

Test cut studies for the fabrication of the CLIC damped structure, TD18_VG2.4_Quad

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Abstract

A pilot study on the fabrication of a quadrant of a CLIC quadrant-type structure was performed with five Japanese companies lead by KEK. This study is for KEK to quickly obtain the experience of the milling required for the fabrication of such quadrant-type structure.

A short bar of about 20cm in length equipped with three cells in the middle was made by each company. We let the company choose the best procedure the company believed. The machines used were three axis milling machine, four axis one and five axis one, spreading in five companies. The tools in all companies were all carbide tools this time due to the lack of lead time.

Typical surface flatness and perpendicularity of reference planes were within ten microns. This level should be improved for the actual full-size quadrant. The typical contour error of the cells was within the periphery tolerance of five microns as long as within its local area. The measured deviations were mostly speculated to the tool shape error. On the other hand, the absolute positioning of the contour shape with respect to the reference planes was of ten micron level due to the poor reference plane quality. This problem is one of the main issues for the fabrication of the full-size quadrant. The typical surface roughness is better than Ra~0.2 micron, depending both on the position and the machining method. It should be discussed whether it is necessary to improve it or not for the fabrication of the actual structure.

Through this pilot study, we concluded that we could go ahead to making the full-size quadrant with some of these companies.

Introduction

Since the wake field from the accelerator structures of CLIC¹ is quite high, the damping of the higher modes in the structure is essential to obtain a high luminosity. Making a structure with the assembly of four rods is one of the ways to realize the damping through the radial channels on disk to maximally damp the higher modes. Since the CLIC recently made a decision² to adopt the X-band frequency following the optimization on frequency and acceleration gradient, the X-band group of KEK became interested in such techniques related to the CLIC stated above.

In the period from 1990's to early 2000, KEK has pursued the research and development with SLAC on the high precision fabrication of X-band accelerator structure and realization of the high gradient³. Here the wake field suppression by detuning with a medium damping was established. The high gradient at the loaded gradient of 50MeV/m was also proven with a little concern on breakdown rate and associated damage of accelerator structure during a long term operation. After ITRP⁴ recommendation, which recommended the super-conducting RF technology for the international linear collider, the KEK X-band group has continued its X-band activities in the high gradient evaluation studies⁵ to establish the high gradient performance in the structures made by KEK and scientifically understand the relation of the high gradient level to the copper surface.

Taking the choice of X-band frequency for CLIC into account and trying to further extend the KEK study on X-band structure, the KEK X-band structure group decided to collaborate with CLIC. In addition to the collaboration toward the high gradient performance, the group identified the precise fabrication of the structure composed of four quadrants as one of the very important technologies to fully study the technologies needed for CLIC. Since the KEK group has developed the high gradient structures comprising of the stack of the thin circular disks, it is new to fabricate the structure totally composed of quadrants which should be made only by milling. Therefore, we set three stages toward the actual fabrication of structure parts; the first stage to find the vendors which have the machine and technology to proceed the precise milling, the second stage to make one quadrant to prove the fabrication technology and the third stage to actually make four quadrant at the same time. On this paper, we present the first stage.

Test cut design

The present test cut was planned for the Japanese vendors and KEK to taste the quadrant design and to obtain the experience from fabrication point of view. The quadrant design was referred to the CERN drawing, CLIAAS110003 shown in Fig. 1. Rather than making a full-length bar, we planned

to make a short one with a few cells. This makes us understand the actual 3D shaping but the management of the long bar was postponed.

The actual 3D design drawing, shown in Fig. 3, was made by extracting a part from the original stp file from CERN with some additional modifications. The tolerance was set as that by CERN in CLIAAS110001 and CLIAAS110002, shown in Fig. 2. Typical fine profile was specified to be within a periphery tolerance of 5 microns.

The tolerance on dimensions and profiles were set but these are set as a target value and NOT the actual specification. This was to fasten this test cut by allowing us to gain the cost-effective experience in a smoothest manner.

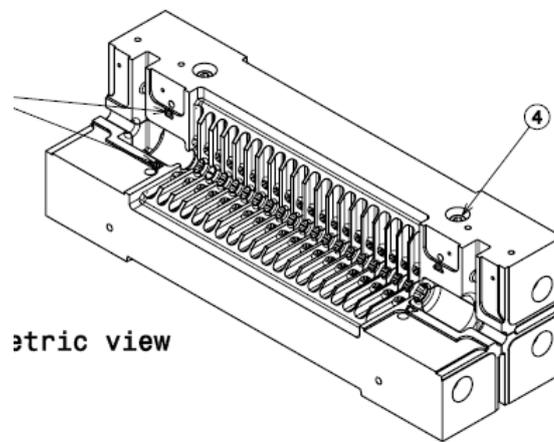


Fig. 1 CERN quadrant structure design, CLIAAS110003.

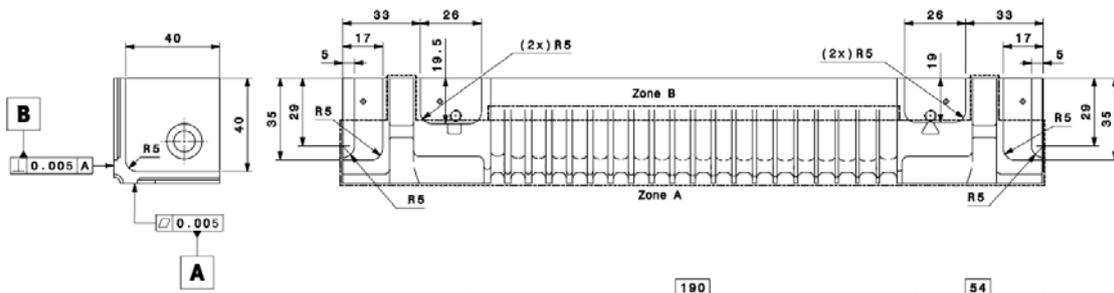


Fig. 2 Tolerance specification, CLIAAS110001, of one of the quadrants of a full structure.

Nomination of five vendors

Though KEK has the experience of X-band accelerator structure fabrication, it is new to mill all over the surface of the structure. Therefore, we decided to start with the test cutting of small sample to taste such a fabrication procedure. We negotiated with the five vendors who have the experience to make X-band accelerator structures and related parts. The following vendors are nominated by us for this study and all agreed to try the cutting based on their talented techniques. Some notes on the vendors related to the experience of the X-band accelerator structure fabrication are described in the table.

Table 1: Five vendors of the test cutting..

Vendor	H	I	M	Y	U
Experience	Once made cells with diamond turning, though after ITRP	Made several structures of 1.3m, 1.8m, 0.5m and 0.6m with KEK	Most actively made damped-detuned cells for KEK to apply final diamond turning	RDDS cells were made at the last stage of GLC	Some accelerator related components are being made
Notes on vendor	Maker which makes accelerators as a whole	Developed high precision machining followed by diffusion bonding	Has made cells for T- and H-series for last several years before ITRP	One of the best milling machine makers in Japan	Rather new vender for KEK to ask various precision machining

ITRP: International Technology Recommendation Panel⁴.

RDDS: Rounded Damped-Detuned Structure.

GLC: Global Linear Collider³.

Details of test cut procedures

Material:

Though the material to be used finally for CLIC is thought to be Zr-precipitation-hardened oxygen free copper material, C15000[#], the material used for the present study is OFC, because of the limited time available for procurement of material. The rough machined bars were made with OFC copper without annealing step and supplied to the vendors.

Tool:

Carbide tool, instead of diamond one, was used because of limited time available and little experience of diamond tool among us. All vendors used this time the ready-made tools with radius of 2mm. The deviation of the tool periphery shape from the circular shape is ± 3 microns or so at best. The average radius deviation from nominal value was compensated effectively though the measurement of some dimensions cut by itself. One of the tools is shown in Fig. 5. The tool cutting edge was preserved without showing any noticeable tool wear after using for 8 hours .

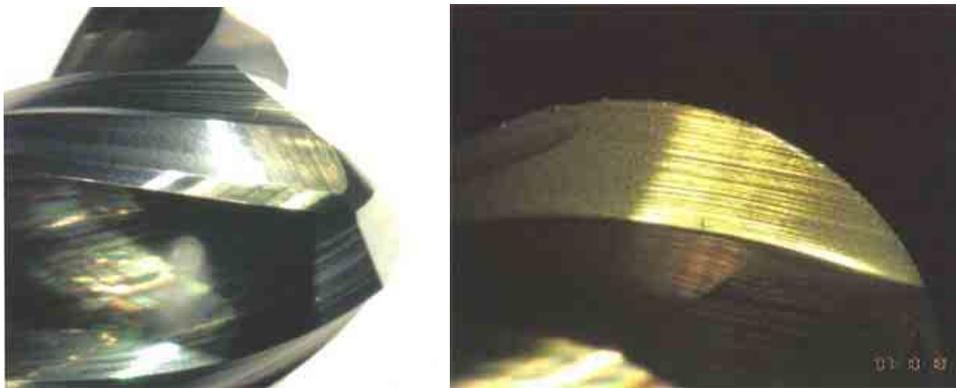


Fig. 5 Left: typical ball end mill with R=2mm and Right: tool cutting edge after cutting.

