13. Cost Effective Cavity Fabrication Method

13.1 Large Grain Niobium Cavity

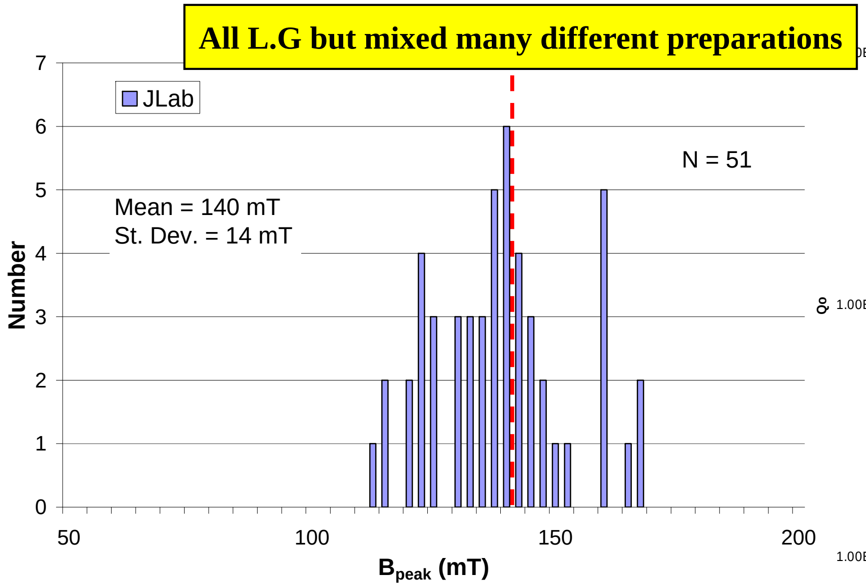
13.2 Seamless Spun Cavity

13.3 Nb bulk Hydro-formed Seamless Cavity

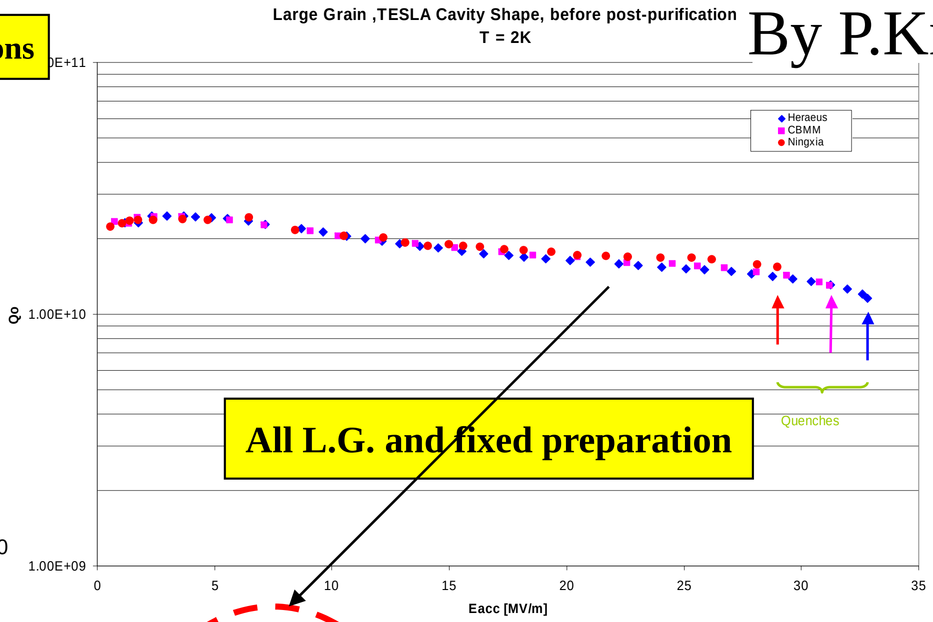
13.4 Nb/Cu Clad Cavity

13.1 Large Grain Cavity

Large grain Nb produce a small performance scatter (5%) but No way to the ILC BCD performance with BCP



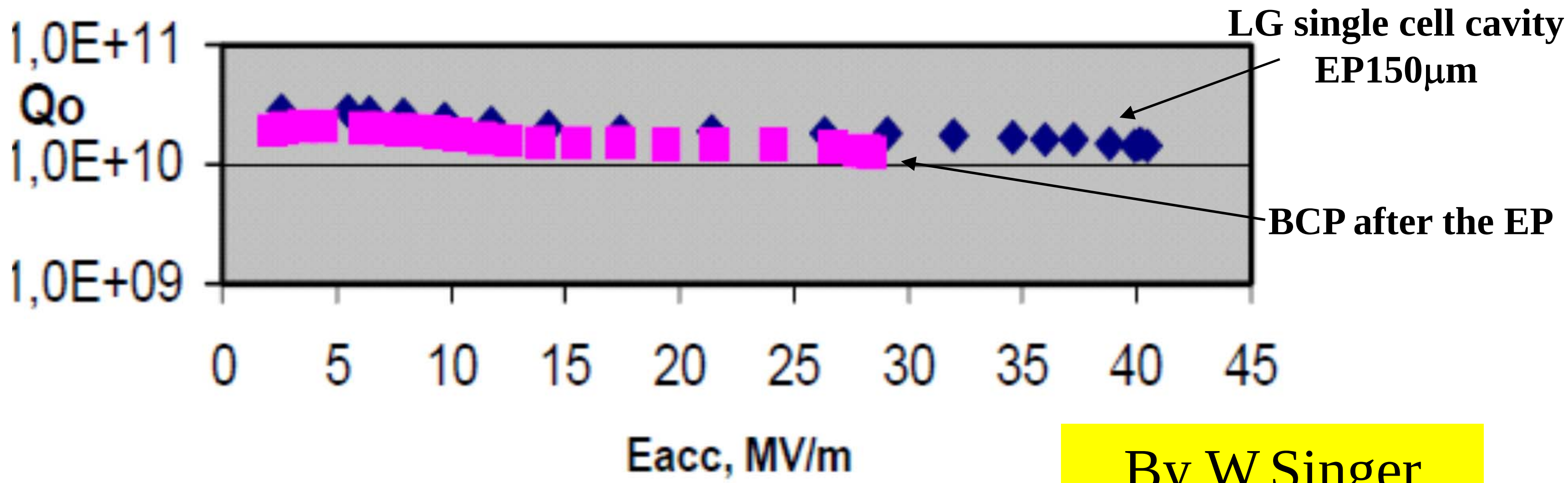
By P.Kneisel



After post purification

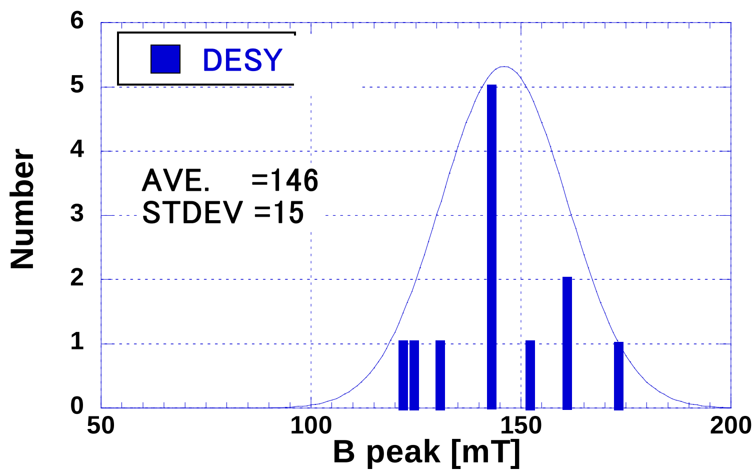
Supplier	Cavity Type	Ta - contents	RRR	Test ½ H_{max} [mT]	Test ½ Q_0 at H_{max}	Test ¾ H_{max} [mT]	Test ¾ Q_0 at H_{max}
W.C.Heraueus	TESLA	<500 ppm	500	140	1.15×10^{10}	146	1.05×10^{10}
Ningxia	TESLA	~ 100 ppm	330	123	1.5×10^{10}	142	1.14×10^{10}
CBMM	TESLA	~ 800 ppm	280	133	1.3×10^{10}	131	1.04×10^{10}
CBMM	Proton Driver	~ 800 ppm	280	139	7.5×10^{9}	148	6.9×10^{9}
CBMM	Proton Driver	~ 800 ppm	280	133	4.4×10^{9}	135	1×10^{10}

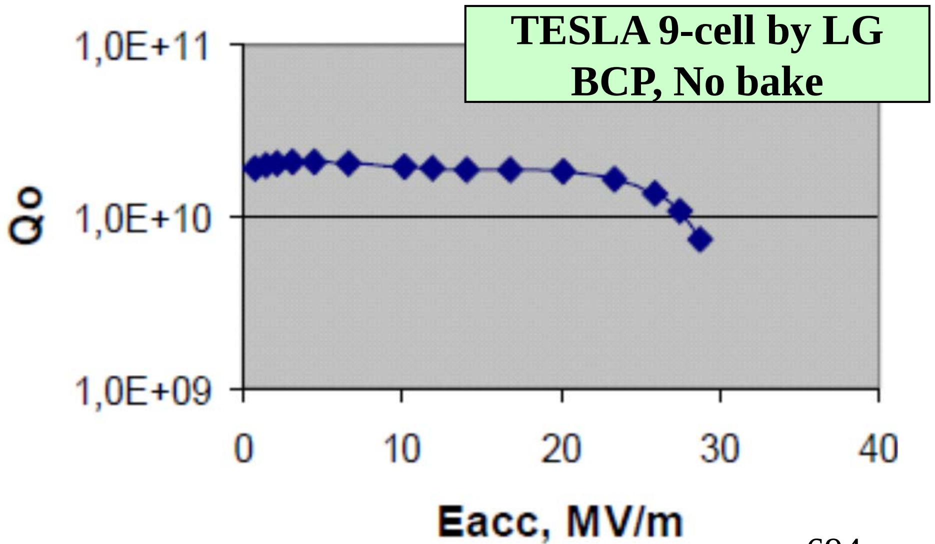
Large grain Nb cavity is close to the ILC BCD performance but The scatter still ~10%



By W.Singer

Statistics of LG with single cell cavity @ DESY

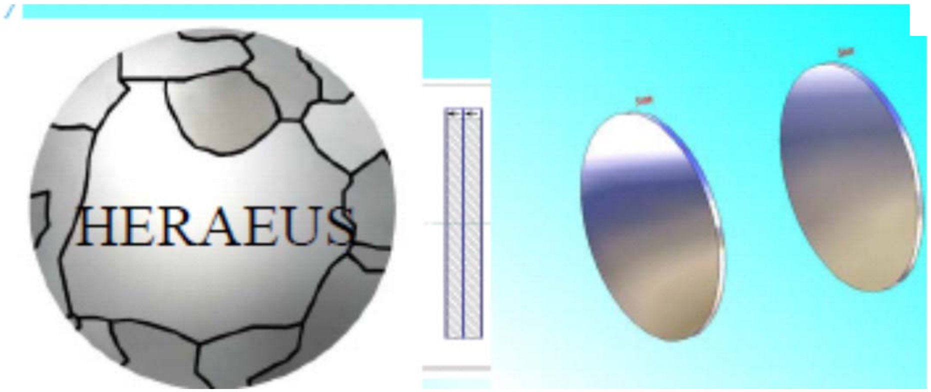




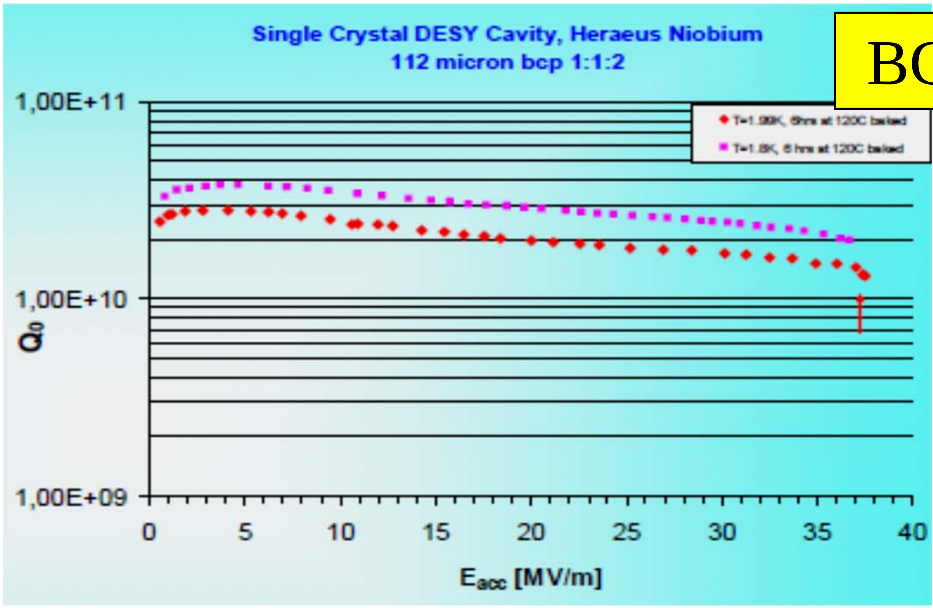
Eacc ave=34.3±3.5MV/m(10.3%)

Single crystal Nb cavity (1.3GHz single cell cavity) @ DESY

By W.Singer



Measured at JLAB by P.Kneisel

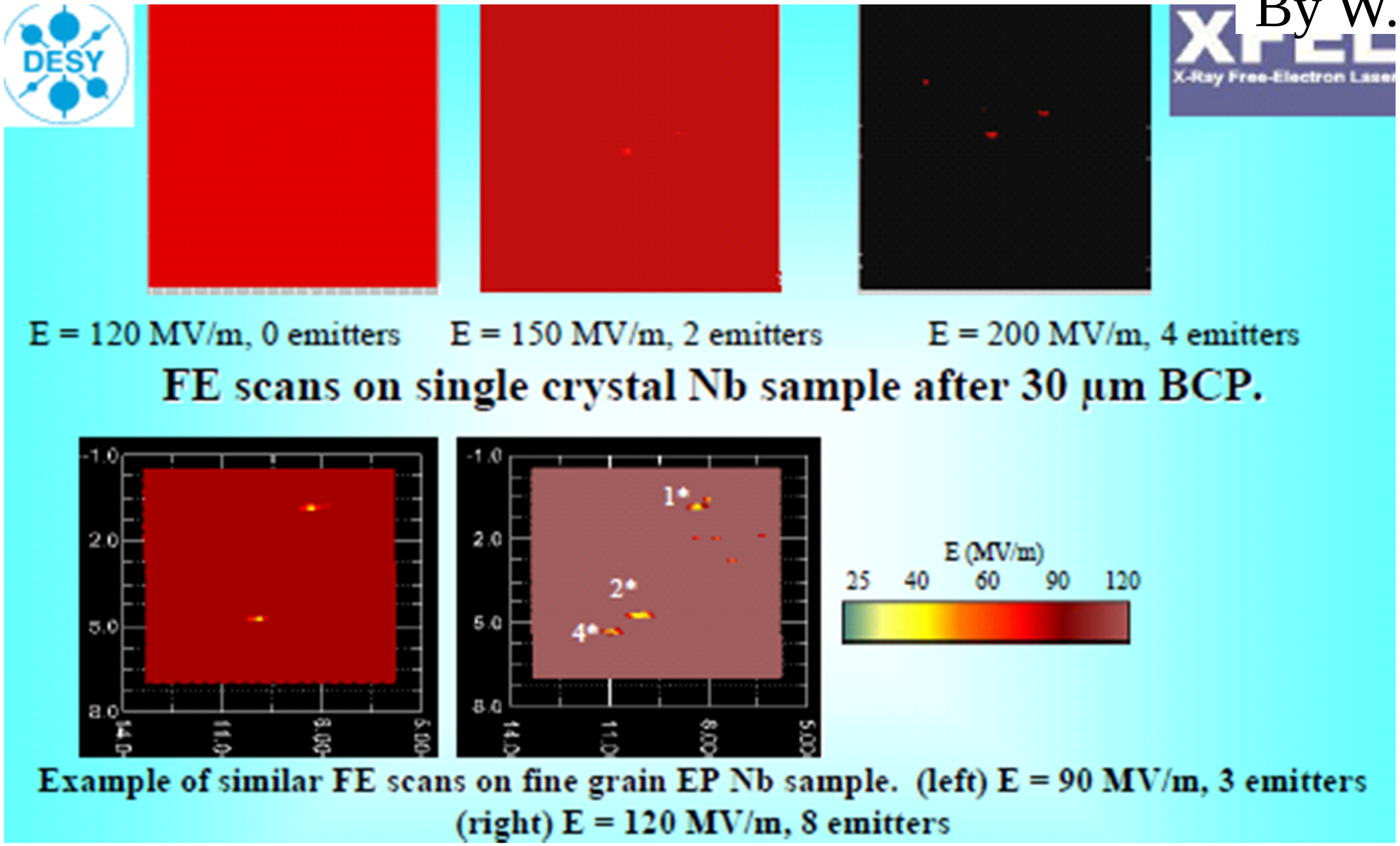


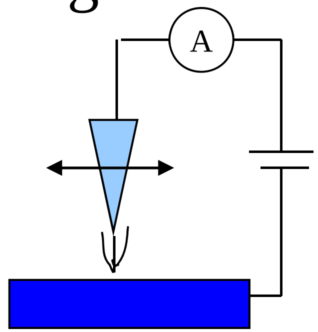
BCP+HPR+Bake

Reached the ILC BCD!

FE. set on field on single crystal niobium

By W.Singer



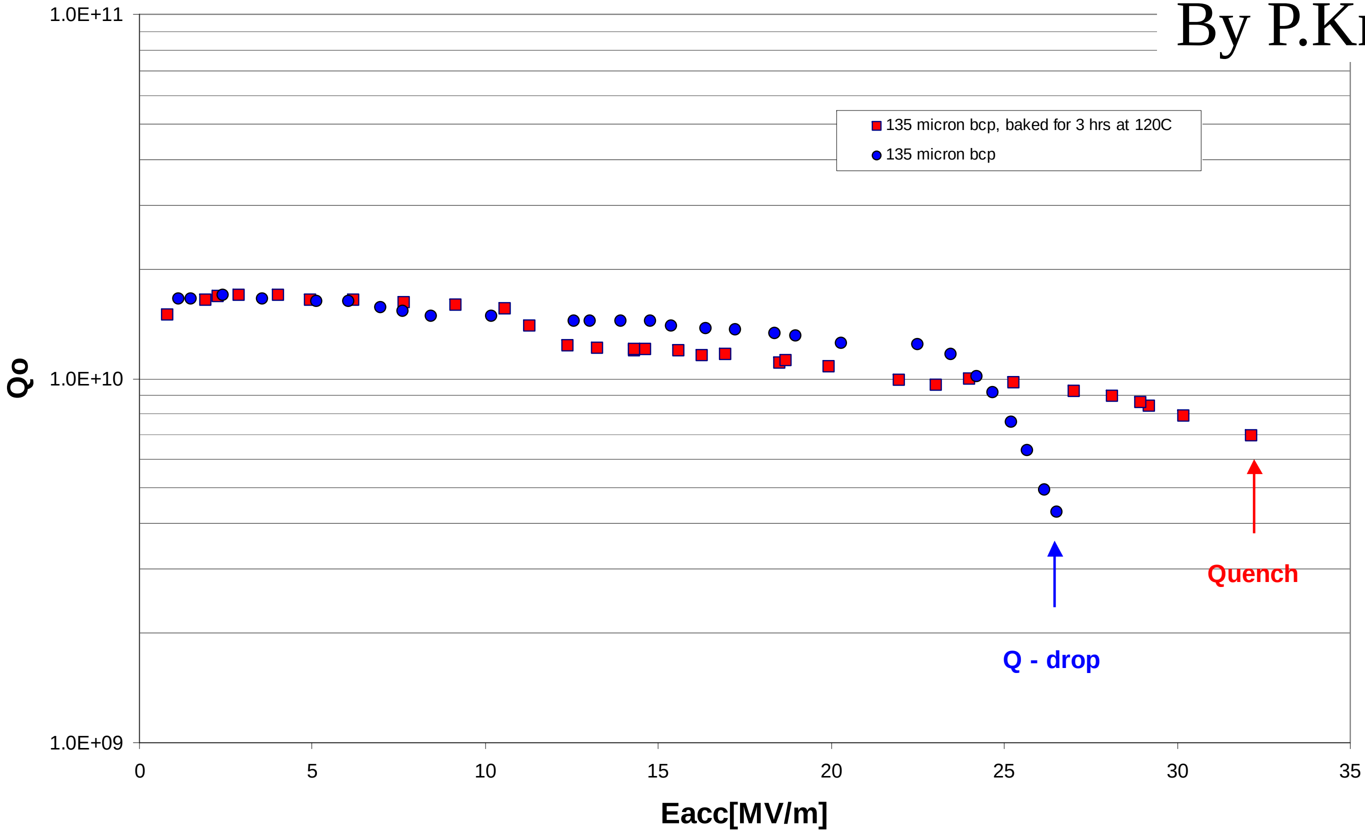


Ep=120MV/m ⇒ Eacc =50MV/m with ICHIRO cavity

Shorter Baking on L.G/Single crystal cavities

Baking effect appears for 3hr on single crystal cavity

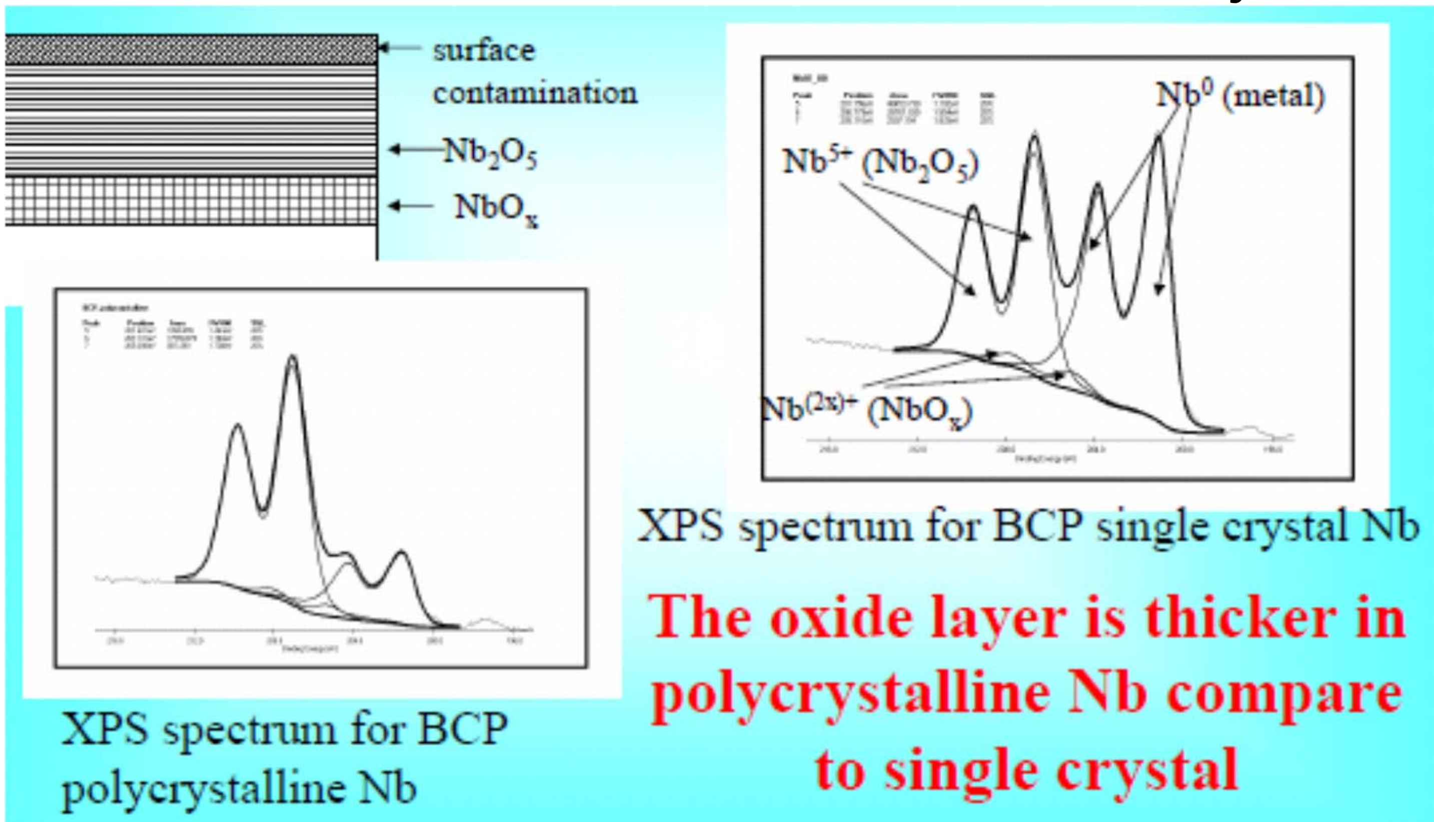
By P.Kneisel



12 hr baking is enough for both BCP'ed/EP'ed cavities.

Oxygen contamination layer is thinner on the LG/Single crystal Niobium

By W.Singer



The thinner oxygen layer can explain why baking period is shorter with LG/single crystal cavities.

Orientation of the Crystal Surface

Miller index

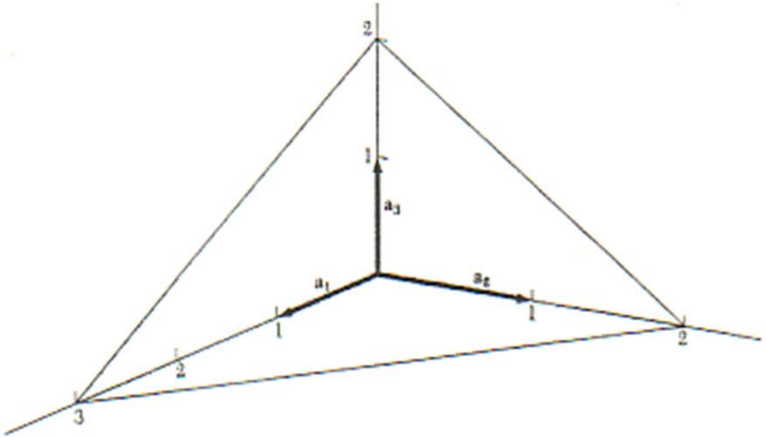


Figure 15 This plane intercepts the a_1, a_2, a_3 axes at $3a_1$, $2a_2$, $2a_3$. The reciprocals of these numbers are $\frac{1}{3}$, $\frac{1}{2}$, $\frac{1}{2}$. The smallest three integers having the same ratio are 2, 3, 3, and thus the indices of the plane are (233).

