Automated Leak Testing for Cylindrical Cell Automotive Battery Modules: Enabling Data Visibility using Industry 4.0

Rohin Titmarsh
Automation Systems Group
WMG, University of Warwick
Coventry, United Kingdom
rohin.titmarsh@warwick.ac.uk

Robert Harrison
Automation Systems Group
WMG, University of Warwick
Coventry, United Kingdom
robert.harrison@warwick.ac.uk

Abstract— **Automating testing within production can have many benefits in terms of productivity, accuracy and visibility of performance. Particularly in the case for air leak testing for small volumes, such as the application of cooling systems for battery modules in packs for automotive use. Accuracy of the test is key in identifying good parts from bad parts. With this volume and application, the external factors must be heavily controlled in order to maintain consistency, so automation becomes an attractive method to control this. Not only this, but using Industry 4.0 technology such as Industrial Internet of Things, IIoT, the operator and engineer can be empowered with data, not only from the results, but of the test equipment and environment itself. This creates opportunities for the data to be fed back into the process upstream and downstream. This paper explores the automation of this application, and how the visibility of the data can inform downstream and support processes, recommending a model to implement that could be scaled to similar applications.**

Keywords—Automated testing, leak testing, Industry 4.0, IoT, IIoT, predictive maintenance, equipment monitoring

I. INTRODUCTION

Within the automotive industry as more Original Equipment Manufacturers, OEMs, push to electrify their products and gain larger market share, not only in the premium niche space, but in the mainstream space also, larger amounts of battery packs must be produced to suit the needs of these products. Packs consist of modules, which must be cooled and heated to maintain optimum performance and longevity of the product whilst in use. Therefore, within the production of these packs, the testing of these cooling systems must be accurate and keep pace with the production of modules. Searching for literature on automated solutions to this type and application of leak testing draws few to no results, so there lies an opportunity to develop this capability.

This paper looks at using automation and emerging technologies within industry, to create a concept for a standalone automated leak testing unit that could be integrated with manufacturing facilities off or on-line. This concept could be suitable for higher volume manufacturers or niche low volume manufacturers. In keeping with new and state-of-the-art manufacturing systems, there are also opportunities to connect and integrate technologies associated with Industry 4.0. For example, a remote-monitoring system using an IoT model and machine learning to offer process analytics and predictive maintenance. The context of this investigation is through the AMPLiFII 2 project, an Innovate UK funded project investigating the implementation of an Automated Module-to-pack Pilot Line For Industrial Innovation. The project is multi-faceted, but the Automation Systems Group's part in the project is to look for process improvements to increase the quality of the product, and further process automation opportunities.

II. LITERATURE REVIEW

A. Leak Testing Technologies and Methods

There are several leak testing technologies and methods available on the market, from the most basic, suitable for development work and the smallest volume production runs, to higher-tech solutions for mass-production. For the concept of a standalone station that could be integrated into a facility, bubble testing is being excluded, as the method is not conducive to collecting data in a controlled way, or being able to control the test in the way that panel-based tests can be driven. Methods considered are pressure decay, mass flow and helium testing [1]. Pressure decay and mass flow are both air based tests. Pressure decay represents the more commonly used approach in industry, applies an overpressure to the component under test to simulate operating conditions [1]. Where the measurement signal from pressure decay tests is related to the size if the test volume, mass flow measurement signals are independent of the test volume, atmospheric pressure and atmospheric temperature, which provide benefits for accuracy as well as a shorter cycle time [1]. Helium testing involves using sniffing devices to detect the helium escaping the component under test. This has advantages and disadvantages, as it could be used to identify leak positions when small amounts are used. However, it is a more costly option and would need to be closely controlled, as trace amounts left over from previous tests could reduce the accuracy of future tests. This can be countered by adding ventilation and monitoring systems to the concept. With all these methods, external influences such as drafts, temperature changes and movements of inlet and outlet pipes must be guarded against.

B. Automated Leak Testing

There are several examples of automated leak testing in other industries available through literature. However for the application of small test volumes, for automotive battery modules there is little to no published papers available. The results of these searches are presented in Table 1.

Several patents were found registered between 1970-2000 but critically none around the time of the emergence of the 4th Industrial Revolution [2] [3] [4] [5].

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There are many benefits to be exploited from automating the test, from reducing the cycle time to increasing efficiencies and productivity of human operators [7]. Critically, for this application, the reliability and reproducibility of those results can be improved by decreasing errors from manual intervention [8]. Fundamentally, if the data being collected is inaccurate then the value from analytics and supporting data systems will be diminished. It is clear that much development work has been done in the space of cooling for automotive battery modules for electric vehicles, including through CFD models [9]. Therefore, the space for developing best practices for testing cooling systems during manufacturing, and the use of data to support this, is open.