Machine:

Since the periphery tolerance of the cell shape is typically 5 microns, we understood that the machine reproducibility should be of the order of 1 micron. All the vendors except one applied the milling machine made by YASDA⁶, one of the five vendors of the present study. This is because many of Japanese companies think the machine made by YASDA is the best in precision view point. Some machines are simultaneous 5 axes machine, while some are 3 axes with an additional precision rotation base. We did not specify the number of axes of simultaneous movement but ask the vendors

[#] CDA No. In JIS it is equivalent to C150 with Zr of 0.1-0.2%.

to use their maximum knowledge to apply to the present target to reach a required precision.

Circumference:

Basically we accepted the environmental situation for each vendor as was. Some vendors set their machine in a very-well air controlled area, while other vendors suffer from the temperature change when a big shutter opens. Since the test cut focused on the fabrication of a few cells in a small area, we believed that we can judge the technology and machine even under the environmental difficulties. It should be noted that the actual fabrication of the full quadrant should carefully be designed because of its bigger size.

Chucking:

The chucking method of the work was not specified and up to each vendor's thought. All the vendors chose the setup with the work pressed somehow onto a Vee block. The way to the fixing varies from a vendor to another.

Cutting fluid:

Usually the machine is controlled with running oils at a temperature close to that of the room. This fluid is also supplied in most of the cases to spread over the work surface.

Typical cutting stage:

In Fig. 6 below shows the typical view of the cutting in a milling machine. The cutting fluid temperature is usually kept following the temperature of the machine bed.

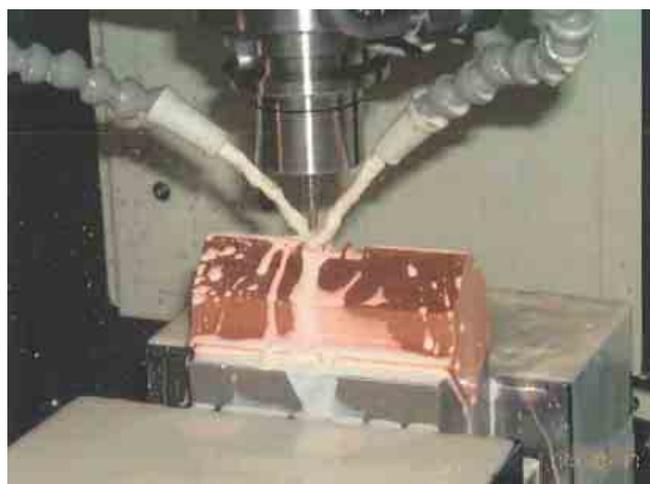


Fig. 6 Typical cutting view.

In the table below, the relevant information was summarized.

Table 2: Relevant cut condition

Vendor	H	I	M	U	Y
Machine maker	YASDA	YASDA	SODICK	YASDA	YASDA
Machine	YBM-800N	YBN-600N	MC650L	H30i	YBM-640V
Free axes	4 axes	3 +1 axes	3 axes	5 axes	3 axes
Temperature (degC) during machining (typical)	20 C \pm 2 (\pm 0.5)	23 C	24 C	(\pm 0.5)	23.5 C
Chucking	V-block	V-block	V-block	V-block	V-block
Tool tilting	0	0	0	3 deg	0
Final cut amount		20 μ m		5 μ m	50 μ m
Cut period	5h / total	4h / final		1h / final	3h / final

Evaluation

We specified the measurement as shown in Fig. 7. We specified the measurement of the profiles along the red lines, the surface roughness measurement at the areas specified in green numbers, the checking of surface continuity at the area with light blue numbers and the inspection of edges specified in dark blue numbers. Actually, we let each vendor evaluate depending on the vendor's capability of the measurement.

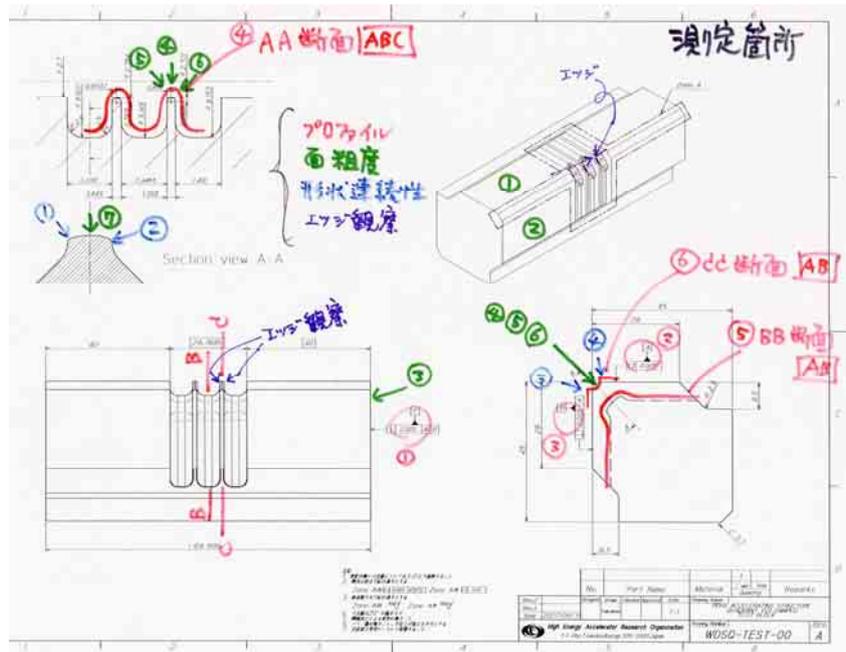


Fig. 7 Specification of measurement.

The typical measurement by CMM at KEK is shown in Fig. 8. The CMM is ZEISS UPMC-850 CARAT, which is located in a clean room at a temperature 20 degC. By this CMM, profiles are measured in a scanning mode with KUM program. A sapphire ball of 2mm in diameter slides along the contour with 0.2N pressure.

The surface roughness was measured by Mitsutoyo Formtracer CS-5000. The inspection by the microscope was performed with a laser microscope, KEYENCE VK-8500.



Fig. 8 KEK CMM typical setup.

Results

It should be noted that the results presented here are those of the first trials for the vendors. Therefore, there is no feedback process based on the KEK measurements so that the chance for the vendors to try the second recovery trial was missing. In this respect, we understand that this study is only for KEK to taste the Japanese vendors at a first glance on the milling capability for CLIC quadrant and is NOT for evaluating and cultivating the vendors in a longer time scale.

Typical measurement results are shown in the appendices in the order of

1. local profile shapes
2. surface roughness
3. microscope view.

Some of the results are described below.

1. Local profile shape

The best is those of “Y” and “U” and they are within tolerance band of 5 microns. Therefore, it shows the feasibility of satisfying the tolerance as long as the positioning in a full-size body is reasonably good. Typical shape error of other vendors is about several microns, except for “M”.

A repeated pattern from cell to cell is seen. It may be due to the tool profile error or machine movement error and should carefully be improved.

2. Surface roughness

The roughness Ra of the reference planes, A and B, made by fly cutting is very good such as that of “I”. The others made by ball end milling are ranging from 0.1 to 0.2 μ m depending on the cutting condition. We assume that the ball end milling is needed for these surfaces in the actual fabrication to make the good dimensional control. How seriously the surface roughness be good or can be deteriorated in the actual fabrication will be determined from the compromise between the need of the good surface roughness and the required cutting period.

The surface roughness at the cell wall is probably important from surface resistance point of view. The points, #7a, #7b and #7c, represent the cell wall and the Ra is ranging from 0.1 to 0.2 micron. Surface roughness values at the point #7a were obtained with the cutoff value set to 0.25mm instead of 0.8mm specified in JIS B 0601-2001. This is because the curved design makes

it difficult to deduce the practical roughness values if we use the nominal cutoff condition. In future, the roughness of this area should be revisited with an understanding of how good the surface roughness should be.

The surface roughness at the damping waveguide channel is not very critical from RF surface point of view. It ranges around 0.1 to 0.2 micron, within a factor of two to the tolerance value and the present surface should be sufficient.

