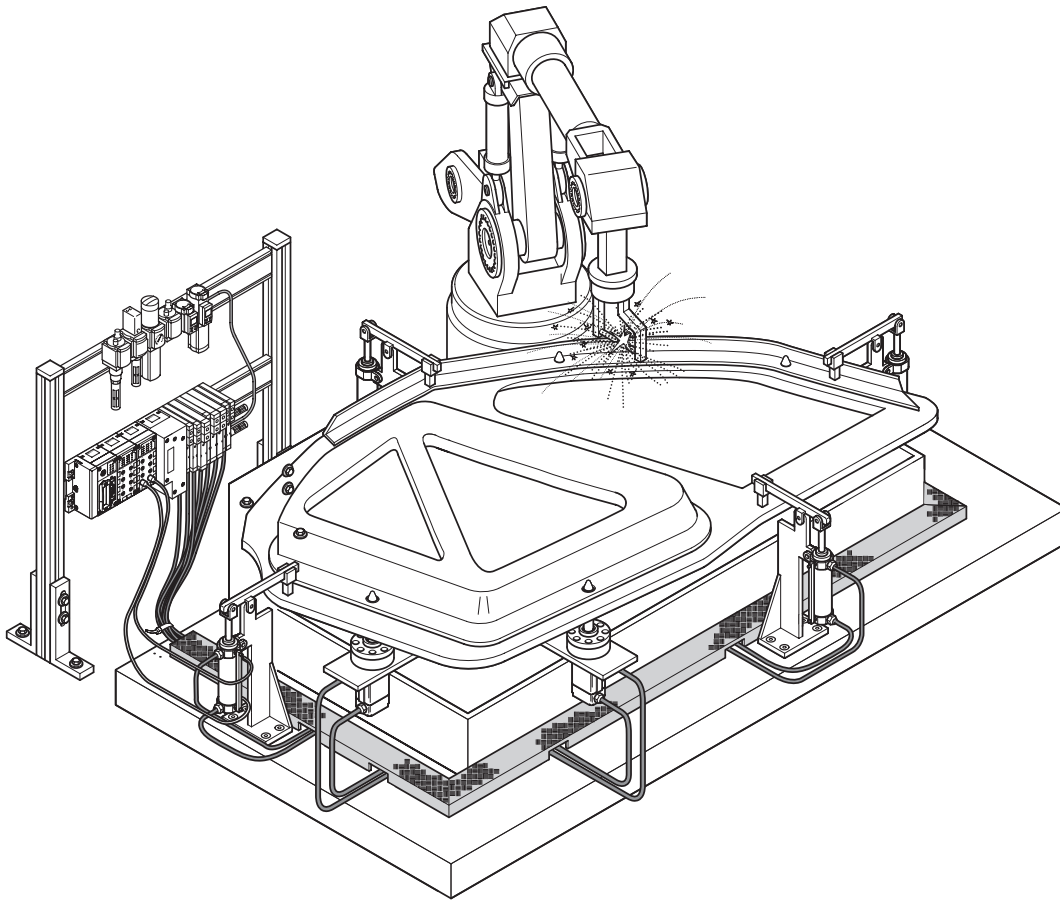


White Paper: Predictive maintenance for pneumatic drives using the example of the servo-pneumatic welding gun



Implementing new trends such as cloud computing, IoT and big data can open up huge savings potential for maintenance in car body manufacture. This white paper uses the example of the servo-pneumatic welding gun to look at how challenges can be overcome and how substantial productivity gains can be achieved with predictive maintenance.

Find out more about:

- Concept and basic architecture
- Step-by-step plan to minimise complexity and risks
- Data analytics and data transparency
- Condition monitoring and AI models
- Business case and data sovereignty

Executive summary

Car body manufacturing with its process chains of tool shop, press shop, body shop and paint shop is an integral part of automotive engineering. It also offers great savings potential in terms of energy and maintenance costs. Energy efficiency in the body shop, with its considerable use of pneumatic drive technology, is a topic that has already been discussed and promoted for a number of years¹.

