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FLUXTROL Inc. Centre for Induction Technology™

Magnetic Flux Control in Induction Installations

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Magnetic Materials for Flux Control

- **Laminations:**
  - Best magnetic properties at low and middle frequencies and high temperature resistance
  - Unlimited dimensions (sheets and strips)
  - Limited machinability (cutting only)
  - Low performance in 3D fields
- **Ferrites**
  - Wide frequency range
  - High permeability at low loading
  - Non-machinable
  - Low temperature resistance and Curie points
  - Low saturation flux density
  - Limited shapes and dimensions
- **Soft Magnetic Composites** (SMC) = Magnetodielectrics (MD)

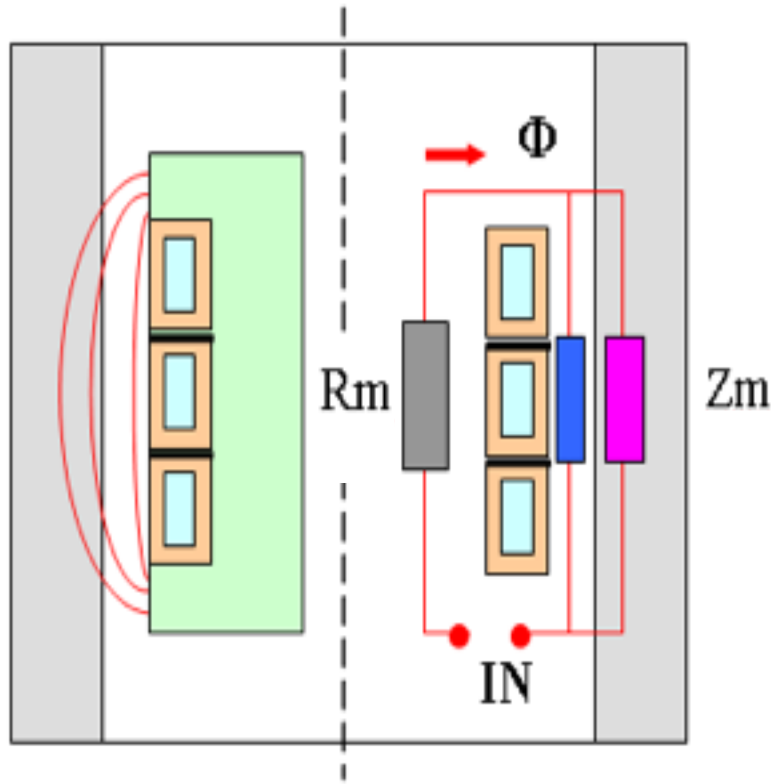
Magnetic Materials for Flux Control

- **Soft Magnetic Composites** (SMC) = Magnetodielectrics
- Very wide frequency range (up to 13 MHz)
- Good magnetic and thermal properties
- Excellent machinability (not for all types)
- Work well in 3D fields
- Limited dimensions
- Higher stock price than laminations
- Combination of laminations in large regular areas and SMC in 3D and complex geometry areas is very promising for induction installations of low and middle frequencies

Magnetic Flux Control

$\Phi = IN / (Zm + Rm)$

Φ – Magnetic Flux causing heating
IN – Ampere turns of the coil
Zm – Reluctance of the "active zone"
Rm – Magnetic reluctance of **return path**, i.e. space inside the coil



Example of ID Coil

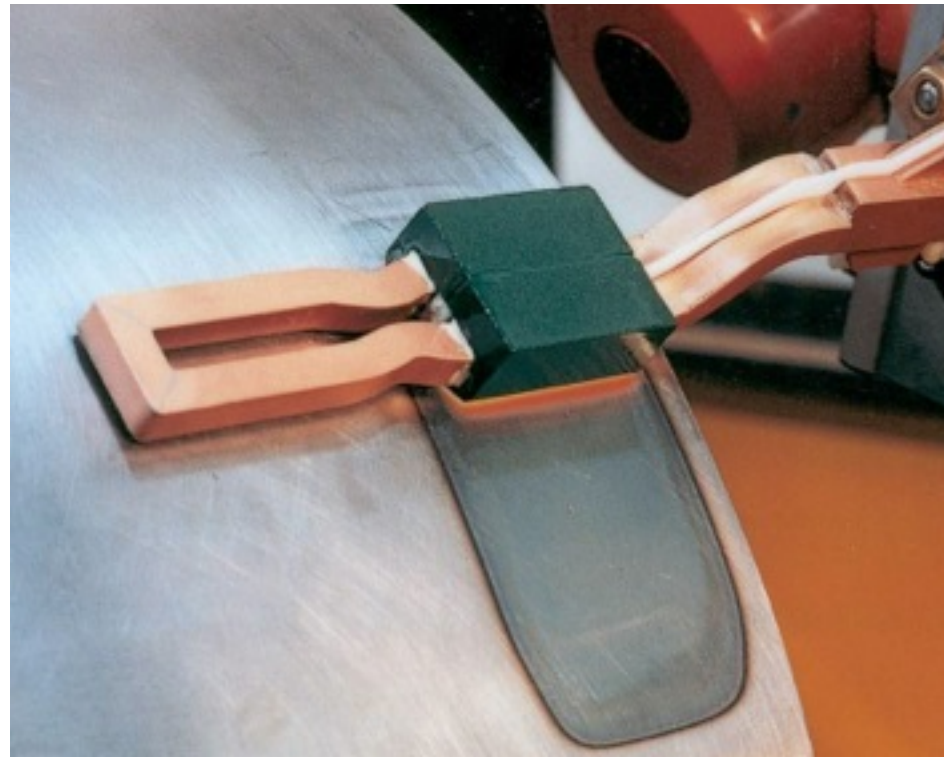
Magnetic core reduces **Rm** by permeability times and for an ideal core **Rm** => 0.
Then **$\Phi = IN / Zm$**

Magnetic flux control is the most effective when there are "bottle necks" on the flux return path

Magnetic Control in Induction Heat Treating and Brazing

Goals:

- Heat Pattern control (quality issue)
- Improvements in coil parameters
- Power savings
- Shorter heating times (production issue)
- Prevention of unintended heating (shielding issue)



Example of concentrator influence on power distribution (hair-pin coil)

