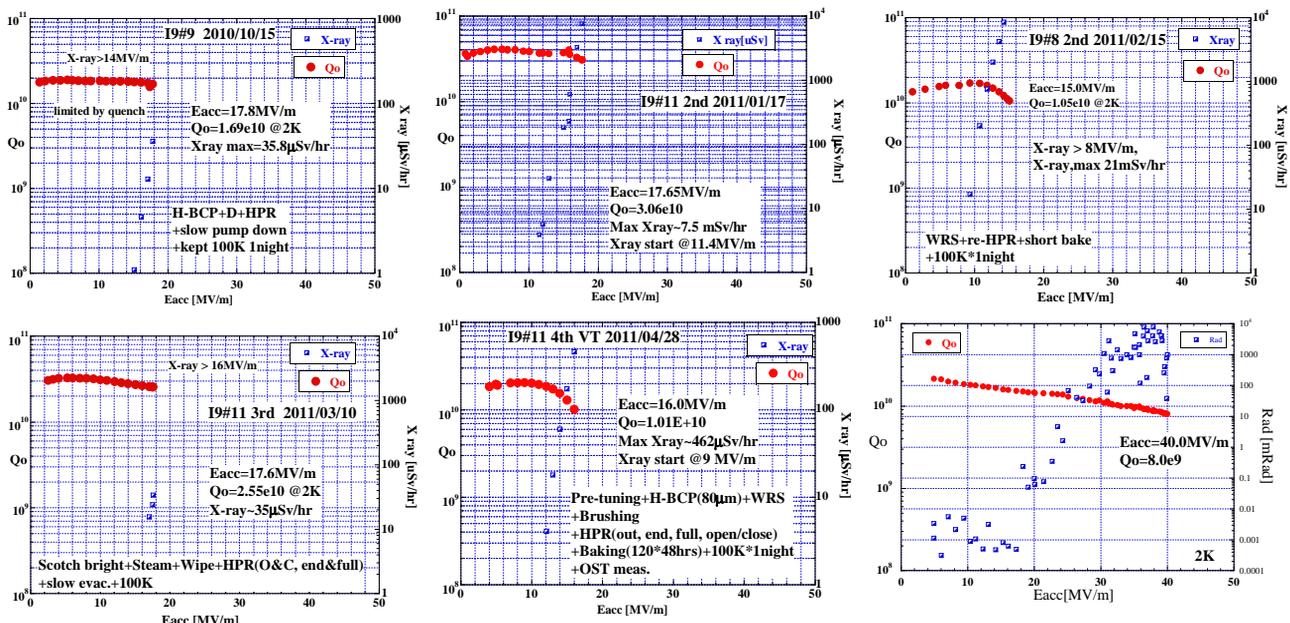


Figure 1: Vertical test results of Ichiro 9-cell cavities at AR East 2nd experimental hall (Top three and Left two) and the result of Ichiro #7 electropolished and VT tested in Jlab.

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METHOD

Generally saying, this kind of problem might relate to many things like cavity shape, fabrication, surface treatment, cleaning, cavity assembly, evacuation, cavity mounting in vertical test system, and so on. Our facility at AR east 2nd experimental hall in KEK has been qualified in single cell cavity study. We suspect first whether there would be problems with 9-cell cavity in the traditional procedure established for single cell cavity study. Field emission couples easily with particle contamination. So we start from this issue. First we investigate all the processes from HPR up to 9-cell cavity evacuation system using particle counter (RION KC-21A). If we find out a problem, we will take cure individually. Finally the all cure procedure is applied to single cell cavities and 9-cell cavities in order to confirm whether the cavity performance is improved.

