



Appendix D

A Digression on Manufacturing Techniques for Magnet Components

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CONTENTS

In this Appendix we will illustrate the main processes that can be used to manufacture the most relevant components of a superconducting magnet for particle accelerators. For each component we will outline most suitable fabrication methods and their advantages related to costs, quantities and tolerances.

Presentation organized in two parts:

- Part 1 – Fabrication Methods
- Part 2 – Magnet Components

PART 1 – Fabrication Methods:

- Machining
 - Milling, Turning...
 - CNC 5-axis
- EDM Wire erosion
- Fine Blanking
- Extrusion & Drawing
- Additive Manufacturing

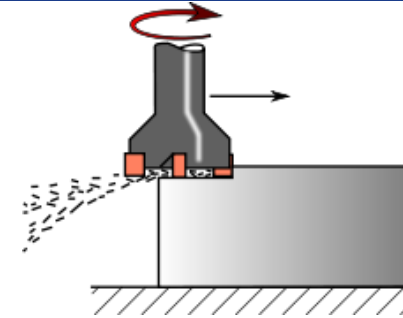
MACHINING: MILLING, TURNING...

Milling is a machining process (cutting process) that uses a milling cutter to remove material from the surface of a work piece...

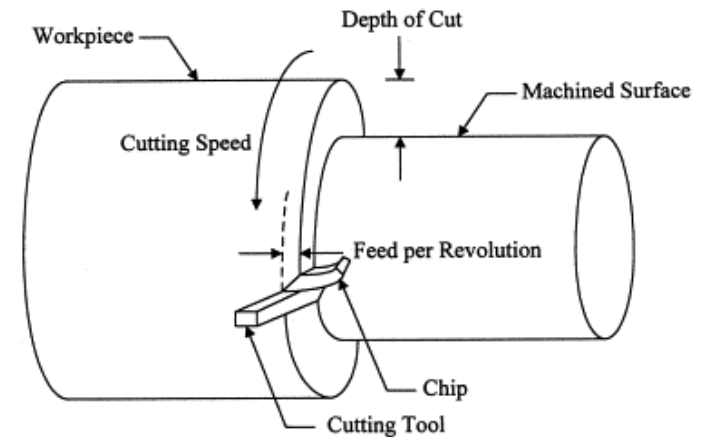
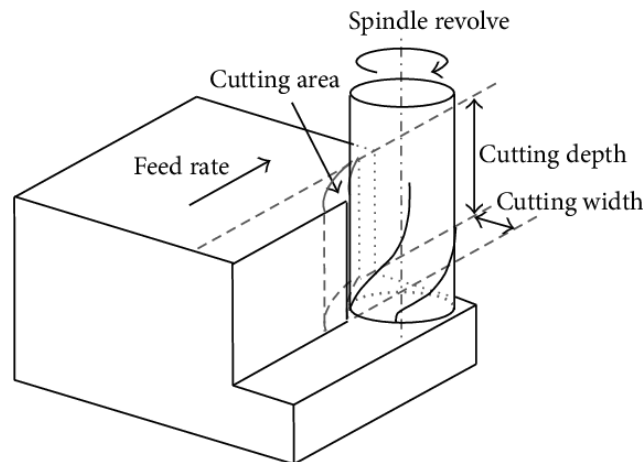
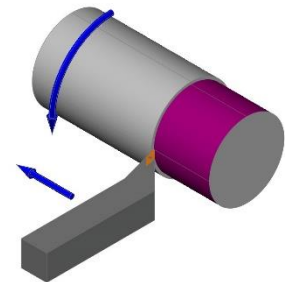
Turning is a machining process in which a cutting tool, typically a non-rotary tool bit, describes a helix toolpath by moving more or less linearly while the work piece rotates...

Many parameters depending on materials, geometry of the work piece, tolerances, surface finishing...:

- Cutting angles
- Cutting speed
- Chip shape and dimensions
- Lubrication
- ...



Courtesy: Wikipedia



CNC machining:

- Computer Numerical Control (CNC) machining...
- 3, 4, 5 axis machining...
- Diverse machine layout

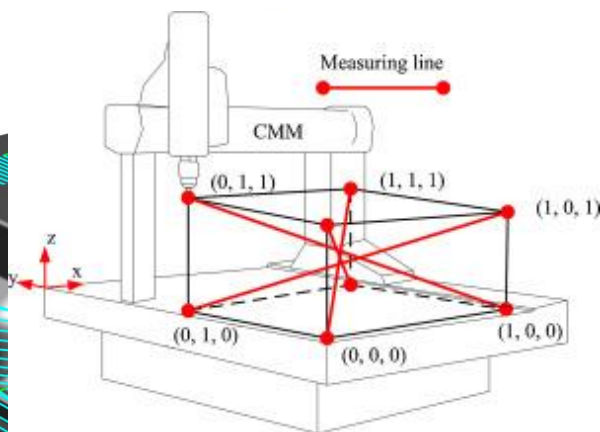
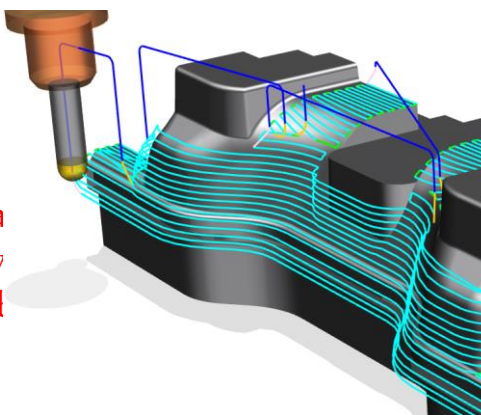
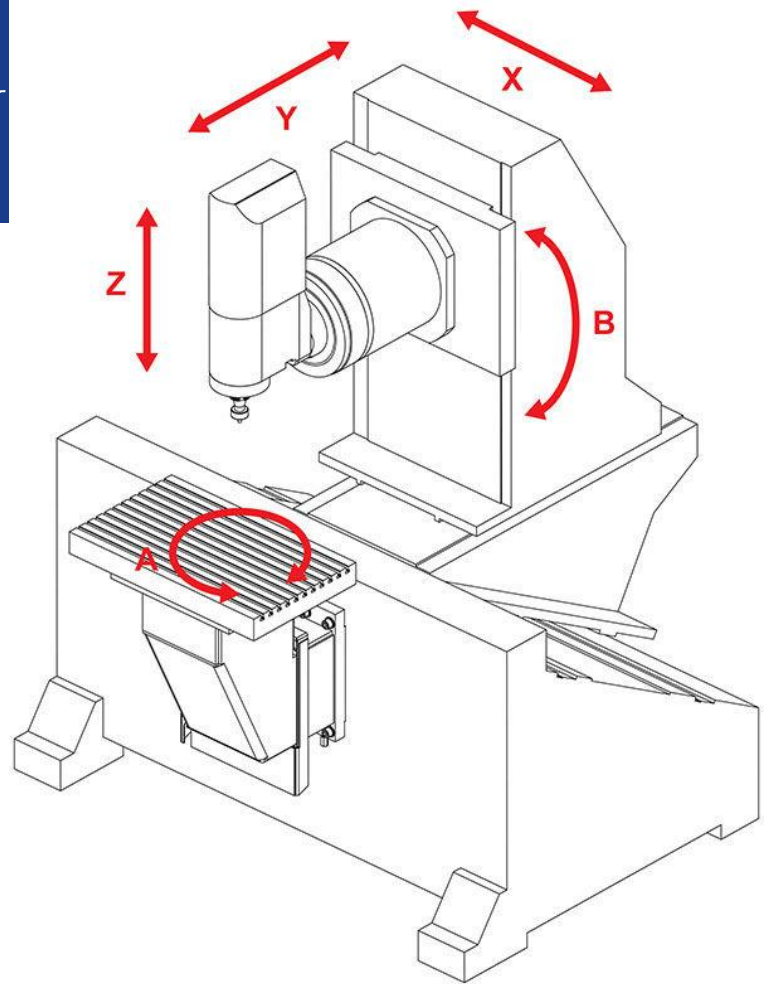
5-axis machining involves using a CNC to move a part or cutting tool along five different axes simultaneously. This enables the machining of very complex part.

Advantages of 5-axis machining:

- Allow single-setup machining to reduce lead time and increase efficiency as well as tolerances!
- Improved tool life, cycle time as a result of tilting the tool/table to maintain optimum cutting parameters.
- CAM simulations for in-depth study of the cutting tool path...

High Precision Machining (state of the art):

- 10 - 20 μm (related to dimensions)
- Number of machine set-up per work piece!
- CAD-CAM-CMM integration
- A coordinate measuring machine (CMM) is a measures the geometry of physical objects by points on the surface of the object with a probe

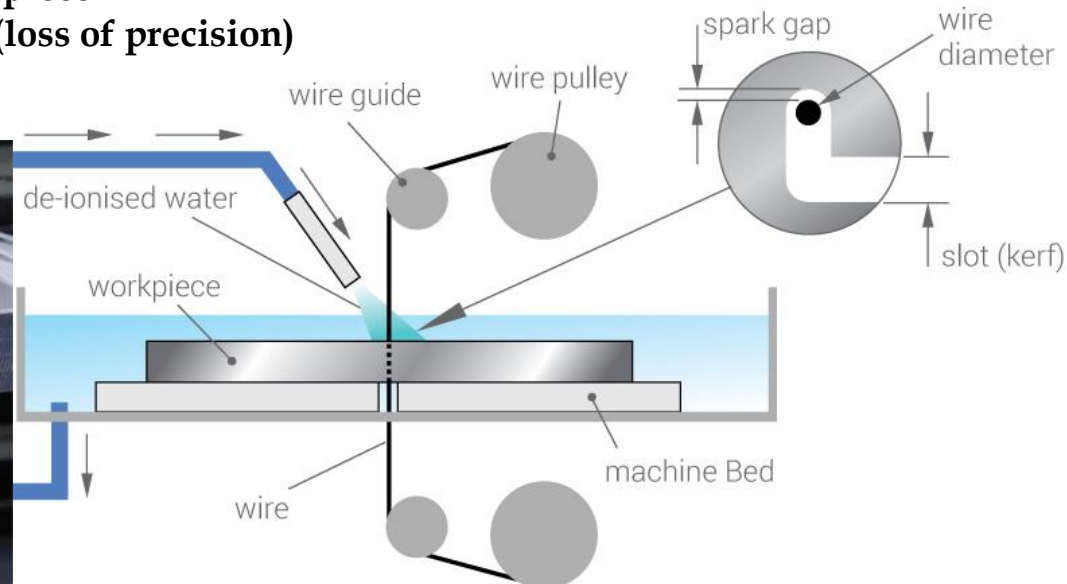
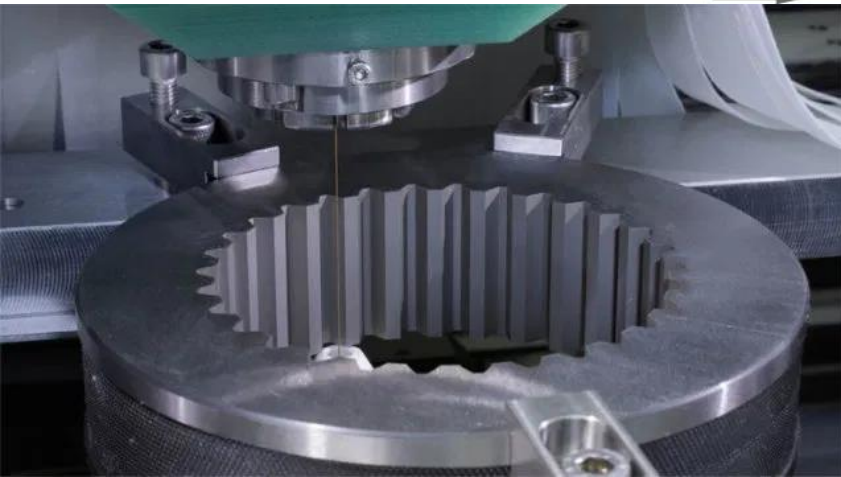


EDM WIRE EROSION

Electrical Discharge Machining is a metal cutting process where material is removed from the work piece through electrical discharges, between the workpiece and a specific tool/electrode

- Tool and electrode are locally/completely submerged in a dielectric fluid (deionized water, oils,..)
- In wire erosion, the tool is a wire constantly fed from a spool
- (+) Efficient for hard metals (otherwise difficult to machine)
- (+) Highly precise (**few hundredths of mm**)
- (+) CNC guided axis...
- (-) Workpiece must be electrically conducting
- (-) Direct contact between piece and dielectric
- (-) **Only prismatic shapes. No enclosed features**
- (-) Very slow. **Tens of minutes to hours per piece**
- (-) **Thickness limited to 3 ÷ 4 hundred mm (loss of precision)**

