Tools for Detecting Process Disruptions in Aluminium Production Based on Data Mining Techniques

Viktor Mann[1], Vitaly Pingin[2], Iliya Puzanov[3], Andrey Zavadyak[4], Yury Shtefanyuk[5] and Tatiana Penkova[6]
1. Chief Technical Officer, RUSAL Global Management B.V., Moscow, Russia
2. Director, Engineering and Technology Directorate
3. Project Manager, Development of High-Amperage Technologies
4. Deputy Director General, Aluminium Smelter Modernization
RUSAL Engineering and Technology Center, Krasnoyarsk, Russia
5. Branch Director, UNITED COMPANY RUSAL IP LTD, Moscow, Russia
6. Senior Research Associate, Institute of Computational Modelling of the Siberian Branch of the Russian Academy of Sciences, Krasnoyarsk, Russia
Corresponding author: penkovatg@gmail.com

Abstract

To detect any process disruptions at early stages and assess risks of productivity reduction in aluminum production, algorithm and software tools were developed to identify and forecast process disruptions using controlled variables based on mathematical statistics, data mining and machine learning methods. Ensemble algorithms were applied to daily average monitoring data to develop so-termed “Voting” and “Meta-classification” predictive models. Such models establish internal patterns in the data to determine the conditions promoting the technological process disruptions, such as anode spikes. Daily average monitoring data were used in the association rule mining to develop a model that generates the rules to assess the process status and disruption probability by analyzing preceding events and revealing cause-and-effect relations in the data. Taking into account the mutual influence of process parameters and specifics of aluminum production technology, an algorithm for identification of the changes in “noise” and “anode current” parameters was elaborated to detect process deviations based on instantaneous monitoring data. The recorded values are used to determine the status of a process disruption. Based on the integration of artificial intelligence and decision-making technologies, a software implementation of methods and algorithms was performed; a pilot Web-enabled information analysis system for the online control of aluminum production process was developed. The system performs the following two main tasks: monitoring of technological parameters (*i.e.*, reduction process data) while displaying the parameter change patterns and warning of process failures while indicating a controlled unit status and generating reports on process conditions and problematic areas of the aluminum production facility. The developed software tools have been tried out in the pilot areas at the Sayanogorsk Aluminum Smelter (RA-300 and RA-550 technologies). The obtained results prove the adequacy of the models and algorithms for application; moreover, they show that further research is needed to achieve more accurate predictions.

Keywords: Aluminum production, Detection of process disruptions, Predictive models, Data mining, Machine learning.

1. Introduction

The achievement of high technical and economic performance in the aluminum industry is largely determined by the quality of technology management and the timely assessment of the technological condition of both the entire aluminum production complex and its individual units [1, 2]. Process disruptions occurring in the aluminum production cycle are a major constraint. One of the most serious process disruptions, leading to a significant reduction in current efficiency, is the deformation of the anode working surface, in the form of a so-called “anode spike” – a formation of a regular cylindrical or conical shape at the bottom surface of the anode block [3, 4]. Such disruption is only identified at the extreme severe stage when the formation develops into a protrusion entering the cathode metal, which is accompanied by a change in the operating conditions. The introduction of production management software and hardware packages makes it possible to accumulate significant amounts of monitoring data and use it for decision-making. The application of Data Mining and Machine Learning to monitor data allows for the identification of characteristic dependencies and the early identification and prediction of the occurrence of disruptions [5, 6].

A large number of papers on the improvement of the performance of reduction cells and the diagnosis of process disruptions in the aluminum production cycle confirms the relevance of this area of research. Existing solutions and results in the field of mathematical modelling of production processes [7, 8], analysis and evaluation of the impact of parameter values on production quality [9, 10], identification of causes of disruptions [11], create a theoretical basis for further research and form a number of hypotheses requiring confirmation.

This paper presents algorithmic and software tools for the detection of anode spikes based on monitored parameter values, using a combination of mathematical statistics, data mining and machine learning methods. The main text is organized as follows. Section 2 presents the problem statement and a description of the initial parameters for daily and instantaneous monitoring. Section 3 presents a description of the algorithmic means of detecting disruptions from average daily monitoring data and considers the building of predictive models based on ensemble algorithms and association rules. Section 4 describes the algorithmic means of detecting process deviations from instantaneous monitoring data, discusses algorithms for identifying changes in time series of parameters and finding problematic anodes. Section 5 shows the results of the software implementation of methods and algorithms in the information-analytical system of online control of aluminum reduction technology.

2. Research Objective and Inputs

The technological parameters of the daily average monitoring characterize the state of operation of the aluminum reduction cells, and the values of these parameters change significantly in the event of process disruptions and changes in the cell operation mode. Analysis of both monitoring data and registered process disruptions makes it possible to identify patterns and develop a classification algorithm: based on new values of the cell operation parameters, it will make the decision about the current process state: either “normal" or “with violation”.

The technological process parameters that are instantaneously sampled are described by a time series, which is a sequence of values obtained at certain points in time. When process disruptions occur (be either an anode spike, an alumina supply problem, an anode effect or others), the character of the time series changes. Indicators of descriptive statistics are used to describe the properties of a time series. Thus, the problem of detecting technology deviations from instantaneous monitoring data comes down to identifying changes in the behavior of the time series based on changes in the descriptive statistics, characterizing a shift in the mean level of the parameter values and an increase in the range of variation.

Development of software and algorithmic tools for detection of process disturbances is performed based on average daily values and instantaneous monitoring of the operation of a group of both RA-300 and RA-550 reduction cells at the Sayanogorsk Aluminum Smelter during 2019–2020. The scope of the daily average monitored parameters of the aluminum production complex consists of about 70 parameters, including, but not limited to: duration of metal tapping, metal level, electrolyte level, electrolyte temperature, alumina dose, bath chemistry parameters,

5. Conclusions

This paper presents the results of the development of algorithmic and software tools that allow detecting and predicting anode spikes based on the values of monitored process parameters, using a combination of mathematical statistics, data mining and machine learning methods.

Based on the application of ensemble algorithms to average daily monitoring data, voting and metaclassification predictive models have been developed which, by identifying internal patterns in the data, determine the object state corresponding to the occurrence of process disruption. Based on the application of association rules technology, a model has been developed that, by analyzing precedent events and identifying cause-effect relationships, generates rules that determine the state of the technology and the likelihood of an anode spike occurrence.

In order to detect process disturbances from instantaneous monitoring data, algorithms have been developed to identify changes in the time series of monitored parameters and to search for "problematic" anodes.

A software implementation of the models and algorithms has been carried out and a prototype of the information-analytical system for the online control of aluminum reduction technology has been developed. The system includes two tasks: monitoring of process parameters with visualization of the dynamics of changes in their values and warning of the occurrence of the process disruptions with the indication of the state of control objects, *e.g.*, potroom, reduction cell and the issuing of information messages. The developed tools have been tested at the pilot sites of the Sayanogorsk Aluminium Smelter (RA-300 and RA-550 technologies).

Further research is concerned with improving models to improve prediction accuracy, developing algorithms that allow the analysis of a set of parameters while taking into account their mutual influence, and expanding the types of disruptions.

6. References

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