Test results of electro-polishing for quarter-wave resonators

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TESLA TECHNOLOGY TTC COLLABORATION

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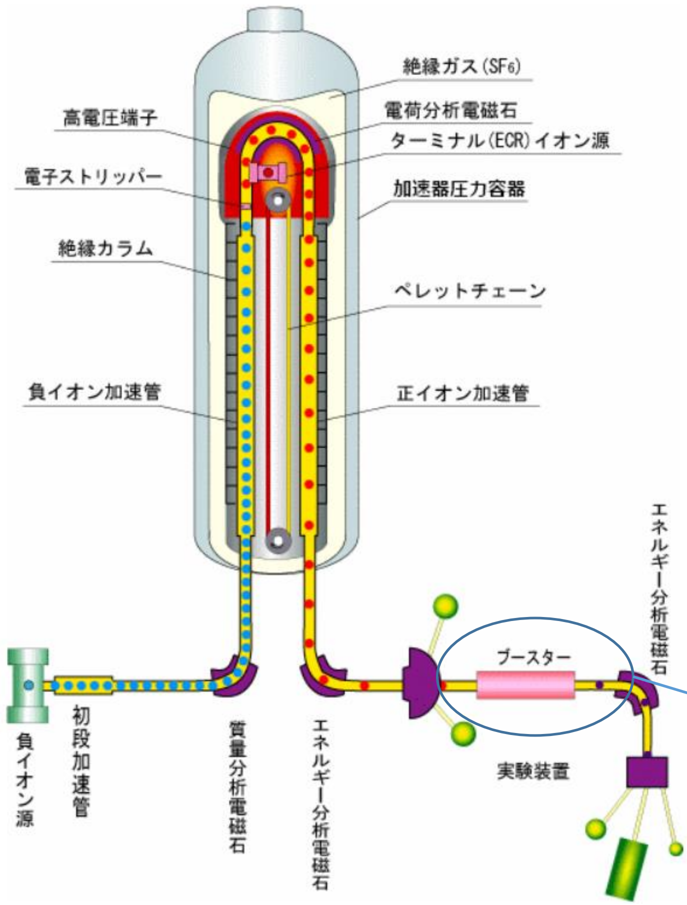


Tokai Tandem Accelerator

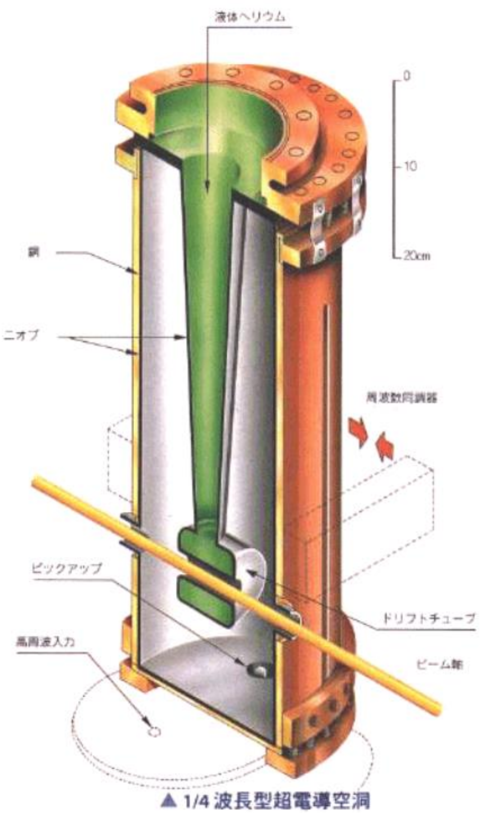
ttps://ttandem.jaea.go.jp/index.html

Tokai Tandem Accelerator of JAEA

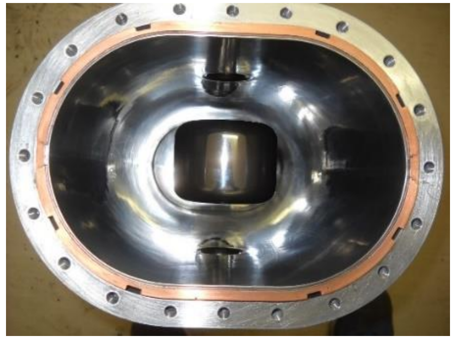
Superconducting booster

At the Tokai Tandem Accelerator of JAEA, research on nuclear physics, nuclear chemistry, material irradiation, etc. using heavy ion beams is being conducted. A superconducting booster has been installed in the latter part of the tandem to increase the beam energy by 2 to 3 times, but it has been out of service for a long time. The specifications of this superconducting booster are model = coaxial 1/4 wavelength resonator (QWR), frequency is 130MHz, optimum beam velocity = 10% of the light velocity, and acceleration electric field = 5.0MV / m @ 4W.

1-2 Quarter-wave resonators (QWR)



Quarter wave resonators
（Outside：copper
Inside：Niobium）



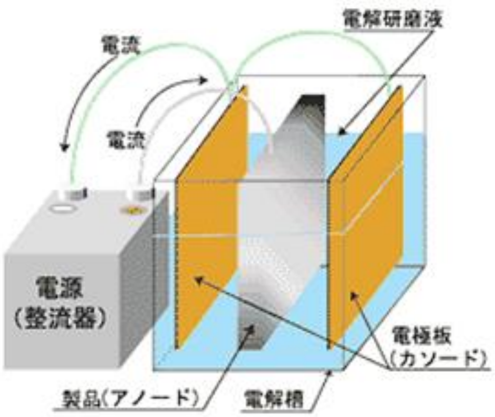
A spare cavity used for experiments (L42)

Currently, we are working on restarting, and we are considering electro-polishing of the preliminary superconducting cavity in preparation for conducting various tests. This cavity is made of a niobium-copper clad plate and has a large opening at the bottom, which allows it to be electro-polished again.

Marui Galvanizing Co., Ltd. and Japan Atomic Energy Agency jointly examined the equipment and conditions for 1/4 wavelength type superconducting cavity inner surface electro-polishing, conducted electro-polishing, and evaluated the surface and cavity performance after polishing.