3. Surface inspection by a microscope

The surface was inspected by an optical microscope. This is attempting to see how the surface pattern makes and to judge whether there is a deformations or burrs around any corners.

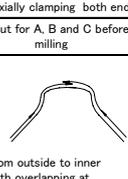
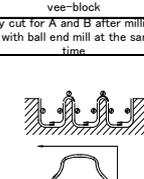
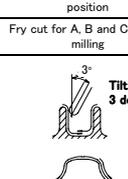
The regular patterns of ball end milling are seen in the smooth areas, on the cell wall and on the flat surface, shown in the second and the third photograph of each case. On the contrary, the surface at the saddle point of the beam hole aperture show somewhat irregular pattern. It is speculated that the non-smooth multi-axis movement of the tool at this area makes the surface view not very smooth. Since the roughness is not easily measured in this area this time, the evaluation of this area should be developed in future.

At some of the ridges are seen somewhat burr-like objects. In some case, it is seen in one side and not seen in the other side, indicating the tool passage improvement can make such ridge formation better and burr-free.

4. Summary

The relevant information and the summary of the measured results are listed in Table 3. We put colored circles to indicate our judgment; Green = good, Grey = marginal and Red = bad. We should admit that this judgment is very rough and intuitive one so that we do not want the reader to judge the technical potential of the vendors from this paper.

Table 3: Cut conditions and summary of measurement by KEK

		H	I	M	U	Y														
Machine	Name	YBM-800N-80NP	YBN-600N	mc650L	H30i	YBM-640V ver.III														
	Maker	YASDA	YASDA	SODICK	YASDA	YASDA														
	Control axes	4 axes	3 axes + 1 axis	3 axes	5 axes	CNC JIGBORER (3 axes)														
Tool	Tool	Ball end mill two grades (Carbide) R2.5mm	DHB R2 x L20		Ball end mill (Carbide, Ultra-fine particle) R2-2 grades Periphery tolerance ±3 μm L70 (brade length 20) Shank φ6	Ball end mill (R2 x 8) HLB2040-080SE Periphery tolerance 1.5 μm														
	Vendor	-	Nisshin		UNION TOOL	UNION TOOL														
Circumference	Temperature	20±2°C (variation in a day ±0.5°C)	23°C	24°C	±0.5°C	23.5°C														
	Cutting fluid		Brother Pasco 1000		Machine oil (Base temperature - 2 degrees)	Brother Pasco 1000														
	Circumference	Precision Jig-Bowler room	Near large shutter	In a prefabricated house	Floor: Piles + 1m concrete base															
Machining in detail	Fixing work	Set vertical on a rotatable plane with axially clamping both ends	Pressed on a vertically standing vee-block		Fix on Vee block in a horizontal position	Pulled with screws toward horizontally set vee-block														
	Reference plane	Fry cut for A, B and C before milling	Fry cut for A and B after milling, C with ball end mill at the same time		Fry cut for A, B and C before milling	Ball end mill at the same time with cell profile														
	Tool passage					Cutting along Contour Line (except for C-plane) targeting the geometrical Ra=0.1 micron														
	Machining parameters		S:9000rpm F:400mm/min t:20 μm最大0.13mm(final)		S:8000rpm F:100mm/min (Geometrical depth=0.5 μm) t:5 μm(final)	S:15000rpm F:1200mm/min t:50 μm(final)														
	Machining time	5 hours for total cutting	4 hours for final cutting		80 minutes for rough and 40 minutes for final (for each groove)	3 hours for final cutting														
	Comments	Fry cutting for reference planes																		
Measurement		Profile: FALCIO-Apex9106(Mitsutoyo) Roughness: Surf-com 570A(Tokyo-Seimitsu)	Measurement done by IIC Profile: CMM (LEITZ) Roughness: Taylor Hobson		Profile: CMM (ZEISS) Roughness: Surf Test SV-400(Mitsutoyo) Surface View: Non-contact 3D CMM OGP															
	Reference planes	(μm) [Straightness] Meas. By vendor	(μm) [Straightness] Meas. By vendor																	
Perpendicularity	Flatness (A)	9.7 [9.8middle high]	0.9 [0.7middle high]	12.8 [12.1middle high]	1.5 [1.7middle high]	3.6 [3.2middle high]														
	Flatness (B)	10.6 [9.1middle high]	1.1 [0.7middle high]	19.3 [12.4middle high]	1.7 [1.6middle high]	4.1 [3.2middle high]														
	Flatness (C)	1.1	0.6	1.1	0.3	0.6														
	Perpendicularity (A - B)	8.1	11	0.9	8.9	1														
	Perpendicularity (A - C)	12	9	2.2	41.9	3.5														
Perpendicularity (B - C)	22.6	0.4	0.4	22.5	0.5															
Profile	Evaluation	C	B	C	A	B														
	Cross-section cut by a plane including beam axis																			
Dimensions	UP	DN	W	Meas. By vendor(W)	UP	DN	W	Meas. By vendor(W)	UP	DN	W	Meas. By vendor(W)	UP	DN	W	Meas. By vendor(W)				
	Cell#18	-0.8	1.4	-0.2	-3.9	0.3	12.6	-0.3	-6.3	288.7	321.9	-1.3	-7.8	-6.5	1.3	-2.9	7.7	4.1	3.4	
	Cell#17	-3.4	3.7	-7.1	-1.7	9.2	15.4	-6.2	5.5	286.1	353.4	-67.3	-9.8	-6.1	-3.2	7.3	10.7	3.4	-0.015	
	Cell#16	-0.7	5	-4	-4	11.2	17.8	-6.7	1.5	12.4	320.8	-3	-9.8	-7.5	-2.1	-3.2	9.2	14.8	5.0	0.002
	A	B	Meas. By vendor (A)	Meas. By vendor (B)	A	B	Meas. By vendor (A)	Meas. By vendor (B)	A	B	Meas. By vendor (A)	Meas. By vendor (B)	A	B	Meas. By vendor (A)	Meas. By vendor (B)	A	B	Meas. By vendor (A)	Meas. By vendor (B)
	Cell#18-WG-depth	12.2	-13.3			-1.5	-1.2	1.5	2.5	10.9	-7.6			5.8	-1.1			-0.5	-4	
	Cell#17-WG-depth	-10.7	-12			-0.5	-1.2	1	2.5	-10.6	-7.6			4.7	-1			-4.8	-5	
	Cell#16-WG-depth	-11	-12.9			-0.4	-1.5	1	3	-7.8	-7.1			4.1	0.2			-3.8	-7	
	A	B	Meas. By vendor (A)	Meas. By vendor (B)	A	B	Meas. By vendor (A)	Meas. By vendor (B)	A	B	Meas. By vendor (A)	Meas. By vendor (B)	A	B	Meas. By vendor (A)	Meas. By vendor (B)	A	B	Meas. By vendor (A)	Meas. By vendor (B)
	Cell#17,#18-disk	12.7	-1.3		2	1.3	-0.7			-12.6	-9.1			2.4	-1.7		1.1	4	-2.3	
Cell#16,#17-disk	13.3	-12.9		4.5	1	-1.3			0.2	-12.6			2	-1.7		2.1	2.9	-2		1
Surface roughness	Evaluation	C	C	D	C	C														
	Ra	Ry	Rad. by vendor (F)	Ra	Ry	Rad. by vendor (F)	Ra	Ry	Rad. by vendor (F)	Ra	Ry	Rad. by vendor (F)	Ra	Ry	Rad. by vendor (F)					
	基準面A[#1]	0.474	2.787	0.7*0.9	0.029	0.228	0.026	0.174	0.829	0.083	1.105	0.1	0.111	0.658	0.0829					
	CAVITY横断面[#7a]	0.22	1.2		0.15	0.86		0.17	0.9	0.21	1.4	0.18	0.23	1.61						
	CAVITY横断面(中央) [#7c]	0.473	2.459		0.094	0.34	0.465	0.14	0.906	0.407	2.853	0.22	0.109	0.73						
	CAVITY横断面(L) [#7c]	0.224	1.357		0.185	1.03		0.115	0.888	0.269	1.587		0.118	0.536						
	WG横断面[#8a]	0.097	0.636	0.12	0.163	1.128		0.139	0.897	0.195	1.125		0.226	1.222						
WG横断面[#8b]	0.163	0.762	0.17	0.176	1.143		0.174	0.951	0.242	1.277		0.081	0.501							
Surface view	Iris (Saddle point area)	Spur along 45 degrees from beam axis direction	Small burrs on one of the disk edges	Spur along beam axis direction	Spur along the radial direction	Spur along beam axis direction														
	Edge between iris to flat surface	Only small burrs (10 microns) on one of the disk edges	Small burrs on one of the disk edges	Very clean edge	Burrs of 20 micron side extruding toward the upper direction	Very clean edge														
	Center area of a cell wall	Small waving pattern. Step of burr at the boundary to R2.5	Gold regular surface pattern but not around iris top at 2a	lip-like spots around center area	Small wave pattern along radial direction, Straight lines along beam direction (roughness)	Regular spur along beam axis direction, rather large scale														
Overall evaluation	Evaluation	B	B	B	B	A														

Conclusion for the trial fabrication of full-size quadrant

Some of the vendors showed fairly reasonable profile shape realization, at least locally. If we take careful care on the positioning of the local shape with respect to the reference planes in the actual full-size structure, we think it possible to address the periphery tolerance of 5 microns. Especially important is the temperature stability or related compensation technique because the work size of 300mm simply changes its length by 5 microns per degree C, whose error is already beyond tolerance.