How can implementing new trends such as cloud computing, IoT and big data now also unlock savings potential for maintenance? This paper describes how challenges in maintenance can be successfully overcome and how significant productivity gains can be achieved in customer projects by incorporating cloud-based added value services, based on the example of the servo-pneumatic welding gun for key accounts in automotive engineering. Component and process data provides important starting points here for interpreting the system condition.

This approach also allows general conclusions to be drawn about maintenance in other industry sectors, wherever pneumatic drives are being used.

¹ Innovation alliance. Planning the efficient use of compressed air in the body shop. Technical report, Green Carbody - Project consortium, 2013.

1. Focus on predictive maintenance

1.1 The challenges

Predictive maintenance is a topic that is increasingly a focus of attention. The step from preventive maintenance to predicting the machine status is a trend, but also a significant challenge, to further optimise maintenance. Can the promise actually be fulfilled? The fact is that, compared to classic condition monitoring approaches, the Industry 4.0 toolkit now provides additional opportunities, for example by gathering machine and process data and evaluating it using AI models in the cloud.

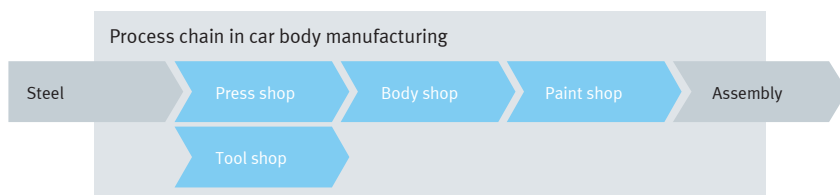


Figure 1. Stages within automotive engineering ¹

1.2 Added value through data interpretation

Nowadays mechatronic system products from Festo, such as drives for welding guns for resistance spot welding, already process a lot of data and compress it so that it can be used as diagnostics for maintenance. But simply providing and displaying data is not enough. The challenge is to use the data from the devices and from the application environment with the knowledge of the processes to deliver real added value for the end customer. Only then can we create new business models and saleable products for the component manufacturers.

As part of the flow of information, the prediction must also be reported back to the relevant system/maintenance technician. This innovation project in the body shop, which has been initiated by the end customer, has been selected and implemented following a specific maturity management process.

First, the project idea is presented in a transparent manner and categorised. Next, the potential of the solution is examined and then confirmed in a proof of concept. This is followed by its implementation in a larger-scale pilot project, and ultimately by its final roll-out for series use with standardised components.

In this context, Festo has already been working on a digital strategy and developed products and services, and above all software solutions, for customers (², ³). However, this type of development demands a new approach, since the Industry 4.0 business requires more dynamic methods than the classic product development in standard business. Not everything can be fixed or specified as requirements in advance. The route to customised solutions, on the other hand, is based on knowledge of the application, and leads to continuous and innovative approaches and shared learning. The experience gained then provides the potential for it to be replicated in the standard business.

This is a tried-and-tested basic process for these projects: start with a specific key account project, learn from it, continuously develop the approach, but then also make sure that it is replicated and that standards are developed.

➤ Added value can only be achieved by correctly interpreting the data. This requires knowledge of the application.

¹ Innovation alliance. Planning the efficient use of compressed air in the body shop. Technical report, Green Carbody - Project consortium, 2013.

² Roger Kehl. The new field of the CIO: digitalisation – from the component to the cloud. Presentation, 2017. Talk at the VDMA Congress.

³ Jan Bredau and Filip Kubis. Predictive maintenance for customised system solutions/servo-pneumatic welding gun. Presentation, 2018. Talk at the VDMA Congress.

1.3 Savings potential as a goal

The goal was to show savings potential in feasibility studies and together create added value.

➤ Algorithms should predict component failures.

