Inductor design in electromagnetic casting

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Electromagnetic Casting (EMC) and Magnetic Suspension Melt Processing (MSMP) are important technologies in the metallurgical industry. They are based on the repulsive forces that an alternating electromagnetic field produces on the surface of diamagnetic liquid metals. They make use of the electromagnetic field for contactless heating, shaping and control of solidification of hot melts. The EMC has primarily been employed for containerless continuous casting but is mainly used to prepare ingots of aluminum alloy [1]. Another important application, extensively used in aeronautics, astronautics, energy and chemical engineering, is in the manufacturing of components of engines made of superalloy materials (Ni,Ti,...) [2]. Advantages of these techniques are to produce components with high surface quality, high cleanness and low contamination.

The EMC problem studied here concerns the case of a vertical column of liquid metal falling down into an electromagnetic field created by vertical inductors. Given the position and shape of the inductors, the magnetic field created by them produces a surface pressure on the vertical column of liquid metal. That surface pressure forces the liquid metal to change its shape until an equilibrium relation on the boundary between the electromagnetic pressures and surface tensions is satisfied. The boundary shape of the liquid metal such that the equilibrium is attained can be found as the solution of a nonlinear free-surface problem, see [3] for details. Our purpose is to design suitable inductors such that the equilibrium shape of the liquid metal be as close as possible to a given target shape.

In a previous work we studied this EMC problem considering the case where the inductors are made of single solid-core wires with a negligible area of the cross-section [4]. Thus, the inductors were represented by points in the horizontal plane. In this paper we consider the more realistic case where each inductor is a set of bundled insulated strands. In this case we represent the inductors by a set of domains in the plane. The electric current density is assumed uniform on the entire cross-section of the inductor. This is a very reasonable approximation for the case where the inductors are made up of multiple individually insulated strands twisted or woven together.

Our goal is to determine the position and shape of the domains in order to have an horizontal cross-section of the molten metal as close as possible to the prescribed shape. For this purpose we consider an approach based on the proposed in [4]. It minimizes a distance between the computed shape and the given target one.

In addition, here we introduce a new technique to consider geometric constrains that prevent the inductors to penetrate the liquid metal. These constraints are more suitable that the box constraints considered in [4] making the considered formulations more effective and robust for the solution of the EMC problem.

The optimization problem is solved employing the *Feasible Arc Interior Point Algorithm*, FAIPA, an interior-point algorithm for nonlinear optimization [5].

We consider several examples to illustrate the behavior of the proposed formulation of the inverse problem. For each example we give the target shape of the liquid metal and the initial shape of the inductors, and report the position and shape of the inductors obtained by the optimization algorithm as well as the evolution of the objective function. The presented examples show that the formulation considered is effective to design suitable inductors.

References

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