Single-shot Induction Coil with Laminations

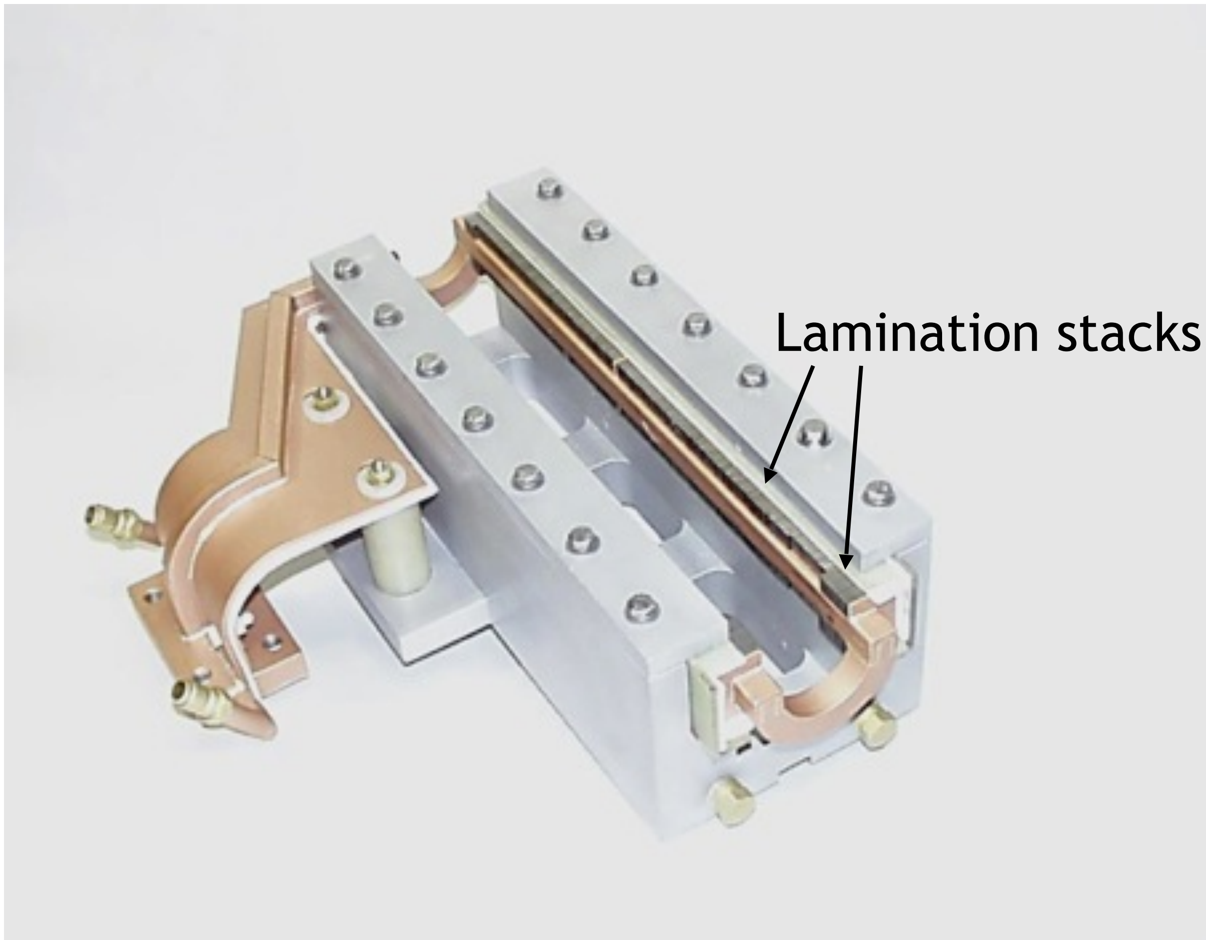
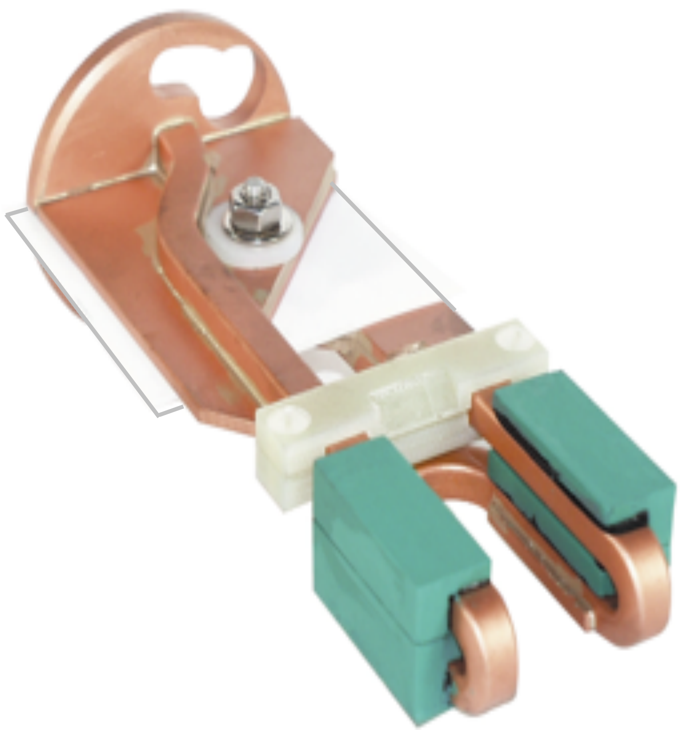


Photo Courtesy of Tucker Induction

Examples of Coils with SMC Controllers



Coil with SMC controller for quality and efficiency improvement in Al part brazing

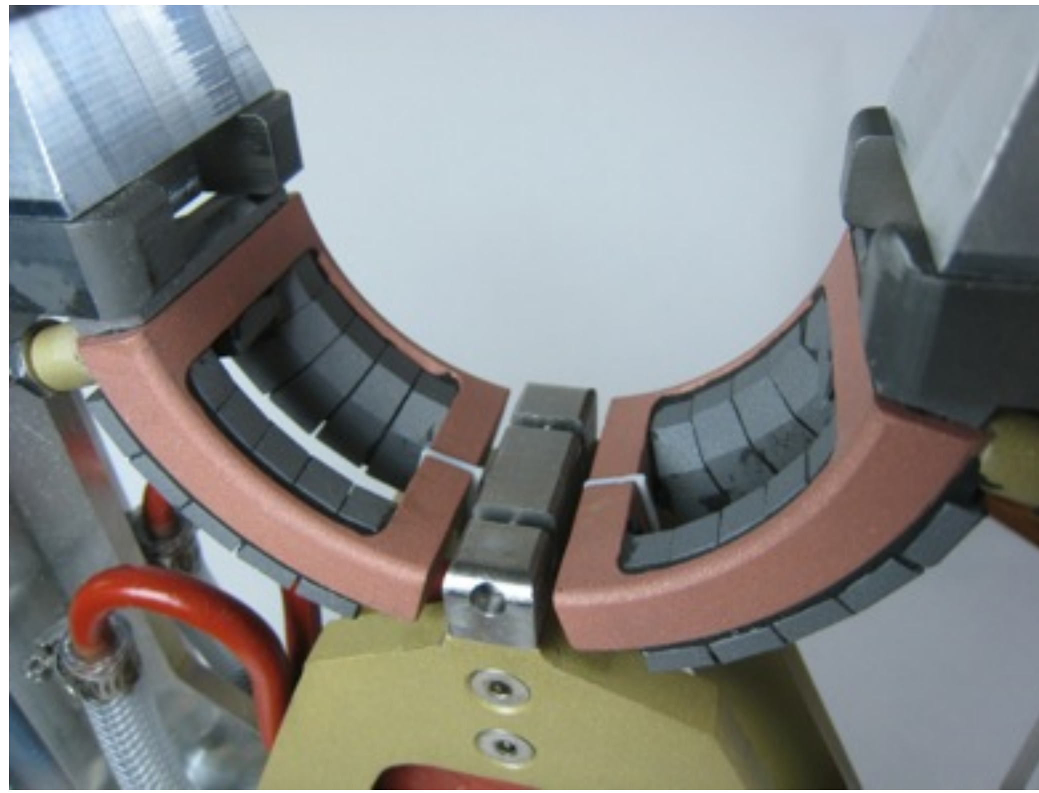
Frequency 25 kHz

Internal coil with Fluxtrol controller (green)