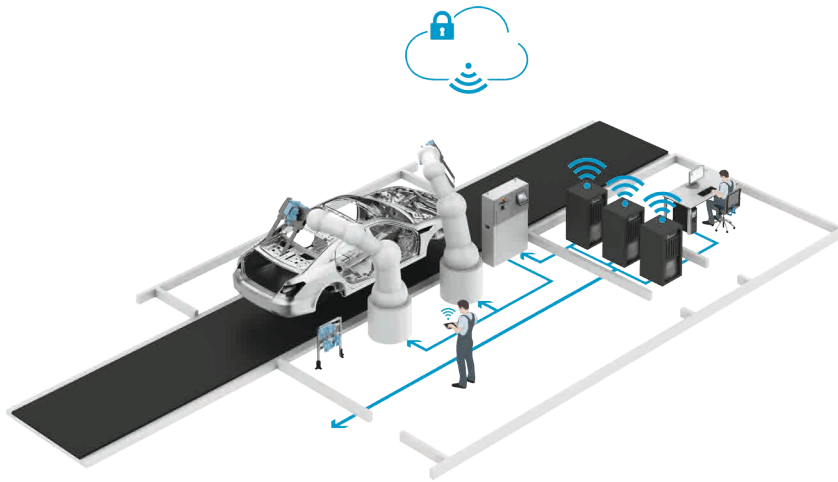


Figure 2. Connecting the welding gun to the cloud via the plant PC

The premise put forward was that a flexibly variable or minimal system of data gathering is crucial in order to control the volume of data (“as little as possible, as much as necessary”). Additional sensors and devices should, if at all possible, be dispensed with. The servo-pneumatic welding gun is a mechatronic system whose drive package and the associated commissioning software has been used in the body shop for years; it is jointly and continuously further developed by the end customer and the technology supplier in line with production-related requirements (Figure 3³).

While production is largely optimised these days, maintenance workloads in the automotive industry still show a potential for optimisation. Machine and system availability is certainly high. But the effort needed to achieve this level of availability (planning maintenance, maintaining stocks of parts, preventive replacement, repair, service calls, etc.) needs to be minimised. The target group for the approach developed here is therefore very clearly maintenance departments. Because of the significant savings potential in the body shop, the objective of the development project was to implement algorithms for condition monitoring right up to the prediction of component failures on the welding gun, and to integrate them into the existing infrastructure.

³ Jan Bredau and Filip Kubis. Predictive maintenance for customised system solutions/servo-pneumatic welding gun. Presentation, 2018. Talk at the VDMA Congress.