INVESTIGATION

Environment of HPR Room

At first we investigated the particle environment in our HPR room. The result is shown in Fig.2. The particle distribution was 0.5(0.1-0.15 μ m), 2.0(0.15-2.0 μ m), 0(0.2-0.3 μ m), 1.5 (0.3-0.3 μ m), and 6 (>0.5 μ m) pieces per 10L. The total number of particles larger than 0.1 μ m size is 10 counts per 10L, that corresponds to class3 in ISO standard and Class100 with Fed.Std.209D in USA. The design of the HPR room was class1000 (Fed.Std.). Our design philosophy of HPR is to isolate the cavity inside and outside. Cavity is mounted in a cleaner box with Class10 (Fed.Std.) and done HPR in better environment. However, in this measurement we found some particles enter the cavity through the bottom opening. To make perfect the isolation, we modified the system to introduce clean air into cavity inside. This modification is so excellent. Even we open entrance door of the HPR room, no particles are counted in the cavity during HPR.

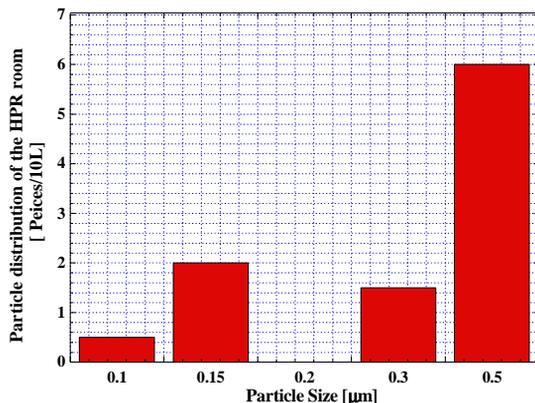


Figure 2: Particle measurement in our HPR room.

HPR Process

- Our HPR process consists of following steps:
- 1) Set cavity in the class10 clean box,
 - 2) Open the valve at the bottom beam cavity pipe,
 - 3) Move up (~1300mm) this box by motor diving,,
 - 4) Turn 90⁰,
 - 5) Move down (~1300mm) into the HPR box standing a nozzle
 - 6) Start to flow clean air,
 - 7) Start HPR (cavity is rotated and the box is moved up/down),
 - 8) Stop HPR,
 - 9) Stop the clean air,
 - 10) Move up and Turn back 90⁰ and Move down
 - 11) Close the bottom valve,
 - 12) Take out the cavity from Clean box.

We measured how many particles come into the cavity during these steps. The results are presented in Fig.3 for single cell cavity and Fig.4 for 9-cell cavity. Four tests results are presented in the single cell cavity tests. The averaged results of eight tests are presented for 9-cell cavity tests. In Fig.3, "Fujikin valve open" means to start clean air flowing. In the single cavity case, many particles come during moving down the cavity, but they are purged out by the clean air flowing. After the HPR, little particles come into the cavity. On

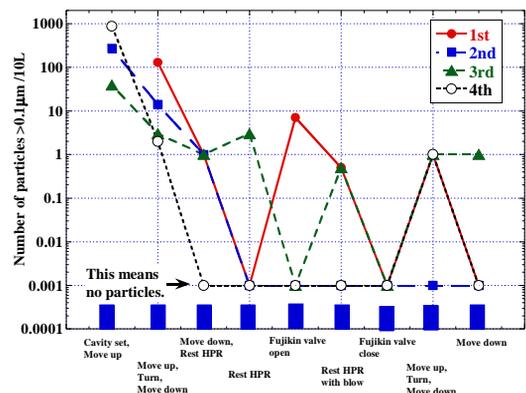


Figure 3: Particle count measurement for HPR steps with single cell cavity.

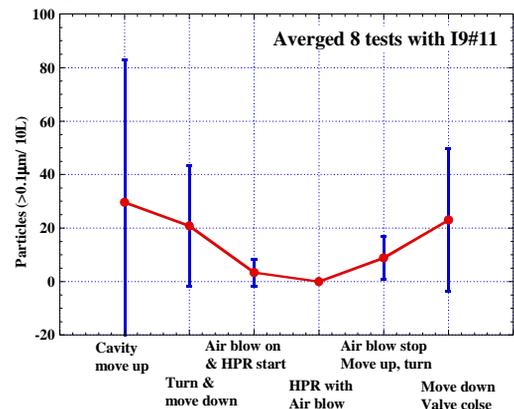


Figure 4: Particle count measurement for HPR steps with 9-cell cavity.



