Automation and Technological Evolution of Trace Element Analysis in the Iron and Steel Industry
~The Role and Prospects of the EMIA and EMGA Series~

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The analysis of trace elements such as carbon, sulfur, oxygen, nitrogen, and hydrogen in steel is an important process directly related to the control of mechanical properties and corrosion resistance. In the past, manual analysis by skilled operators was standard practice, but from the perspective of eliminating human variability, stabilizing measurement accuracy, and improving throughput, there is now a strong demand for operator-independent operation and automation of the analyzers themselves. HORIBA's EMIA series (carbon and sulfur analyzers) and EMGA series (oxygen, nitrogen, and hydrogen analyzers) have evolved in response to these industrial needs. This paper reviews the technological development of the EMIA and EMGA series and their progress toward automation, and discusses the role of analyzers in the steel industry and their future prospects.

Introduction

In the manufacturing industry, efforts to maintain stable product quality while simultaneously increasing productivity are becoming increasingly important, driven by intensifying competition in the global market and the need to address sustainability. In particular, the steel industry faces a pronounced need for traceability across the entire manufacturing process and real-time quality evaluation, due to the advancement of material properties and the adoption of international quality assurance standards[1].

Against this backdrop, the analysis of trace elements such as carbon, sulfur, oxygen, nitrogen, and hydrogen in steel is a critical process directly linked to the management of mechanical properties and corrosion resistance. These components significantly affect properties such as toughness and susceptibility to cracking, necessitating precise quantification at the ppm level. Traditionally, manual analyses performed by skilled operators were the norm, but there has been a strong demand for simplifying and automating the operation of analytical instruments to eliminate human variability, stabilize measurement accuracy, and improve throughput[2].

HORIBA's EMIA series (carbon and sulfur analyzers) and EMGA series (oxygen, nitrogen, and hydrogen analyzers) have evolved in response to these industrial needs[3]. In recent years, with the trend toward smart factories as part of Industry 4.0, analytical instruments are also required to offer network connectivity, remote operability, and automatic adaptation of measurement conditions[4],[5].

The Japanese Steel Industry and Demand for Analytical Instruments

Increasing Quality Requirements in the Steel Industry

Japan's steel industry has long supported the development of diverse sectors—including construction, automotive, machinery, shipbuilding, and energy—by supplying high-quality and highly reliable steel. Since the 1980s, the demand for functional properties such as lightweight construction, high strength, and improved corrosion resistance has increased, resulting in more complex material design and the need for advanced quality management throughout the manufacturing process[6].

Among these rising quality requirements, the quantitative management of trace elements—such as oxygen, nitrogen, and hydrogen in steel—has become particularly important. Even in minute quantities, these elements can significantly impact the mechanical properties of materials. For example, oxygen reduces ductility and toughness; nitrogen causes age hardening and degrades ductility; and hydrogen leads to delayed fracture[1]. Therefore, precise and highly reproducible analysis at the on the order of ppm is essential for improving product reliability and reducing defect rates (see Table 1).

Table 1 Effects of each element on steel materials

Element	Effect on Steel
carbon (C)	Affects mechanical properties
	Affects hardness
sulfur (S)	Corrosion resistance
	Deteriorates workability and weldability
oxygen (O)	Fatigue strength
	Reduces ductility and toughness
nitrogen (N)	Increases strength but reduces ductility and toughness
hydrogen (H)	Delayed fracture
	Reduces ductility

Furthermore, as international standardization of quality assurance progresses, compliance with overseas standards such as ASTM and ISO, in addition to JIS (Japanese Industrial Standards), is becoming indispensable. Analytical instruments are consequently required to deliver even greater precision, reliability, and reproducibility[1].

On-Site Needs for Trace Element Analysis

Historically, chemical composition analysis of steel depended on manual work by skilled operators. In particular, qualitative methods such as spark testing were susceptible to significant variability and errors due to differences in operator skill and procedures (see Figure 1). Such operator dependency and high workload posed major challenges to achieving stable quality assurance.

HORIBA's EMIA and EMGA series emerged to address these challenges. These instruments combine highly sensitive measurement technologies based on chemical reactions with automated operation systems, enabling a shift from human-dependent analysis to instrument-based, high-precision, and highly reproducible analysis. Figure 2 shows an example of oxygen, nitrogen, and hydrogen analysis using EMGA, demonstrating highly reproducible results.