1-3 What about electro-polishing (EP) ?

General method of EP（schematics）



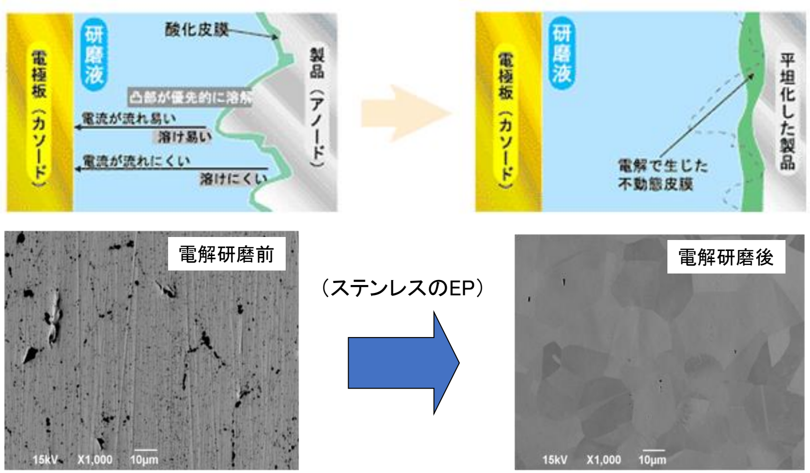
（Electro-polishing, EP for short）

A technology that dissolves and polishes the metal surface by electrolyzing the object (metal to be polished) as the anode in an electrolytic solution with a counter electrode (cathode).
Improves surface flatness, corrosion resistance, and cleanliness.

General reaction of EP

Anode : $M \rightarrow M^{n+} + ne^-$
$H_2O \rightarrow 1/2O_2 + 2H + 2e^-$
Cathode : $2H^+ + 2e^- \rightarrow H_2$
$M^{n+} + ne^- \rightarrow M$
（M:polished metal, n:atomic value）

How EP progresses（schematics）



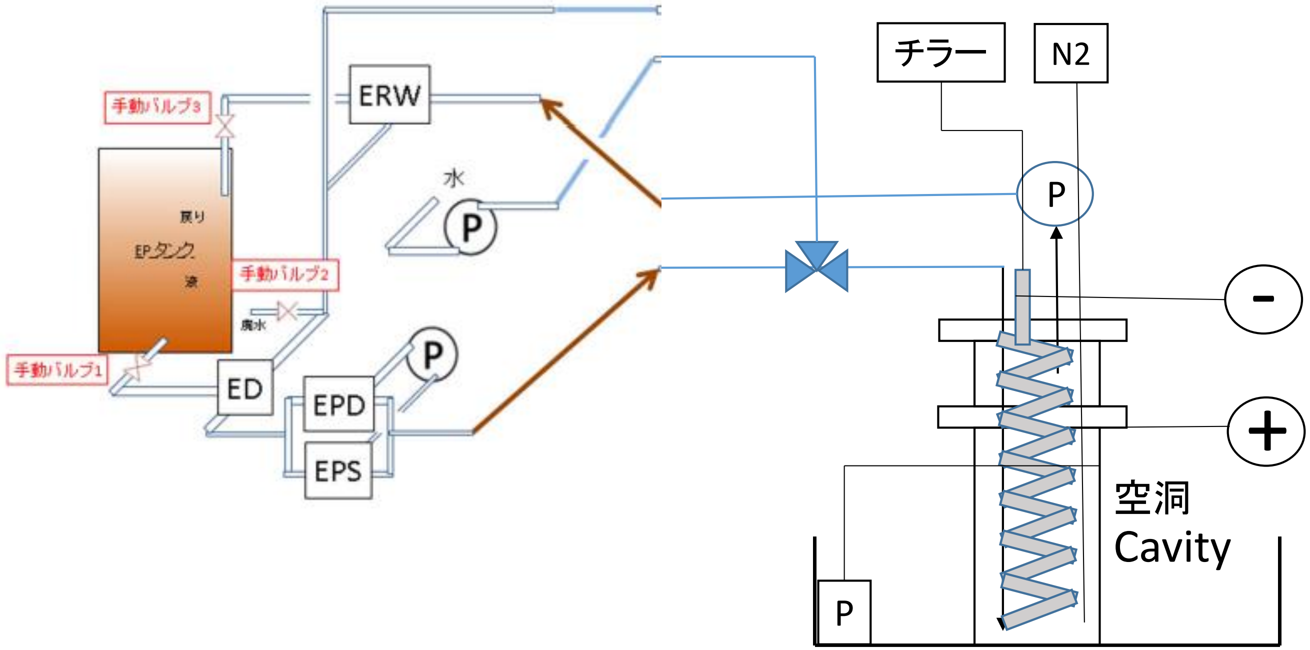
Since the protruding part of the product is close to the cathode, electricity flows easily and it melts easily.
Since the amount of melting is proportional to the amount of electricity, the convex portion melts preferentially.
As a result, the unevenness gradually disappears and the surface becomes flat.

Niobium cavity EP

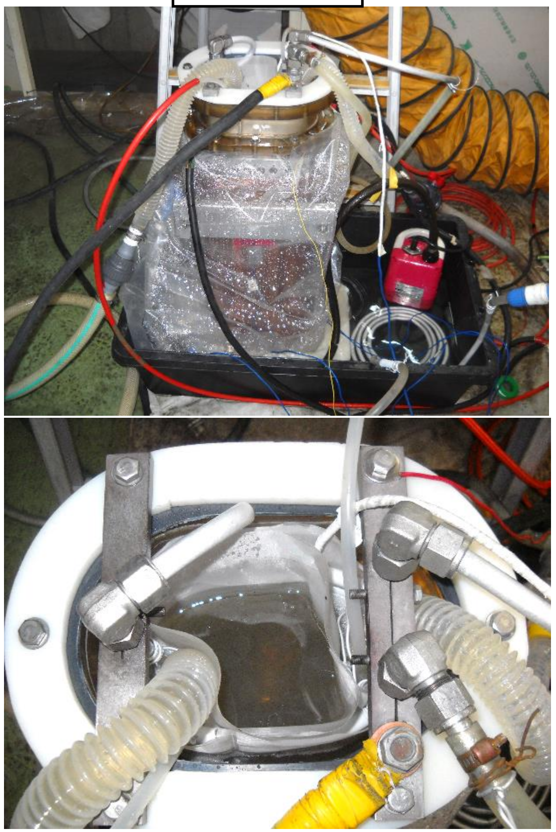
In 1.3GHz niobium superconducting cavities, electro-polishing is applied to the inner surface to improve cavity performance.