The carbide tool seems good enough to cut the shapes within a required precision. However, it may not easily meet the surface roughness tolerance, $R_a=0.1\mu\text{m}$, which is determined as a quarter of the skin depth at X-band. Therefore, we think it reasonable to proceed with the carbide tool until we are well ready to use diamond tool and also we understand the origin of the specification well. The tolerance of the circularity of the tool is about ± 2 to 3 microns in the ready-made tools. The selection of the good tool (in precision) out of many bought tools is needed. If it is still a problem, then we should make the tool vendor to make a specially-made precise one. However, we do not think it necessary to do it for the fabrication of a full-size quadrant, though we understand that it is still marginal.

The machining time needed for these four cells are ranging from a few hours to the order of half a day. In the full-size quadrant, the number of cells increases by a factor of 5 and we conclude that it is still feasible to proceed as the extension of the present machining technology, though the long-term stability issues should carefully be overcome.

The reference surfaces, A and B, were machined independently from the cell profiles in most of the vendors. This condition may change in the full-size structure machining because it is important to make the reference surface at the same time with the shaping of cells to make the relative positioning as a whole. It takes more time to create such reference planes by ball end milling but we conclude that it is inevitable.

Thinking these in mind, we finally concluded that some of the vendors among the present vendors can make the reasonable trial cutting of the full-size quadrant based on the present machine and environment.

Acknowledgments

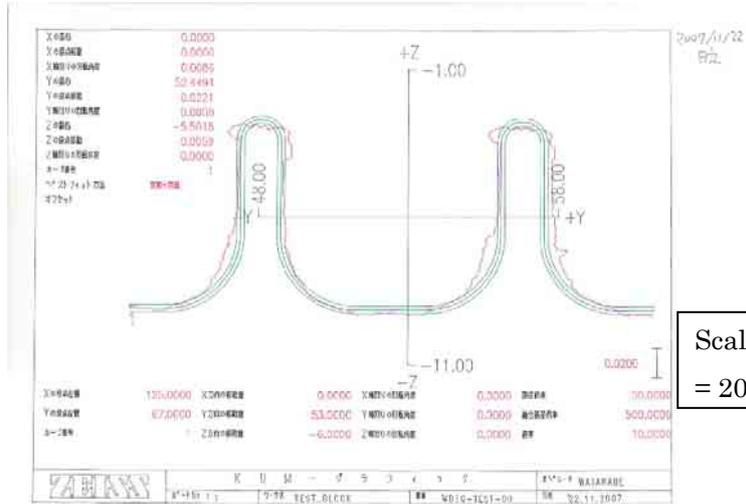
This program has been supported by the collaboration between two laboratories, CERN and KEK, for the normal conducting high-gradient studies. The Agreement of Collaborations, including this program, between two laboratories, CERN and KEK, will formally be engaged in future. In this respect, the authors greatly thank the directors in general of both laboratories for this effort. They especially thank Profs. J-P. Delahaye of CERN and Y. Kamiya of KEK for encouraging this program from its early stage.

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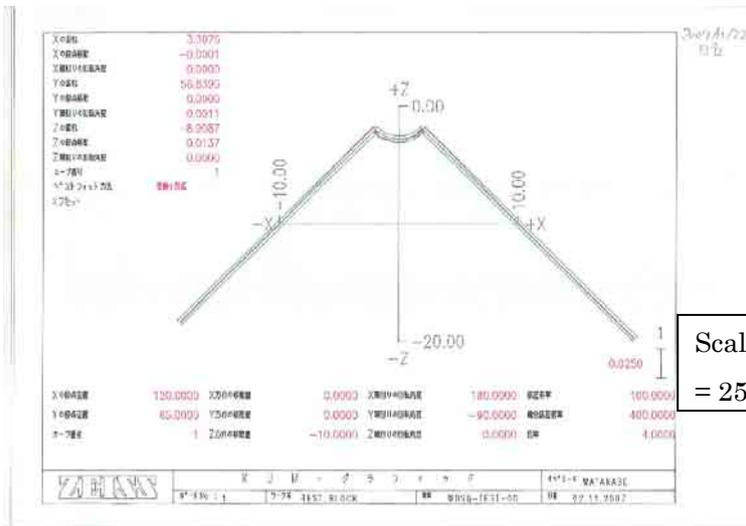
Appendix

In the following pages are shown the measured results. All the data was taken by KEK except for those described.

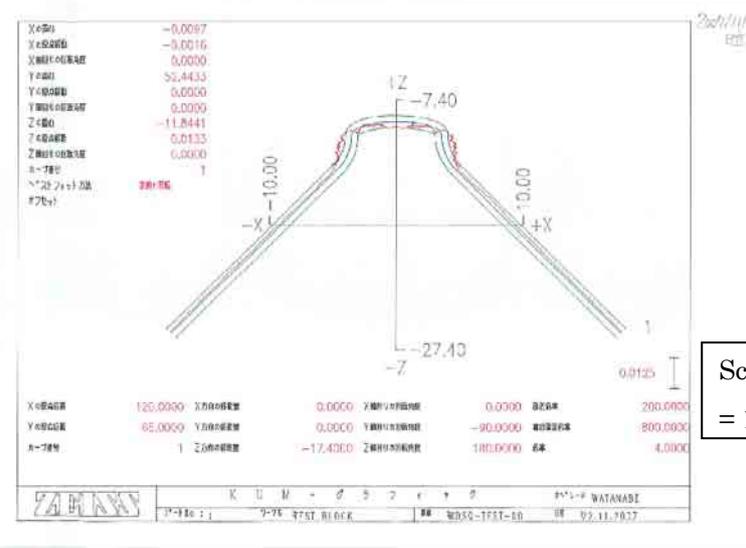
Local profile shape from the vendor "H"



Scale bar = 20 μ m

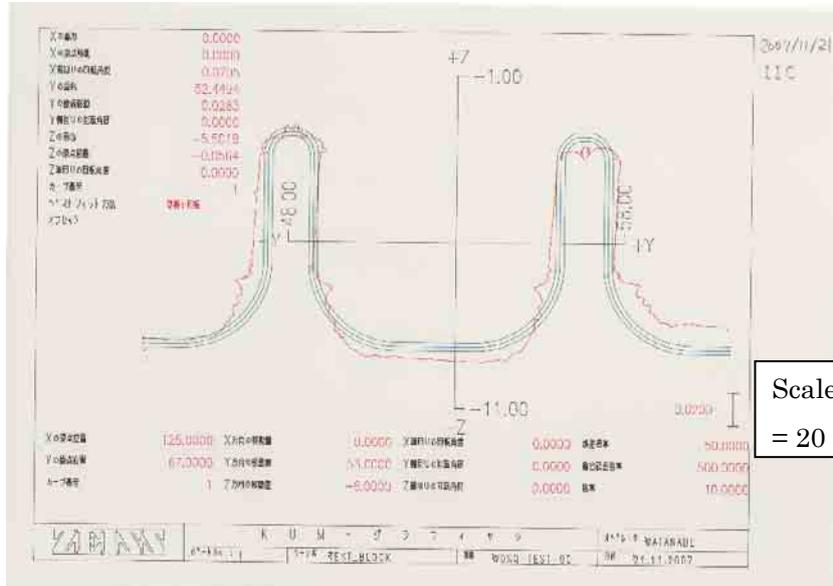


Scale bar = 25 μ m



Scale bar = 12.5 μ m

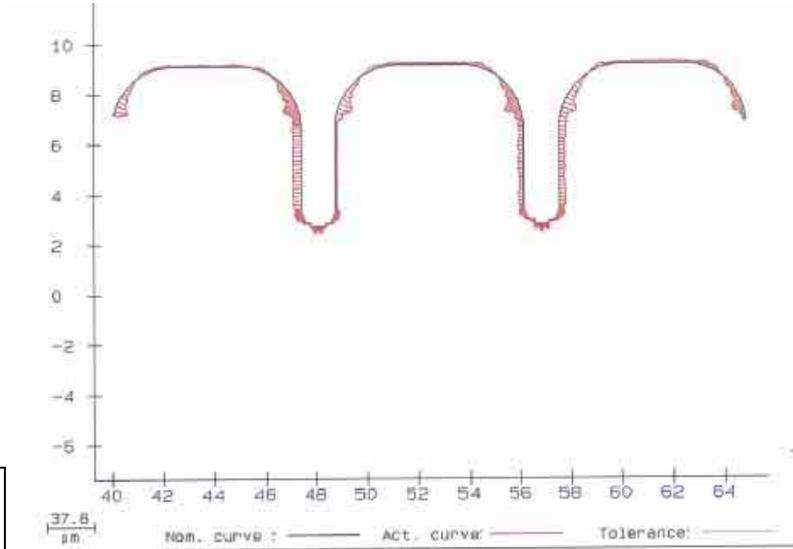
Local profile shape from the vendor "T"



