Development for Mass-Production of Superconducting Cavity by MHI

ERL2015 “ERL and SRF, Stability, Synchronization, Special Requirements, HOM Dumping”

June 10. 2015

MITSUBISHI HEAVY INDUSTRIES, LTD.

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2. MHI's development histories for mass-production
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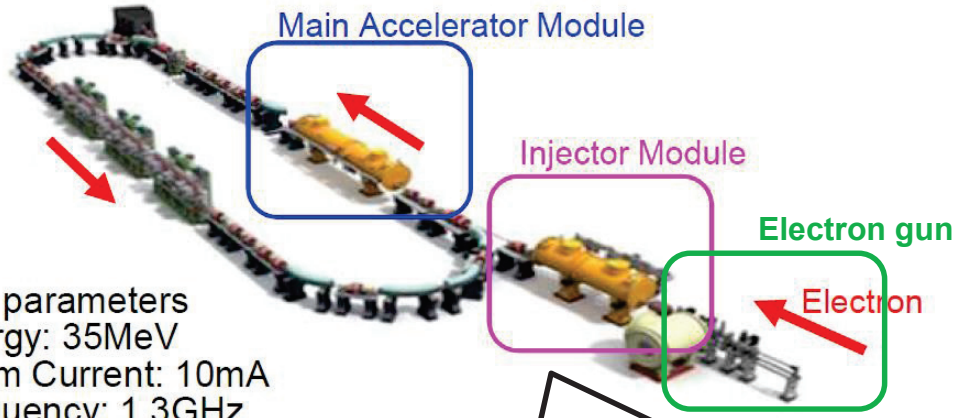
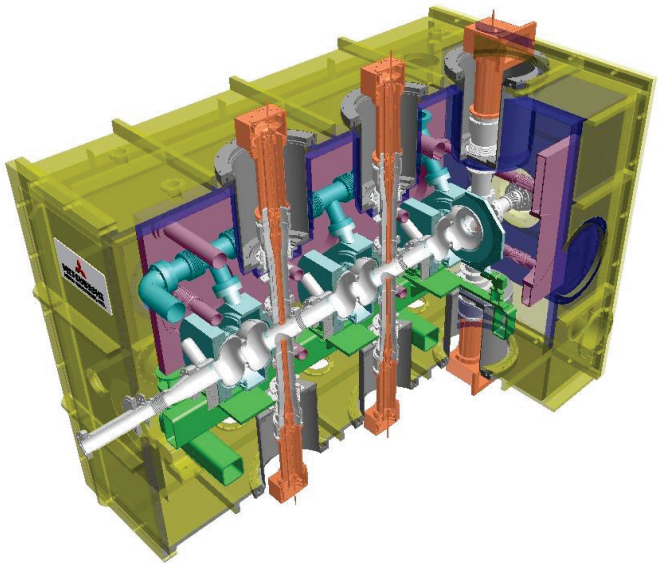
   - Reducing the number of parts
   - Batch Process
3. Summary

1. MHI's work for ERL (cERL Injector Module)



cERL parameters
- Energy: 35MeV
- Beam Current: 10mA
- Frequency: 1.3GHz

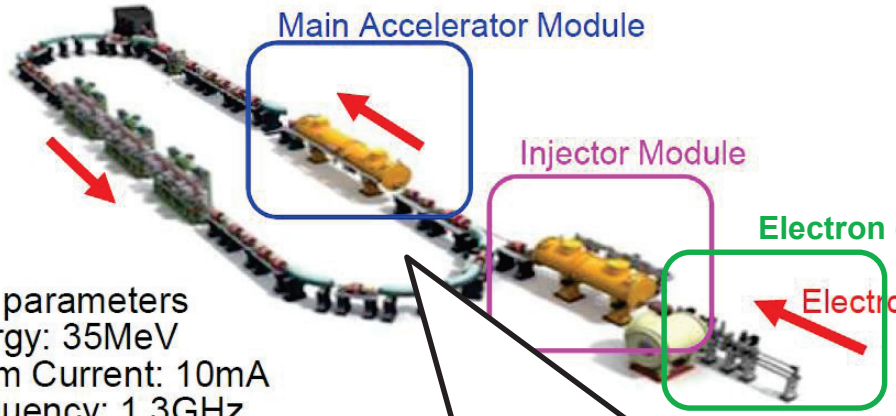


Injector Module（2-cell cavity × 3）

○This module conforms Japanese high pressure gas safety law

Assembly at KEK

1. MHI's work for ERL (cERL Main Accelerator Module)



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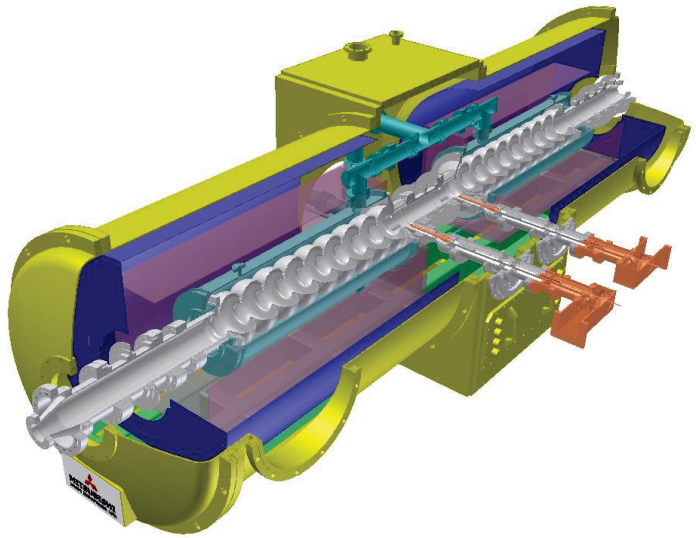
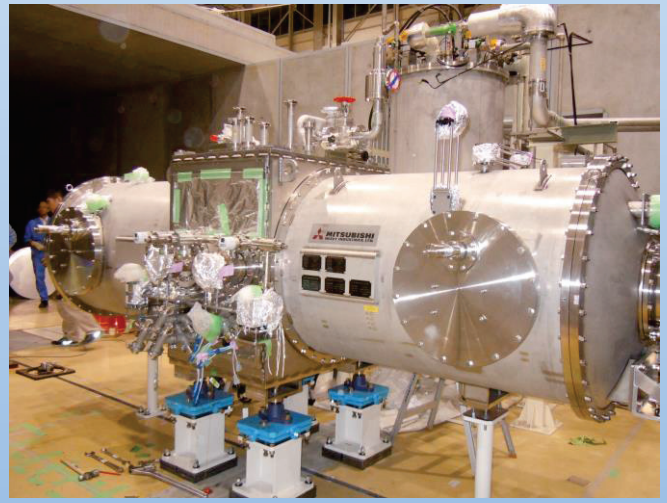


Main Accelerator Module（9-cell cavity × 2）

Assembly at KEK



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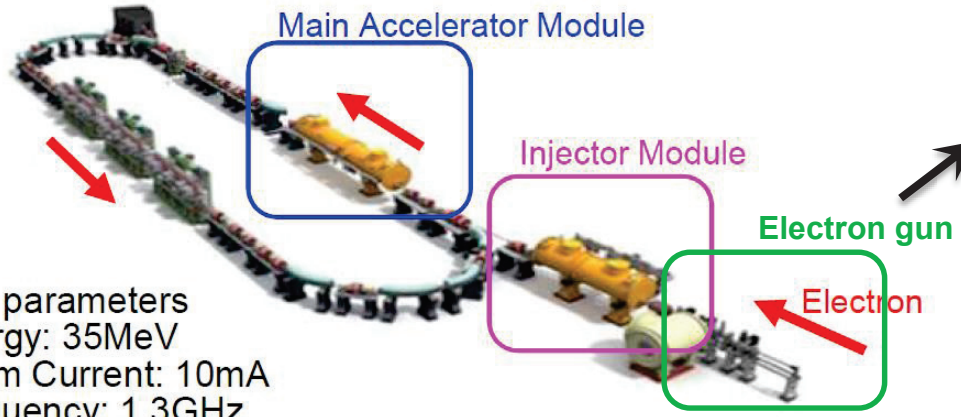
1. MHI's work for ERL (SRF Electron Gun)



cERL parameters
- Energy: 35MeV
- Beam Current: 10mA
- Frequency: 1.3GHz

■Present
・DC gun

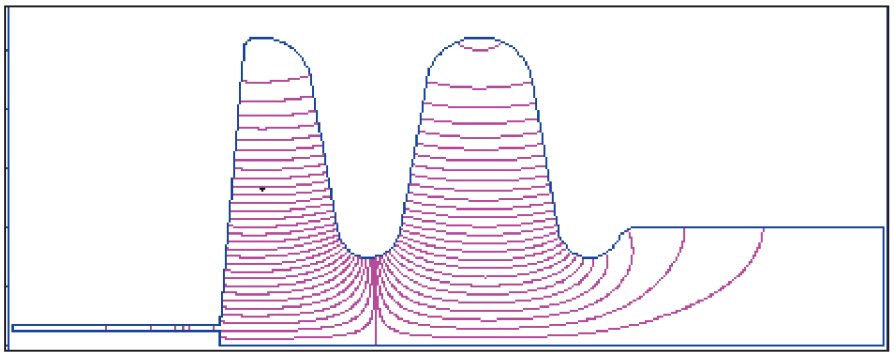
■Future
・**High intensity electron gun**
⇒SRF electron gun

SRF electron gun

(Collaboration with KEK)

