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Digital Transformation in Quality

Quality and Business Improvement (ACMA 4038)

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2219433 24.04.2026

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1 Introduction

Industry 4.0 technologies such as Internet of Things (IoT), digital dashboards, and advanced process monitoring systems are transforming modern manufacturing processes by enhancing traceability, data availability, and decision-making (Thoben, Wiesner and Wuest, 2017). These technologies are especially valuable in powder metallurgy, where chemical purity, particle morphology, and process stability must be tightly controlled to meet demanding specifications for additive manufacturing and thermal spray applications (German, 2016; Gibson, Rosen and Stucker, 2021).

This report evaluates the application of Industry 4.0 technologies in a Dry Gas Atomisation (DGA) facility producing Nickel, Stainless Steel, and Cobalt alloys, and investigates how real-time gas monitoring and digital dashboards can support continuous improvement (CI). Atomisation processes are sensitive to variations in melt temperature, gas flow, and chamber atmosphere, which directly affect oxygen/nitrogen pickup, particle size distribution, and powder quality (Atkinson, 2005; Hirt and Pöhlandt, 2020).

2 Case Study – Overview

2.1 – Case Study Preparation – Process Setup

LSN Diffusion LTD uses 350kg/750kg induction furnace(s) to melt nickel-based, stainless steel, and cobalt alloys before pouring the melt into a dry gas atomisation chamber, where high-pressure nitrogen gas disintegrates the melt stream into fine metal droplets. Nitrogen is commonly used in stainless steel and nickel powder atomisation because it achieves good cooling rates and cost efficiency (MPIF, 2021).

Powder is collected through a cyclone system, separated from residual gas, and taken through vibratory sieving to produce required size fractions (PSD) for downstream users in additive manufacturing and surface engineering (Frazier, 2014).

2.2 Role in Manufacturing Chain

The powder produced must meet strict standards such as ISO/ASTM 52907:2020 for chemical composition, flowability, morphology, and particle size distribution. Any deviations in nitrogen or oxygen content can compromise mechanical properties and printability in AM systems (Gu et al., 2018; Lu et al., 2017). LSN works to strict customer specifications and gas levels are critical in most applications due to their reactions when being welded, fused or deposited under high energy transfer systems such as HVOF, PTA or Laser Bed Fusion.