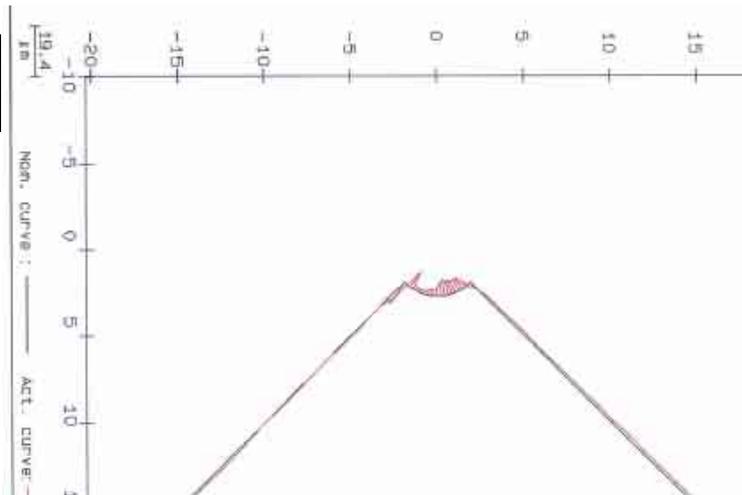
Scale bar
= 20 μm

The other two shapes are not measured.

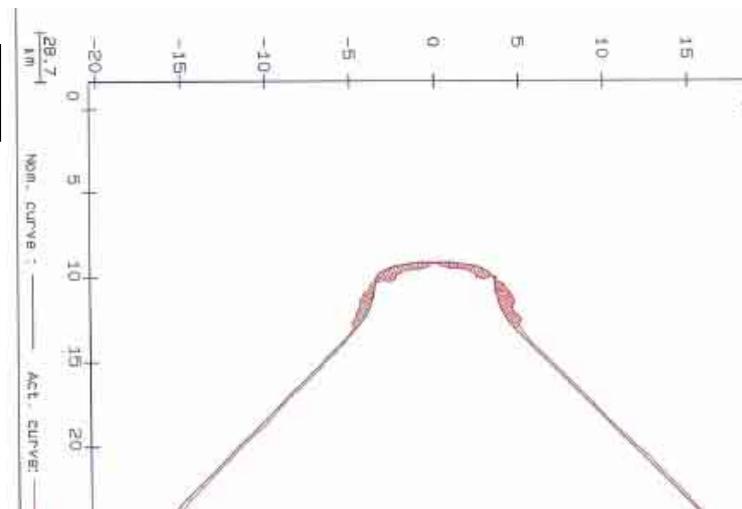
**Profile measurement by the vendor "T"
(CMM with QUINDOS by LEITZ)**



Scale bar
= 38 μm

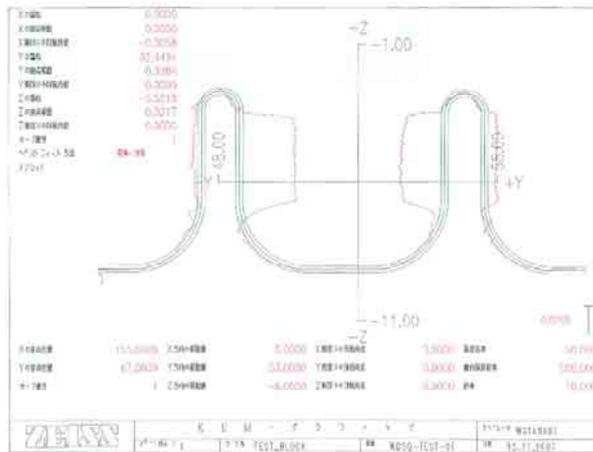


Scale bar
= 20 μm

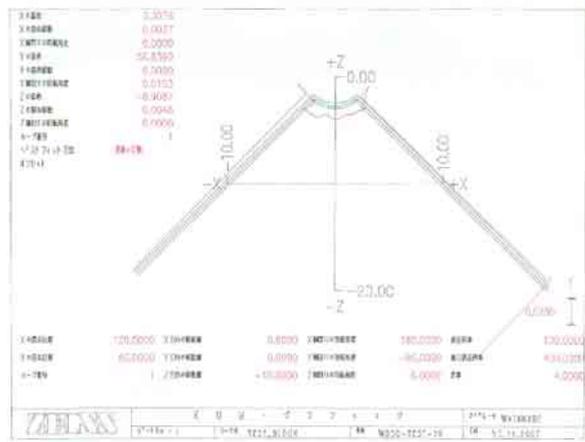


Scale bar
= 29 μm

Local profile shape from the vendor "M"

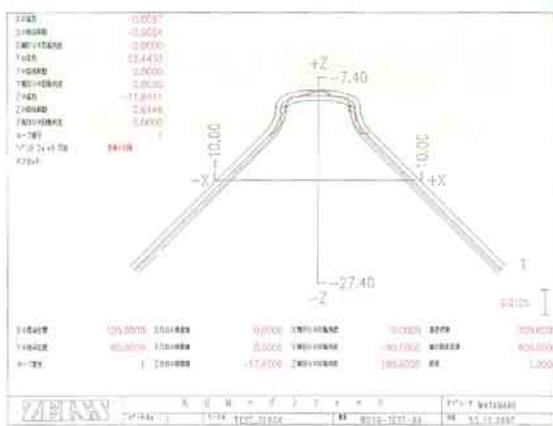


Scale bar = 20 μm



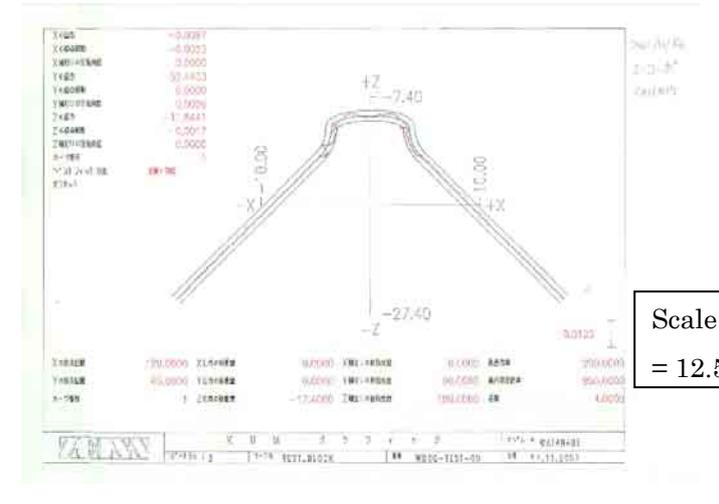
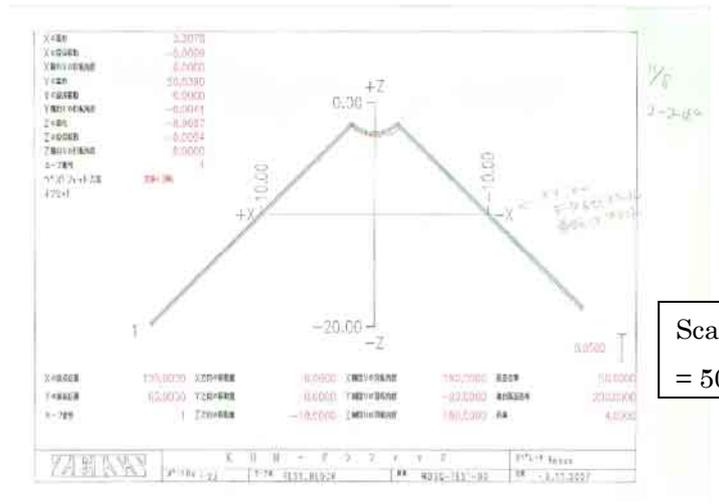
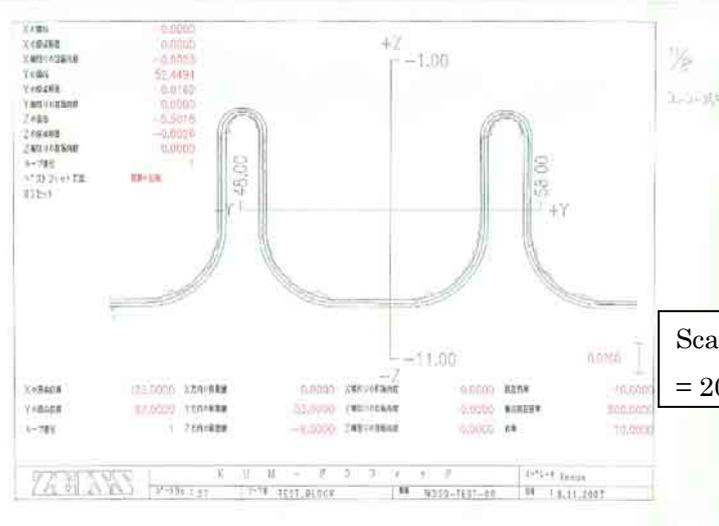
Scale bar = 25 μm