1-4 EP setup of QWRs

A schematic of EP setup



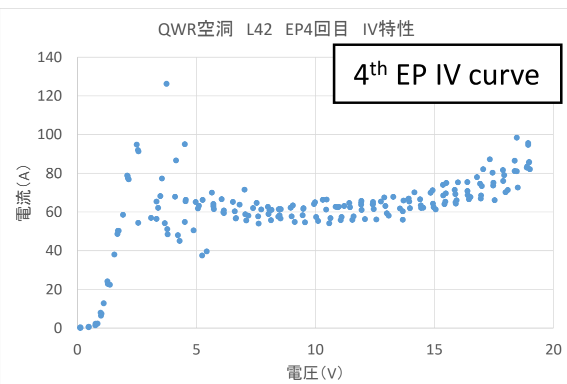
EP setup

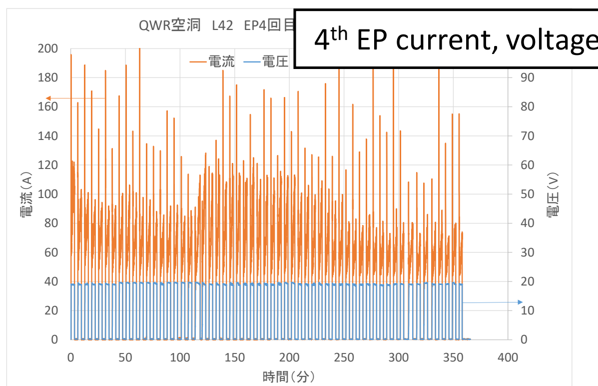


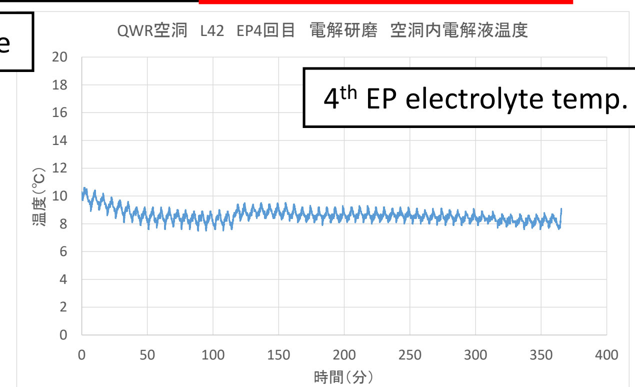
- Place the cavity with the opening facing up. Electrodes and electrolyte hoses were inserted through the openings.
- The electrolyte was circulated by a pump.
  (Injected into the bottom of the cavity, recovered from the top)
- Cavity cooling by cooling water shower using vat and submersible pump
- There were no serious problems with the EP implementation.

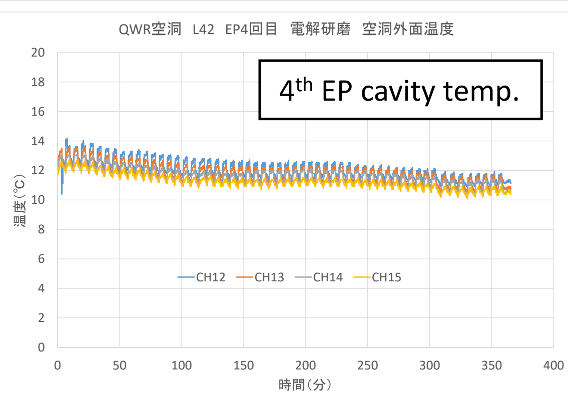
2-1 EP parameters and logged data

	1st EP	2nd EP	3rd EP	4th EP
Electrolyte	H_2SO_4(98%):HF(55%) =9:1(USED)	H_2SO_4(98%):HF(55%) =9:1(NEW)	H_2SO_4(98%):HF(55%) =9:1(USED)	H_2SO_4(98%):HF(55%) =9:1(NEW)
Voltage	～18V	～20V	～20V	～20V
Voltage apply	Continuous	3min-ON/3min-OFF	Continuous	3min-ON/3min-OFF
Cavity cooling	None	Done	Done	Done
N_2 bubbling	None	Done	Done	Done
Target removal	30µm	20µm	25µm	25µm