Advances in quantitative analysis technology have enabled the steel industry to achieve both quality stabilization and mass production, and automation has long been strongly demanded not only for improved analytical precision but also for reduced labor and enhanced safety.

HORIBA's EMIA and EMGA series meet these needs with high sensitivity and reproducibility, providing standardized quantitative results rapidly. Various automation features—such as automatic crucible ejection and autosamplers—enable unmanned nighttime operation, positioning the EMIA and EMGA series as "automation-compatible quality evaluation platforms" highly regarded by the steel industry both domestically and internationally[2],[3].

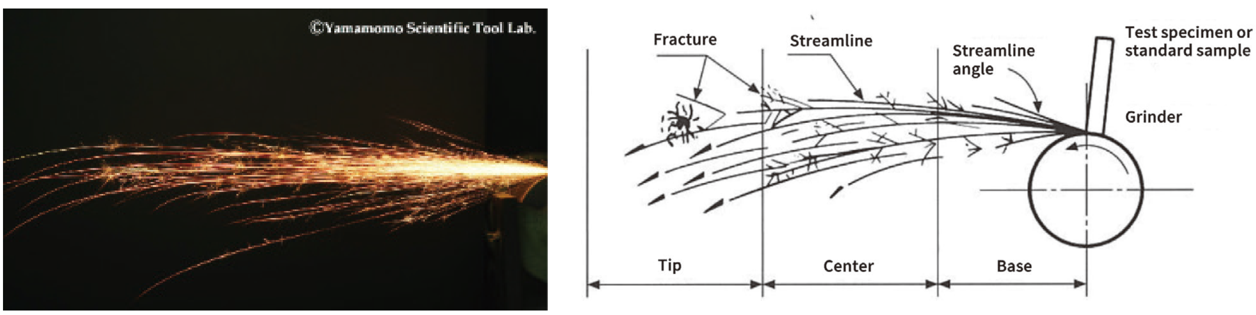

Figure 1 JIS G 0566(1980) Spark test method for steel.*

*Photo by Yamamoto Scientific Tool Laboratory Co., Ltd. https://www.ystl.jp/products/spark/index.html

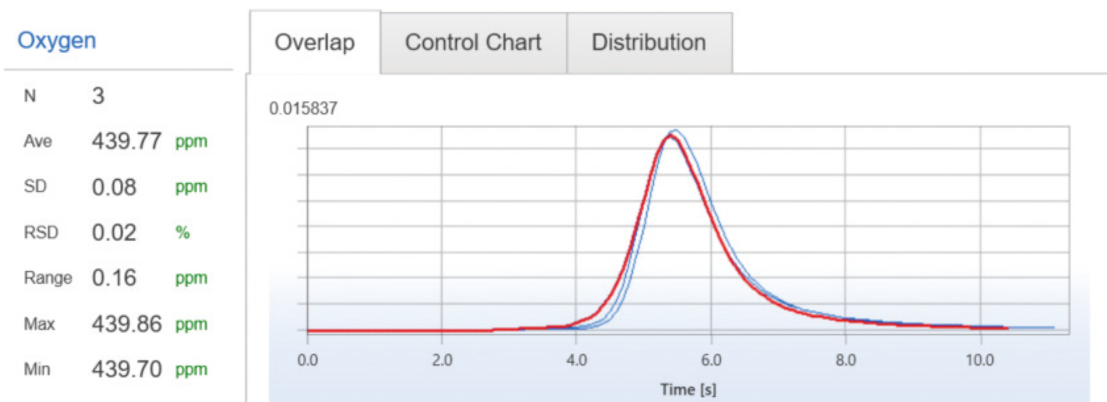

Figure 2 Example of EMGA analysis results.

Technical Evolution and Automation of the EMIA and EMGA Series

Overview of Analytical Principles and Instrument Configuration

HORIBA's EMIA and EMGA series are specialized instruments for quantitative analysis of trace elements in inorganic materials such as steel. The former targets carbon and sulfur analysis, while the latter addresses oxygen, nitrogen, and hydrogen, with both series offering highly sensitive and precise measurements.

The EMIA series employs a method in which samples are combusted at high temperature, and the resulting CO_2 and SO_2 gases are quantified using non-dispersive infrared absorption (NDIR) (see Figure 3). In contrast, the EMGA series melts samples in an inert gas atmosphere, detects CO, N_2, and H_2 generated through oxidation and carbon reduction using thermal conductivity detection (TCD) and NDIR (see Figure 4).

