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Harnessing Industry 4.0 to Optimize Performance in the Aluminum Industry

AIR PRODUCTS

Harnessing Industry 4.0 to Optimize Performance in the Aluminum Industry

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Abstract

The global economy and environmental legislation are driving change in the modern aluminum industry, compelling manufacturing sites to optimize their processes to drive down costs and reduce their carbon footprint. Manufacturing has advanced from steam power to electric power, to computing controls, and now to the fourth industrial revolution of digitization of industrial processes and increased connectivity, delivering unprecedented optimization capabilities. This Industrial Internet of Things (IIoT, also called Industry 4.0) is beginning to shape the way aluminum processors are designed and operated, introducing new ways of working, with increased data access for all levels of personnel, from maintenance to management.

Smart systems, incorporating sensors and wireless communication, together with internet-enabled data storage and processing technology (commonly referred to as the Cloud) are making more and more data available, which brings about new challenges in analyzing and managing large data sets. In-depth process knowledge is key to filtering through the data to identify key performance indicators and interpret trends and associations correctly, leading to the creation of computer models of the aluminum processing equipment (or digital twins). The growth of self-learning computer programs (i.e., machine learning and artificial intelligence), along with the increased computing power that the Cloud brings, has led to capabilities that can be used to streamline data analysis and improve the understanding of relationships between key parameters in aluminum manufacturing processes. This paper reviews aluminum industry practices and looks at the current state-of-the-art in Industry 4.0, focusing on key concepts and how they can be applied to the aluminum industry.

Introduction

Emerging technologies are moving aluminum foundries forward from computers and automation into the fourth industrial revolution (known as Industry 4.0 or IIoT).[1-2] Intelligent machines use sensors to gather information from the world around them and are connected to data acquisition systems.[3-4] Integration of virtual models with real-world data provides a novel approach for predicting and influencing control systems in the plant, providing significant economic, social, and environmental benefits (Figure 1).

Intelligent machines can be used to optimize the performance of aluminum operations by taking advantage of wireless sensors, high bandwidth Internet, and Cloud technology. These systems create a significant amount of data, posing new challenges in data management and analyses. Cloud computing provides significantly more processing power, compared with local on-site systems, along with other benefits, such as remote data access and control.[5] Even with the increased data and computing power available, it is still important to incorporate expert process knowledge and experience into the intelligent systems to identify key parameters and validate measurements in order to ensure meaningful results.

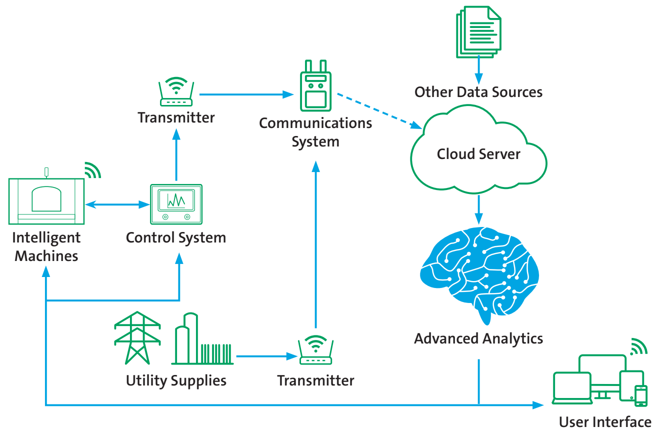

Figure 1. Simplified view of an Industry 4.0 plant.

Aluminum Industry 4.0 Drivers

The focus of the aluminum industry is to use Industry 4.0 to help achieve efficiency targets, while improving safety, productivity, and environmental performance—the triple bottom line.[6] Escalating environmental demands have increased sustainability regulations worldwide, compelling companies to take responsibility for reducing emissions and improving waste management.[7-8] IIoT provides a means for traceability of aluminum throughout the value chain, making it possible to certify manufacturers for sustainable performance.[9-10] Data transparency throughout the aluminum value chain is also important for quality assurance and compliance, ensuring that all stages of production are systematically monitored, tested, and communicated to achieve quality expectations while reducing costs and improving customer/supplier relations.[11]

