Summary in English of "Optimization of metal melting inductor design using electromagnetic levitation."

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1 Object of work

In order to melt a specific group of metals, such as those with high melting points, metals that are difficult to melt, or those that require high purity, specific methods must be used. One of them is Electromagnetic Levitation Melting, a technique that allows to melt electrically conductive materials without contact with the crucible. This method is based on the induction of eddy currents in a metal sample by an alternating electromagnetic field. These eddy currents inductively heat the sample while generating electromagnetic forces. When the field is generated by an appropriately shaped inductor, these forces can reach sufficient magnitude to levitate the sample. The advantages of such a process are:

- The sample does not experience significant temperature differences.
- The sample is thoroughly stirred electromagnetically in the liquid state.

The disadvantage is the upper limit on the size of the melted sample set by the ratio of surface tension to density. Therefore, electromagnetic levitation melting is an excellent method for melting small samples of materials with: high melting temperature, reactive and requiring high purity. Due to the relatively low efficiency of the process, it is expedient to work towards increasing it. To increase the efficiency of the process, there is a need to study the effects of parameters related to the inductor, charge and current source on the buoyancy force and active power generated in the charge.

2 Objective and thesis

The purpose of this work is to develop an optimization methodology, select a suitable optimization method and verify it for the selected model of an inductor for Electromagnetic Levitation Melting (ETL) of metals.

Based on this, the thesis of the paper is formulated: there is an optimization methodology that, for the selected optimization method, yields an optimal or suboptimal solution. In addition, there is a method for validating the simulation model that can confirm its reliability.

3 Scope of work

In the course of the project, the following tasks were completed:

- Developed a computational model of the electromagnetic field for ETL,
- Carried out preliminary calculations of the inductor for the ETL,
- Developed a computational model of the electromagnetic field coupled to the temperature field for ETL, based on the inductor available to researchers,
- Validated the correctness of the calculations for the EM-T model based on the comparison of the calculated quantities with measurements in the experiment, using an aluminum charge,
- Optimized the geometry of the verified model,
- Purchased an inductor with the geometry resulting from the optimization process and compared their properties with each other,
- Verified how the optimized inductor performed for the titanium charge,
- Prepared a computational model of the electromagnetic field coupled to the temperature field and fluid dynamics for a scenario in which maintaining the charge in a liquid state was of interest,
- Conducted an experimental investigation of the charge deformation after melting and compared it to the simulation results,
- Optimized the shape of the inductor in terms of process efficiency for the scenario in which maintaining the charge in a molten state was of interest.

4 Dissertation layout

Section "Theoretical introduction" presents the basic issues related to Electromagnetic Levitation Melting (ETL). These include electromagnetic field analysis, thermal model, upward force and fluid dynamics considerations. The second aspect is the practical applications of the considered metal melting technique, which include both production and research areas. In addition, a review of optimization methods has been made, the most appropriate of which are used in later chapters.

Chapter "Simulation models" presents computational models for the three approaches considered. For the EM model, the analysis is limited to the analysis of the three-dimensionally modeled electromagnetic field. For the EM-T model, the proposed model includes analysis of the electromagnetic field and the temperature field along with convective and radiative heat transfer. Convective heat transfer was modeled using fluid dynamics, and material properties were updated with changing temperature. On the other hand, an inductor model for electromagnetic levitation melting was proposed for the EM-T-FD model, which simulates the behavior of the charge after the melting temperature is reached. The initial geometry of the charge is a sphere, which is consistent with the assumptions made in previous chapters. The result of the model is a new charge geometry that reflects the shape of the charge observed during experiments.

In the chapter "EM-T research", the work is presented in four sections:

- The first section presents the experimental validation of the model. The experimental validation of the model was carried out using aluminum alloy, due to the ease of measurements. Measurements included electrical parameters, positions of the melted charge during levitation, melting time and temperature distribution in its area. Verification showed satisfactory agreement between the computational model and the simulated position of the charge. The study confirmed the good representativeness of the developed numerical model, making it a useful tool for future optimization of the levitation melting system.

- The second section deals with the optimization of an inductor for levitating metal melting. This work uses a model prepared for an existing inductor. The first stage of the work is the exploration of the solution space and the selection of an appropriate optimization algorithm. The optimization is based on the simulation model and the estimated objective function, which is updated based on the results obtained in subsequent iterations. The result of the optimization is to obtain a suboptimal geometry of the inductor.

- On the other hand, the third section of this chapter experimentally investigated the effect of changing the geometric parameters of the inductors on the electrical parameters of the system, the charge melting time and the charge rising force. The measurements were carried out for two inductors for ETL, the first of which was the basis, and the second of which was the result of optimization aimed at finding the best geometric parameters for the presented class of inductors. The result of the study was confirmation of higher process efficiency for the optimized inductor and encouragement to use it.

- At the very end, an analysis of the feasibility of using the optimized inductor, formed on the basis of the earlier research, for melting titanium was carried out. A two-parameter analysis was carried out for different values of intensity and position of the charge. Based on this, a thermal analysis of the melting of the titanium charge was carried out.

In the section "EM-T-FD research", the results of the simulation of the charge geometry after the melting temperature is reached are presented. Then, based on this, the process of optimization of the inductor was carried out assuming the actual charge geometry, which changes during melting. The optimization parameters are the same as those presented for the EM-T calculation. The objective function includes the efficiency of the process. The problem is solved in two stages, first the solution space in which the optimum was expected to be found is sampled, then the optimization process was performed on this basis.