An Approach for Low Cost Fabrication of the Coil Structure

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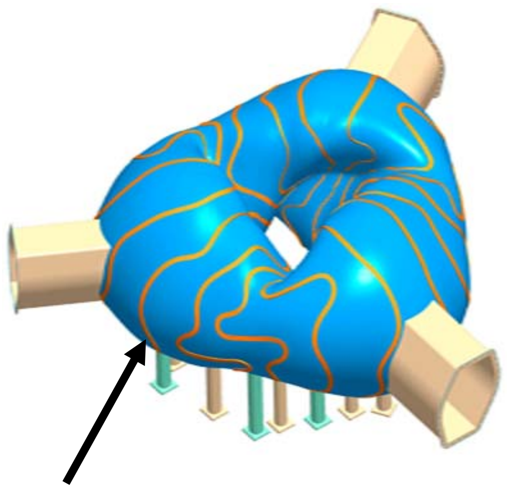
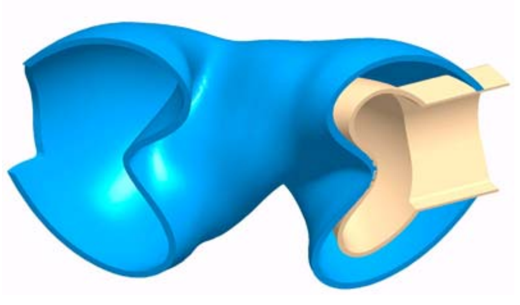
Fabrication of the Coil Structure



Interior grooves show on exterior for clarity



Material: JK2LB low carbon, boron steel

Mass: ~ 3 x 10^6 kg for 3 field periods

Construction: Monolithic for field period

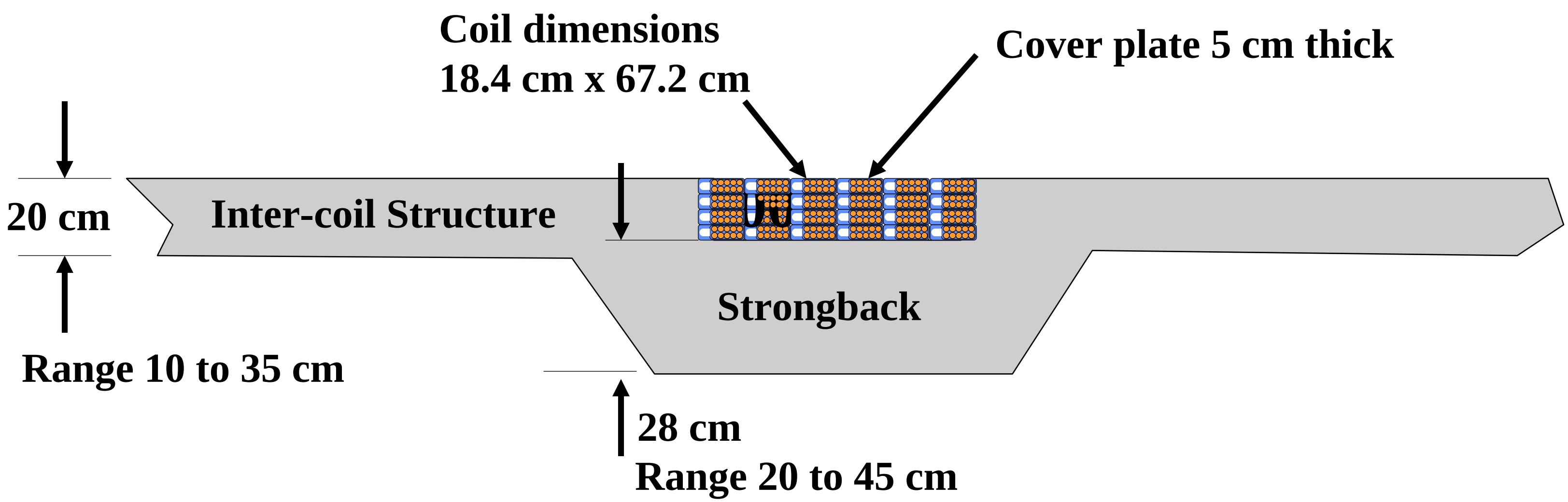
Fabrication Location: At construction site

Fabrication: Additive machining – arc deposition of near net shape, final machining of coil grooves by robot milling machines on inner surface and field period interfaces

Coil Fabrication: Coil cables will be wound into the grooves with robot winding machines

Accuracy of Coils: EM forces will be analyzed to determine displacement. Placement of the grooves will be compensated so the coils will be in proper location when coils are energized.