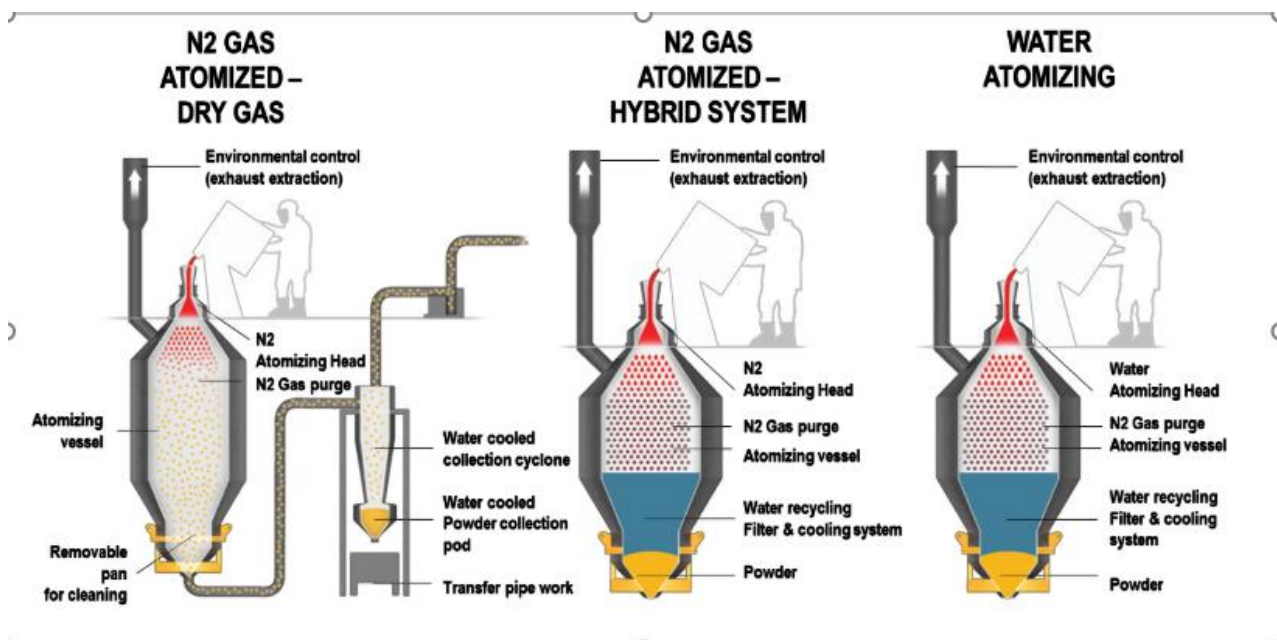


Figure 1 - Illustration of Atomising Technology within LSN

3 Current State and Problem Identification

3.1 Current Issue within LSN Manufacturing Facility

Several challenges typify large-scale nitrogen atomisation facilities:

1. Variation in Oxygen and Nitrogen Content

Both nitrogen solubility and oxygen pickup can fluctuate depending on gas purity, chamber sealing, and melt superheat (Bolton, Fan and Patel, 2020; Bordatchev et al., 2018).

Temperatures range on alloy-melt from 1400 degrees Celsius to 1800 which affects the gas-to-metal ratio and the pickup due to the cooling rates varying from alloy to alloy. LSN manufactures in oxygen as the atomising booths are exposed to environment and are not sealed in argon or nitrogen rich environments. If it was commercially viable the use of Nitrogen/Argon rich atomising environment would be beneficial but due to the current setup within atomising and costs attributed to re-design and implementation.

2. Mixed Digital and Manual Data Recording

LSN currently utilises manual and digital readings in a hybrid method for data collection, this brings about issues in relation to accurate data entry, when the quality and technical team are analysing data in relation to material chemistry, melt temperatures, pour times and elemental gas levels obtaining accurate data is critical in the generation of optimised melt settings in relation to gas to metal ratio (Atomising Head and PSI) controls, pour times of molten metal and the physical make up

Manually entered furnace temperatures, pressures, and chemical readings introduce transcription errors and incomplete datasets (Mohamed, Al-Jaroodi and Jawhar, 2019).

3. Non-Transparent Gas Supply Conditions

LSN utilises BOC supply of Nitrogen in its liquid form at point of delivery, this is then converted via heat exchangers to Gas which is then piped directly into the manufacturing facility to supply atomisation and purge gas.

The purity of the incoming gas is critical in relation to reducing impurities within the final atomised metal powder and consistency in the flow is critical to maintaining the correct atomising pressure to ensure gas to metal ratio is maintained throughout the entirety of the melt flow.

Without real-time visibility of nitrogen pressure, temperature, flow rate, and purity, operators cannot quickly identify deviations (Gao, Wang and Teti, 2020).

4. Delayed Process Feedback

LSN utilises ICP analysis post atomisation of metal to conduct chemical analysis of the atomised metal powder. Once the molten pool has been atomised into metal powder sub 500um. If chemical elements are out of specification the production process is circa 65% complete with no means of altering the chemistry of the metal powder. Oxygen levels are obtained via combustion analysis and although faster than ICP methods the process of atomisation is already complete at this point.

Quality-critical parameters such as oxygen ingress or pressure fluctuation are often discovered only during post-batch analysis (Cai, Wang and Wu, 2021).

3.2 Risks Identified within Present Manufacturing Setup

Uncontrolled nitrogen absorption in molten metal – Influenced by delivery of atomisation gas, purge level within the atomisation tower, hold time within the nitrogen purged powder collection pod.