Common components of both instruments include a precisely controlled furnace (impulse furnace), gas flow paths, gas purification systems, and detection units. The furnace vaporizes samples at high temperature, converts them into measurable gases, and utilizes the superior gas selectivity of NDIR detectors for measurement.

Advances in Operability and Automation Features

Early analytical instruments required manual execution of preprocessing, crucible exchange, and sample loading, making analytical accuracy and throughput dependent on operator skill. In contrast, the EMIA and EMGA series have undergone the following technological advancements to realize automation and efficiency[3]:

1. Continuous measurement via autosampler integration
2. Shortened measurement cycles with automatic crucible cooling and ejection mechanisms
3. Elimination of errors and contamination risks through sample ID management systems
4. Recipe-based measurement conditions to eliminate user operation differences
5. Device status monitoring and error notification to minimize downtime
6. Full automation of sample analysis via pneumatic tube transport

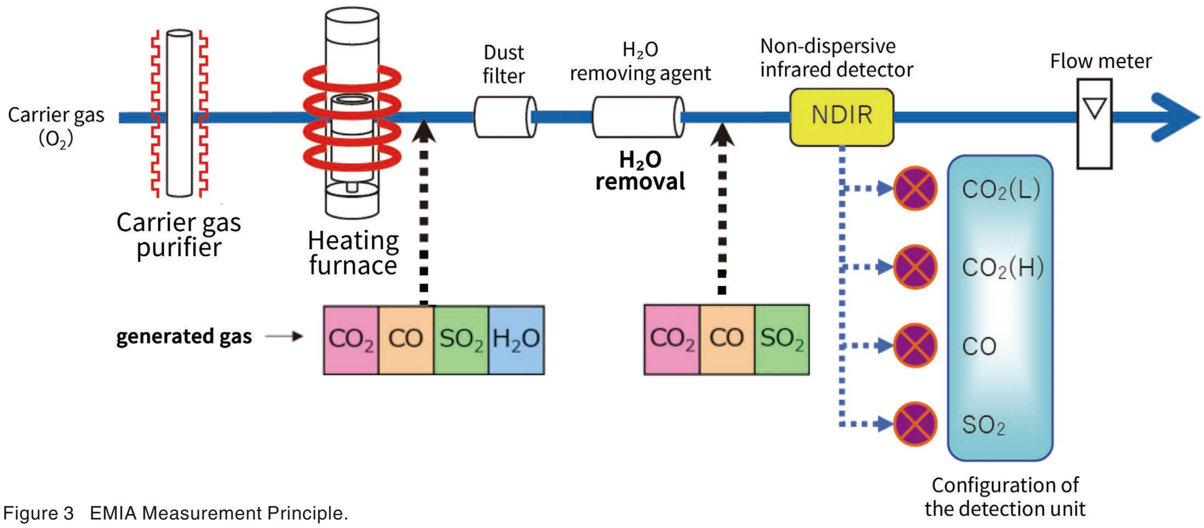

Figure 3 EMIA Measurement Principle.

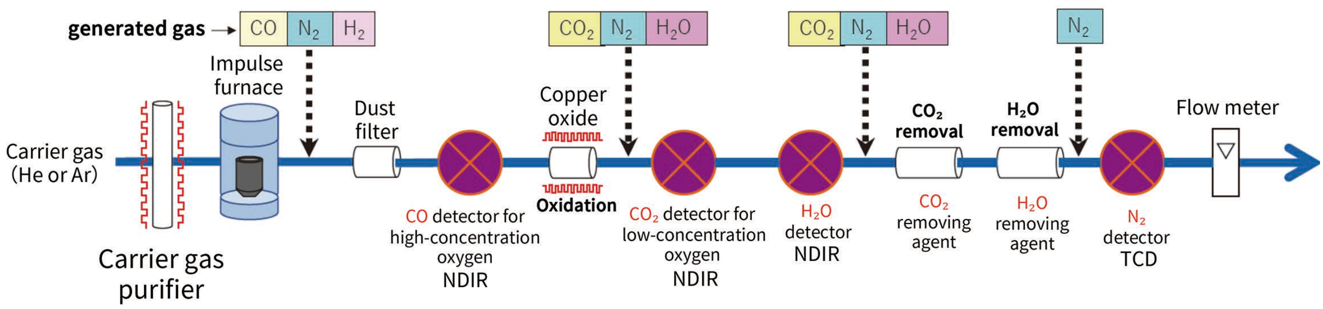

Figure 4 EMGA Measurement Principle.