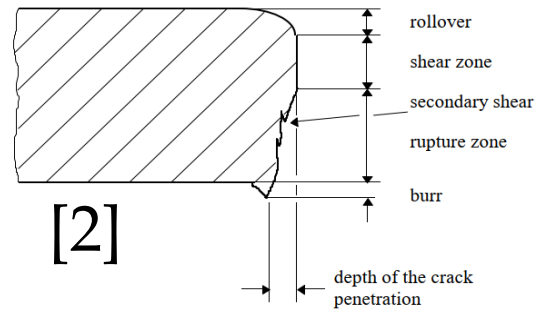
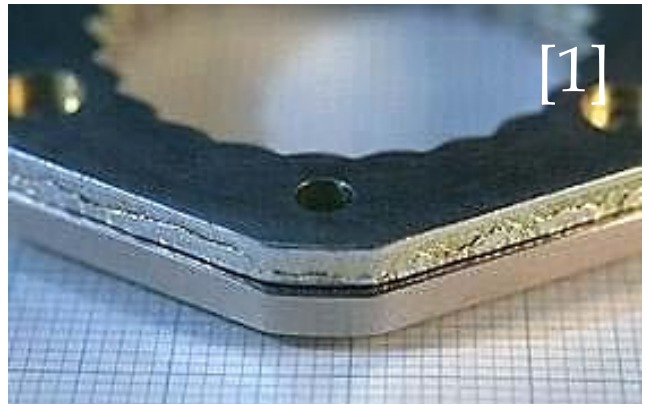
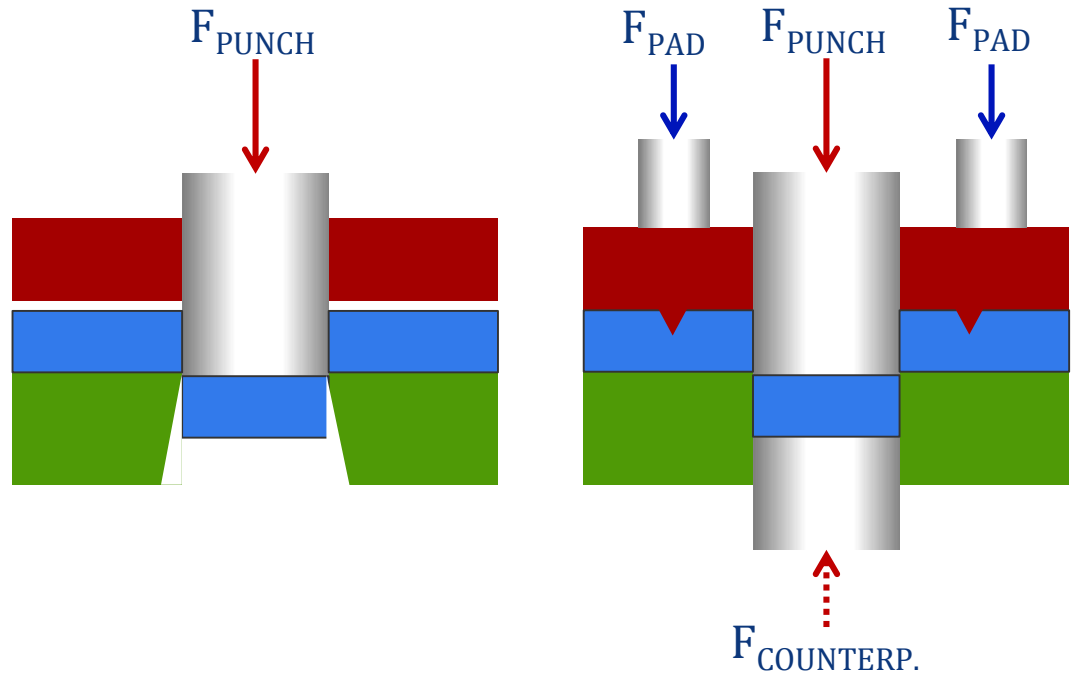
Typical D_{WIRE} : 0.25mm
 $[D_{CUT} \sim 0.35mm]$
 D_{WIRE} can go down to 0.1mm



METALWORKING VIA PLASTIC DEFORMATION

- **Shearing or Die Cutting:** process which cuts stock without the formation of chips or the use of burning or melting...a punch (or moving blade) is used to push a work piece against the die (or fixed blade), which is fixed.
 - **FINE BLANKING** is a particular Die Cutting process...
 - **Cuts only prismatic shapes**
 - Limited thickness
 - Entails large facilities with expensive tools
 - Suitable for large series production
 - Ensures tight tolerances, repeatability and small dispersion...
- **Metal Forming** is the metalworking process of fashioning metal parts and objects through mechanical deformation; the work piece is reshaped without adding or removing material.
 - **EXTRUSION AND DRAWING** are two particular metal forming processes...
 - **Produce only prismatic shapes**
 - Entail large facilities with expensive tools
 - Suitable for large series production
 - Ensure tight tolerances, repeatability and small dispersion...

BLANKING vs. FINE BLANKING



Fine blanking:

- Rupture zone much reduced
- Better surface results at edge
- More precise. More repeatable

[1] Influence of height and location of V-ring indenter on Void Volume Fraction variations during fine blanking process, F. Biglari et al. [2020]

[2] Blanking, Shearing and Trimming, Hyunok K. et al [link]

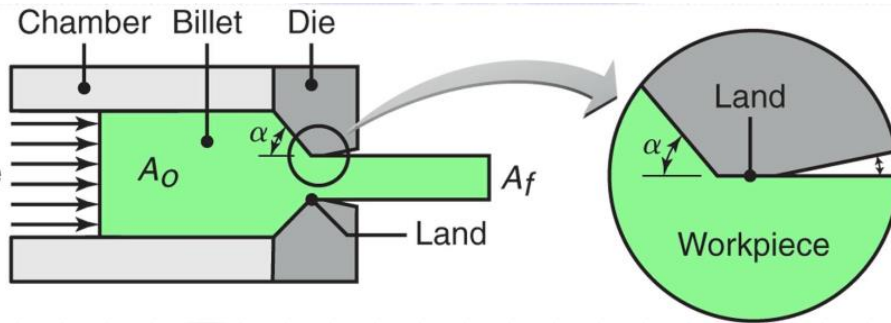
	Rupture zone	Depth of crack
Trad. Blank.	Up to most of the thickness	Few/10 mm
Fine Blank.	Negligible	Few/100 mm

EXTRUSION & DRAWING PROCESSES

Extrusion

A billet is pushed through a die

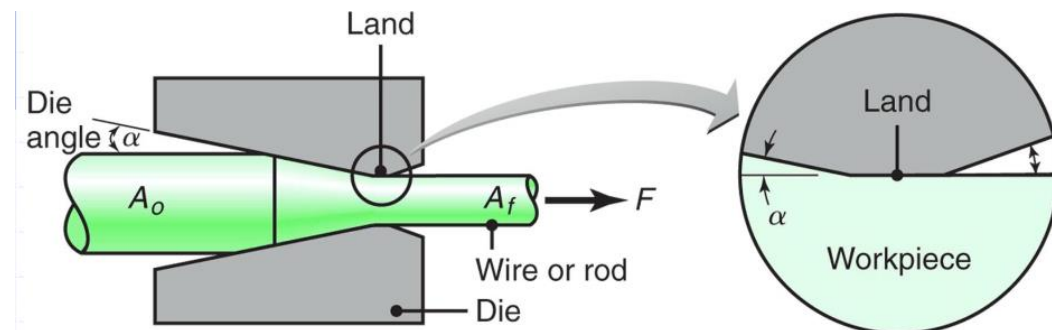
- Triaxial compressive stresses above elastic limit
→ Large cross section reduction and geometrical deformations feasible
- Can be:
 - COLD: good dimensional tolerances and surface finish. Work Hardening to be managed...
 - HOT: for materials with low ductility at room temperature



Drawing

A Tube/wire/rod is pulled through a die

- intrinsic limits to process, due to tensile leading loads and friction
 - Limited geometrical changes. Typically used for reduction of cross section only
 - Multiple passes needed
- Usually done COLD
- Efficient for thin products
- Low cost and simple tooling
- High precision
- Thermal treatment to compensate work-hardening





ADDITIVE MANUFACTURING

CERN AM WORKSHOP:

Selective Laser Melting (SLM) is an AM technique designed to use a high power-density laser to melt and fuse metallic powders.

What sets SLM apart from other 3D printing processes is the ability to fully melt the powder, rather than heating it up to a specific point where the powder grains can fuse together (sintering)...

Advantages in terms of reduced porosity, greater control over crystal structure...

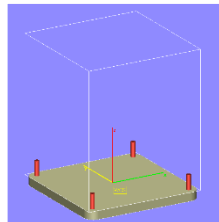


Machine:

- SLM 280HL (SLM Solutions)
- 400 W laser (1070 nm)
- Tri-axis scanning system

Build volume:

- 280 x 280 x 360 mm^3
- FULL CAD-CAM integration



Materials:

- Currently: niobium (R&D)
- others: Stainless Steel 316L/
titanium alloy



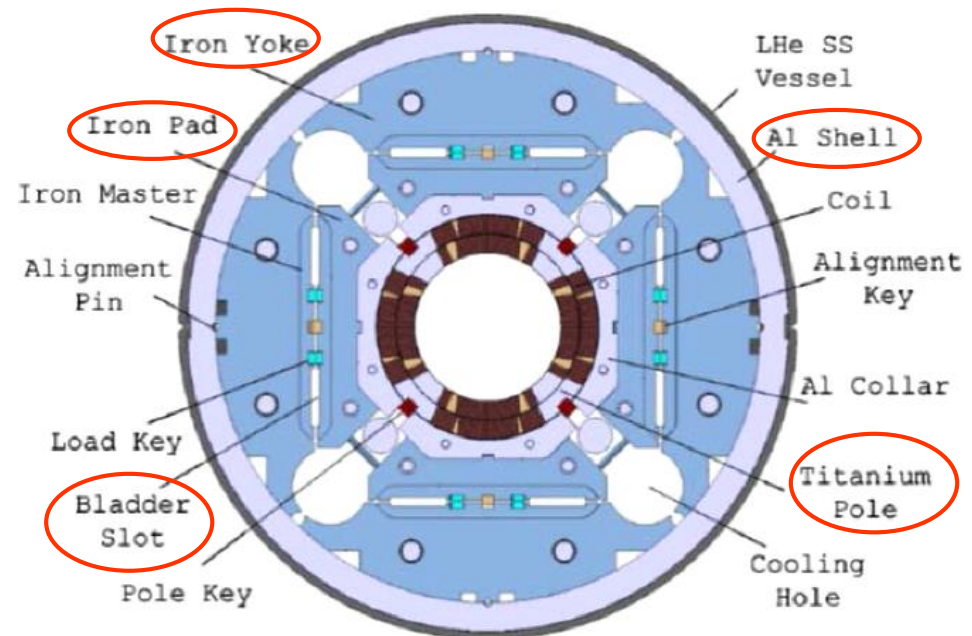
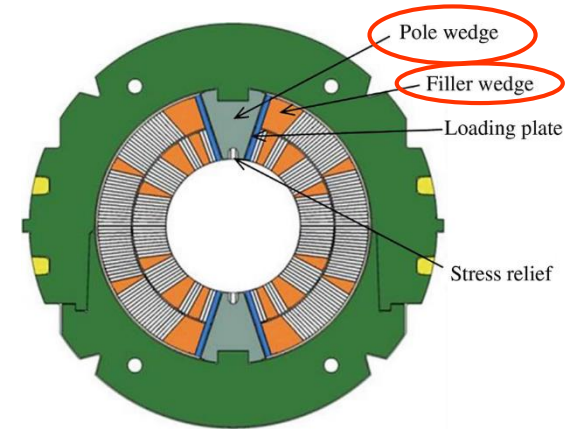


Metal Additive Manufacturing: how does it work ?

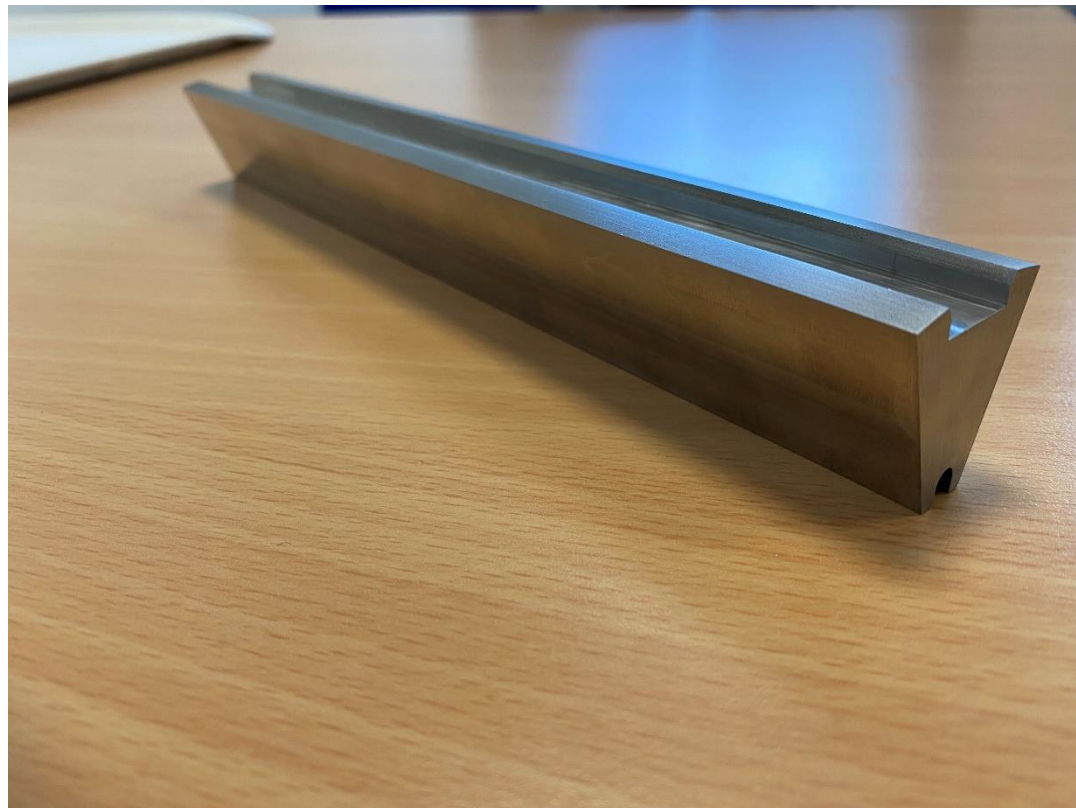


PART 2 - Magnet Components:

- Poles
- End Spacers
- Aluminum Shells
- Collars and Iron Laminations
- Wedges
- Bladders
- CCcosT Former