2. Implementation on the servo-pneumatic welding gun

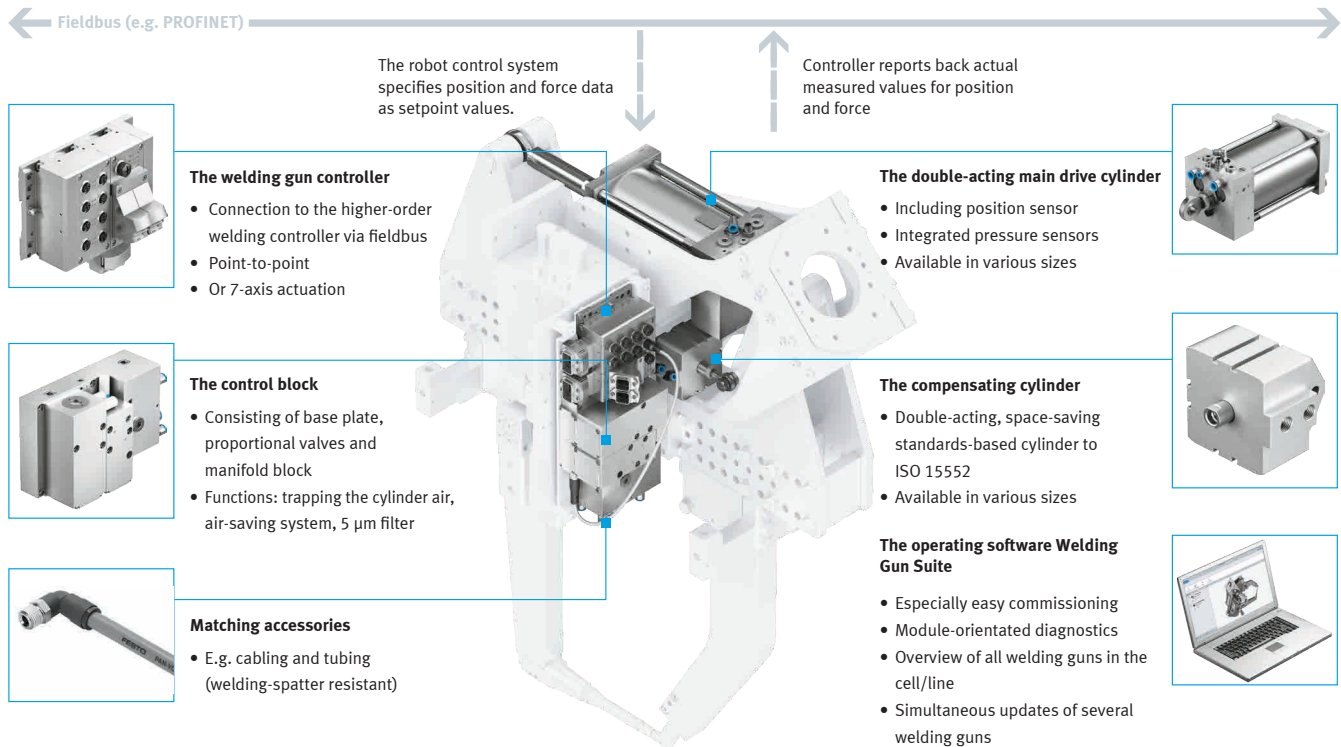


Figure 3. The main components of the servo-pneumatic welding gun

Welding guns come in C and X designs. Modern drive systems predominantly use closed-loop control, either servo-electric or servo-pneumatic.

The servo-pneumatic drive system consists of:

- Drive cylinder with integrated pressure and position sensors
 - Compensating cylinder with regulator for the balancer function
 - Controller with fieldbus connection to the robot (generally PROFINET)
 - PC software with graphic interface for commissioning, operation and diagnostics
- The robot provides the system with the setpoint values for position and force control.

2.1 Concept and basic architecture

In the concept, a software program (Festo Welding Gun Cloud Connector) is added to the existing plant PC of the robot cell. This gathers the welding gun's diagnostic data and sends it to a cloud entry point. Running in the cloud is a maintenance application that visualises the data in the browser (maintenance dashboards) and evaluates it with respect to the expected service life on the basis of causes of wear and learned failure causes (Figure 4).

2.2 Step-by-step plan

To meet the long-term goal of predictive maintenance, a step-by-step plan was created in order to reduce the complexity and risk inherent in implementation and to generate added value for the maintenance technician with each step.

- 1 Definition, formulation of a hypothesis and cloud connectivity
- 2 Gathering, displaying and evaluating data; condition monitoring models
- 3 Creating physical models and AI models with a focus on predictive maintenance
- 4 Roll-out of the predictive maintenance product

➤ Step-by-step approach minimises complexity and risks.

