Computational Digital Twin for Induction Furnaces

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Motivation

The client produces high grade refractories for coil lining, working lining, topping and spout areas for induction furnaces often used in the melting process of all grades of steels and iron as well as non-ferrous alloys. A virtual model of the induction furnace integrated with AI can help assess the impact of the client's solution for their industrial customers and aid in data-driven decision making.

A digital twin of the induction furnace can uncover insights into the operations and identify optimal processing parameters for maximizing the number of heats in a melt. The tool can provide valuable assistance in implementing energy efficient operating practices based on the predictions of the refractory condition.

The customer can use the tool to simulate furnace operations with the help of process data and identify the areas of improvement in terms of charge composition, refractory lining life, overall productivity, energy consumption, cost per unit mass of steel produced and process safety.

Problem

In an induction furnace, metal charge is melted in a crucible lined with refractory material. As suboptimal furnace operating parameters and reduced lining life can lead to increased downtime, it becomes necessary to develop mathematical models that can simulate the furnace performance for identifying the optimal process parameters under given constraints.

A digital model of the furnace can be used to analyze how efficiency changes as different input parameters are changed and can help the operator identify if a patching of the refractory is required after the heat. Process operations can be planned in advance if total melting time can be predicted for a given furnace conditions and parameters can be selected in a way to maximize the total efficiency and the number of heats before lining degrades below the desired threshold.

Data is obtained from different customers of the client which also comprises the operational data of induction furnaces of different sizes. The tool needs to have functionalities that can handle a variety of operational and design parameters of the furnace for the respective customers, produce well interpretable process visualizations and predictive analytics and allow training of machine learning models using user-selected features.

Solution

The digital twin tool developed consists of modules for uploading the furnace operational data, performing data preprocessing steps such as data imputation, noise reduction, data visualization using different exploratory data analysis methods and building data-driven models using subsets of uploaded data for predicting furnace conditions using a user-selected ML pipeline.

Initial exploratory data analysis conducted revealed dependency of the input energy on the total heat time and efficiency which can only be modeled using non-linear models for efficiency and total heat time predictions. Inter-relationships between furnace parameters were studied to understand the conditions that affect the feasibility and control of the melting process.

Different ML models (Linear Regression, Deep learning, XGBoost, PORT, CDiNN) were explored to make heat-level predictions of various induction furnace parameters in a campaign. The heat-level models were then used for making predictions for an entire campaign given an initial condition. The lack of refractory lining thickness profile after every melt was treated as a missing data problem and an optimization framework was then developed to find the profile that minimizes the error in predictions.

An integrated solution was developed for the 2D and 3D visualization of induction furnace operation and refractory lining with the aim to aid the insights obtained using the descriptive and predictive algorithms.