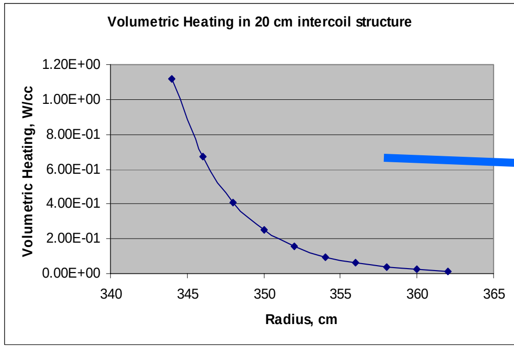
Nominal Cross-Section

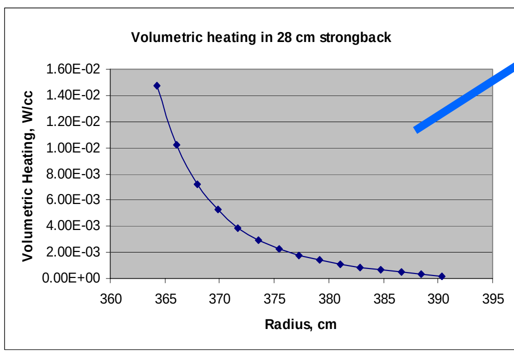


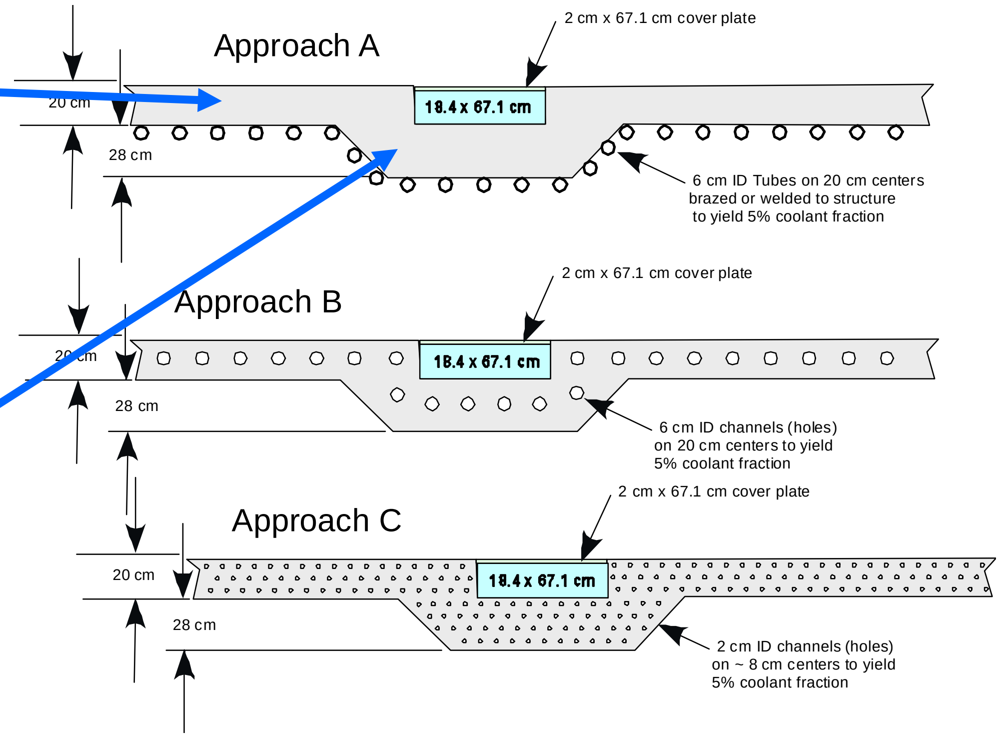
This is the nominal coil cross-section to be fabricated. The thicknesses will vary depending on the predicted local EM forces, thicker inboard and thinner outboard.

Heating the Structure

Cooling the Structure



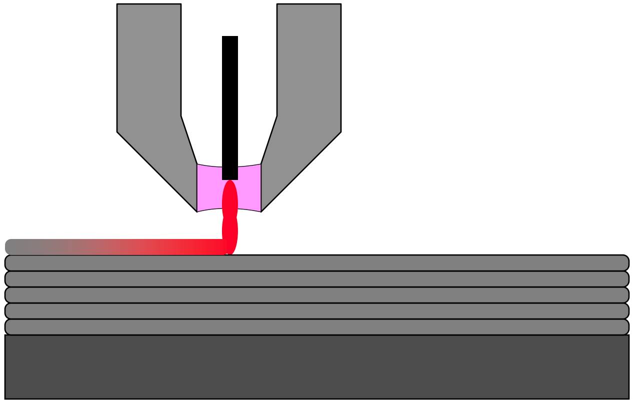




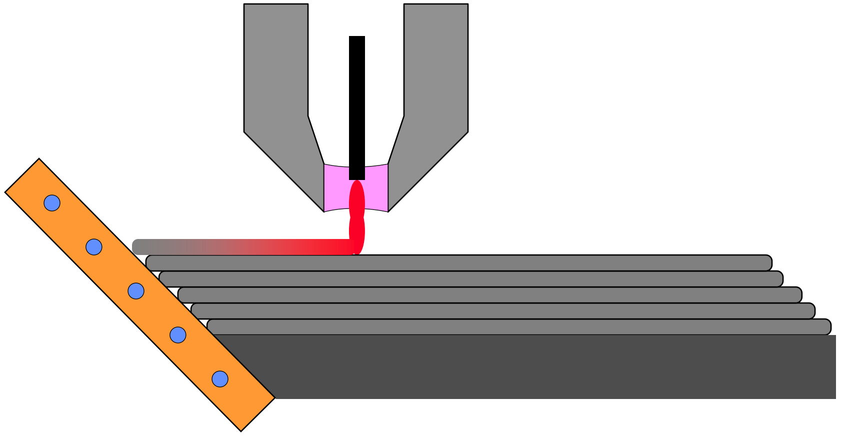
These are suggested approaches for cooling the coil structure, either A) externally with brazed or welded tubes that can be located where desired or B & C) with internal cooling channels fabricated in place.

Since the preferred cooling method is to run the coolant channels parallel to the coils, the number of channels for the inter coil cooling will have to be adjusted with manifolds or branches as the width between the coils varies.