Courtesy Eldec Induction

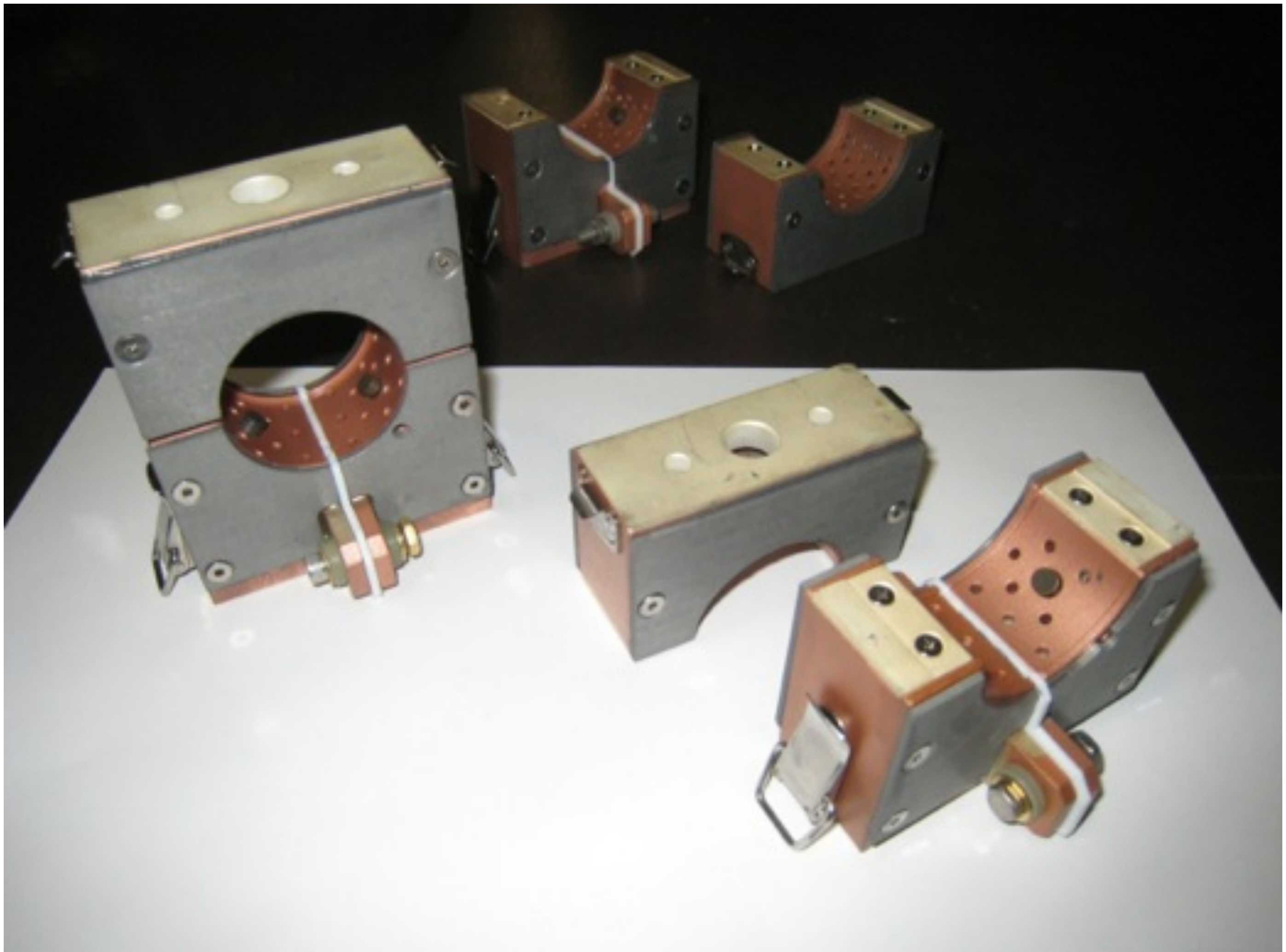
Rotational Hardening of Crankshafts

Hardness pattern



Optimized induction coil with sections of SMC concentrators

Typical Clam Shell Coils with Magnetic Side Shields



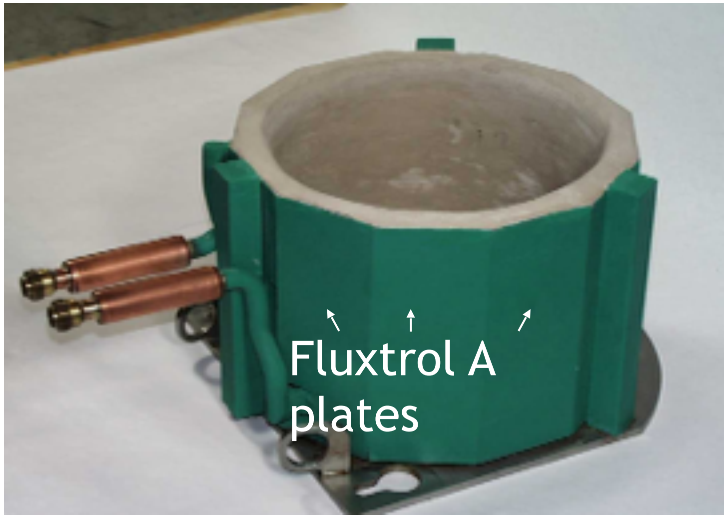
Magnetic Control in Coreless Melting Furnaces

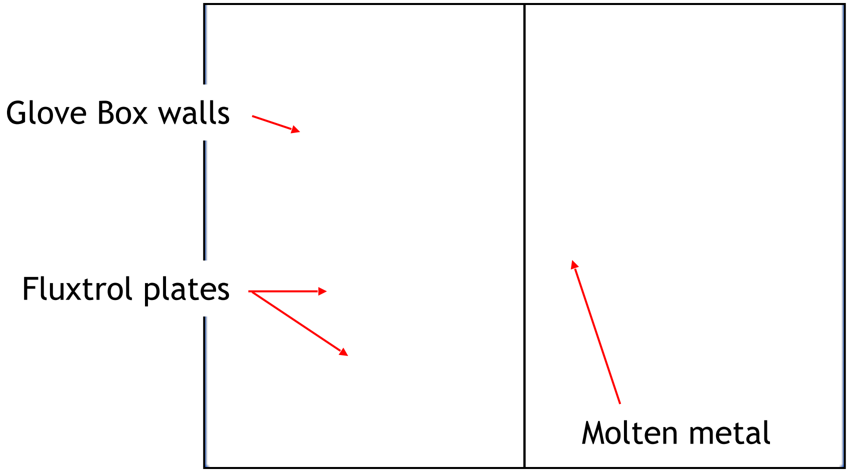
- Improvement of furnace parameters (efficiency, power factor)
- Optimal distribution of power in the melt
- Induction coil shielding:
  - reduction of losses in the furnace structure
  - reduction of losses in chamber and possibility to reduce the chamber diameter (vacuum furnaces)
  - field reduction on work places (Maximum Permissible Levels compliance)
- Special applications such as Cold Crucible Furnaces

Melting Inductor for Glove Box

SMC shields on the side and bottom surfaces allowed to:

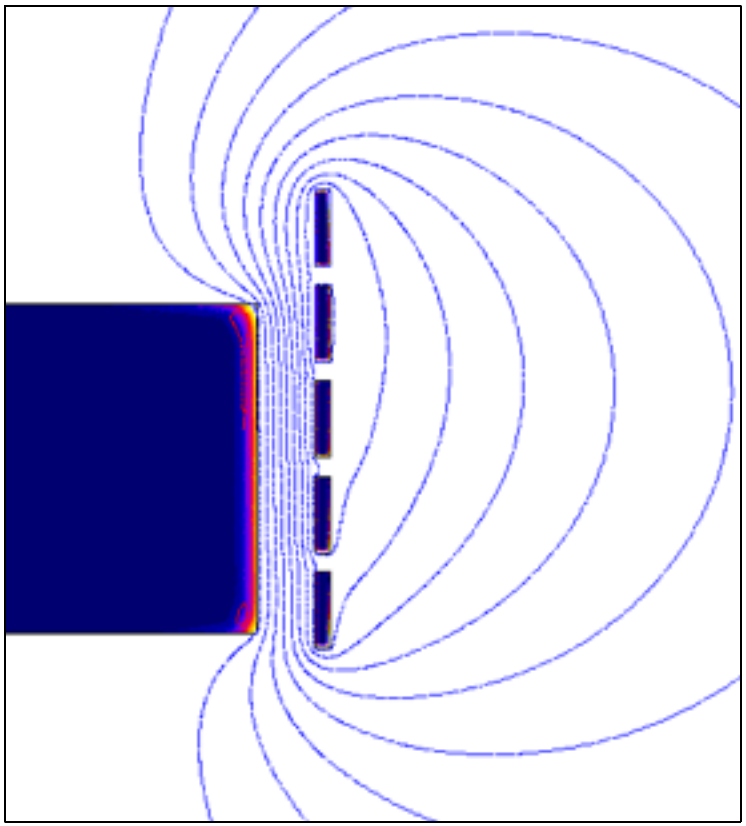
- Strongly reduce losses in the chamber walls and bottom plate
- Increase the furnace volume in the same chamber
- Increase coil efficiency from 23 to 63% due to reduced losses in chamber walls, bottom plate and in the coil