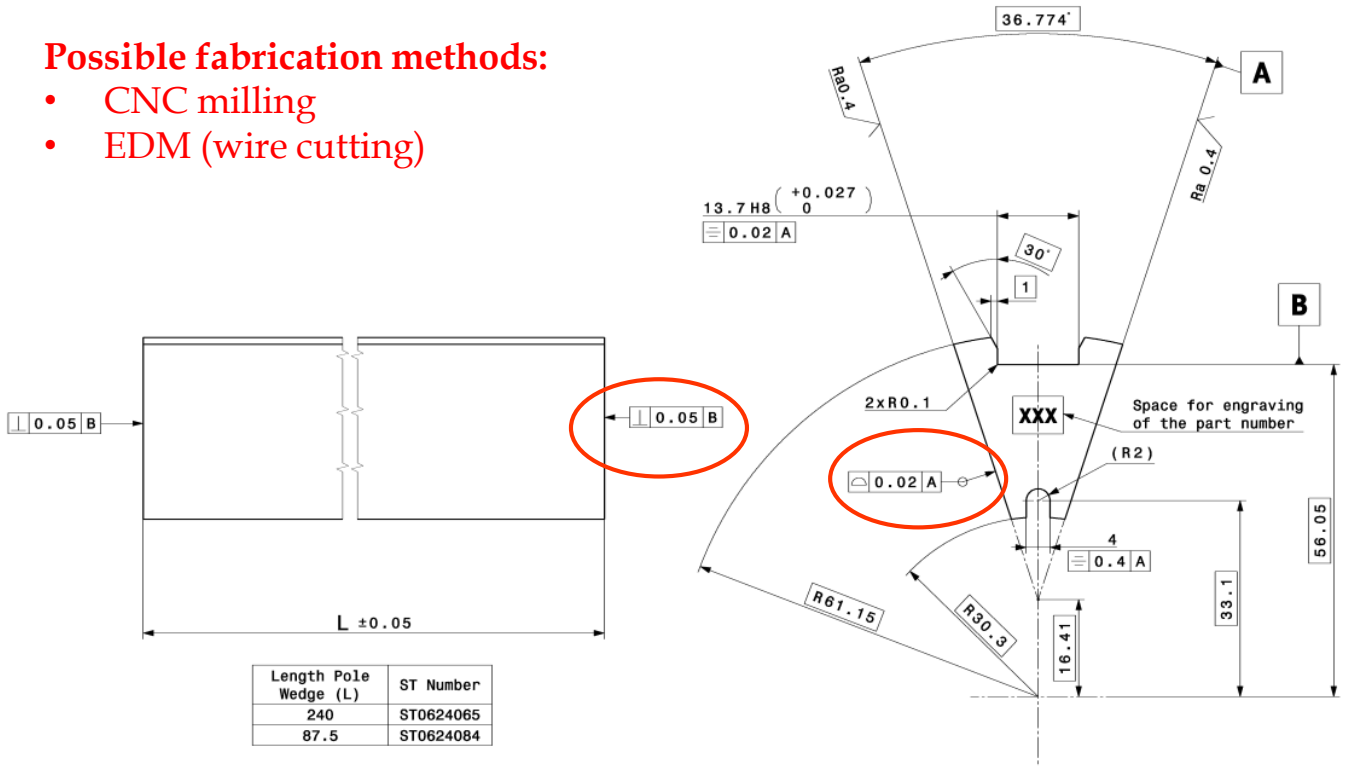
POLES



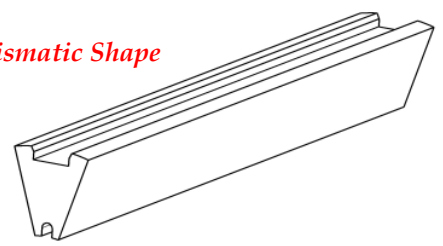
HL-LCH Dipole Titanium Poles

Possible fabrication methods:

- CNC milling
- EDM (wire cutting)



Prismatic Shape



NOTE: According to ISO5459: 2011

Mass: 0.53 kg

UNLESS OTHERWISE MENTIONED, APPLICABLE ISO GPS STANDARDS ARE THOSE PRIOR TO 2010-08-01 REGARDLESS OF THE DRAWING DATE

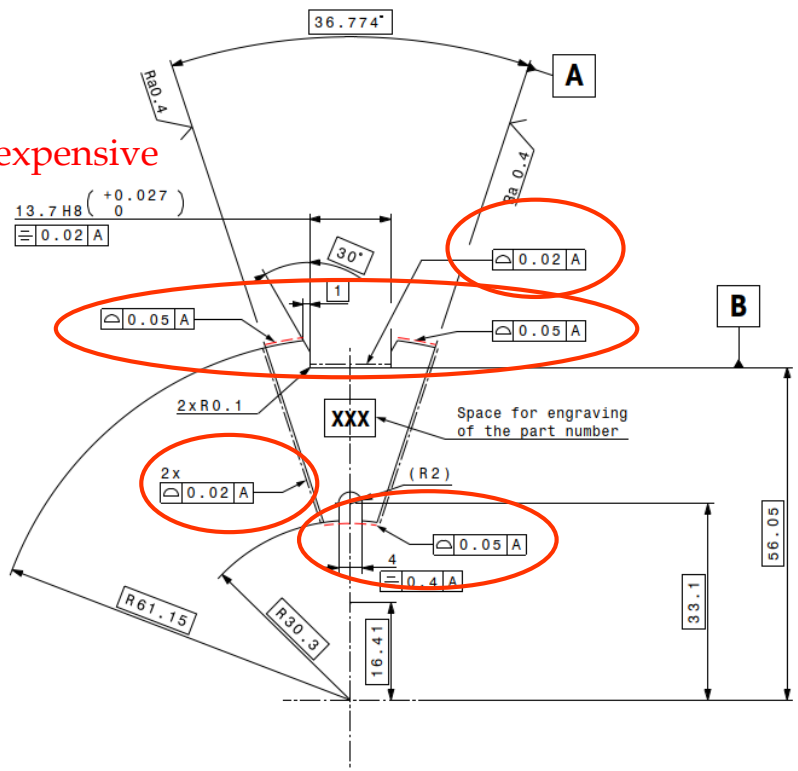
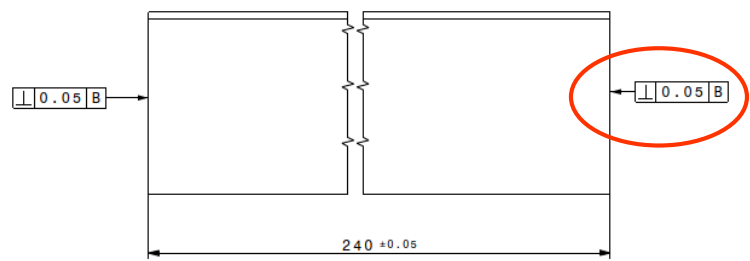
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QTY	DESCRIPTION	POS	MAT.	OBSERVATIONS	REF. CERN
ENG/ASS	S. ENB/S. ASS				
ISO 2768-fk	\checkmark Ra 3.2	(V)	ISO 13715-1:2003	0.2/0.3	
Magnet Bending High Field - Collared Coil Assembly					
11T DIPOLE - COLLARED COILS LONG	SCALE 1:1	2016-04-08	2016-04-08	2016-04-08	
11T DIPOLE - POLE WEDGE LONG	SCALE 1:1				
11T DIPOLE - COILS COLLARED - PO	SCALE 1:1				
11T DIPOLE - POLE WEDGE LONG	SCALE 1:1				
CAD Document Number: ST0624065_02					
REPLACES					
NON VALABLE POUR EXECUTION					
NOT VALID FOR EXECUTION					
LHCBM_H_C0054					SIZE: 2

IND.	DATE	NOM/NOME	ZONE	MODIFICATION
E	2017-11-29	J. MARTIN-CARO CRISTINA		Length changed to 87.5, before 47.5mm
D	2017-11-21	J. MARTIN-CARO CRISTINA		Dimension 33.1mm before 33mm
C	2017-11-21	J. MARTIN-CARO CRISTINA		Dimension 16.41mm before 16.513mm
B	2017-09-19	J. MARTIN-CARO CRISTINA		Changed surface profile tolerance to 0.02 before 0.2
A	2017-07-28	J. MARTIN-CARO CRISTINA		Updated dimensions and tolerances

HL-LCH Dipole Titanium Poles

Possible fabrication methods:

- CNC milling → OK
- EDM (wire cutting) → top quality but too expensive

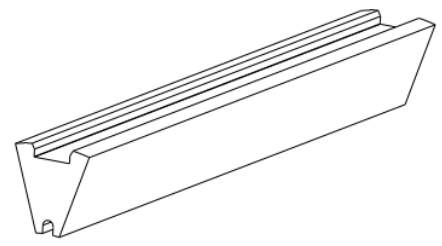


NOTE: According to ISO5459: 2011

Mass: 0.53 kg

UNLESS OTHERWISE MENTIONED, APPLICABLE ISO GPS STANDARDS ARE THOSE PRIOR TO 2010-08-01 REGARDLESS OF THE DRAWING DATE

Prismatic Shape

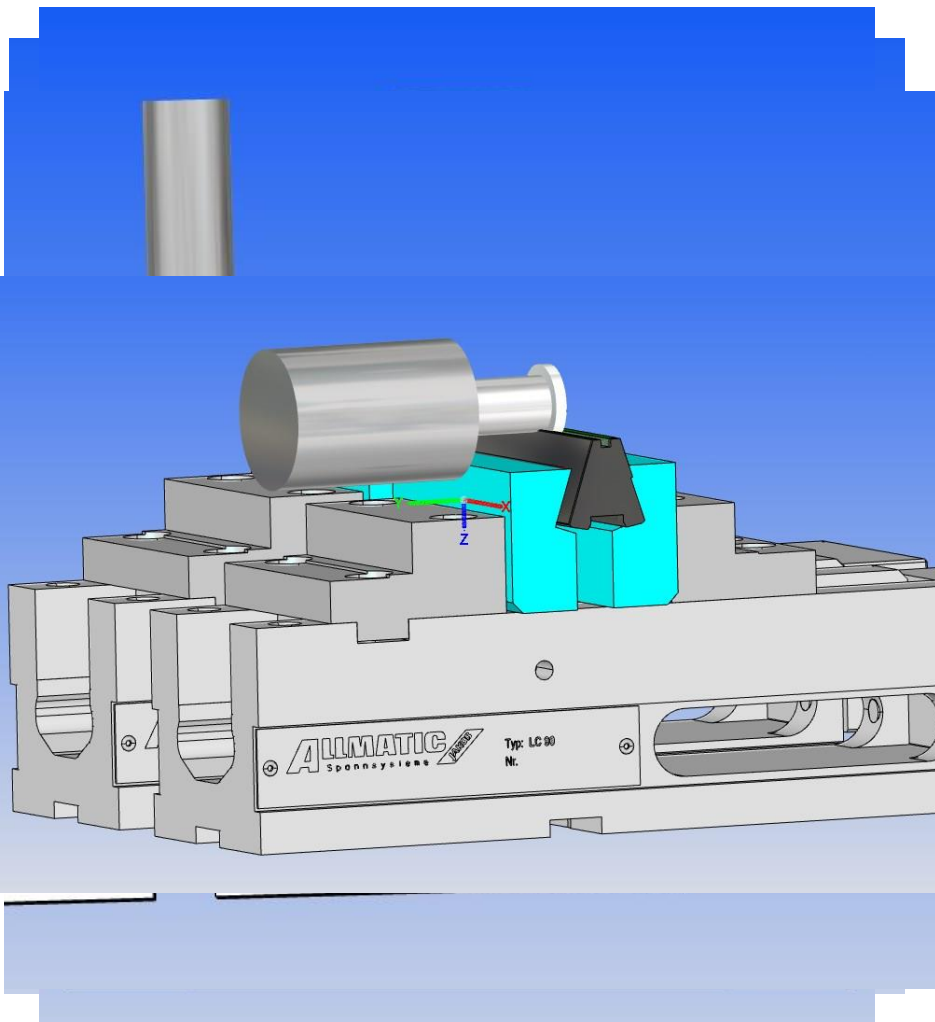


NON-CONFORMITY ACCEPTANCE :
 WE ACCEPT SHAPE TOLERANCE UP TO 0.05 mm ON INNER AND OUTER DIAMETER

NOTA :
 REFERENCE DRAWING LHCBMH_C0054 IND.E

1	1	Titanium Ti-6Al-4V			
QUA	DESCRIPTION	POS	MAT.	OBSERVATIONS	REF. CERN
ISO 2768-fK		√ Ra 3.2 (✓)		ISO 13715	1:0.3 1:0.3
11T DIPOLE - COLLARED COILS LONG			SCALE	DRAWN	L. Renaglia 2018-02-23
POLE WEDGE LONG			CONTROLLED		
11T DIPOLE - BOBINES COLLAREES - PO			RELEASED		
LE CALE LONGUE			APPROVED		
			CAD Document Number	ST0947807_02	
			REPLACES		
NON VALABLE POUR EXECUTION			DATE		SIZE IND.
NOT VALID FOR EXECUTION					2

HL-LCH Dipole Titanium Poles



Possible machining steps:

1. Ti rod (raw material)
2. Typical jig interface machined
3. Rough machining (sides)
4. Rough machining (top)
5. Rough machining (top plane)
6. **Change tools but not set-up**
7. **Final machining (sides + top)**
8. Change set-up jigs and tools
9. Machine bottom groove
10. Finish the bottom

HL-LCH Dipole Titanium Poles



<i>Material</i>	Titanium (high spring back, high cutting tool wearing)
<i>Raw Material shape</i>	Any...could be $f(qty)$...Rods is a good option
<i>Tolerance</i>	Hundredths of mm (0.02 is already at the limit...)
<i>Quantity</i>	Several tens to few thousands
<i>Manuf. Setup Time</i>	Weeks
<i>Production Time</i>	Up to few hours per piece
<i>Tools Cost</i>	Negligible
<i>Cost x piece</i>	~ few hundred EUR $\rightarrow f(qty)$

