

# INDUSTRIALIZATION OF ILC FROM A VIEW POINT OF INDUSTRY

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## Abstract

Cavity performance has been improved by various efforts to meet the ILC spec stably in these days. For industrialization, not only Quality but also Cost and Delivery time, that is, QCD are important. We report our activities for stable quality and cost reduction in this report.

## INTRODUCTION

MHI has supplied 1.3 GHz superconducting RF cavity for STF project (STF is a project at KEK to build and operate a test linac with high-gradient superconducting cavities, as a prototype of the main linac systems for ILC.) in several years [1]. To improve cavity performance, we have done several activities as shown Table 1 on STF cavity fabrication. Clean area was not used in cavity assembling at phase 1.0, but air top gun in clean area are used in cavity assembling at phase 2.0. The EBW conditions were always improved.

In recent vertical test at KEK, almost STF cavities reached  $E_{acc} = 31.5$  MV/m which is specification of ILC as shown figure 1. MHI-#12 - #21 (as shown figure.2) are governing high pressure gas safety law in Japan. The average  $E_{acc}$  of these cavities is 37 MV/m, and the range of  $E_{acc}$  is from 35 MV/m to 40.7 MV/m.

Table 1: Activities for Improvement of Cavity Performance

Phase	1.0	1.5	2.0	2-a
Cavity No.	#1-4	#5-6 #7-9	#10-11	#12-22 #23-26
Thickness of thinning	2.5 mm	2.0 mm	>	>
Bead condition	Bumpy	Smoother	Flatter	More stable
Shape of groove	Butt	>	Step	>
Frequency of *CP	Only after thinning	Each step (Just before EBW)	>	>
Management of cleanness	Air duster	>	>	Air top gun
		Clean area	>	>

\*CP: Chemical polishing

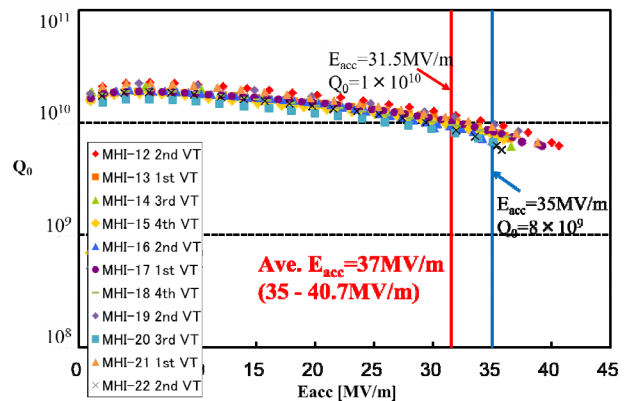


Figure 1: Q-E curve of recent vertical test for STF cavities.



Figure.2: STF cavities governing high pressure gas safety law in Japan.

## INDICATORS OF INDUSTRIALIZATION

To realize the ILC project, we industry need to consider about not only cavity quality but also cost and delivery time for fabrication, that is, industry needs to consider about QCD. QCD are important things for industrialization. It is important how we should reduce cost and shorten delivery time while keeping the quality. In the case of ILC, the detail of QCD is as below.

### Quality

ILC spec is  $E_{acc} = 31.5$  MV/m,  $Q_0 = 1 \times 10^{10}$ . It is important how we can maintain the higher performance of cavity.

### Cost

Construction costs for ILC are about 8 billion dollars and the level of a cavity cost is \$50k to \$100k. Industry needs to know the target price of all expenses and needs cost reduction to the target price in order to realize the ILC project. The method of cost reduction depends on

the target price. Because it is not easy to keep higher quality by low cost.

**Delivery time**

- Now we assume for 16,000 cavities as below,
- Preparation : 2 years
- Construction : 8 years
- Production of cavity with jacket : 6 years

**IMPROVE MENT OF THE CAVITY QUALITY BY VARIOUS INSPECTION**

As mentioned above, various improvements of cavity fabrication have been done. In addition to fabrication method, monitoring or inspection system as below is also important to keep the cavity performance because cavity RF vertical test is too expensive.