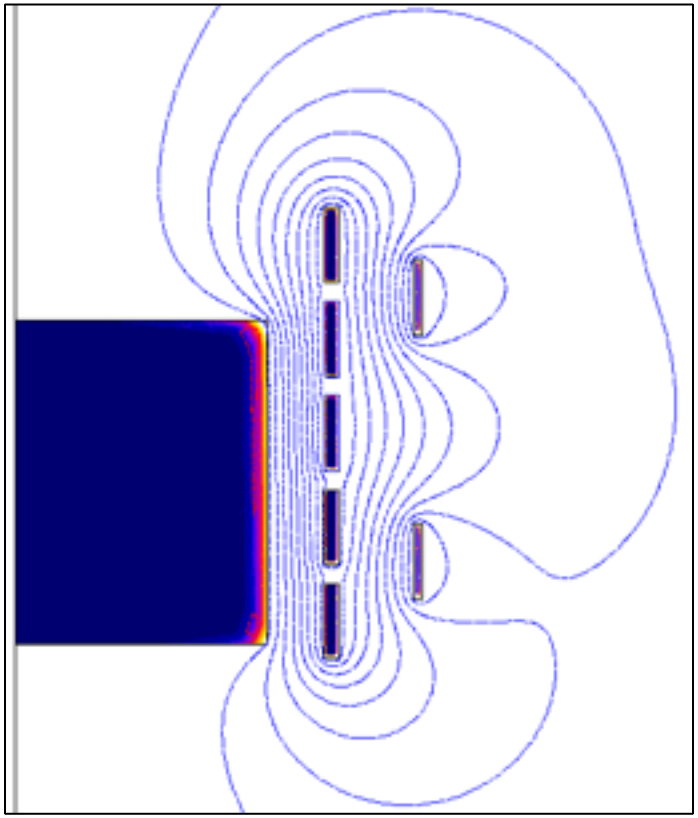




Magnetic field lines and color map of power density in a shielded coil

Induction Furnace Shielding



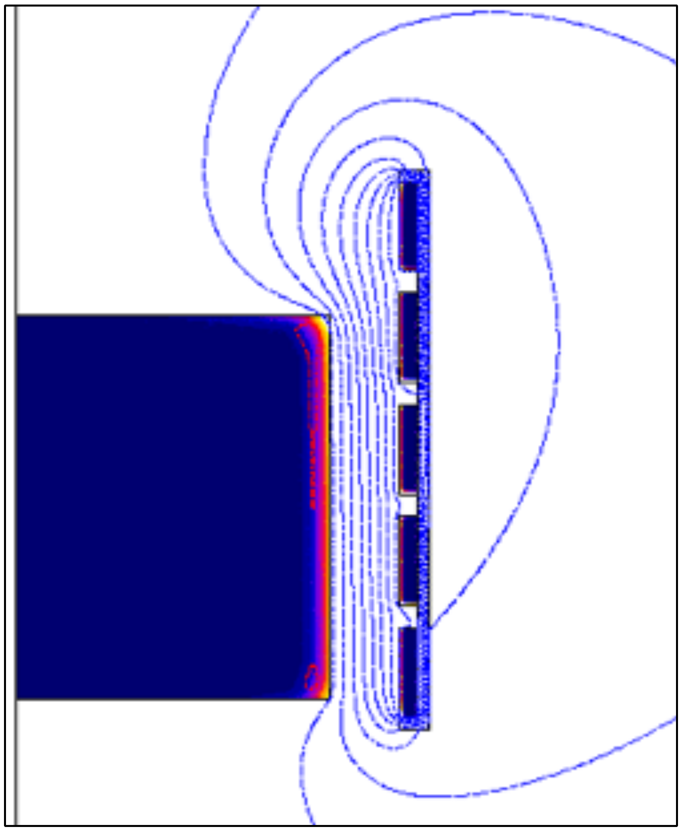


Bare Inductor Inductor with Faraday Rings

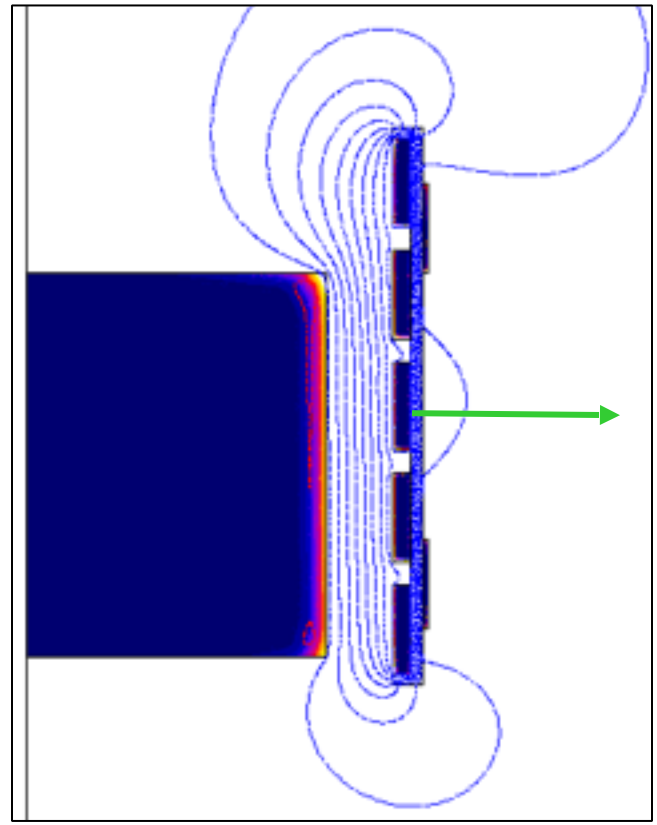
Coil ID = 860 mm, H = 600 mm, F = 3000 Hz