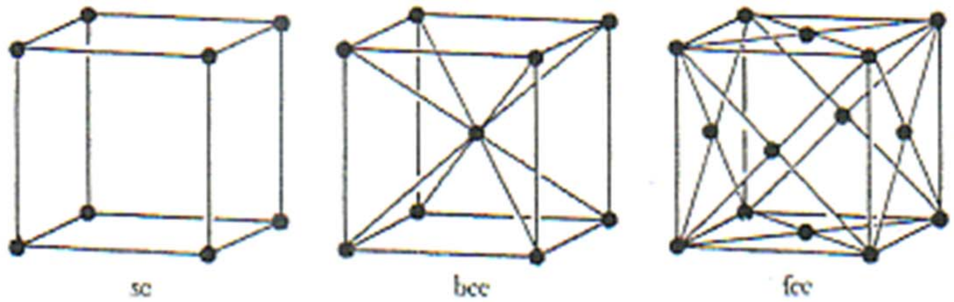
Ex. $(3a_1,2a_2,2a_3)$

$(a_1/3,a_2/2,a_3/2)$

x 6

(2,3,3)

Nb



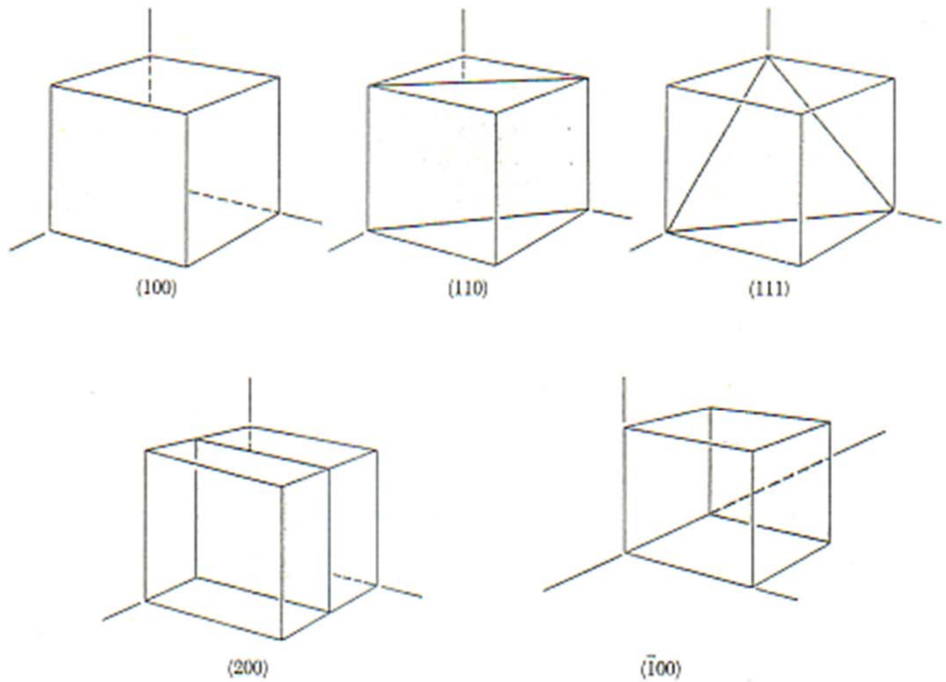
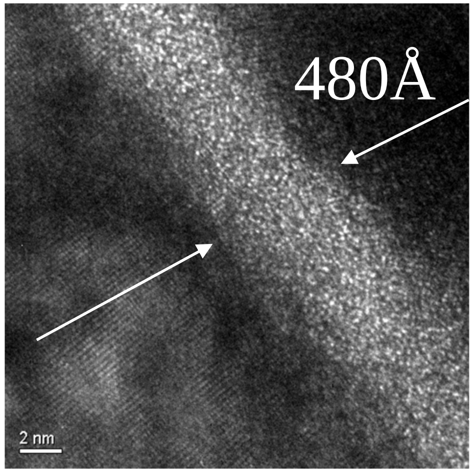


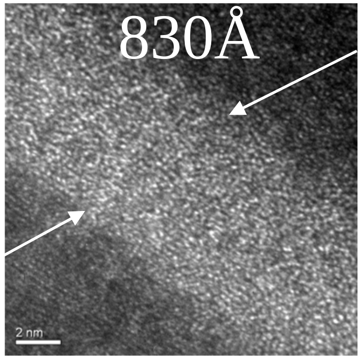
Figure 16 Indices of important planes in a cubic crystal. The plane (200) is parallel to (100) and to $(\bar{1}00)$.

Thickness of oxygen contamination layer is different among crystal orientations

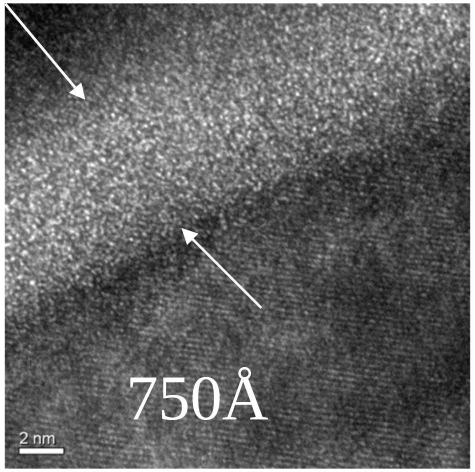
By P.Russel, NC State University



(1,0,0)



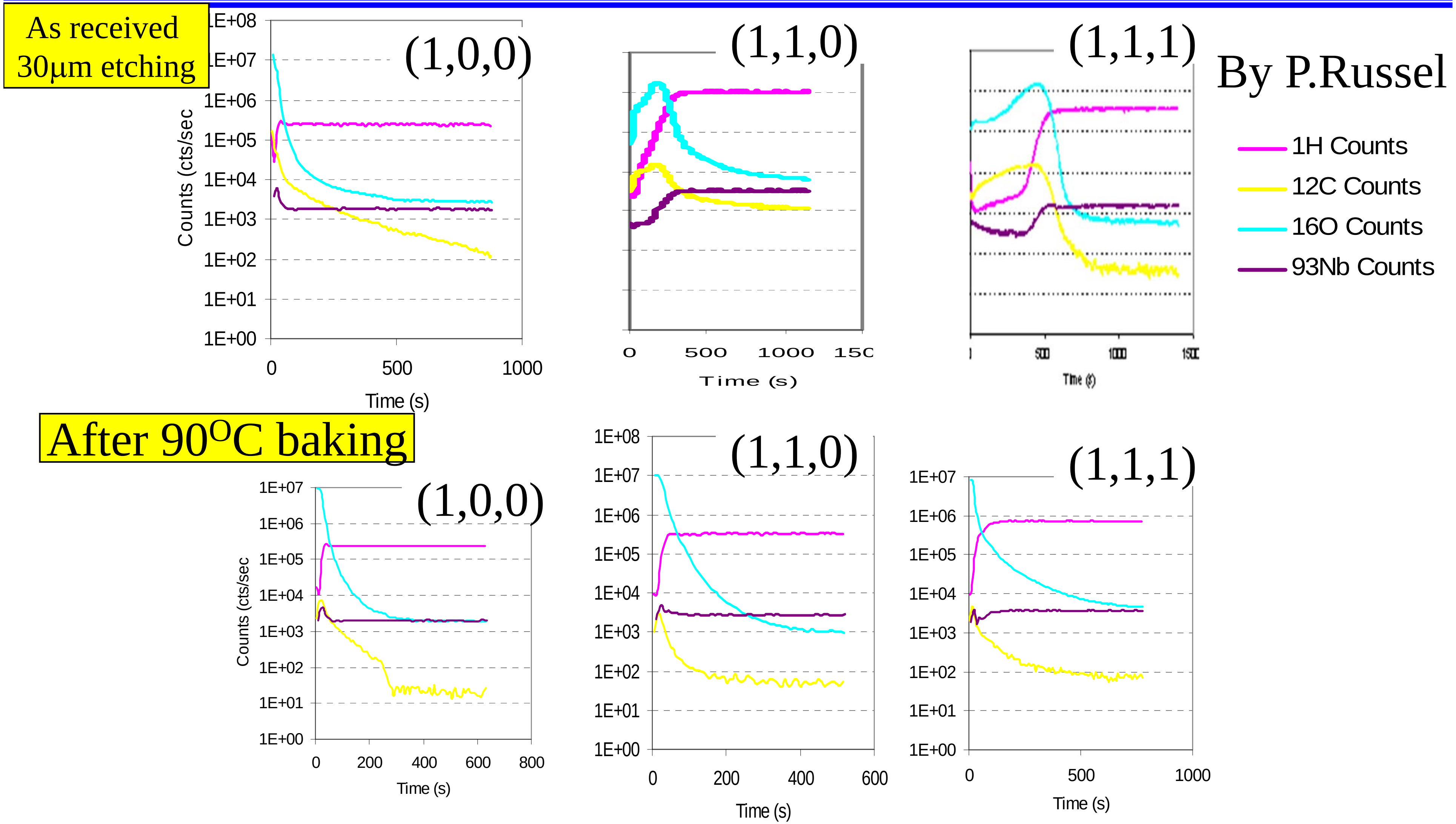
(1,1,0)



(1,1,1)

Orientation	(1,0,0)	(1,1,0)	(1,1,1)
Surface density ratio	1	$\sqrt{2}$	$\frac{1}{\sqrt{3}}$
O thickness [Å]	480	830	750

(1,1,0) and (1,1,1) surfaces have ticker O/C contamination layers with as received



After 90^{O}C baking, the O/C contamination layers disappear.
Q-slope might be related to the contamination?

Benefits/Disadvantages of LG Nb

Benefits

1) Cost reduction

   Opinions are distributed 10-50% reductions

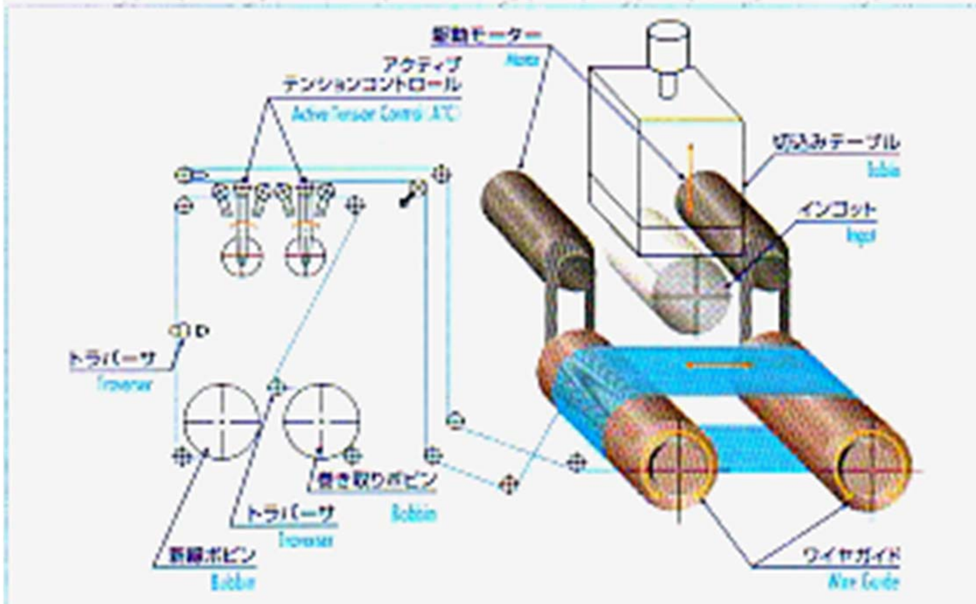
   Development of the ingot slice machine is a key.

2) Narrow performance scatter
3) Shorter Baking period
4) No Magnetic shield ??

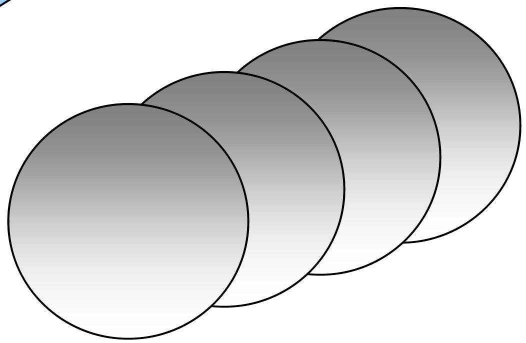
Disadvantages

1) Machining error
2) Stiffness

An Idea for Cost-effective Nb sheet production



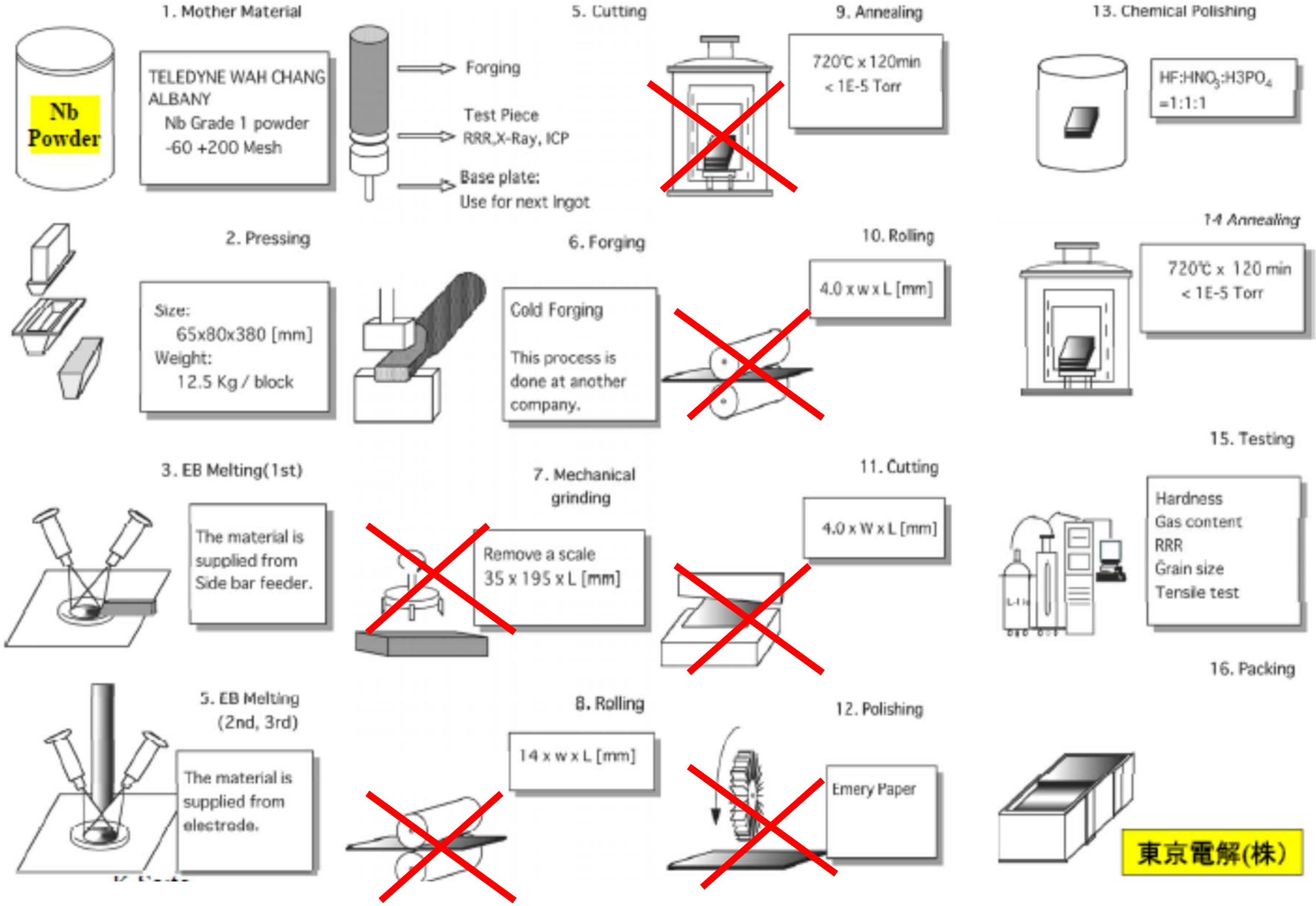
インゴットをスライス



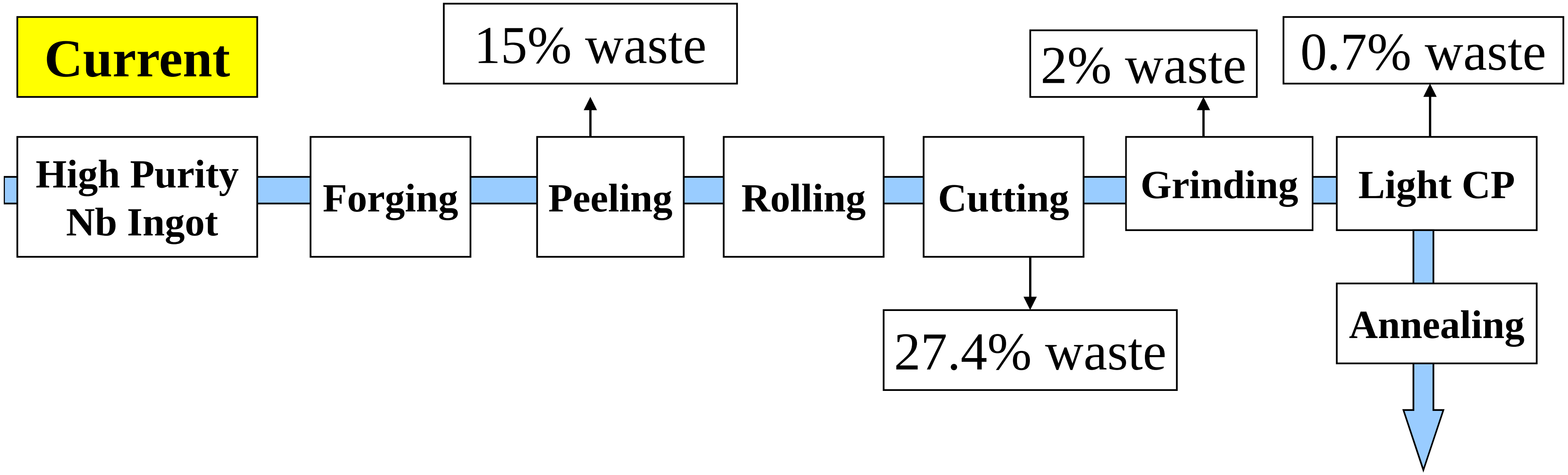
11-13/May/2011
K.Saito

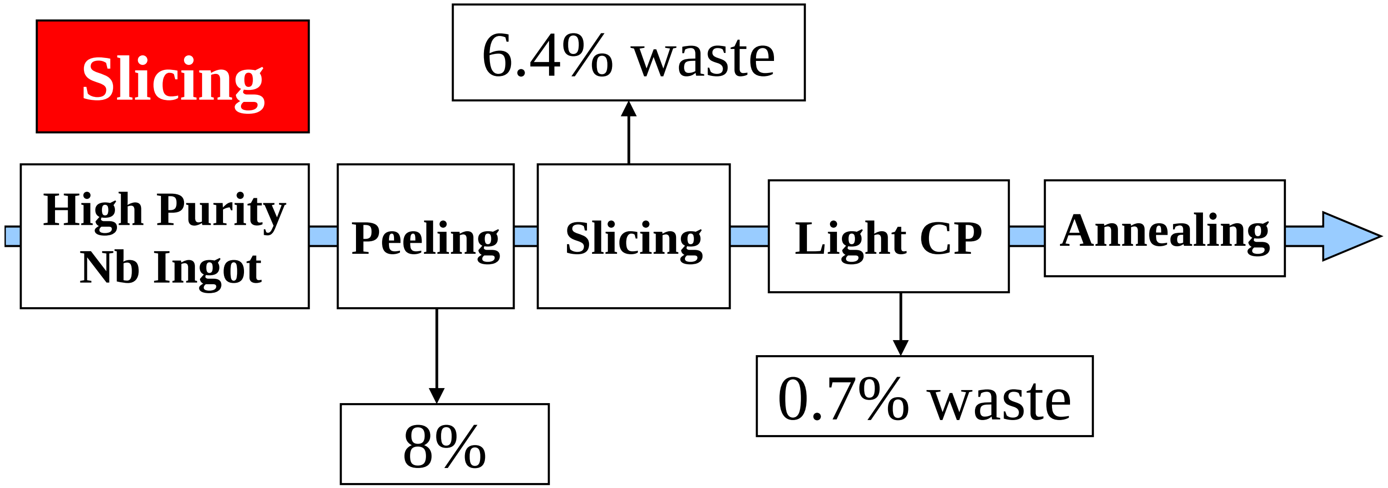
How simple in the sheet Nb production from L.G. ingot

By H.Umezawa



Estimated Nb waste in high purity Nb sheet production



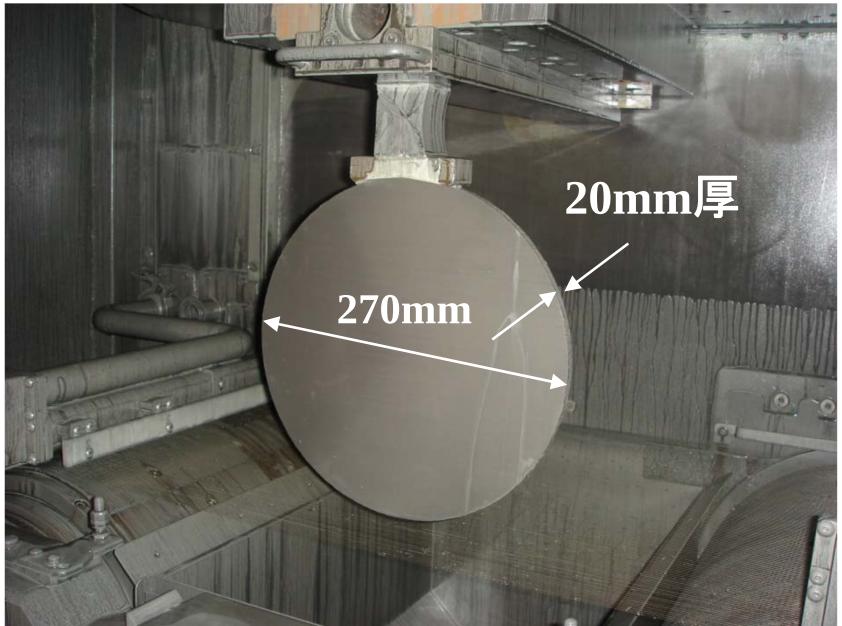


	Waste ratio [%]
Current	**45.1**
Slicing	**15.1**

Successfully Developed Wire Sawing Method for Nb Ingot

KEK/Tokyodenkai/Izumi-tech

インゴットのスライス法に関する
特許申請中！



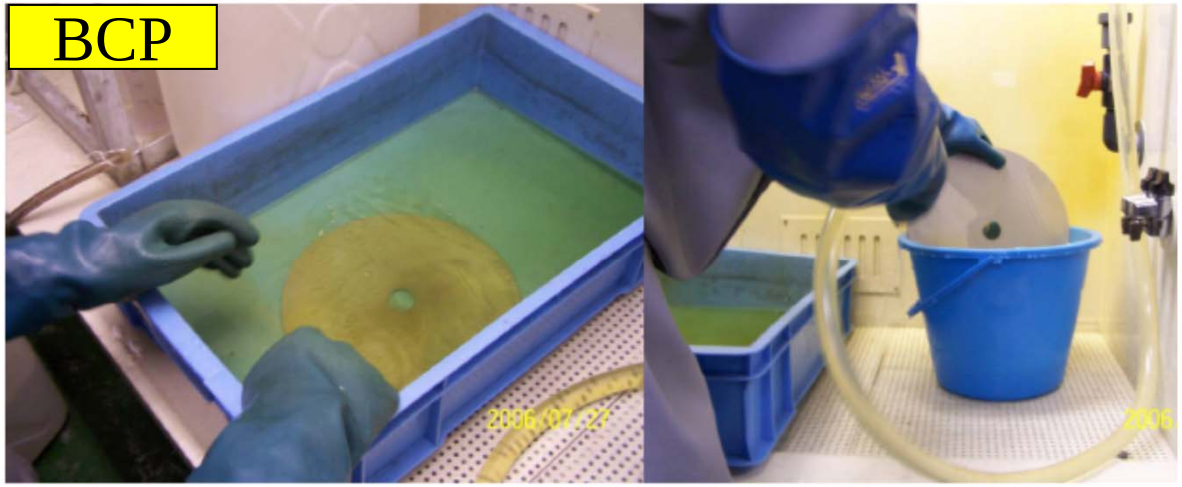
所時間:39時間

LG Nb ingot Wire sawing sample

ニオブ材料コスト半減か！？

Material cleaning @ KEK

BCP

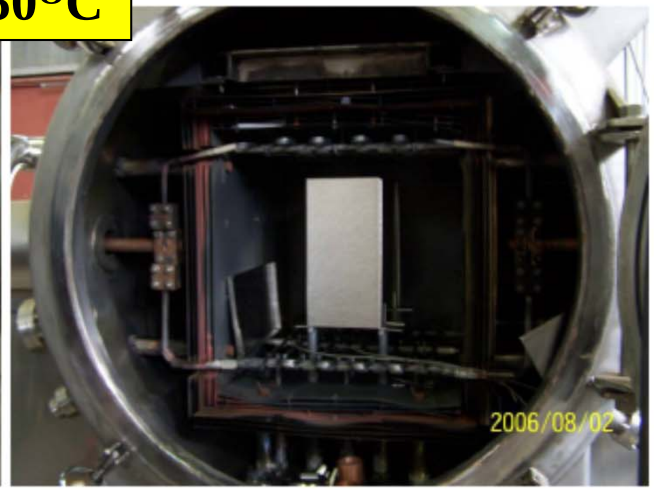


Ultrasonic rinsing

HF, HNO3 and H3PO4 in the ratio 1:1:1; about one minute per piece.