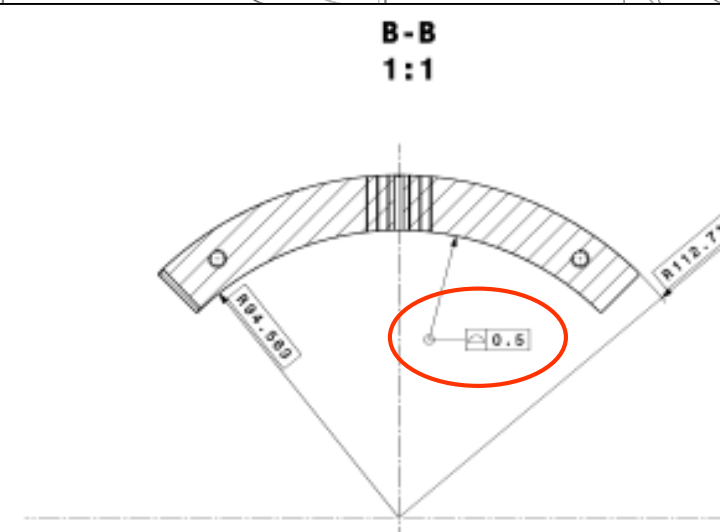
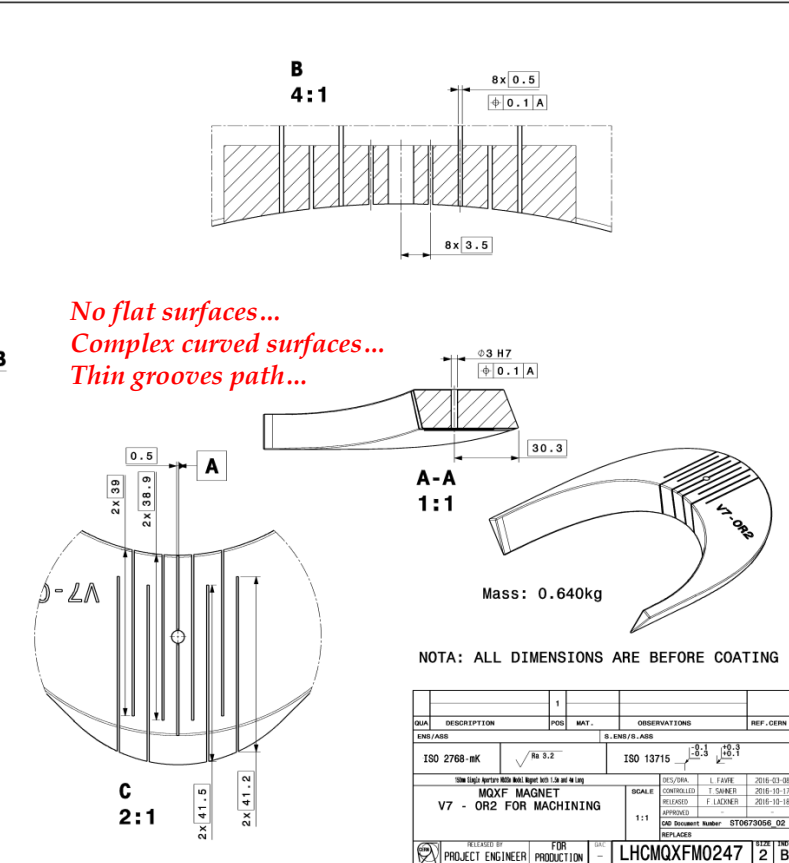
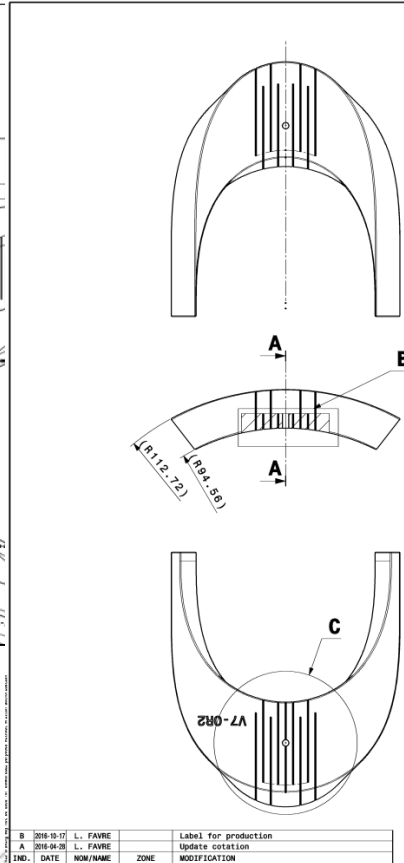
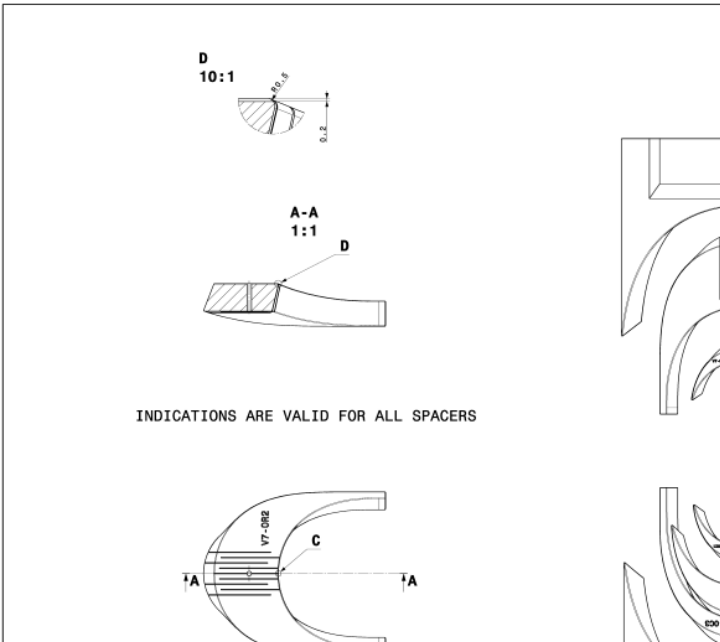
Advantages of machining:

- Good compromise between features (time/cost/tolerance/repeatability/quantity)
- Less expensive wrt EDM (wire cutting)...EDM remains interesting in case of prototyping as well as very small batches (top quality ensured)

Drawbacks:

- Not cost effective for very large quantities...in that case maybe change the raw material shape...start from cold drawn special profiles...
- Machining step to be studied in-depth to obtain required tolerances
- Tolerances show typical dispersion related to machining...
- Well defined strategy for metrology (CMM) control to be defined wrt quality assurance...

End Spacers



IND.	DATE	NOM/NAME	ZONE	MODIFICATION
B	2016-10-17	L. FAVRE		Label for production
A	2016-04-28	L. FAVRE		Update cotation

Possible fabrication methods:

- 5-axis CNC milling
- EDM (wire cutting)
- Additive Manufacturing...

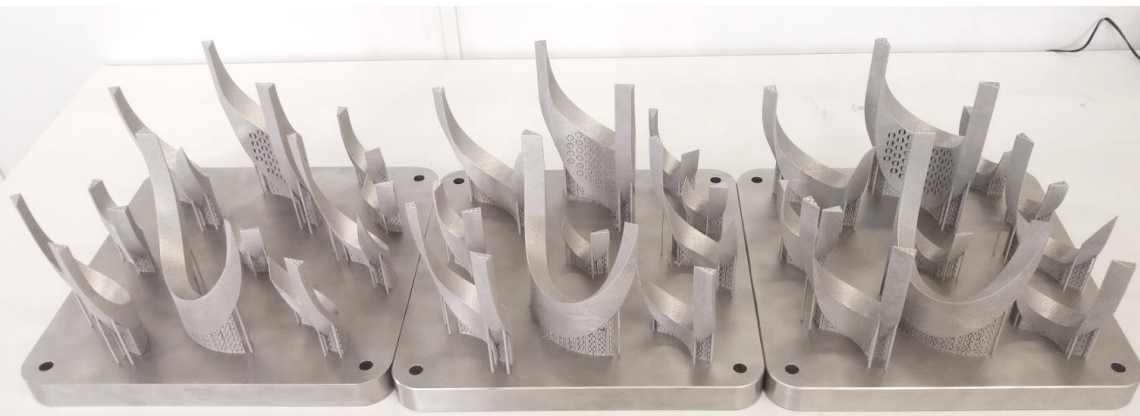
-MATERIAL SEE TECHNICAL SPECIFICATION

-FOR DATUM REFER TO ISO 5459:2011

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INDICATIONS ARE VALID FOR ALL SPACERS

End Spacers



End spacers after the SLM process

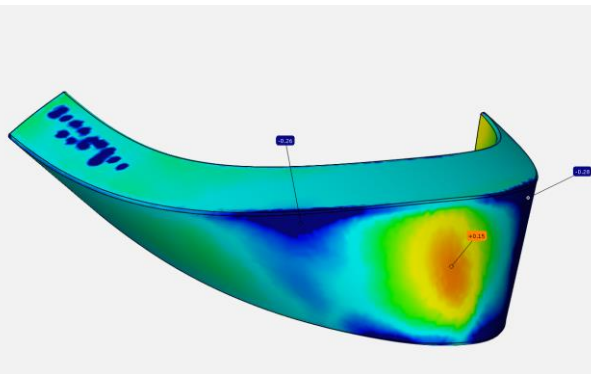


End spacers during coil assembly at FNAL

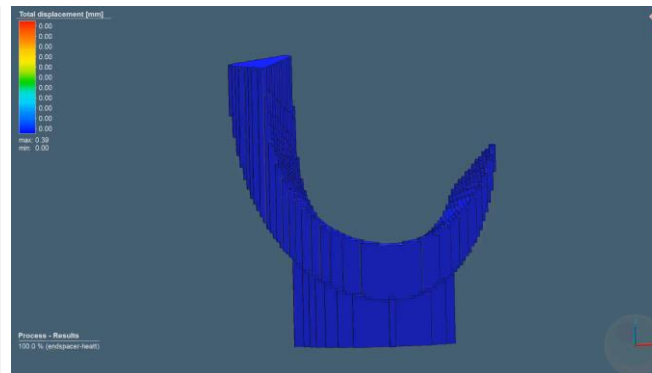


End spacers after the support removal

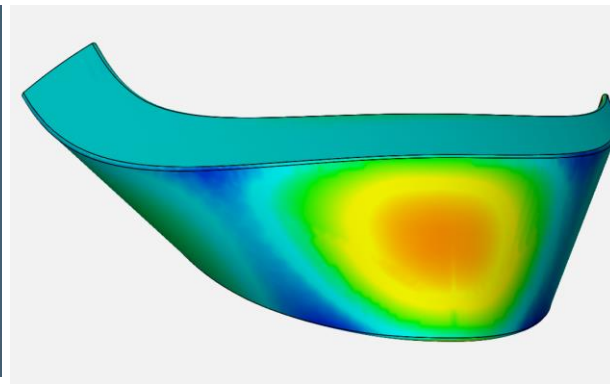
- The SLM process generates uneven heating of the components being manufactured
 - Similar to welding, deformation can occur.
 - These deformation can be predicted by simulation (advanced multiphysics FEM).
 - Compensation of the geometry could be possible to ensure geometry accuracy...



3D scanner

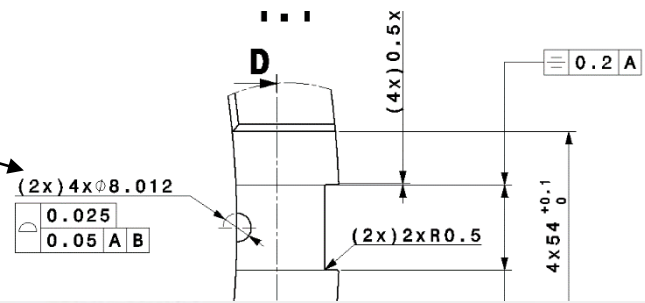
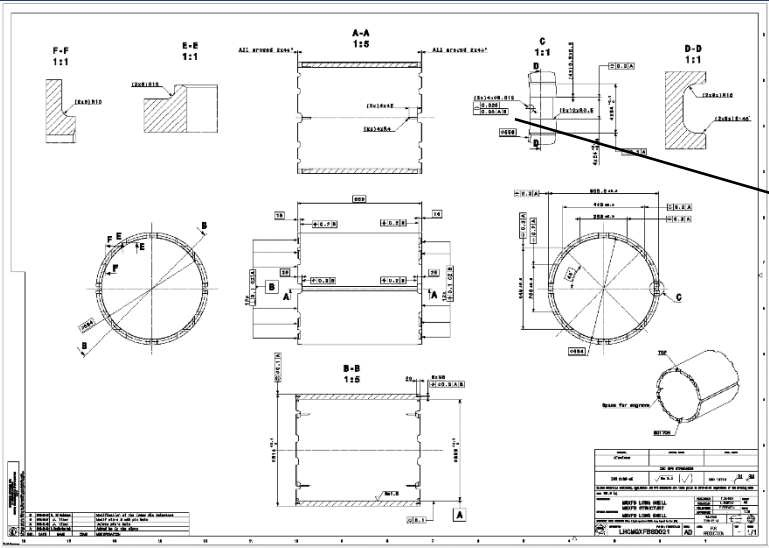