Load – molten steel, Dia. 670 mm

Induction Furnace Shielding



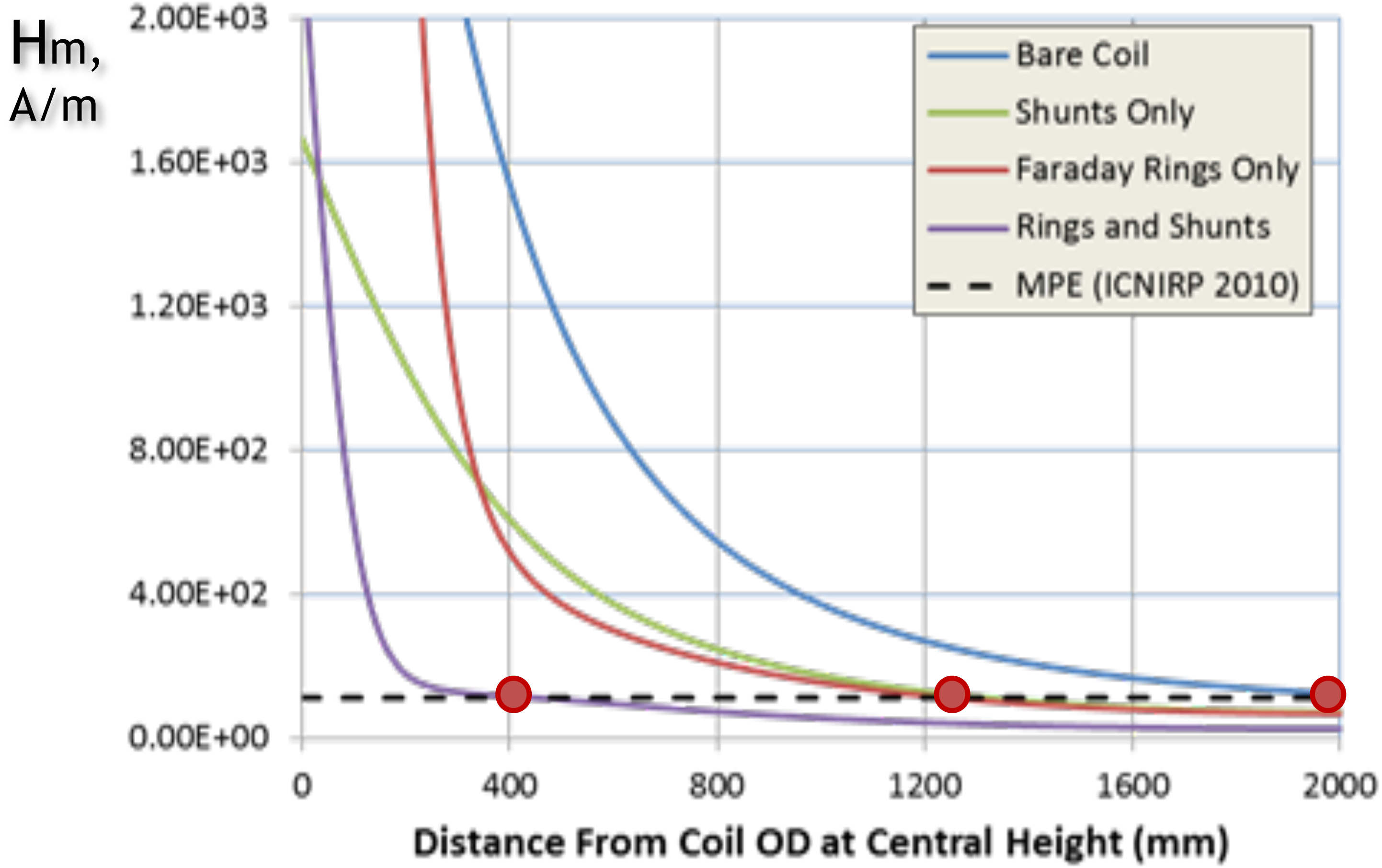
Inductor with Magnetic Shunts



Inductor with Faraday Rings and Shunts

F = 3000 Hz; Load – molten steel

External Magnetic Field Strength



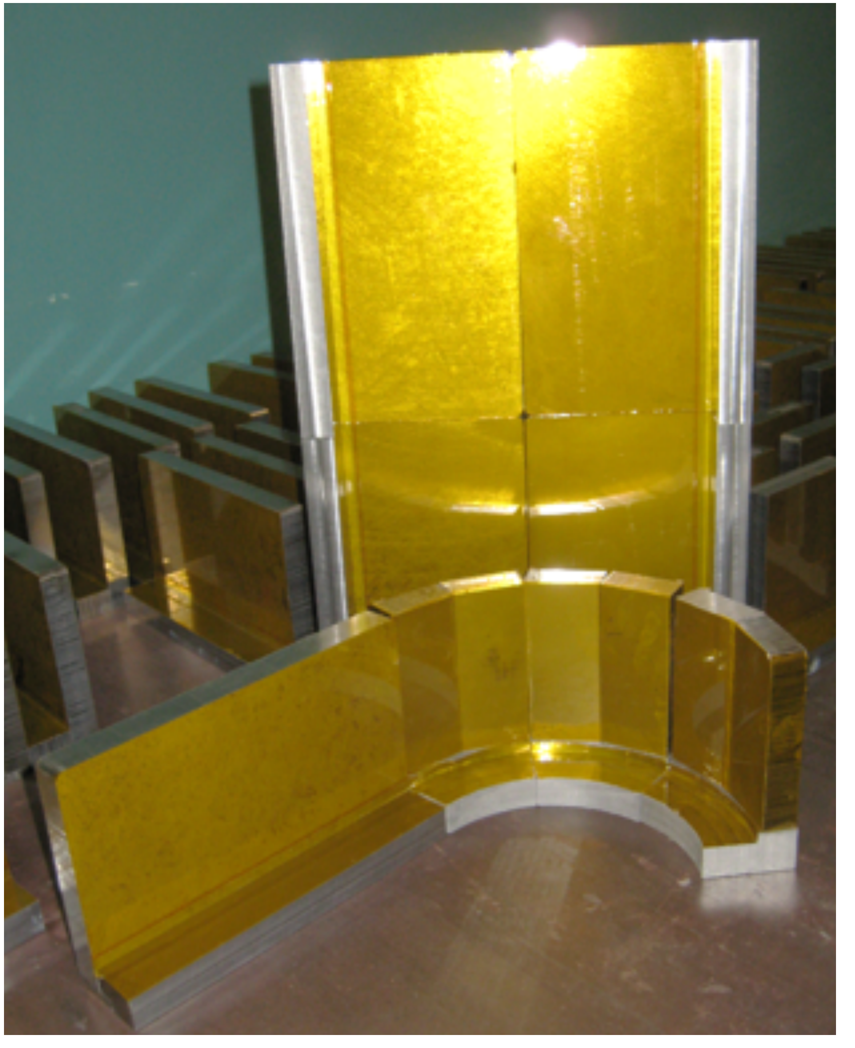
MPE level for 3 kHz is 113 A/m internationally (ICNIRP 2010) and 163 A/m in USA (IEEE C95.1)

Parameter Comparison

Condition	Pmelt kW	Prings kW	Pturns kW	Ptotal kW	U V	I A	kVAs	Eff. %	Field 500 mm from OD A/m
Bare Coil	200	N/A	33.9	234	825	5050	4170	85.4	720
Rings Only	200	18.5	46.5	265	827	6810	5630	75.5	340
Shunts Only	200	N/A	36.8	237	848	4630	3926	84.4	230
Shunts and Rings	200	1	40	240	852	4760	4055	83.3	72

MPL in Canada is 4.9 A/m for
Controlled environment

SMC Shunts for Vacuum Furnace

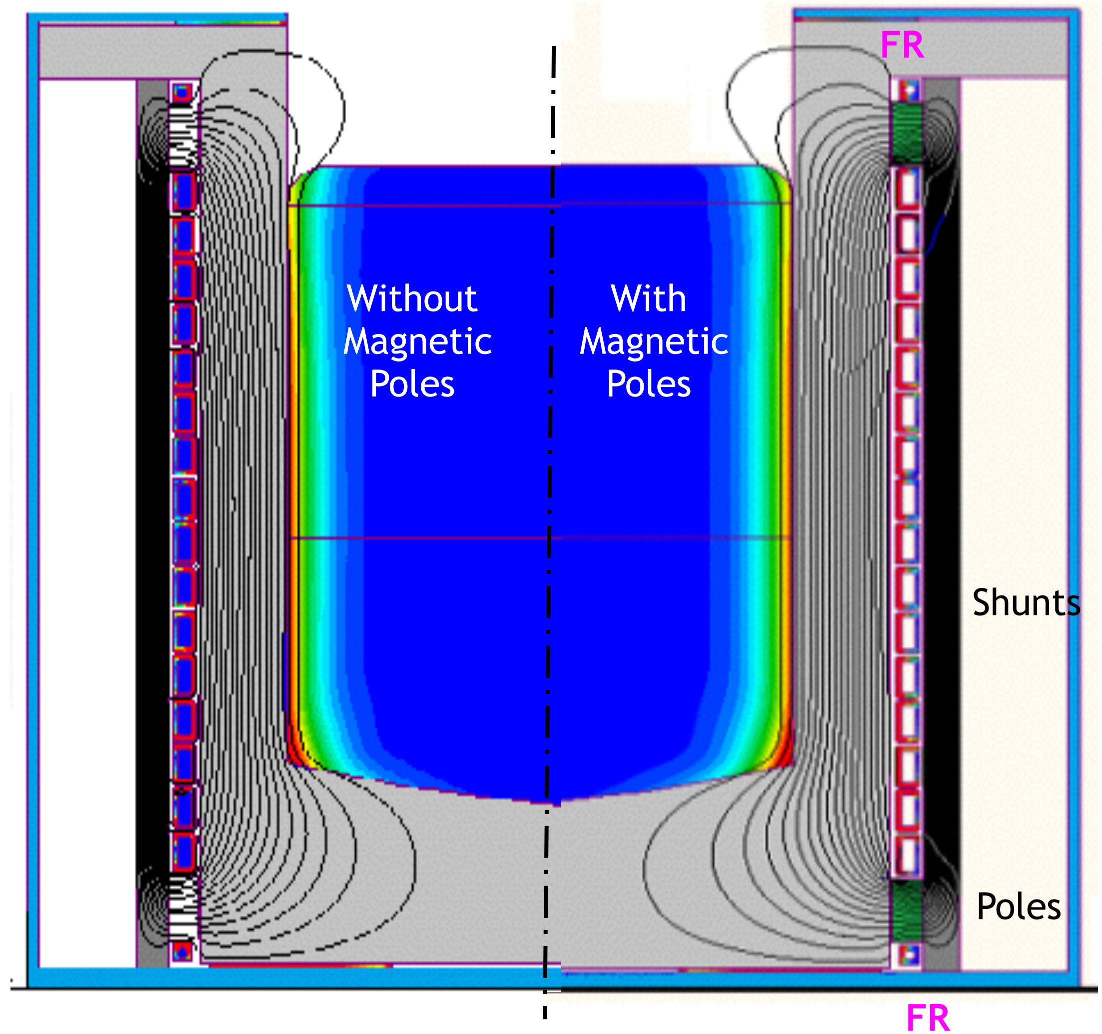


Material: Fluxtrol LF with Kapton tape on the surface

Simulation of Crucible Furnace

Case story:
- Crucible steel melting furnace with rated capacitance 10 tons
- Internal crucible dimensions 1220 x 1020 mm
- Winding has two sections with 8 turns each
- Coil ID 1500 mm, height 1115 mm
- Furnace has two Faraday rings and 16 shunts made of steel M250-35A, thickness #0.35 mm
- Frequency 280-300 Hz
- Voltage 2000 V

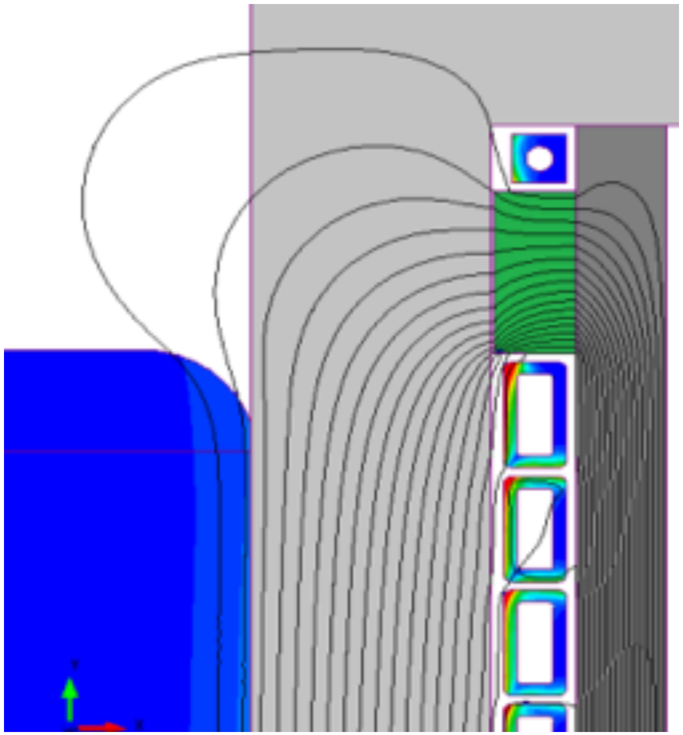
Innovations in simulation:
- Use of magnetic poles made of Fluxtrol LF
- Losses in magnetic materials are taken into account