C. *Industry 4.0 Technologies*

Industry 4.0 has introduced new technologies focused on the integration of machines and data. Predictive maintenance and equipment monitoring are methods and technologies that are not necessarily new, but through the use of big data and the Internet of Things, IoT, or IIoT as it can be known, can be harnessed and used in ways that thoroughly enhance productivity and visibility of key process and product data [6] [7]. It is highly likely that the product data will already be visible, as this will be in the form of the leak rate or pressure drop in most cases found. The process data however may not always be clear. For example, the data of the number of tests that have been performed, or amount of pressure the valves have been subjected to cyclically may not be available. This information could help to inform whether the next test cycles would produce erroneous results, or operationally, whether parts need to be serviced or replaced before another production run.

TABLE I SEARCH TERMS AND THEIR RESULTS

Search term	**Relevant sources found**	**Industries/applications discussed**
cooling system leak testing automation	4 - patents	Refrigeration systems, Internal combustion engines, Welding apparatus
automotive manufacturing cooling system testing	0	Internal combustion engines,
automated leak testing	0	Oil & Gas pipelines
"detection of leaks" test generation	0	Oil & Gas pipelines, Android OS development
automated air leak testing	0	Industrial facilities
electric vehicle battery system	0	EV batteries, Module design, Pack design
automotive battery cooling system leak testing	1 - article	CFD
cooling system leak testing automation	0	Pipelines
automotive manufacturing cooling system leak testing	2 - articles	Internal combustion engines

III. METHODOLOGY

Using the technologies discussed in the literature review, a concept can be pieced together for the test station. The first step, taking into consideration the external factors that can influence the testing using pressure decay or mass flow, an enclosure for the test station must be designed. Key design considerations for this enclosure include the following factors:

- Temperature monitored – as a minimum, if the temperature rises or falls below a certain point, possibly inline with the temperature conditions that the cooling systems were manufactured in, the test should be halted or re-run

- Temperature controlled – on top of monitoring the temperature, controlling the temperature of the enclosure to maintain a stable level would not be essential but desirable

- Materials – the enclosure panels can be made of heat reflecting materials and colour

- Guard door – the enclosure can be completely sealed so that operators and drafts can not interfere with the test running. This could include an automatic locking mechanism so it is not possible to open the door while the test is running if desired

Figure 1 shows a schema of how the mechanism by which flow of information can connect the operator, engineer and data sources, through a combined dashboard.

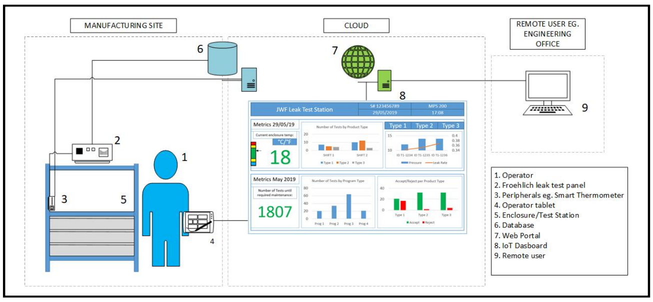

FIGURE 1 AUTOMATED PROCESS SCHEMA

- Item 1 identifies the operator. The operator would insert and remove the device under test and then be able to monitor the test as it runs without having to get involved, through the use of a dashboard, item 8.

- Item 2 represents the test panel, which controls the air flow into the device under test, along with all the other relevant test settings.

- Item 3 represents peripherals. These could be in the form of bar code scanners to read part numbers, which could inform the automatic selection of a test program, eliminating the chance for operator error. It could also include the thermometer to monitor the temperature of the atmosphere within the test enclosure. The temperature readings could be fed into the panel to give a go/no-go signal to the panel whether to run the test, if satisfactory levels are met.

- Item 4 represents the operator's device to access the dashboard of metrics for the test.

- Item 5 is the test enclosure. This is illustrative.

- Item 6 represents the database on which the test results and process data is stored. This could reside physically,

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within the manufacturing site, which would add benefits when considering cyber-security. However, there are also benefits to it residing in the cloud, for example less maintenance of hardware.

- Item 7 acts as the web interface to access the data stored on the database.

- Item 8 shows an example of metrics that could be displayed on the dashboard. Data could also be shown depending on a user/role-based access system, showing the most relevant information for that particular user.

- Item 9 shows a remote site, for example the engineers office or a supplier monitoring desk if a support contract was in place.