2b部横断面

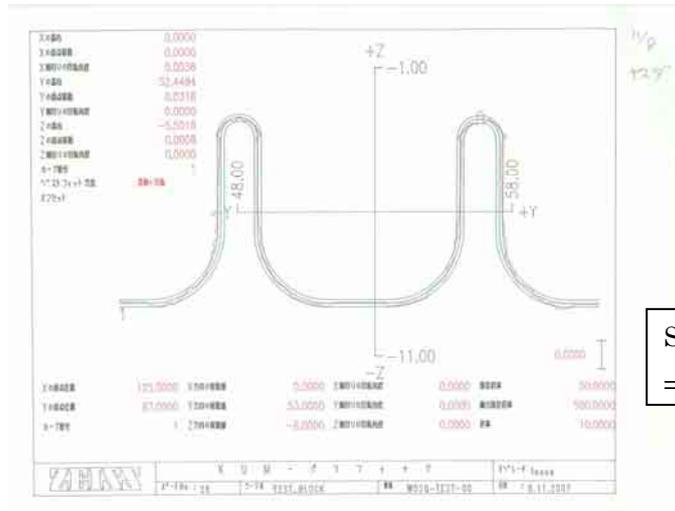


Scale bar = 12.5 μm

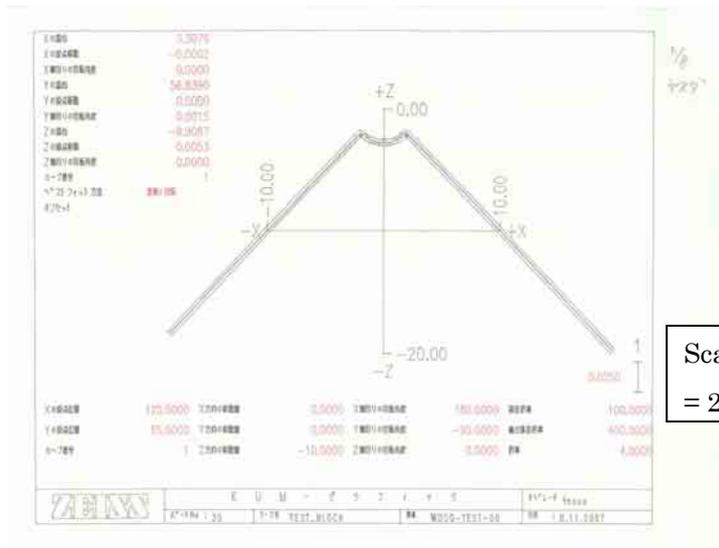
Local profile shape from the vendor "U"



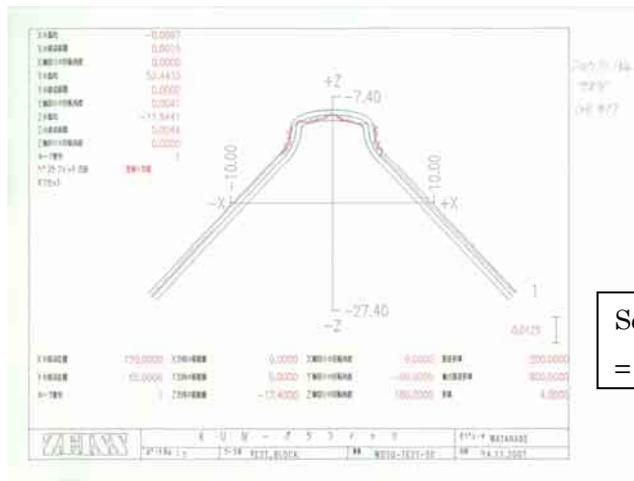
Local profile shape from the vendor "Y"



Scale bar = 20 μm

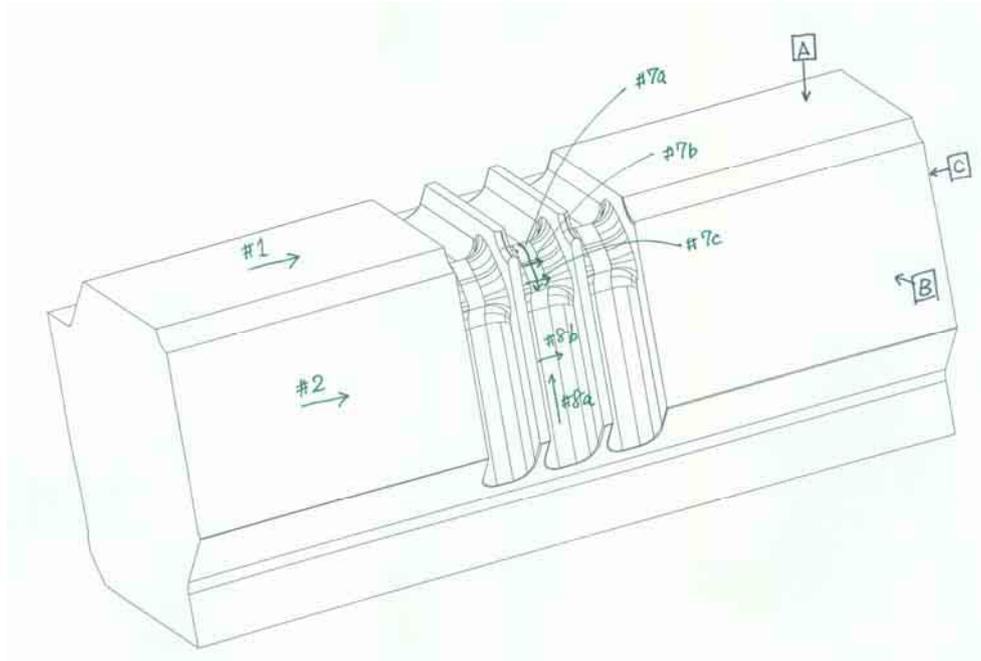


Scale bar = 25 μm

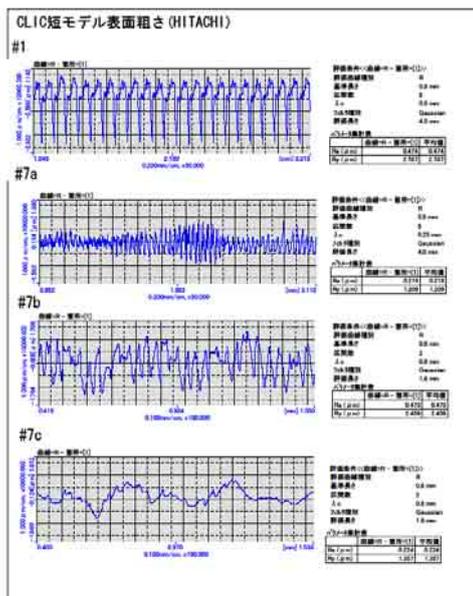


Scale bar = 12.5 μm

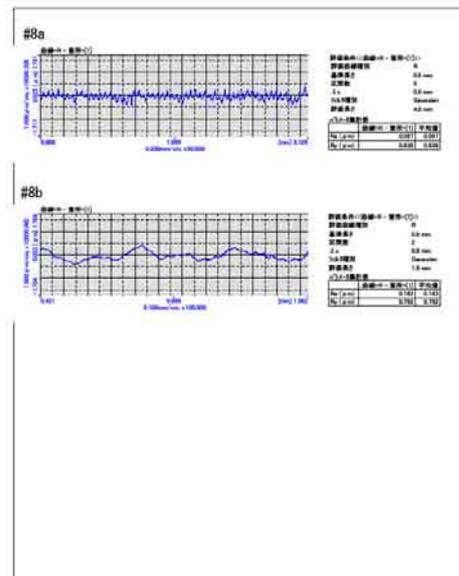
Points and direction of surface roughness measurement