Oxygen pickup during pouring or chamber leaks, the molten pool is open to atmospheric oxygen during the pouring from the furnace until it contacts the tundish which is controlled in relation to oxygen by preheating the tundish and de-oxygenation the surrounding area by utilising Montselas burners. The flame is set up as de-oxygenating in its nature to reduce the oxygen content, this is controlled by ensuring the propane release from the gas tank is consistent with obtaining the correct flame output.

Variation in particle size distribution due to pressure instability, if gas flow is not optimised during delivery to the atomising head and pressure fluctuations are present during the introduction of nitrogen gas the PSD of the atomised powder can be greatly affected.

Each atomising head design at LSN is matched to alloy class and PSD requirement based on the incoming gas supply being constant and consistent. Losses or increases to pressure during introduction to the molten pool have a direct correlation to the size and morphological outcome in relation to the powder droplet formed (Zhang *et al.*, 2022).

Difficult, slow root-cause analysis due to scattered data sources (Pan, Guo and Li, 2021)

4 Introduction to Industry 4.0 and Applicable Technologies

4.1 Real Time Gas Monitoring – (IoT Sensors)

Working in correlation with BOC, LSN has introduced more regulated gas delivery devices and monitoring in real time the delivery of gas to the atomising tower. Additional automated valves have been placed within the manufacturing environment to regulate gas pressures supplied by the main gas pumps on the outer of the building within the nitrogen plant. The plant is specified to supply ten atomising towers 1000psi of pressure each running simultaneously, as LSN is only running four towers' spikes were monitored during ramp up of delivery demand.

IoT-enabled monitoring devices provide continuous data on nitrogen pressure, purity, temperature, and mass flow rate. IoT has proven highly effective in improving process traceability and reducing human error in industrial environments (Srinivasan et al., 2020).

This directly supports improved control of nitrogen levels, gas-to-metal ratios, and chamber atmosphere—all of which influence powder purity and morphology (Atkinson, 2005).



Figure 2 - BOC Liquid Nitrogen Gas Plant

4.2 Digital Dashboard and Visual Information

Before the implementation of the new gas delivery system the LSN production team relied on manual dial readings to determine the incoming gas pressure being delivered to the atomising head, the new PLC controlled BOC system delivers digital output for real time data monitoring of gas pressures.

Alongside the introduction of tighter nitrogen controls, health and safety improvements were identified during the implementation of digital dashboarding and a new thermal vision system has been developed and integrated into production to reduce operator reliance on when the molten metal pool was becoming superheated posing a risk to both the operational team and the condition of the actual induction furnace.

Existing oxygen sensors within the atomising tower and temperature sensors were already in place but located away from the main control panel for the furnace have now been integrated into the digital dashboard for real time monitoring of the critical characteristics within the atomisation production process.

Digital dashboards transform complex real-time data streams into operator-friendly interfaces. Visualising trends enhances decision-making and enables rapid detection of anomalies (Manyika et al., 2017).

In atomisation, dashboards allow live monitoring of:

- Melt superheat – Bridging risk
- N₂ pressure at source
- Chamber O₂ levels
- Cyclone temperature.

These tools support Industry 4.0-aligned continuous improvement by providing actionable insights (Kumar and Singh, 2022).

