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Poka-yokes and traceability in iron foundries: integrated strategies for quality and waste reduction

Poka-yokes and traceability in iron foundries: integrated strategies for quality and scrap reduction

Guilherme Casagrande de Miranda – Getulio Vargas Foundation (FGV)

SUMMARY

This paper explores the synergy between Poka-Yokes and traceability technologies to optimize product quality and reduce scrap in iron foundries, environments characterized by high process variability. We will address how the implementation of error-proofing devices (Poka-Yokes) in critical processes, such as melting, metal treatment, and casting, minimizes the occurrence of defects. Concomitantly, traceability technologies (RFID, IoT, MES), exemplified by the Ladle Tracker system from SinterCast (SinterCast, [nd]) and the DISA TAG solution from DISAGROUP (DISAGROUP, [nd]), and infrared camera monitoring from OPTRIS (OPTRIS, [nd]), ensure the identification and continuous monitoring of parts and their parameters, from melting to demolding. The aim is to demonstrate how this integrated approach not only prevents failures through automatic blocking, but also enables accurate analysis of the root cause of non-conformities, resulting in significant gains in productivity and quality.

Keywords: Poka-Yoke. Traceability. Foundry. Quality. Scrap.

ABSTRACT

This article explores the synergy between Poka-Yokes and traceability technologies to optimize product quality and reduce scrap in iron foundries, environments characterized by high process variability. We will address how the implementation of error-proofing devices (Poka-Yokes) in critical processes, such as melting, metal treatment, and pouring, minimizes defect occurrence. Concomitantly, traceability technologies (RFID, IoT, MES), exemplified by SinterCast's Ladle Tracker system (SinterCast, [sd]) and DISAGROUP's DISA TAG solution (DISAGROUP, [sd]), and monitoring with infrared cameras like OPTRIS (OPTRIS, [sd]), ensure continuous identification and monitoring of parts and their parameters, from melting to demolding. The aim is to demonstrate how this integrated approach not only prevents failures through automatic blocking but also allows precise root cause analysis of non-conformities, resulting in significant gains in productivity and quality.

Keywords: Poka-Yoke. Traceability. Foundry. Quality. Scrap.

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1. INTRODUCTION

The iron foundry industry, with its intrinsic complexity and the influence of numerous process variables, faces ongoing challenges in ensuring product quality and minimization of scrap. Small deviations at any stage can lead to non-compliance, impacting efficiency and profitability. In this scenario, the integration of error prevention methodologies and monitoring technologies becomes crucial. This article proposes to analyze the strategic combination of Poka-Yokes (error-proof devices) in critical casting processes with the implementation of traceability systems product. The goal is to demonstrate how this synergistic approach can not only prevent occurrence of defects at the source, through automatic blocking, but also provide a detailed production history, essential for root cause analysis and continuous improvement, covering the process from melting the metal to demolding the part.

2. THEORETICAL FRAMEWORK

The search for quality in manufacturing has led to the evolution of several methodologies and tools. Two approaches, Poka-Yoke and Traceability, although distinct in their primary application, are complementary to achieve excellence in the production of castings.

2.1 POKA-YOKES: PREVENTING ERRORS AT THE SOURCE

Poka-Yoke, a Japanese term meaning "mistake-proofing" or "avoiding inadvertent mistakes", refers to any mechanism in a manufacturing process that helps prevent errors occur or to make them immediately obvious. Developed by Shigeo Shingo in the system Toyota production Poka-Yokes are designed to eliminate the possibility of defects human or process, acting before or at the time of the failure occurrence. In a casting, where variables such as temperature, alloy composition, mold conditions and casting process are critical, Poka-Yokes can be implemented to ensure that certain steps are performed correctly.

In foundries, examples of Poka-Yokes include the use of temperature sensors to ensure that the metal is only poured when it reaches the exact temperature, avoiding problems of filling or uneven solidification. Fitting systems are used to ensure that cores or mold parts are assembled in the correct position, preventing

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inverted or misaligned assemblies. Additionally, automated weighing checks the weight correct amount of additives or alloys before they are added to the furnace, preventing compositions out-of-specification chemicals. Presence checkers, in turn, confirm the existence of all necessary components before the pouring stage.

2.2 PRODUCT TRACEABILITY: THE COMPLETE HISTORY OF QUALITY

Traceability is the ability to track the history, application or location of an item or its characteristic by means of registered identifications. In foundries, where a part goes through numerous transformations and influences of variables, traceability is crucial to identify the origin of any defect. It allows that, when faced with a reject or customer complaint, it is possible to reconstruct the entire production process of that part, from the batch of raw material up to the conditions of pouring and heat treatment.