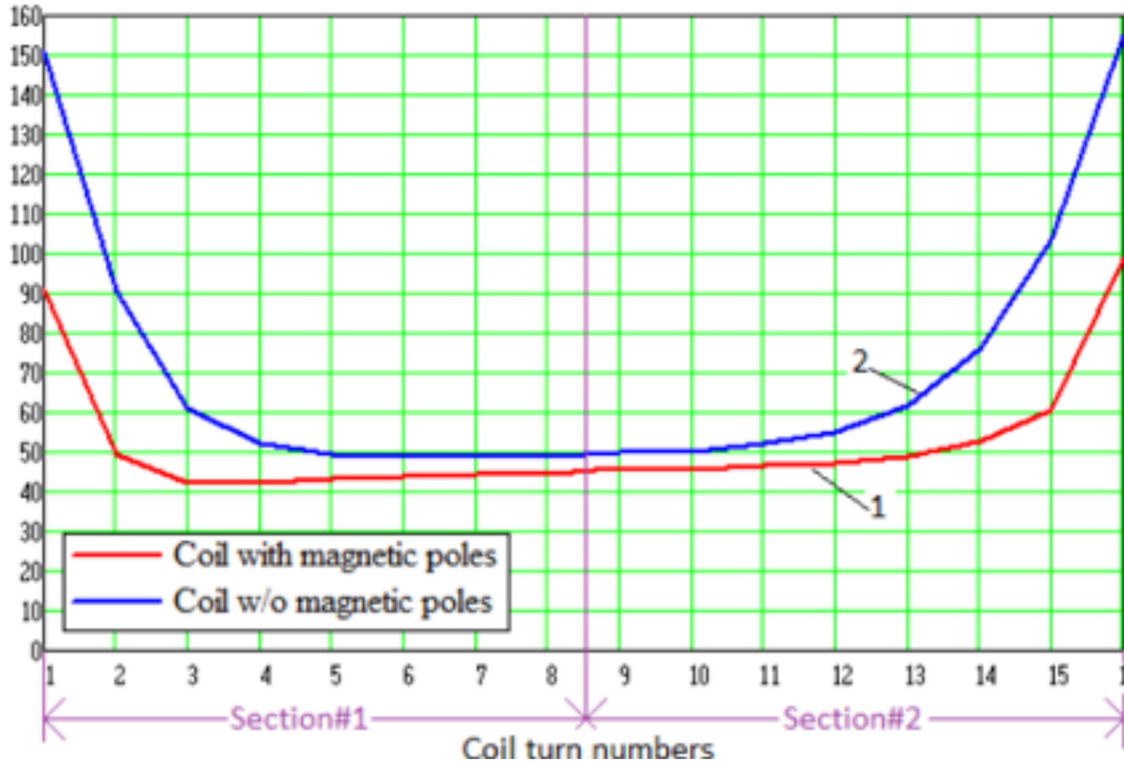
Magnetic field lines in crucible furnace

Study made by Elmag Corp.

Losses in Winding Sections



Magnetic field lines in end area



Losses in winding sections with and without poles for the same load power

Induction Furnace Parameters Change

Case	Load power kW	Frequency Hz	Furnace A	Coil Losses kW	Faraday Rings kW	Furnace Power kW	Efficiency, %	Furnace kVAR's
With MP	*4110*	*286*	*24040*	*850*	*6*	*5000*	*82.2*	*47800*
W/O MP	*4110*	*291*	*25320*	*1155*	*36*	*5366*	*76.6*	*50350*
Difference	*0*	*-*	*-1280*	*-305*	*-30*	*-366*	*+5.6*	*-2,550*

Economical effect evaluation:
- Annual energy savings due to magnetic poles (3000 hrs/year) is 1,120 MWhr
- Annual savings on energy (price 0.1 $/kWhr) is appr. $112,000
- Reduction in cooling water demand
- Possible savings in capital investments:
    - $5,000 due to reduced capacitors battery (reactive power saving 2.55 MVAr)
    - $36,6 00 due to smaller inverters (rated power may be reduced by 366 kW)

Magnetic Flux Control in Induction CC Furnace for Titanium Power Production

Project was performed in collaboration of Iowa State University, Ames* with Fluxtrol, Inc.

*Presentation: **Advances in Ti Alloy Powder Production by Close-Coupled Gas Atomization**

A.J. Heidloff, J.R. Rieken, D. Byrd, I.E. Anderson
Materials Science and Engineering, Iowa State University, Ames, IA

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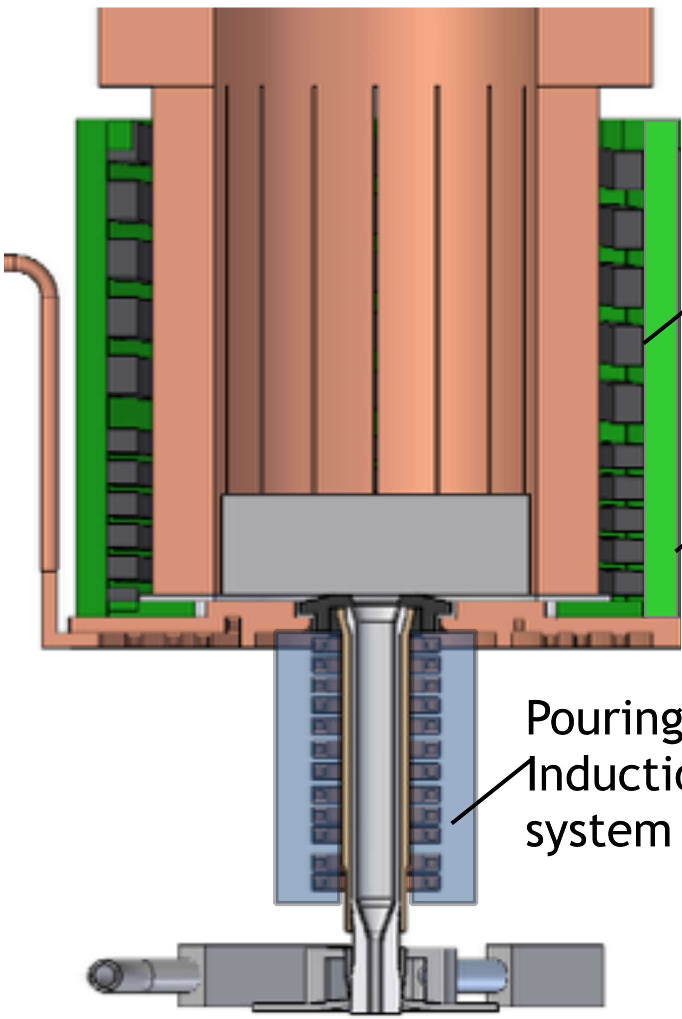
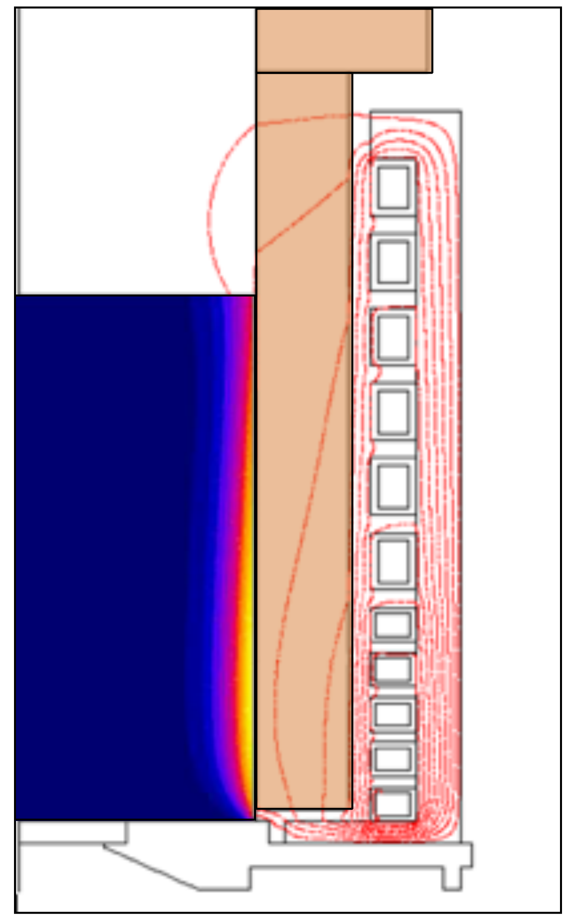
Induction System for Melting and Bottom Pouring of Ti Alloys