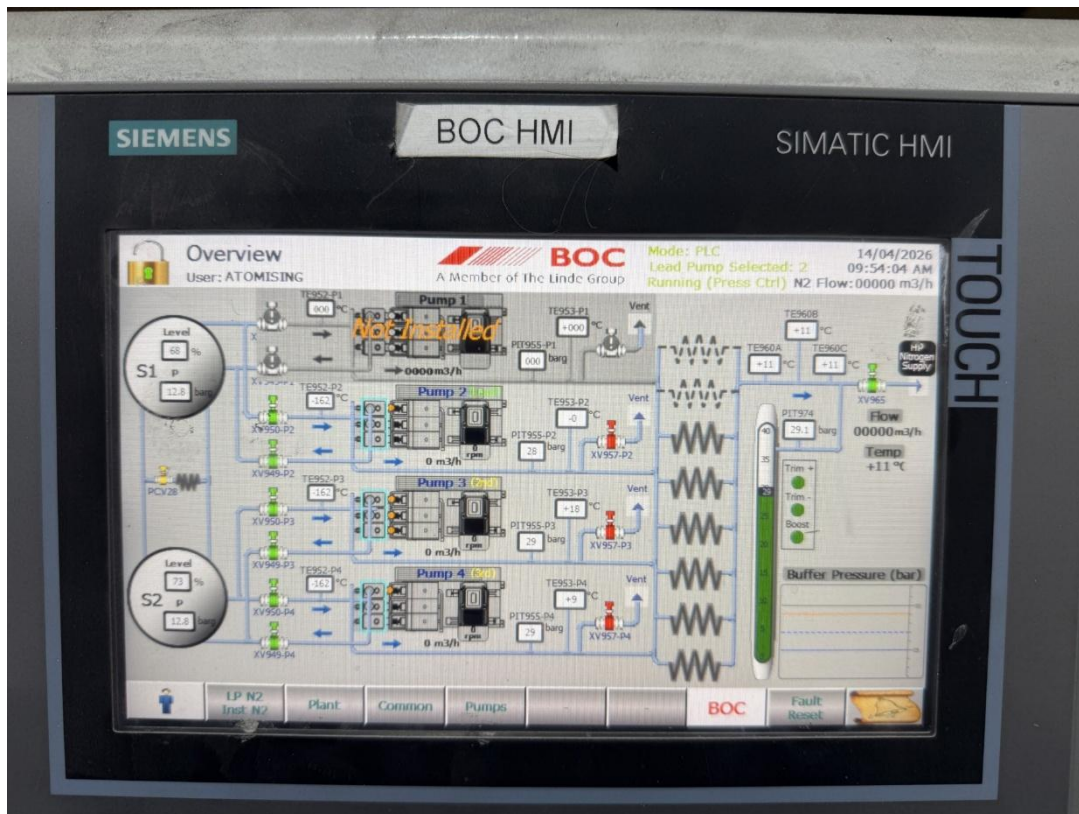


Figure 3 - BOC Control Panel Internal LSN

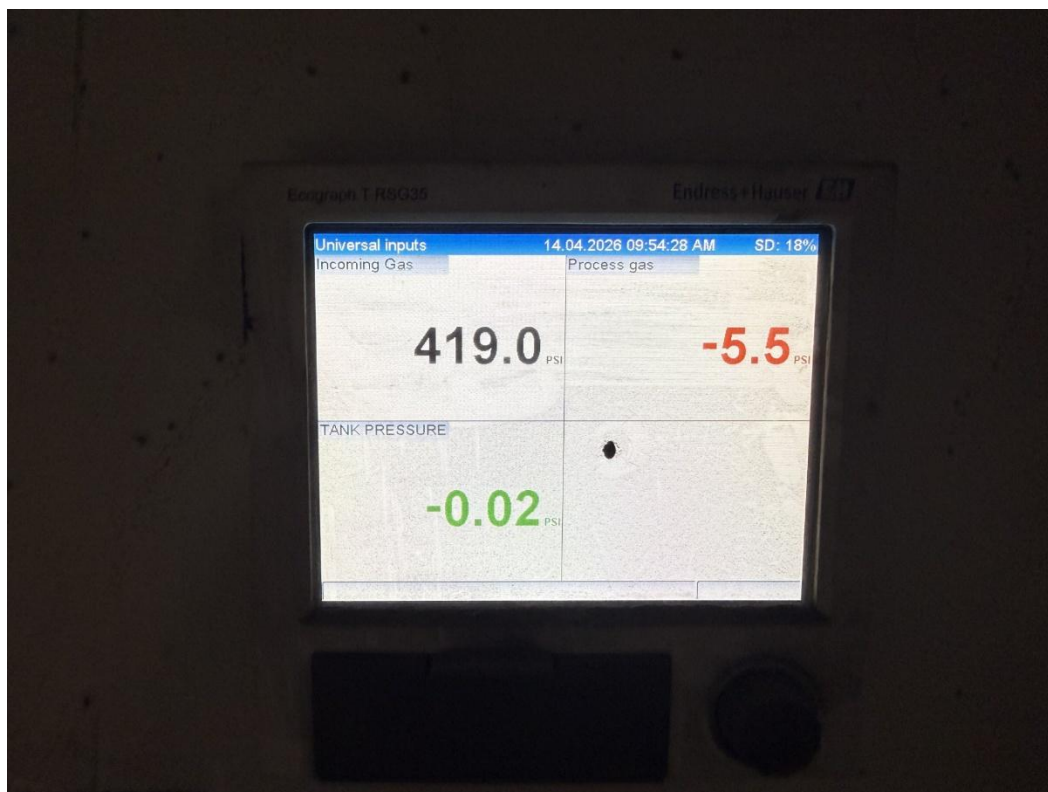


Figure 4 - Atomising Control Panel – Highlights live gas pressures delivered to atomising towers and overall incoming gas pressure available at the tower during processing.