Surface roughness measurement results of vendor "H"

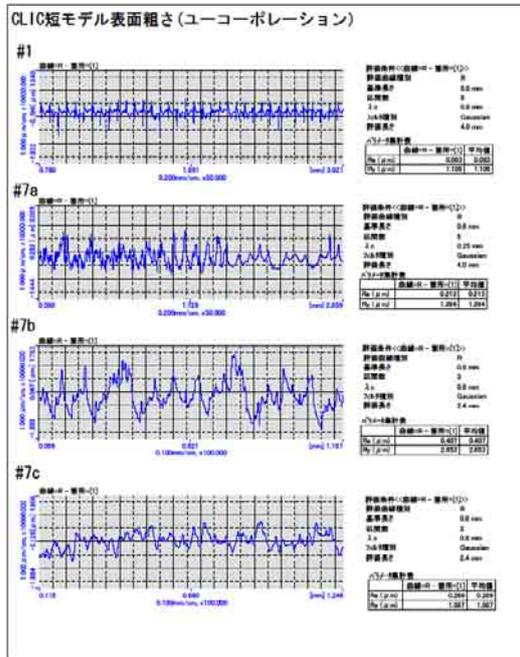


1 of 2

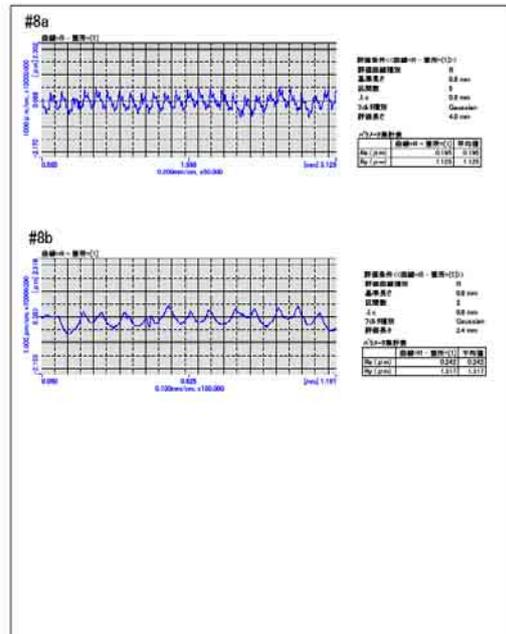


2 of 2

Surface roughness measurement results of vendor "U"

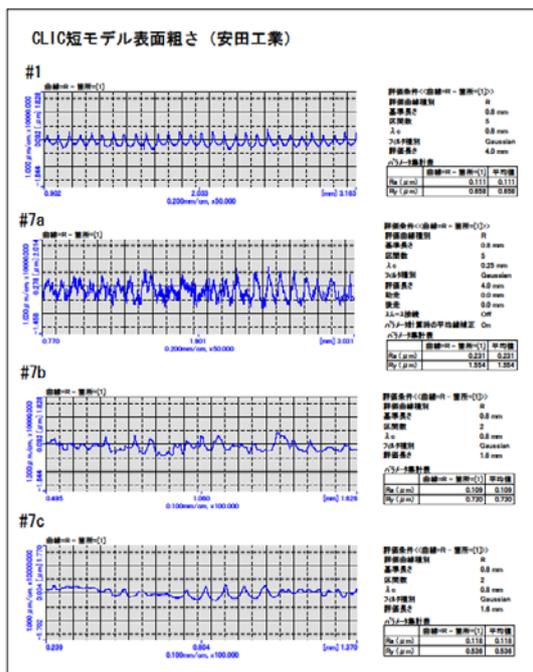


1 of 2

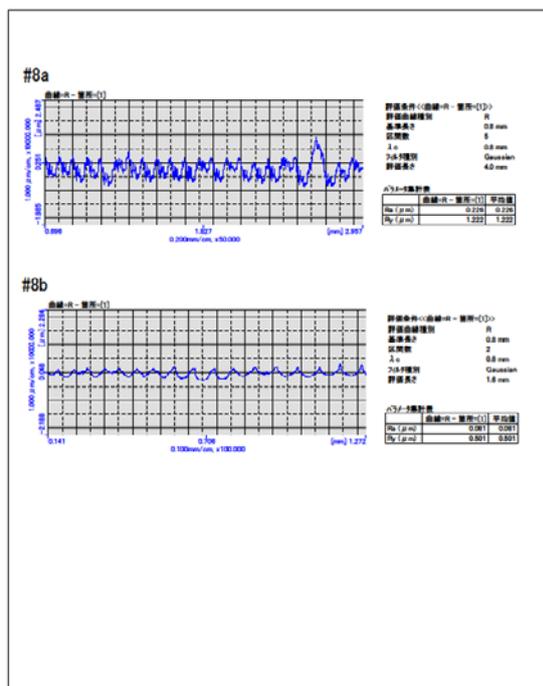


2 of 2

Surface roughness measurement results of vendor "Y"

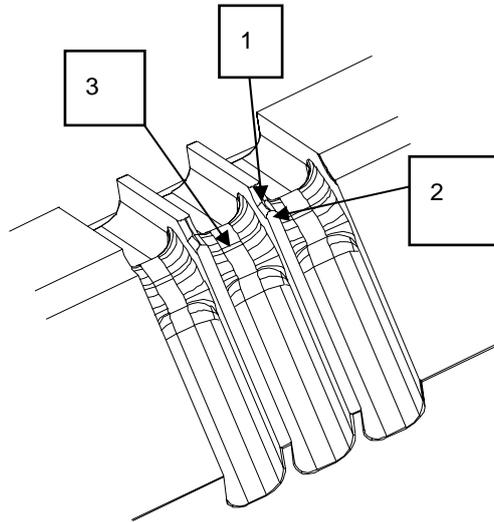


1 of 2

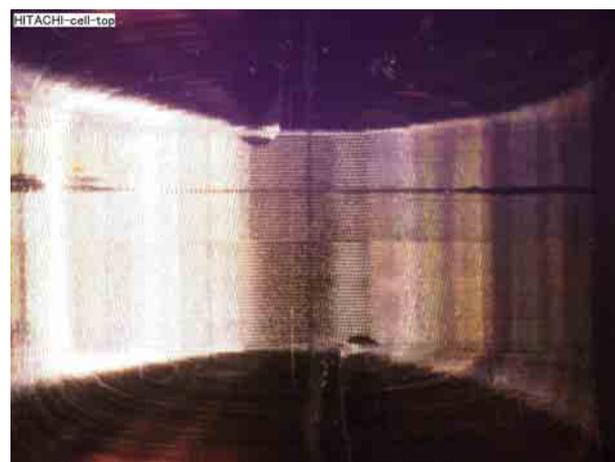


2 of 2

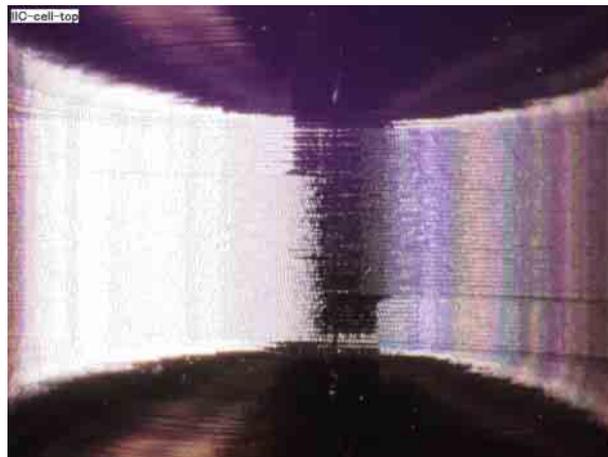
Points for inspection with a microscope.