Annealing @ 750^{O}C

Ti box



Deep Drawing on CBMM material

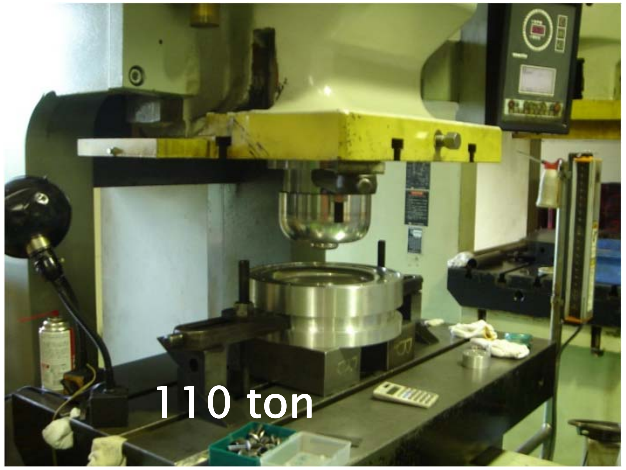
Thickness

Before Deep Drawing

Large Grain from CBMM

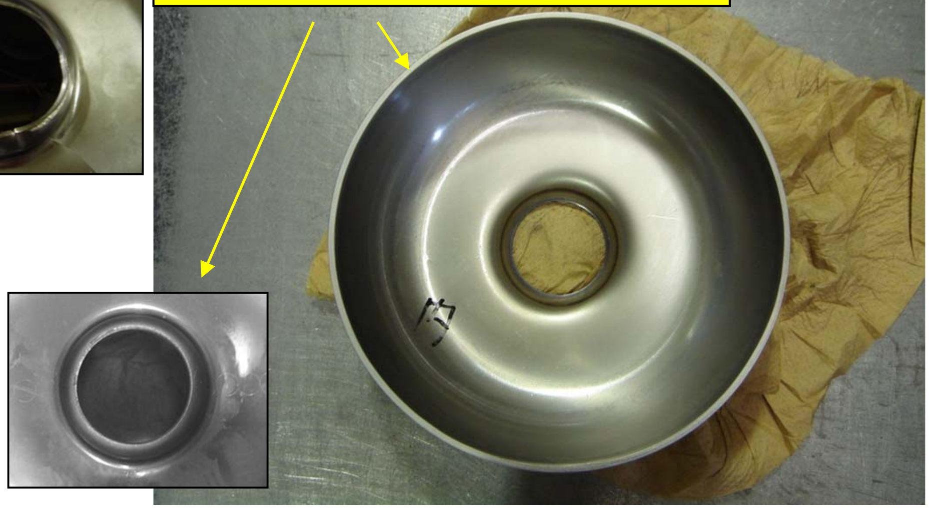
: 2.75, 2.80 mm

Fine Grain : 2.80 mm

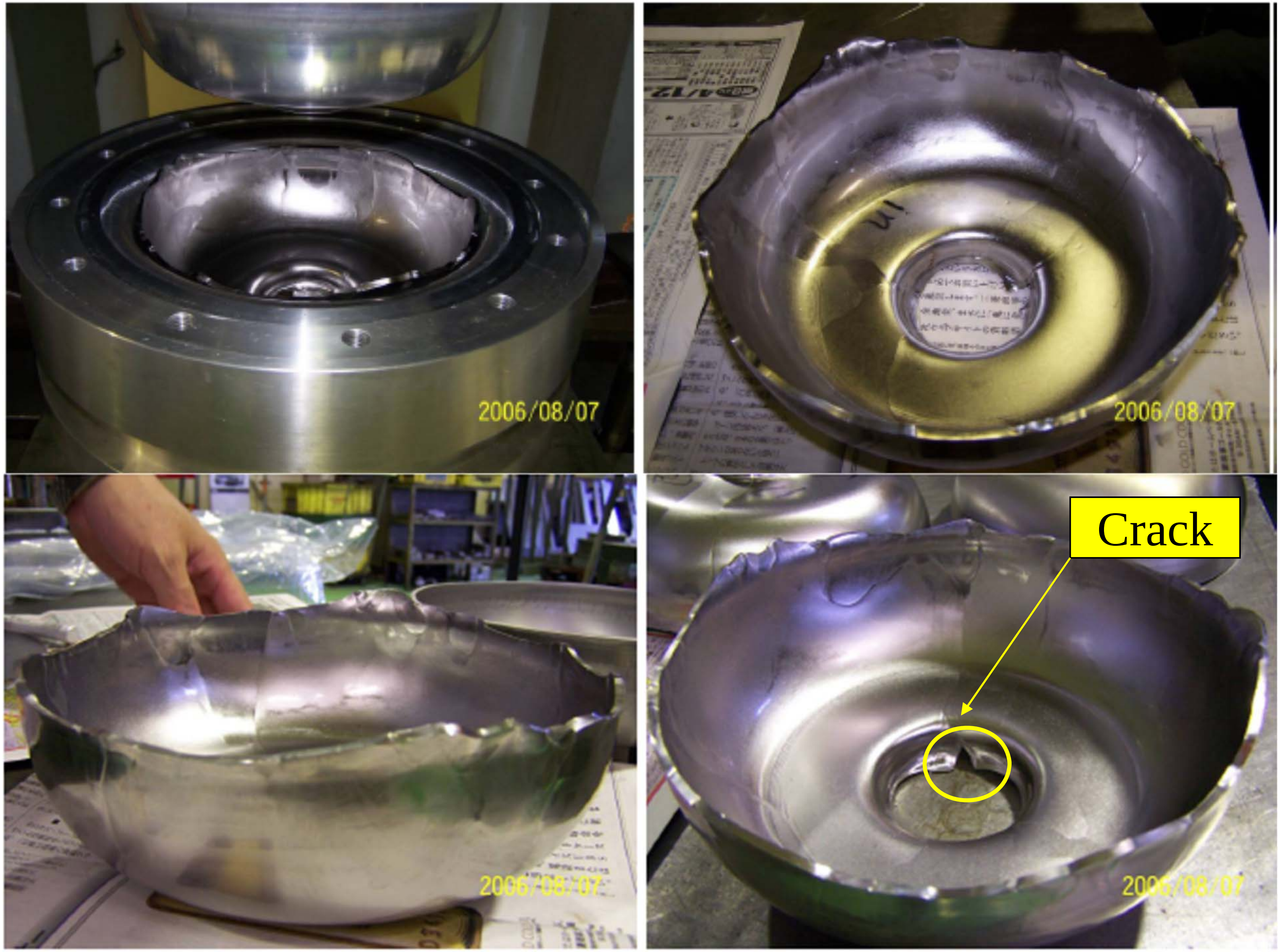


CBMM large grain

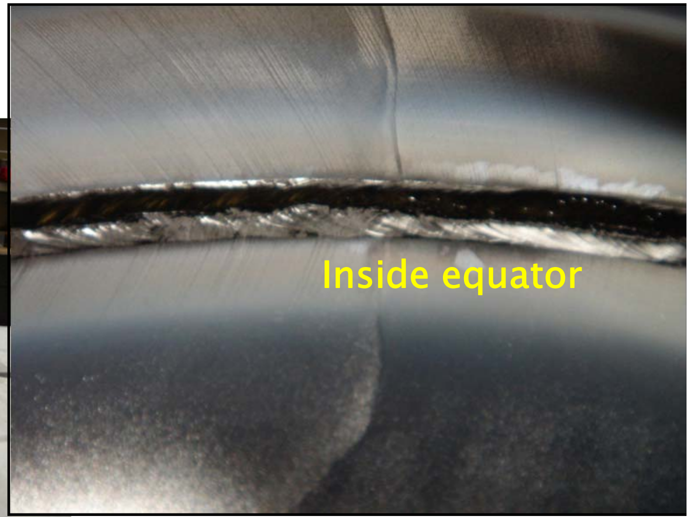
Tokyo Denkai fine grain



Deep Drawing for Ningxia material



EBW @ KEK Machine Shop

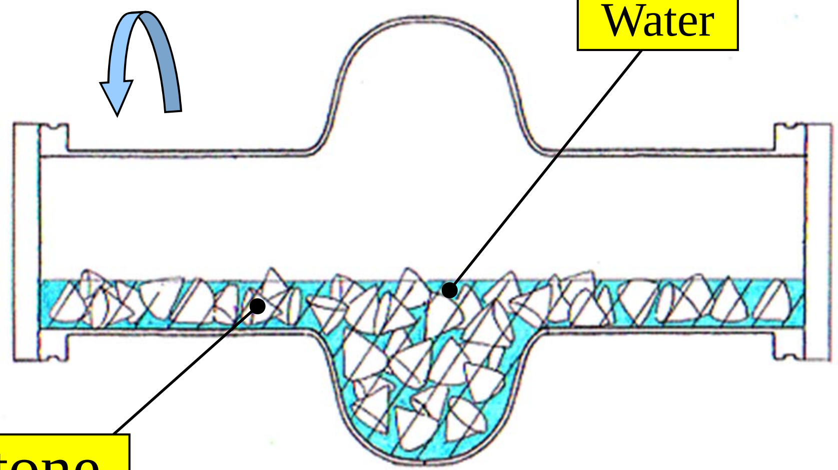


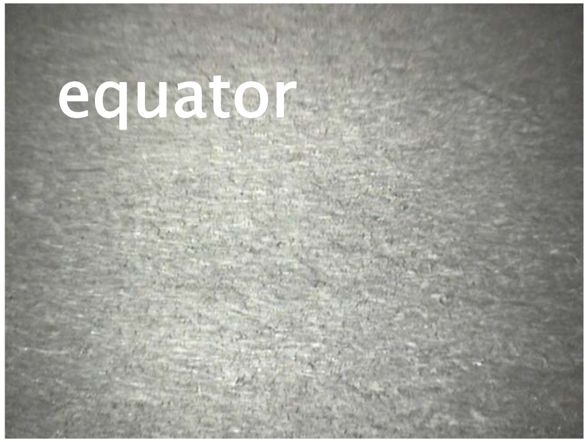
CBP(Centrifugal Barrel Polishing)

Rotated ~100rpm on a oppositely rotating table

CBMM cavity

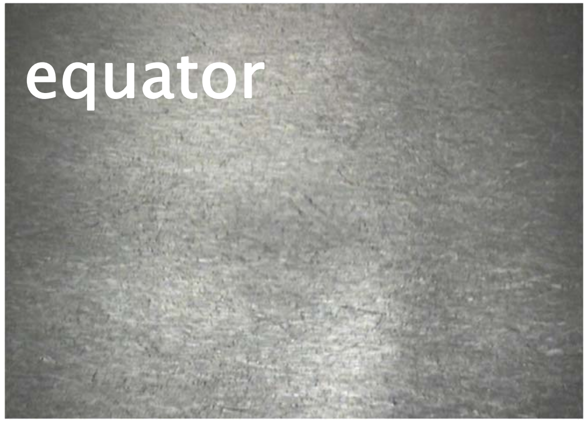
Rough stone : 5 times
Green stone : Once
Brown stone : Once
White stone : Once
Totally ~ 200 **μm removed @ equator**





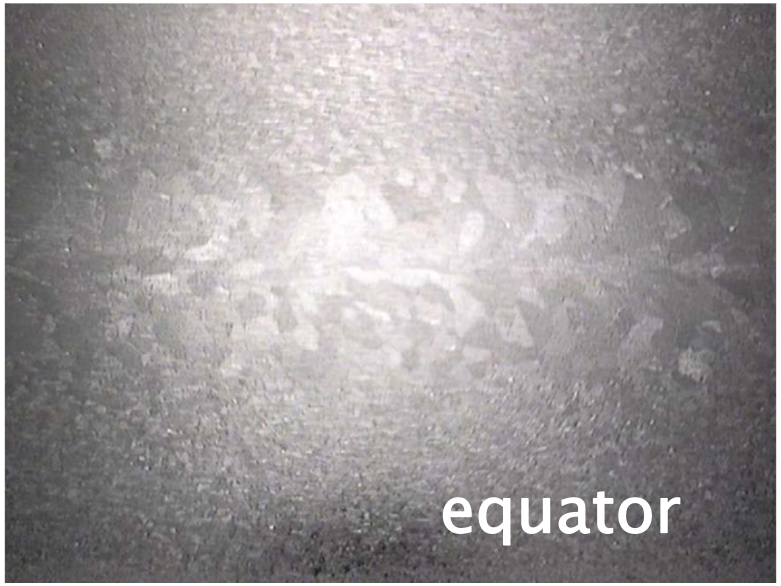
Fine grain cavity after CBP

Remove
large defects!



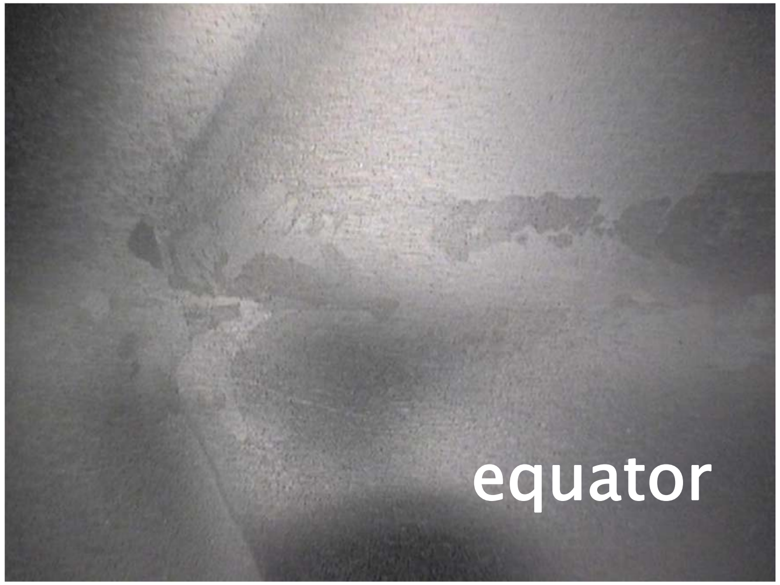
Large grain cavity after CBP

Surface Cleaning by BCP(~10μm) after BCP



Fine Grain Cavity after CP and Annealing

10 μm **each**



Large Grain Cavity after CP and Annealing

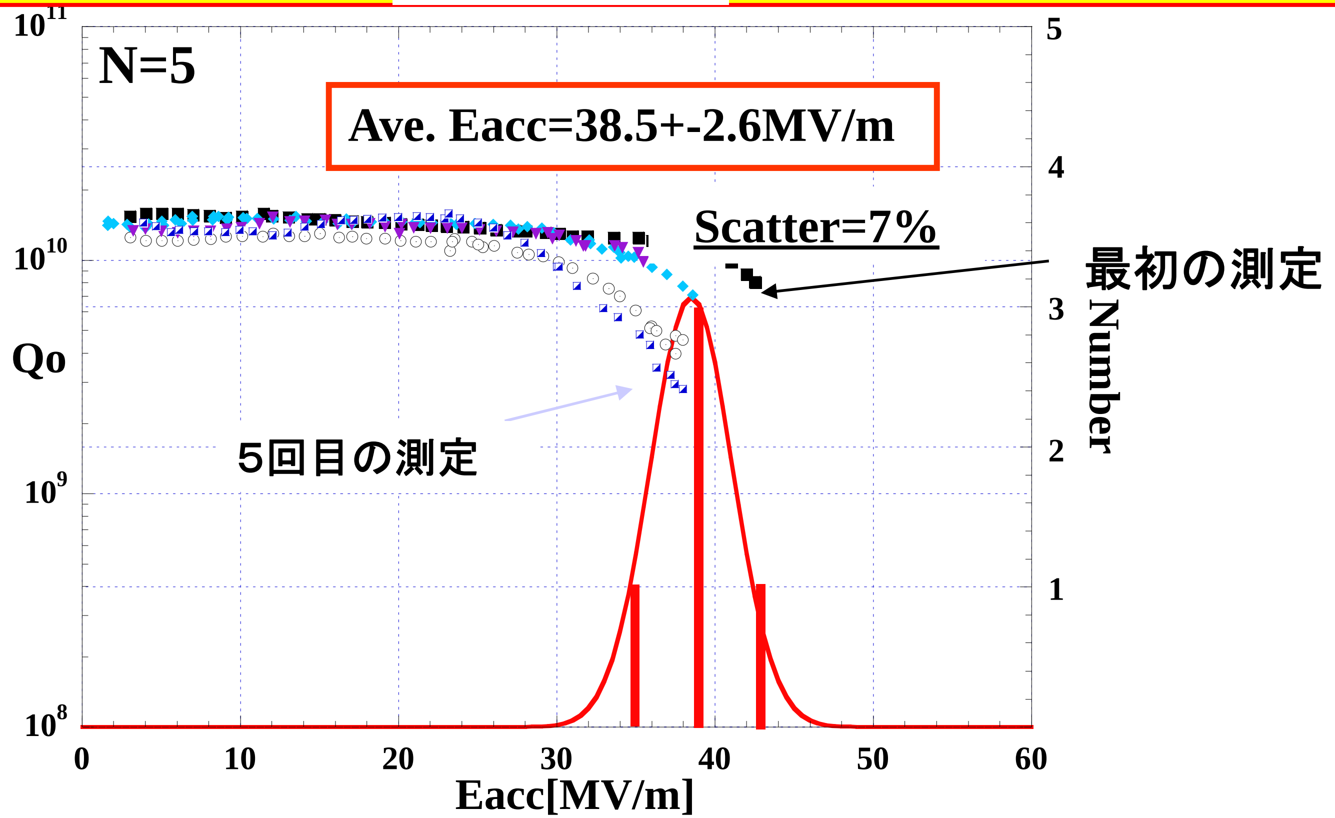
インゴットスライス法によるニオブ板材から製作した巨大結晶単セル空洞のTight Loop試験結果

CBP+AN+CP(170μm)

CPでの研磨量が170μm程度必要であることが、P.Kneiselの研究で分かっている。

+CP(30μm) +Wiping +HPR (15min.)+Baking(120^{O}C*48hrs)+縦測定

Tight Loop Test



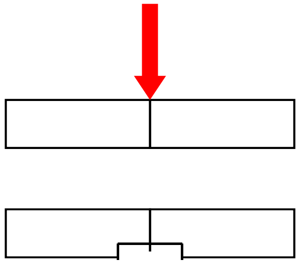
Q-slopeのonsetが追加CPと供に下がってくる。
エッチングされて粒界ステップが大きくなる。 Magnetic field enhancement?

巨大結晶9ーセル空洞のEBWの問題点と対策

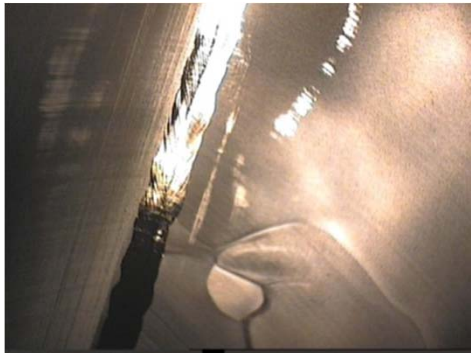
EBWの時のニオブドロップだれを補正した
従来トリム加工とそのEBWシーム

結晶異方性による成型歪を強制修正するために
嵌めあいにしたトリム加工とそのEBWシーム

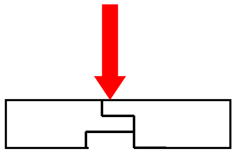
電子ビーム



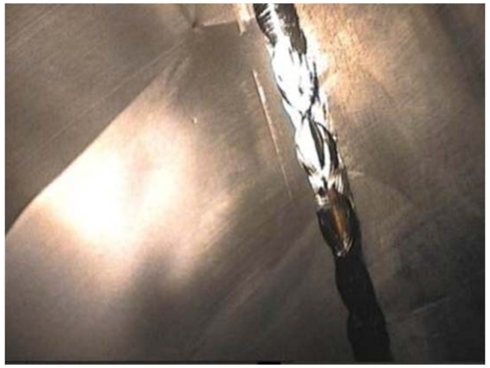
我々のトリム法



電子ビーム

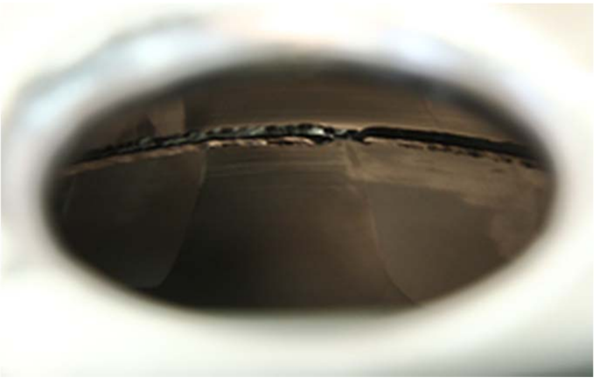


今回ENDセルに適用した
嵌合トリム



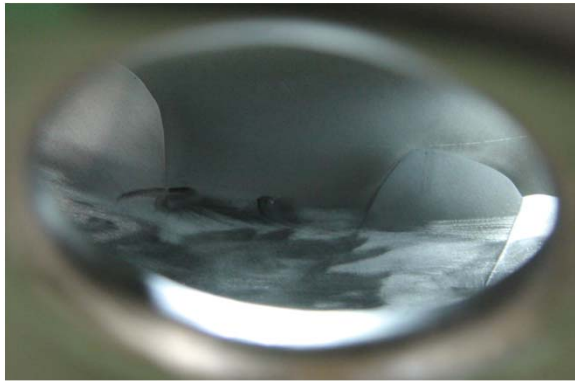
赤道部電子溶接部のトリム形状とEBWシーム(空洞内面)

Dumbbell組立EBW途中で起こったEBWシーム不良部とその局部機械研磨除去



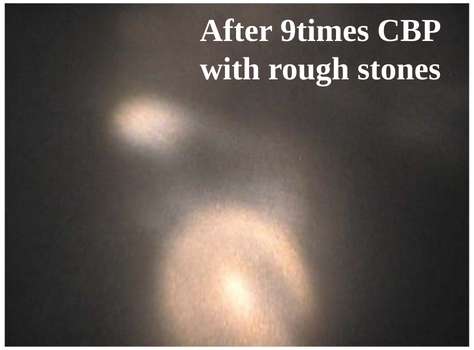
EBW不具合箇所(5セル赤道部)