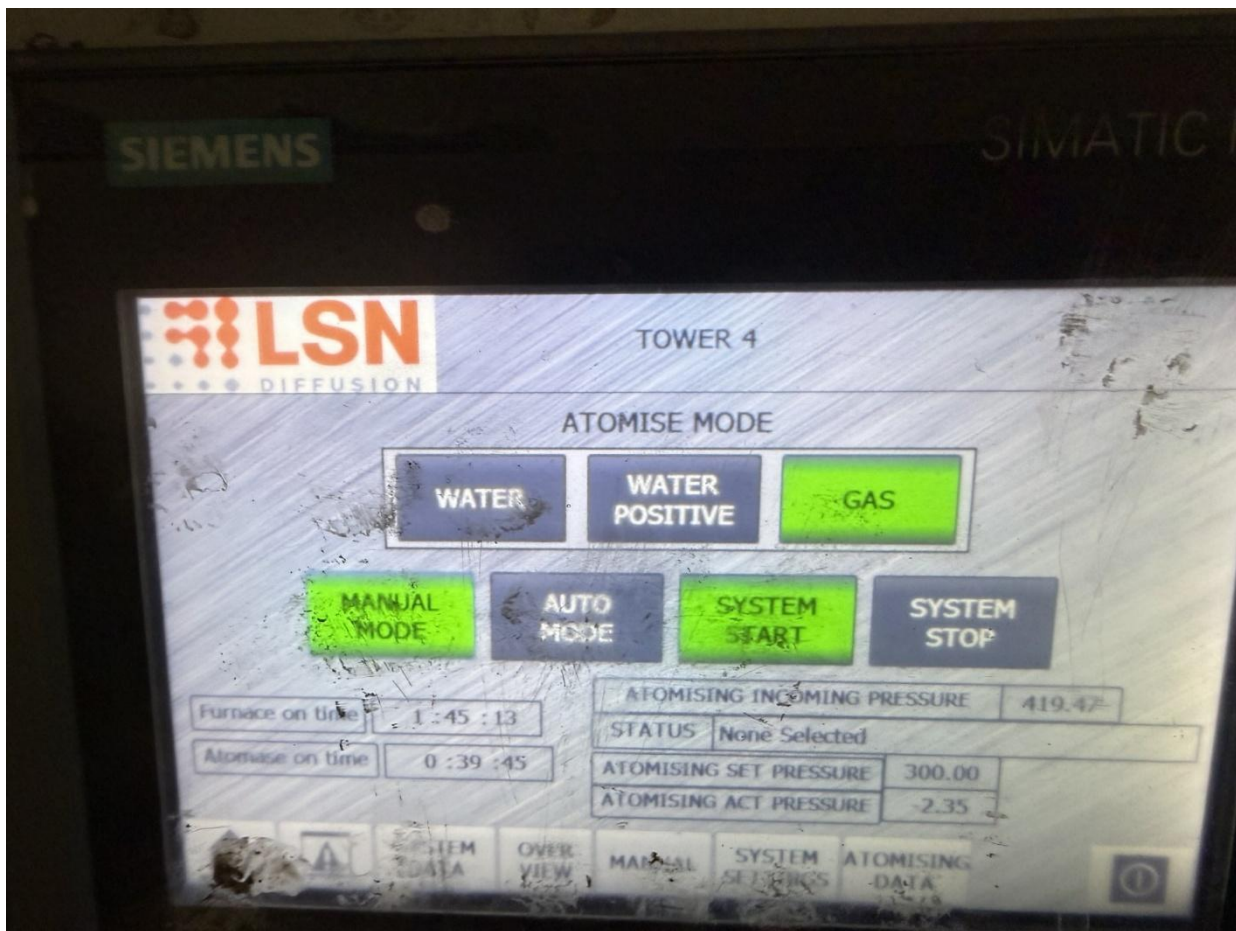


Figure 5 - Atomising Control Panel where Gas Pressures are Set to deliver correct Atomising Gas Pressure to the Atomising Head

5 Continuous Improvement (CI) Plan: DMAIC Framework

5.1 Define

Main objectives include:

- Reduce oxygen variation by 50% within atomising chamber. More accurate gas purge levels to reduce oxygen monitored in real time.
- Stabilise nitrogen absorption
- Increase traceability and reduce manual logging – Automated live PLC controlled system removing the requirement for manual logging of gas purge time and pressures within the atomising chamber.
- Improve operator reaction time with real-time dashboards

These align with CI principles highlighted by Thoben et al. (2017) and Gao et al. (2020).

5.2 Measure

IoT sensors record:

- N₂ pressure and flow at atomisation head insert. Purge levels of Nitrogen within the chamber reduce oxygen content.
- Gas purity at supply inlet – BOC controlled system.
- Atomising Tower Vessel O₂ contamination levels. Oxygen meter is linked to purge system for nitrogen gas.
- Furnace temperature – Reduces waste of energy and from a health and safety perspective reduces the chance of alloy super heating.

This approach supports accurate, high-resolution data collection necessary for energy-intensive processes (Mohamed et al., 2019).

5.3 Analyse

Historical and real-time data can be correlated to:

- Identify links between nitrogen pressure dips and nitrogen uptake
- Detect oxygen spikes caused by seal degradation / vessel intake (MPIF, 2021)
- Analyse superheat stability effects on powder quality (Atkinson, 2005)