Figure 5: Window at the clean box to access the bottom valve.

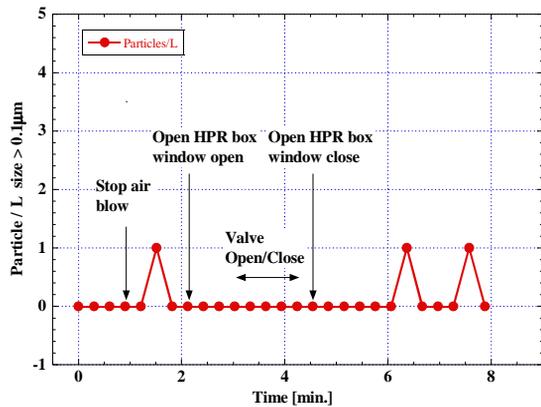


Figure 6: Particle occurrence during the bottom valve operation through the small window at the clean box.

the other hand many particles come into the cavity in the step moving up/down after HPR. This is a big difference between single cell cavity and 9-cell cavity. These particles might come from the support jig of the 9-cell cavity. In the single cell cavity, naked cavity is mounted in the clean box, so dusts might be little.

To stop the particle contamination perfectly during taking out 9-cell cavity steps, small window was attached on the clean box in order to close the bottom valve at HPR position as seen in Fig.5. Initially we worried about coming particles through this window for the HPR room. We tested the valve operation using a 9-cell cavity and found no particles come into the cavity (Fig.6).



Figure 7: Particle count measurement in the cavity assembly area.

Cavity Assembly Area

In the past, we have checked the particle environment in the class10 cavity assembly area. This time we re-checked it again. Tube head of the particle counter was put in a single cell cavity or 9-cell cavity sitting in the cavity assembly area as seen in Fig.7. Particle count

measurement took place for 2hr. The total volume of the 340L air was measured. No particles larger than 0.1µm were observed in the particle counter. Our cavity assembly area is very clean and no responsibility for the bad cavity performance.

Cavity Assembly Procedure

Particle occurrence during cavity assembly was investigated using single cell cavity with MO sealing. In our traditional cavity assembly method, we were not so much careful about particle contamination from bolts and nuts. We have used aluminum alloy bolts, stainless nuts, stainless washer and copper gaskets for MO cavities, and stainless bolts, stainless nuts, stainless washers and indium seal for our other standard cavities. We have re-used these without any cleaning. Fig.8 shows the particles counted inside of the cavity closed to the top flange on a MO cavity by our traditional cavity assembly. 240 particles were counted totally. Lots of particles come into the cavity especially during bolt tightening. However, this measurement might make over estimation because the particle counter breaths air to analyze particles but no air breathing happens in real cavity assembly. Anyway we really learned many particle occurrences in our traditional cavity assembly.

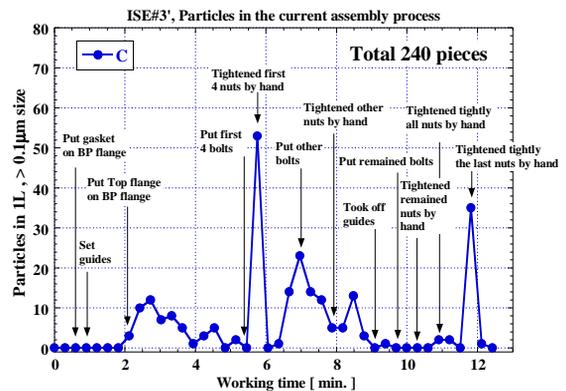


Figure 8: Particle occurrence during our traditional cavity assembly method.