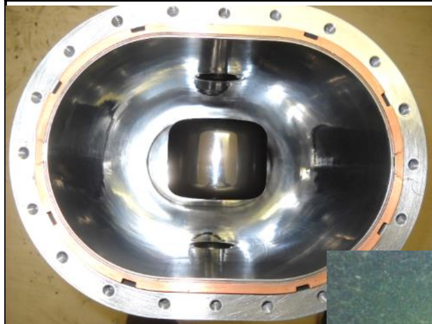
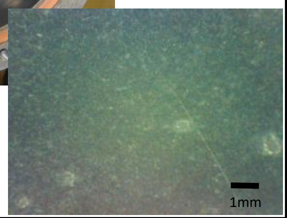
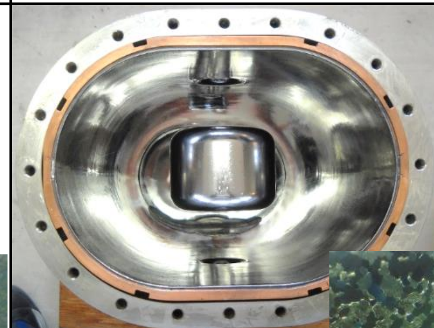
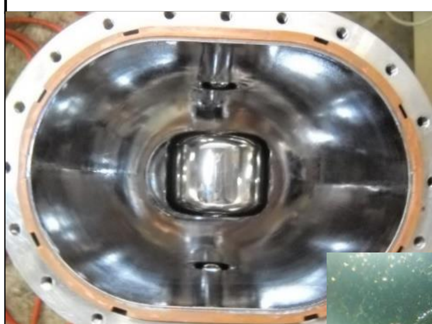
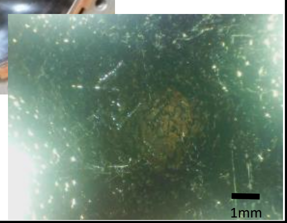
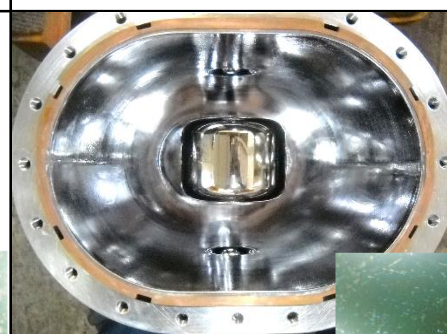


- 4 times EP (total removal 100µm) were performed using one cavity (L42).
- The logged data of 4th EP is shown.
  In IV curve, plateau region was shown around >5V.
  Cavity temperature was around 10-14℃ using water cooling.
  Electrolyte temperature in the cavity was under 10 ℃ .
  EP current was around 80 A.

EP current, voltage, temperature were almost on target.

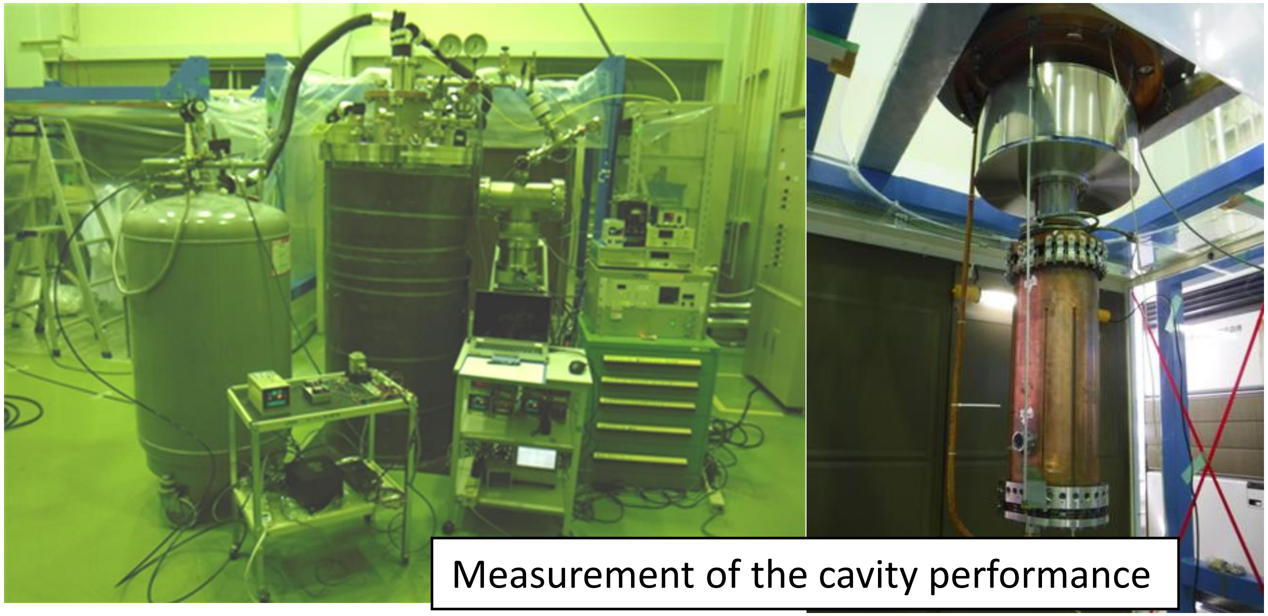
EP experiment (Phase 1)

2-2 Results of EP (surface inspection and roughness)

Before EP (Mechanical polish)	After 1st EP	After 2nd EP
  Ra＝0.11μm Rz＝1.21μm	  Ra＝0.67μm Rz＝3.40μm	  Ra＝0.48μm Rz＝2.53μm
After 3rd EP	**After 4th EP**	**A legend**
  Ra＝0.47μm Rz＝2.24μm	  Ra＝0.45μm Rz＝2.06μm	Digital camera photo Surface roughness（Average of 4 points） Microscope photo（×200）

- After 1st EP, the surface roughness became worse（It seems that the conditions were not optimized）.
- After 2nd – 4th EP, the surface roughness tended to improve (The conditions seem to have improved).
- After 4th EP, the surface became more glossy but roughness was larger than before EP.