リューターによる部分機械研磨

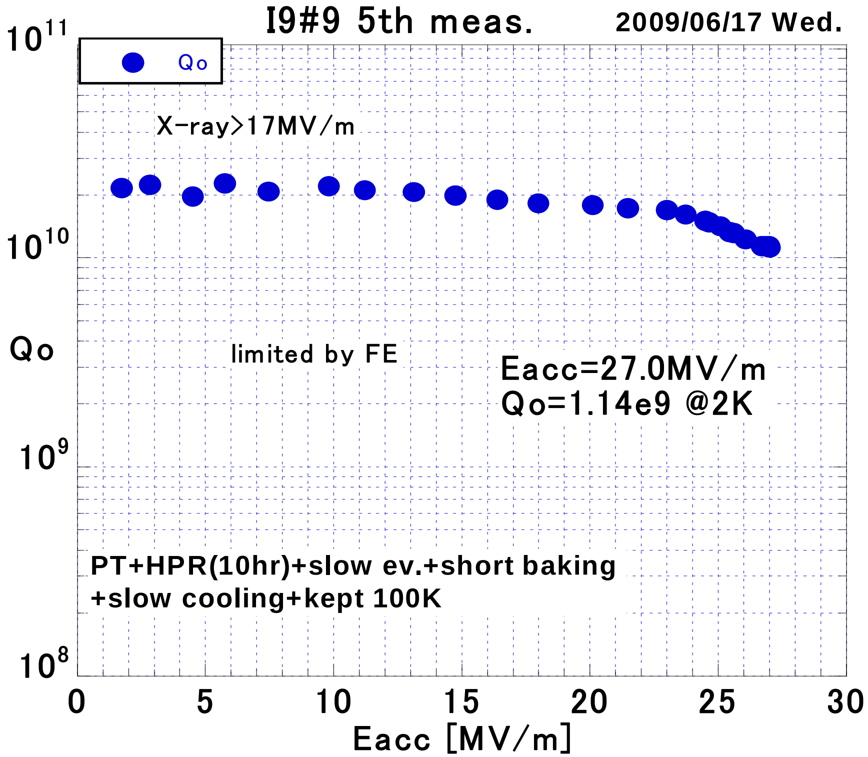


機械研磨後

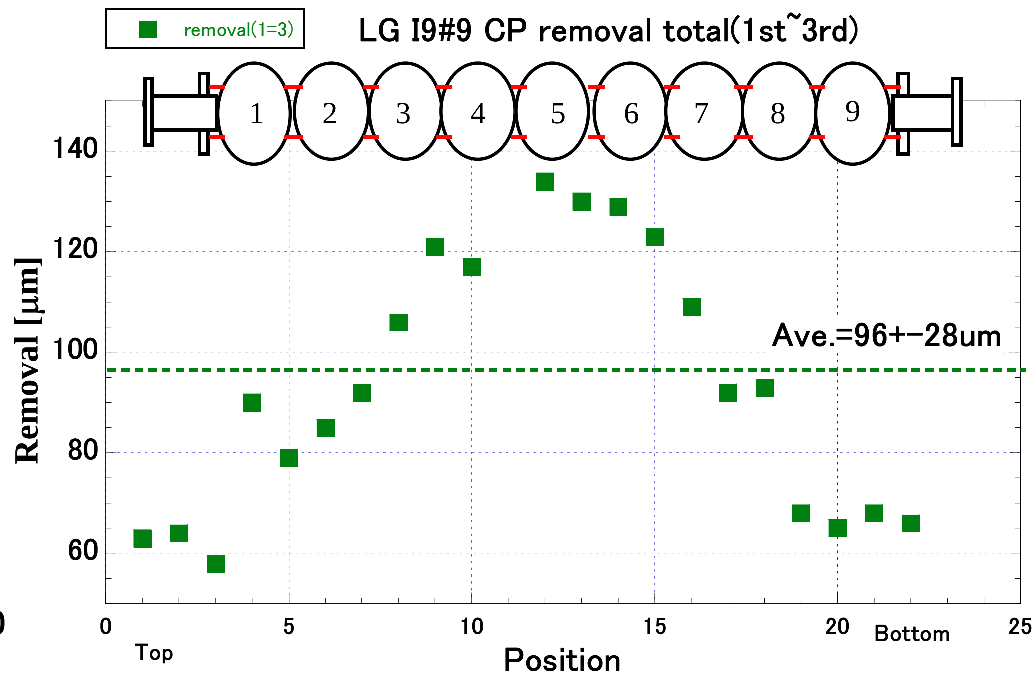
遠心バレル研磨による赤道部EBWの欠陥部の除去



Ichiro#9 LG 9-Cell Cavity の性能



96μm CP後の性能



現行CPでの研磨分布

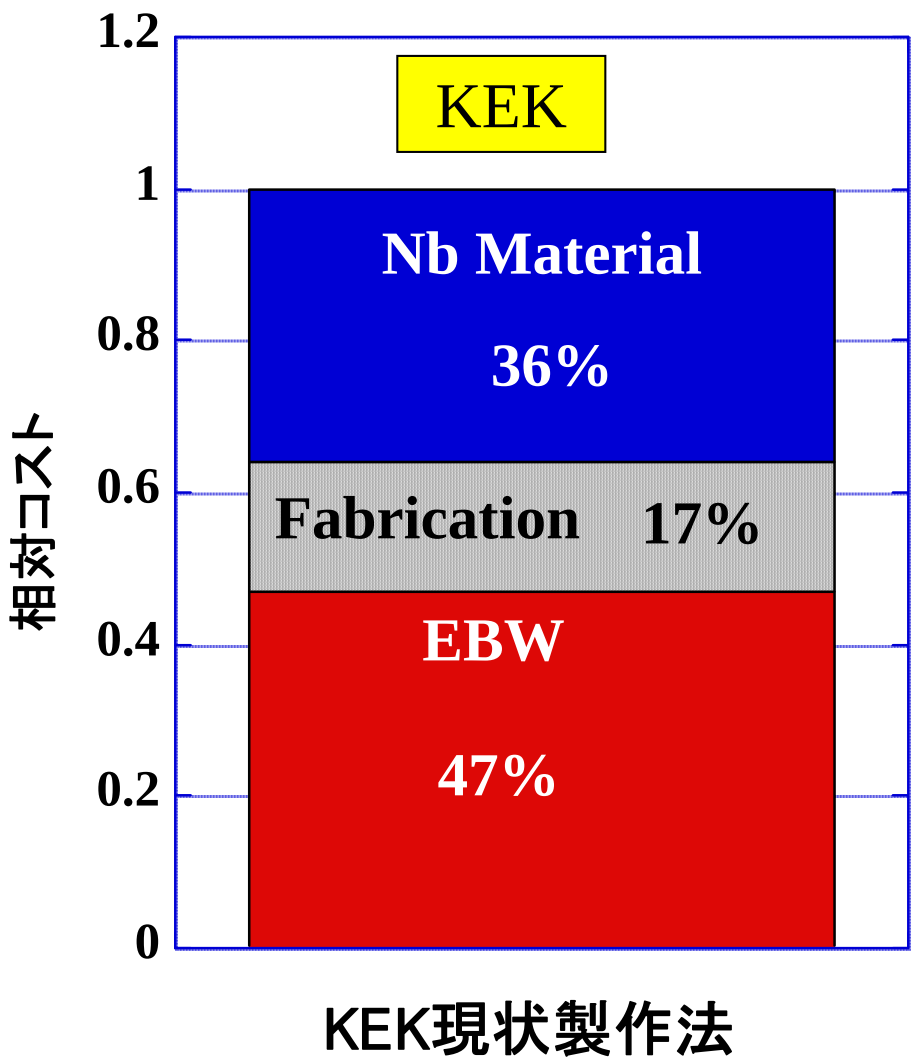
一様研磨できるCP法の開発が急務である。

Large Grain Nb Material

- 巨大結晶ニオブ空洞は、高電界性向上に大きなPotentialを持つ。処理方法が簡単な化学研磨で35MV/mの高電界が得られる可能性がある。
- これまで、巨大結晶ニオブ板材を製作する良い方法がなかったが、我々はシリコンウエハースライス技術を応用して、インゴットをスライスして２０枚レベルのL-バンド空洞用ニオブ円板を４５時間で製作することに成功した。この方法は、大きなニオブ材コスト削減をもたらすであろう。
- その空洞から単セル/９セル超伝導空洞を製作した。
- ９セル空洞の製作では、電子ビーム溶接に若干の問題が発生したが、空洞は完成できた。今後の課題は電子ビーム溶接法の改善である。
- 遠心バレル研磨の後、化学研磨を追加しながら９セル空洞の性能を調べている。平均研磨量100ミクロンで、27MV/mの加速電界を得た。これは、電解研磨並みの性能結果である。
- 単セル空洞の試験結果から170ミクロン以上化学研磨を増やすと、Q-slopeのon-setが下がってくる傾向があり、９セル空洞で各セル一様に化学研磨することが重要である。我々の現行の化学研磨法は、一様研磨できず、改善する必要がある。

13.2 Nb Seamless Cavity

Present Fabrication Cost



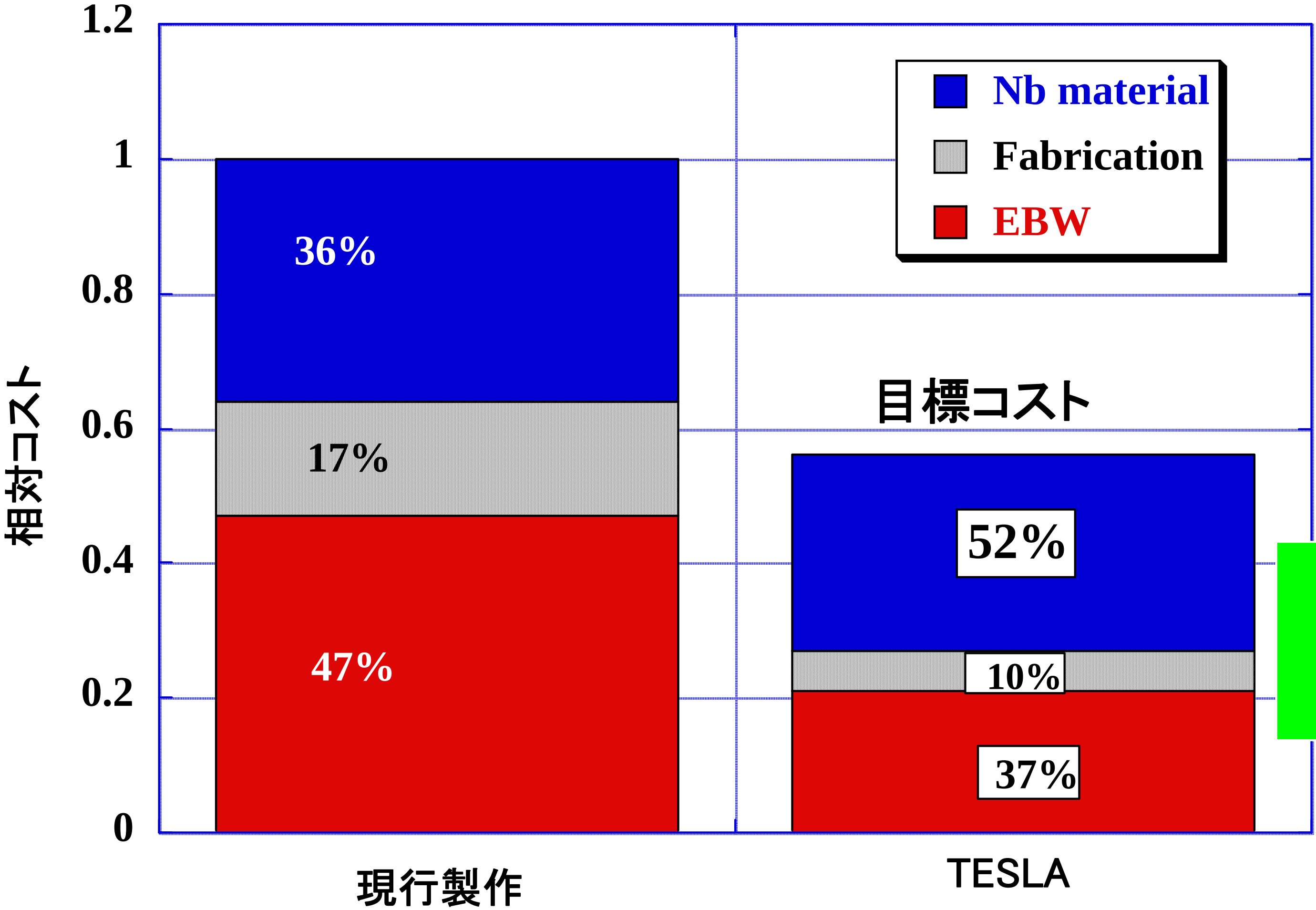
ニオブ材料費とEBWが全体の80%を占めている。

コスト削減のためにはこの二つを何とかしなければならない。

Europe (INFN-LNL, DESY):
Nb bulk seamless cavityの開発

KEK:
Nb/Cu clad cavityの開発

Estimated TESLA Fabrication Cost：Mass-production Effect

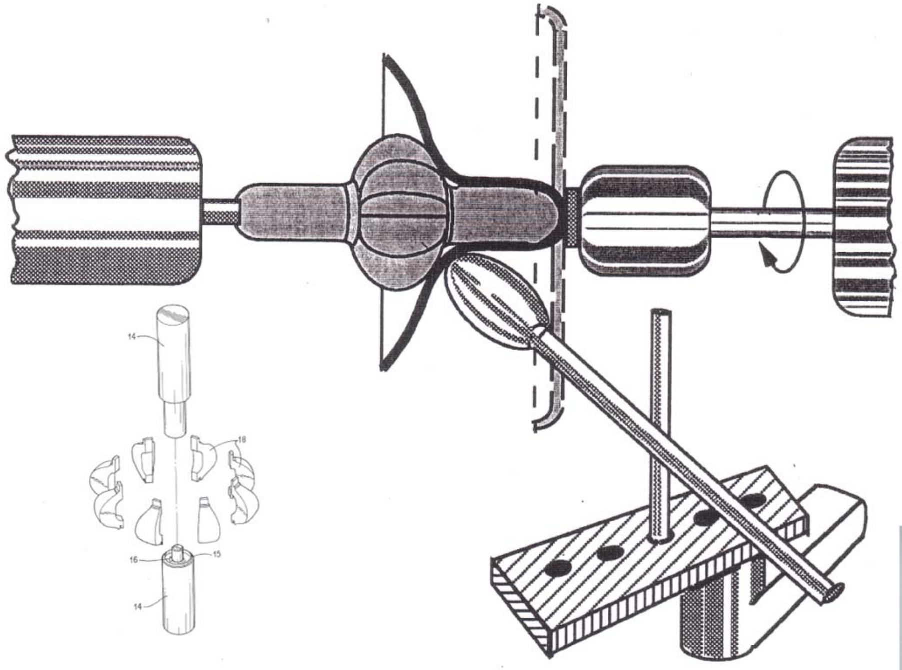


KEK

量産効果
(もう少し詳細な検討必要）

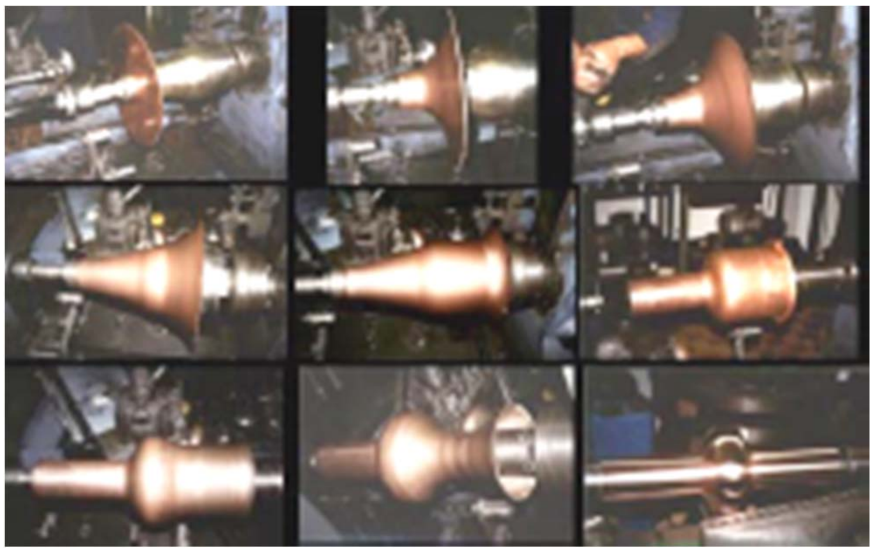
量産効果を入れても現行製作法の延長では、まだ高コストか？

Spun Cavity in Italy(INFN-LNL)

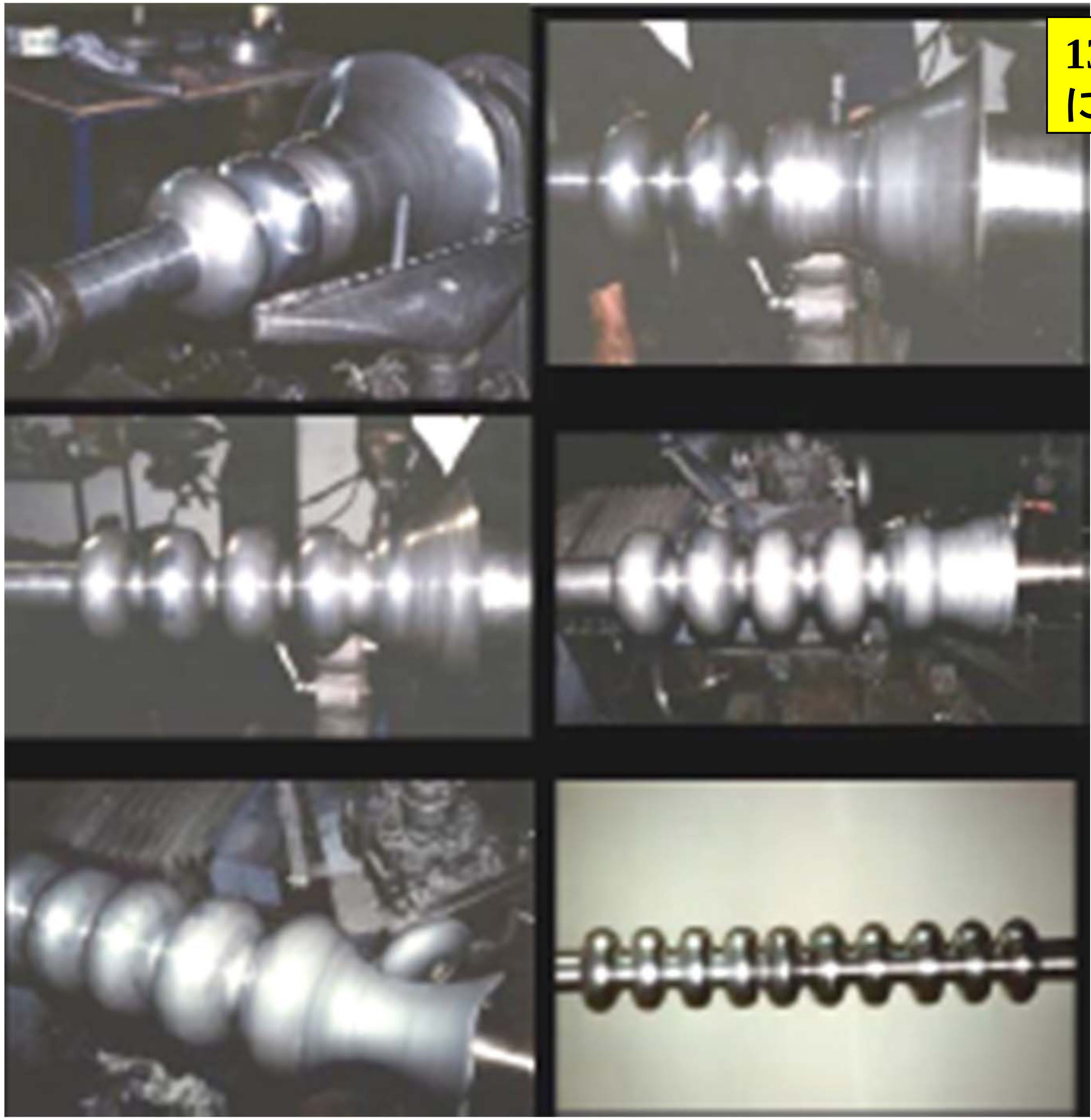


一枚板からスピニング技術
（回転絞り）で空洞を製作する。

By V.Palmieri



Spun Multi-cell Cavity



1300MHz Nb 9-cell空洞の製作にも成功。

Seamless Pipe Technology in Italy

Deep drawing

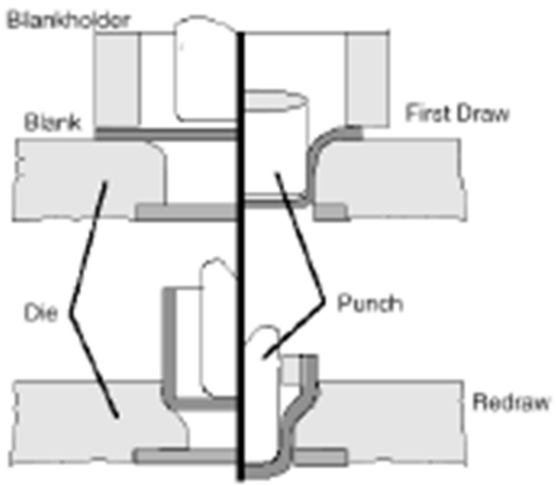
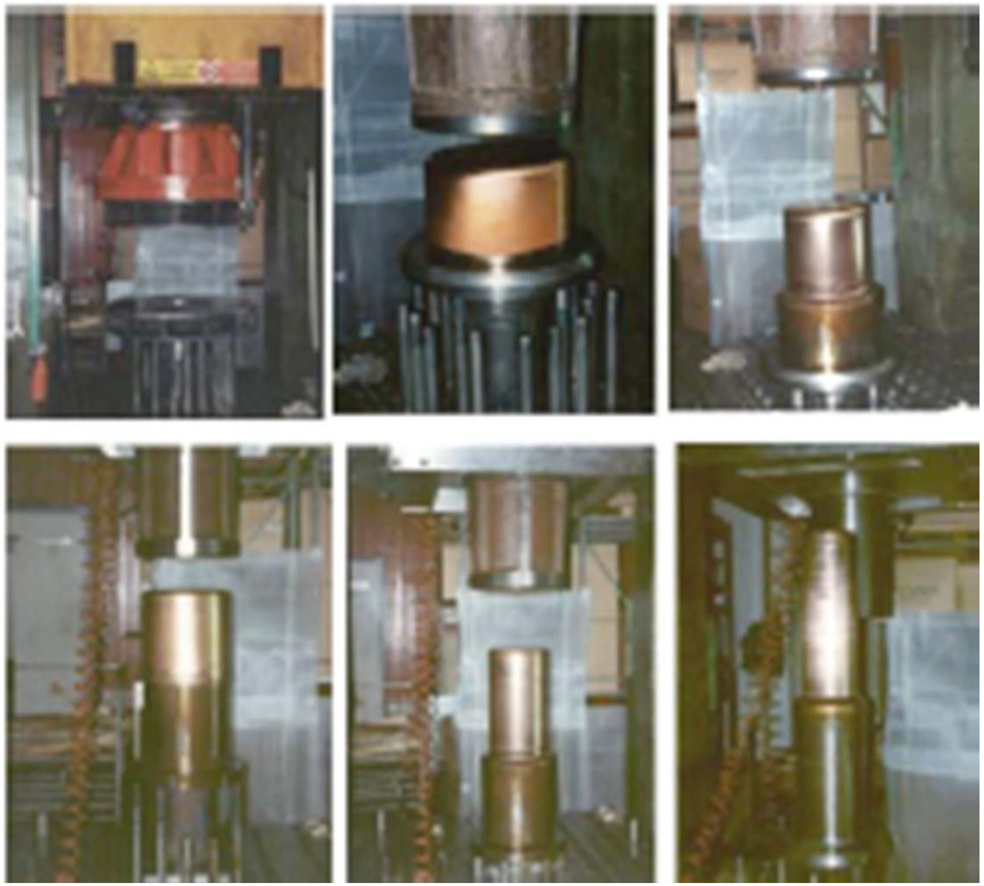


Fig. 4 – Direct Deep-Drawing of seamless tubes from circular blanks. Top picture: First drawing of a blank. Bottom picture: Redrawing of the cup into a taller one with a smaller diameter. On the left is displayed the configuration before drawing, while that on the right is during the operation.



Reverse Deep Drawing Technology in Italy

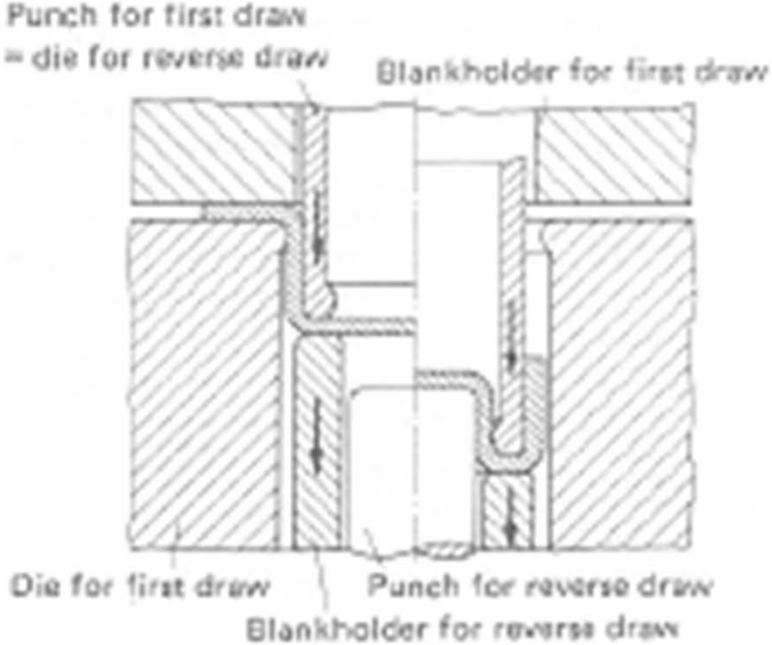
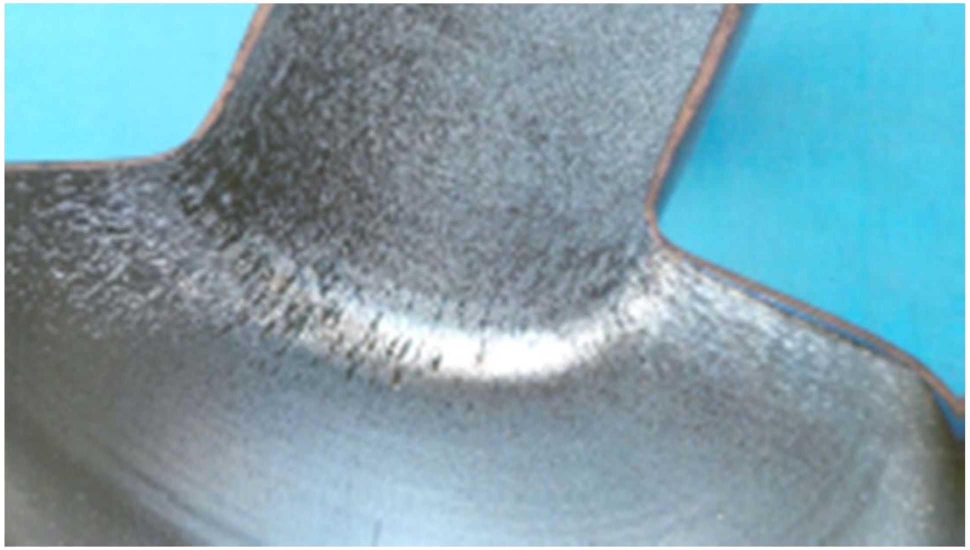
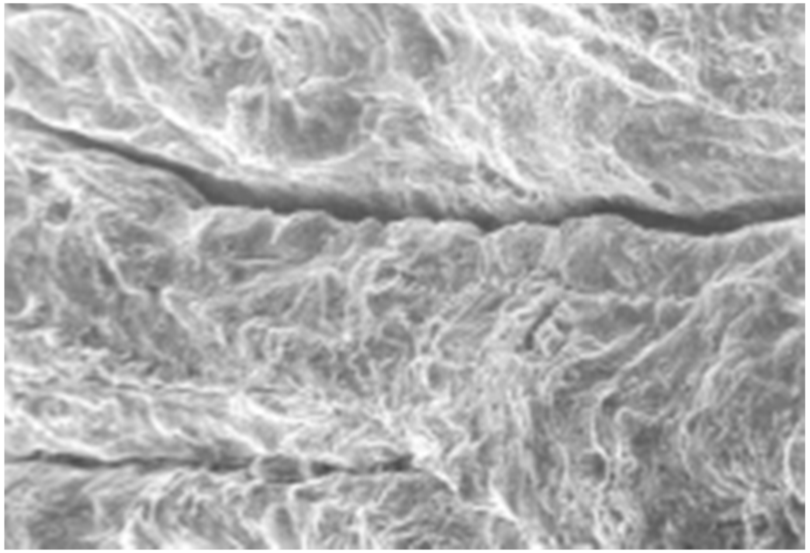


Fig. 7 – Reverse deep-drawing of seamless tubes. During each redrawing, the external surface of the cup to be drawn becomes the internal of the drawn part.