- Material inspection by using eddy current
- Dimension inspection
- Welding condition
- Visual test of cavity inner surface and welding bead
- Inspection of HP-code
- Vacuum test
- Condition of EP and HPR

Cavity needs these inspections and monitoring of condition, but the criteria of some inspection or condition are not clear. So it is necessary to decide the criteria for industrialization. On the other hand, repairing technique of the pit of welding bead is improving at KEK [2]. This technique will have a big impact on the industrialization.

**IMPROVEMENT FOR CAVITY FABRICATION METHOD FOR COST REDUCTION**

The principles for cost reduction in mass-production are reducing number of parts, automation or outsourcing, batch process and reducing process time (e.g. Change of fabrication procedure, using special jig and machine or optimization of machine time and layout).

Since STF project was started, MHI has proposed some new fabricating methods based on these principles as shown below [3-6]. Some of them were applied to production or R&D cavities. Some of them are proposal for cost reduction. Improvements in R&D cavities for cost reduction are shown in detail, and Table 2 shows the summary of improvement for cavity fabrication method for cost reduction.

**Improvement Applied to Production Cavities**

- The items as following are applied to STF cavities.
- To simplify inner conductor of HOM (High Order Mode ) coupler design
- Reduction of machining of HOM cup, beam tube and base-plate by using forming
- Retainer flange for monitor port
- Welding 2 cavities in one batch

**Improvement Applied to R&D Cavities**

- The items as following are applied to R&D cavities.
- Automatic finishing by robot for cell’s inner surface from human hand (applied to MHI-B cavity)
- Using LBW instead of EBW for stiffener and flanges (applied to MHI-A cavity)
- Seamless dumbbell (applied to MHI-B cavity)
- Welding all equator line of cavity in succession by vertical position without purge of vacuum chamber (applied to MHI-C cavity)
- LBW for baseplate consisted of Nb ring and Ti plate (applied to MHI-C cavity)

**Improvement under Developing or Proposal**

- The items as following are under developing or our proposal.
- Welding 4 cavities in one batch
- Combination of pick-up port and flanges
- Vacuum chucking for turning

Table 2: Summary of Improvement for Cavity Fabrication Method for Cost Reduction

Phase	Cavity No.	Assy direction	Stiffener welding	Baseplate welding	Cavity quantity at final welding in one batch	New Procedure or new design
-	MHI-A 9cell	Horizontal	LBW	EBW	1	
	MHI-B 2cell	Vertical	-	-	1	Seamless dumbbell
	MHI-C 9cell		LBW	LBW	1	
STF 2-a	#23-26			EBW	2	Retainer flange for monitor port
future	-			LBW	4	

**FABRICATION OF MHI-A CAVITY (R&D)**

MHI-A cavity was manufactured to establish LBW for stiffener ring and flanges and to establish deep drawing for HOM cup. The vertical test of the cavity was carried out at KEK to inspect the influences to cavity performance by new techniques. The result of first vertical test is shown figure 1. MHI-A cavity achieved Eacc=29.5 MV/m without problem at LBW points and HOM coupler. Except for No.8 cell this cavity has capacity of good performance. So we found LBW and HOM cup can be available for production of future cavities.

**Feature of MHI-A Cavity (shown Figure 3)**

- Using deep drawing of HOM cup
- No finishing for inner surface of HOM cup
- Using LBW for stiffener and flanges with argon gas atmosphere and oxygen content controlled
- Same design of STF cavity.

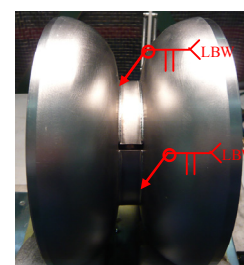


Figure 3: MHI-A cavity.

## FABRICATION OF MHI-B CAVITY (R&D)

MHI-B cavity was manufactured to establish seamless dumbbell as shown figure 4. This cavity is under testing at JLab to inspect the influences to cavity performance by seamless dumbbell.