The ability for intelligent machines to make autonomous decisions is leading to the decentralization of decisions in the plant, reducing human error, decreasing administrative tasks, and optimizing personnel.[10] Continuous monitoring of equipment allows for faster diagnosis during a breakdown, resulting in reduced downtime and enabling smart maintenance.[12] Advanced measurement techniques through the addition of sensors into manufacturing processes enhances continuous improvement programs to optimize energy usage and improve productivity.[13] Consequently, efficiencies and plant uptime are increased, leading to reduced carbon emissions and improved economics.[14-15]

Safety on the shop floor is paramount and a key driver for any sustainable operation. Intelligent machines provide another tool toward reducing accidents, where equipment and personnel can be monitored in real time and autonomous machines can reduce or eliminate the number of personnel present in dangerous areas.[16] This is changing the ratio of shop floor jobs to jobs that are computer related.[14,17] For example, autonomous vehicles eliminate the need for personnel to drive vehicles, allowing them to focus on other tasks.[18] Industry has struggled to bring in sufficient younger workers, resulting in less personnel with key experience available to run complex systems. However, intelligent equipment combined with machine learning and artificial intelligence, allow virtual systems to "gain experience" that can be used to predict performance for guiding and advising operating personnel.[1,17] Resulting processes are less reliant on operator experience and can reduce the time it takes to bring someone from a beginner to expert level in the aluminum plant.

IIoT Challenges

The IIoT revolution is interconnecting equipment everywhere, logging ever-increasing amounts of data. Traditional analytical methods are not capable of adequately interpreting complicated relationships between large volumes of many interconnecting parameters. Big data analytics uses advanced statistical techniques to discover patterns in large data sets in order to extract information to build a virtual understanding of relationships between different parameters. These virtual systems can predict future performance, based on statistical relationships and often include machine learning algorithms, which adapt their understanding as new data is incorporated into the model.[4,17,19] Notwithstanding these advanced analytical techniques, outputs from complex models still require scrutiny from process experts to ensure that the relationships reflect physical laws.

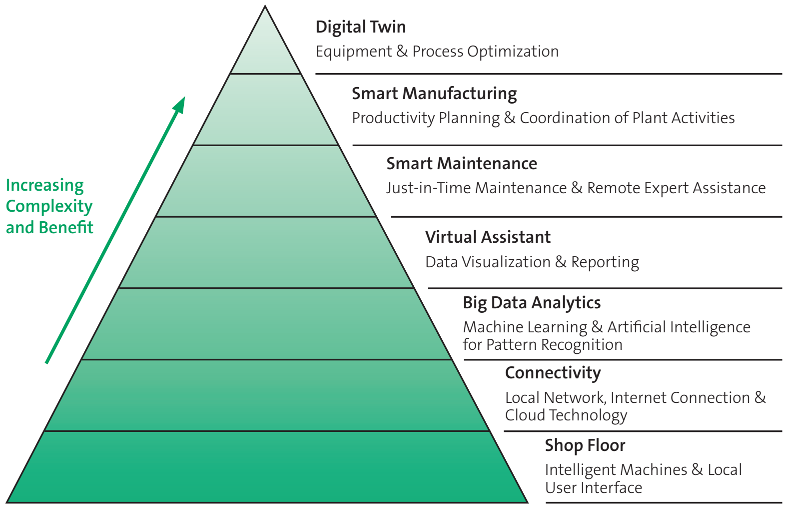

Figure 2. Different IIoT implementation levels.

Extensive connectivity between aluminum manufacturing equipment highlights the importance of data security, integrity, and accessibility. Various aspects of data security need to be considered, including protection from unauthorized users, preventing modification to the underlying data, and physical security of the infrastructure. Standard security protocols—such as encryption, good password management, firewalls, updated security, and anti-virus/malware systems—should be used to protect data from unauthorized users.[5] Similar methods need to be implemented to protect data from modification, especially during data transmission, where using technologies like virtual private networks (VPN), in addition to encryption, will help ensure data security.[20] Straightforward physical security means (like door locks) should not be overlooked when safeguarding information, where physically restricted access can help protect the infrastructure located on-site.