2-3 Cavity performance measurement

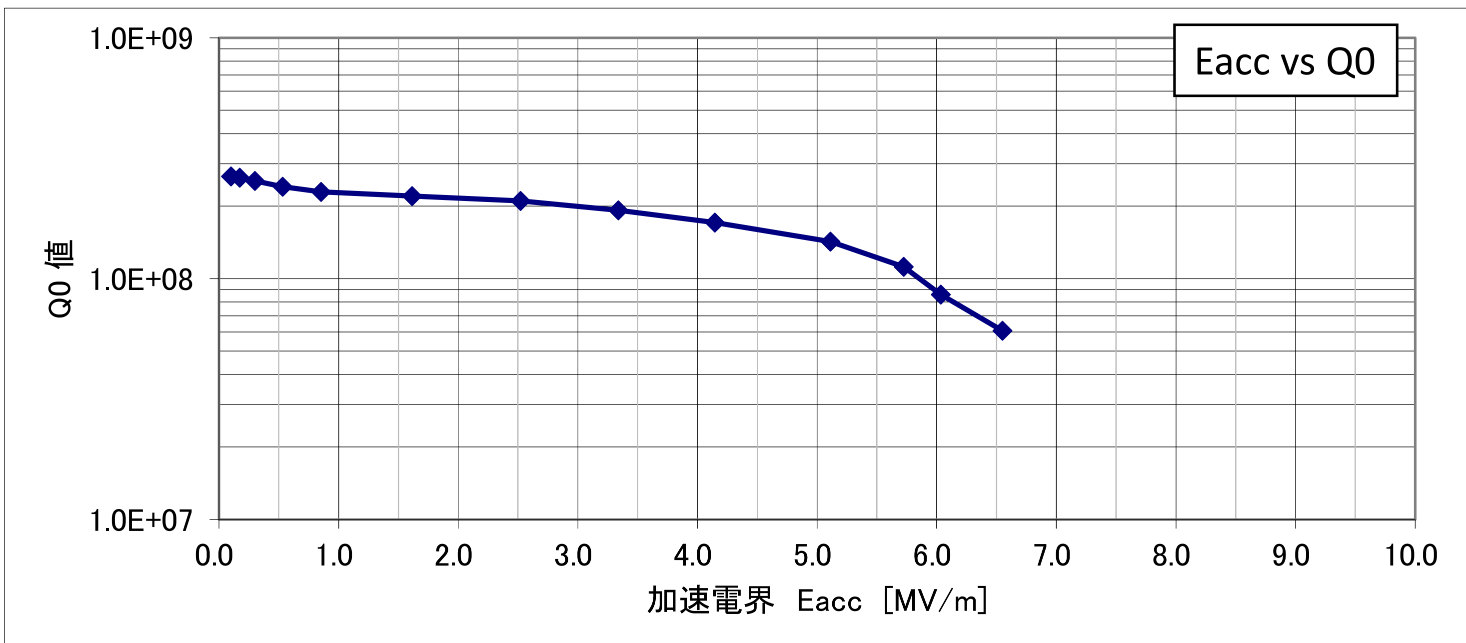


Measurement of the cavity performance

After Phase 1 EP, the cavity performance was measured at 4.2K.

Low electric field Q_0 value was 2.7E8 and the cavity performance was 4.2MV/m @4W

It did not reach the standard value（5.0MV/m＠4W）



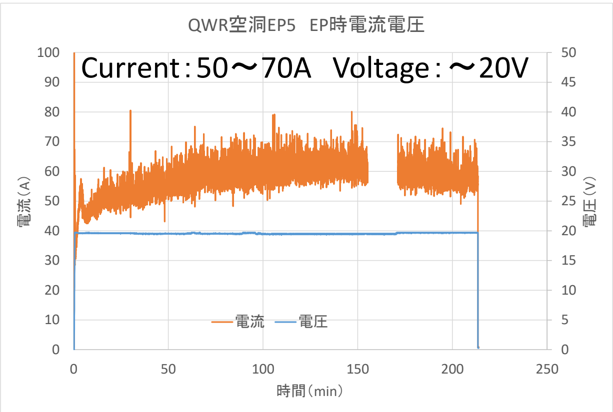
The main reason seems to be rough surface and high surface resistance.

It is necessary to review the EP conditions, electrodes, methods, etc.

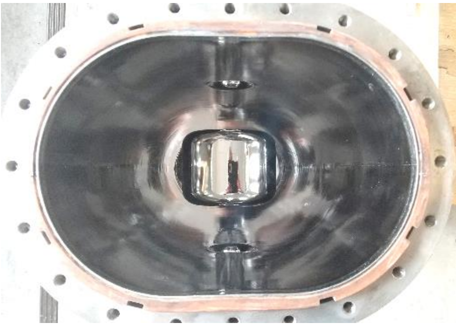
Phase 2 EP experiments

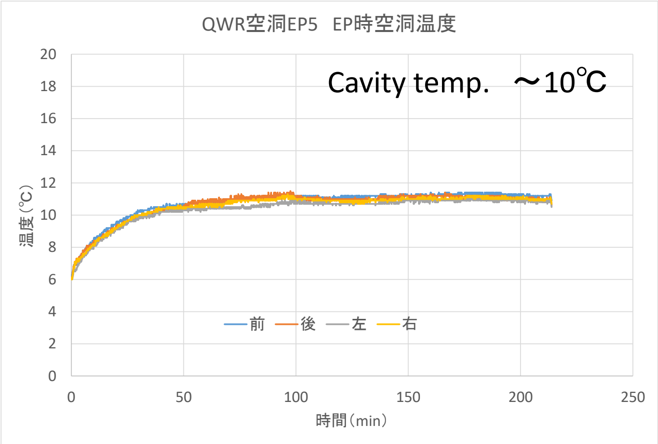
3-1 Cathode surface area increase

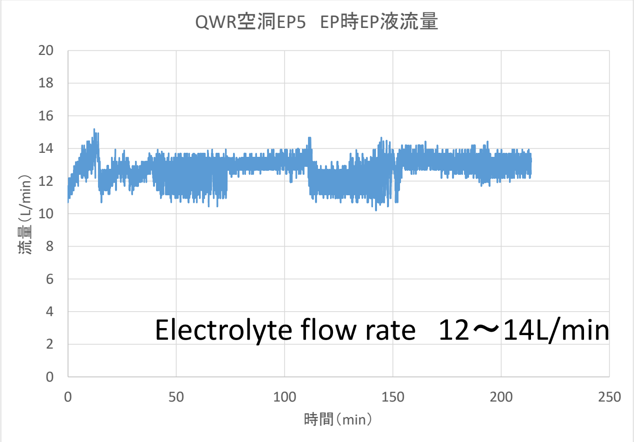
A schematic of electrode, auxiliary electrode