Data-driven analysis is supported by typical findings in process metallurgy and Industry 4.0 research (Pan et al., 2021; Cai et al., 2021).

5.4 Improve

1. Real-Time Gas Control

Improves stability of nitrogen flow and purity, reducing nitrogen variability (Bolton et al., 2020).

2. Oxygen Monitoring

Real-time chamber oxygen detection allows rapid action before contamination occurs (ISO/ASTM 52907:2020).

3. Digital Dashboards

Provide trending data, alarms, and process insights—tools demonstrated to reduce reaction time and enhance CI cycles (Manyika et al., 2017).

4. Automated Data Logging

Eliminates transcription errors and strengthens quality documentation (Gibson et al., 2021).

5.5 Control

The improved system is sustained through:

- Continuous dashboard monitoring – Digital screens and outputs such as alarms to warn team of any issues.
- Regular data reviews – With real time data backed up in cloud-based data software the information is available in real time and can be easily analysed for efficiency.
- Automated alarms – The oxygen monitoring is now linked to audible alarm with warning lights. Likewise, the sensors for Nitrogen are run off Siemens PLC software which links to both LSN and BOC systems.
- Maintenance procedures guided by real-time data – The live dashboards supplied by BOC are linked to LSN's Infraspark maintenance management system. The advancements in cloud-based software which allows data transfer between systems reduce the amount of time taken to analyse data and reduce the requirements for multiple software systems for data analysis with the introduction of automated dashboards etc.

This aligns with recommended practices for smart manufacturing control loops (Gao et al., 2020).

