# Embedded conductors in solidified molten metal for winding packs for high-field stellarators

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## Abstract

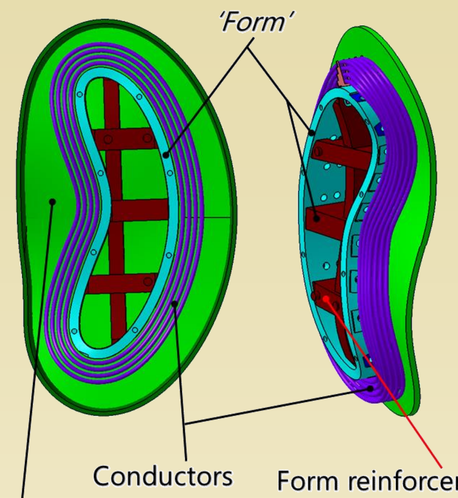
- The concept of ***metal-embedded conductors*** located inside a solidified metallic matrix (previously in a molten state) is studied and tested, intended for winding packs for high-field stellarators.
- Conductors have an external metallic jacked and insulation internal to it. Superconductors might be possible.
- The winding packs and the electrical insulation of conductors in high-field stellarators require particularly high strength, and still keeping the dimensional accuracy and long-term positioning of the conductors in contorted coils. The current study advances a new potential option for the needs.
- **Content:**

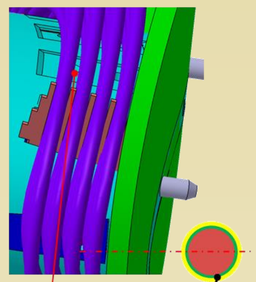
i) Description of the concept.
ii) Tests and simulation performed.
iii) Results.

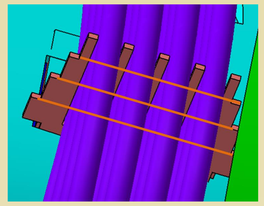
## Problem. Previous concepts

- Stellarator coils are contorted and require high accuracy (min. 0.1%). Enough long-term positioning accuracy of the conductors in a winding pack under high fields only appears feasible if each conductor turn is positioned by metallic structures.
- *Radial plates* accurately keep the (long-term) position of the conductors under high fields and protect the insulation from high stresses. But, the fabrication of contorted stellarator radial plates [1] (grooves require accuracy ~0.01%) is expected even more difficult than for ITER.
- *Stacked conductors* with strong metallic jacket and internal insulation was proposed for the FFHR heliotron reactor design [2]. For modular stellarators, achieving perfect contact and robust welding among contiguous conductors appears difficult.
- If many turns per winding pack are intended (decreases certain stresses), the grooves in radial plates require even higher accuracy.

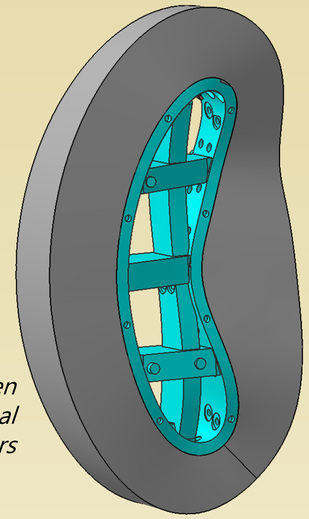
## Concept of metal-embedded conductors



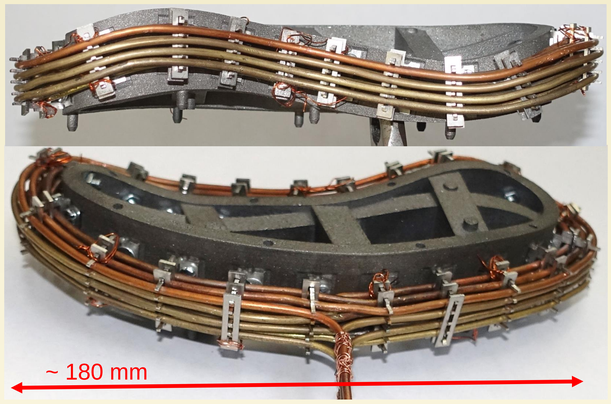
*Concept of the positioning element for the conductors, called 'Positioning Comb'*