Inner surface after this EP







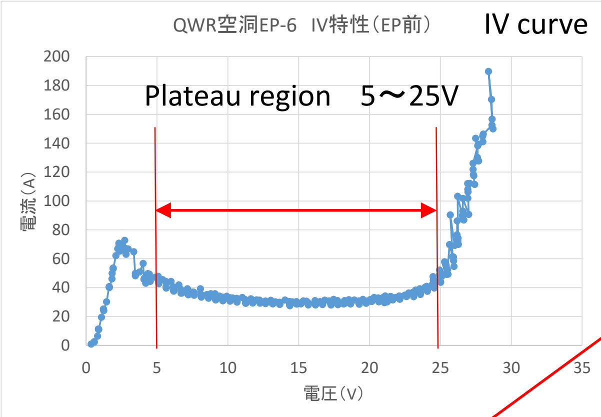
Average current comparison

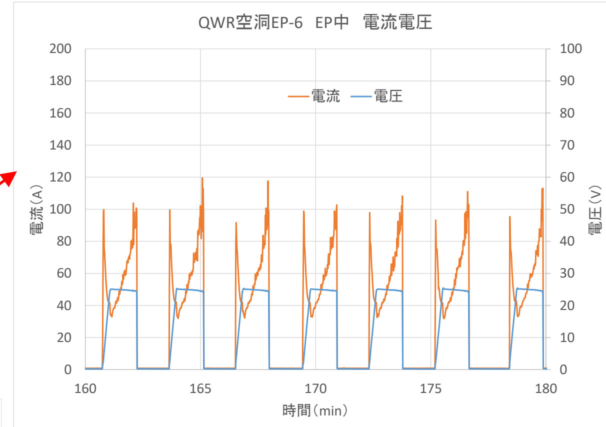
	Average current (ON)	Average cavity temperature	Average EP acid temperature	Voltage	Voltage application method	EP acid
Phase1 1st	125.4A	34.9℃	19.6℃	18V	Semi-continuous	USED
Phase1 2nd	47.4A	10.1℃	9.2℃	20V	Intermittent	NEW
Phase1 3rd	61.0A	12.1℃	11.1℃	20V	Continuous	USED
Phase1 4th	66.4A	11.5℃	8.6℃	20V	Intermittent	NEW
Phase2 1st (this EP)	57.3A	10.6℃	9.8℃	20V	Continuous	NEW

- An auxiliary electrode was added to the conventional electrode in order to increase the current density and improve the polished surface by increasing the cathode area. (Approx. 30% increase in electrode area, red line in the above schematic)
- No clear improvement was seen (details later).

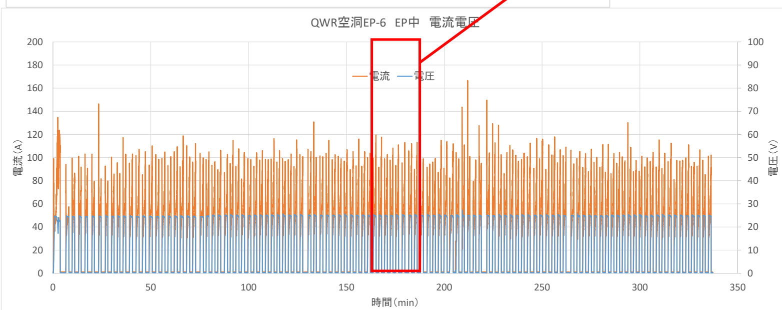
→There is no problem with the conventional electrode.

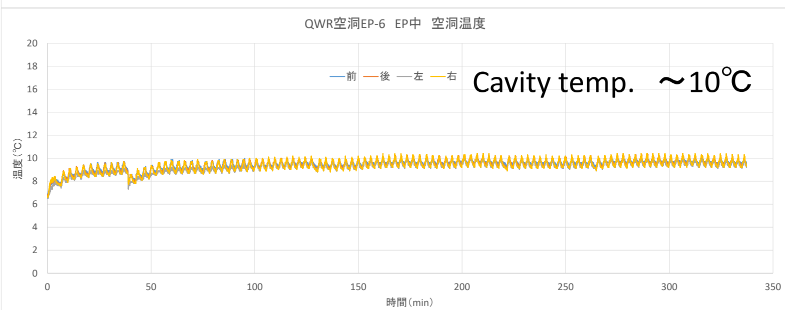
3-2 Applied voltage increase

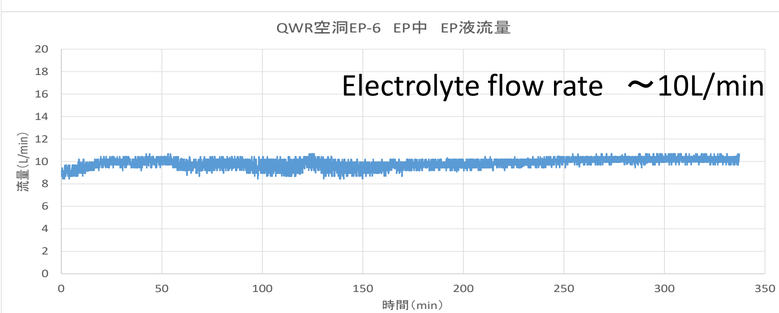




Current : 40〜100A
Voltage : 〜25V
1min-ON/1min-OFF







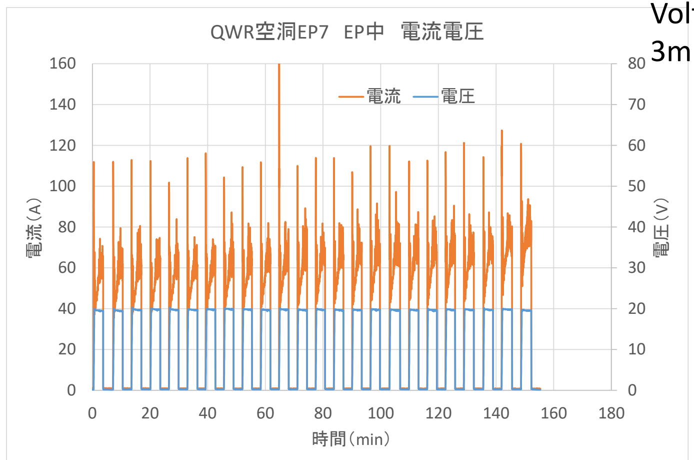
Inner surface after this EP

- To confirm the range of the plateau region, the IV characteristics were confirmed from 0 to 30V.
- An increase in current was observed from 25V in the IV curve.