Plasma Arc Deposition

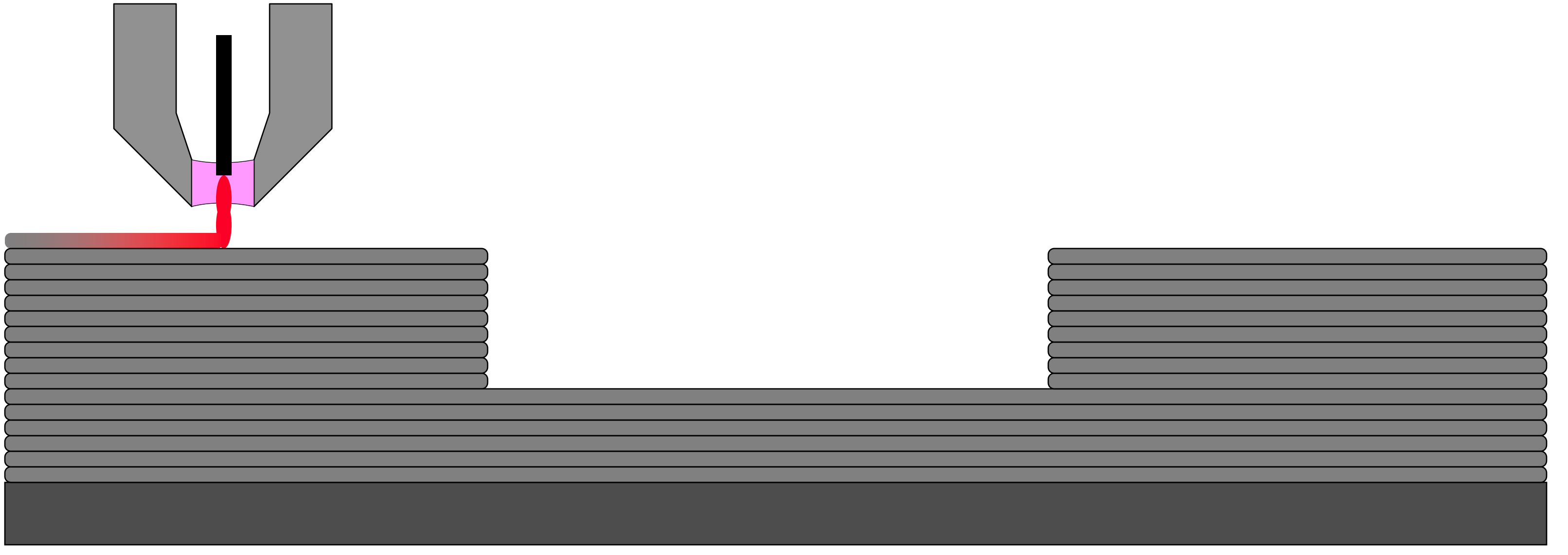


The deposition wire is fed into the plasma arc and the material deposited in layers



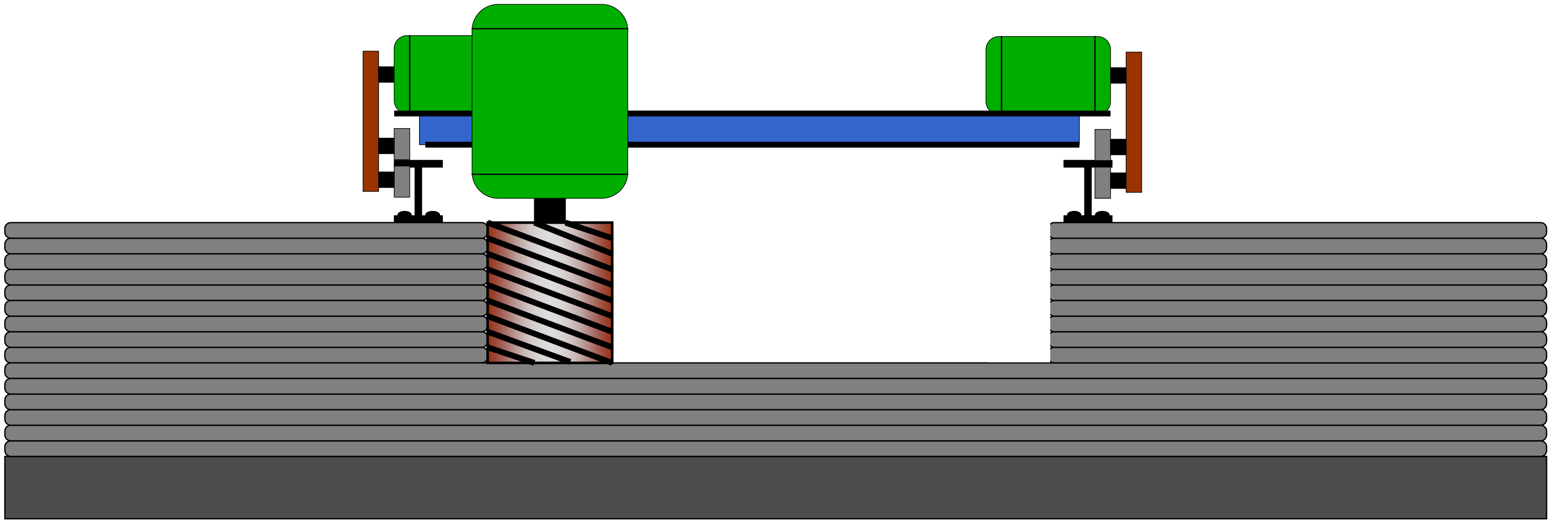
Overhanging features can be created with cooled slip plates