6 Expected Impact / Outcomes

Table 1 – Expected outcomes based on modelling of LSN Data

KPI	Before (Actual)	After (Predicted)	Citations
Oxygen variation	±35 ppm	±12–15 ppm	Atkinson (2005); ISO/ASTM 52907 (2020)
Nitrogen variability	±0.04 wt%	±0.015 wt%	Bolton et al. (2020)
Manual data errors	Present	Improved	Mohamed et al. (2019)
Operator response time	Moderate	Fast	Manyika et al. (2017)
Yield stability	Variable	Improved	Bordatchev et al. (2018)

These improvements are consistent with Industry 4.0 outcomes reported in manufacturing literature (Cai et al., 2021; Thoben et al., 2017). Data was calculated by LSN technical team via modelling at Swansea university. The figures were modelled using current production data, it must be noted that these figures at time of writing are predictive and until significant production trials are complete at LSN. Regression Modelling and Thermodynamic modelling was utilised with the support of Claude AI to model.

Thank you to Dr Daniel Butcher for supplying the data.

7 Challenges and Mitigation

Technical

Sensor drift and integration difficulties are common challenges in metallurgical environments (Srinivasan et al., 2020). Routine calibration and phased retrofitting mitigate these issues. Integration of new work systems in heavy industry is also heavy in relation to setup challenges, due to the pressures and temperatures utilise within the manufacturing setup at LSN the equipment utilised is usually specialised in its design (Sofoluwe *et al.*, 2024)

By working closely with suppliers of equipment and ensuring correct installation and training on the use of equipment LSN has successfully introduced new equipment as it moves to a more digitalised working environment.

Cultural

Operator resistance can occur when new monitoring systems are introduced (Manyika et al., 2017). Training and involvement in the rollout reduce resistance. LSN delivers training and upskilling to team members before any full roll out of manufacturing changes within the plant to ensure safety and product integrity are at the forefront of everyone's mind before introducing any new technology.

Organisational

Budget constraints and legacy IT systems are frequent barriers (Pan et al., 2021). Phased implementation and cloud-based dashboards help reduce capital cost. The technical/engineering team have worked closely alongside our IT department during the introduction of new technologies to ensure a smooth transition to implement the new technologies.

Due to the nature of the power delivery to the equipment, it was critical to ensure that all data cables were shrouded and protected from electrical interference during operation, so cable / data point routing was critical in ensuring the data obtained was live and accurate. As an SME and privately owned all CAPEX expenditure within LSN must be well thought through in relation to return on investment.

LSN as an SME with 12 years of operation has now recognised the advancements in industry relating to live systems and the use of PLC to help the business monitor performance in real time.

8 Conclusion

Industry 4.0 technologies offer significant opportunities to improve purity control, process stability, and data integrity in a 1,000 kg nitrogen-based DGA facility. Real-time gas monitoring and digital dashboards enhance continuous improvement by reducing oxygen and nitrogen variability, improving traceability, and enabling faster operator responses. These findings are consistent with global research into smart manufacturing and powder metallurgy (Gao et al., 2020; German, 2016; MPIF, 2021).

The implementation of the new technology has allowed the atomising team to react in real time to pressure fluctuations in gas readings throughout the manufacturing system and therefore react in real time to situations as opposed to production being completed and non-conforming (NOK) results being logged after the fact and rework / remelt activities having to take place to ensure conforming product is delivered to the customer. It must be noted that these technologies are used to help manage production outputs within LSN they cannot control it.

The live dashboard has also allowed LSN Diffusion Ltd. to work on new KPIs in relation to gas cost per KG of powder produced and analyse in real time the amount of gas being used per atomising tower and allow refinement of atomising parameters to maintain product quality and integrity whilst also bringing about cost savings in the amount of gas to metal required to obtain conforming product.

The technical trials as of April 2026 are still ongoing in relation to optimising the atomising system but early signs are good in relation to product integrity, the introduction of live monitoring has been well received by the manufacturing team in relation to monitoring in real time the parameters which are crucial to alloy integrity, coupled with the safety aspect of working with metals at this temperature the increased safety aspect of real time monitoring has been well received.