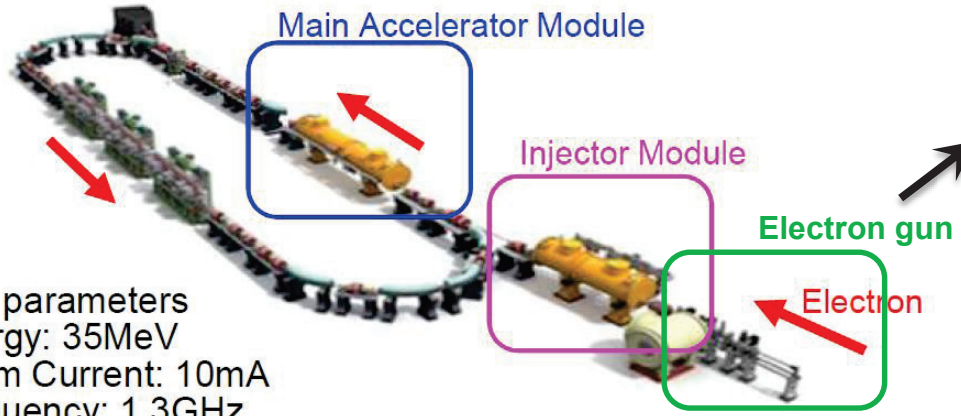
Drive frequency	; 1.3GHz
Beam Energy	; 2MeV
Beam current(ave.)	; 100mA
Electric field(Esp)	; <50Mv/m
Normalized emittance	; <1πmm mrad
Spread of Beam energy	; <2 keV (<0.1 %)
Number of the cell	; 1.5 cell

STEP1; Design of the shape of the cavity



Electric field distribution (SUPERFISH)

1. MHI's work for ERL (SRF Electron Gun)



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- Energy: 35MeV
- Beam Current: 10mA
- Frequency: 1.3GHz

■Present
・DC gun

■Future
・**High intensity electron gun**
⇒SRF electron gun

MHI is also developing **"high power coupler"** with KEK（Reported in next section）

SRF electron gun

(Collaboration with KEK)

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Beam Energy	; 2MeV
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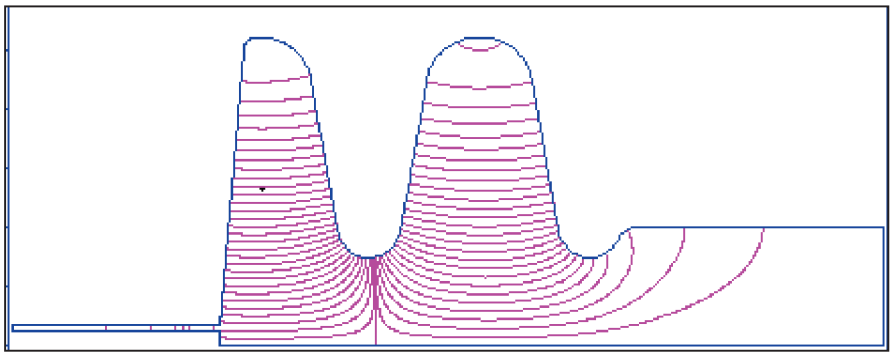


Electric field distribution (SUPERFISH)

1. MHI's work for ERL (SRF Electron Gun)

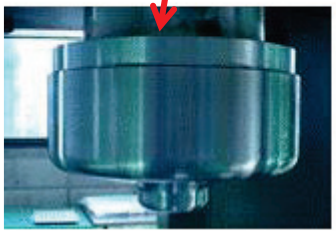
Procedure of press of half-cells

Press machine

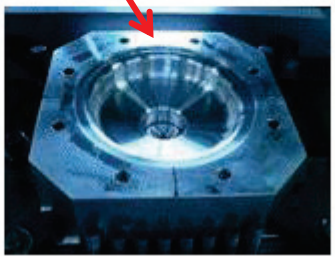
Before press

In the middle of press

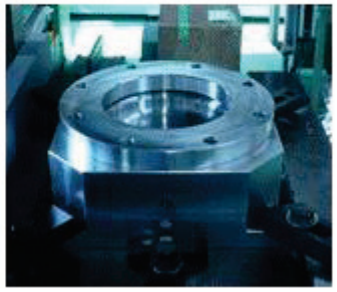
After press



PUNCH



DIE



Wrinkle holder

Nb sheet

Half-cell

No wrinkles, cracks

1. MHI's work for ERL (SRF Electron Gun)

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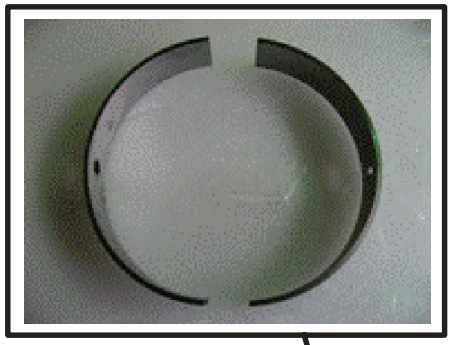
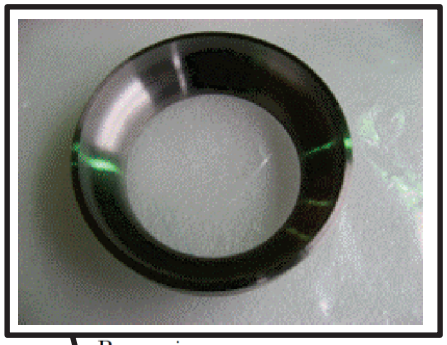
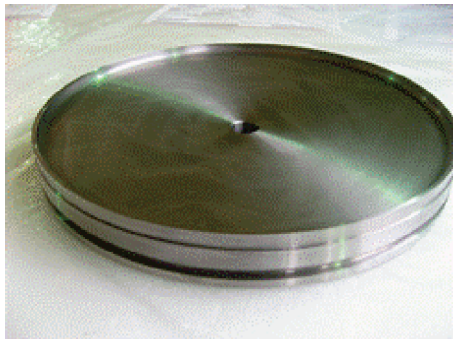
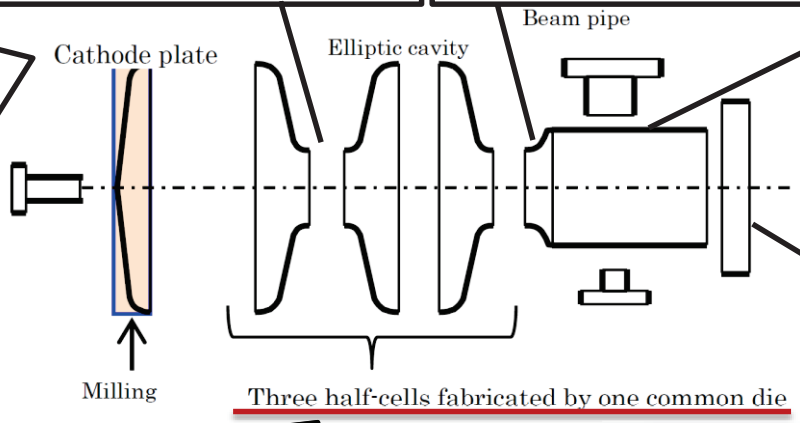
STEP2; Prototype#1









EBW

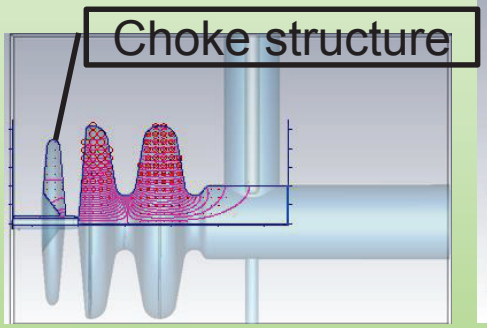
⇒ VT is under preparation in KEK

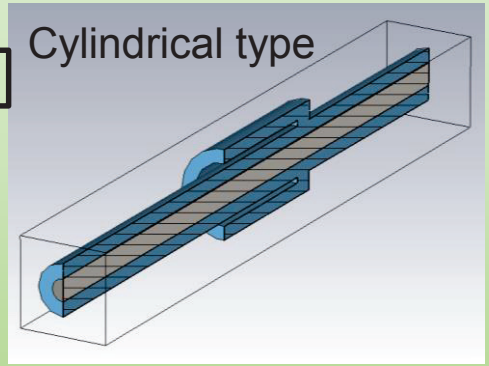
1. MHI's work for ERL (SRF Electron Gun)

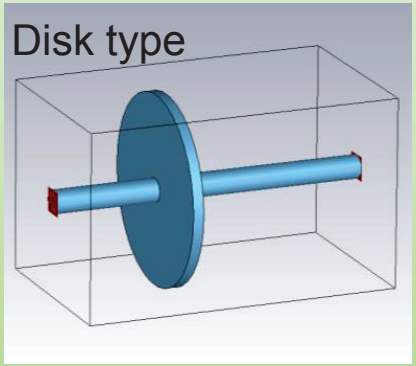
■Choke structure

Optimization

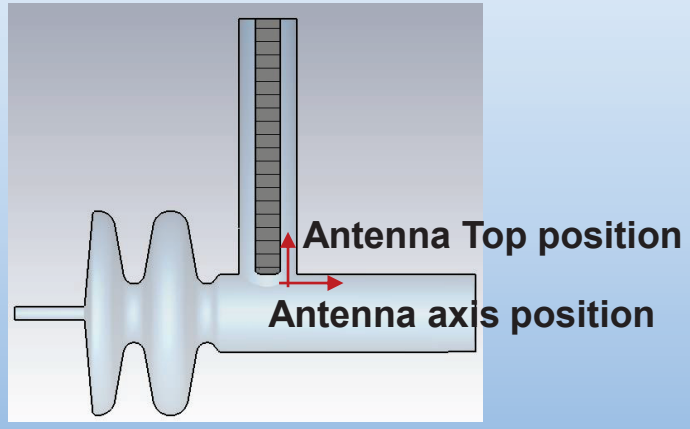
- resonance frequency ; 1.3GHz
- bandwidth ; >10MHz @-30dB
- Easy to change the cathodes
- Design for HPR
- Tunable
- Rigidity etc…

