Electromagnetic processing from AC to DC field and multiphysics modeling: a way for process innovation

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Introduction: Comsol Multiphysics is a useful modeling tool for the development of innovative EM processes from AC to DC field . Three examples are considered : *(1) Cold crucible*, *(2) EM pump*, *(3) DC magnet*. Application fields are respectively aeronautic, nuclear and automotive.

Computational Methods: MHD applications involve modeling Maxwell's and fluid flow equations with free surface motion.

Coupling example – EM pump case :

1-Electromagnetic : time harmonic

$$(j\omega\sigma-\omega^2\varepsilon_0\varepsilon_r)A+\nabla\times(\mu_0^{-1}\mu_r^{-1}\nabla\times A)-\sigma u\times(\nabla\times A)=Je$$

Lorentz term

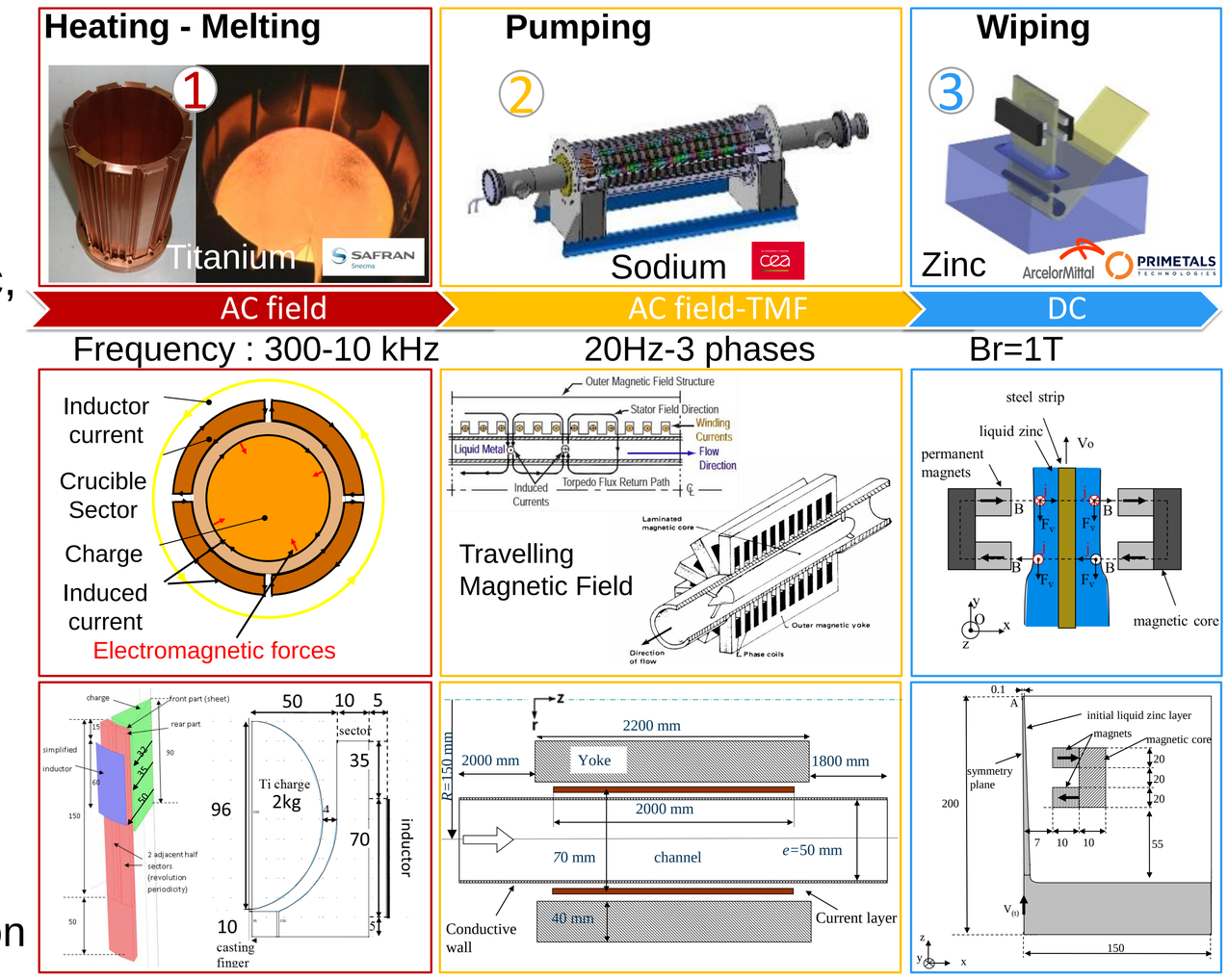
2-Fluid mechanics : transient

$$\rho\frac{\partial\vec{u}}{\partial t}+\rho(\vec{u}.\vec{\nabla})\vec{u}=-\vec{\nabla}p+\vec{F}_{em}+\nabla.\left[\mu_e(\nabla\vec{u}+(\nabla\vec{u})^T)\right]$$