### Feature of MHI-B

- Number of cell is two.
- No welding seam on iris (seamless dumbbell).
- Finishing for inner surface of dumbbell is automatic buffing by robot.
- Cell's design is the same as STF cavity

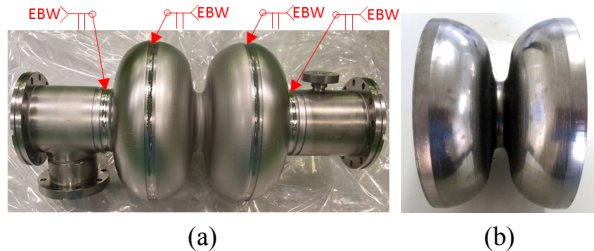


Figure 4: (a) Over view of MHI-B cavity, (b) Seamless dumbbell.

### Seamless Dumbbell

Figure 5 shows the flow of forming for seamless dumbbell. The quality of inner surface of dumbbell depends on the condition of the seamless pipe. The seamless pipe was made by deep drawing.

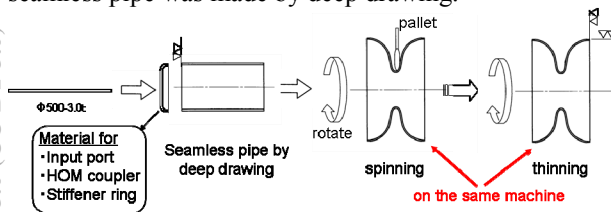


Figure 5: Flow of seamless dumbbell.

## FABRICATION OF MHI-C CAVITY (R&D)

MHI-C cavity was manufactured to establish welding all equator line of cavity in succession by vertical position without purge of vacuum chamber and LBW for baseplate consisted of Nb ring and Ti plate. The result of first vertical test is shown figure 1. MHI-C cavity achieved  $E_{acc}=36.7$  MV/m without problem as shown figure 6. So we found these fabrication method can be available for production of future cavities.

### Feature of MHI-C (shown Figure 6)

- Welding all equator line in one batch.
- Welding the cavity by vertical position.
- LBW for baseplate consisted of Nb ring and Ti plate.

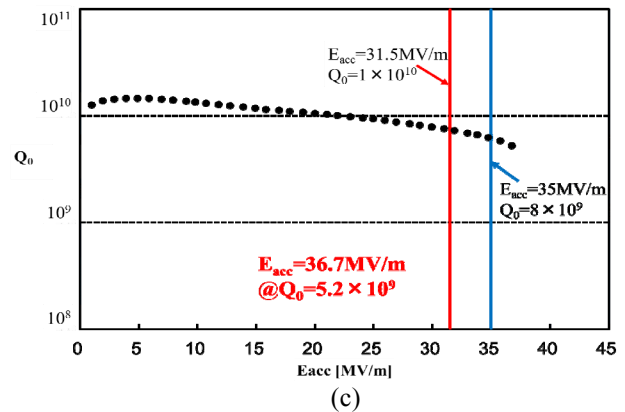
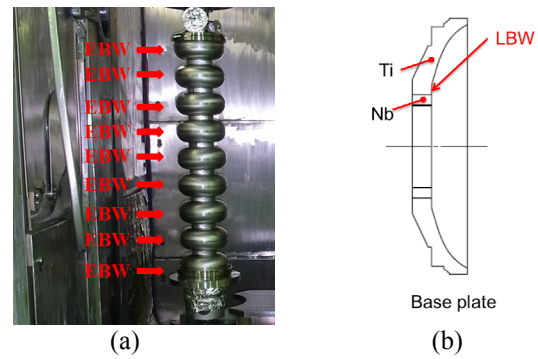


Figure 6: (a) Over view of MHI-C cavity and welding position, (b) Baseplate, (c) Q-E curve of MHI-C cavity.