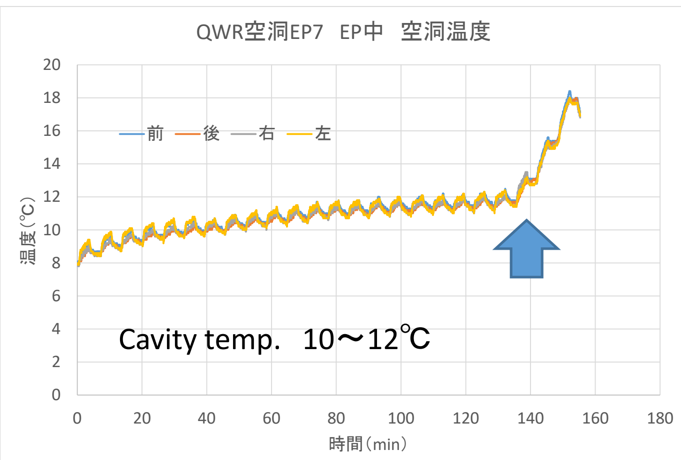
→5〜25 V is set as the plateau region from the shape of the curve and EP was performed at 25V that is the upper limit of the plateau.

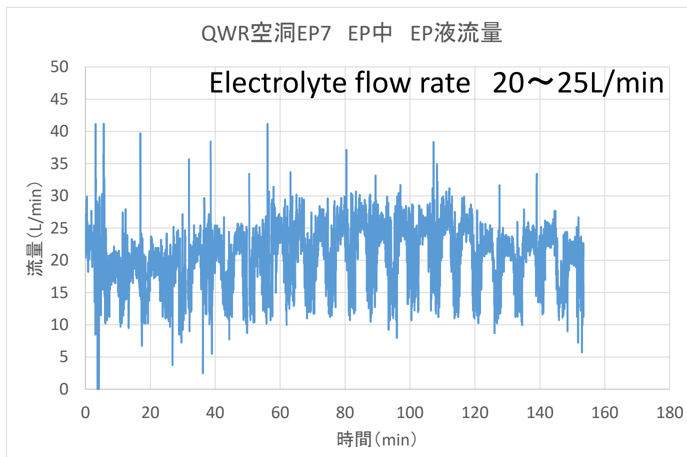
- No clear improvement was seen (details later).

→There is no problem with the conventional 20V.