Plasma Arc Deposition



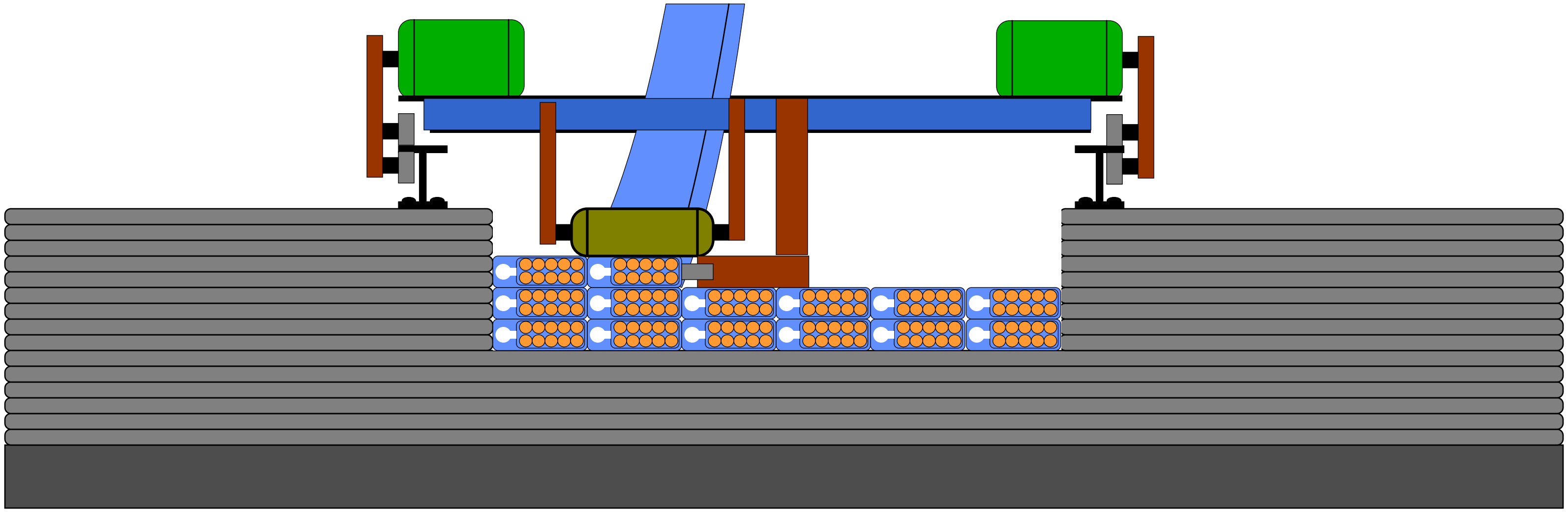
Features can be added as the material is deposited by starting and stopping the deposition. These features (such as coil grooves and mounting interfaces) are near-net shape that require only minimal machining. All other surfaces probably will require no machining.

Groove Fabrication



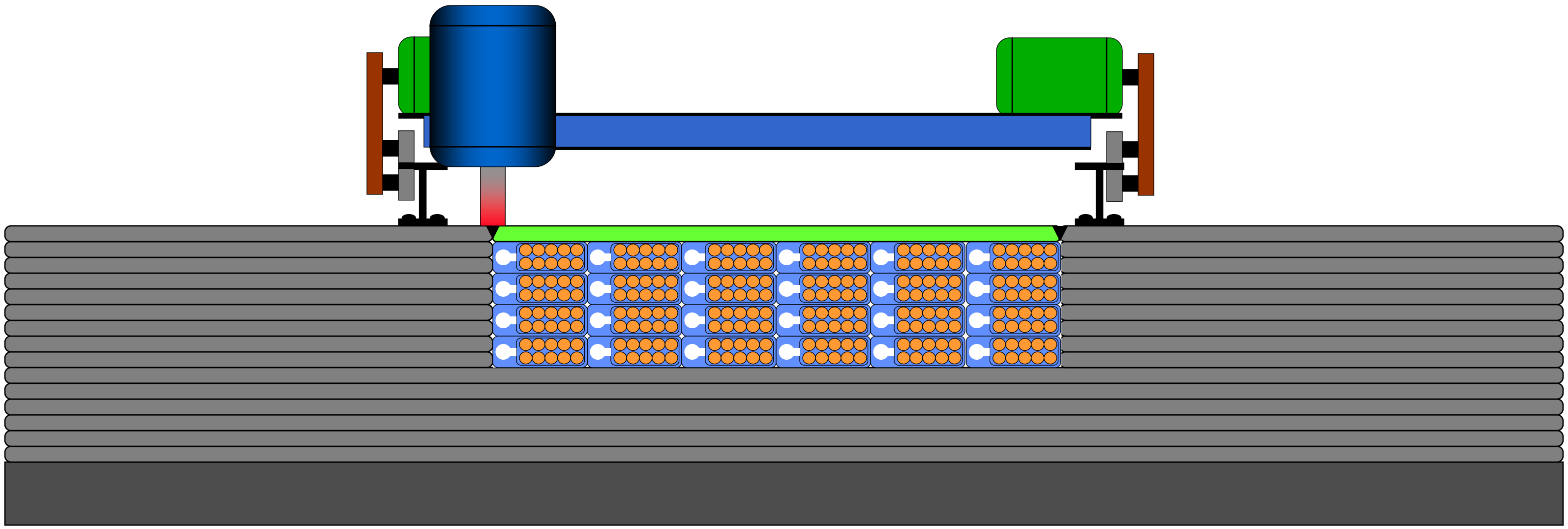
Guide rails and fiducial reference datums will be added to the structure parts to guide the milling machines for final groove machining.

Groove Fabrication



A similar machine will use the same rails and fiducial datums to install the superconducting cables into the coil groove

Securing Coil Cover



After all the cable is in place for the coil, the cover place will be installed and friction-stir welded in place to secure the coil.