We investigated ultrasonic cleaning effect of the bolts/nuts/washers before using for cavity assembly. The result is presented in Fig.9. The total number of particles reduced to 32 pieces from 240 pieces in none cleaned case. Cleaning of the bolts, nuts and washer is very effective to protect the particle contamination in cavity contamination but is not perfect yet.

Clamping of MO seal gasket was investigated as seen in Fig.10. MO seal uses a 1.5 mm thick copper gasket of 90 mm inner/110 mm outer diameters. This gasket could twist a little due to the remained stress. When we put the gasket on the MO flange, small gap could be made between the gasket and flanges. Particles could enter the cavity through this gap in the

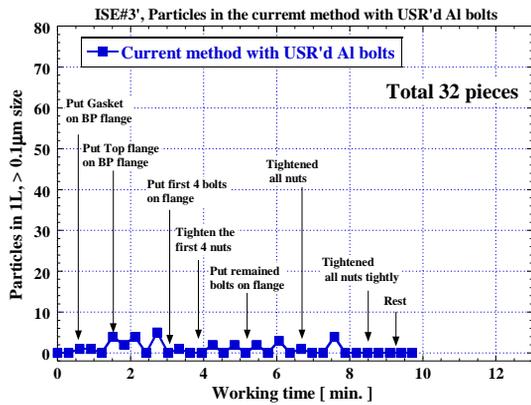


Figure 9: Ultrasonic cleaning effect of bolts, nuts and washers before use.

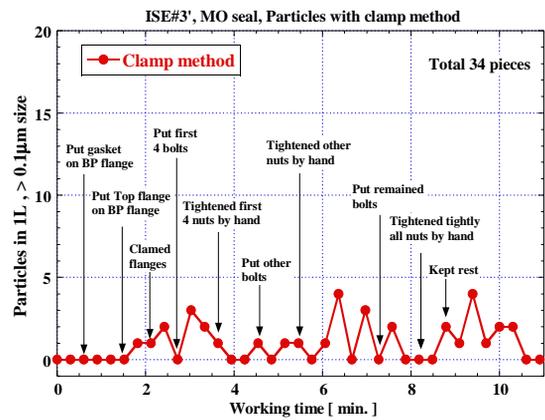


Figure 11: Clamping effect of the MO flanges.



Figure 10: Clamping of the MO flanges.

early stage of bolt tightening. Clamping the flanges before starting bolt tightening might be effective to reduce the gap. The result of clamping test is shown in Fig.11. The total number of particles reduced to 34 pieces. Clamping is very effective for MO seal but not perfect yet.

Bolt material dependence of the particle contamination was investigated on aluminum alloy and stainless. We often use aluminum alloy bolts for MO seal. MO sealed cavity often suffered from field emission problem. It is might relate to the particle contamination from aluminum bolts. In this investigation we assembled the MO top flange using aluminum alloy bolts or stainless ones for individual test.

Particles are measured at inside of cavity close to the MO seal. Bolts were not cleaned before use. The result is shown in Fig.12. It is seen aluminum alloy bolt produces more particles (about a factor 2) than stainless bolt.

In Fig.12, the result of clean air flow is also presented on aluminum alloy bolts. In this test, clean air was flowed during bolt tightening and pressurized a little.

It suggests a perfect cure against the particle contamination in cavity assembly.

Effect of the clean air flow was investigated in more detail. Clean air through a final filter at use-point was

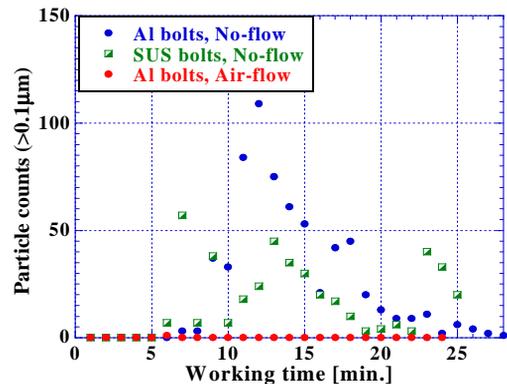


Figure 12: Bolt material dependence of particle contamination.