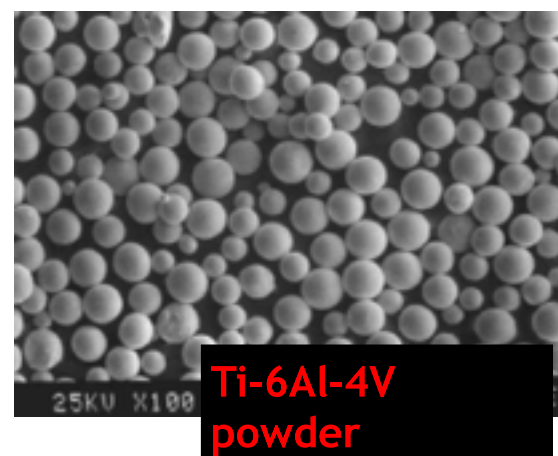


Power density map and magnetic lines for new coil

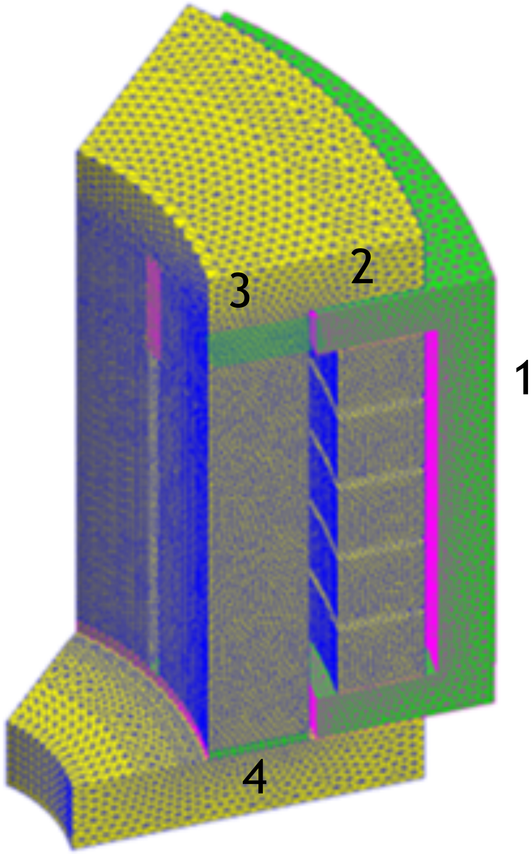
Results of Magnetic Shunts Installation

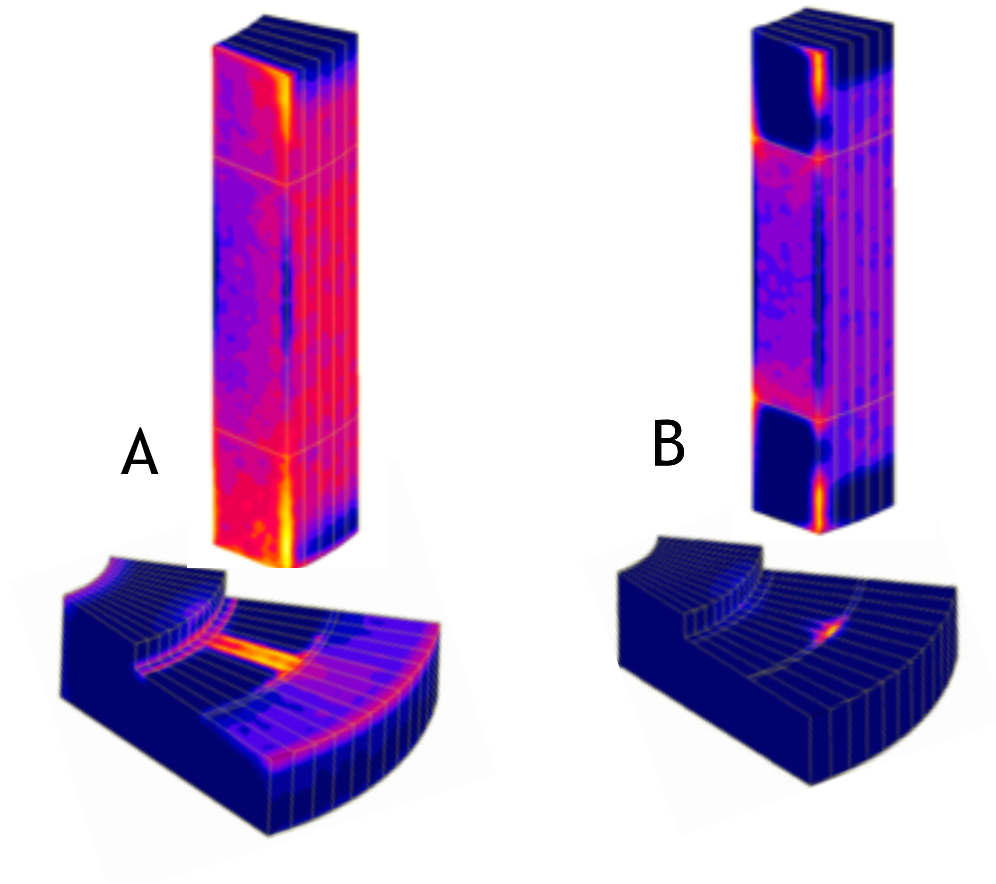
Design	Pmelt kW	Pcoil kW	Pleads kW	P cruc	Ptotal kW	Eff-cy %	I kA
Origin	*50*	*33.8*	*10.5*	*66.8*	*161*	*31*	*2.18*
New	50	16.5	6.0	33.5	106	47	1.50

New induction coil with different turn density and magnetic shunts with poles increased system efficiency from 31 to 47%, allowed to pour more material from the crucible, improved matching of the furnace to generator and reduced water consumption per kg of powder by 25 %



3D Study of CCF with Magnetic Controllers



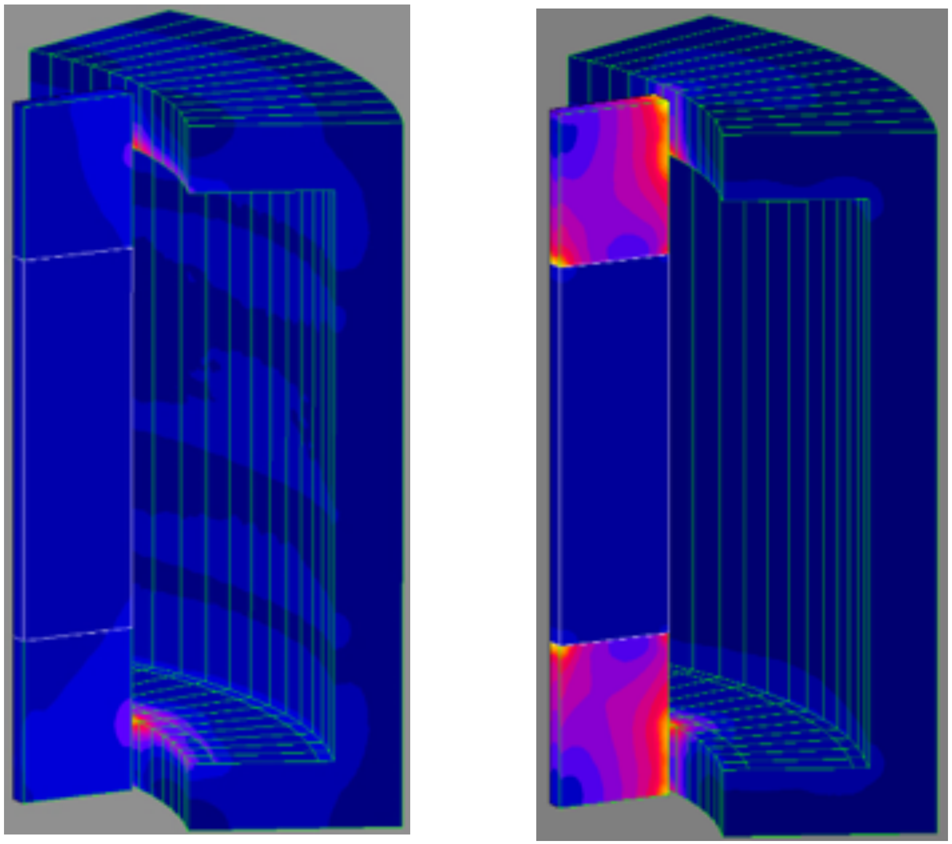


“Wedge” with meshed surfaces:
1 – shunts; 2 – poles; 3 – inserts;
4 – magnetic ring

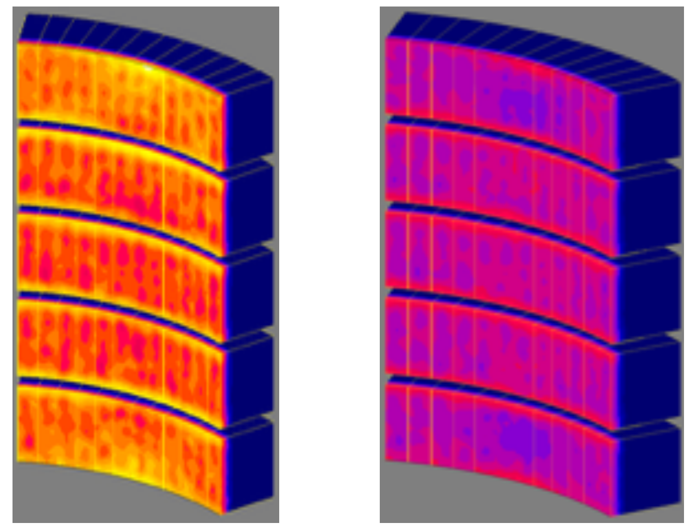
Current density maps on CC fingers and on Faraday ring surfaces:
A – no inserts and magnetic ring;
B – with top and bottom inserts