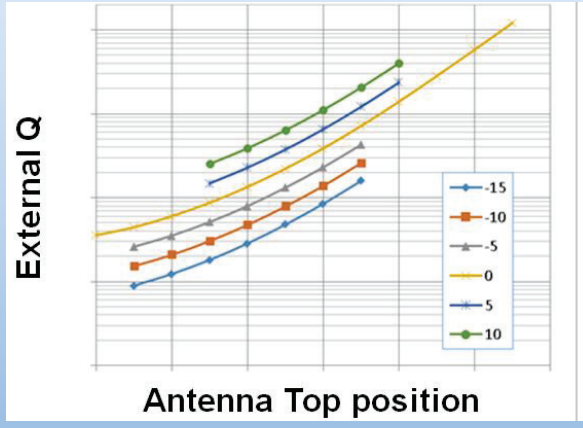


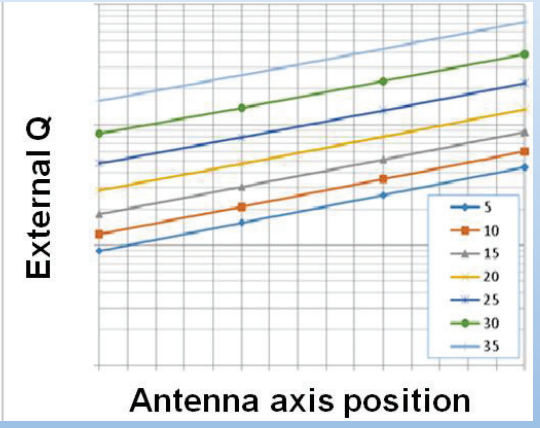




■Coupling calculation of Input coupler







1. MHI's work for ERL (RRR measurement of Cu plating)

(Collaboration with KEK)

■Purpose

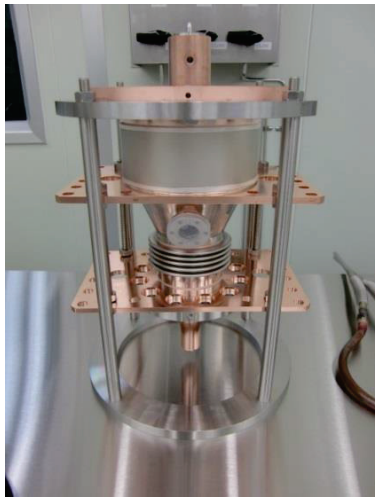
・Cu plating for input coupler requires **high electric conductivity** to suppress RF resistance and **low thermal conductivity** to suppress heat transfer.

Thin(μm) copper plating film on stainless steel plate and high RRR(nearly 50) are required.

■Method

・To obtain high electric conductivity, MHI adopts electroplating in an acid sulfate bath performed in the periodic reverse (PR) process.

・3 samples(10μm/20μm/30μm Cu plating and 1μm Ni strike plating on t1mm stainless plate) are prepared and measured RRR of each samples.



Reference; H.Sakai, TTC2014@DESY

1. MHI's work for ERL (RRR measurement of Cu plating)

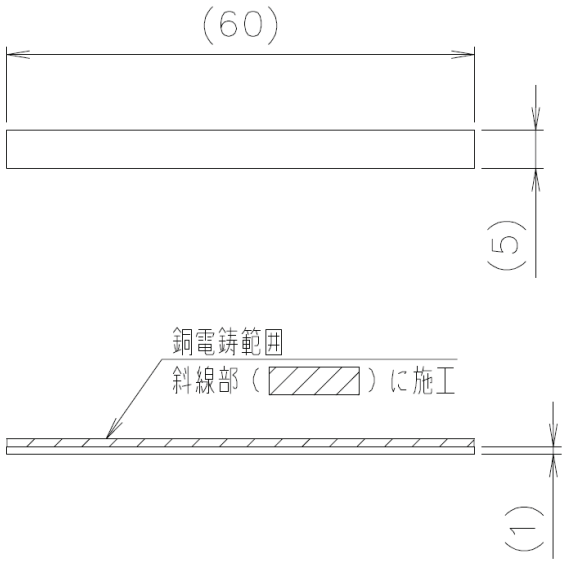
$RRR_{Cu} = \rho_{Cu@300K} / \rho_{Cu@4K}$ （ρ：resistivity)

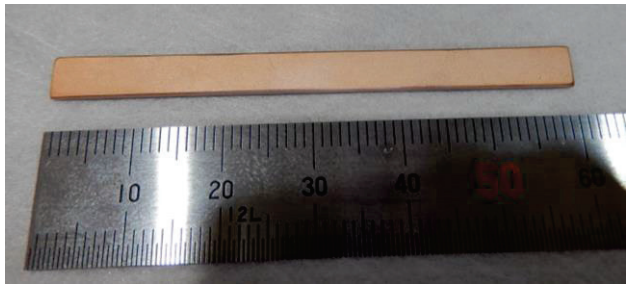
- It is difficult to measure directly the resistivity of the Cu plating.
  → measured both Cu plated/unplated samples and calculated RRR
- Heat treatment has an influence on the resistivity.
  → measured both with/without heat-treated(800℃) samples.

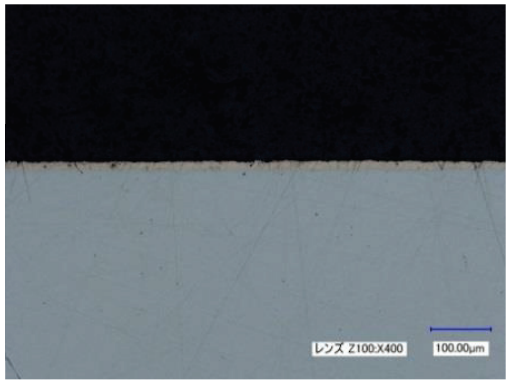
No.	Cu plating Thickness	Heat Treatment
1	Stainless Steel 1mm + Cu plating 10μm	no HT
2	Stainless Steel 1mm + Cu plating 20μm	no HT
3	Stainless Steel 1mm + Cu plating 30μm	no HT
4	Stainless Steel 1mm (Cu 10μm removed)	no HT
5	Stainless Steel 1mm (Cu 20μm removed)	no HT
6	Stainless Steel 1mm (Cu 30μm removed)	no HT
7	Stainless Steel 1mm + Cu plating 10μm	after HT
8	Stainless Steel 1mm + Cu plating 20μm	after HT
9	Stainless Steel 1mm + Cu plating 30μm	after HT
10	Stainless Steel 1mm (Cu 10μm removed)	after HT
11	Stainless Steel 1mm (Cu 20μm removed)	after HT
12	Stainless Steel 1mm (Cu 30μm removed)	after HT

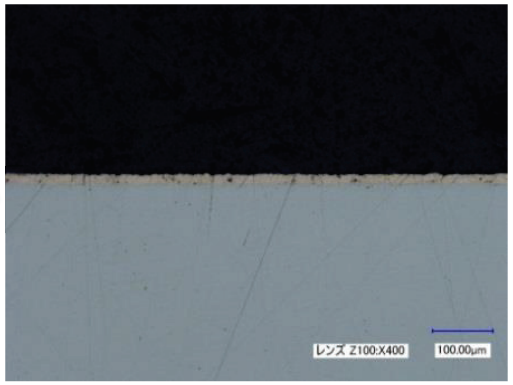
1. MHI's work for ERL (RRR measurement of Cu plating)

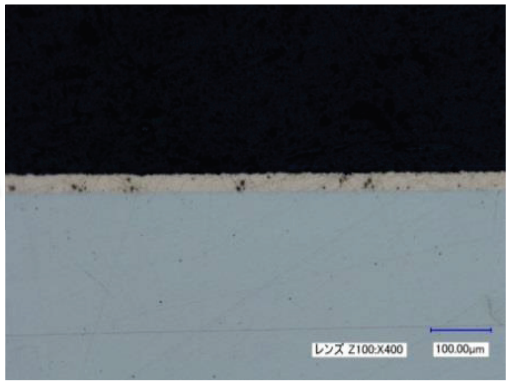
Substrate : 316L stainless steel
Ni strike : 1μm
Cu plating method : periodic reverse copper electroplating
Heat treatment : 800℃ 2H in a vacuum furnace
Measured Cu plating thickness by laser microscope.