Coupling terms

EM time average forces

3-Free surface : ALE formulation + surface tension integration



Results: **1-**Cold crucible with improved energetic efficiency was defined and designed. A better levitation gives the opportunity to increase overheating of the melt : key parameter for investment casting.

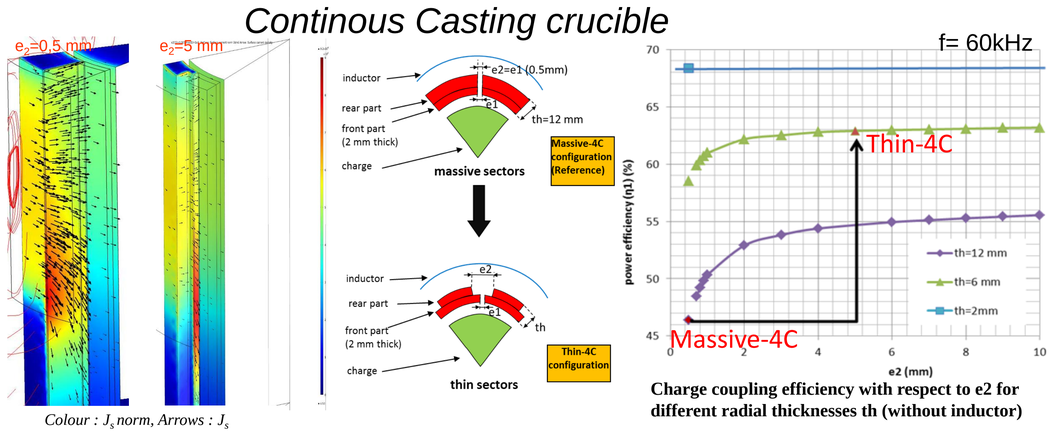
2-Magnetohydrodynamics (MHD) effects resulting from a strong coupling between fluid flow and EM is evaluated in a large annular linear pump for nuclear applications with high flow rate of sodium (up to 4 m^3/s). Significant ends effects are observed for large velocities with entrainment of magnetic field. Hartman effect leads to an expulsion of the electric current and the corresponding forces near the wall.

3-Control of zinc coating thickness for hot-dip coating with DC magnetic field thanks to EM braking effect was demonstrate and seems very promising to increase strip velocity of the galvanizing lines.

AC- cold crucible

1

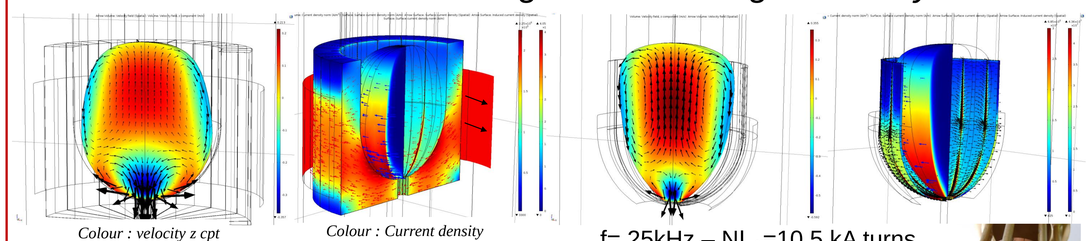
Continous Casting crucible



Colour : J_s norm, Arrows : J_s

Charge coupling efficiency with respect to e2 for different radial thicknesses th (without inductor)