In Figure 2 an example of a dashboard for the leak test process is shown. On it are statistics based on product results,

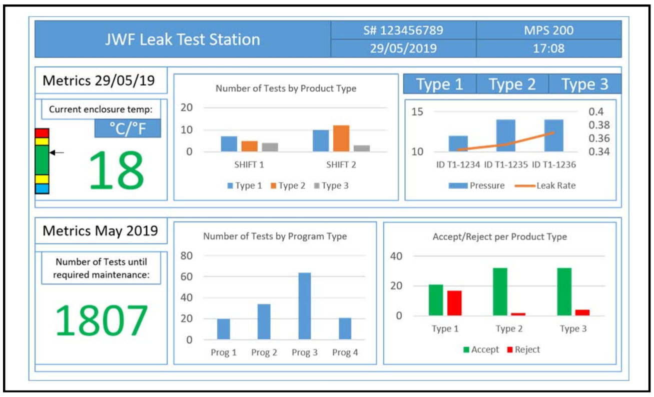

FIGURE 2 IIoT DASHBOARD SHOWING PROCESS DATA

which could include control charts for certain product types, and operational statistics for the station itself. These could be observed by the operator and engineer, each having a tailored view to suit their role. For example, the engineer could have more operational statistics than the operator, to aid their function in tracking maintenance and ordering spare parts. In this form, it enables an advanced equipment monitoring process to be developed. In combination with a predictive maintenance model, there is the potential to drastically reduce machine downtime.

IV. CASE STUDY

The case study presented in this paper is for a cylindrical cell battery module manufacturing line, as part of the Automated Module-to-pack Pilot Line For Industrial Innovation (AMPLiFII) project. The line was designed for flexible manufacturing, and can support module designs that include a cooling system installed. The leak testing for cooled modules currently uses pressure decay, however that test panel could be replaced for a mass flow system, for reduced cycle time for larger production runs. The flexibility of this line means that having the leak test station integrated into the line is not required, but using this approach means that the product must be transported from the line to the test station during manufacturing. If an organisation were to want the leak test station integrated, then several leak test stations may be required, or the line configured in such a way that the leak test station intersects the track at multiple points. Figure 2 shows the process as designed for the levels of automation discussed in this paper. Current process dictates that a cooling system is tested multiple times during the process, to ensure no faults forward. This currently includes firstly testing the cooling system as an assembly in a jig. The subsequent tests are once the cooling system assembly has been inserted into the module and other parts and process carried out. Therefore, barcode reading and automatic program selection become essential at this stage, as operators could easily select the wrong program, particularly if different size and type modules are being produced on the flexible line at one time.

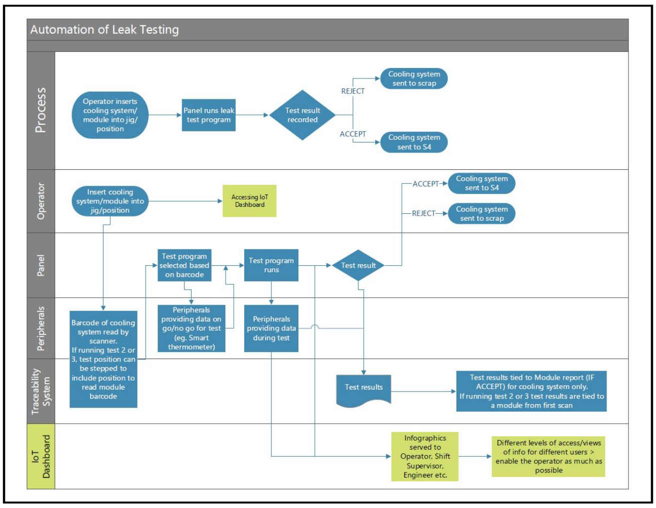

FIGURE 3 AUTOMATED PROCESS FLOW

V. CONCLUSIONS & FURTHER WORK

The main objective of this paper was to provide a technical proposal for integrating leak testing methods and devices to a manufacturing line for cylindrical cell battery modules. This is achieved through the analysis of leak testing technologies, combined with the view of Industry 4.0 technologies in development and available on the market today. The concept can be scalable and adaptable through modifications. As a standalone test unit, or as an integrated unit to a manufacturing line, there are key considerations to monitor and control, as to not reduce the reproducibility and reliability of tests. When properly controlled, this data and information can be communicated and accessed by operators and engineers to enhance the usage of this test.

The authors look to setting up collaborative projects where solutions as described in this paper can be constructed, tested and put into use. The commercial viability, performance and flexibility would all be key indicators of the proposed product success as a testing solution. Other areas of automation and technologies related to Industry 4.0 can also be applied, such as augmented reality (AR) to inform operators of real-time data, such as temperature readings and when the test is running, and completed. A connected supply chain could also be incorporated, linked to machine learning algorithms monitoring the current use and future planned use, to automatically schedule machine services and part changes.

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