For traceability in foundries, several technologies can be used. Radio Frequency Identification (RFID) enables automated tracking of items, An example being the **Ladle Tracker from SinterCast** (SinterCast, [sd]), which uses RFID tags attached to each metal transfer pan. Antennas positioned at key points on the process tracks the pans, recording metal parameters such as temperature, weight and chemical composition, connecting the molding history to the liquid metal history. Barcodes and QR Codes are cost-effective solutions for identifying batches or parts specific, recording process parameters at key points. **DISAGROUP** offers the **DISA TAG** solution (DISAGROUP, [nd]), which adds a unique ID to each casting through automatic marking on the produced mold, allowing the part to be linked to the process parameters collected during production for defect investigation. Sensors and the Internet of Things (IoT) enable continuous data collection at critical stages (metal temperature, sand humidity, injection pressure), which can be associated with specific parts, creating a detailed history. Infrared cameras, such as those from **OPTRIS** (OPTRIS, [sd]), can provide online and non-contact temperature measurements, adding accuracy to traceability data. Finally, Execution Systems Manufacturing Execution Systems (MES) integrate RFID data, barcodes, bars and sensors, providing a real-time and comprehensive view of the process, managing production orders, part status and quality controls.

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3. MATERIAL AND METHOD

For this article, a systematic literature review on Poka-Yokes was carried out, traceability and its applications in iron casting processes. The research covered scientific databases, journals in the area of production engineering and metallurgy, in addition of technical literature on quality management systems and advanced manufacturing (Industry 4.0), including technologies from companies such as SinterCast, DISAGROUP and OPTRIS. They were analyzed case studies and articles describing the successful implementation of both methodologies in manufacturing environments, focusing on how the combination impacts the reduction of defects and the ability to analyze. The collection of qualitative data aimed to identify the best practices and challenges inherent in the integration of these tools.

3.1 THE CASTING PROCESS: POKA-YOKES AND CASTING POINTS TRACEABILITY

To contextualize the application of Poka-Yokes and traceability, we describe the steps main aspects of the iron casting process, highlighting critical points and the application of tools.

1. Melting and Preparation of Metal. In this step, scrap and alloying elements are loaded into furnaces and melts, with the chemical composition and temperature of the liquid metal being crucial to the final quality. Poka-Yokes here include automated weighing and dosing systems additives to ensure the correct proportion, preventing leakage if the composition is out of specification. Continuous temperature sensors also act as Poka-Yokes, blocking the leak from the furnace to the transfer ladle if the metal temperature is outside the optimal operating range. The traceability parameters associated with the pan transfer via RFID (using the **SinterCast Ladle Tracker** (SinterCast, [sd])) cover melting batch ID, detailed chemical composition, exact metal temperature leaked, weight of the metal in the pan and the ID of the pan itself.

2. Metal Treatment (in the Transfer Ladle), which involves processes such as nodularization or inoculation to adjust the microstructure of the iron. Poka-Yokes at this stage include sensors that check the correct amount of material injected, blocking the process if the dosage is incorrect, and treatment time controls to ensure the minimum or maximum duration. Traceability parameters added to the pan via RFID

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include the type and quantity of material injected, the treatment time in the pan and a new temperature measurement of metal after treatment.

3. Molding and Core Making is the stage of producing molds and cores. Poka-Yokes here involve tools and jigs that ensure correct positioning of the males in the mold, preventing inverted or misaligned assemblies. Humidity sensors and sand compaction ensures the quality of the mold, blocking continuity if out of specification, and visual checkers or sensors confirm that all mold sections are assembled correctly and without burrs. The traceability parameters associated with the Mold ID (automatically applied by **DISA TAG** solution (DISAGROUP, [sd])) include date and time of molding, sand parameters, ID of cores used (if applicable) and the molding machine number.

4. Pouring is a critical step where the liquid metal is transferred into the molds. Poka-Yokes at this point are critical to preventing defects; they include control of inoculation (sensors that check the correct amount), metal flow detection for ensure correct start and end, detection of clogged pipe by pressure transmitter, control fading time to avoid loss of inoculant effect, and control of fading time leak to prevent interrupted leaks. Online temperature measurement with systems like **OPTRIS** (OPTRIS, [sd]) act as Poka-Yoke, blocking instantly if the leak temperature is outside the ideal range. The parameters of traceability added to the part/mold ID include pour time, quantity of casting metal, amount of inoculation in casting, fading time, metal temperature during the leak (recorded by the OPTRIS system), leaking pan ID and all previously assigned molding and sand process data.

5. Solidification and Cooling, where the liquid metal solidifies. A Poka-Yoke in this phase is the cooling time control, which blocks the demolding of the part while the predetermined time for that alloy and thickness is not reached, ensuring complete solidification and avoiding internal stresses. This information is engraved with the part, making the dwell time in the mold/actual cooling time and the environmental conditions of the area cooling traceability parameters associated with the part ID.