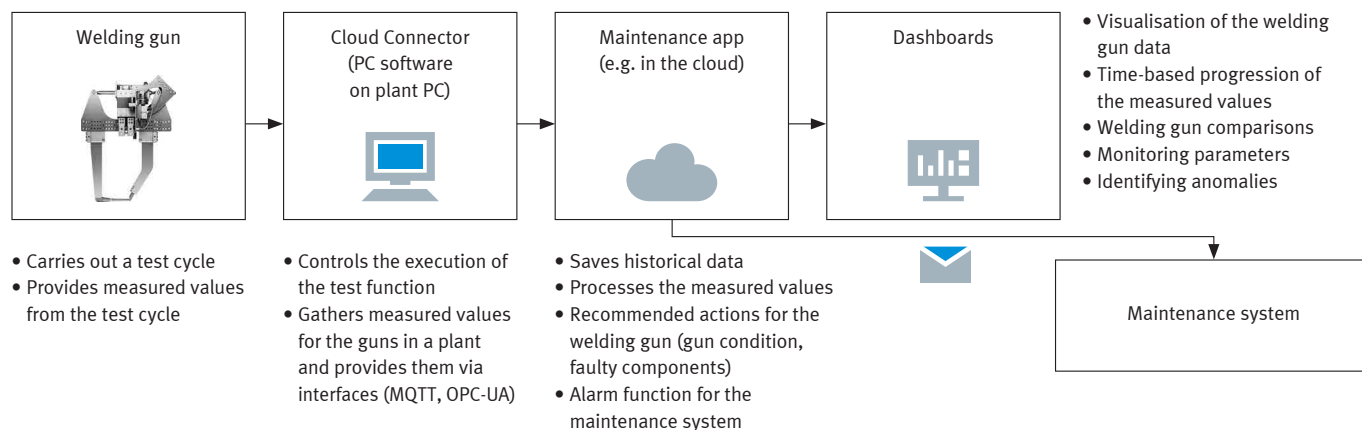


Figure 4. Connecting the welding gun to the cloud via the plant PC

The first challenge for both end customers and system suppliers is to transfer the welding gun's data from production to the cloud. Requirements for network traffic, processor loads and data security were not yet known at this time. If these requirements cannot be identified and implemented, the use case cannot be realised using this basic architecture.

2.3 Test function of the drive system

The definition of the data to be saved was influenced by discussions about the expectations of the data scientists, and by what is technically feasible and technically useful. While the data scientist wanted sensor and environmental data with the highest possible resolution, the welding gun experts had to apply the brakes: the components used that have been tried and tested for many years cannot provide the Festo Welding Gun Cloud Connector with the sensor data within milliseconds.

Apart from this purely technological restriction, the welding gun domain experts were unanimous that saving data to this level of detail does not offer any added value and would only have resulted in increased costs for the data transfer and processing in the cloud. Instead, it was decided to carry out a test cycle during which the welding gun, outside of productive operation, was aligned in a specific orientation approximately 3 to 5 times a day and had to carry out prescribed motion tasks (positioning and building up force). During the motion, characteristic values such as positioning times or friction in the welding gun were measured and processed further in the cloud application as the result of the test function.

In addition to this process data, component data (e.g. firmware version, serial number), calibration data, controller data and operating data (e.g. number of weld spots, operating hours) was also transferred and saved. This data also provides important information that is required to interpret the welding gun's condition.

With this solution, the volume of data is low; less than 10 KB of data is transferred per day and welding gun.

➤ Process and component data provides valuable information – despite the limited data scope.

2.4 Formulating a hypothesis

The definition of the test function is closely linked to the topic of formulating a hypothesis. The suppliers of the IoT solutions should formulate hypotheses early on about the correlation between measured variables and fault effects/events. This should also take the know-how of the domain expert into consideration in the hype phase of IoT and big data. This should increase the probability of the projects' success without stumbling around in the dark with a purely data-driven approach.

There was an assumption that the positioning times, force build-up times and friction of the welding gun was related to cylinder wear, cylinder failure, cylinder leaks, system leakages or unexpected external stress (Figure 5). This should be demonstrated in steps 2 and 3 of the step-by-step plan.

2.5 Gathering and evaluating data

Following the successful test in an initial pilot system, the application software was rolled out to 250 welding guns. The welding gun data was continuously gathered and evaluated. Since then around 2,500 systems have been connected.

Initial tests in the body shop resulted in heavy traffic in the production network. This was influenced by the software, so the Welding Gun Cloud Connector was adapted. The test function data shown in the dashboard pointed to an unexpected timing sequence of the test function and required regular checking by the welding gun experts. They needed to clarify whether it was caused by a bug in the cloud communication or by other effects (physical model).