## FABRICATION OF STF #23-26

STF #23-26 are under fabrication by new design and new procedure. These cavities have retainer flange for monitor port as shown figure 7. We can weld monitor port and flange separately from HOM coupler. Also 2 cavities will be welded at all equator lines in one batch. We will weld 4 cavities in one batch in future as shown figure 8.

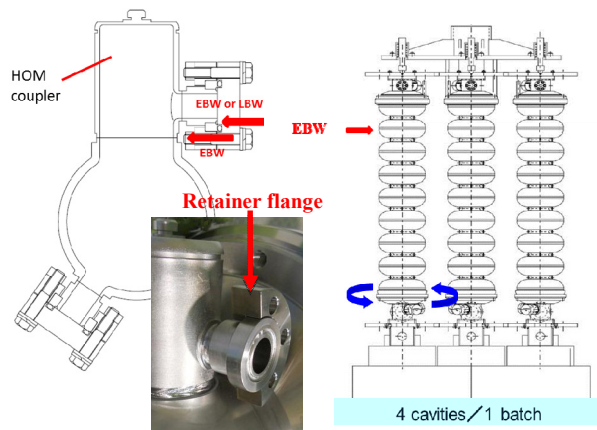


Figure 7: Retainer flange for monitor port.

Figure 8: Welding 4 cavities in one batch.

### IMPROVEMENT UNDER DEVELOPING AND PROPOSAL

We are developing some improvement and we have some proposals for cost reduction as below.

#### Combination of Pick up Port and Flange

To reduce the number of parts for cost reduction, combination of pick up port and flange is under consideration as shown figure 9. In case of present status it needs 2 pieces and 2 welding line per a port. In case of this proposal it needs only 1 piece and welding line per a port. So it can reduce 3 parts per cavity and can reduce 3 welding line per cavity. We need to change port material for hardness (e.g. NbZr or low RRR Nb) and need to test for the influence of EP.

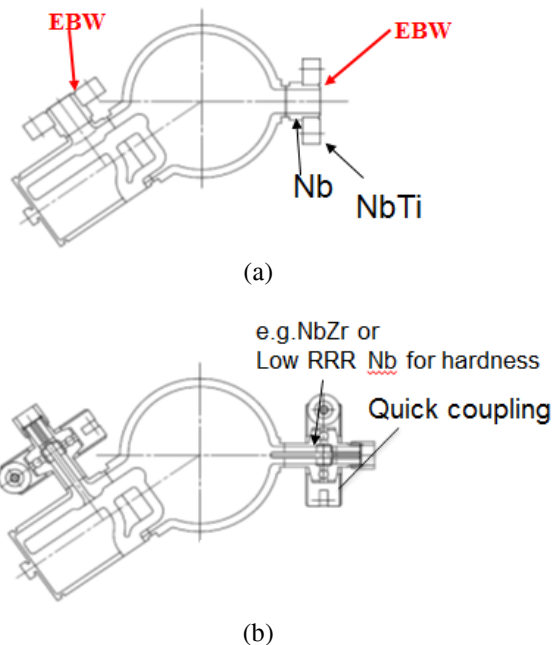


Figure 9: Combination of pick up port and flange (a) Present status, (b) Proposal.

#### Vacuum Chucking for Turning

To reduce process time for cost reduction, we are using special jig and machine as shown figure 10. It is machinable 3 sections in a single setup by using vacuum chucking jig, and it lead to reduce process time and to reduce cost.

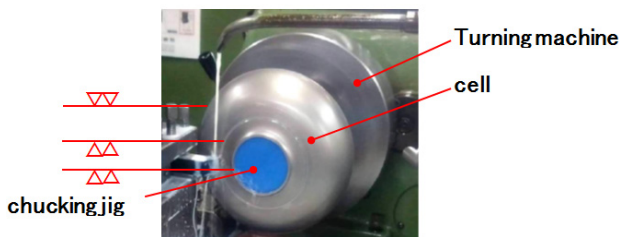


Figure 10: Vacuum chucking for turning.