9 Reference List

- Atkinson, H.V. (2005) 'Theories of gas atomization of metals', *Progress in Materials Science*, 50(3), pp. 341–412.
- Bolton, J., Fan, Z. and Patel, J. (2020) 'Process control in metal powder atomisation for additive manufacturing', *Journal of Materials Processing Technology*, 282, pp. 1–12.
- Bordatchev, E.V. et al. (2018) 'Powder characteristics and their effect on additive manufacturing process performance', *Additive Manufacturing*, 21, pp. 295–305.
- Cai, J., Wang, H. and Wu, Y. (2021) 'Industry 4.0 enabling technologies for smart manufacturing: A review', *Journal of Manufacturing Systems*, 58, pp. 1–13.
- Campbell, J. (2015) *Complete Casting Handbook*. 2nd edn. Oxford: Butterworth-Heinemann.
- Frazier, W.E. (2014) 'Metal additive manufacturing: A review', *Journal of Materials Engineering and Performance*, 23(6), pp. 1917–1928.
- Gao, R. X., Wang, L. and Teti, R. (2020) 'Real-time monitoring for smart manufacturing', *Procedia CIRP*, 93, pp. 681–688.
- German, R.M. (2016) *Powder Metallurgy and Particulate Materials Processing*. Princeton, NJ: Metal Powder Industries Federation.
- Gibson, I., Rosen, D. and Stucker, B. (2021) *Additive Manufacturing Technologies*. 3rd edn. New York: Springer.
- Gu, D. et al. (2018) 'Effects of powder consistency on additive manufacturing quality', *Materials Science and Engineering A*, 730, pp. 1–15.
- Hirt, G. and Pöhlandt, K. (2020) 'Gas atomisation of metal powders: Fundamentals and process overview', in Hirt, G. (ed.) *Metal Forming Handbook*. Berlin: Springer, pp. 751–788.
- ISO/ASTM 52907:2020 (2020) *Additive manufacturing — Feedstock materials — Metal powders — Characteristics and testing methods*. Geneva: ISO.
- Kumar, A. and Singh, H. (2022) 'Implementation of Industry 4.0 in metal processing industries: A review', *Materials Today: Proceedings*, 56, pp. 380–387.
- Lu, Y. et al. (2017) 'Powder characteristics and their impact on additive manufacturing', *Progress in Additive Manufacturing*, 2(3), pp. 129–136.
- Manyika, J. et al. (2017) *Manufacturing the Future: The Next Era of Global Growth and Innovation*. McKinsey Global Institute.
- Mohamed, N., Al-Jaroodi, J. and Jawhar, I. (2019) 'Industrial Internet of Things: Challenges and opportunities', *International Journal of Computer Applications*, 975, pp. 8887–8895.

- MPIF (Metal Powder Industries Federation) (2021) *Gas Atomization Technology Handbook*. Princeton, NJ: MPIF.
- Pan, Y., Guo, X. and Li, M. (2021) 'Digital twins in process manufacturing: Applications and challenges', *Computers in Industry*, 134, pp. 1–12.
- Peterson, K. and Branscomb, D. (2018) 'Implementing predictive maintenance in large-scale industrial systems', *Journal of Manufacturing Systems*, 47, pp. 70–80.
- Srinivasan, M. et al. (2020) 'Real-time process monitoring in additive and powder metallurgy manufacturing', *Sensors*, 20(20), pp. 1–23.
- Thoben, K.D., Wiesner, S. and Wuest, T. (2017) 'Industry 4.0 and smart manufacturing: A review of related technologies and challenges', *Procedia CIRP*, 63, pp. 110–115.
- Zhang, X., Tao, Y., Jia, J. and Qu, J. (2022) 'A review of research on powder prepared by gas atomization', *Powder Metallurgy Industry*, 32(3), pp. 96–106.
- Sofoluwe, O.O., Adefemi, A., Ekemezie, I.O. and Babayeju, O.A. (2024) 'Challenges and strategies in high-pressure high-temperature equipment maintenance', *World Journal of Advanced Engineering Technology and Sciences*, 12(1), pp. 250–262.