Cracking Problem of Spun Cavity Technology in the Early State

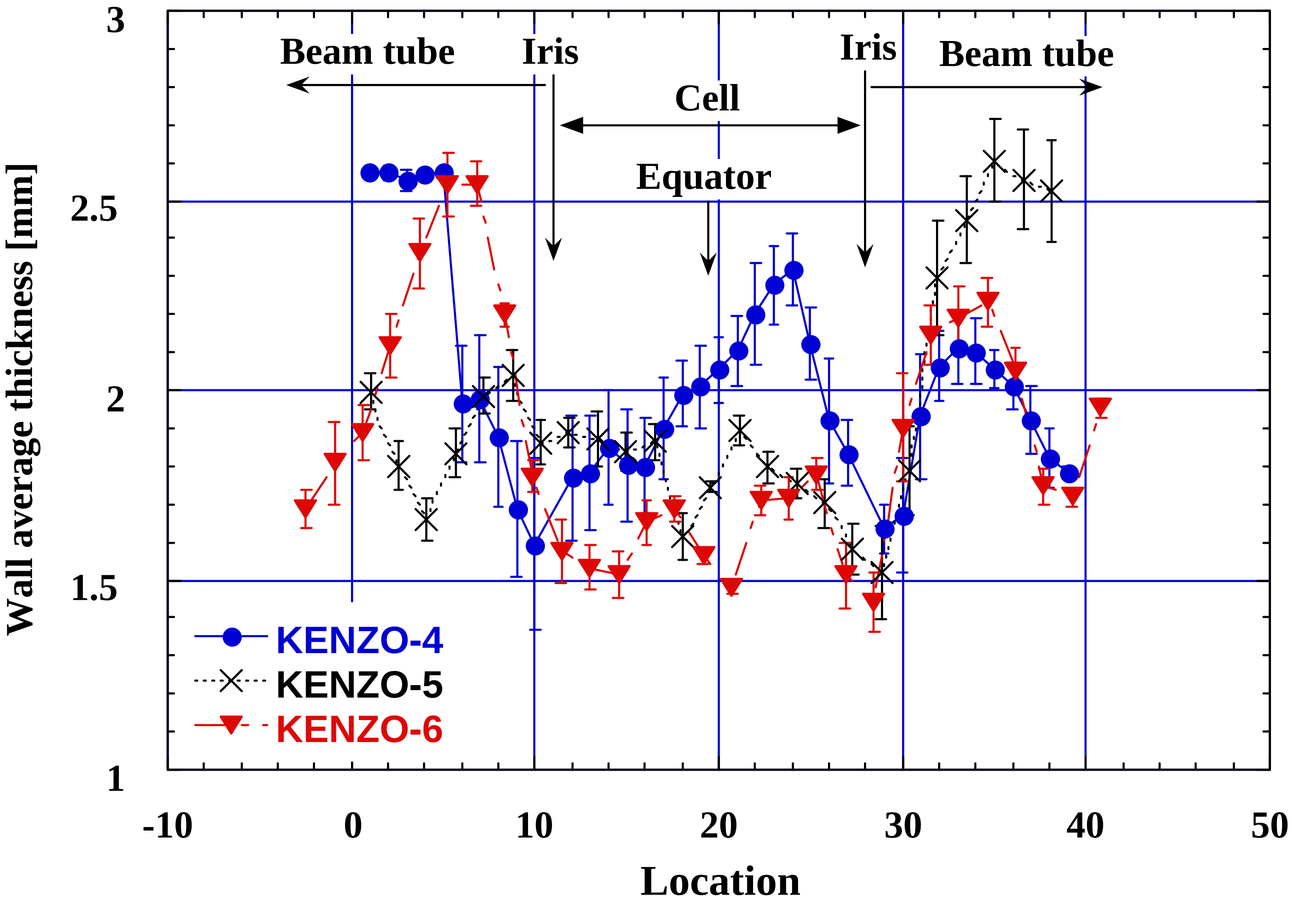
初期の空洞。現在だいぶ改善された。





None Uniform Wall Thickness

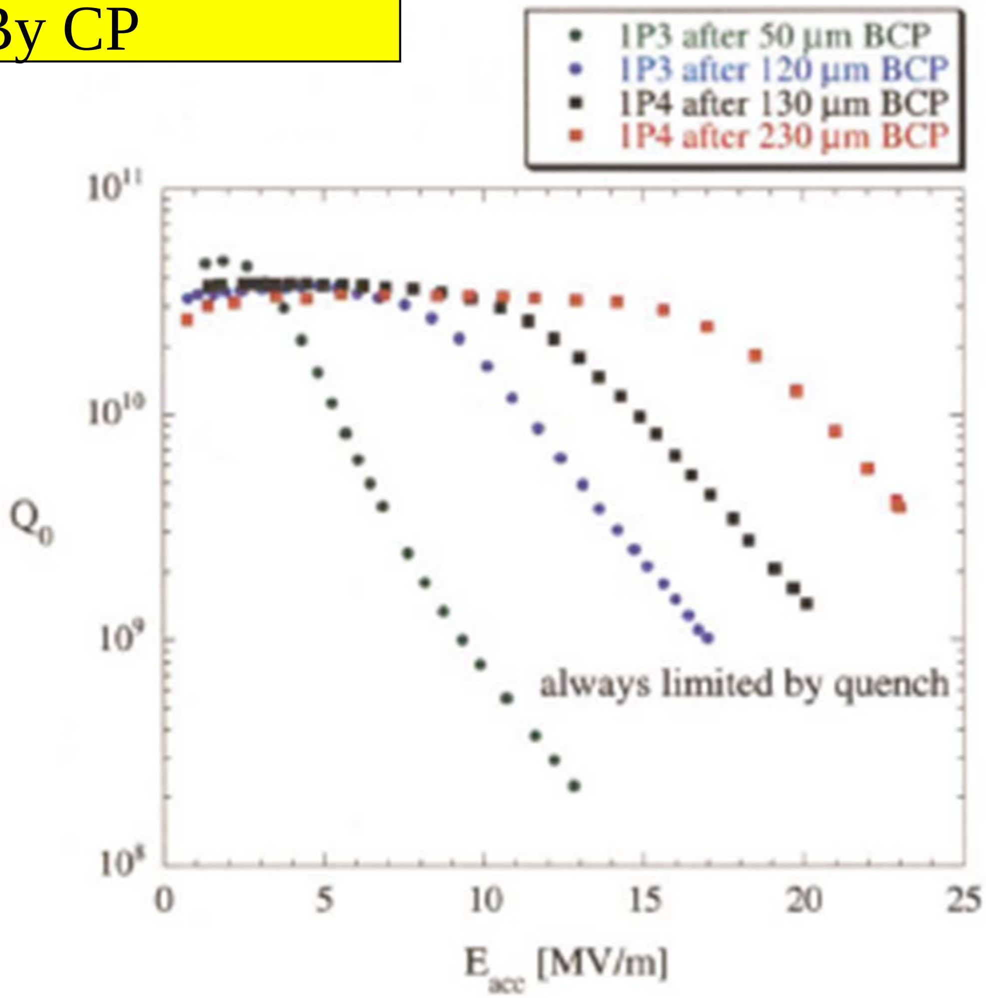
肉厚がばらつく。セル毎にLorentz detuning感度が異なり、
周波数エラーが発生。Field amplitudeのエラーが大きくなる。

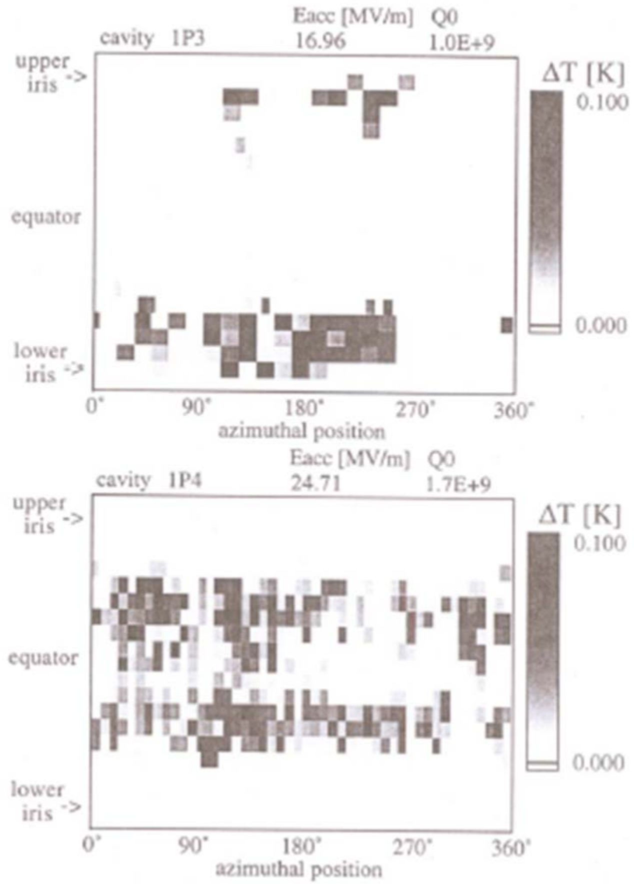


現在では、この問題はかなり改善された。

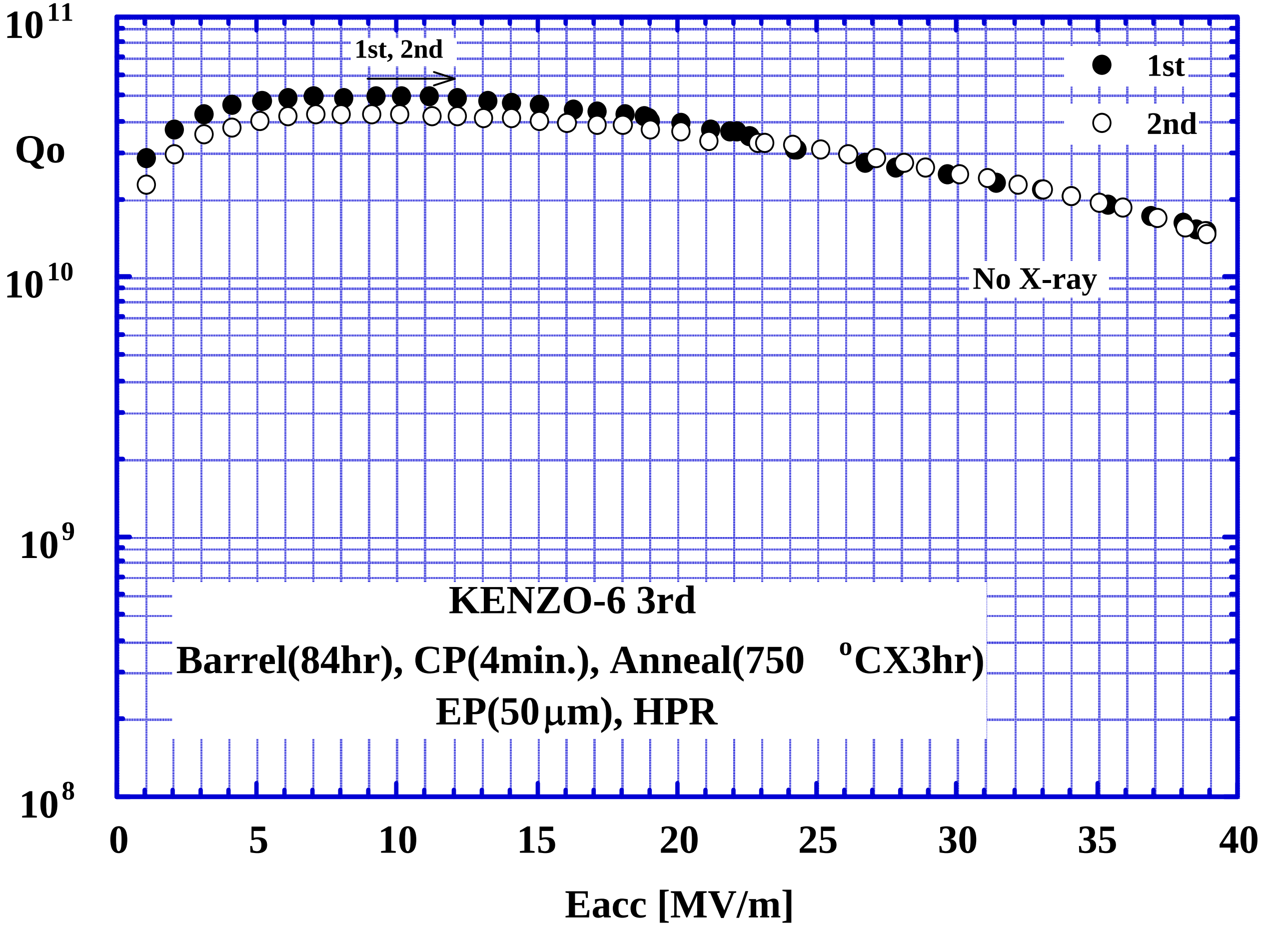
Cavity Performance of Spun Nb Bulk Cavity

Jlab/INFN-LNL
By CP





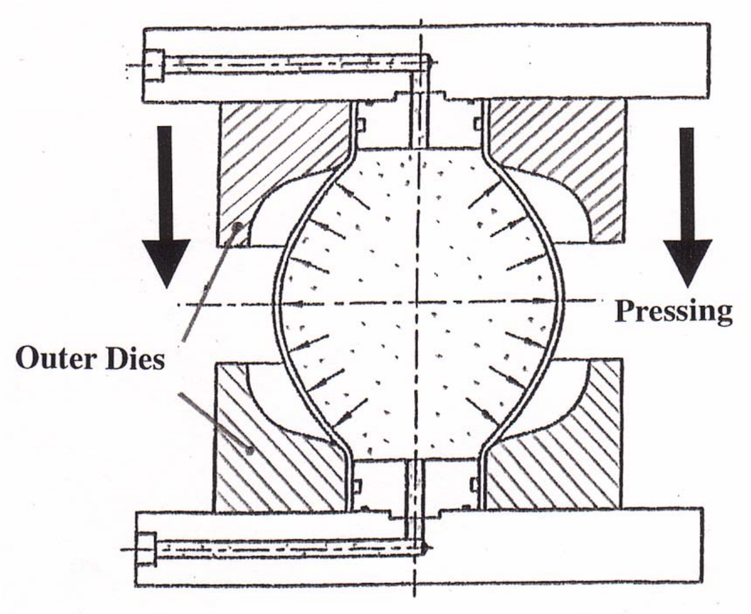
Electropolishing of Spun Cavity

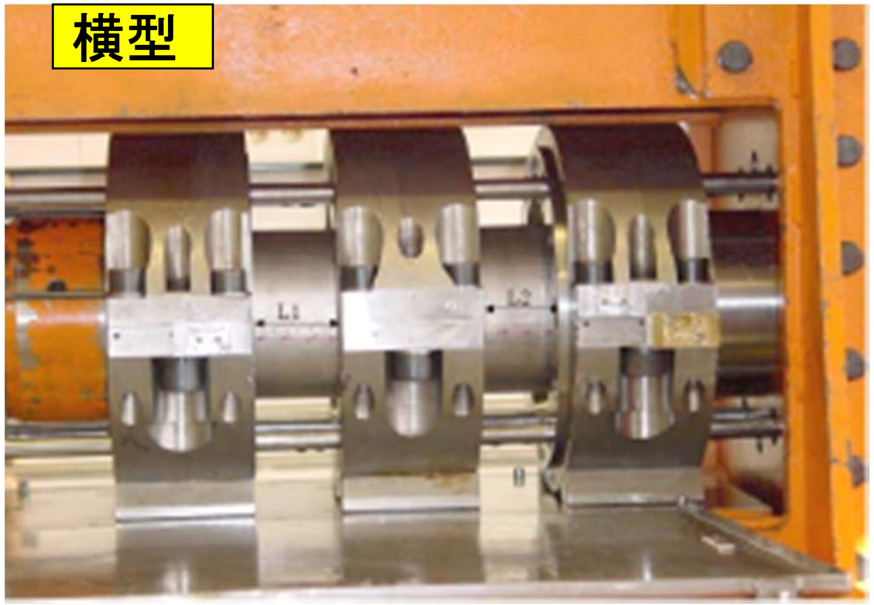


KEK/INFN-LNL

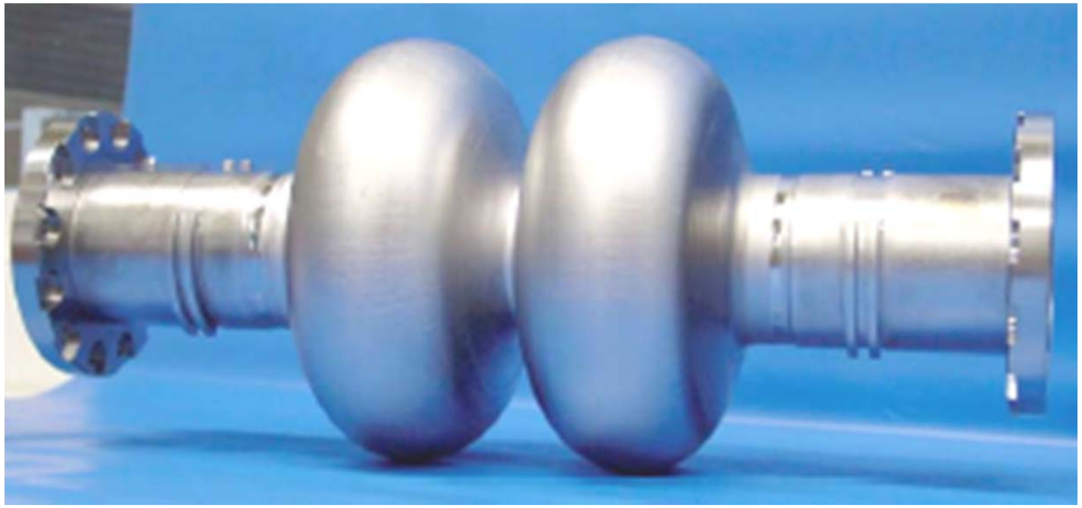
空洞性能Okay。

Hydroforming of Nb Bulk Cavity in DESY





DESY Hydroformed Cavities



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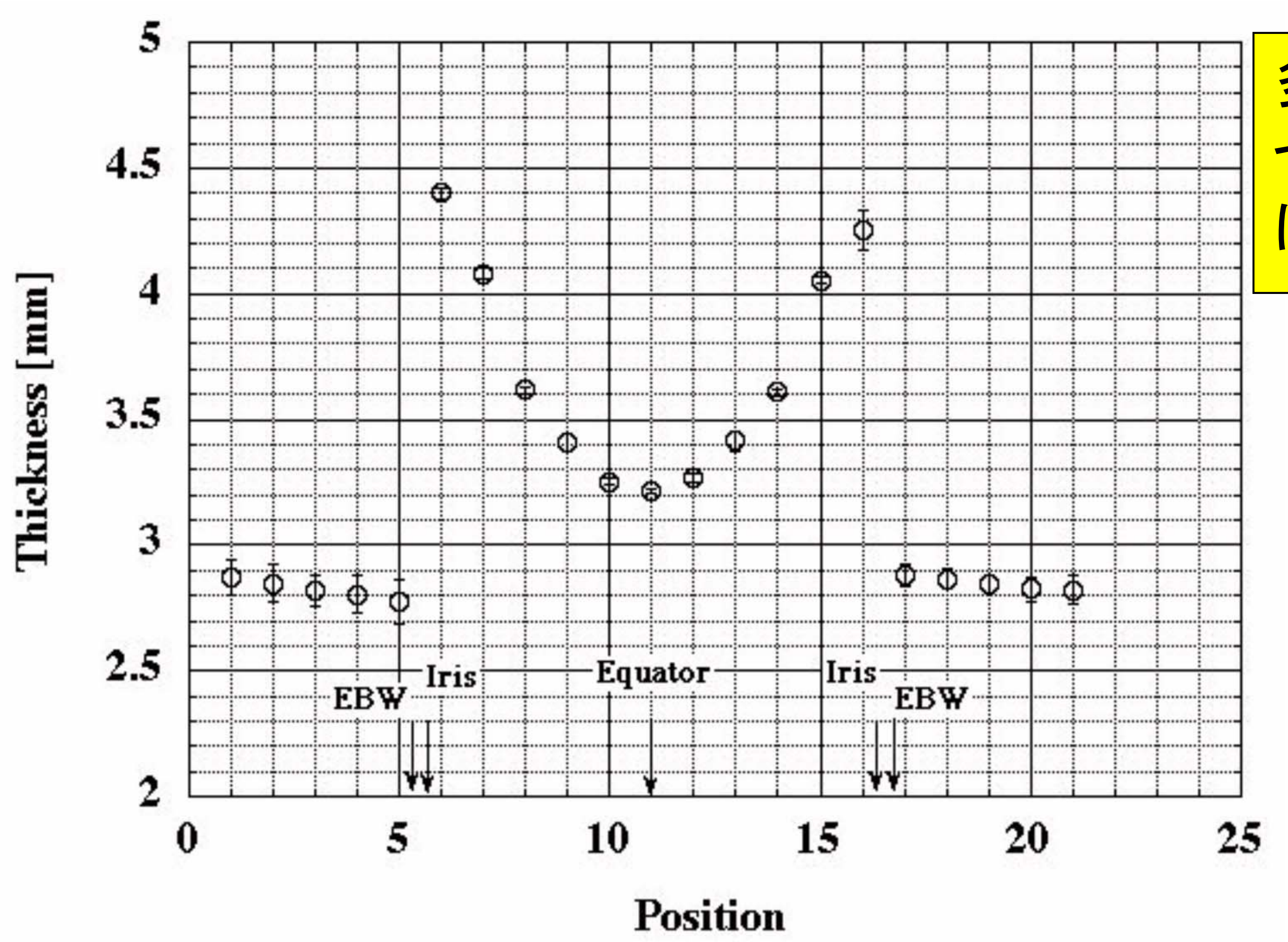
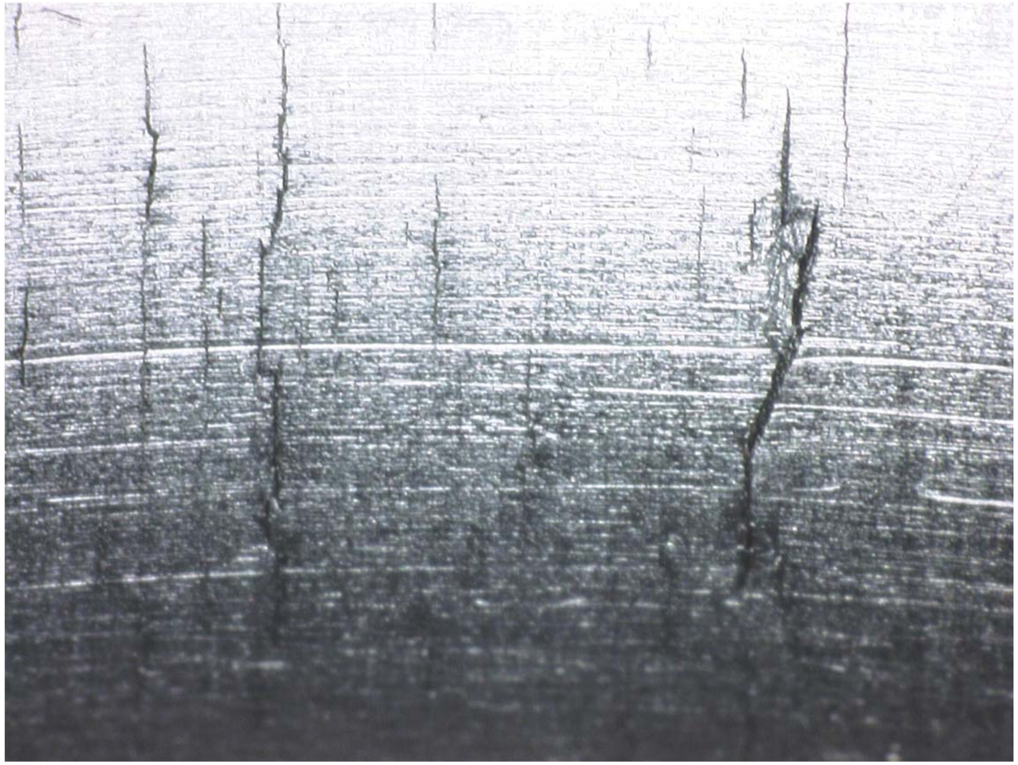
Wall thickness distribution with hydroforming