Sample shape	Requirement	Result
	10 μm	13.7 μm
	20 μm	19.3 μm
	30 μm	31.1 μm









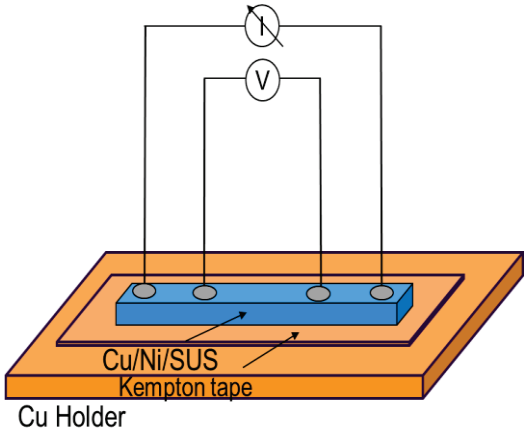
1. MHI's work for ERL (RRR measurement of Cu plating)

Measurement

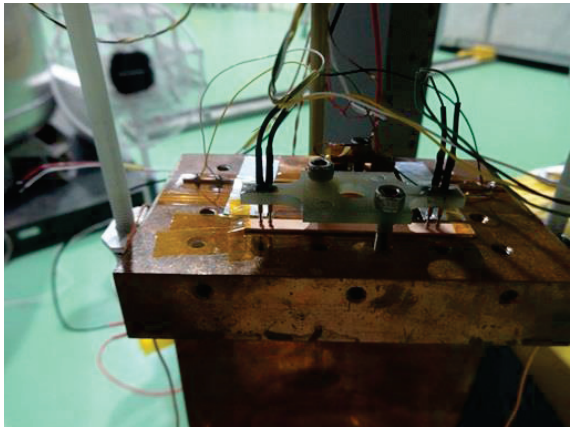
- Cu Plated TP
- Cu Unplated TP

↓

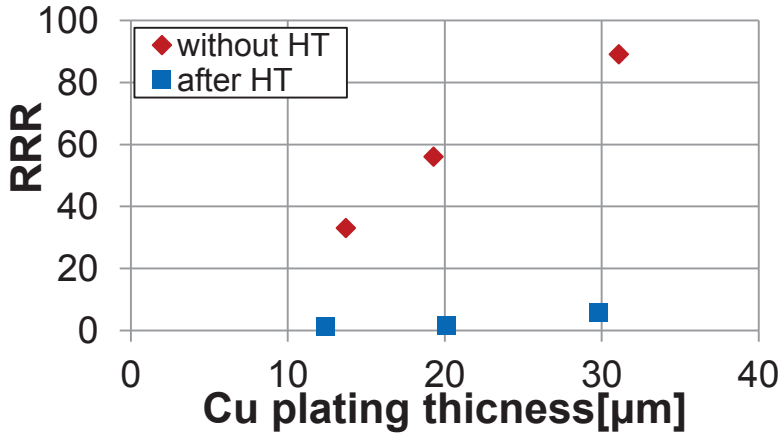
Calculate RRR



(Contact by soldering)



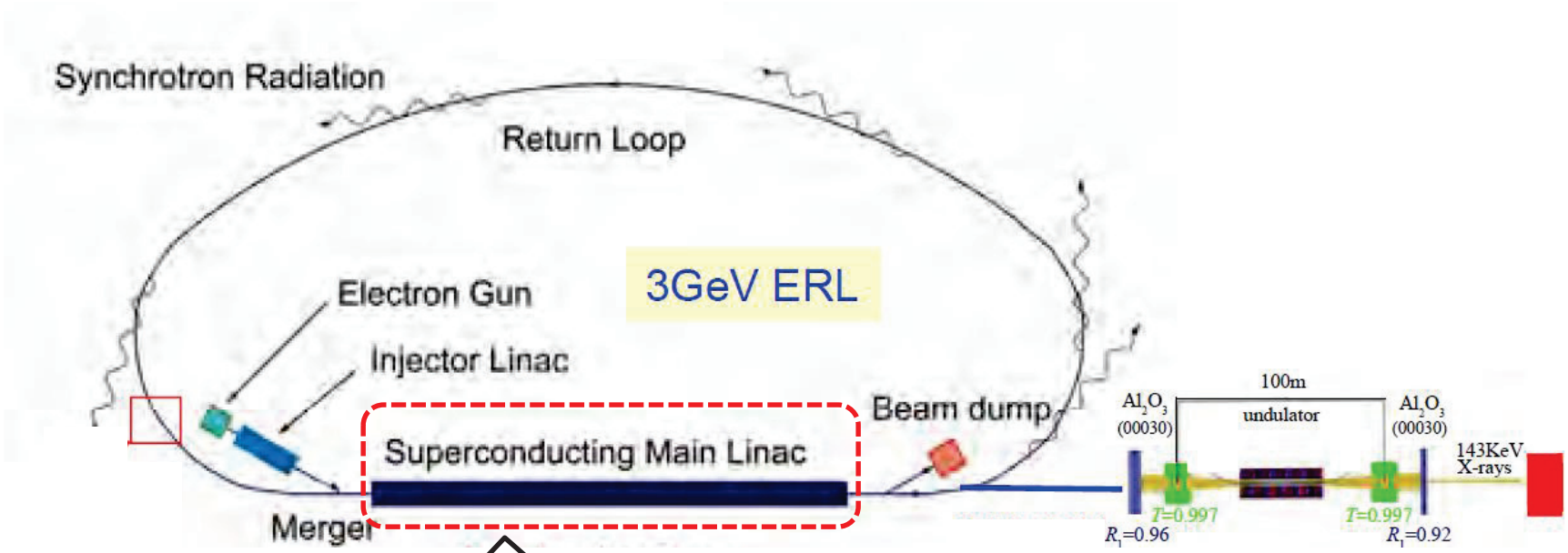
Result



without HT		after HT	
Thickness [μm]	RRR	Thickness [μm]	RRR
13.7	33	12.4	1.4
19.3	56	20.1	1.7
31.1	89	29.8	5.7

⇒ Heat treatment decreases Cu plating(on Stainless steel) RRR.

2. MHI's development histories for mass-production



Reference; KEK Report 2012-4「Energy Recovery Linac Conceptual Design Report」

We need to prepare for the mass-production

2. MHI's development histories for mass-production

Phase	Cavity No.	Welding process for stiffener	Welding process for baseplate	Number of the cavity for final welding per 1 chamber	New process
R&D	MHI-A 9cell	**LBW**	EBW	1	
	MHI-B 2cell	-	-	1	**Seamless dumbbell**
	MHI-C 9cell	LBW	LBW	1	9seam / 1batch
	MHI-D 9cell	LBW	EBW	**1 +3 dummy**	**Unification of monitor port and flange**
STF 2-a	#23-26	LBW	EBW	**2**	Using retainer ring for monitor port
STF 2-b	#27-30	LBW	EBW	**4**	

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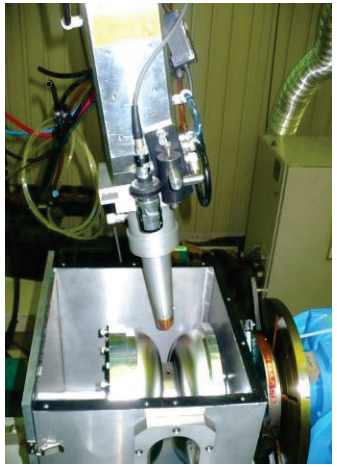

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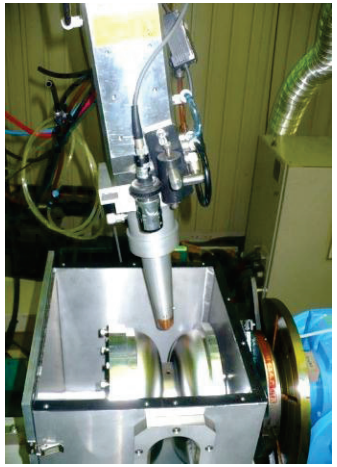

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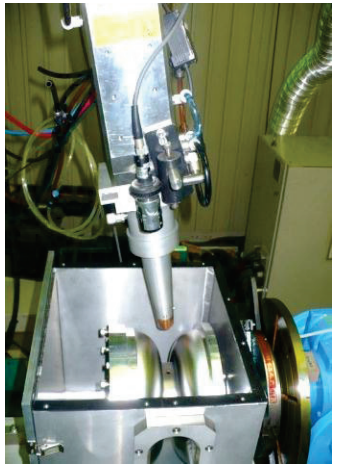

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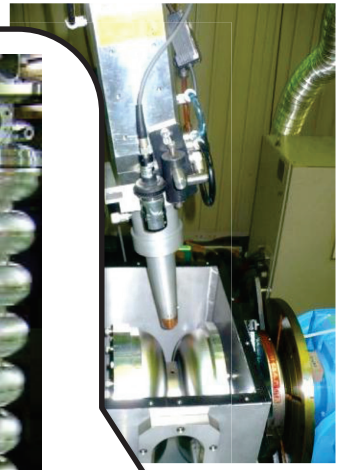
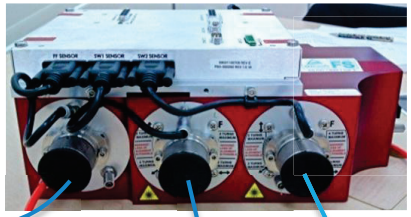


Increasing production line

Laser can be swiched by beam switch to multi station through fiber

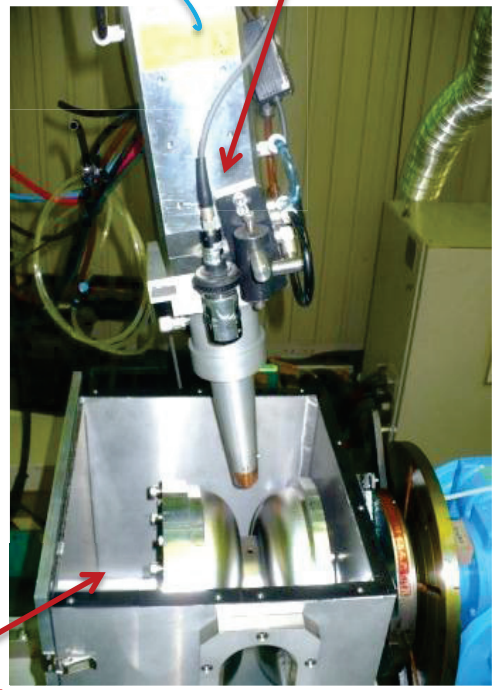
Beam switch



Optical laser head

Oscillator

(another station)