SLM process simulation



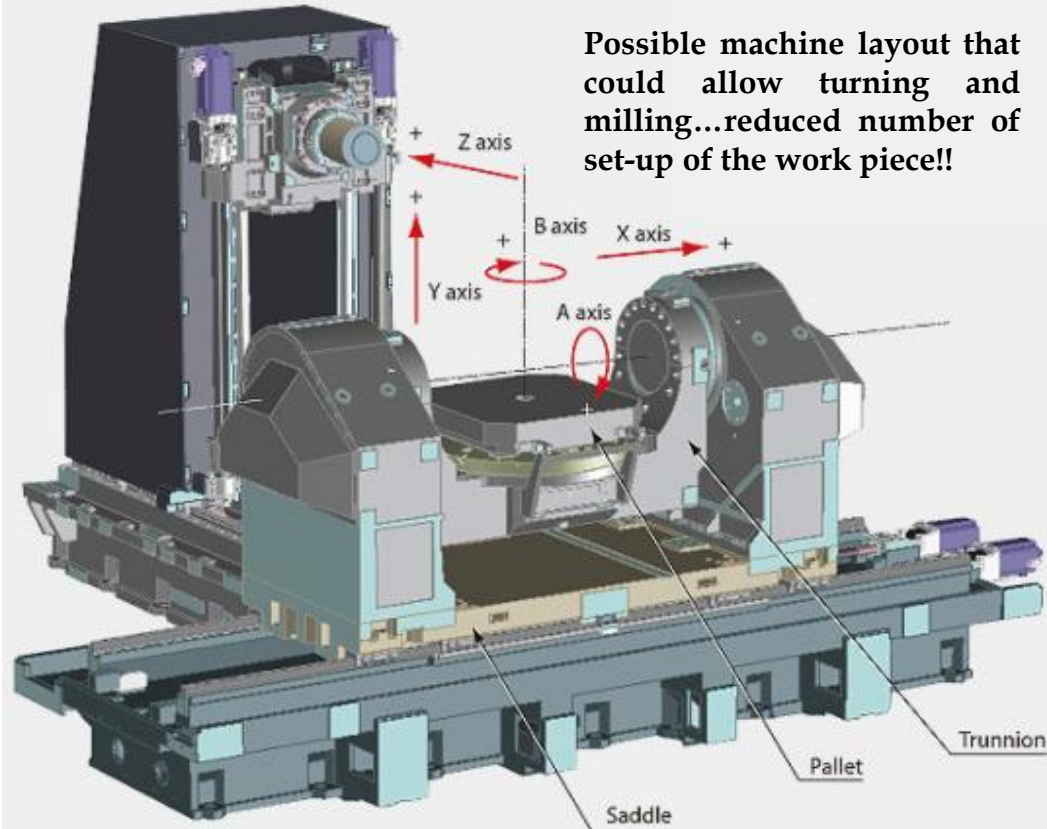
Simulation result

Aluminum Shells



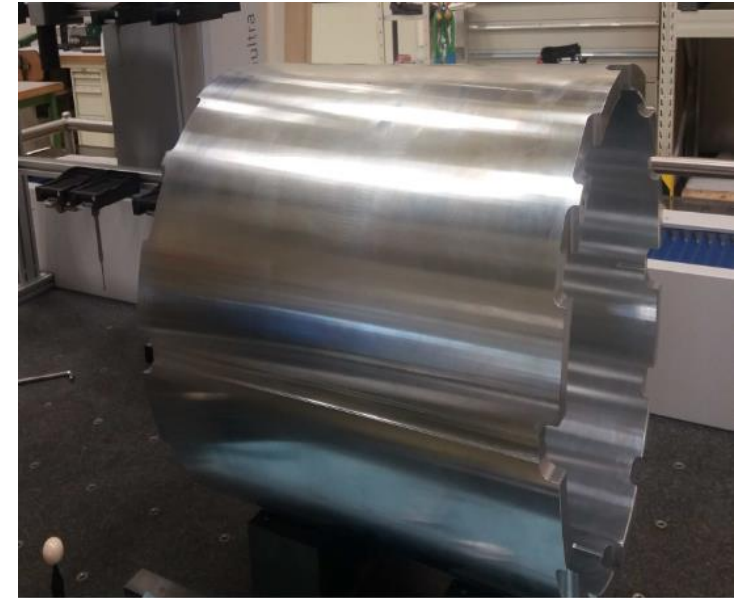
Possible machining steps:

- Raw Material from open die forging or ring rolling forging
- Pre-machining by turning
- Pre-machining by milling
- Final turning
- Final milling
- Metrology
- Test assembling (Go/no go)



Possible machine layout that could allow turning and milling...reduced number of set-up of the work piece!!

Aluminum Shells



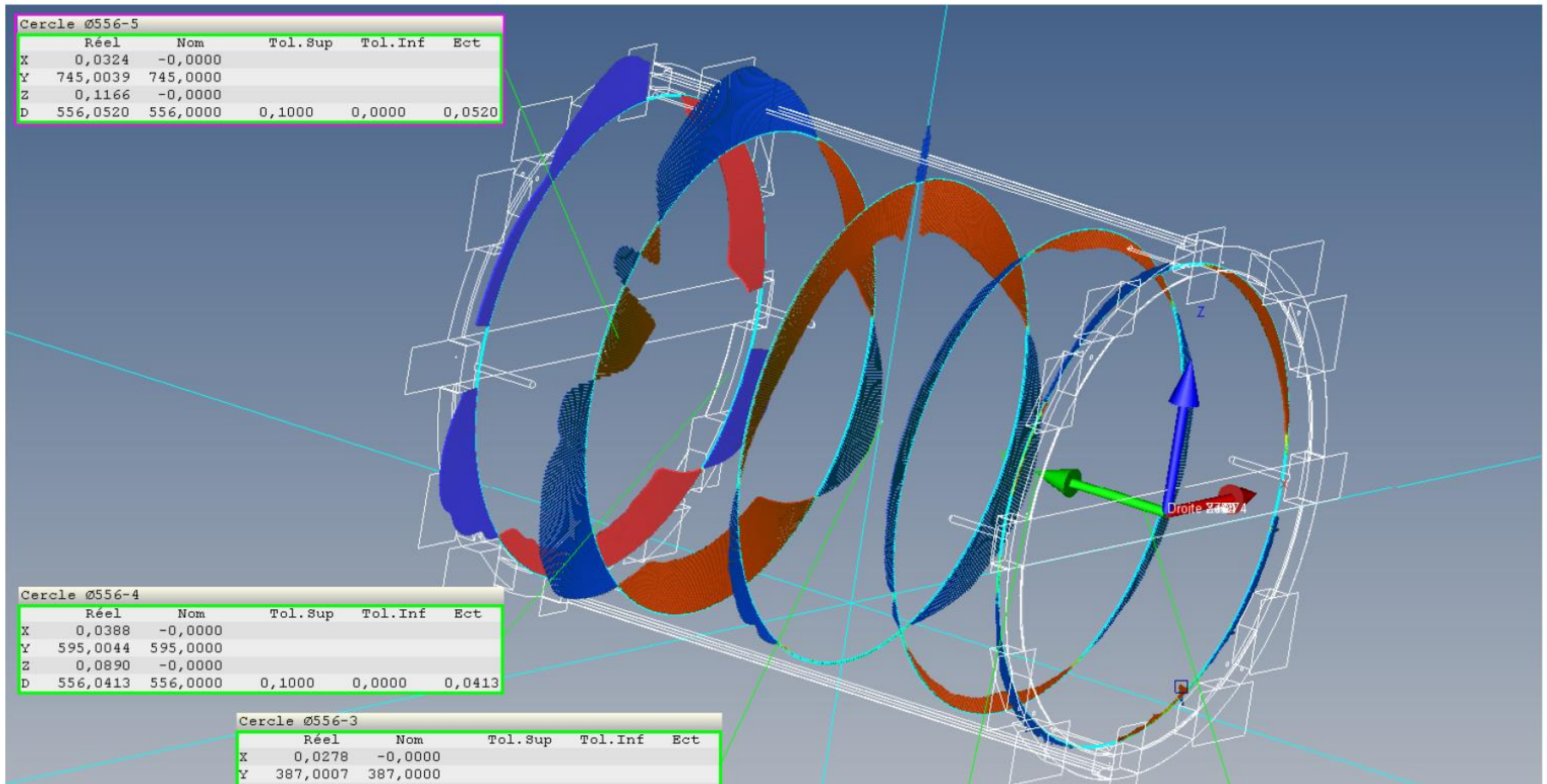
< 10kCHF/Shell

- 60% raw material
- 40% machining
- Qty: ~ 100

Main Challenges:

- Raw Material: Quality of forging
- Manage the release of internal stresses during machining operations
- Tight tolerances for the 2x4 grooves
- Uncertainty of measurement (even with CMM!)

CMM Metrology measurements...



Main Factors Influencing Manufacturing

Material

- Pure Iron (ARMCO®)
- Stainless Steels
- Electrical Steel

Geometrical Features

- Required Tolerances
- Shape (prism...)
- Thickness
 - Thick
 - Medium
 - Fine (shims)

Quantity



Usual manufacturing techniques:

- CNC Milling
- Shearing (*traditional vs. fine blanking*)
- 'NO Tool' Cutting (laser, wire EDM, water jet)

Milling Thick Collars



<i>Material</i>	Any
<i>Raw Material shape</i>	Any (*) (could be $f(qty)$)
<i>Tolerance</i>	Hundredths of mm
<i>Thickness</i>	Any
<i>Geometry constraints</i>	No concave sharp edges Minimum 'hole' features
<i>Quantity</i>	Prototype to medium size batch (few kpcs)
<i>Manuf. Setup Time</i>	Weeks
<i>Production Time</i>	Up to Tens of minutes per piece
<i>Tools Cost</i>	Negligible
<i>Cost x piece</i>	~ Tens ÷ few hundred EUR → $f(qty)$

Advantages:

- Good compromise between features (time/cost/tolerance/repeatability/quantity)
- Only viable process for thick laminations
- Good flexibility to change also during manufacturing

Drawbacks:

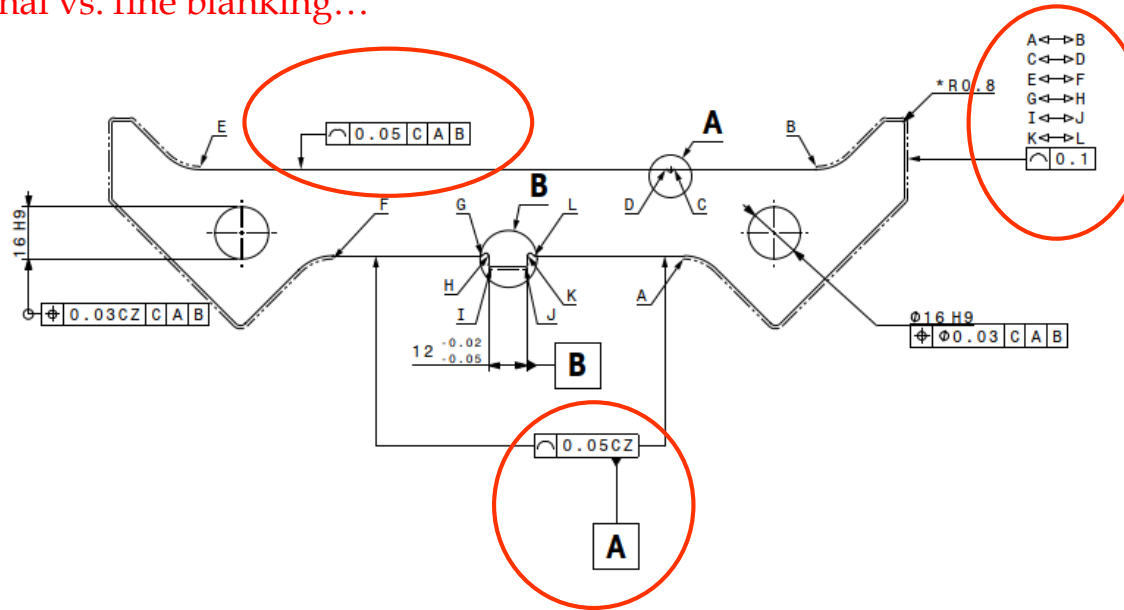
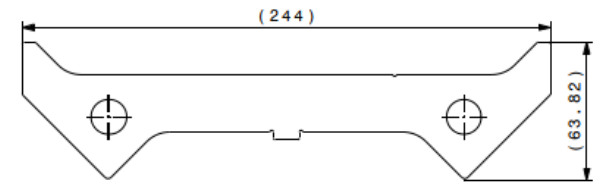
- Not cost effective for thin parts
- May call for upstream process for raw material preparation (*)
- Increased geometrical complexity directly amplifies manuf. costs and time





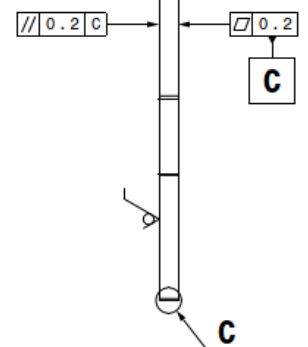
Possible fabrication methods:

- CNC milling (How many axis?)
- EDM (wire cutting) + milling
- Shearing (or die cutting)...
- Traditional vs. fine blanking...



Thickness

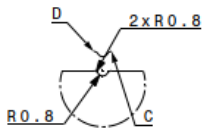
(5.8 ± 0.15)



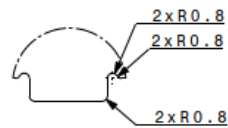
Prismatic shape

* all external corners are R0,8mm

A
2:1

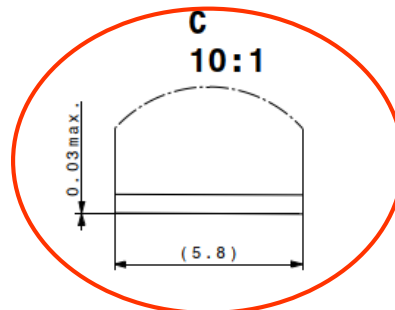


B
2:1



Valid for all internal corners

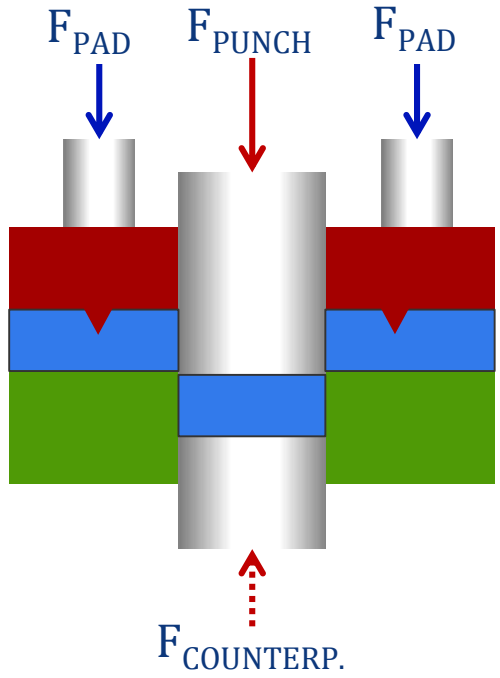
C
10:1



MATERIAL	INITIAL STATE	FINAL STATE
Steel		
ISO GPS STANDARDS		
ISO 2768-mK	√ Ra 3.2 (✓)	ISO 13715
NOTE: UNLESS OTHERWISE MENTIONED, APPLICABLE ISO GPS STANDARDS ARE THOSE PRIOR TO 2010-08-01 REGARDLESS OF THE DRAWING DATE		
MASS 328 g		
DESIGNATION	CHECKED	J. TISON
MQXFB LOADPAD LAMINATION	RELEASED	FORMAT A2
MQXFB COLLARED COIL	APPROVED	SCALE 1:1
MQXFB LOADPAD LAMINATION	DESIGNED	2018-12-07
EQUIPMENT CODE	UNIQUE	ISO Single aperture hole Press & Service Report 000 - Pack Assembly
REFERENCES	Doc. No.	ST0604008_00
LHCMQXFB0048	CHK	AF
NOT VALID FOR EXECUTION	IND	-
	SHEET	1/1