Figure 13: Cavity assembly using clean air flow.

introduced the cavity as seen in Fig.13. Mesh size of the filter is 0.03µm. The air is flowed for a few minutes after connecting the filter to input coupler port

Table 1: Effect of clean air flow

Worker	Traditional method with Al alloy bolts	Traditional method with stainless bolts	Clean air flow with Al alloy bolts
A	698 (In seal)	73 (In seal)	0 (MO Cu)
B	575 (MO Cu)	333 (MO Cu)	7 (MO Cu)
C	2239 (MO Cu)	424 MO (Cu)	1 (MO Cu)
D	123 (In seal)	27 (In seal)	7 (MO Cu)

in order to purge particles. Top flange was mounted on the cavity flange with our indium sealing (standard cavity) or with MO copper gasket sealing. Particles were measured at inside of the cavity close to the Top flange. The test results are summarized in Table 1.

Four workers tested. For instance, worker A measured particles during traditional assembly of the standard cavity with indium seal (In wire of 0.8mm diameter) using aluminum alloy bolts. The total number of the particles bigger than 0.1µm was 698 pieces. Secondly he assembled the same cavity again using stainless bolts, then the total number of particles was 73 pieces. Finally he assembled the MO cavity with copper gasket using aluminum alloy bolts, and then the total number of particles was zero. Other workers B, C and D also tested in the same way. Lot of particles was measured in our traditional cavity assembly method for both standard and MO seal cavities. The number is scattered among workers. On the other hand, the number of particles is less than 10 pieces and does not depend on worker if the clean air flow assembly is used.

Vacuum Evacuation

So far we have not so concerned about cavity evacuation. In our standard evacuation method, after connecting cavity on evacuation station, evacuation is started quickly and the vacuum pressure becomes lower than 1E-2 Pa within 5 minutes (fast evacuation). Dr. R. Geng has pointed the importance of slow evacuation in the KEK/Jlab collaboration for I9#5 and I9#7 S0 tight loop study [2]. We added slow evacuation line in our vacuum evacuation stand for 9-cell cavity as seen in Fig.14 in order to investigate effect of the slow evacuation (single cell cavity is drawn instead of 9-cell cavity in this figure). Particle is measured at the inside of cavity close to input port as seen in Fig.14.

The first finding in this investigation is vacuum valve operation produces lots of particles. The measurement results are summarized in Table 2. The valve number in Table 2 corresponds to the valve location in Fig.14. Result depends on the location in this measurement. Particle counter is much sensitive for the input coupler valve (1) because the particle

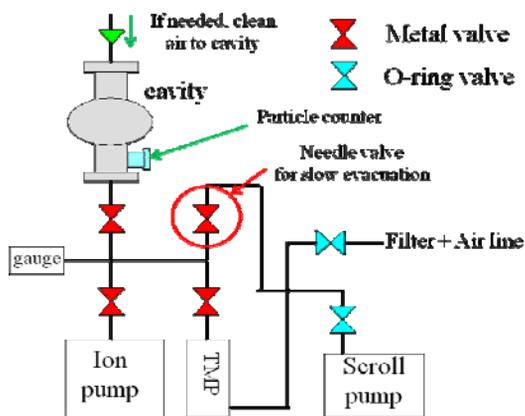


Figure 14: Valve location and added slow evacuation line.

Table 2: Particle from valve operation

Location	Averaged number of particle (>0.1µm)	Max.	Min.
(1) Input coupler metal valve	15.4	22	1
Input coupler bellows push/pull	1.6	3	0
(2) Turbo head metal valve	7.2	17	1
(3) Scroll valve	13.2	33	0
(4) Slow evacuation valve	3.4	7	0
(5) Needle valve	14.2	29	3

counter's breath head locates closest position. The number itself has not so important meaning but we leaned valve operation generates the lots of particle contamination. Input coupler valve operation must be careful not to introduce particles into the cavity. We measured particles came in cavity at the input coupler valve opening under a vacuum pressure in the evacuation line. The result is summarized on the middle column in Table 3. No particles come in the cavity if we open the valve at a lower pressure in the evacuation line than that of cavity inside.