Levitation Melting crucible – 2kg of Ti alloy



Colour : velocity z cpt
Arrows : velocity field

Colour : Current density norm, Arrows : Ji,J_s

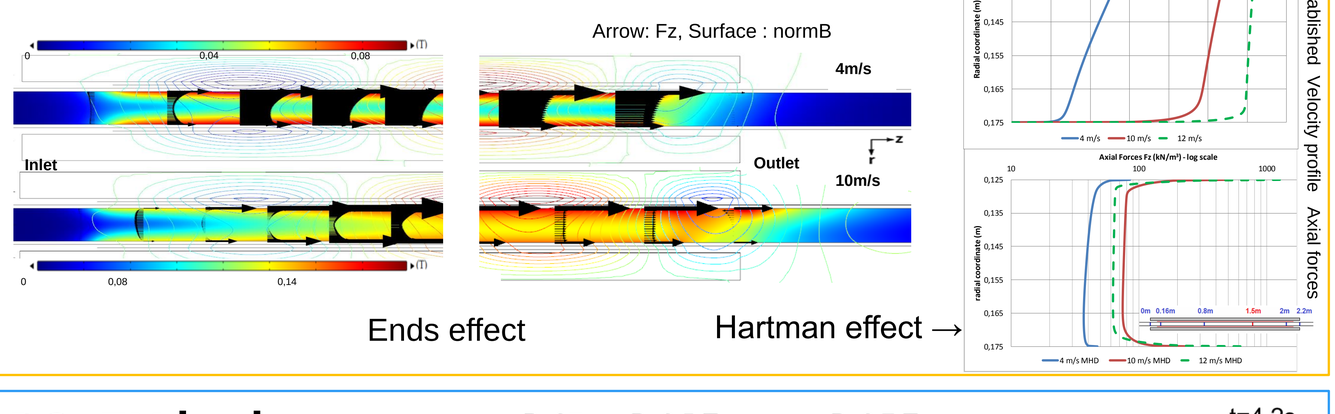
f= 25kHz – NI_{eff}=10,5 kA turns

(a) Efficiency η=26% -**Total power =152 kW** (b) Efficiency η=36%- **Total power =86 kW**

Numerically calculated quasi-steady state shape of a liquid titanium charge for (a) massive and (b) thin-LM crucible (same inductor current)

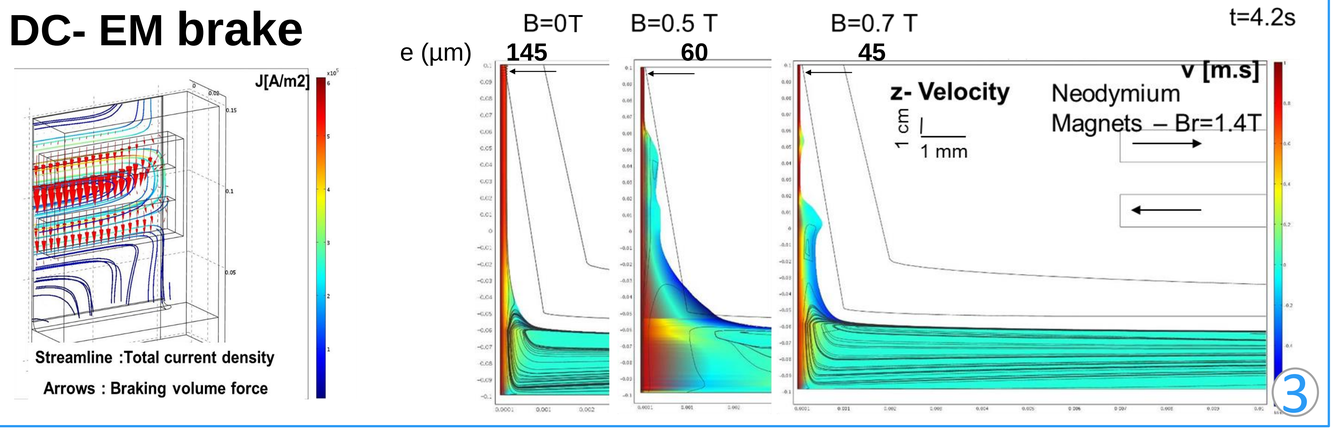
AC-TMF- Annular linear pump

2



DC- EM brake

3



Conclusions: Better understandings of each configuration thanks to a multiphysics modeling approach allows us to optimize design for industrial needs and to figure out more complex EM system.

References:

1. Dumont, R.Ernst, C.Garnier, H.Gathfan, P.Petitpas (2012), Journal of Iron and Steel Research Int.,19 p.669-672.
2. C. Roman, M. Dumont, S. Letout, C. Courtessole, S. Vitry, F. Rey, Y. Fautrelle, HES 2013, Padova, Italy
3. M. Dumont, R. Ernst, Y. Fautrelle, B. Grenier, J.J. Hardy, M. Anderhuber (2011), Compel,Vol.30, 5.

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