As shown in Figure 5, the EMGA-730 released in the 1980s was HORIBA's first automated analytical instrument. At the time, it featured automatic crucible cleaning, a robot specialized for X-axis movement, and Y-Z axis control via pneumatic cylinders. As shown in Figure 6, there were two system types: one with automatic weighing and another centered on a sample stocker, allowing users to select based on their requirements[6].

Figure 7 illustrates the basic operational flow of automated analysis at that time, focusing mainly on weighing and

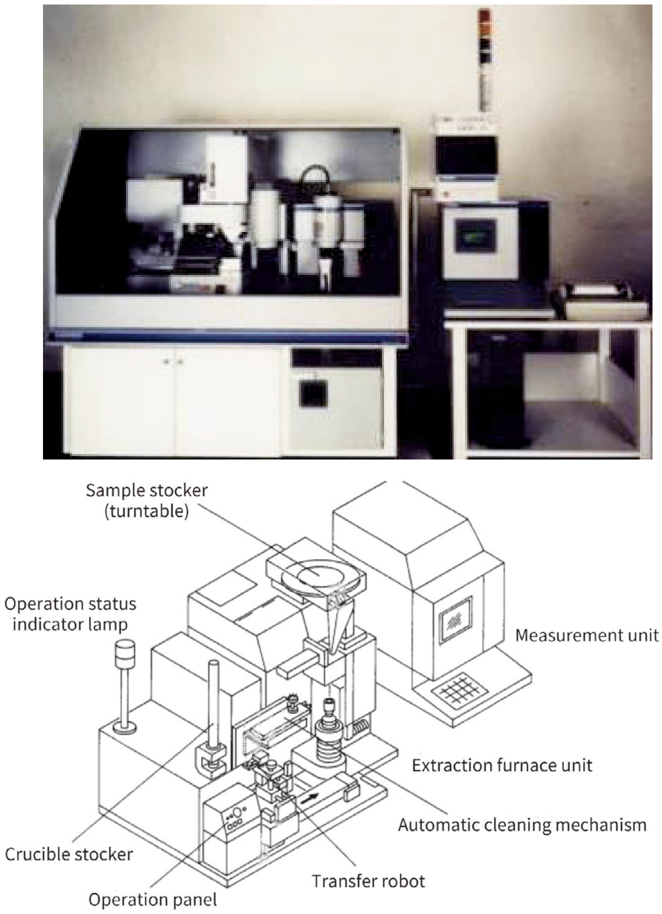

Figure 5 The first automation system, EMGA-730 (top)
System configuration with sample stocker function (bottom).

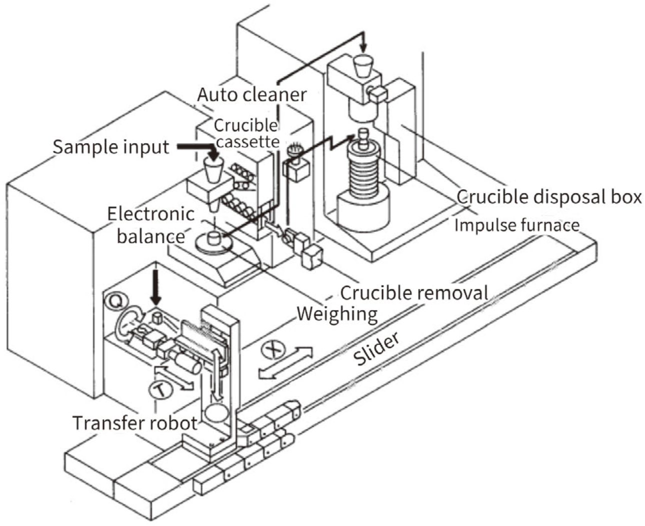

Figure 6 Automated system EMGA-730 with automatic weighing function.