IND.	DATE	NAME	ZONE	MODIFICATION
F	2018-12-07	J. Tison		Tolerance upgrade
E	2018-11-09	T. SAHNER		Tolerance modification
D	2018-06-19	S. Martin Caro Cruz		Tolerance upgrade
C	2018-04-17	J. Tison		Add ratings
B	2018-03-19	S. Martin Caro Cruz		Added the Rolling Direction

Fine Blanking – Thin Collars and Laminations



<i>Material</i>	Any
<i>Raw Material shape</i>	Coils
<i>Tolerance</i>	Few hundredths of mm (for typical laminations sizes)
<i>Thickness</i>	Up 5 ÷ 7mm (depending on materials)
<i>Geometry constraints</i>	sharp edges (bad both as result and for tooling) Minimum 'hole' features (e.g. no pins)
<i>Quantity</i>	Large size batch (many tens of thousands minimum)
<i>Manuf. Setup Time</i>	months
<i>Production Time</i>	Few seconds per piece
<i>Tools Cost</i>	Many tens of kEUR (50÷100k)
<i>Cost x piece</i>	Few EUR

Advantages:

- Highest productivity, repeatability, tolerances
- Immune to shape complexity (up to a certain extent!)
- Reduced raw material preparation

Drawbacks:

- Lowest flexibility to change during manufacturing
- Highest setup times and costs
- Only large quantities

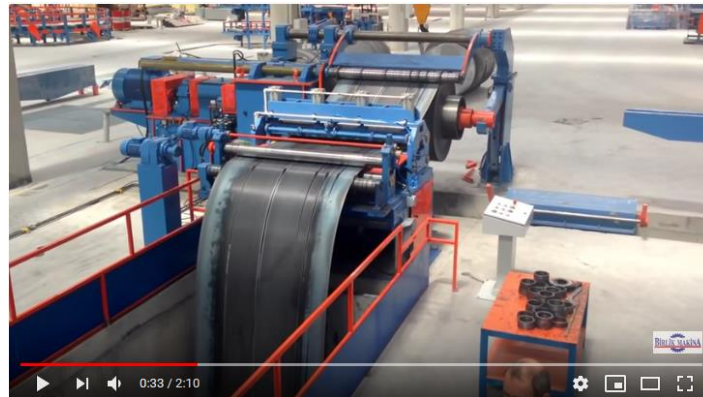
Fine Blanking: RAW Material

Sheets:

- Nowadays, not anymore a standard @ fine-blanking suppliers
- **Should be avoided.** Except (MAYBE) for very (VERY) large productions

Coils:

- Size required by fine-blanking supplier can differ from provided raw (decoiler diameters, press size, ...)
- Either know the wished size before, OR be ready to go through Slitting/Recoiling

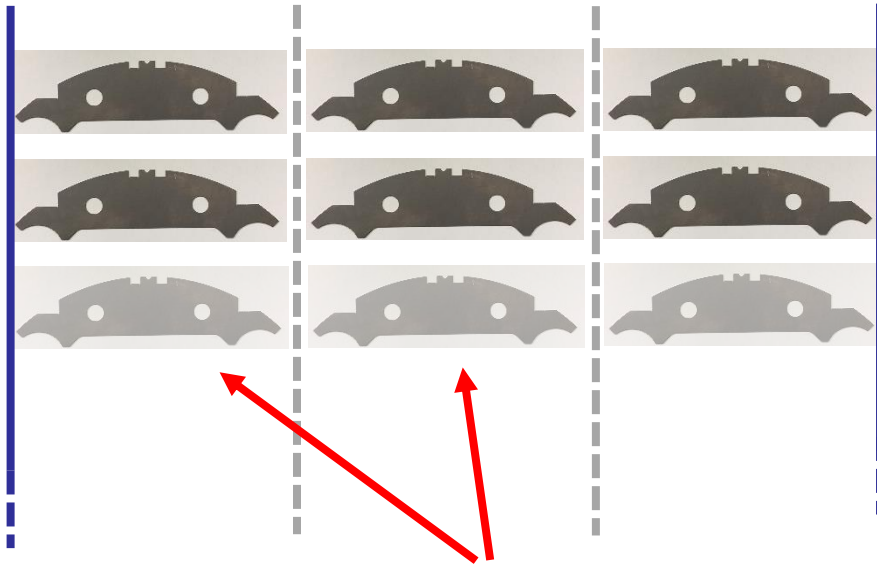


<https://www.youtube.com/watch?v=S0f7BOQZXOs>

Fine Blanking: LAYOUT

Layout of parts on de-coiled sheet:

- Also influences required coil dimensions
- Depending on which material and its properties: watch out for different springback due to position w.r.t. the sheet and lamination direction

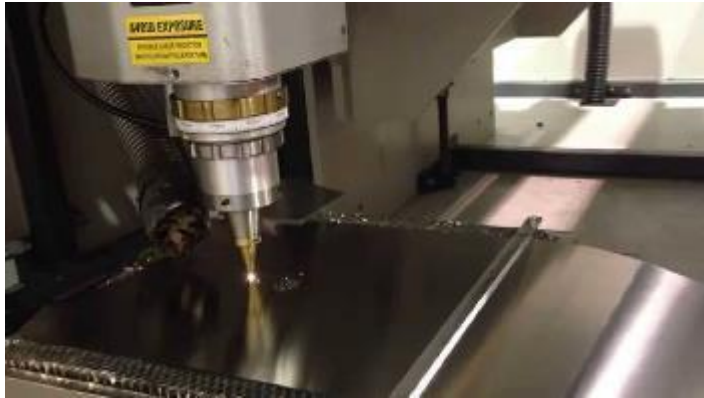


Potentially different behavior depending on position



Angle w.r.t. lamination might not work (warping)

Laser Cutting Laminations



<https://www.youtube.com/watch?v=ADiWMuLcJsQ>

<i>Material</i>	Any
<i>Raw Material shape</i>	Sheets or Coils
<i>Tolerance</i>	Few hundredths of mm (for typical laminations sizes)
<i>Thickness</i>	Only fine (up to $1 \div 1.5$ mm)
<i>Geometry constraints</i>	Size of laser beam, especially for thicker pcs
<i>Quantity</i>	Any batch size
<i>Manuf. Setup Time</i>	Days to few weeks
<i>Production Time</i>	many seconds per piece
<i>Tools Cost</i>	Negligible
<i>Cost x piece</i>	Few tens EUR

Advantages:

- Good compromise : batches, productivity, repeatability, tolerances
- Immune to shape complexity
- Reduced raw material preparation

Drawbacks:

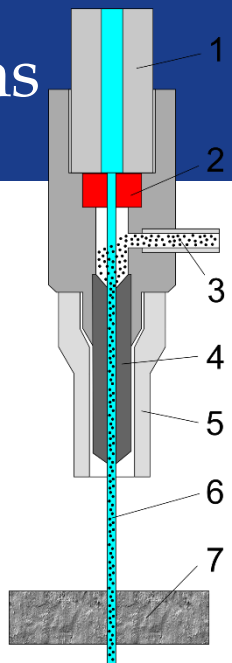
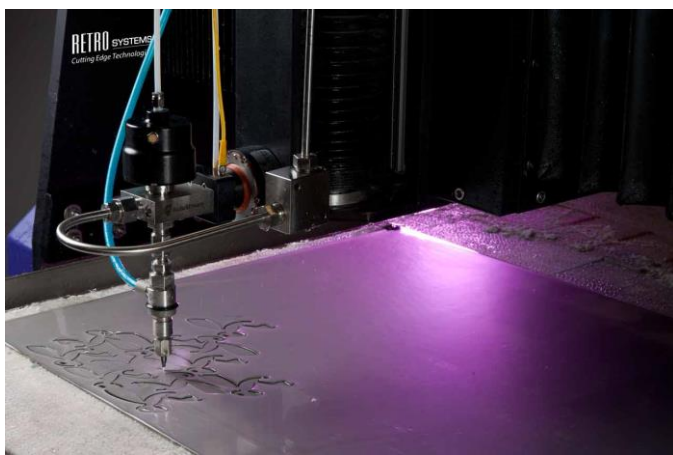
- Molten edges, especially as thickness grows
- Thermal effects influence precision



Further techniques for Collars and Laminations

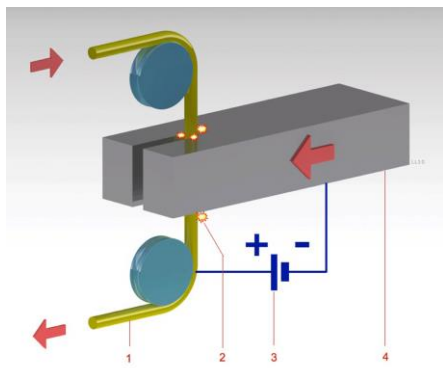
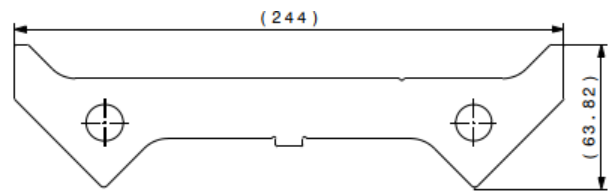
Water Jet:

- Rough cut edge
- Precision: **few tenths of mm**, quickly worsening as function of thickness
- Good preparatory process for milling



Wire Erosion

- Highly precise (**few hundredths of mm**)
- Very slow (tens of minutes to hours per piece)
- Enclosed geometries not possible
- Good for prototypes and small batches

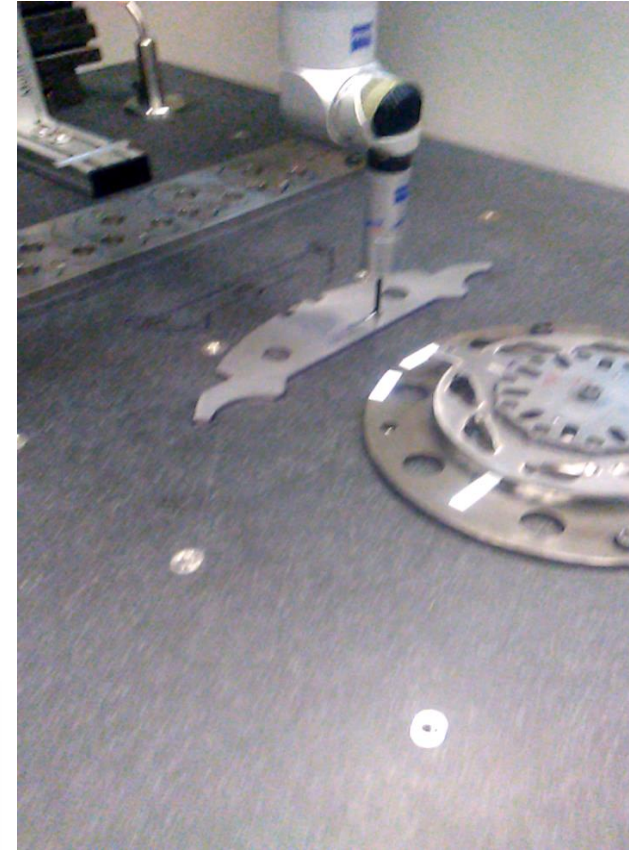


Quality Control for Collars and Laminations

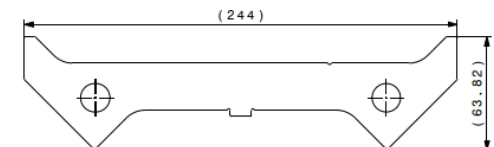
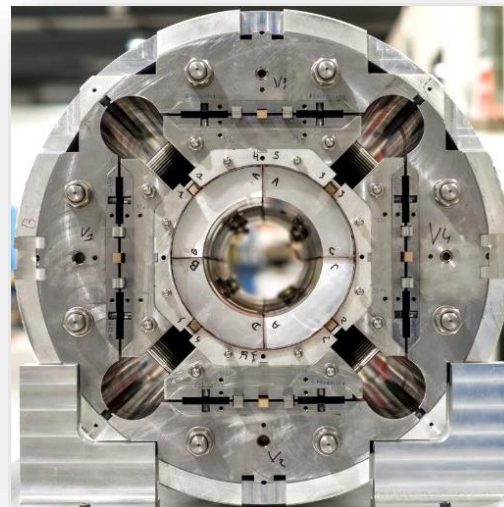
Different processes = different output variability
 Different quantities = different influence of such variability