Concept to Fabricate Structure

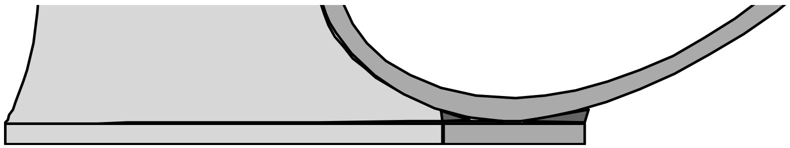
1. Start with solid base

Concept to Fabricate Structure

1. Start with solid base
2. Begin to create structure

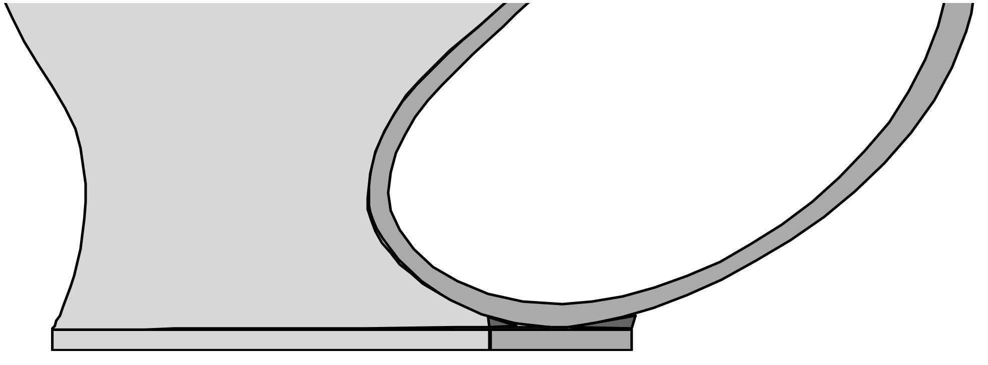
Concept to Fabricate Structure

1. Start with solid base
2. Begin to create structure
3. Continue to add layers



Concept to Fabricate Structure

1. Start with solid base
2. Begin to create structure
3. Continue to add layers
4. Ditto



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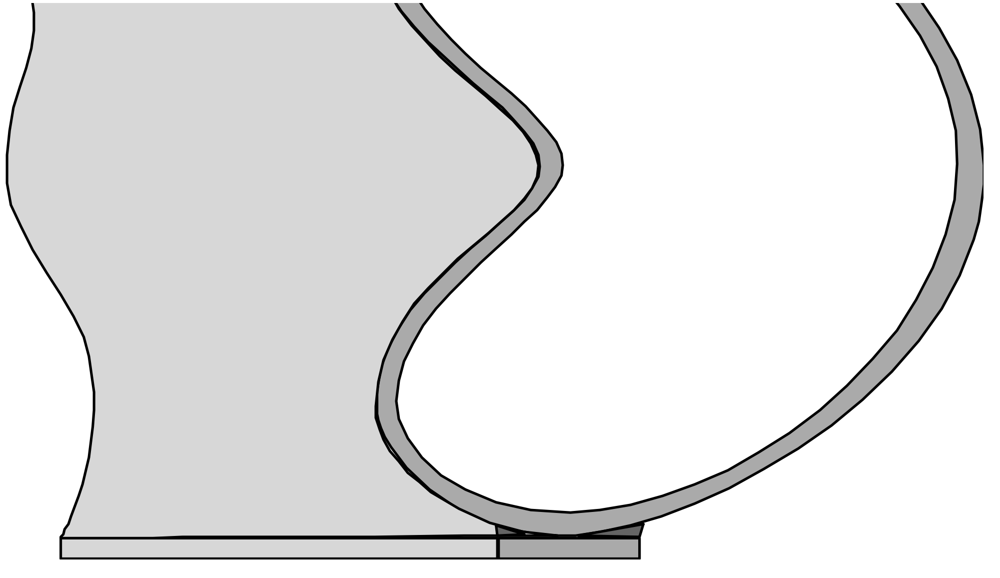
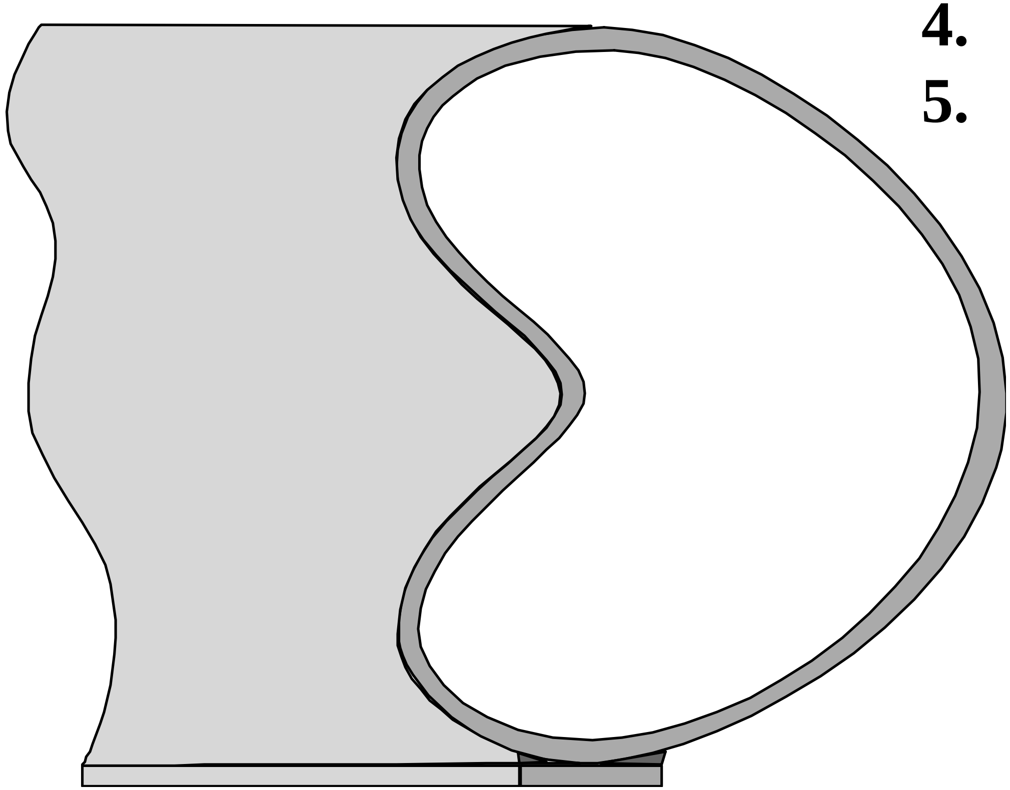