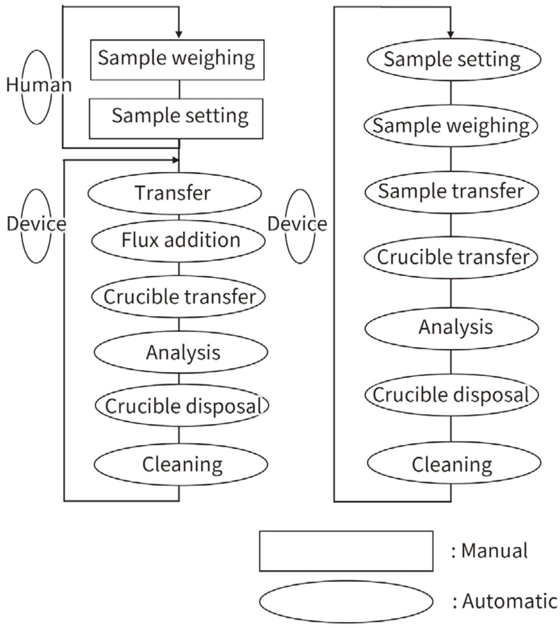

Figure 7 Basic operation of automation equipment.

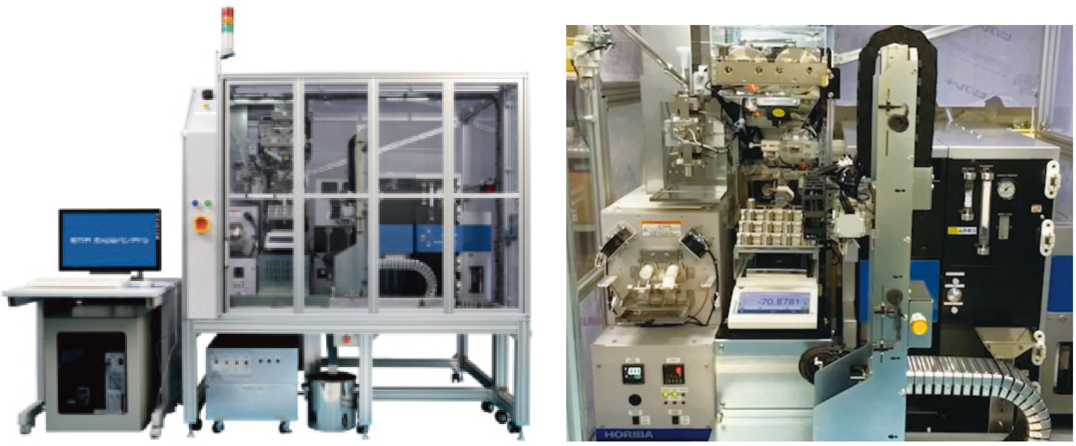

Figure 8 EMIA-2000 automatic machine (left) and interior (right).

sample loading. The central issue in automation was how to reduce the labor required for sample processing, apart from the instrument's own operation.

Forty years later, the EMIA series has further evolved, and the latest fully automated EMIA-2000 features a robotic arm capable of free XYZ-axis movement, enabling advanced operations as shown below (Figure 8).

As depicted in Figure 9, the crucible is extracted from the heating unit by the robotic arm and transported to its designated position. This operation is designed for highly accurate positioning via gravity transport and fine control with air cylinders.

Subsequently, as shown in Figure 10, the robot accurately loads samples and flux, and performs automatic weighing. Unlike the two initial automation configurations, the current model integrates these processes into a single unified system.

Finally, the robot inserts the sample into the main unit (EMIA-Pro/Expert) (Figures 11 and 12). Unlike previous designs relying on linear axis movement, free control

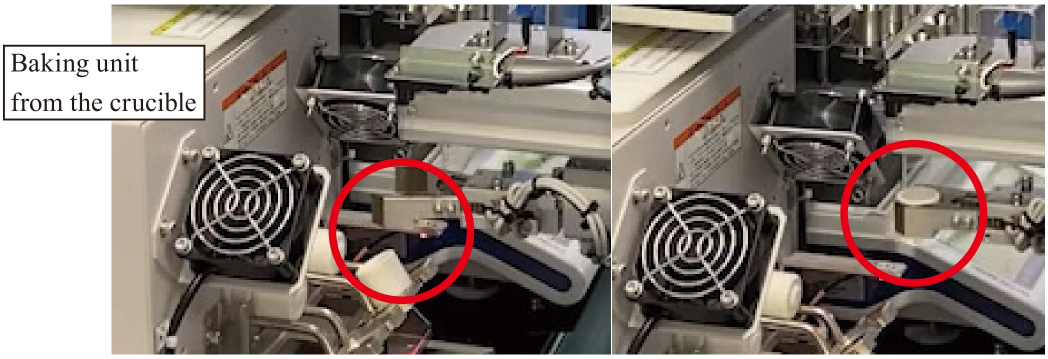

Figure 9 Crucible set from the baking unit from the crucible.