Despite the extensive domain expertise and the manageable complexity of the cloud communication software, assessing the results involved a noticeable workload on both sides. The following illustrations show an example of a dashboard containing simple asset data up to the fault curves.

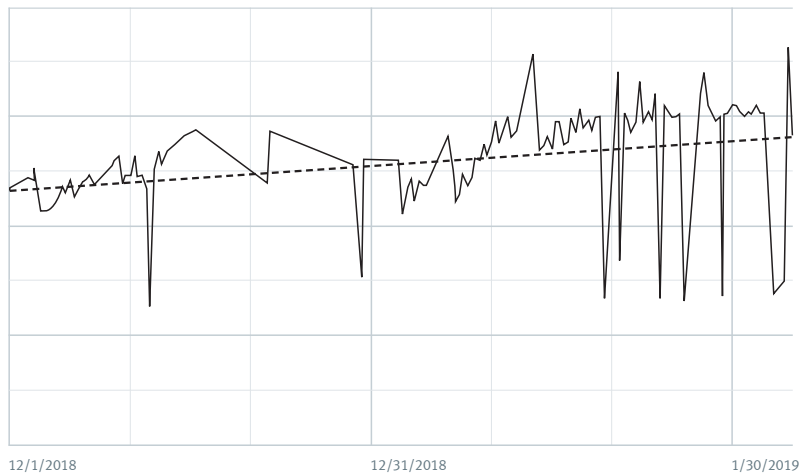


Figure 5. Progression of the main cylinder's positioning times

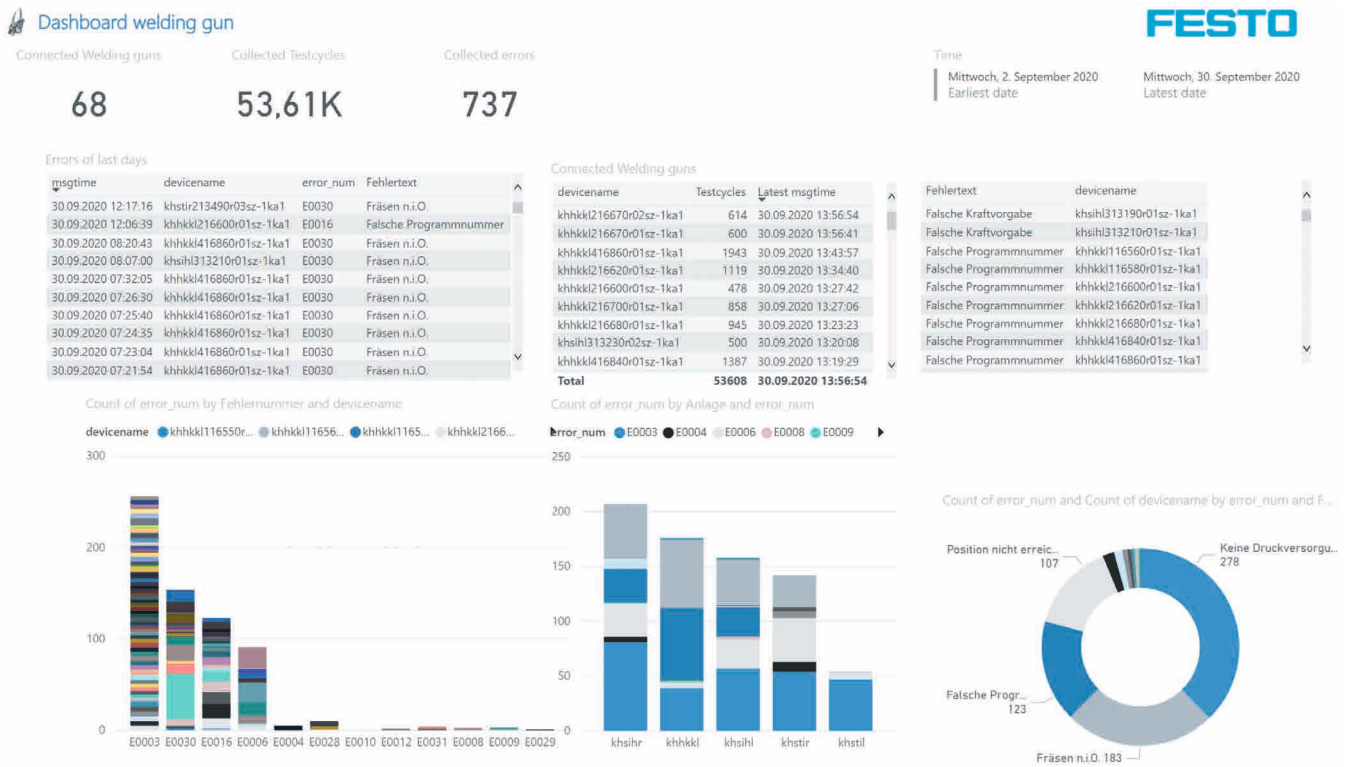
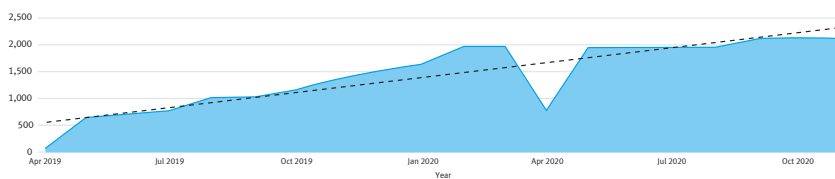