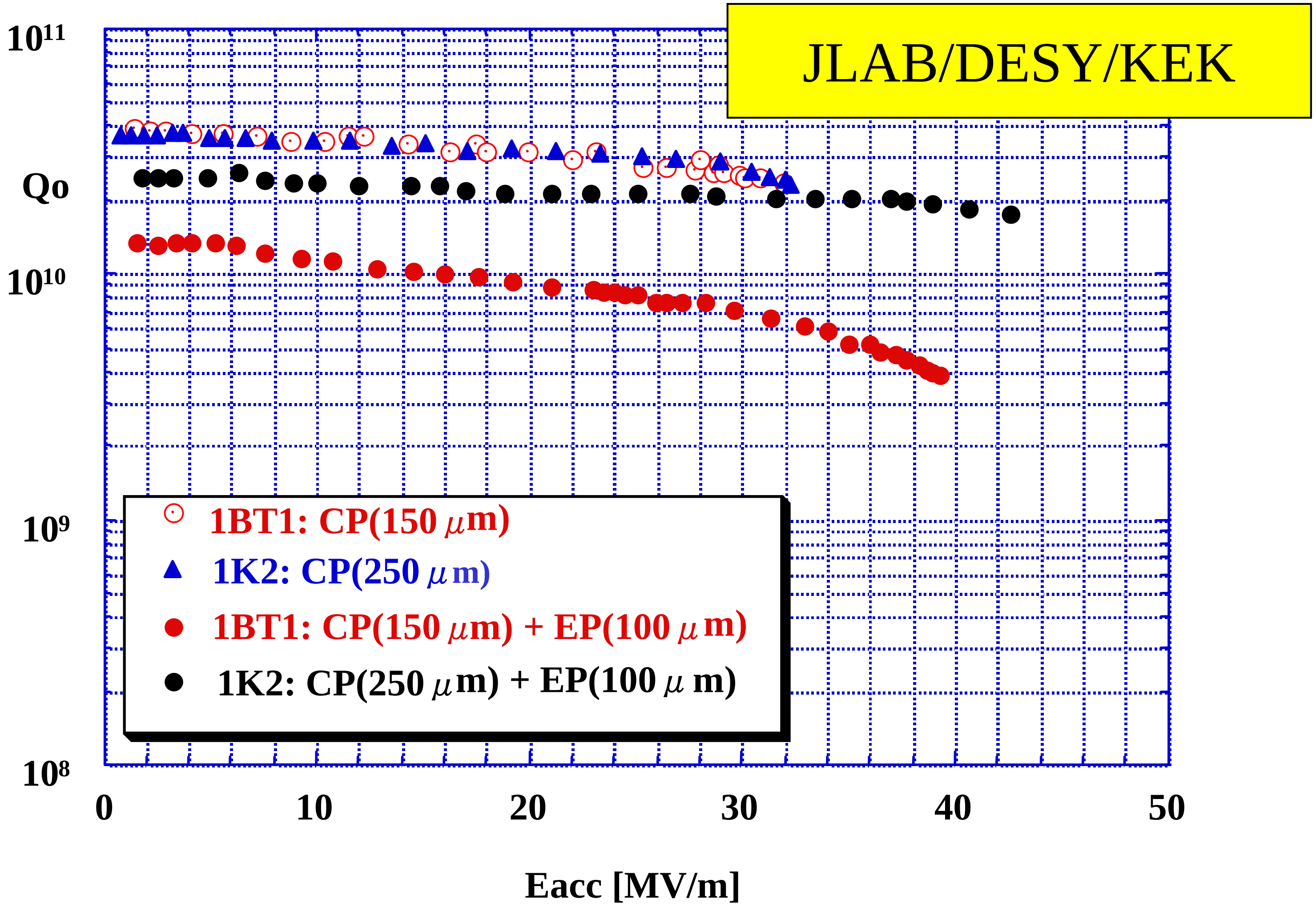
多連空洞の場合、
セル間で肉厚分布が
ばらつきにくい。

Cracking in Nb Bulk Seamless Cavity in DESY



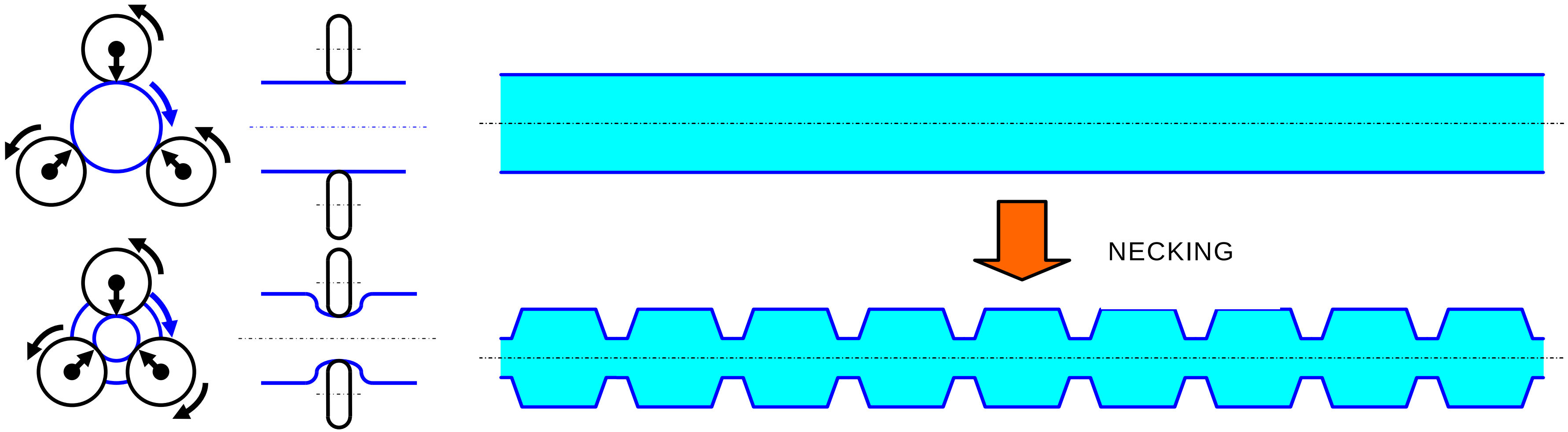
遠心バレル研磨のような強力な機械研磨が必要。

Electropolished Hydroformed Cavity

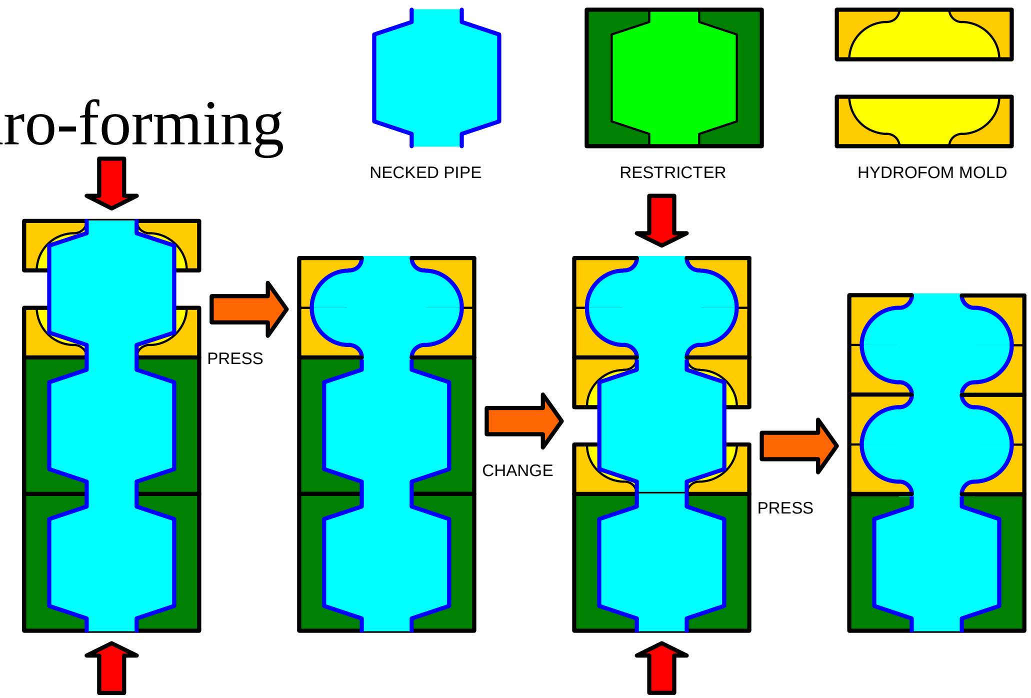


40MV/mを早期に達成。性能の信頼性大。

Necking and Hydro-forming machines in KEK

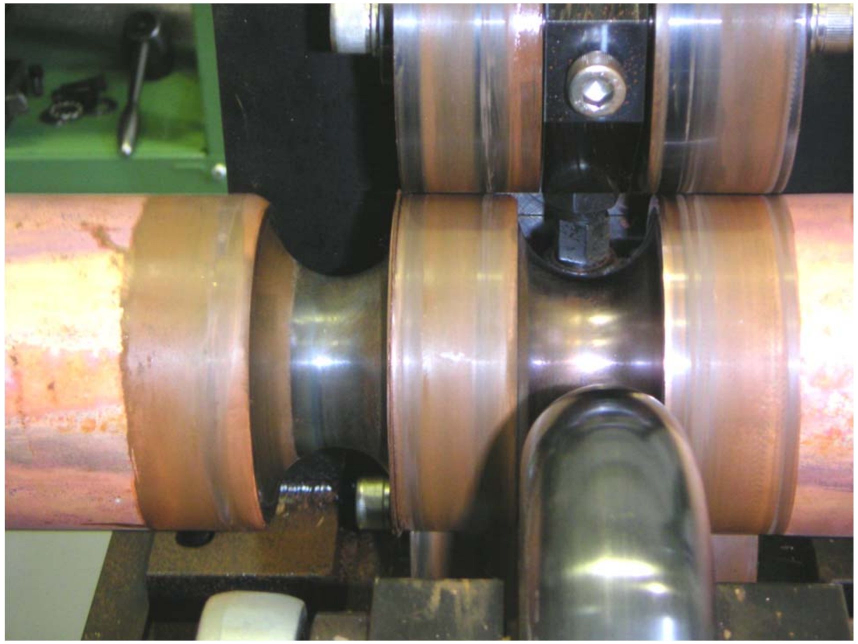


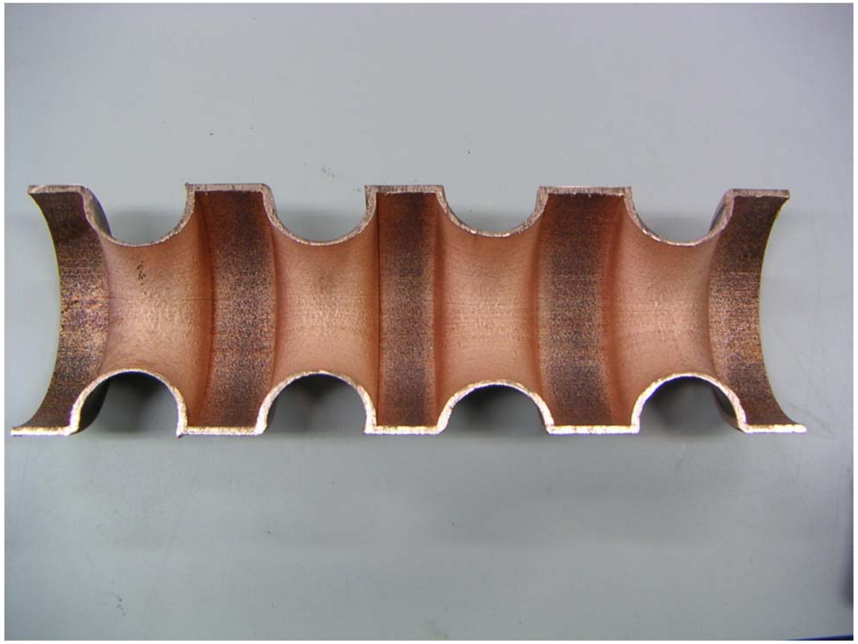
Hydro-forming



Machines will be constructed at KEK in JFY2005.

Successful Multi-necking test ϕ100 to ϕ50 copper tube



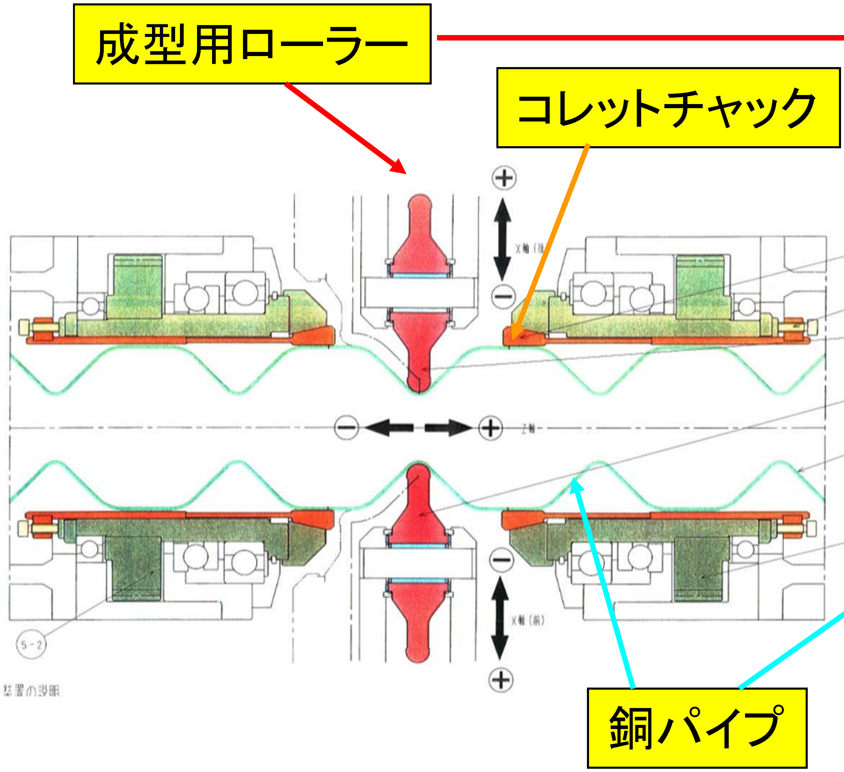


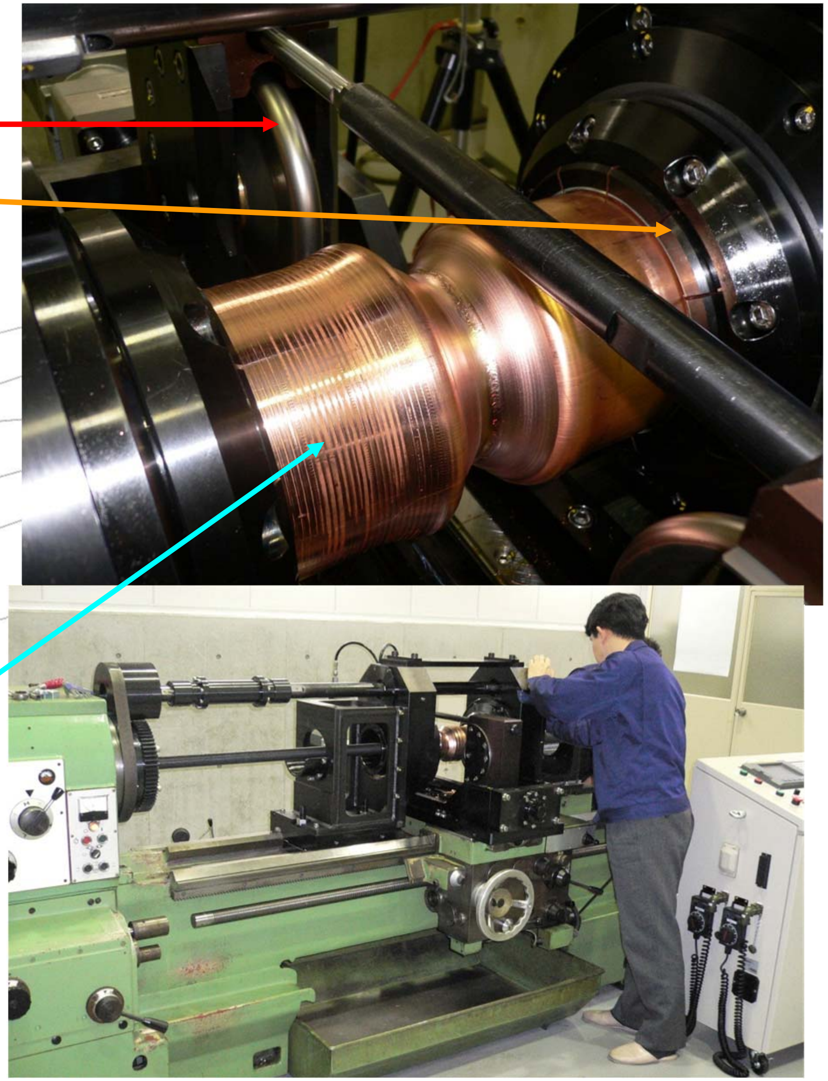
ϕ138 to ϕ60 necking test → Necking system design → Necking system fabrication

in 2005 JFY

Nb/Cu Clad Seamless Cavity
ネッキング装置＋液圧成形装置

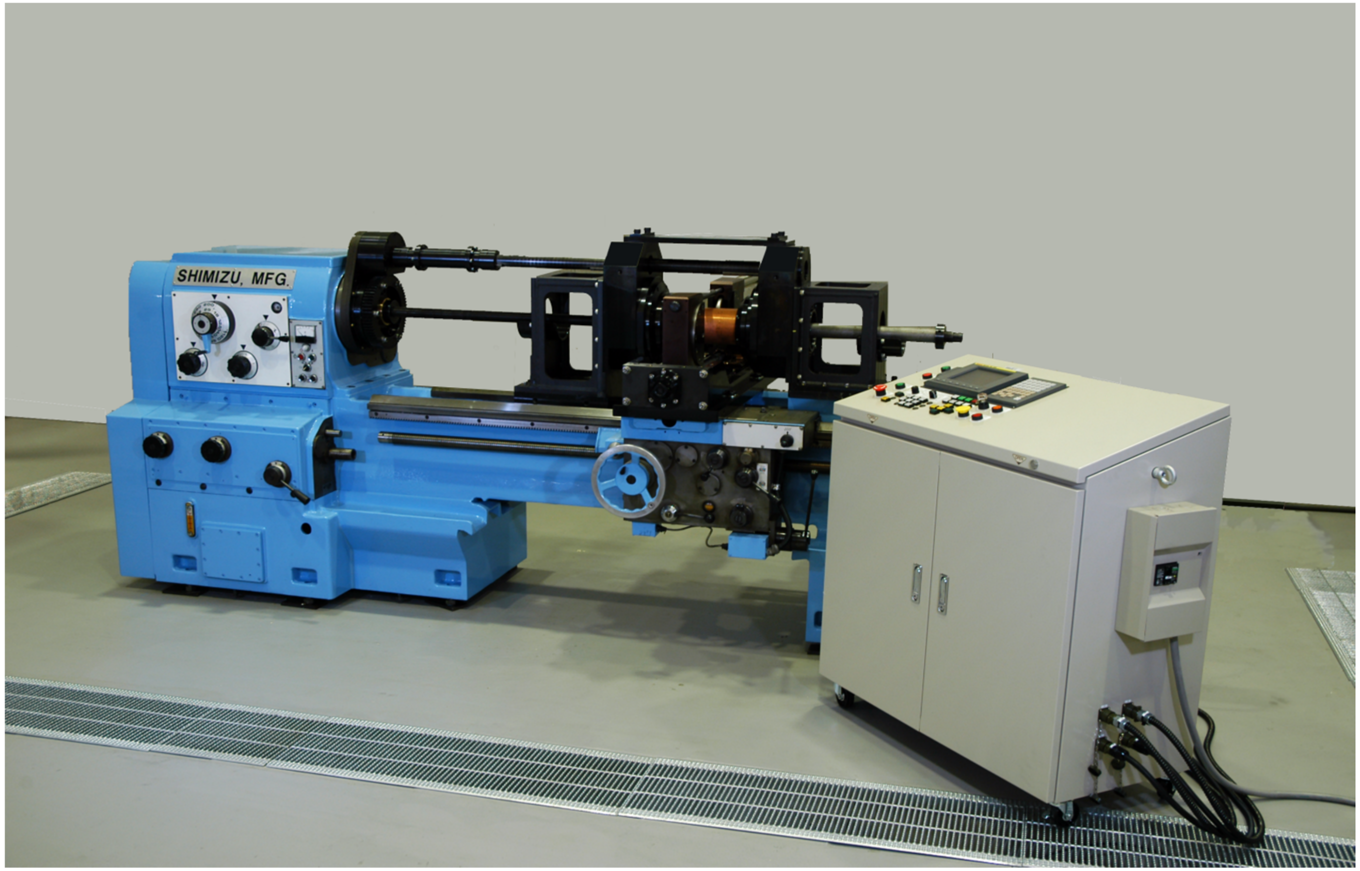
３セル用ネッキング装置の製作





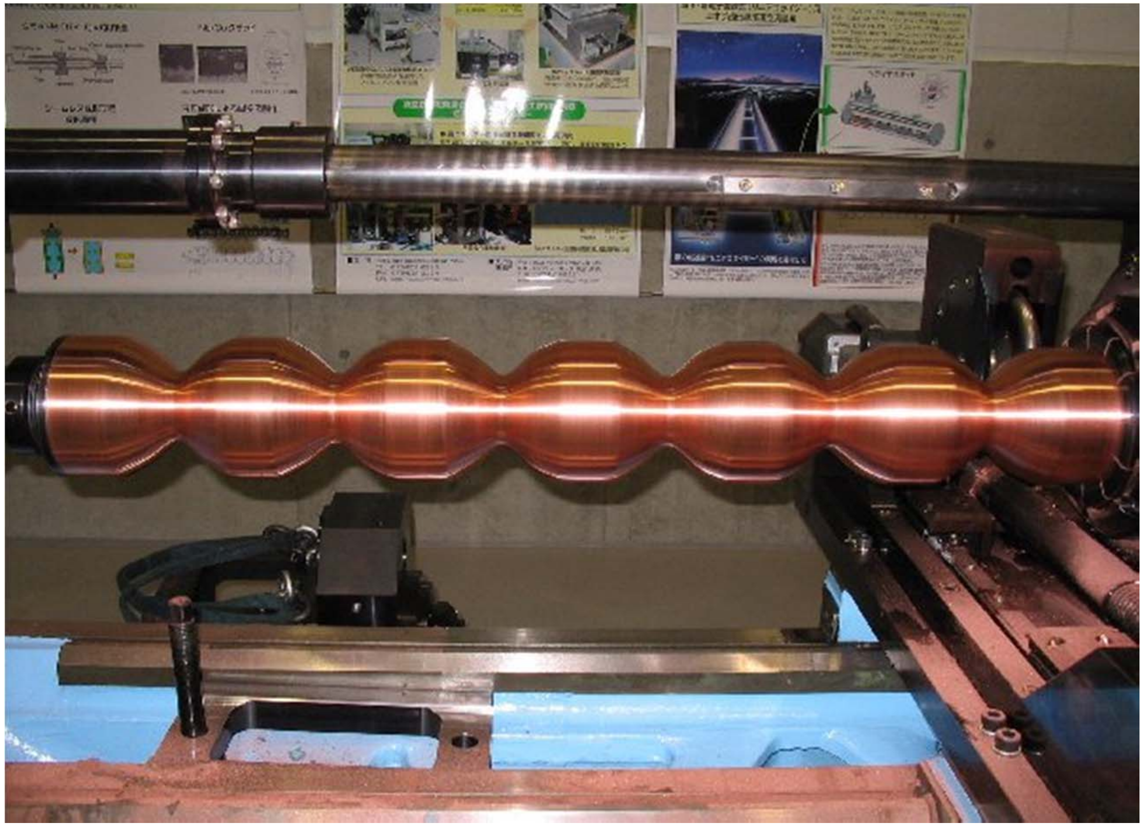
３セル用ネッキング装置は完成。
銅パイプで３セル用のテストを開始した。

Necking machine



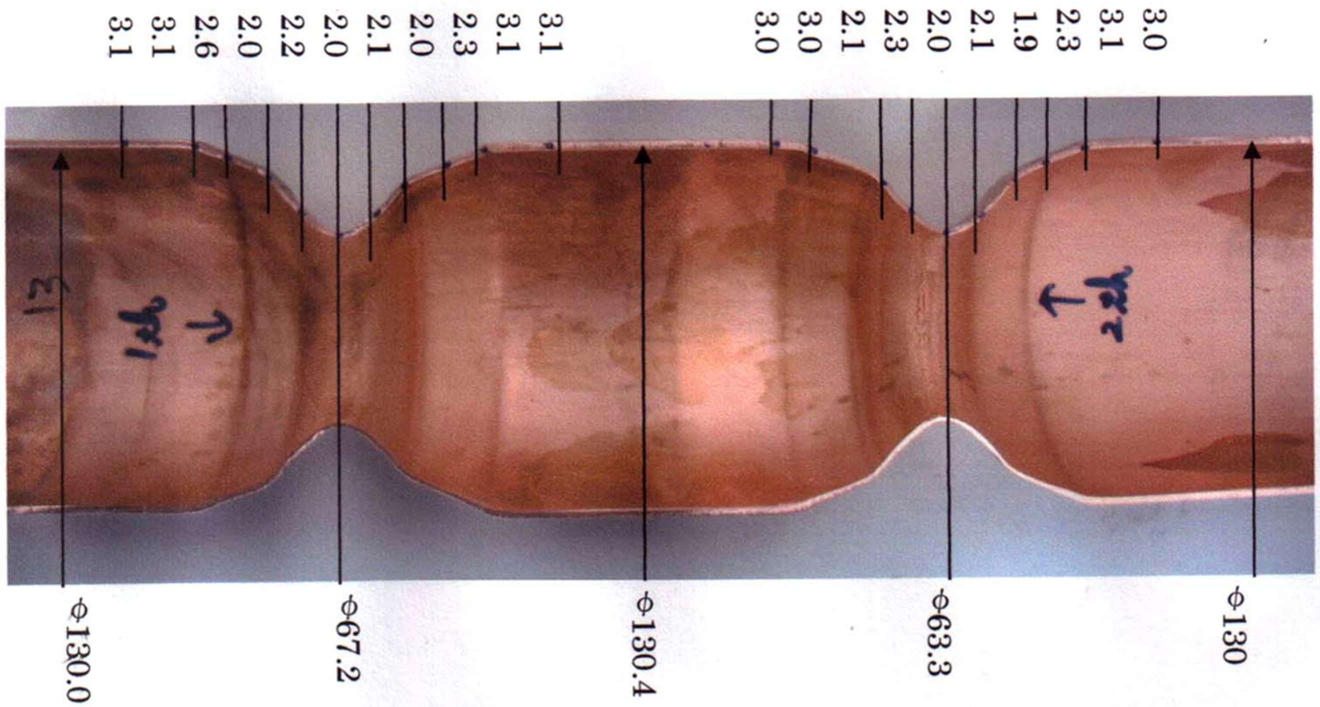
First successful necking test

Availability of Improvement for 9-cell

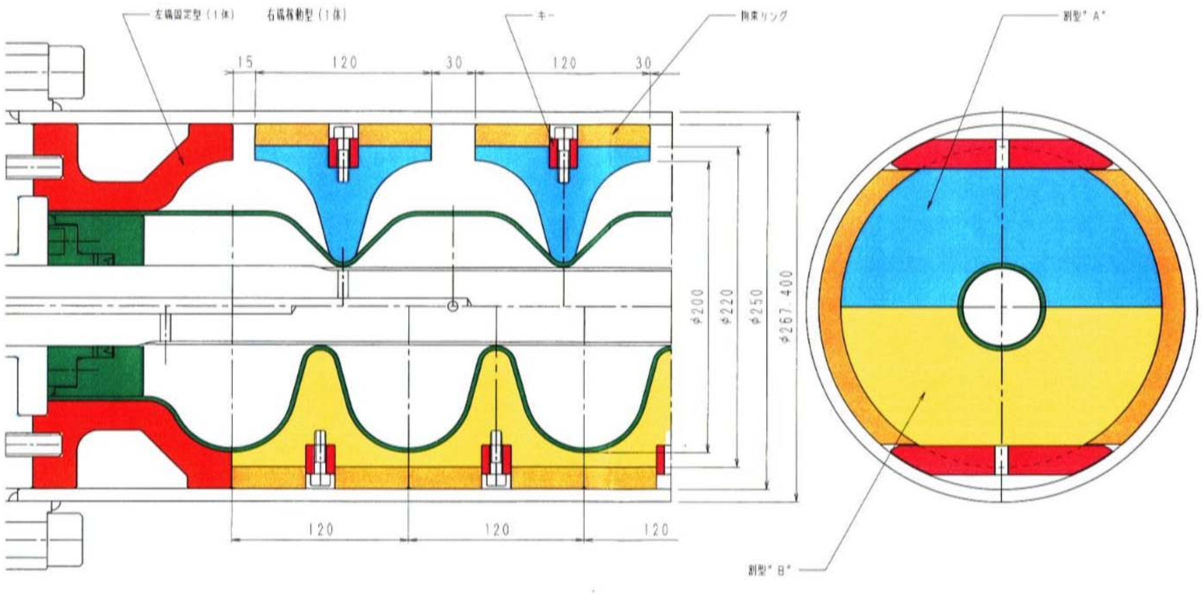


Thickness variation of necked pipe

材料：JIS H3300 C1220T　130ϕ×3t×500L



Nb/Cu Clad Seamless Cavity　３セル用液圧成形装置



設計は完了
製作を開始。

	11月	12月	1月	2月	3月	4月
液圧成形実験装置						
（1）設計						
（2）製作						
（3）装置完成						
（4）加工実験						3連成形