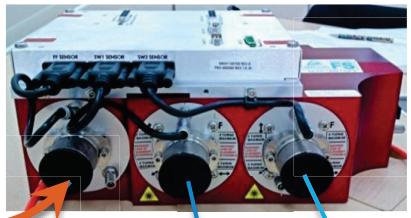
Shield gas box

Welding station

Increasing production line

Laser can be swiched by beam switch to multi station through fiber

Beam switch



Optical laser head

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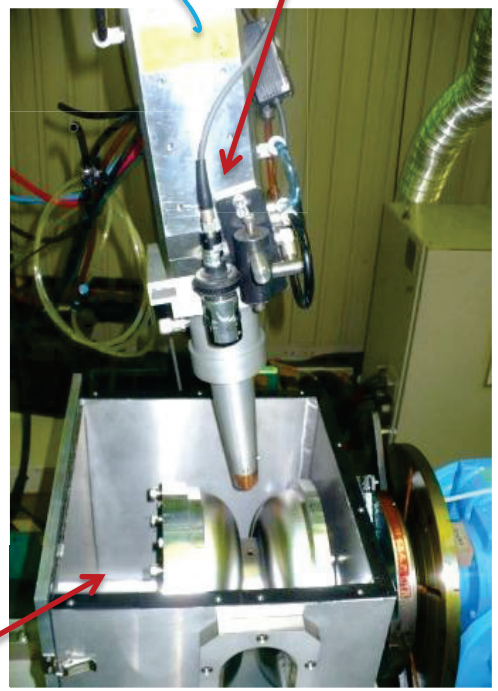

Shield gas box

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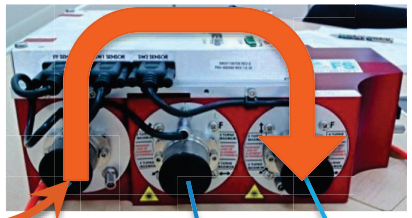
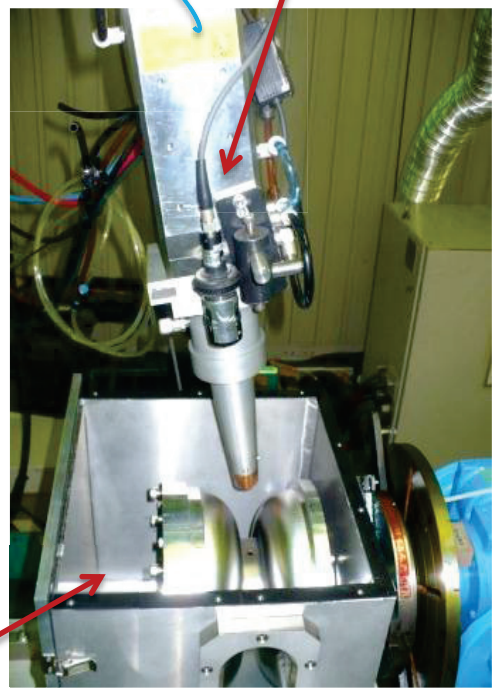
Laser can be swiched by beam switch to multi station through fiber

Beam switch



Optical laser head

(another station)