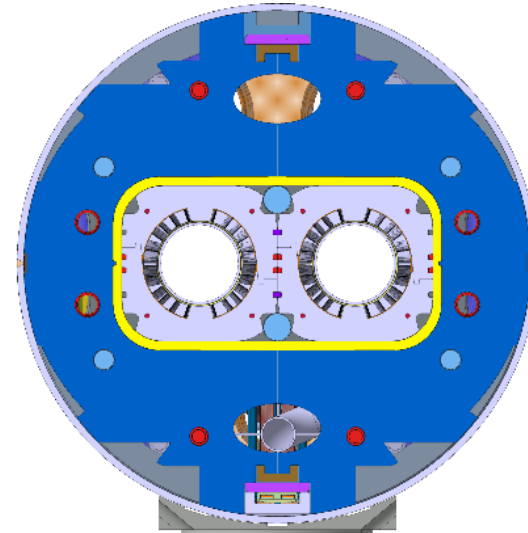
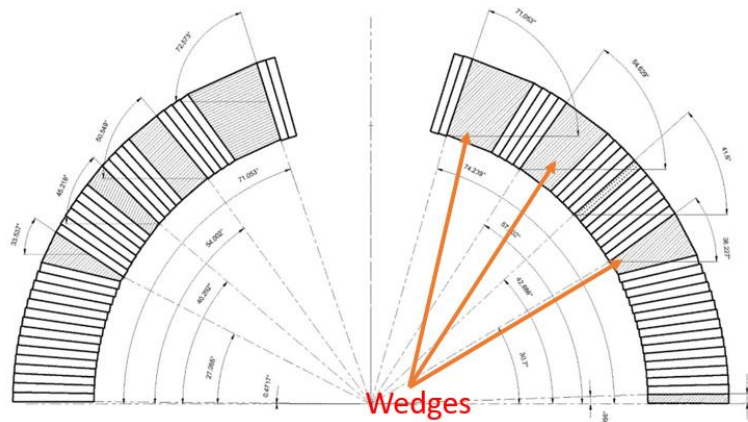
Depending on the specific situation, the correct recipe comes from a good mix of:

- *Full vs statistical* quality control
- *Online vs offline* control
- Definition of correct requirement: *strict tolerance OR variability?*
- *Full metrology vs minimum set of features* (Go/No-Go, Jigs)



Courtesy Malvestiti SPA

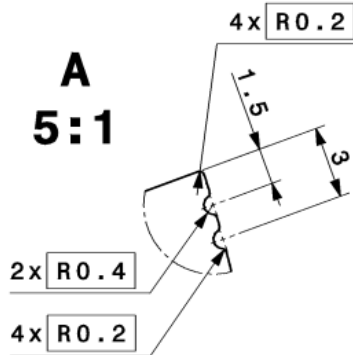




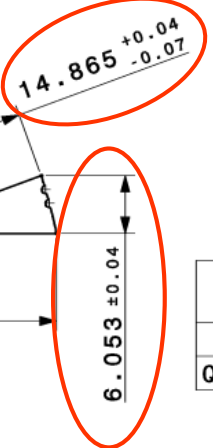
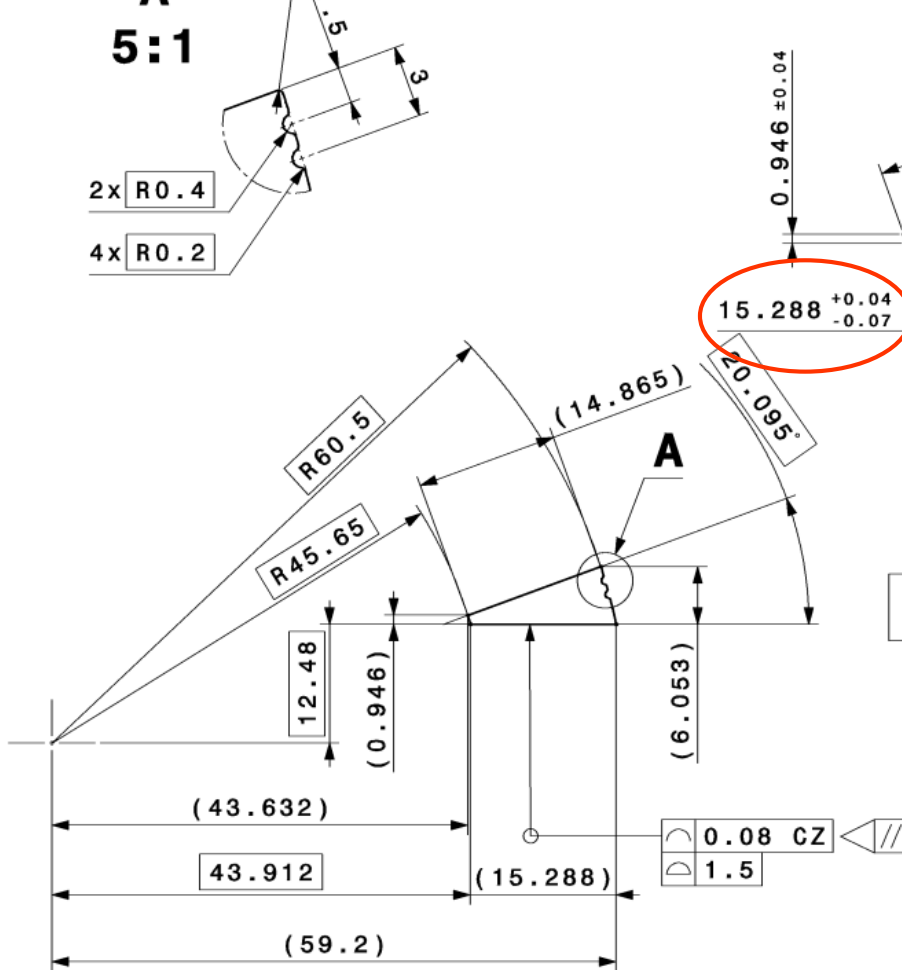
Raw Material:

- Generally Cu or Cu Alloys
- Become part of the coil after the winding process...
- Submitted to thermal treatment
 - Curing thermal cycle in case of NbTi
 - Reaction thermal cycle in case of Nb₃Sn
- Possible issues resulting from dramatic loss of mechanical properties following thermal treatment...
- If needed, use of Oxide Dispersion Strengthened Copper Alloys to reduce loss of mechanical properties even after thermal cycles...

A
5:1



see below the tolerance accepted for contracting the extrusion

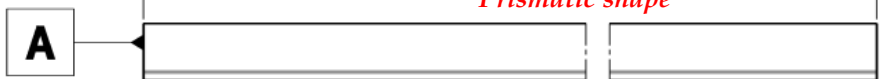


Length

	Wedge Type	Length /mm	Length /mm	Length /mm
DS11T	4	1254	940	430
QUANTITY	1	3	1	1

L=see specific table

Prismatic shape



UNLESS OTHERWISE MENTIONED, APPLICABLE ISO GPS STANDARDS ARE THOSE PRIOR TO 2010-08-01 REGARDLESS OF THE DRAWING DATE

ISO 1101:2012

1		1	CEP DISCUP C3/30		
QUA	DESCRIPTION	POS	MAT.	OBSERVATIONS	REF. CERN
ENS/ASS			S.ENS/S.ASS		

nK

√ Ra 1.6

ISO 13715

-0.1 / -0.2

Bending High Field - Collared Coil Assembly

DIPOLE - COIL 5M
WEDGE 4 OUTER
DIPOLE - BOBINE 5M
LE EXTERIEURE 4

SCALE
2:1

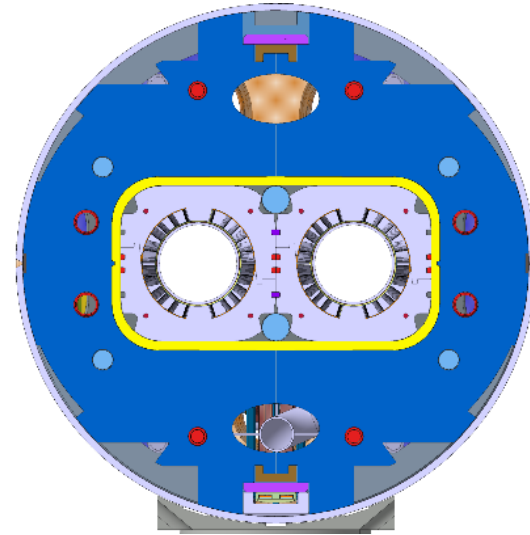
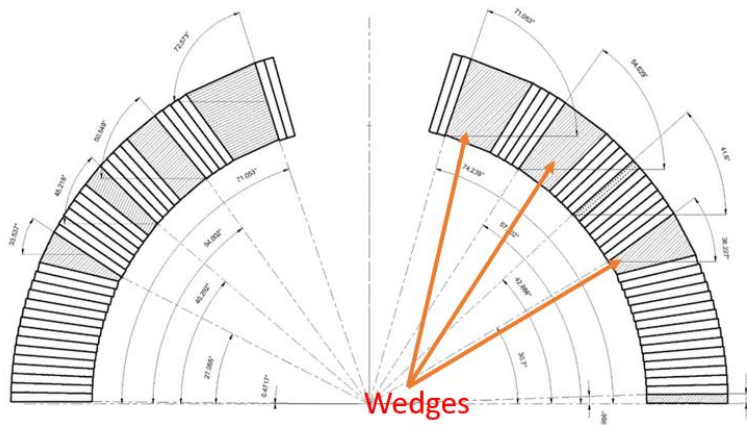
DES/DRA.	R. MARTINS CARD	2016-05-12
CONTROLLED	T. SAHNER	2018-02-09
RELEASED	C. LOFFLER	2018-02-09
APPROVED	-	-
CAD Document Number ST0690770_02		
REPLACES		

Possible fabrication methods:

- CNC milling (critical shape!)
- EDM (wire cutting)...too long parts!
- Extrusion or Drawing... (compatible with qty and costs?)

IND.	DATE	NOM/NAME	ZONE	MODIFICATION
A	2017-06-29	T. SAHNER		Modification of Radii, ISO Tolerances

RELEASED BY	FOR PRODUCTION	GAC	LHCMBH_C0030	SIZE	IND.
PROJECT ENGINEER		-		3	D



Extrusion and Drawings:

- **Machining to be considered only for prototyping**...very expensive and challenging for long and thin parts!!
- Depending on the shape **Extrusion and/or Drawing could be suitable for a production of at least few hundreds meters...**
- Relevant is the choice of cold/hot working to obtain suitable tolerances as well as mechanical properties (cold working implies work hardening...intermediate thermal cycles could be necessary...)
- Costs could be estimated at few (1 ÷ 5) EUR/cm for a production of few km (at least 1 ÷ 2 km) ...
- Machining could be 5 ÷ 10 times more expensive...depending on quantities and materials.
- AM could be envisaged if a machine with compatible dimensions is available...but Cu Alloys are still not 3D printable...
- EDM is not suitable due to dimensions.

Bladders

Bladders are assembly tools used to preload the magnet during assembly (HL-LHC quadrupole design...).

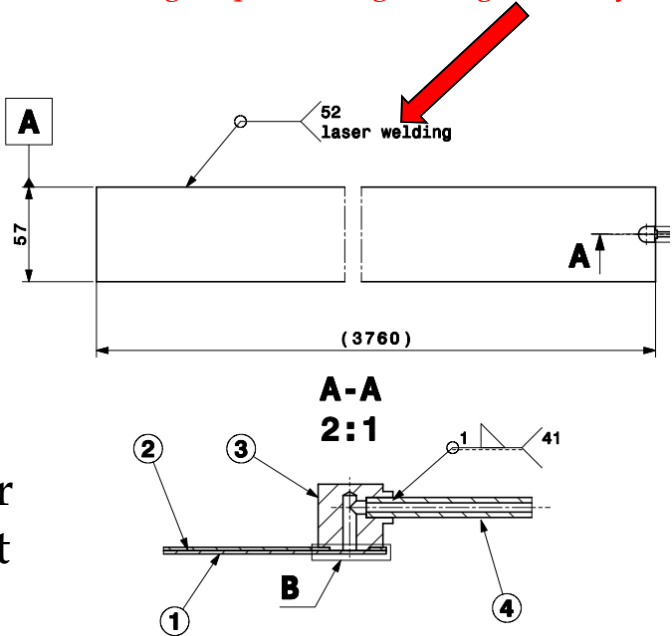
Actually they are long rectangular pockets with an inlet to provide pressure...

Old fabrication method:

- Precise milling of two stainless steel foils (0.5mm thickness)
- Positioning jigs...
- Laser welding of the foils
- Milling of the inlet components
- Tig welding of the inlet parts

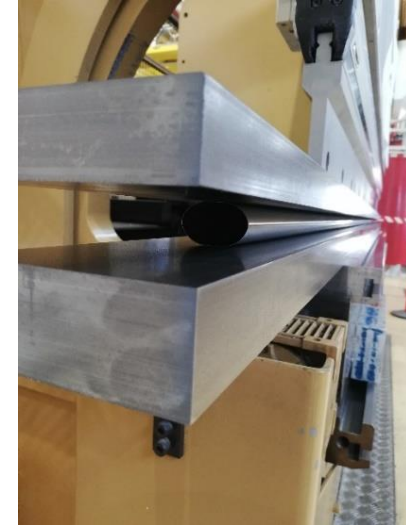
~ 500CHF/Bladder
 ~ 10kCHF/Magnet

Relevant risk of leak, pressure of 400bars for the magnet preloading during assembly...