When considering data accessibility and latency (data transmission delay), requirements depend on the application. For safety critical and direct control applications, requiring real-time closed-loop feedback, essentially zero latency is required in order to protect human life and assets.[21] These applications should be installed locally and are typically part of an on-site PLC or similar system. Other applications that do not fit into these categories, have more flexibility for data accessibility and latency. For example, a system that provides feedback to management on the overall system performance can have latency between minutes, hours, or in some cases even days, where longer term trends are analyzed.[22] Additionally, if there is a loss in data accessibility for a short period of time (on the order of minutes or hours), no major disruptions to production would occur. For systems that provide feedback to operators on operational improvements (non-safety related), a latency of seconds or minutes may be permissible in cases where the process has a longer time constant than the data latency. These types of applications are amenable to Cloud-based applications since the processes can handle the delays in transmitting and receiving data to and from the Cloud.[23]

Aside from technical solutions, there will always be issues relating to the attitudes of people. Change is inevitable and yet people are often fearful or dismissive of new procedures. The real challenge is convincing them of the benefits, which can only really be done through trial or demonstration. Changing personnel behavior could be the cornerstone of making the IIoT transition successful.

Industry 4.0 Implementation

Aluminum foundries can implement various aspects of Industry 4.0 with increasing complexity and benefit. Some of the levels are shown in Figure 2 with complexity and benefit increasing as you move up the different levels.

Virtual Assistant: Personal or one-on-one services are ideal, but can be unachievable for some applications. Industry 4.0 can make this ideal a reality for aluminum foundries by bringing data visibility to all levels of personnel through remote data access. This is increasingly being done by providing services whereby key performance parameters are organized into user friendly interfaces that are accessible through online dashboards and apps.[22,24] Reporting is another common feature that allows data trends to be communicated with the end user, either by email or SMS. These data visualization services can be easily tailored to provide customized information to relevant personnel. For example, a production manager might be interested in productivity data, whereas maintenance personnel would be more concerned with equipment diagnostics and operation. A useful extension to reporting is the ability to program pre-set alarms to be sent to relevant people who can react and solve potential issues before they become larger problems.

Smart Maintenance: Continuous monitoring of equipment provides live and historical operational data to technicians and other maintenance personnel. Maintenance managers can therefore plan maintenance to reduce equipment downtime by evaluating equipment data to identify potential problems before they progress to catastrophic failures.[3] For example, temperature sensors might show that the temperature of a component is increasing, thereby indicating that a filter needs cleaning or replacing. Carrying out this task in a timely manner could prevent the need to replace the entire piece of equipment later, potentially saving significant costs and downtime.[12]

Smart maintenance utilizes equipment performance data to diagnose issues that arise before a technician goes to a site. This can significantly reduce stoppages by providing insight into possible solutions and identifying what tools or components are needed. User interface technology provides technicians with effective data access through advanced visualization techniques, where wearable technology, such as smart glasses and head-mounted displays, can replace traditional handheld devices, like laptops and tablets.[25-26] The emergence of augmented and virtual reality software can display information for on and off-site personnel in unprecedented ways, providing expert assistance anytime and anywhere.[27-28] IIoT technology improves communication, providing means for online maintenance collaboration, whereby off-site users can view live streaming video alongside real-time data and on-site users can combine computer models with real-life experience.[29]

The next step for smart maintenance is to use equipment and operational data to predict future performance, rather than simply for diagnosing and preventing problems. This is referred to as equipment condition monitoring (Figure 3). Machine learning predictive modeling techniques analyze the interdependence between key data parameters and how they affect performance.[30] Continuous equipment condition monitoring captures historical data throughout normal operating conditions, providing a baseline performance model that is representative of the typical operation. The model can decipher when certain interrelated parameters diverge from "the normal" and, therefore, identify when exceptions occur in order to provide equipment maintenance warnings.[31] These models can not only be applied across multiple pieces of equipment, but the learnings from individual equipment and even different sites can be used for improvements across multiple plants, improving overall company performance.[19]