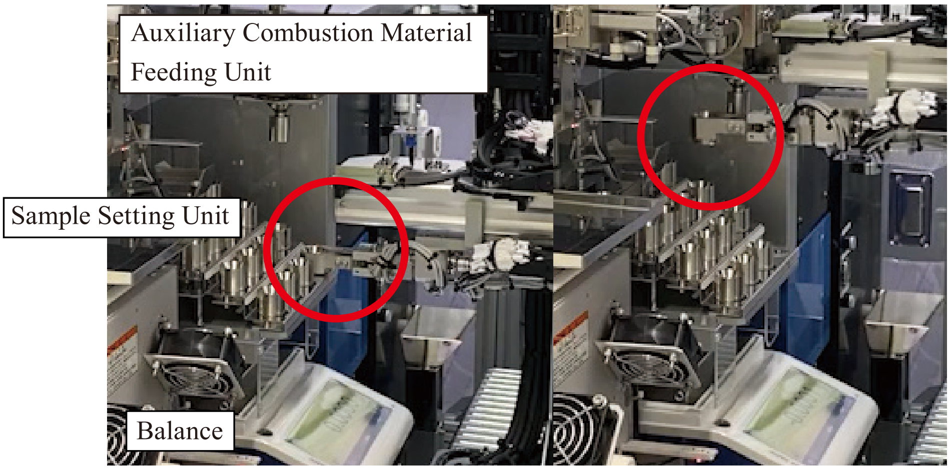

Figure 10 Sample sets, weighing.

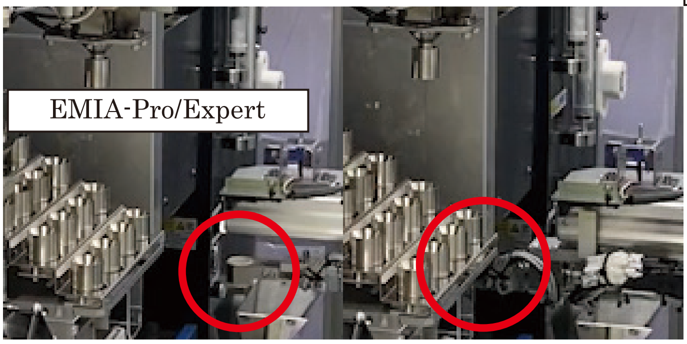

Figure 11 Sample set for EMIA - Pro/Expert.

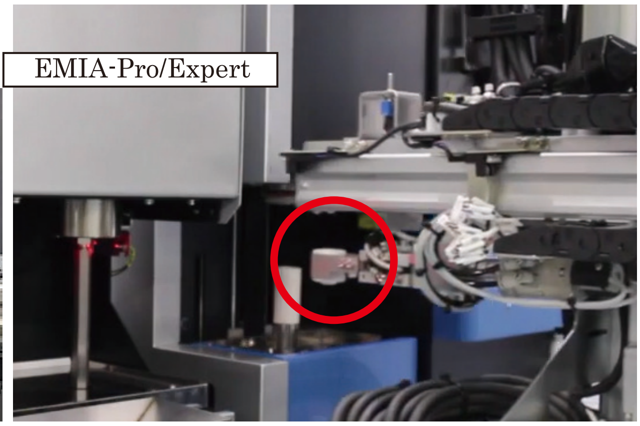

Figure 12 EMIA-Pro/Expert sample set (angle change).

of the X-Y-Z axes allows flexible adaptation to the shape of safety covers and instrument layout.

Thus, automation of processes such as sample setting and weighing directly reduces operator workload and labor hours, and the EMIA and EMGA series continue to meet market demands for automation.