Table 3: Particles produced at the input coupler operation

Opened the input coupler metal valve(1) at a vacuum pressure of the evacuation line		Opened the scroll top valve(3) suddenly at a vacuum pressure of the cavity
Vacuum pressure [mbarr]	Particles > 0.1µm	Particles > 0.1µm
710	0	9
650	0	11
500	0	2
6.1E-2	0	7

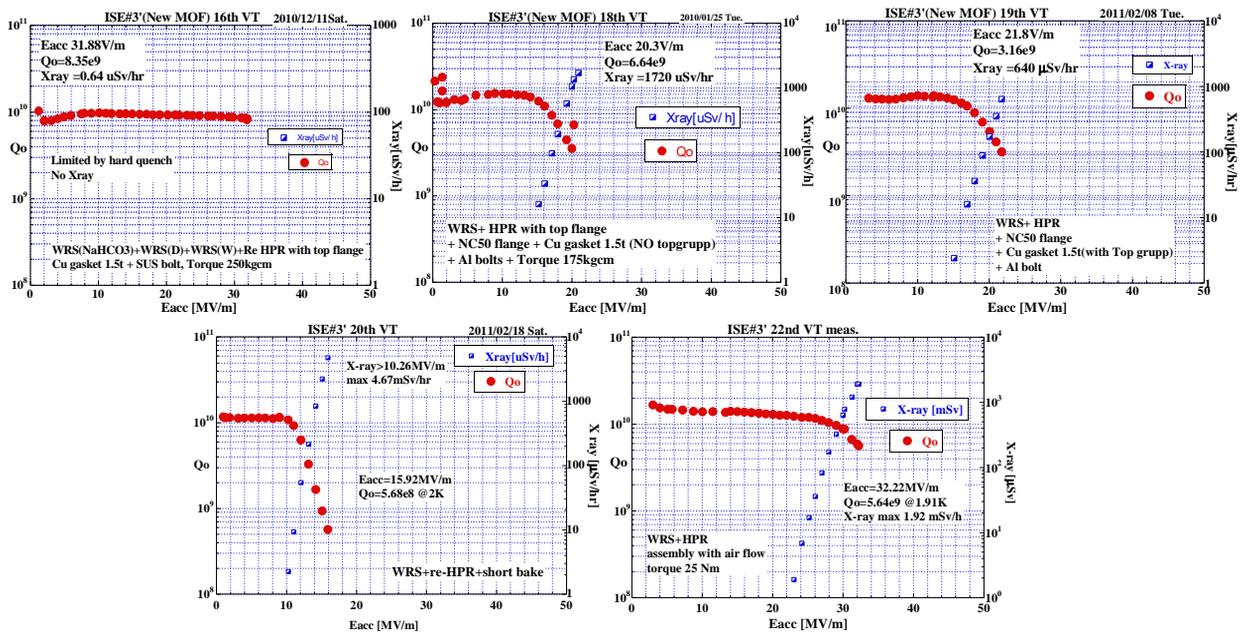


Figure 15: Cavity performance history of a single cell cavity (ISE#3' with MO seal) and performance change by the new improved procedure.

Secondly we investigated particle production by turbulence to simulate fast evacuation. The result is summarized on the right column in Table 3.

In this experiment, the evacuation line including cavity was kept at an under pressure, then the valve (3) at the scroll pump was suddenly opened. The fast valve operation would produce turbulence at the cavity, and then particle could enter the cavity. Really we detected particles at the cavity input port. We learned fast opening of the scroll valve produces particles. Slow evacuation can reduce this risk as Dr. R. Geng pointed. in the 2nd and 3rd tests

CAVITY PERFORMANCE BY IMPROVED

We took all cures mentioned above and treated a MO seal single cell cavity and a 9-cell cavity with all indium seal. Slow evacuation took place for the 9-cell cavity but none for the single cell cavity.