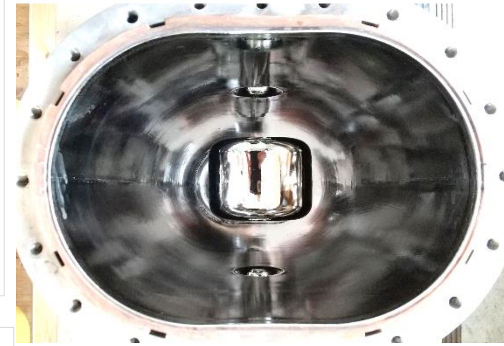


Current : 40〜80A
Voltage : 〜20V
3min-ON/3min-OFF





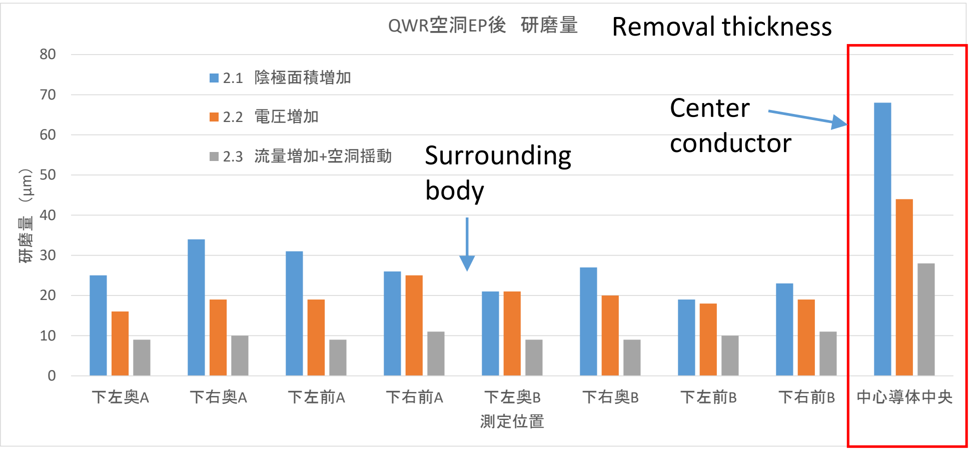
Inner surface after this EP

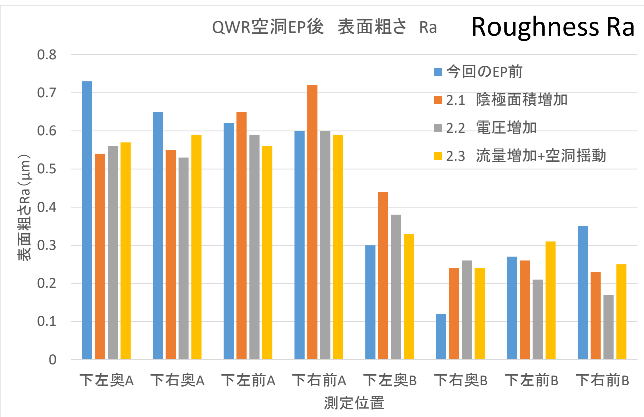


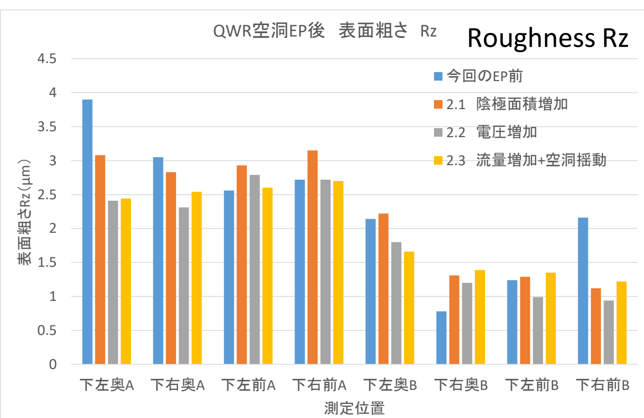
A hole in the center conductor

- Electrolyte flow rate was increased to 〜20L/min and it was shaken by shaking the cavity by hand to improve agitating effect during EP.
- EP was stopped due to temperature and odor abnormalities during EP. The cause was that the center conductor had a hole and the electrolyte was leaking into the cavity cooling water.

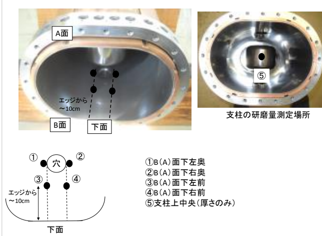
EP experiment (Phase 2)　3-4　Removal thickness, surface inspection and roughness



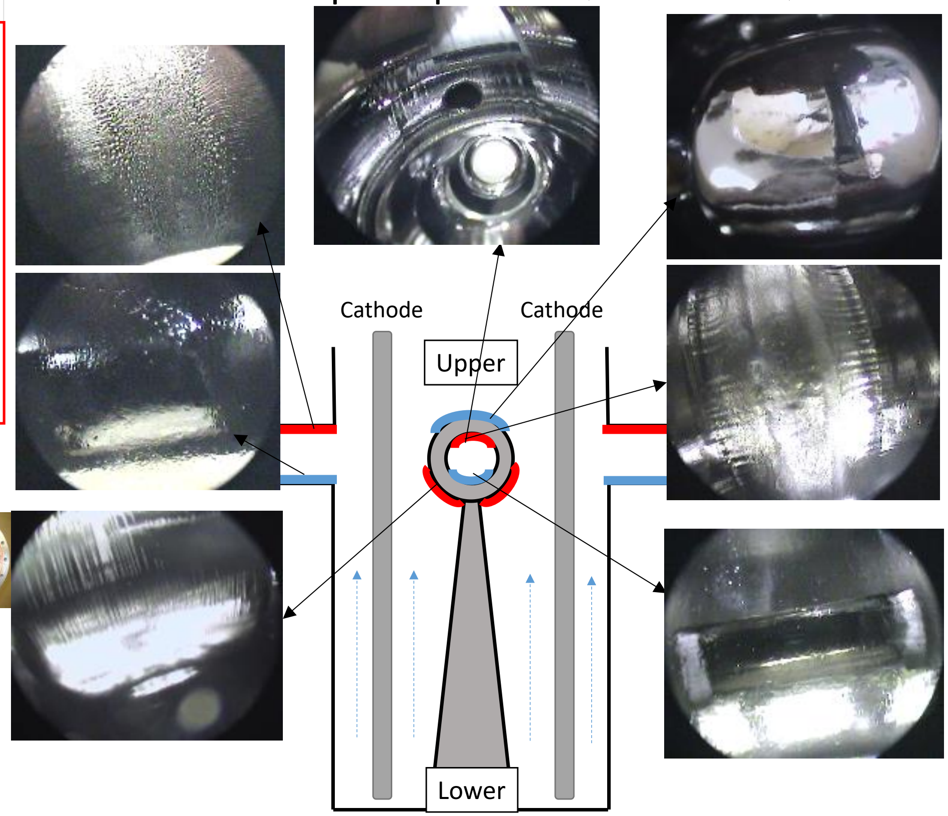




Measurement points



Endoscope inspection（After all EP）



Results of removal and roughness evaluation

- The removal thickness of center conductor is 2-3 times larger than that of body part.
- The surface roughness has no proper tendency and has not changed significantly in case of phase 2 EP.

Results of endoscope inspection

- Upward surfaces at EP (blue lines) were relatively flat and glossy.
- Downward surfaces at EP (red lines) were relatively rough and had bubble traces.

4 Summary and next step

▪The inner surface of the QWR (spare cavity) used for the superconducting booster of the Tokai tandem accelerator was re-polished by electro-polishing.

▪Electro-polishing (EP) set-up and operation could be carried out without serious problems.
A total of about 100 μm polishing was performed in Phase 1 experiments in four stages.

▪Compared to before electro-polishing (surface after mechanical polishing), the surface gloss seemed to be improved, but the surface roughness value became worse.

▪ As a result of the cavity performance measurement in liquid helium (4.2K), the performance was 4.2MV/m@4W with a Q0 value of 2.7E8 at a low electric field.
This did not reach the standard value (5.0MV/m@4W).

▪ Phase 2 experiments were conducted to improve the EP parameters.
Electrode area, voltage, and agitation were examined, but no significant improvement was observed.

▪The removal thickness of the center conductor was much larger than other parts,
and a hole was opened during the Phase 2 experiment.
No significant improvement in surface roughness was observed.

▪The upward surface at EP was glossy, but the downward surface was rough with bubble traces.

4 Summary and next step

Next step

It is necessary to…

- Suppress bubble diffusion and internal accumulation to improve inner surface.
- Investigate the cause of uneven removal and state of electrolysis.

for that purpose…

- Confirmation of cavity oscillation, electrolyte stirring and agitation effect
- Review of electrode shape and improvement of bubble cover
- Improvement of electrolyte flow method
- Optimization of voltage ON/OFF application conditions

Thank you for your attention.