Hydroforming of Seamless 3-cell cavity @ KEK

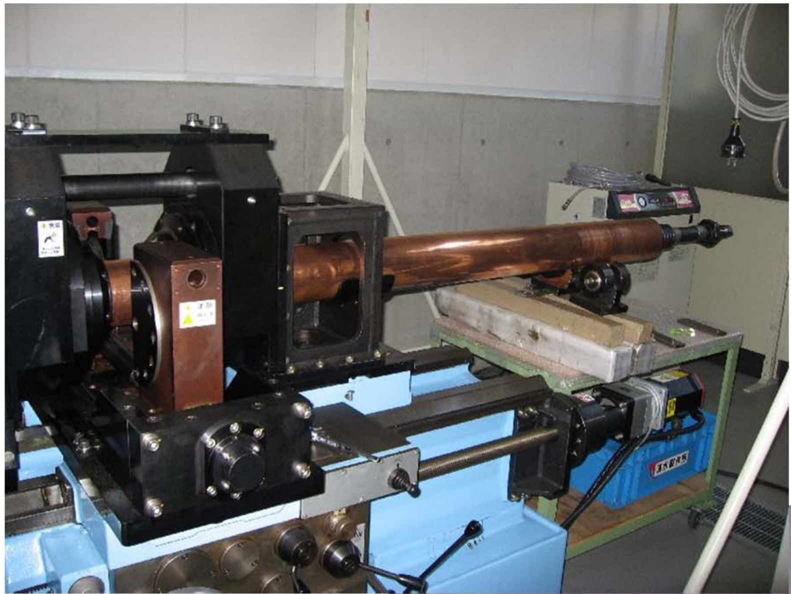
仕上げ金型の組み立て

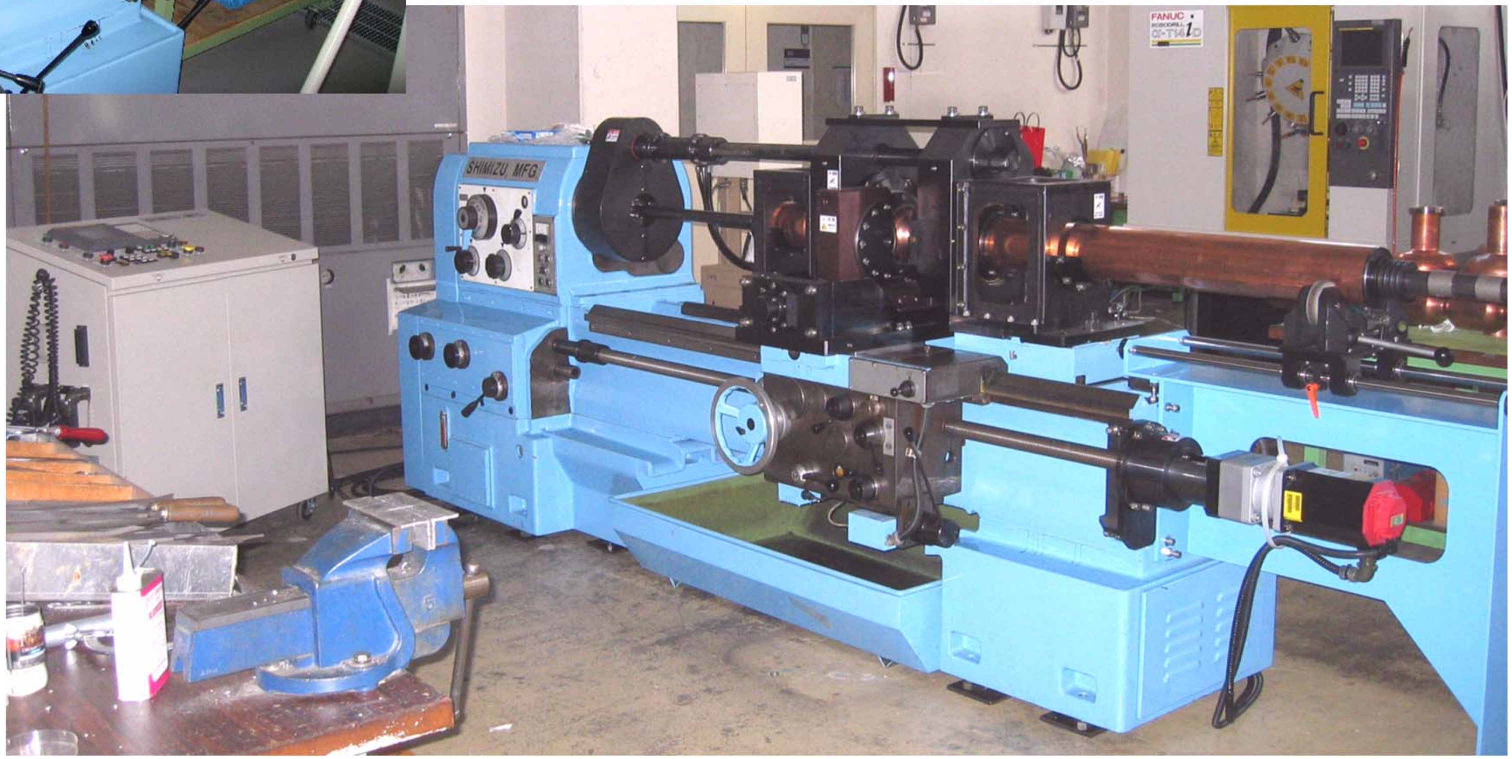
仕上げ金型の取り外し

Seamless ICHIRO 3-cell Cavity (Copper model)の完成

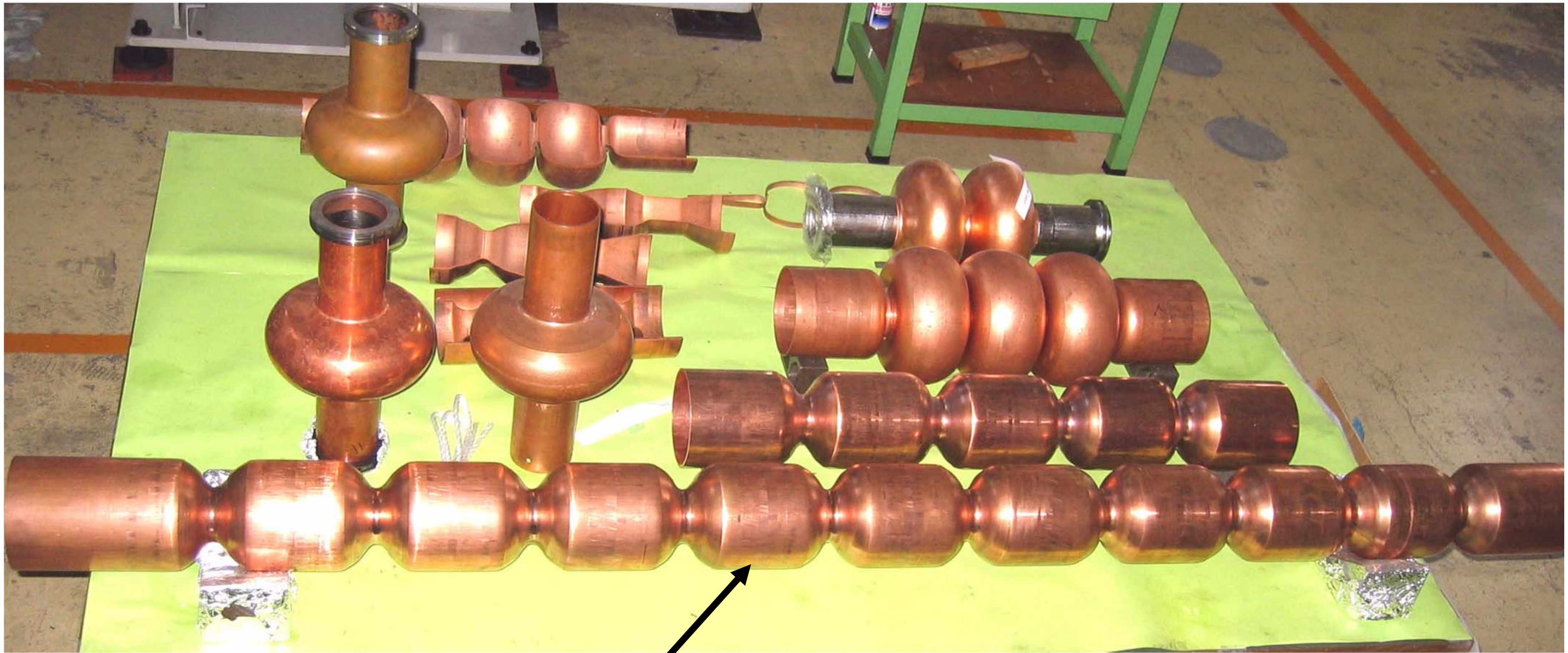
KEK工作センター

9-cell Necking machine





Necked 9-Cell

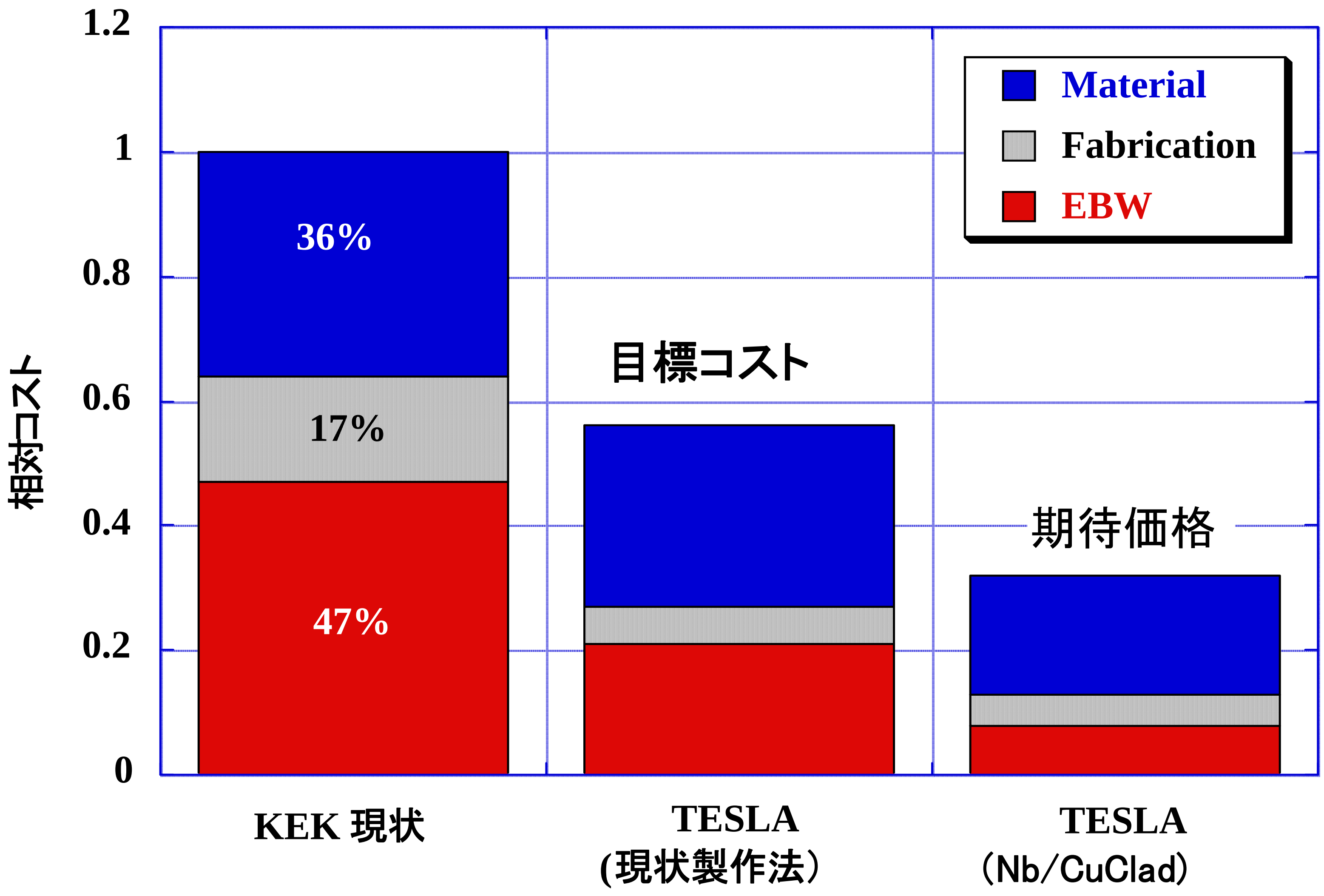


Necked 9-Cell

DESY 3-cell Seamless x 3 Cavity

13.3 Nb/Cu Clad Seamless Cavity

Nb/Cu Clad Cavityのコスト評価



Nb/Cu Clad Cavity, KEK

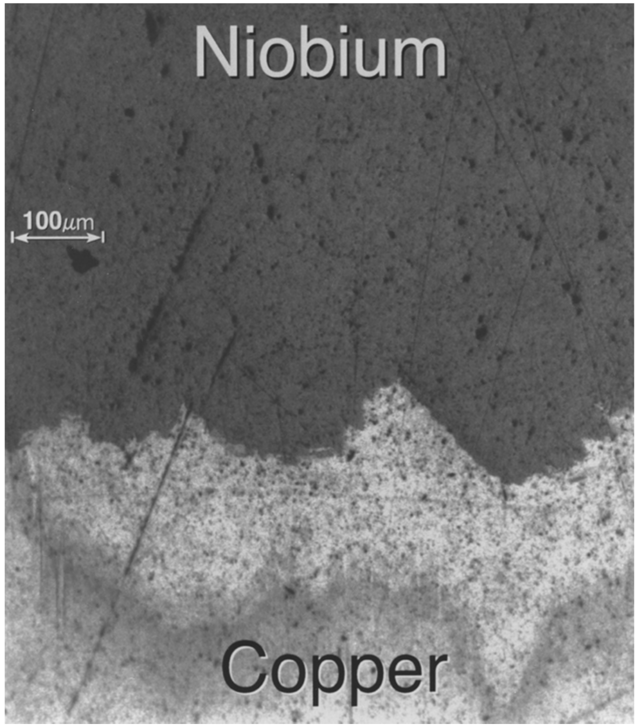
EPが使える

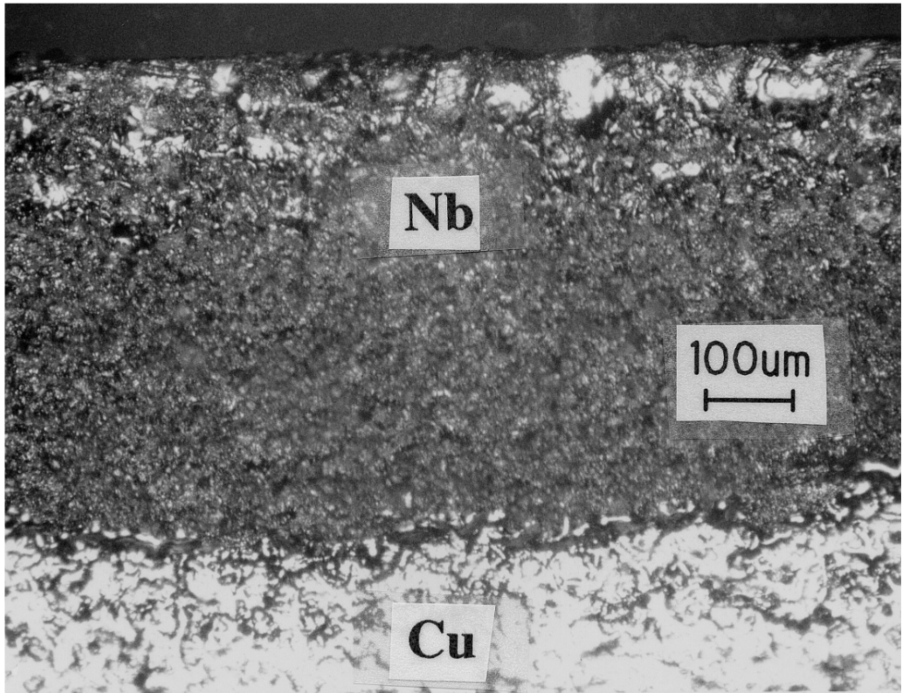
解くべきCoupled Problems

1) EBWを極力減らす
2) Nb材の量を大幅にへらす
3) 空洞性能を保証する

→ 空洞がNbのバルク性を維持

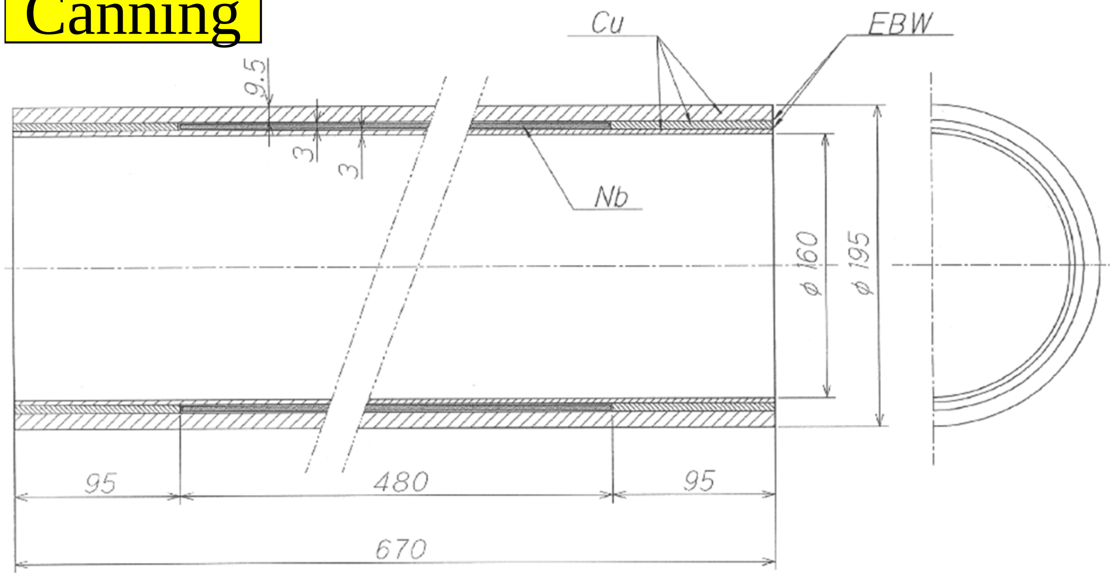
→ 厚肉銅に薄肉ニオブの接合パイプから液圧成型／スピニング法で空洞を一体成型する



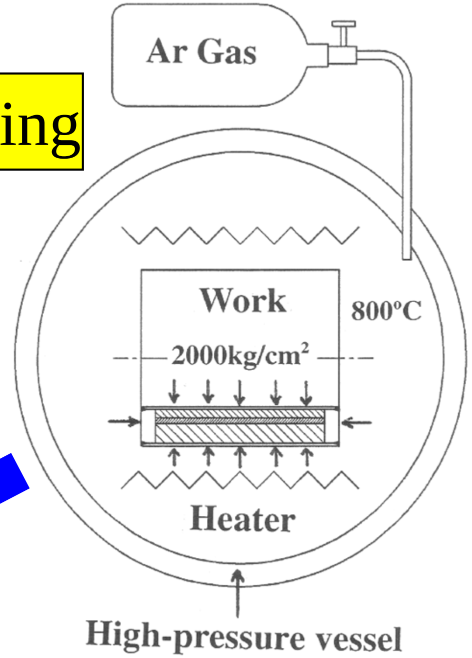


Idea of KEK

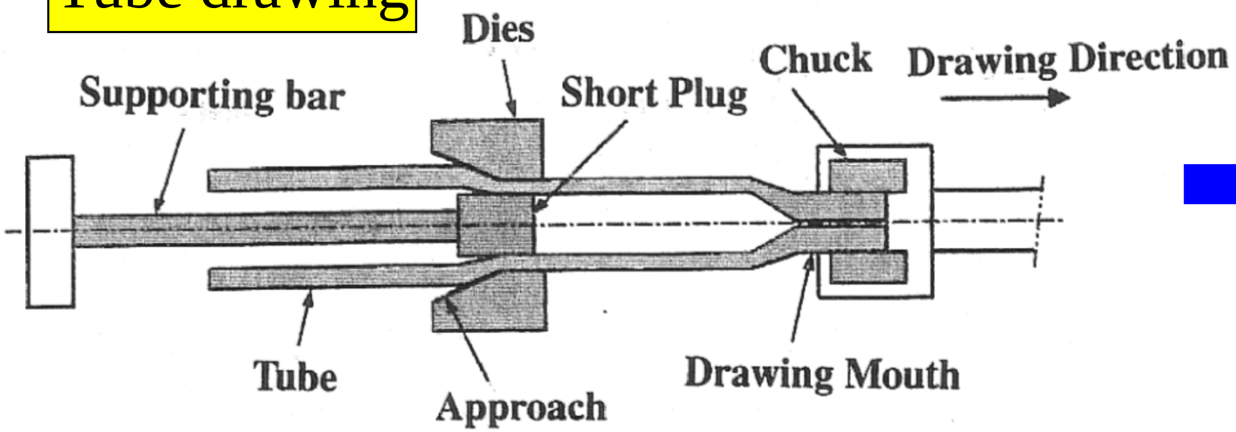
Canning



Bonding

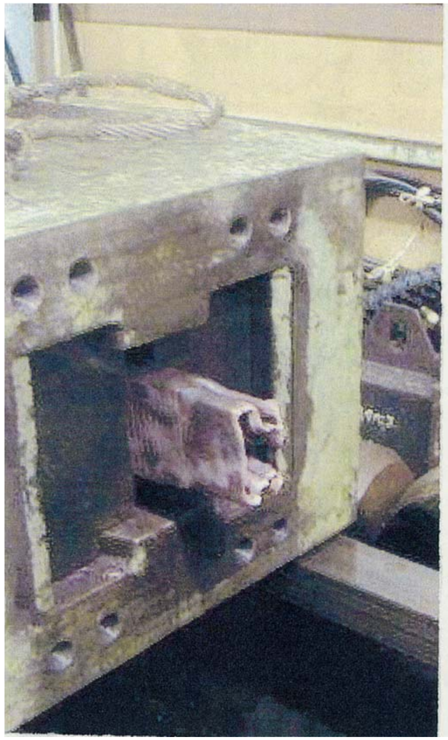


Tube drawing



Clad pipe

Tube Drawing



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/奥田金属（福井県）

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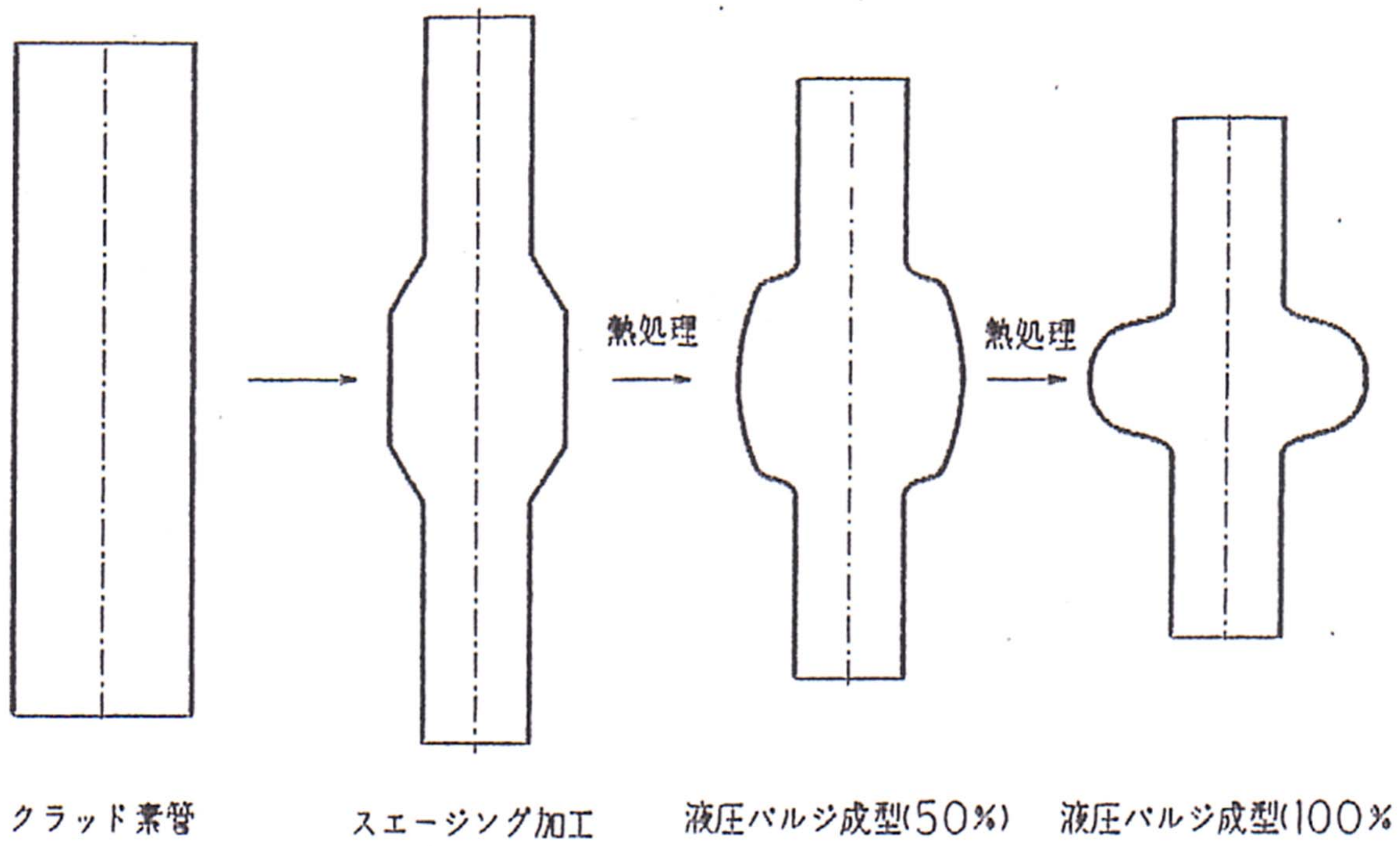
Drawn Nb/Cu Clad Tubes and Cutting