Concept to Fabricate Structure

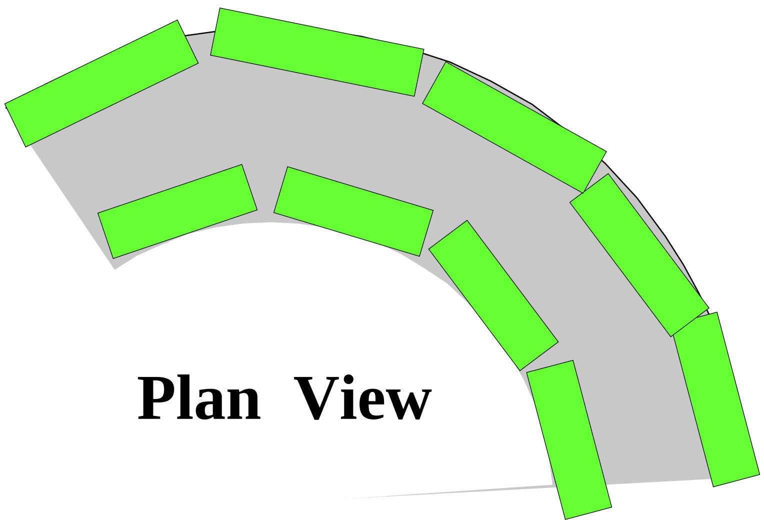


1. **Start with solid base**
2. **Begin to create structure**
3. **Continue to add layers**
4. **Ditto**
5. **Until it is complete for a field period**

Employing Multiple Build Robots

Multiple robots will be required to build a field period in roughly a year

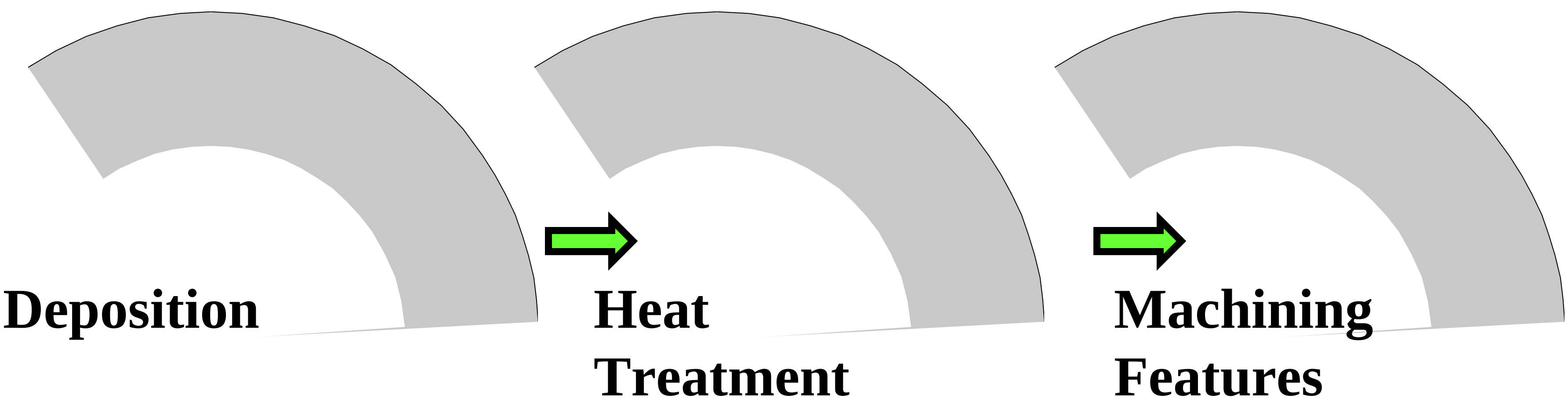
Each robot will be assigned a zone to build