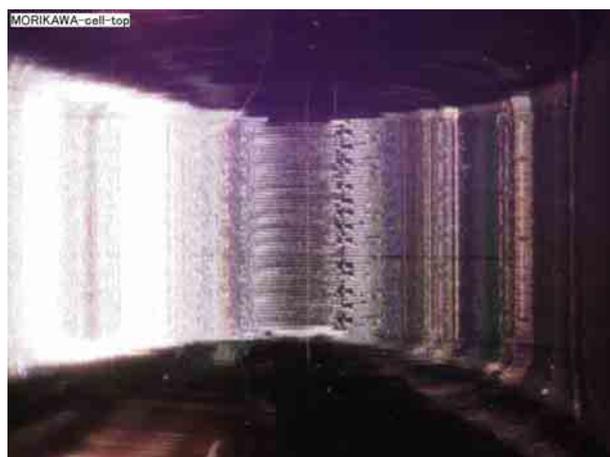
Microscope view of that of vendor “H”



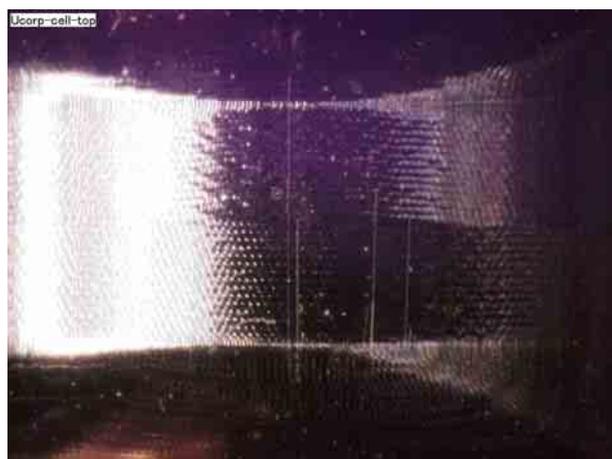
Microscope view of that of vendor "T"



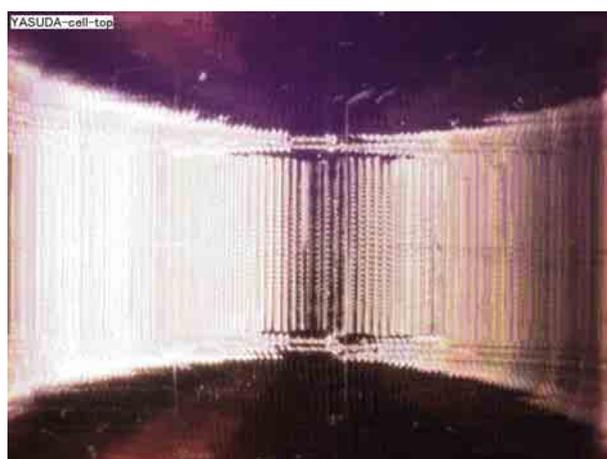
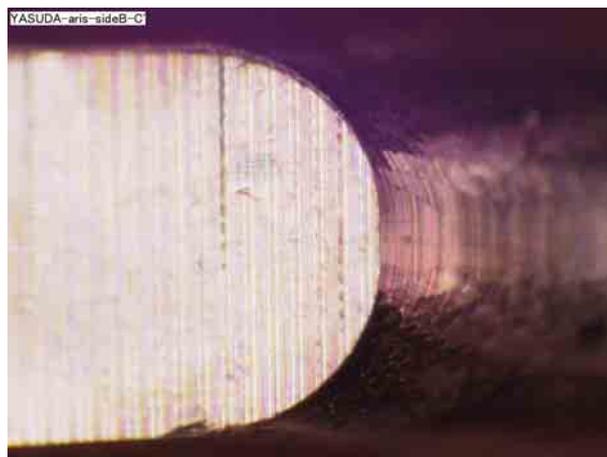
Microscope view of that of vendor “M”



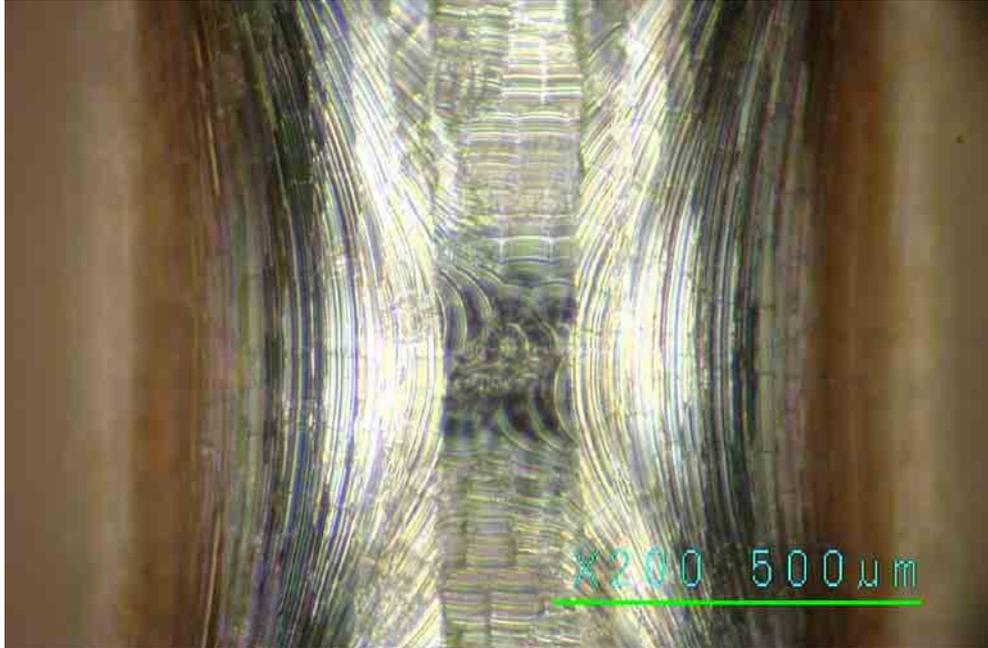
Microscope view of that of vendor “U”



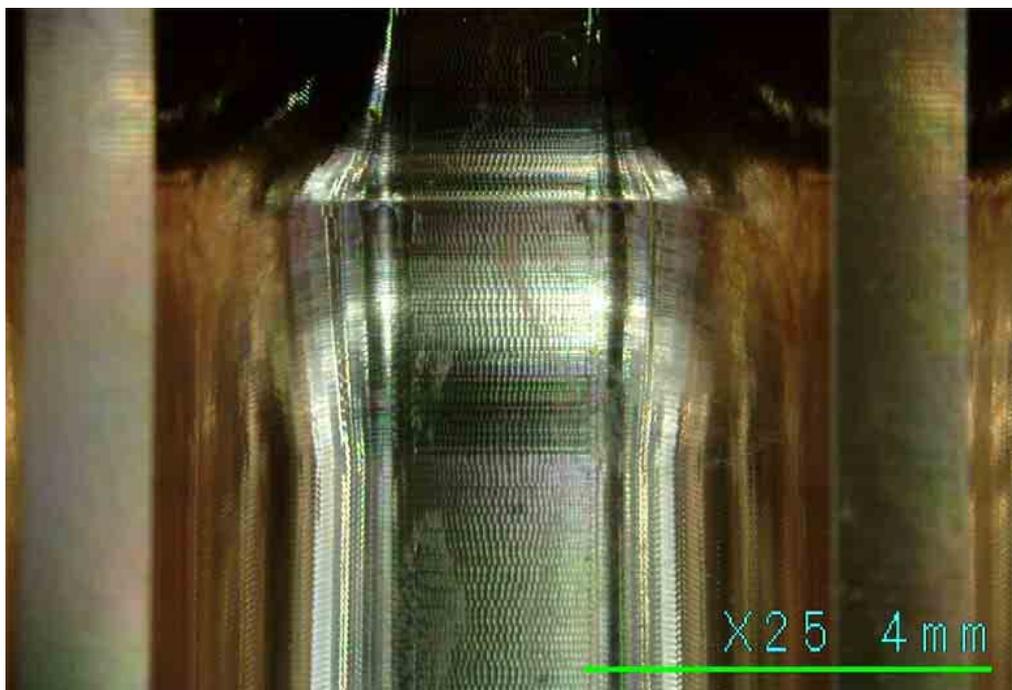
Microscope view of that of vendor “Y”



Microscope view of taken by the vendor “Y”



Saddle point at the iris aperture.



Cell wall to damping waveguide.

References

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- ¹ I. Wilson, “The Compact Linear Collider CLIC”, CLIC NOTE 617, CERN-AB-2004-100, Geneva, 2004.
 - ² H. H. Braun, “Towards a Multi TeV Linear Collider; Drive Beam Generation with CTF3”, APAC07, Asian Partical Accelerator Conference, Indore, India, 2007.
 - ³ International Study Group Progress Report, KEK Report 2000-07, SLAC R-559, April 2000.
 - ⁴ ITRP International Technology Recommendation Panel, presented in Beijing, China, 2004, <http://www.interactions.org/cms/?pid=1014290>.
 - ⁵ “Normal Conducting High-Gradient Studies at KEK”, T. Higo et al., THP038, LINAC06, Knoxville, Tennessee, USA, 2006.
 - ⁶ http://www.yasda.co.jp/la_English/index.htm