Effect of Magnetic Inserts in CC Slits

Conditions: same power in the load

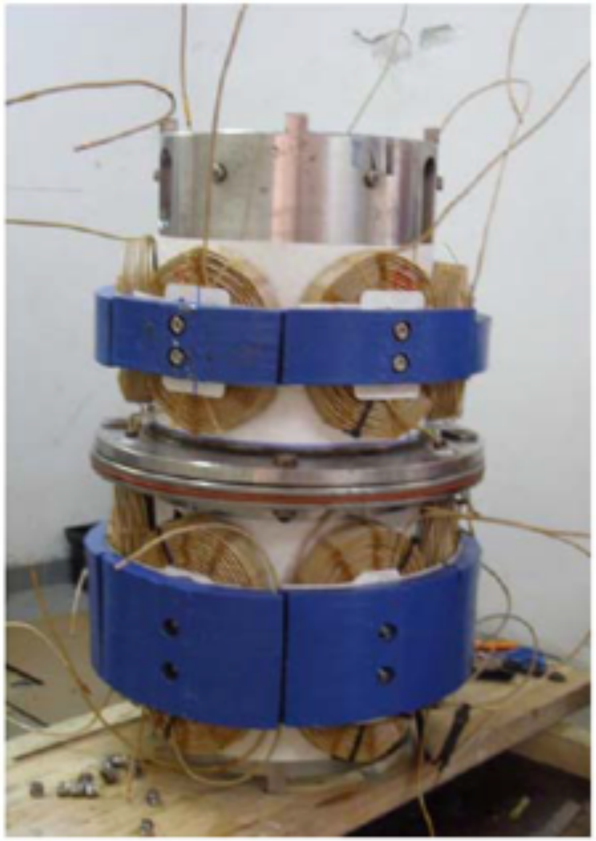


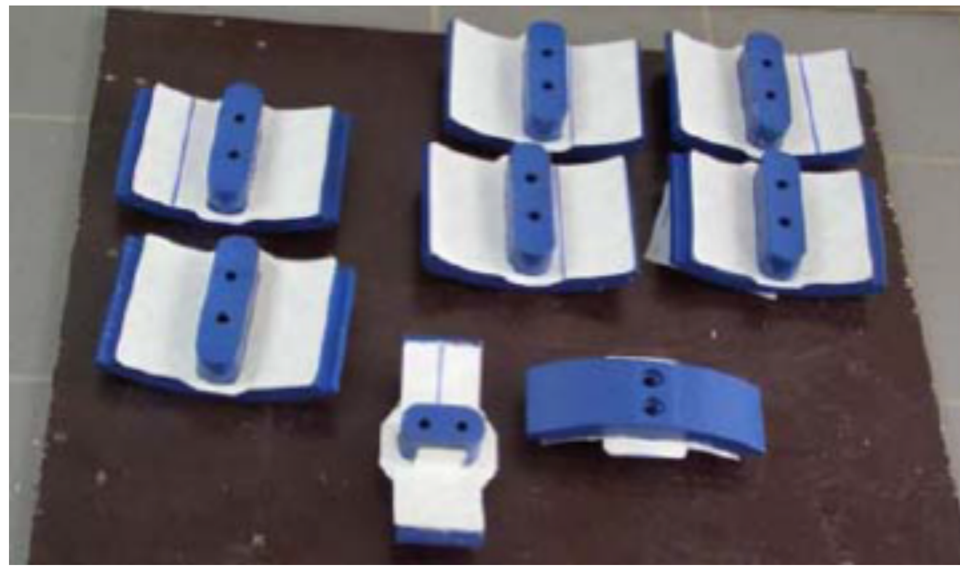
Magnetic flux density of on the surface of crucible fingers and magnetic controllers



Current density on the coil turns' surface without (left) and with magnetic inserts

Example of Electromagnetic Stirrer





EM stirrer for steel continuous casting. Frequency 7-50 Hz (harmonics). Both laminations or MDM may be used in this application

Courtesy Net Shape Cast, Inc.

Conclusions

- Magnetic flux control in systems for induction heating and EM processing of materials is used for a very long time but is still under evaluated
- New materials and computer simulation allow us to optimize magnetic circuits and meet strict demands of industry
- Both Laminations and Soft Magnetic Composites may be used at lower frequencies (up to 20 kHz)
- For higher frequencies SMC may be effectively used with some competition from ferrites

THANK YOU!

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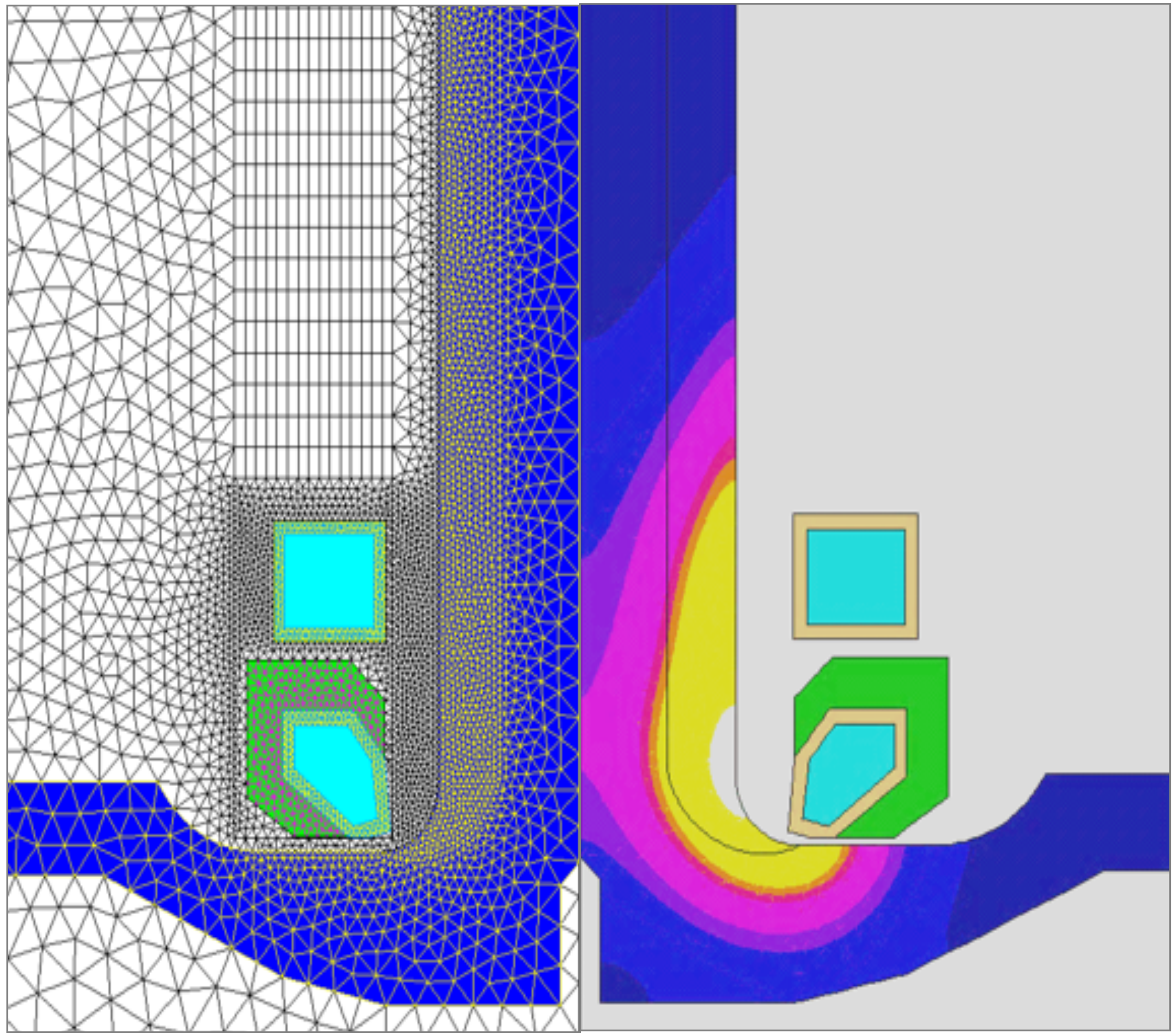

Optimized scanning coil with SMC concentrator