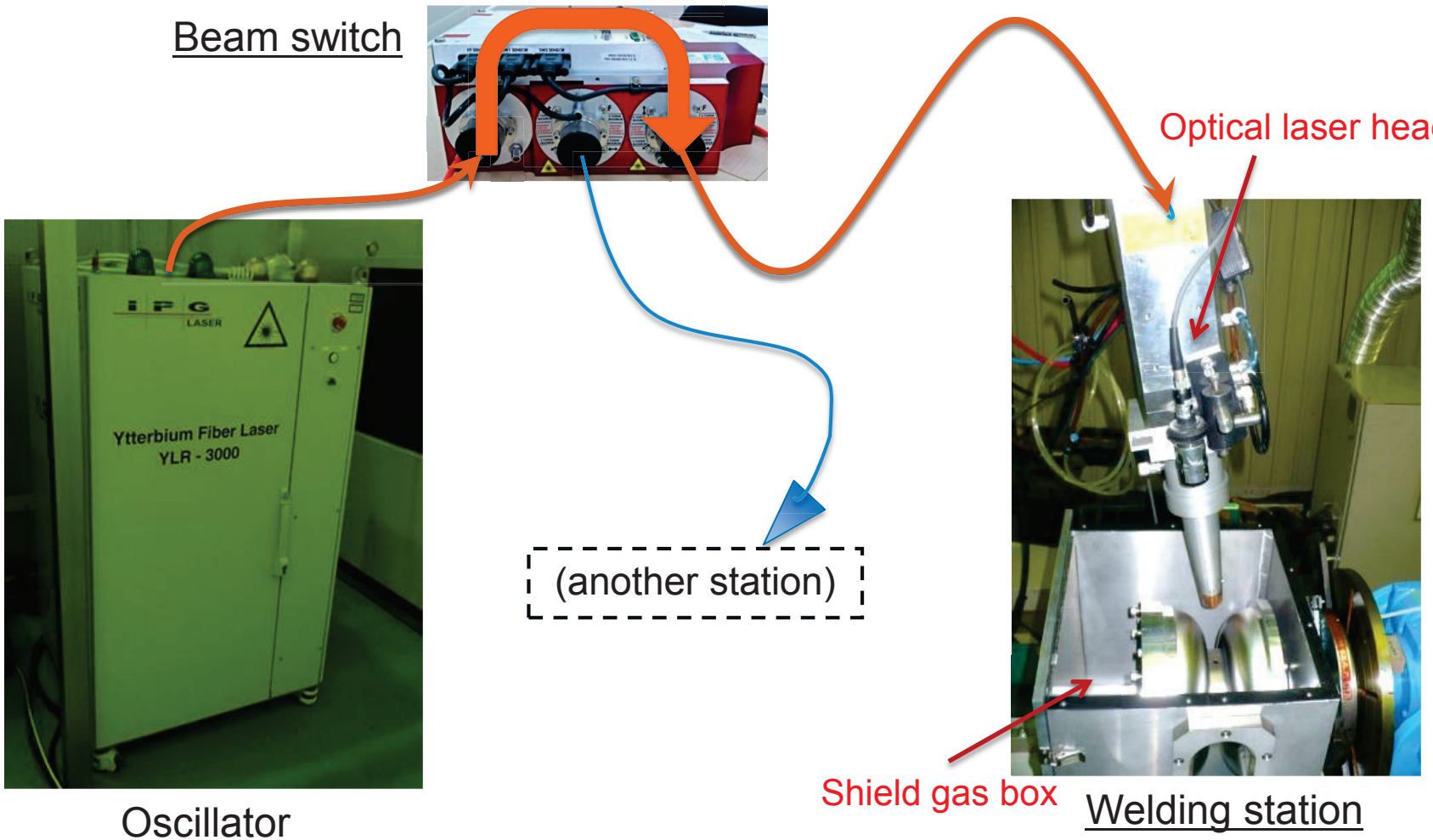
Shield gas box

Oscillator

Welding station

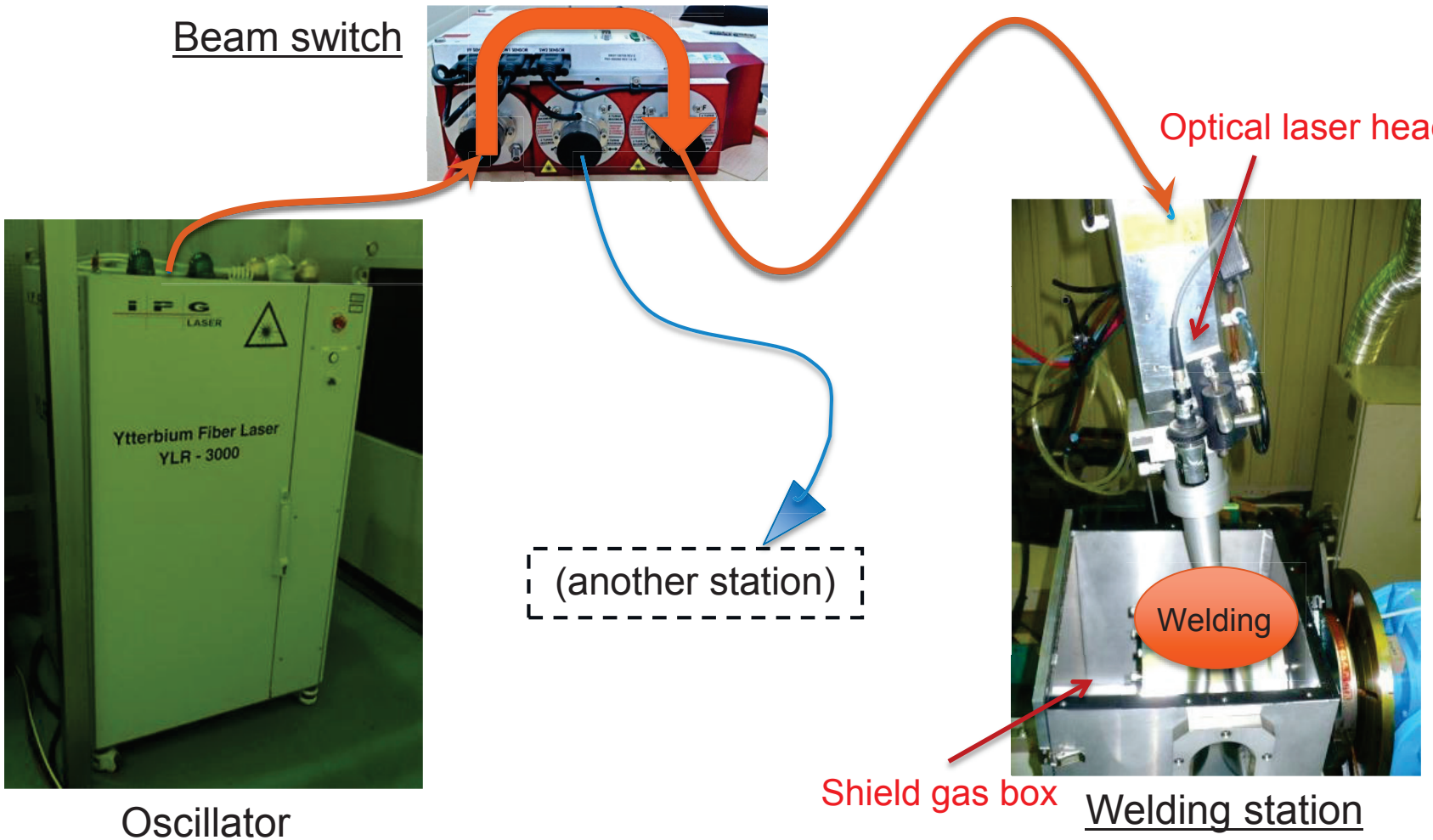
Increasing production line

Laser can be swiched by beam switch to multi station through fiber



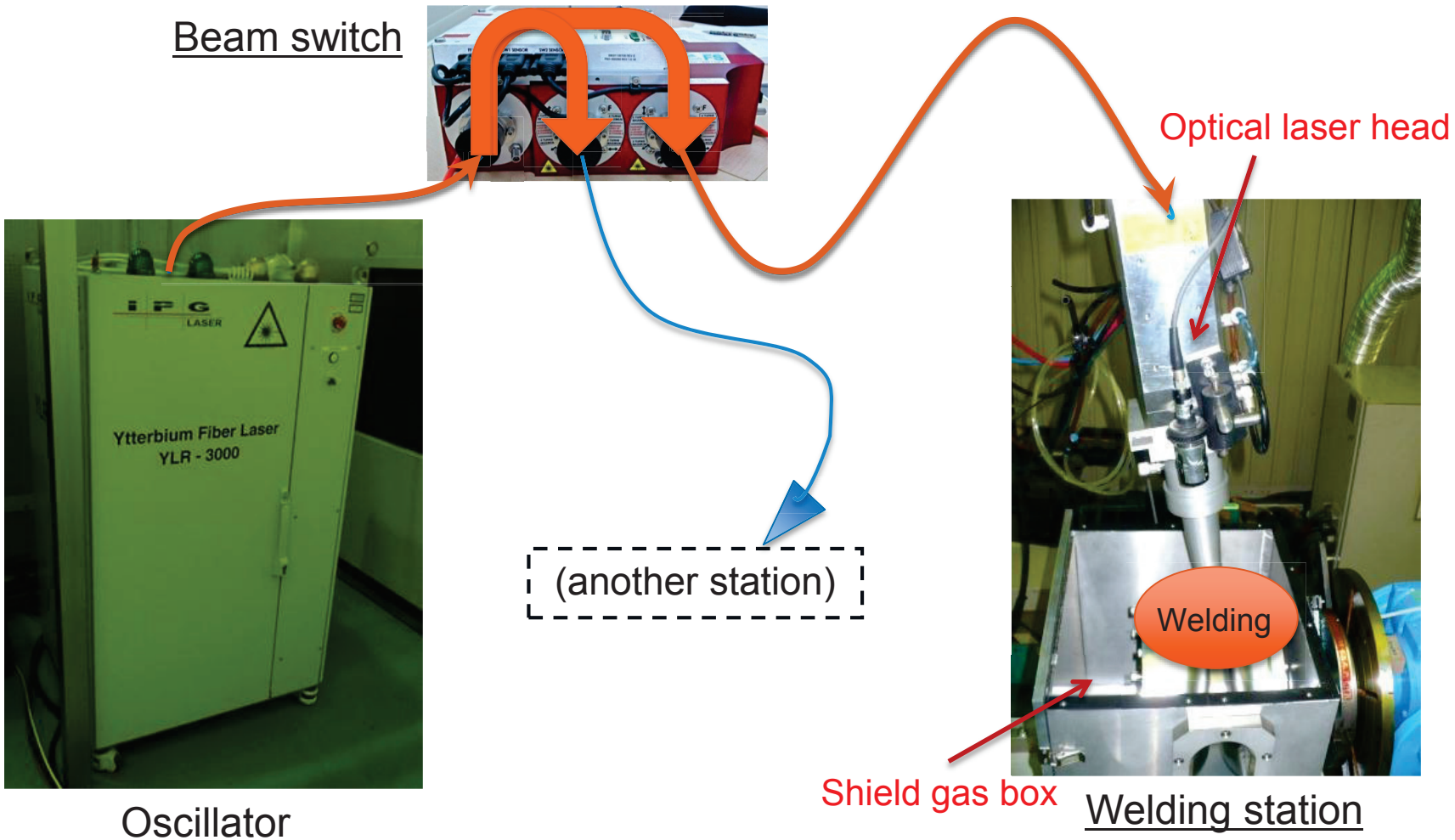
Increasing production line

Laser can be swiched by beam switch to multi station through fiber



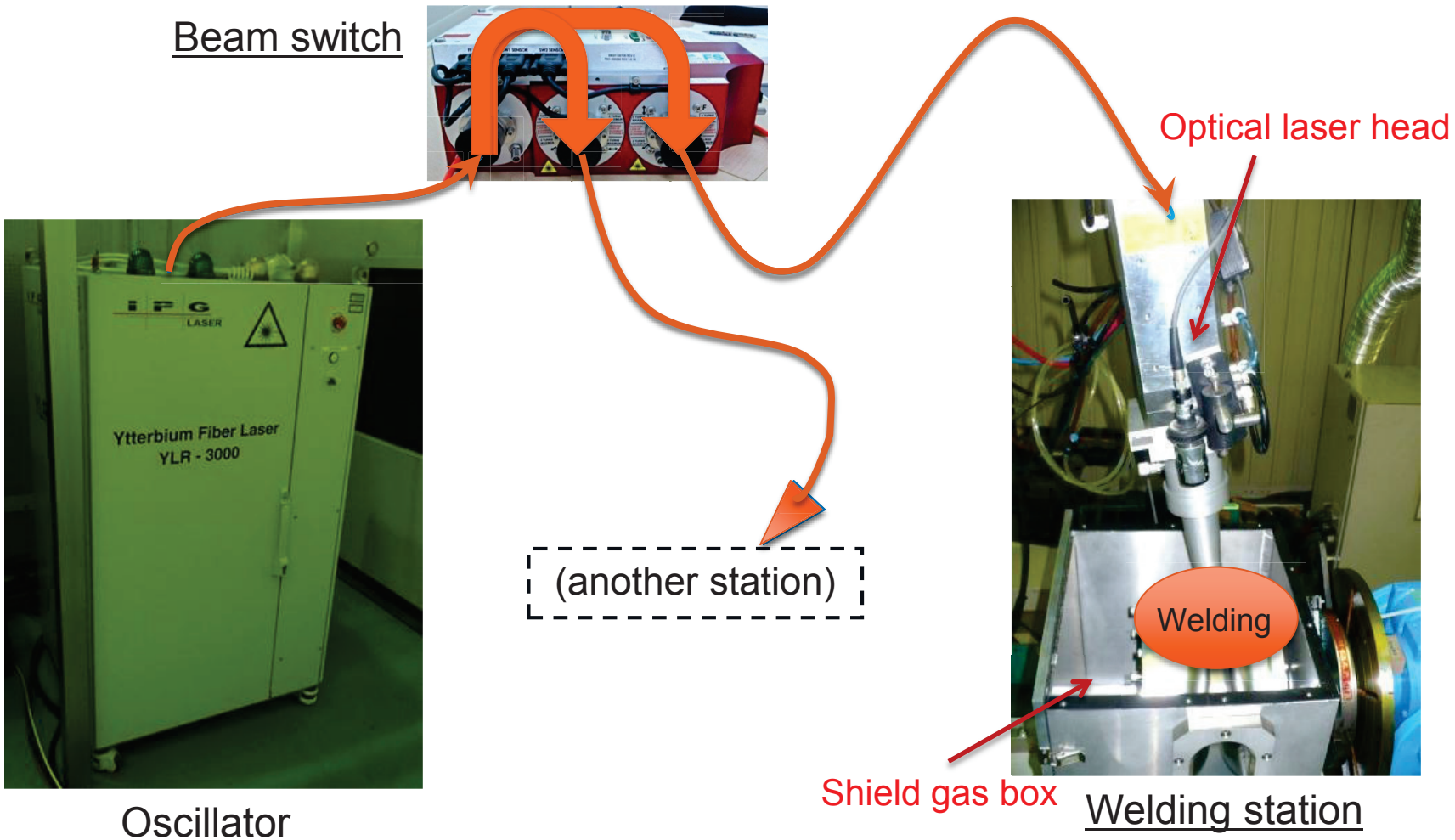
Increasing production line

Laser can be swiched by beam switch to multi station through fiber



Increasing production line

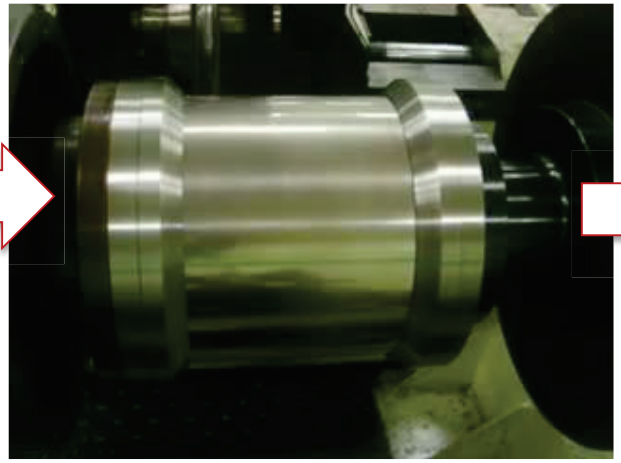
Laser can be swiched by beam switch to multi station through fiber