Case Studies and Evaluation in the Steel Industry

Analytical instruments such as the EMIA and EMGA series are now deployed not only in quality assurance departments but also in key production processes such as steelmaking and rolling. In particular, rapid analysis of samples taken from manufacturing lines and immediate reflection of results in furnace conditions have become standard practice at major steel manufacturers. Such real-time integrated operations provide the following operational benefits:

1. Suppression of quality fluctuations through immediate feedback from analysis to process control
2. Enhanced traceability via accumulation and visualization of data
3. Reduced operator workload and training costs through automated measurement operations

The EMIA and EMGA series are being redefined as intelligent analytical systems that support real-time optimization of production processes, transcending the role of simple measurement devices. Case studies in the steel industry demonstrate that these instruments have evolved from tools for "obtaining data" to strategic solutions for achieving both quality and efficiency.

Prospects for Automated Instruments

Maturation and Multifunctionality of Automation Mechanisms

In recent years, automation technologies for analytical instruments have advanced significantly beyond mere labor-saving in specimen processing, showing major progress in areas such as user interfaces, control algorithms, and autonomous decision-making capabilities. Integration between autosamplers and transport systems, as well as sophisticated self-detection and recovery from errors, are becoming increasingly refined, transforming instruments from passive tools into systems that "judge and propose together" with the user.

Against this background, the following extended functionalities are anticipated for the EMIA and EMGA series:

1. Enhancement of automatic correction of measurement conditions and error prediction functions using AI
2. Fully automated switching of measurement profiles through specimen information reading (barcode, RFID)
3. Implementation of job scheduling and load balancing control among multiple analytical instruments
4. Dynamic measurement interruption and resumption mechanisms, and flexible recalculation modes

Impact of Automation on the Workplace

Advancements in automation at analytical sites are shifting the role of operators from "manual controllers" to "monitors and optimizers." This transition is expected to reduce dependence on individual expertise, lower training costs, and accelerate troubleshooting. As material complexity and the development of new materials progress, rationalizing the setting and standardization of test conditions will become increasingly important.

In the future, the realization of "contactless operation"—where operators can monitor and control remotely without being physically present—and "real-time condition optimization AI" that adapts to lot differences and specimen shapes, as well as "prediction-driven analysis," where instruments actively propose measurement timing based on data from other processes, will further reduce labor and promote the automation of analytical procedures.

The Future of Automated Analytical Instruments

Looking ahead, analytical instruments represented by the EMIA and EMGA series will assume roles not only as "high-precision measurement devices" but also as "autonomous decision-support systems" positioned between manufacturing and quality assurance. Especially in the context of emerging trends such as carbon neutrality and smart material development, analytical instruments will be required to function within broader information networks rather than as standalone devices. Furthermore, HORIBA aims to pioneer automated analysis using AI and machine learning.

The design philosophy for such instruments should be based on three pillars: user-centricity, trouble-free operation, and future scalability. HORIBA's product development is expected to continue evolving around these principles.

Conclusion

This paper has discussed the advancement of quality assurance in Japan's steel industry and the corresponding technical evolution of analytical instruments, focusing on the history, current status, and future of HORIBA's EMIA and EMGA series automation systems.

Trace element analysis is an extremely important process directly linked to ensuring the reliability of steel products, and its automation and precision significantly influence overall manufacturing efficiency and quality. The EMIA and EMGA series have responded to diverse user needs not only by improving analytical accuracy, but also by incorporating features such as autosamplers, automatic ejection mechanisms, recipe management for measurement conditions, network connectivity, and remote monitoring for smart factory compatibility. As a result, analytical instruments have expanded their roles from "inspection devices" to "components of the manufacturing process" and "information systems supporting management decisions."

Looking forward, further development of Industry 4.0, as well as the integration of AI-based automatic anomaly detection, measurement condition optimization, and real-time connectivity with LIMS (Laboratory Information Management Systems) and ERP (Enterprise Resource Planning) systems, will continue to raise the functional requirements for analytical instruments. In particular, to address societal demands such as realizing a decarbonized society and ensuring transparency in global supply chains, the existence of analytical instruments capable of reliably supplying high-quality data will be indispensable.

With a foundation of long-accumulated analytical technology and instrument development expertise, HORIBA's EMIA and EMGA automation systems are expected to continue serving as central pillars supporting the smart transformation and quality innovation of manufacturing, further enhancing competitiveness in the global market.

* Editorial note: This content is based on HORIBA's investigation at the year of publication unless otherwise stated.

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