Single Cell Cavity Result

Single cell cavity result is presented in Fig.15 (in the last page in this paper) with previous results to see how the change happened in the cavity performance trend. MO sealed single cell cavity (ISE#3') also suffered from field emission problem since last January 2011. In the last test (ISE#3' 22nd meas.), this cavity was ultrasonic rinsed (WRS), taken HPR, dried for one hour in class 10 clean-room similar as standard procedure. Subsequently it was assemble using clean air flow method and vacuum evacuated by fast evacuation. The result was changed clearly by this new procedure. Still field emission is seen but it should be emphasized X-ray onset was pushed up to 23MV/m.

9-Cell Cavity Result

As mentioned already, I9#11 cavity is made of large grain material. It is fabricated by all inner EBW method which is different from our all other 9-cell cavities. CBP did not take place for this cavity prior to bulk horizontal BCP because the EBW seam should be good. In the I9#11 4th test, it was removed by 80µm additionally and totally 140µm by horizontal BCP which can remove equally each cell. It tested by the traditional procedure (I9#11 4th VT). Subsequently it was re-rinsed by HPR. In this HPR end groups were rinsed more carefully. After drying for one night in the class10 clean-room, it was assembled with clean air flow method. Slow evacuation took place in the vacuum evacuation.

The result is presented in Fig.16. One can notice the clear change in the cavity performance when the result is compared with results in Fig.1. It has to be

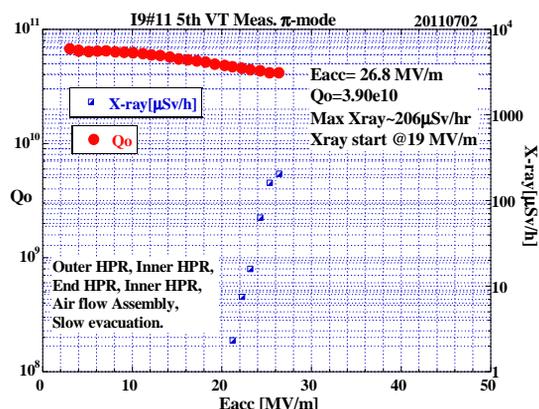


Figure 16: Cavity performance of 9-cell cavity treated by the new improved procedure.

emphasized that X-ray onset was pushed up to 20MV/m from 10-15 MV/m in the previous results. The gradient was limited at 26.8MV/m by hard quench. The clean air flow and slow evacuation could contribute to reduce the particle contamination problem and push up the X-ray onset.

SUMMARY

We suffered from field emission problem in last half of year. We investigated our facility from particle contamination point of view. We found out environment particles enter cavity during our HPR process. We cured this problem by clean air flow during HPR and quick closing bottom valve at HPR position in order to isolate perfectly the cavity inside from the environment.

We found out our traditional cavity assembly method has a big risk on particle contamination from bolts and nuts. We solved this problem by clean air flow method. It has to be emphasized that this method is very simple and the effect is less worker dependent.

Our evacuation system also has a particle contamination at valve operation. We fixed this problem by careful valve operation or slow evacuation.

After taking all cures for such problems, we treated a single cell cavity and a 9-cell cavity by new improved procedure. As the results, X-ray onset was pushed up to 20MV/m from 10-15 MV/m in both single cell and 9-cell cavities. Field emission is also reduced remarkably. We believe these cures should contribute to improved cavity performance. We are planning to see the reproducibility in cavity performance by this improved procedure.

REFERENCES

- [1] F. Furuta et al. "High gradient results of Ichiro 9-cell cavity in collaboration with KEK and Jlab", TUPO014, SRF2011, Chicago, IL.
- [2] R. L. Geng, Private communication.