Plan View

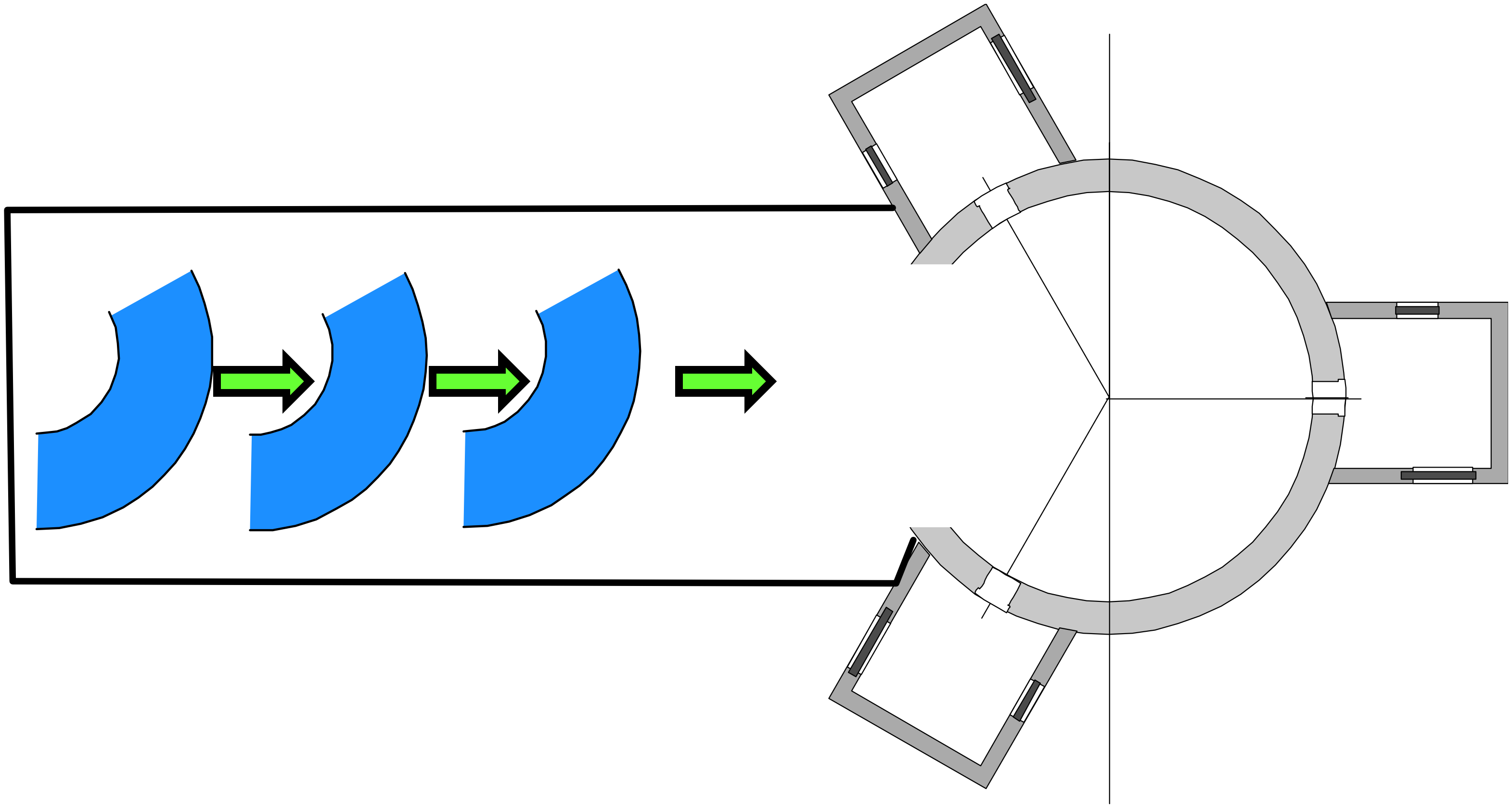
Staging of Field Period Structures

- The most cost effective approach is to construct one field period at a time, but staged to move deposition, heat treatment, and machining equipment from one FP to another as required.
- After the first FP is completed, it will be moved into place in the Reactor Building.
- All three FPs should be completed in roughly 3 years.



Construction Sequence

- The coil sectors will probably be fabricated close to the Reactor Building and moved inside the Reactor Building



Preliminary Costing

- A preliminary engineering cost estimate has been developed
- Additional detail can be added as needed
- Costs will be discussed in \$2006 and provided in \$1992 (0.7464)
- Total mass is 10^6 kg ($393 m^3$ x 7800 kg/m^3)
- Cost of specialty steel, JK2LB, in wire form is \$20/kg (estimate)
- Build each segment (FP) separately in sequence
- Build Time is driven by deposition rate but is adjustable by using more robots (10 assumed)

Cost of Deposition

DEPOSITION			
Segment Weight	kg	1,000,000	
Wire Unit Cost	$/kg	$20	**Awaiting Kobe Steel quote**
Material Cost	$	$20,000,000	
Deposition Rate Per Robot	kg/hr	20	
# of Deposition Robots		10	**Assumption of 10 robots**
Deposition Rate	kg/hr	200	
Up Time (availability)		0.85	
Deposition Time	days	245	**Driving schedule item**
Robot Unit Cost	$/robot	$500,000	**Representative cost**
Total Robot Cost	$	$5,000,000	
Raising Platform Cost	$	$1,000,000	
Control System Cost	$	$1,000,000	
Deposition System Cost	$	$7,000,000	
Amortization	Segments	6	
Amortization Cost	$/hr	$198	
Electricity Unit Cost	$/kwh	$0.05	
Electricity Usage Per Robot	kw	100	
Electricity Cost	$/hr	$50	
Operator Cost/hr	$/hr	$100	
# of Operators		4	
Labor Cost	$/hr	$400	
Overhead Factor		1.5	
Deposition Rate	$/hr	$973	
Deposited Segment Cost	**$**	**$25,720,588**	**Most significant cost**

Cost of Stress Relief

STRESS RELIEF			
Segment Weight	kg	1,000,000	
Stress Relief Time	days	30	**Typical low temp time**
Insulation	$	$2,000,000	
Heating System	$	$2,000,000	
Heat Treat System Cost	$	$4,000,000	
Amortization	Segments	6	
Amortization Cost	$/hr	$926	
Electricity Unit Cost	$/kwh	$0.05	
Electricity Usage Per Robot	kw	10,000	
Electricity Cost	$/hr	$500	
Operator Cost/hr	$/hr	$100	
# of Operators		1	**Minimal operators**
Labor Cost	$/hr	$100	
Overhead Factor		1.5	
Heat Treat Rate	$/hr	$2,289	
Stress Relief Cost	**$**	**$1,648,000**	