Figure 6. Sample representation of a dashboard

Connected welding guns



Executed test cycles

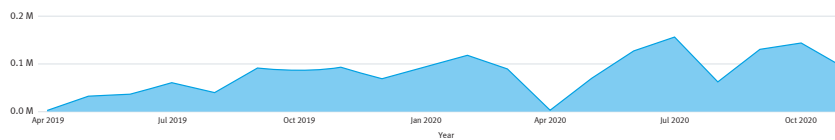


Figure 7. Connected welding guns and executed test cycles in the time-based sequence

2.6 Data transparency: 25% fewer malfunctions

The data is visualised in the browser using Power BI, a business analytics application. To reduce the complexity and interfaces in this early phase of the project, the project team deliberately decided against a higher-performing solution. The software allows the dashboards to be configured with minimal effort and just with a knowledge of Excel. Even just the ability to visualise overviews (What firmware is running where? Which controller parameters are used and in which gun?) provides the maintenance technician with added value. If there is a stoppage, they can make an initial diagnosis of the cause of the fault based on the fault pattern. After the test phase, once the dashboards are stable, they will be successively replaced with higher-performance and lower-cost web interfaces tailored to the use case.

After evaluating the welding gun data, it was possible to identify further cases of wear before the actual failure. These were gathered and evaluated in a cost/benefit analysis at the end of the year. All in all, the downtimes for malfunctions of more than 30 minutes could be reduced by 22%. The number of malfunctions was reduced by 25%.

➤ By evaluating the data in simple dashboards downtimes were reduced by 22% and malfunctions by 25%.

2.7 Condition monitoring and AI models

In addition to evaluating friction characteristic curves or positioning times over the service life, initial limit values for these characteristic values should already be determined in the second stage so that the welding gun status could then be visualised via the maintenance dashboard in line with VDMA Standard Sheet 24582 4.

As in condition monitoring, the question was raised during the course of the project about the correct limit values for a warning or a critical alarm. Due to the large variety of gun geometries, different controller parameters and even fewer empirically established figures (too few component failures for statistical relevance), determining the limits is now an essential task.

Originally, according to the step-by-step plan, the welding gun's characteristic values were to be monitored based on its condition before predictive monitoring methods were applied. However, in order to also gather empirically established figures using the machine learning methods at an early stage, the correlation between the results of the test function and the feedback about faults from maintenance was also examined using this approach.