New fabrication method:

- Cold drawing of the calibrated round tube
- Flatten the tubes with press or rolling machine
- Milling of the end pieces
- Tig welding of the end pieces and capillary tube



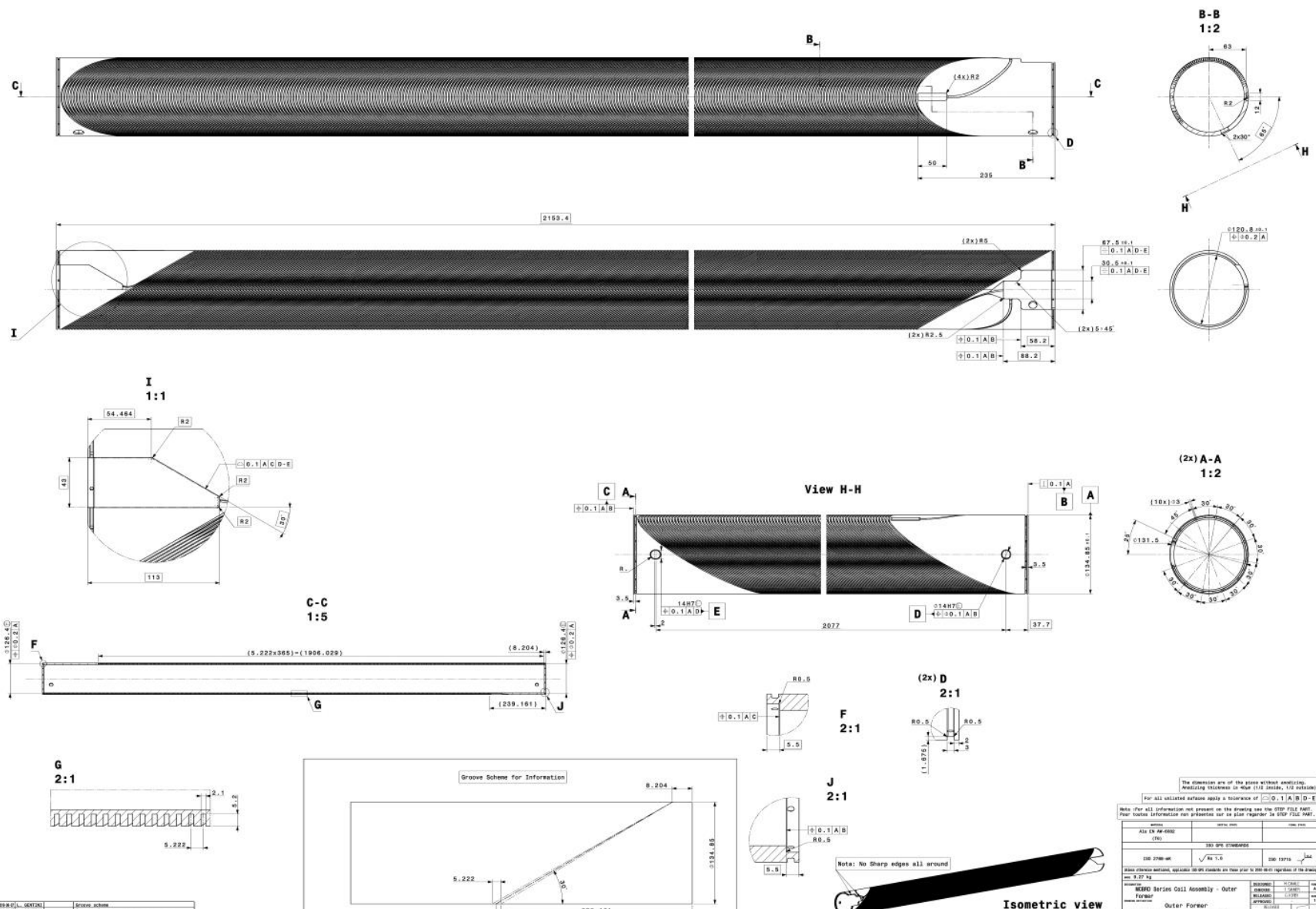
~ 350CHF/Bladder
~ 7kCHF/Magnet

Advantages of the new fabrication method:

- 30% Cost reduction compare to initial design
- Removed of the longitudinal welds (main causes of the cracks)...improved reliability!
- Possibility to re-use the bladders and to repair them if needed

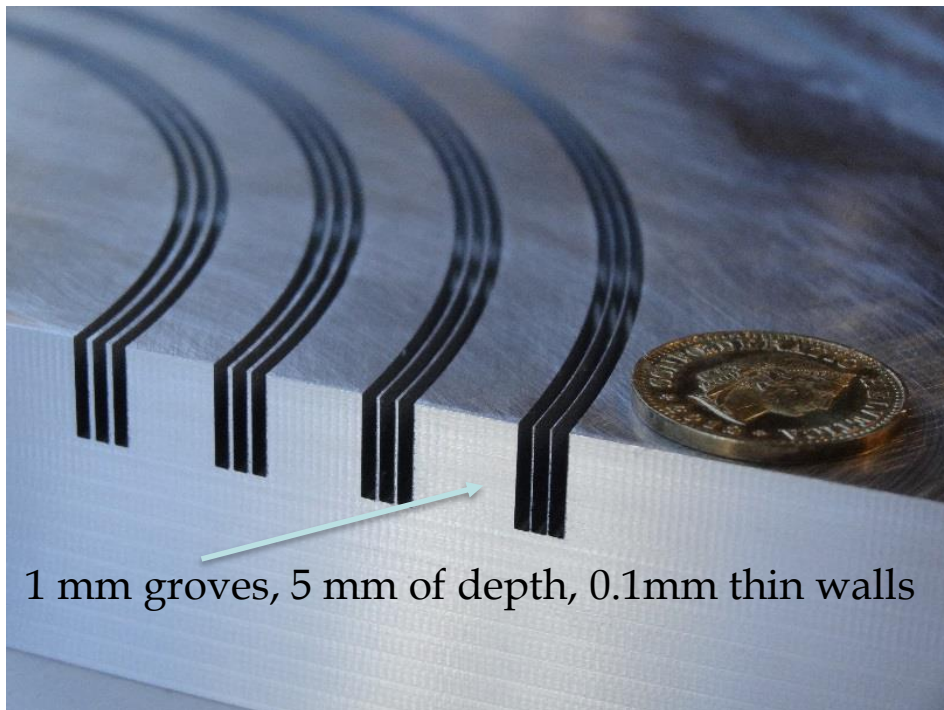


MCBRD Series Coil Assembly - Outer Former

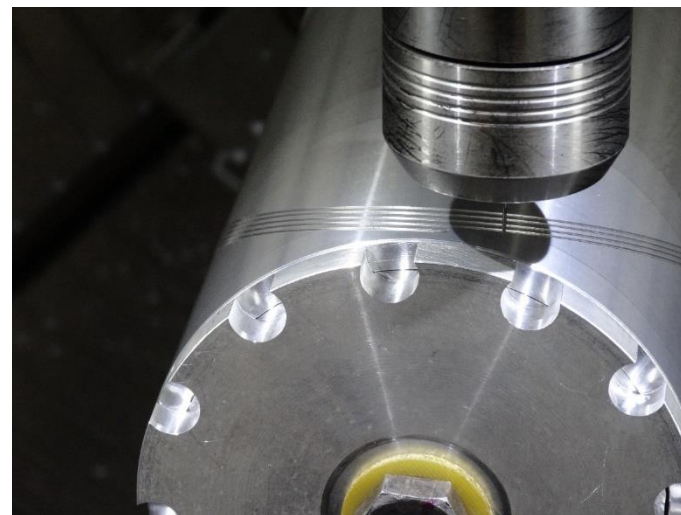


A.

● Prototyping



- ✓ Several prototypes done
- ✓ Different materials tested
- ✓ Search for machining feasibility limits



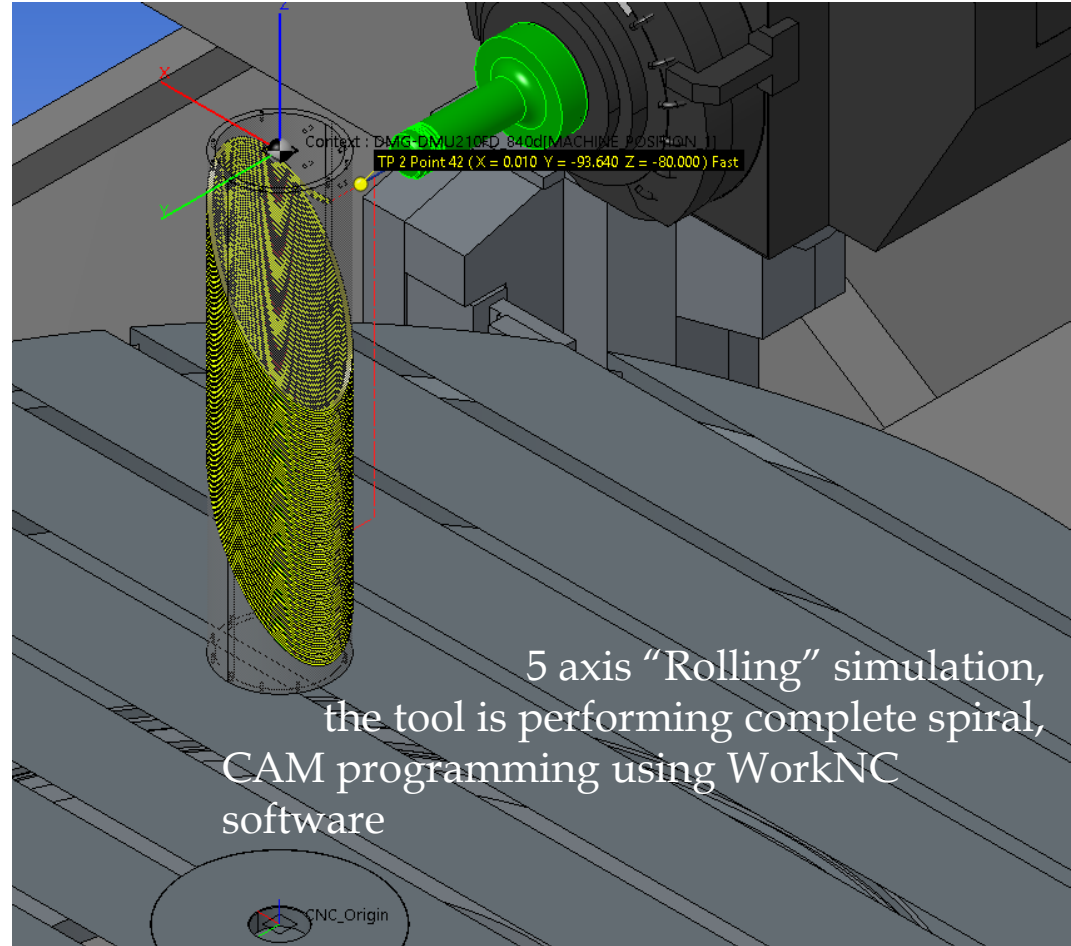
- Tooling / Programming strategy choice



High feed mills for roughing
Ø2 mm, 45k rpm, 0.06 plunge

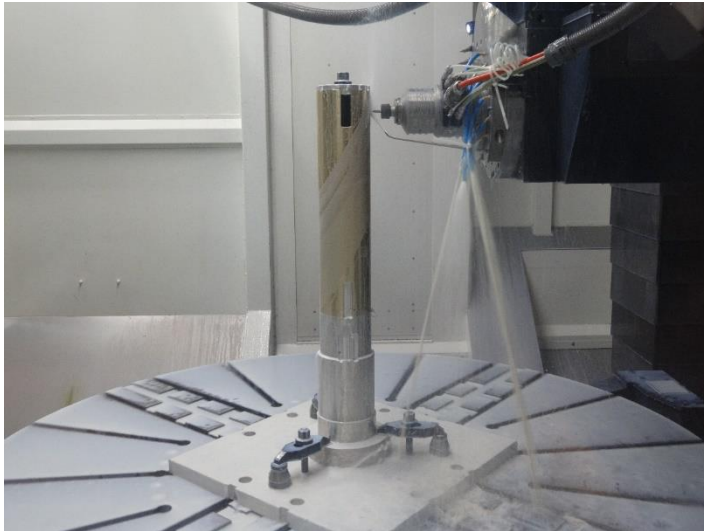


Finishing with
2-floute carbide



5 axis "Rolling" simulation,
the tool is performing complete spiral,
CAM programming using WorkNC
software

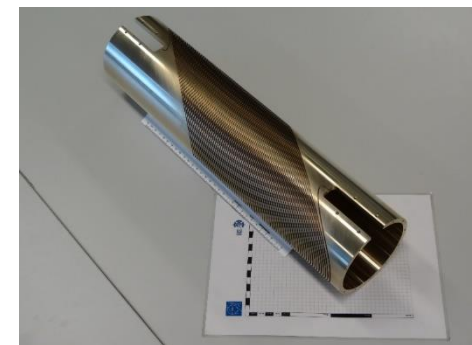
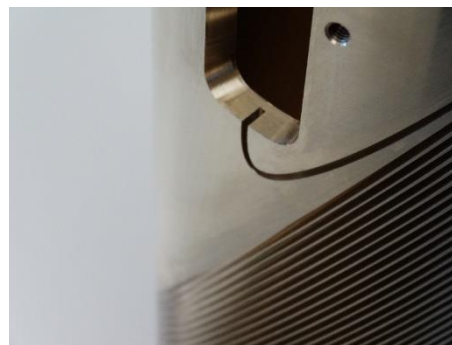
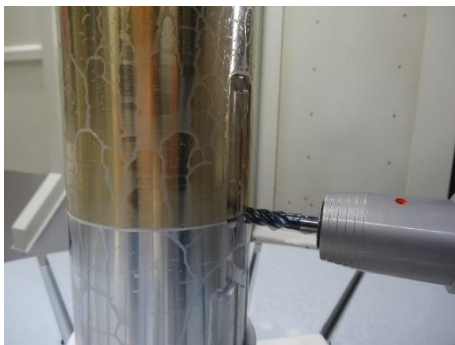
- 500 mm assembly



Machining in vertical position on 5 axis DMU210



4 x assemblies manufactured in 2016



MCBRD Series Coil CCCT

- Present main workshop projects

- 2158 mm long assembly in aluminum



New WFL M40 millturn, 7-axis turning / milling centre (workpieces up to 3000 mm of length)

- Magnetic Design, Mechanical Design, 3D models, FEM analyses...
 - Functional and Technical Specification...
 - Drawings... Geometrical Dimensioning & Tolerancing (GD&T)
 - Drawings + Technical Specifications → Fabrication, Contracts...
- We need to master GD&T... strong impact on:
 - Quality of the assembling
 - Magnet performances
 - Tight tolerances, repeatability and small dispersion...
 - Fabrication method
 - Costs
 - Choice of raw materials
- Choice of Fabrication methods:
 - Geometrical shapes and Tolerances, quantities, raw materials, costs



THANK YOU FOR YOUR ATTENTION

Appendix D

A Digression on Manufacturing Techniques for Magnet Components

A. Dallocchio; M. Garlasché; P. Moyret; K. Scibor; R. Gerard

European Organization for Nuclear Research (CERN)

 EN Engineering Department



MAIN REFERENCE BOOKS

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- Childs T.; Maekawa, K. & Obikawa T.and Yamane, Y., Metal Machining: Theory and Applications, Butterworth-Heinemann, 2000
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- Rao P. N.; Manufacturing Technology – Metal Cutting and Machine Tools, (Volume II), McGraw-Hill Education – 4th Ed., 2018
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