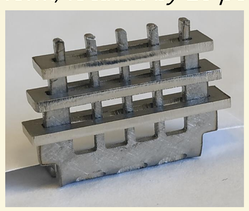
*In grey, solidified molten metal with internal embedded conductors*

## Materials, manufacturing methods and fabrication of the trial coil

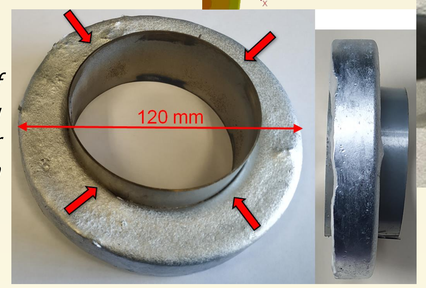
- The next is a particular implementation of the concept. Others are possible.
- **Form**: Additively manufactured, maraging steel, keeps 70% of the yield strength ($S_y$ > 1000 MPa) at 500 ºC, to keep shape during casting.
- **Matrix** material: Zamak 2 Zinc alloy (Zn + Al & others), good castability, low melting point (~385 ºC), intermediate Su ~360 MPa, Sy = 280±10 MPa.
- **Positioning combs** fabricated in SS 304 by laser cutting. Bolted to the form.
- **Conductor**: Only the jacked installed. It is a hollow brass pipe (some of copper) of ø2 mm. No internal insulation and copper cable in this test.



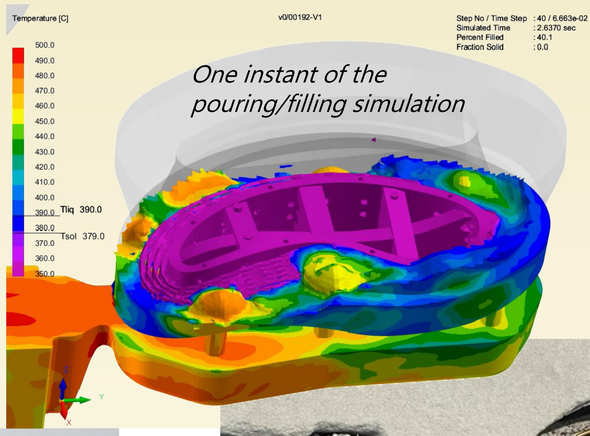

*Turns of hollow brass pipe wound on the form, located by 20 positioning combs*



*Picture of a positioning comb*




*Initial test of Zamak casting around a circular steel form*




*One instant of the pouring/filling simulation*

- Simulation made by QuikCAST code in Azterlan.
- Material, Zamak 2. Casting at 500 ºC.
- Chemically bonded sand mould.
- Low turbulence and good filling is observed.
- Resulted insignificant shrinkage porosity/voids.
- Uniform solidification.
- Preheating of the form and conductors recommended (↓outgassing & ther. stresses)

*Sand mould compacted with organic binder, form, conductors, casting filter and sand inside the form core ; prepared for casting in URKOASE S.L.*

## Summary and conclusions

- The concept of metal-embedded conductors has been studied and tested. Intended for winding packs for high-field stellarators.
- The concept implies casting a strong low-melting point metal in-between conductors, which are properly wound on a strong supporting structure.
- The conductors are composed of external jacket, insulation and conductor.
- A casting simulation indicates satisfactory casting (low porosity/voids, good flow).
- A trial coil has been produced. It consists of an AM maraging steel form, brass conductors and positioning elements.
- Zamak casting will be produced soon, and analysis (porosity, internal defects, accuracy) will be performed subsequently.

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**References**

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