The initial results show, for example, that there is a correlation between the failure of a main cylinder and the parameters recorded by the test function. It was then possible to train a model that correctly predicted a failure during the course of the project. Based on the result, cylinders were replaced as a preventive measure. Tests confirmed that the cylinders were coming close to the end of their service life.

➤ Proven by machine learning: there is a correlation between the failure of a main cylinder and the parameters recorded by a test function that makes it possible to predict the service life of the cylinders.

⁴ VDMA. Fieldbus-neutral reference architecture for condition monitoring in factory automation. Standard Sheet 24582, 2014. Industry standard.

2.8 Business case and data sovereignty

In addition to working out the technological basis, the topic of business models is essential for Festo. Is it pure development or an actual product? There are two approaches:

- Case A: Data is provided by the system supplier, the end customer/operator evaluates it themselves.
- Case B: Data is compressed, evaluated by the system supplier and the operator is supplied with information/instructions on maintenance.

As a system supplier, it is our goal to offer the customer an open product that they can use according to their needs. Without data from the customer, the product cannot be optimised either. This results in a win-win situation. However, the software should not just be an add-on, but it should be a long-term, saleable product.

In this case, the decision was made on the customer side to leave the evaluation and analysis to the domain experts of the pneumatics supplier. The Festo software gets data from production and mirrors results back to the end user. This approach is called “software as a service” (SaaS).

In terms of data sovereignty, the user can always decide what data it supplies to the domain expert (in this case Festo). Due to the speed of development in the IoT environment (increasing processing power of the hardware, gateways, cloud solutions, new algorithms), the idea of making a sale and maintaining a single software delivery over many years was not considered appropriate. This led to a subscription model in which the costs were calculated per welding gun and per year, and with the software being continuously improved. The development of a business model and the corresponding product positioning strategy must take place at the beginning, it cannot be left until after the technology has been developed.



Data sovereignty remains with the user at all times.

Festo offers software as a service (SaaS) here.

2.9 Partners

The variety of technologies, which in some cases were unfamiliar, meant that the welding gun experts were assisted by IT experts who were able to provide advice on the configuration of cloud components such as IoT hubs, databases or websites.

Various workshops were held to outline future methods for the different cloud services and local maintenance systems to communicate together.

3. Conclusion and outlook

Reducing unforeseen production downtimes and costs related to service/complaints requires a minimum level of cooperation between the system supplier and end customer. The introduction of maintenance strategies involves a mutual understanding and trust, since there is an initial financial commitment and it is not possible to guarantee long-term added value at the beginning of the project. A lean approach for the implementation of predictive maintenance in production can work as long as domain experts are supported by IT experts, programmers and data scientists.

The step-by-step approach is considered to be effective because the project risks are minimised and added value can be generated in maintenance even in intermediate steps.

In the case of the welding gun, data transparency and early detection of cylinder failures are the first successful outcomes. This meant that around a quarter of major malfunctions or downtimes in the car body shop could be avoided since repairs could take place during idle times.

Furthermore, this approach has the advantage that the status of the welding guns can be visualised in the customer's control system. This can be used to generate automatic orders and an individual gun lifecycle, while various filter functions and options for comparison can be created. The early detection of leaks in the components results in a reduction of energy consumption.

Key factors for this successful improvement of maintenance are the perseverance of the project partners and the deliberate incorporation of phases in which only data and fault cases are gathered and evaluated over an extended period. The development of the technology and the demonstration of added values must go hand in hand. In addition, a business model for positioning the software product needs to be defined.

In the next steps, algorithms for detecting component failures are refined (e.g. detection of broken brackets). An interface should be created between this software and the cloud solution in order to display limit value violations in the existing maintenance systems.

➤ Early detection of imminent failures, status modelling in the customer's control system, individual welding gun lifecycle and energy savings are the value added by Industry 4.0 approaches.

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