2. MHI's development histories for mass-production

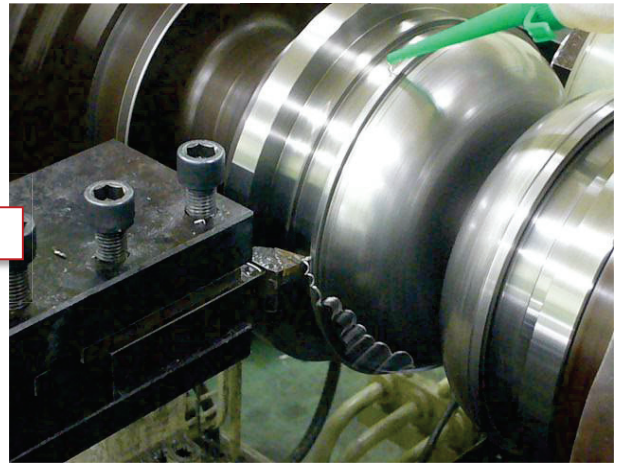
Reducing the number of parts ~Seamless dumbbell~

①Deep drawing from sheet

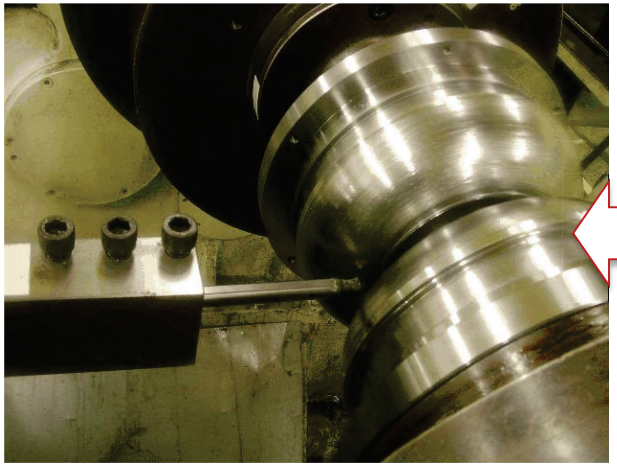


②Set of pipe

③Spinning



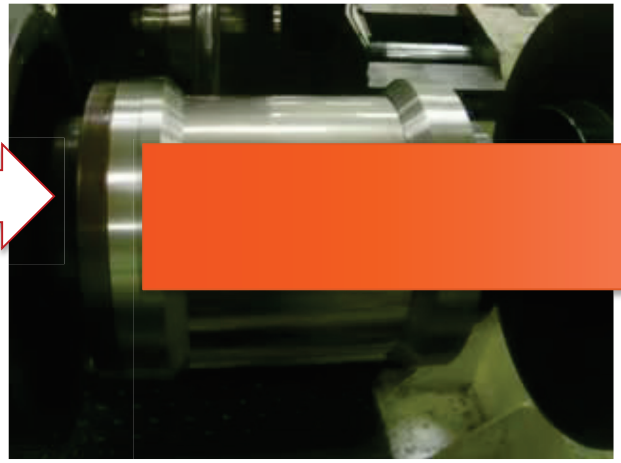
⑤Turning for thinning of equator



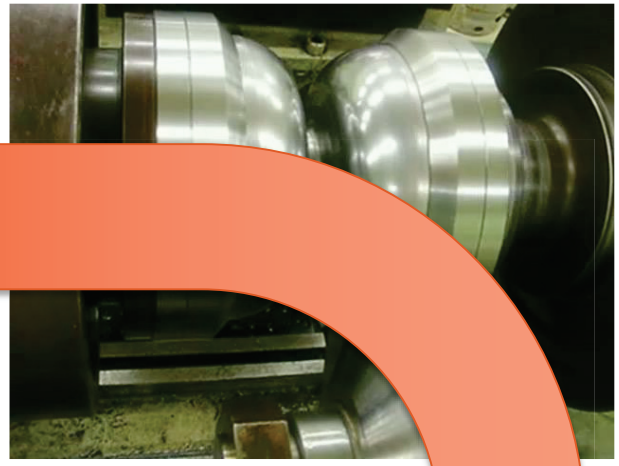
⑥Turning for stiffener

Reducing the number of parts ~Seamless dumbbell~

①Deep drawing from sheet

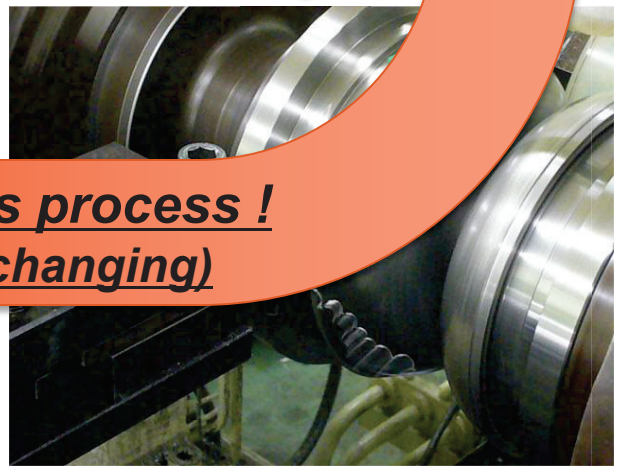


②Set of pipe



③Spinning

⑥Turning for stiffener



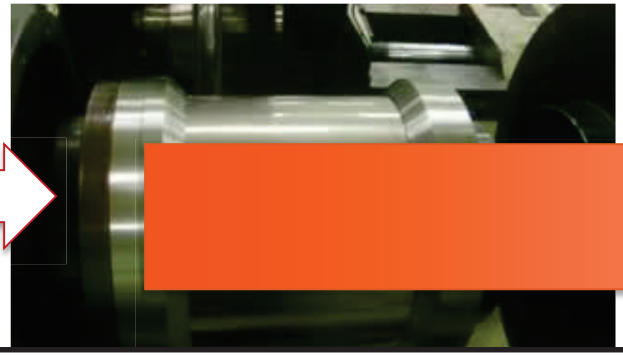
⑤Turning for thinning of equator

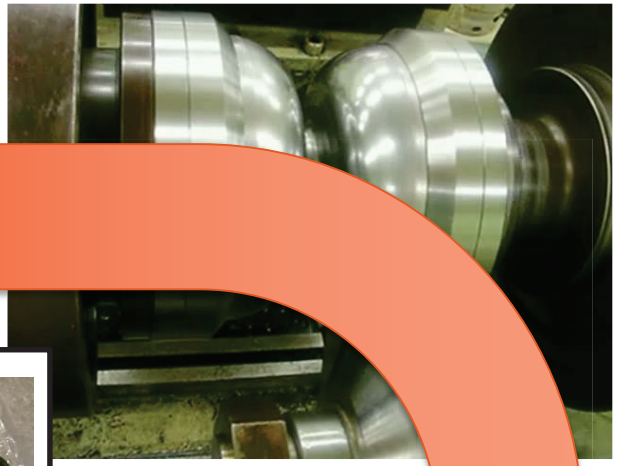
Seamless process !
(no grip-changing)

2. MHI's development histories for mass-production

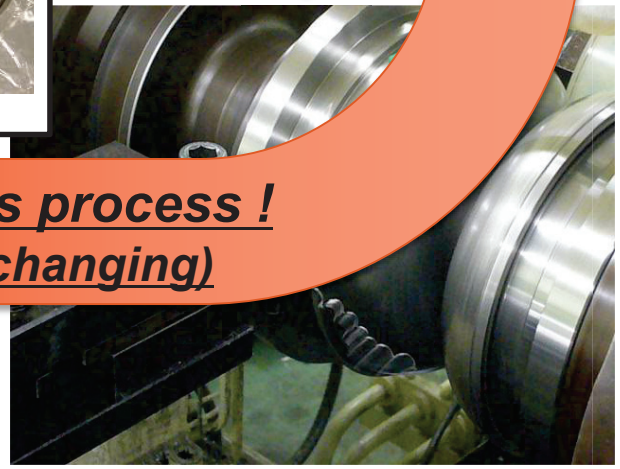
Reducing the number of parts ~Seamless dumbbell~

①Deep drawing from sheet





③Spinning



Seamless process !
(no grip-changing)