Smart Manufacturing: Smart manufacturing is a "fully integrated, collaborative manufacturing system that responds in real time to meet changing demands and conditions in the factory."[32] This combines the previously discussed aspects of IIoT into one overall system to optimize operations around production, quality, and maintenance. By combining market conditions with real-time information from the shop floor, equipment throughout the manufacturing process can operate in a way to limit waiting and downtime and adjust to market needs for customized production.[22] Due to the connectivity of equipment to a central program, different manufacturing steps can be coordinated and operated remotely for maximum efficiency and safety.[33] Additionally, inputs and outputs from the manufacturing process can be tracked for quality assurance and accounting needs. Combining connected equipment with production plans and predictive maintenance allows maintenance to be planned in a way to minimize the impact on productivity.

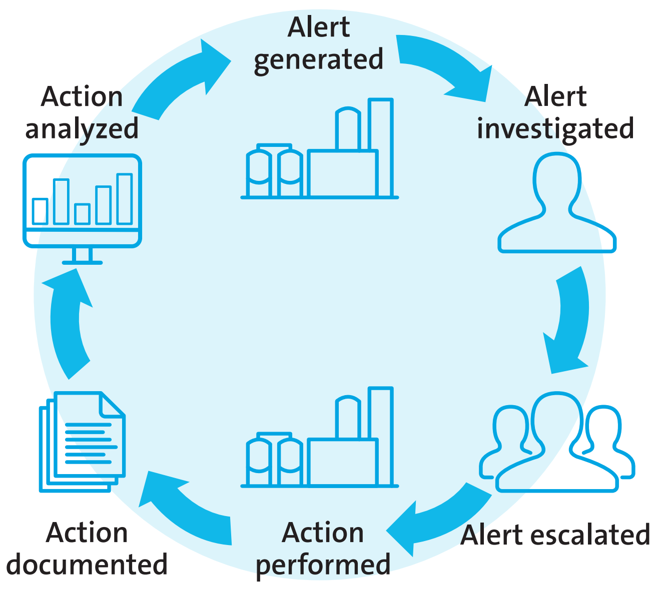

Figure 3. Equipment condition monitoring alert processes.

Digital Twin: Incorporating a range of IIoT methodologies, the digital twin concept can be considered the pinnacle of Industry 4.0. Essentially, a digital twin produces a virtual representation (or model) of the aluminum manufacturing process, which can be used to predict future performance and adapt operating practices to improve safety and sustainability. A digital twin is constructed based on historical data that is continuously updated in real time for the purposes of advanced optimization. In manufacturing, the digital twin often refers to data models for specific equipment or machinery for the purposes of improving efficiency, reducing downtime, and streamlining decision making.[15,34]

Aspects of digital twin technology have been put into practice in a number of applications, including the predictive maintenance methodology described previously.[19] Similarly, digital twin models can be used to optimize equipment operation, focusing on increasing output and reducing waste, which can be extended to monitor entire production lines to analyze wider aspects, such as operator performance and tracking products throughout the production process.[22]

The next phase for digital twin development is to achieve accurate modeling of physical processes, such as melting or heat treatment of metals. Digital twin models of processes incorporate physical principles and statistical data analysis for predicting performance. One example used in secondary aluminum processing calculates when enough energy has been used to melt the charge material and provide the operators with an alert once the aluminum has reached tapping temperature. Applying digital twin process models to aluminum melting can not only save time and energy, but also increase yield and reduce greenhouse gas emissions. The use of this digital twin for an aluminum rotary furnace has recently been implemented and the results will be featured in a future article in *Light Metal Age*.

Conclusion

Industries around the world are embracing the Industry 4.0 revolution. These methodologies can be applied throughout the aluminum value chain—from primary production to manufacturing components, through to recycling—supporting sustainability goals and increasing profitability. Data availability and visualization software can improve the understanding of the manufacturing process, steering production planning, improving plant efficiency, and reducing waste. Advanced maintenance techniques assist with planning and remote problem solving, increasing equipment running time. Smart manufacturing and digital twin modeling bring Industry 4.0 technology together to accurately replicate physical systems, providing insights into interrelating parameters for optimizing associated equipment, which can then predict performance and lead to increased productivity, yield and safety, while reducing carbon emissions.

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