### MONITORING OF MANUFACTURING TIME

In addition to these new fabrication methods, it is important for mass production to monitor manufacturing time for each process. Figure 11 shows the working-hours transition of the coupler and accelerator body manufacturing for other project (not STF). Figure 11-(a) shows that working hour goes down at first and it becomes stable. It seems that lot production effect is appeared. And figure 11-(b) shows that unstable states are appeared during the process of mass production. This may be lead to analyse and remove the causes of these unstable states and recover the productivity.

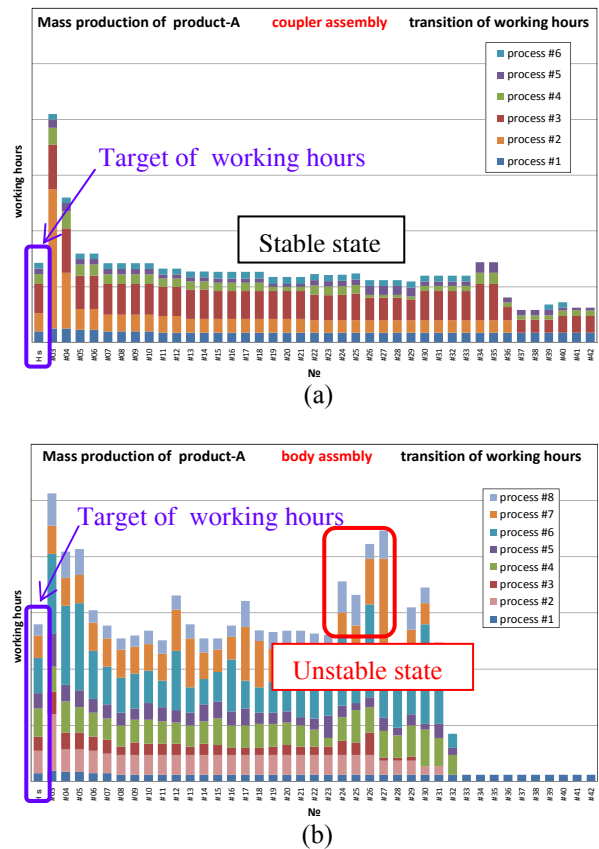


Figure 11: Manufacturing working hours transition (a) Stable, (b) Unstable.

### COST ANALYSIS

We analysed cost ratio of cavity with LHe jacket for more than 3,000 cavities without Nb, NbTi and management cost. Table 3 shows the result of cost analysis. This analysis was done by our company, so this ratio depends on each company. The ratio of material for LHe jacket is much higher by spec of own rigidity, accuracy and frequency tuner type, so it needs to review of titanium thickness and the structure. And the ratio of surface process for cavity is much higher, so it needs to develop a low-cost procedure for EP or new surface process. We industry and laboratory need to cooperate with each other and make efforts to good solution.

Table 3: Cost Ratio of Cavity with LHe Jacket

	Material	HP-code	Mechanical Machining	Welding & Assembly	Inspection	Surface process	Sub-total
Cavity	3*	1	12	15	5	23	59
LHe Jacket	13	1	6	5	3	0	28
Jigs & Factory investment	0	0	2	2	2	9	13
Sub-total	16	2	20	22	10	32	100

(\*): without Nb/NbTi. Only Ti.

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## CONCLUSION

- QCD are important things for Industrialization. Industry need to know target price for making efforts to the target.
- We have improved the quality of cavity step by step and almost achieved the ILC spec. We have to maintain the level of quality by various inspections. The criteria of inspection are important for management.
- We have reduced the cost and shorten the delivery time by changing the design and improving the productivity step by step. Improving the productivity is realized by monitoring each process at production site.
- As the material of LHe jacket and surface process of the cavity are much expensive, some improvements are needed from the view point of cost reduction.
- We keep to propose and verify various improvements steadily in according with general principle of cost reduction for realizing ILC as a industry.

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