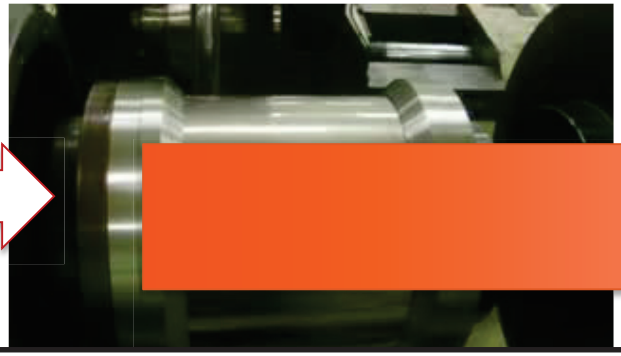
⑥Turning for stiffener

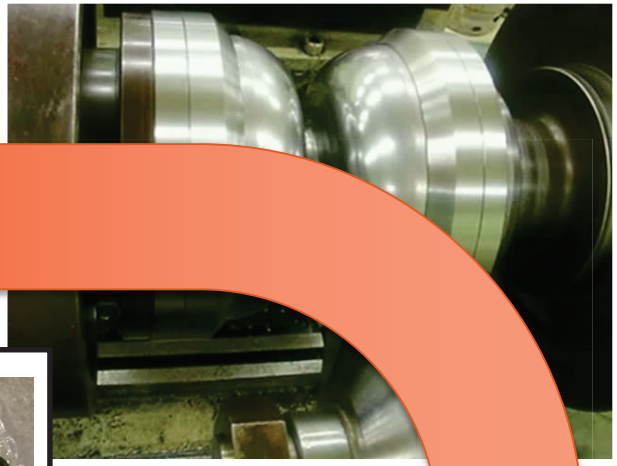
⑤Turning for thinning of equator

2. MHI's development histories for mass-production

Reducing the number of parts ~Seamless dumbbell~

①Deep drawing from sheet





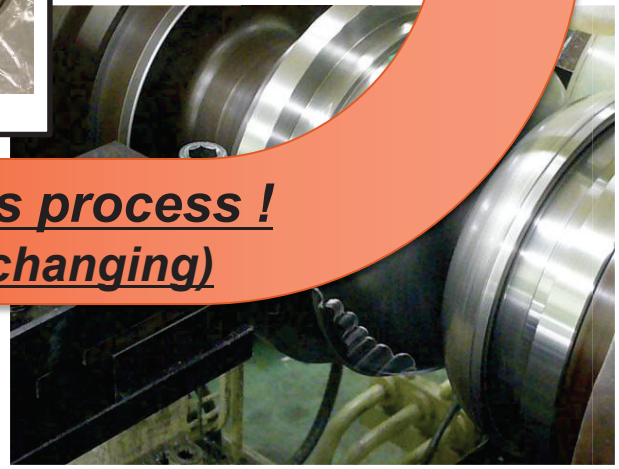
③Spinning

- Seamless dumbbell is applied to MHI-B 2cell cavity
- VT in JLab ⇒ 32.4 MV/m

Thanks to
Dr. Rimmer-san in JLab
Dr. Geng-san in JLab
Prof. Kako-san in KEK

Seamless process !
(no grip-changing)

⑥Turning for stiffener

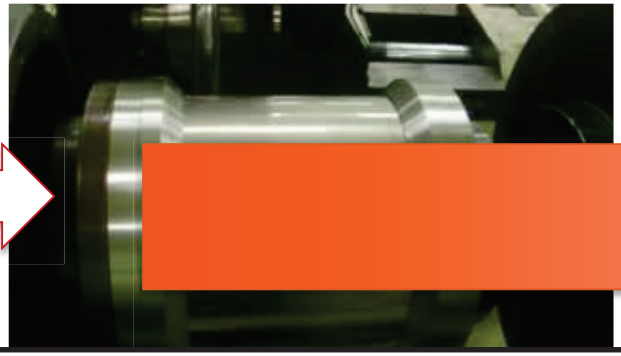


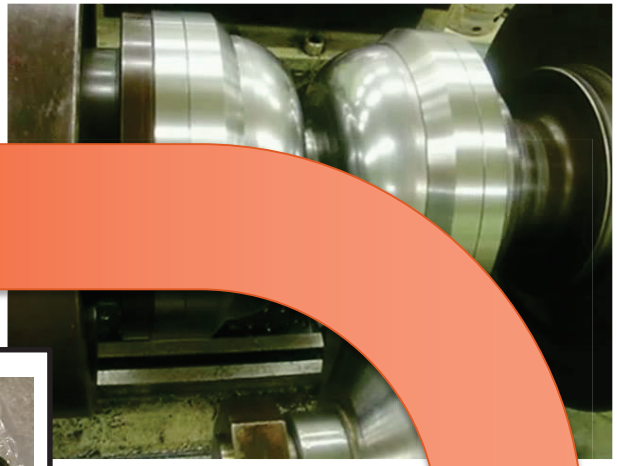
⑤Turning for thinning of equator

2. MHI's development histories for mass-production

Reducing the number of parts ~Seamless dumbbell~

①Deep drawing from sheet





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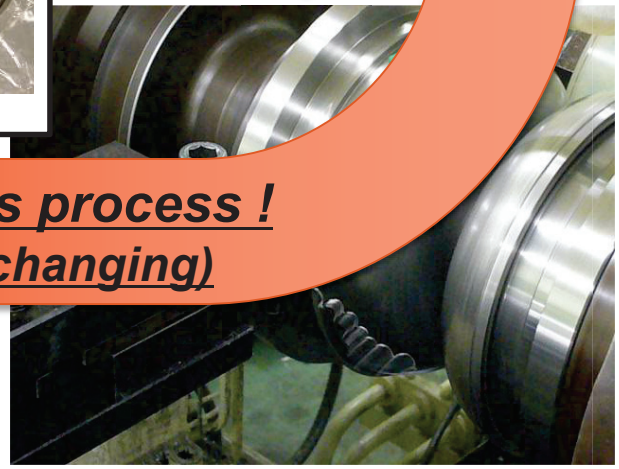
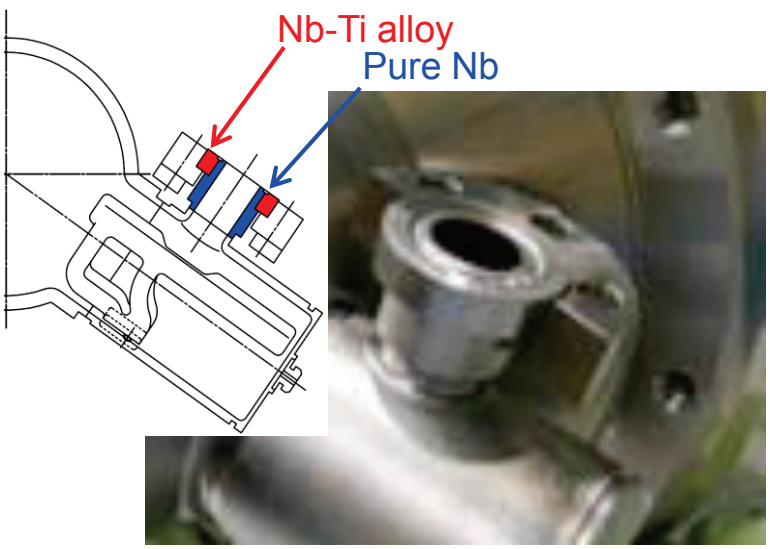
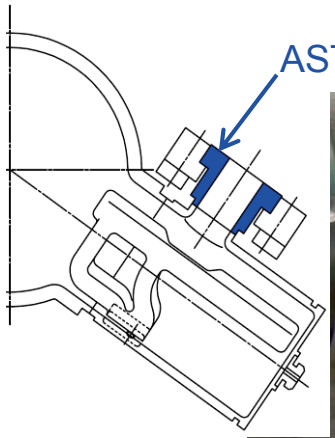
⑥Turning for stiffener



⑤Turning for thinning of equator

Reducing the number of parts ~Unification of parts~



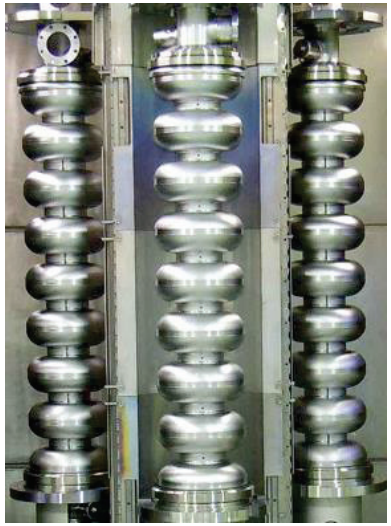


Under vertical test in KEK

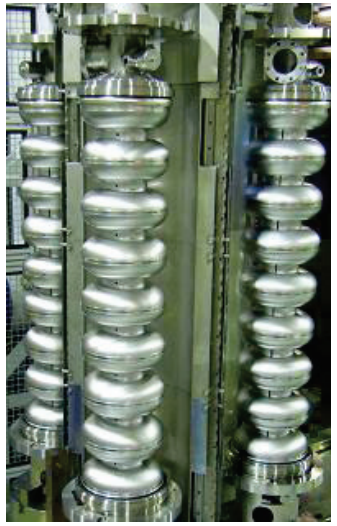
2. MHI's development histories for mass-production

Batch Process

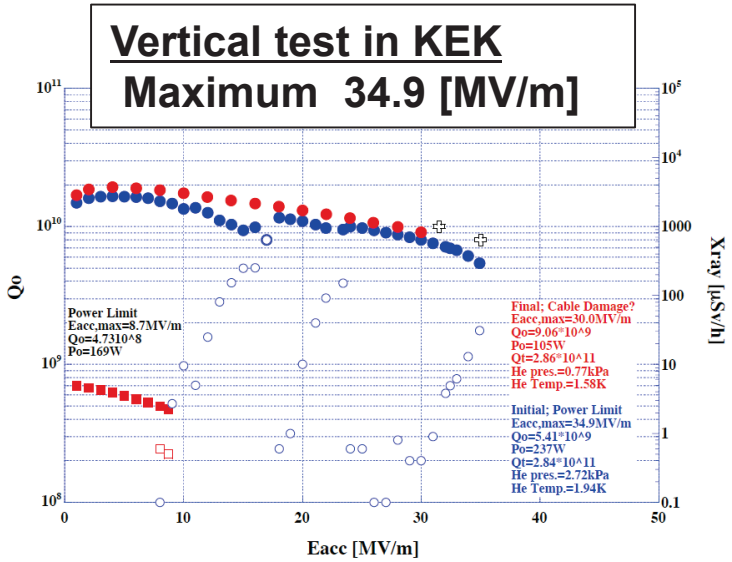
①4 sets of 9-cell cavity parts



②Before welding



③After welding



3. Summary

- MHI has fabricated the main components for KEK cERL.
  - Injector module
  - Main acceralator module
- MHI has improved mass-productin method.
  - Laser beam welding
  - Seamless dumbbell
  - Changing the material of HOM coupler
  - Batch process
- MHI is also developing now.
  - SRF Electron gun (Currently in progress)
  - Coupler (Currently in progress)

Thank you for your attention !