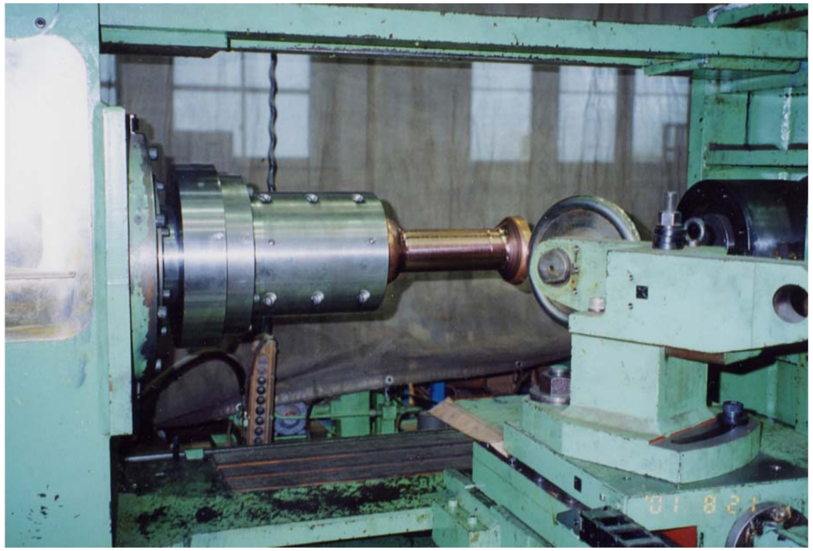
新日鉄/KEK

11-13/May/2011
K.Saito

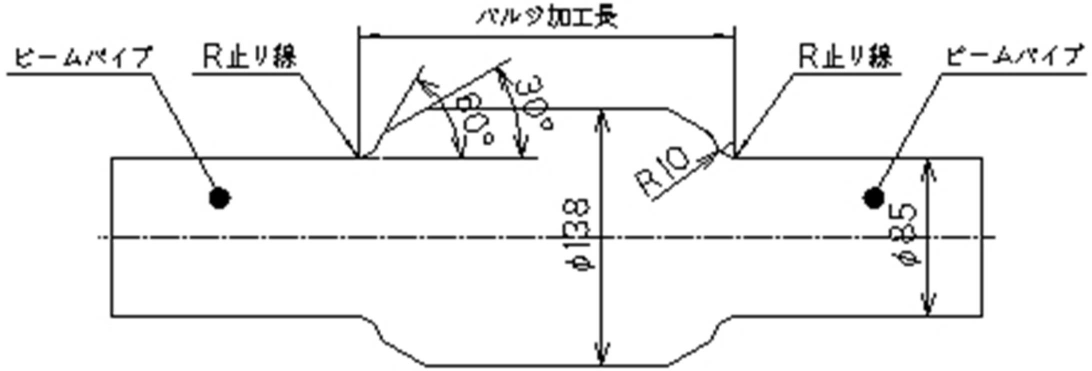
Fabrication Process in KEK for Hydroforming

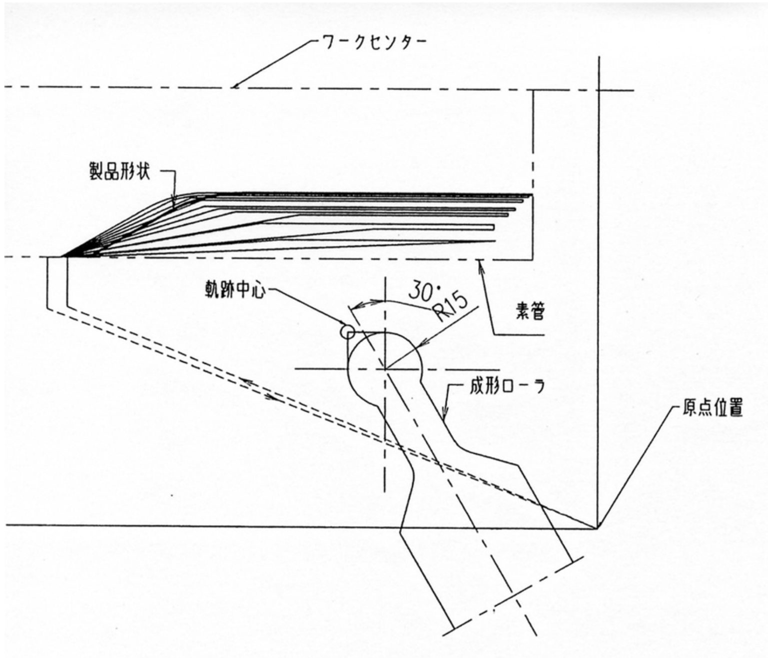


Beam Pipe 部のスエジング

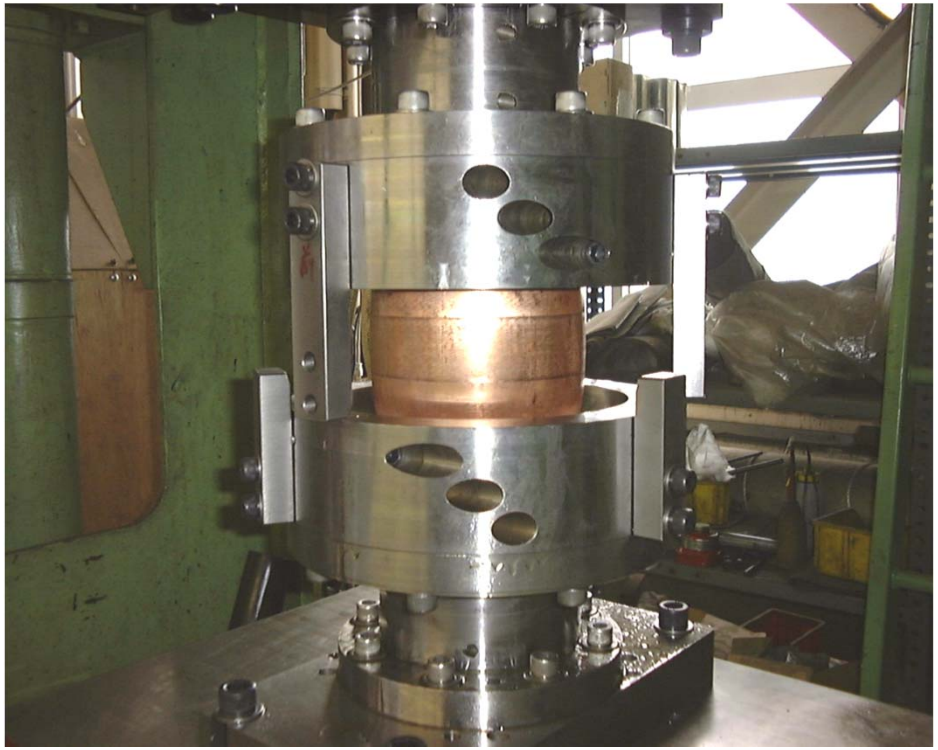


幸伸技研(静岡県三島市）





Hydroforming of Nb/Cu Clad Cavity in KEK



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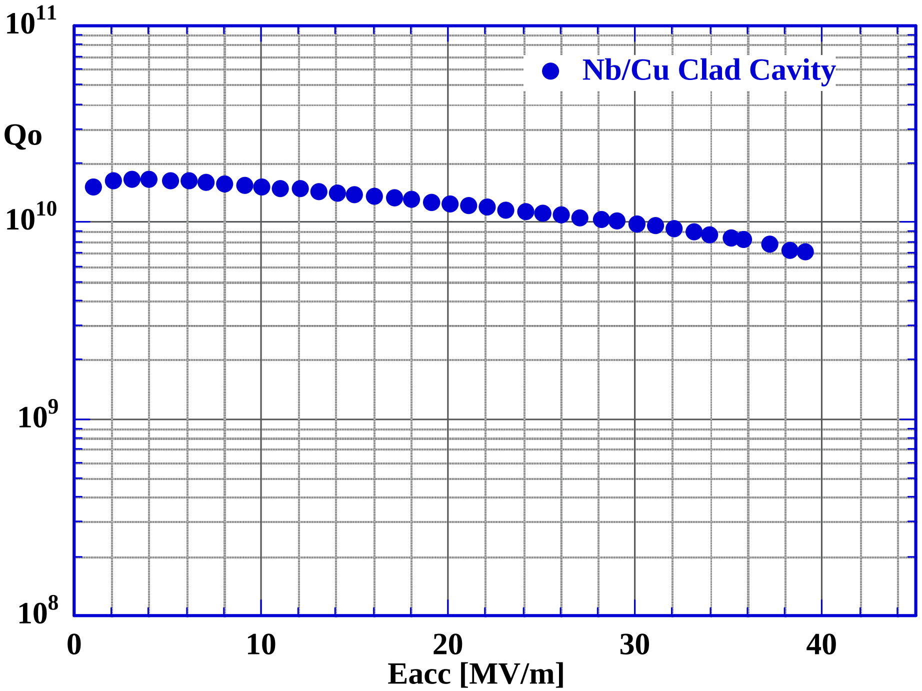
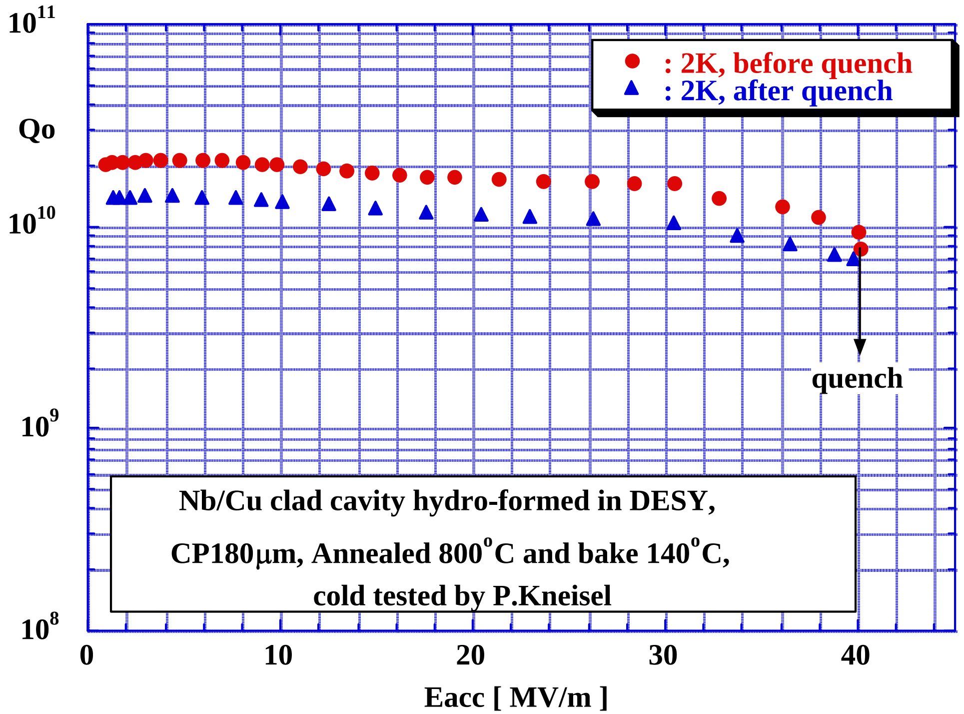
K.Saito

Cavity Performance

KEK/新日鉄(株)/DESY

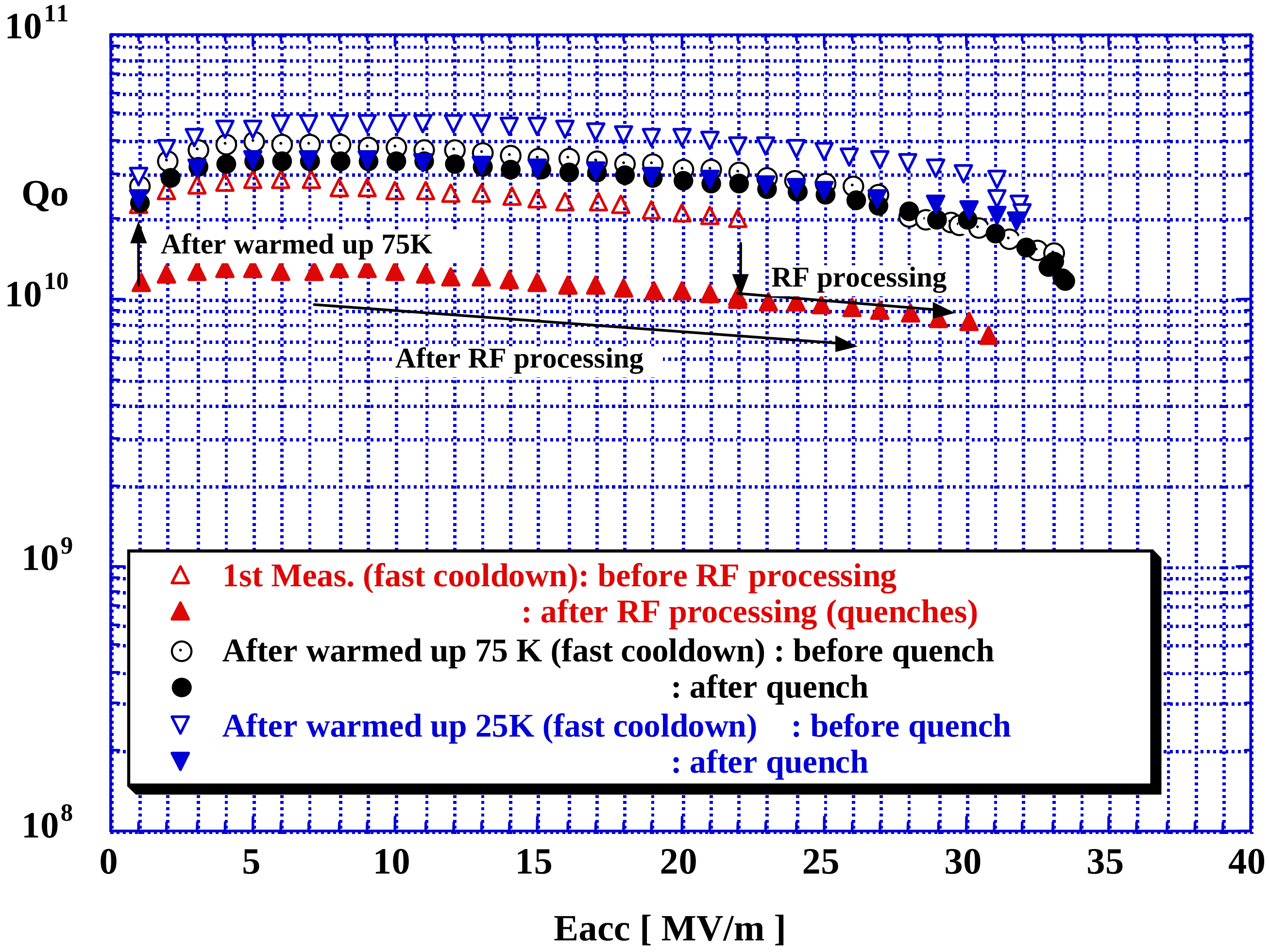


JLAB/DESY/KEK



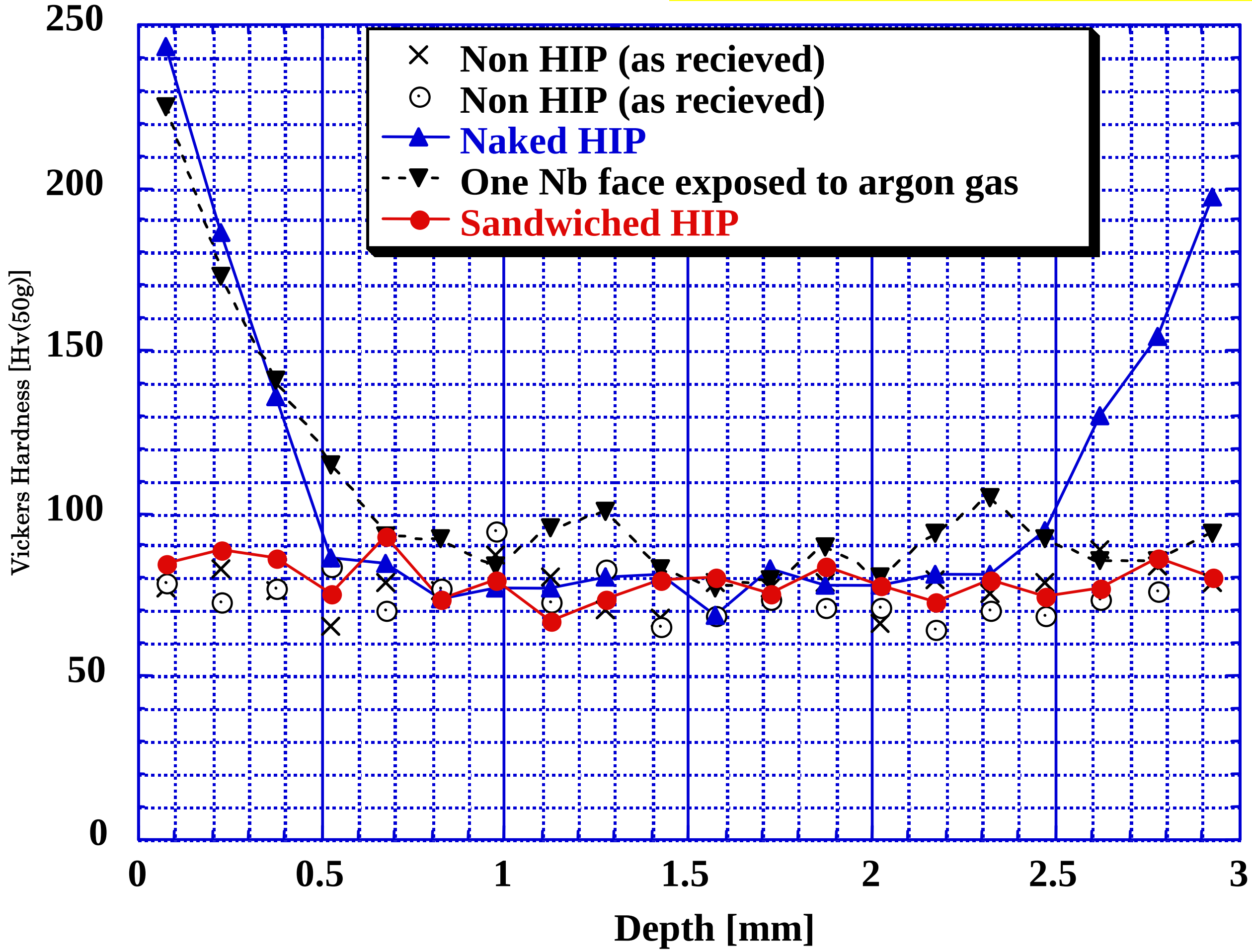
数少ない製作で40MV/mを達成。信頼性の向上

Flux Trapping Problem

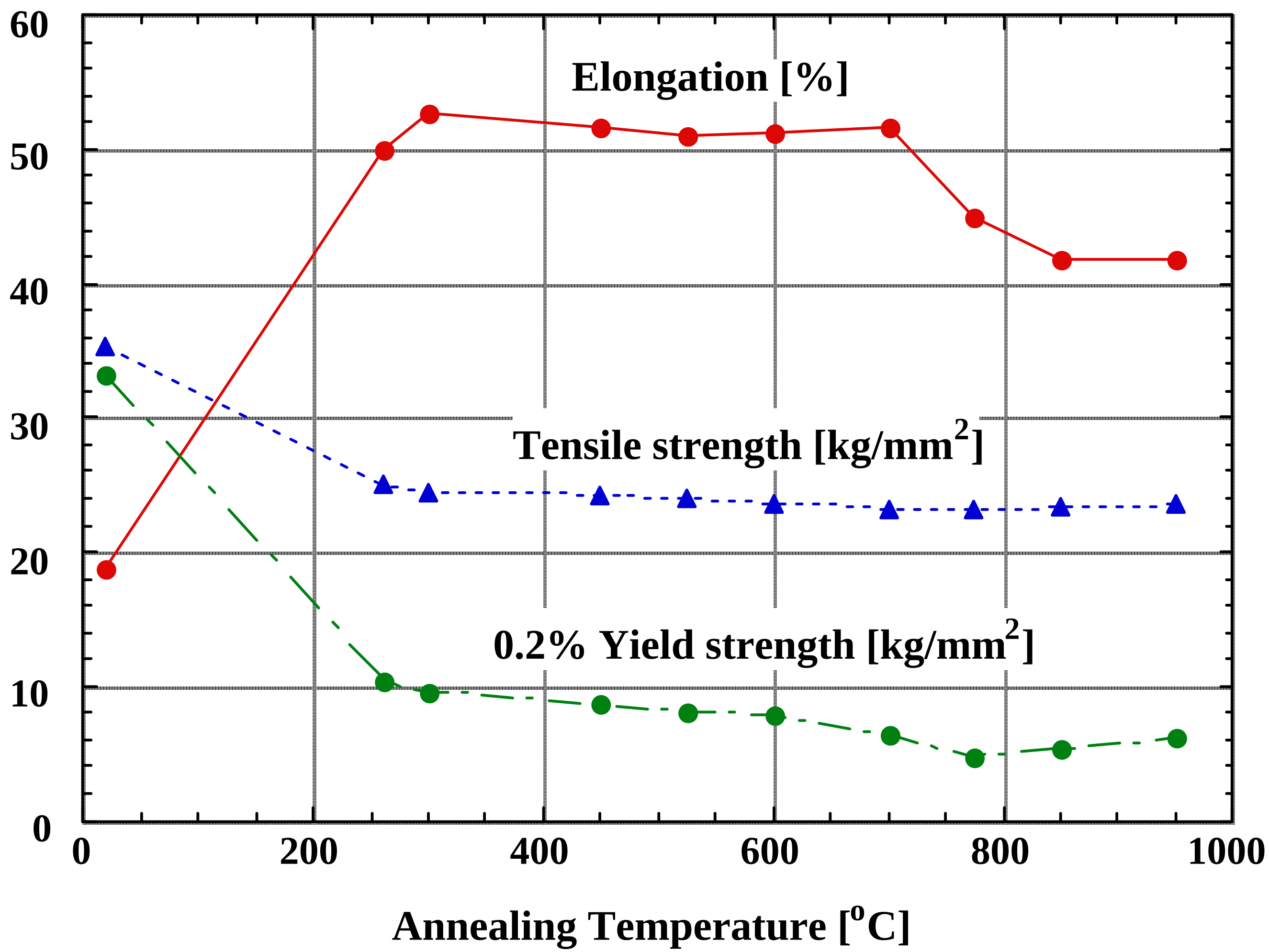


Merits of The Sandwich Structure

No material degradation



Better Formability with Clad Nb/Cu Material



加工性が
向上する。

13. Summary

- シームス空洞の製作技術は、技術的にも空洞性能の面でもreadyなった。
- Nb/Cu Clad 空洞は大きなコスト削減が期待できる。
- 但し、flux trappingの問題を解決する必要がある。