Cost of Coil Channel Machining

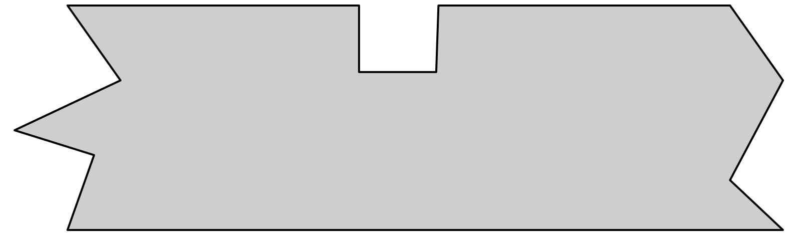
COIL CHANNEL MACHINING			
Length of Channel	m	236	CAD determination
Depth of Channel	m	0.184	
Width of Channel	m	0.671	
Fraction Rough Out		0.25	Probably high
Amount of Rough Machining	kg	57,255	
Rough Machining Rate	kg/hr	77.28	
Up Time		0.85	
# of Milling Machines		2	Arbitrary number
Rough Machining Time	days	18	
Floor Finishing Feed Rate	m/hr	6.980	
Cutter Diameter	m	0.096	
Total Length of Cut	m	1652	
Up Time		0.85	
Floor Finishing Time	days	6	
Sidewall Finishing Rate	m/hr	24	
Total Length of Cut	m	472	
Up Time		0.85	
Sidewall Finishing Time	days	0	
Total Machining Time	days	24	
Milling Machine Cost	$	$2,000,000	
Amortization	segments	25	
Amortization Cost	$/hr	$273	
Operator Cost/hr	$/hr	$100	
# of Operators		4	3 operators + QA
Labor Cost	$/hr	$400	
Overhead Factor		1.5	
Machining Rate	$/hr	$1,009	
Coil Channel Machining Cost	**$**	**$591,957**	

Cost of Coil Cable and Cover Installation

COIL CABLE and COVER INSTALLATION			
Cable Installation and Friction Stir Weld Speed	m/hr	5.334	
# of Installation Machines		1	
Coil Length	m	236	
Cover width	m	0.184	
Cover thickness	m	0.05	
Mass of cover	kg	16935	**Arbitrary number**
Unit Cost	$/kg	$10	
Cover material costs	$	$169,354	
# of cables per coil		24	**Arbitrary number**
Up Time		0.75	
Cable Installation Time	days	58.99	
Coil Cover Installation and welding	days	2.46	
Complete Coil and Cover Installation		61.45	
Installation Machine Cost	$	$2,500,000	
Amortization	segments	25	
Amortization Cost	$/hr	$68	
Operator Cost/hr	$/hr	$100	
# of Operators		2	
Labor Cost	$/hr	$200	
Overhead Factor		1.5	
Machining Rate	$/hr	$402	
Installation Cost	**$**	**$592,445**	

Cost of Cooling Channel Machining

This is a representative way of cooling the structure using machined channels with a friction stir welded cover plate.

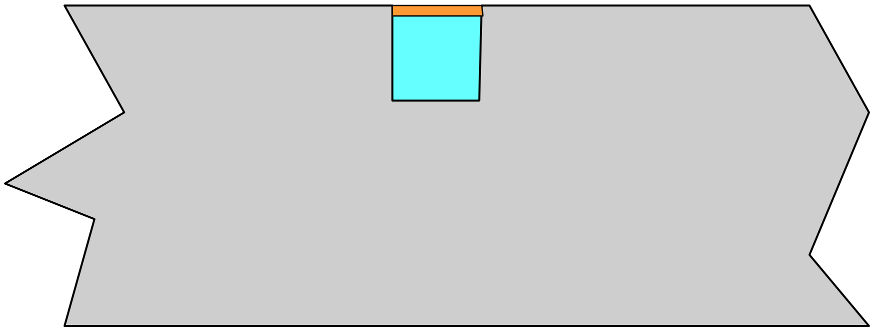


COOLING CHANNEL MACHINING		
Length of Channel	m	2360
Depth of Channel	m	0.025
Width of Channel	m	0.025
# of Milling Machines		2
Machining Rate	m/hr	6.980
Up Time		0.85
Channel Machining Time	days	8
Milling Machine Cost	$	$2,000,000
Amortization	segments	25
Amortization Cost	$/hr	$804
Operator Cost/hr	$/hr	$100
# of Operators		4
Labor Cost	$/hr	$400
Overhead Factor		1.5
Machining Rate	$/hr	$1,807
Cooling channel Machining Cost	**$**	**$359,334**

Arbitrary size

Cost of Cooling Channel Closeout

This is a representative way of cooling the structure using machined channels with a friction stir welded cover plate.



COOLING CHANNEL CLOSEOUT		
Friction Stir Weld Speed	m/hr	5.334
# of Installation Machines		2
Coil Length	m	2360
Up Time		0.85
Coil Installation Time	days	10.84
Installation Machine Cost	$	$2,000,000
Amortization	segments	25
Amortization Cost	$/hr	$615
Operator Cost/hr	$/hr	$100
# of Operators		4
Labor Cost	$/hr	400
Overhead Factor		1.5
Machining Rate	$/hr	$1,522
Cooling Channel Closeout Cost	**$**	**396,157**

Arbitrary size

Summary Schedule and Costs

Cost/Segment	$	$29,308,481	
Mass Cost/Segment	$/kg	$29.31	$21.88 in $1992
Cycle Time for Segment 1	days	380	
Additional Time for Each Additional Segment	days	245	
Total Time for 3 Segments	days	870	

Fabrication Elements	Days	Cost
Deposition	245	$25,720,588
Stress Relief	30	$1,648,000
Coil Channel Machining	24	$591,957
Coil Cable and Cover Installation	61	$592,445
Cooling Channel Machining	8	$359,334
Cooling Channel Closeout	11	$396,157
Segment Totals (d, $)	380	$29,308,481
Total, Three Segments (d,$)	870	$87,925,443

~ 2.4 yr fabrication time

This is a good approximation of the coil structure fabrication cost using advanced low cost techniques. This compares to $75/kg ($56 in $92) that results in $225M.