6. Demoulding and Finishing involves the removal and processing of the casting. Poka-Yokes here include "go/no go" templates to quickly check if the part is

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within dimensional tolerances, assisted visual inspection (jigs or light stations) for highlight visual defects, and heat treatment controls that ensure that parts only advance if the cycle was complete and within the parameters. The traceability parameters added to the part ID include demolding date and time, visual inspection results and dimensional, heat treatment parameters (if any), the final part ID (keeping the link with mold and ladle ID via DISA TAG and SinterCast Ladle Tracker) and results of non-destructive testing (NDT) or mechanical testing.

4. RESULTS AND DISCUSSION

Integration of Poka-Yokes into critical foundry processes, followed by traceability robustness of the parts, generates a virtuous cycle of quality improvement and waste reduction. The Poka-Yokes act as prevention, stopping common errors from occurring at the source. example, temperature sensors in the leak and dosage control systems in alloy treatments prevent critical parameters from being out of specification, preventing problems such as incomplete casting or inadequate metallographic structures. This means that fewer defective parts reach subsequent stages of the process.

When, despite the Poka-Yokes, a non-conformity still occurs or is detected, the traceability system comes into action. By consulting the history of the part through its RFID information (such as the **SinterCast Ladle Tracker** (SinterCast, [n.d.]) that connects the history of the metal pan to the hollow molds) or its unique marking **(DISA TAG** (DISAGROUP, [sd]) which links the part to the production parameters), it is possible to identify precisely the process variables associated with that part. If a batch of castings present cracks, the traceability system can reveal that these parts have undergone a heat treatment with specific parameters (time and temperature), or that were produced from a batch of metal with a slightly different composition or even if an inoculation Poka-Yoke was not triggered correctly due to a failure in the system. This pinpointing capability is impossible without a traceability system effective.

The application of the **SinterCast Ladle Tracker** (SinterCast, [sd]) allows foundries to monitor the progress of metal pans throughout the process, recording crucial data of the metal, which is vital for the quality of the casting. In addition, the **DISA TAG** (DISAGROUP, [sd]) optimizes the casting process by associating a unique ID with each

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casting, allowing users to link the part to a casting by scanning this ID. specific cause of defect or consult the process parameters collected during the production. The inclusion of systems such as **OPTRIS** infrared cameras (OPTRIS, [sd]) at the leak point adds a layer of accuracy in temperature measurement, ensuring that the metal is poured within the ideal thermal window, and this critical information is automatically linked to the part history. This detailed, part-level view individual, it is essential to investigate the root causes and determine which parameters process led to a defective part, optimizing quality, reducing waste and minimizing downtime.

Specific Poka-Yokes, such as Instant Lock Leak Sensors (flow detection, clogged pipe, fading time, online temperature measurement with systems such as **OPTRIS** (OPTRIS, [sd])), are crucial for preventing serious defects that would otherwise result in immediate scrap or costly rework. The information generated by these Poka-Yokes (such as the reason for blocking, the parameter exceeded) is also integrated into the traceability of the part (even if it is an "aborted" or "non-cast" part), providing valuable data for process improvement. The Time Control Poka-Yoke cooling, for example, not only prevents premature demolding, but also records the real time, enriching the history of the piece.

The integration between Poka-Yokes and traceability offers multiple benefits:

- **Proactive Scrap Reduction:** Poka-Yokes reduce the occurrence of defects at the source, with automatic blocks at critical points.
- **Effective Root Cause Analysis:** Traceability allows you to quickly identify the origin of any non-conformity, facilitating specific corrective actions, with the help of systems such as the SinterCast Ladle Tracker, DISA TAG and Poka-Yokes records.
- **Continuous Process Improvement:** Traceability data, combined with failures that Poka-Yokes have managed to prevent or indicate, provide valuable insights to optimize further the process and re-evaluate existing Poka-Yokes.
- **Greater Product Reliability:** Parts produced under a Poka-Yokes regime and traceability offers greater quality assurance to the customer.
- **Optimization of Variable Management:** Continuous monitoring of process variables is enhanced by combination, allowing for finer adjustments and preventative interventions.

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The discussion should also address challenges such as initial investment in technologies and the need for staff training to operate and maintain these integrated systems. In However, gains in efficiency, reduction of costs with rework and scrap, and improvement of reputation of the foundry justify the implementation of this integrated approach.

FINAL CONSIDERATIONS

The joint adoption of Poka-Yokes and traceability systems represents a leap forward significant qualitative for iron foundries. While Poka-Yokes act in the line head-on, preventing the occurrence of errors and defects in the main processes through automatic locks, traceability, supported by technologies such as Ladle Tracker from SinterCast (SinterCast, [sd]) and the DISA TAG from DISAGROUP (DISAGROUP, [sd]), in addition to monitoring solutions such as those from OPTRIS (OPTRIS, [sd]), it provides the intelligence needed to understand and correct any errors that may escape. This synergy not only minimizes scrap and associated costs, but also increases the quality of the final product, strengthens customer confidence and positions the foundry at a level of operational and technological excellence. Implementing this approach is an investment strategic in the sustainability and competitiveness of the foundry industry, paving the way path to a future with less waste and greater precision.

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