Symbiosis of Toolmaking and Serial Production

Guideline to the Development of Predictive Maintenance Systems for Serial Producers and Toolmaking Companies

Unforeseen downtimes in serial production are always accompanied by high costs, making it essential for machines to be serviced in time. Because sensor, transmission and data storage technology have taken a big leap forward in recent years, predictive maintenance has already been realized in some industries, demonstrating a tangible benefit of Industry 4.0. The WZL and the WBA have developed a guideline for this.

Production breakdown is the worst-case scenario for every serial producer! In automotive production, five minutes of downtime costs an average of EUR 100,000 [1]. Other industries do not have to cope with financial consequences through production downtime as serious as this. However, to avoid unnecessarily high costs due to unforeseen downtimes in serial production, all responsible parties have to service machines and systems before critical components fail. As the maintenance strategy of choice, predictive maintenance has become prominent in some industries and shows great potential regarding Industry 4.0.

For this reason, the department of Business Development of the Chair of Production Engineering at the Laboratory for Machine Tools and Production Engineering (WZL) of RWTH Aachen University, Germany, has developed a guideline in cooperation with consultants of the WBA Tooling Academy Aachen, Germany, as well as serial producers and toolmaking companies. This guideline aims to enable companies to develop predictive maintenance systems on their own [2].

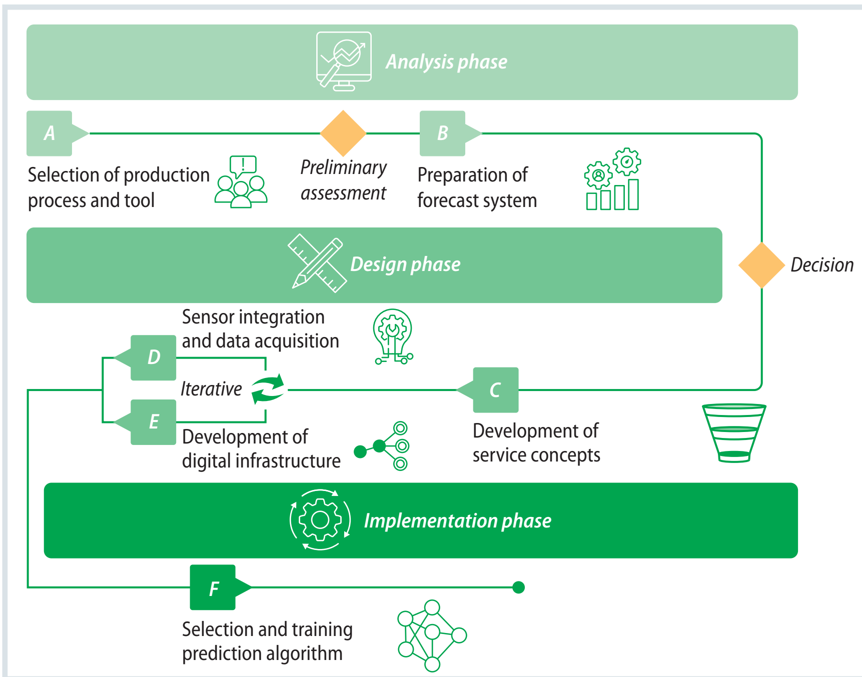

Fig. 1. The guideline for the development of predictive maintenance solutions is divided into three phases: analysis, design and implementation Source: WZL; graphic: © Hanser

The Starting Situation

In industrial practice, downtimes in the serial production of plastic parts can hardly be predicted because pooled process and tool know-how is not available. In terms of the process as well as the quality of plastic products, the used injection molding tools play a crucial role. This means that tool and die making serve as the enabler of serial production, with injection molds being the most important tool category, accounting for 56% of all tools manufactured in Germany [3].

Serial producers often have important process information, but little knowledge about how much their tools are stressed during production. Toolmaking companies, by contrast, have significant know-how about the tools, but rarely have access to process information that is a prerequisite for the application of predictive maintenance measures.

For this reason, close and cooperative partnership between serial producers and toolmaking companies is essential for the application of predictive maintenance. This allows productivity gains and mutual competitive advantages to be achieved through knowledge sharing.

Structure and Objective of the Guideline

The development of predictive maintenance systems is particularly interesting for injection molding companies and their mold-making partners who repeatedly experience tool-related failures in their serial production due to unforeseen disturbances. Predictive maintenance can help these companies to predict incidents like tool failures and to derive counter-measures. This creates the opportunity for toolmaking companies to expand their existing service portfolio. By offering predictive maintenance solutions, toolmaking companies can increase the customer benefit over the entire life cycle of tools and develop supplementary business fields.

The development of such solutions in a cooperation arrangement between serial producers and toolmaking companies requires several iterative steps, which can be skipped or simplified depending on the degree of maturity of existing preliminary work. The generic process described in the guideline presents the systematic development of predictive maintenance solutions in three phases with a total of six steps (**Fig. 1**).

In the initial analysis phase, all relevant prerequisites and requirements for predictive maintenance are recorded. In the design phase, tool, infrastructure and service solutions are developed. Finally, the implementation phase deals with the commissioning, the training of algorithms as well as the definition of interaction points and workflows. The individual steps are described in more detail below.

Analysis Phase: Definition of Requirements

In the analysis phase, the observation area is first defined by identifying and selecting relevant production processes and tools. Predictive maintenance solutions are particularly suitable for cost-intensive products that are manufactured in large quantities with tool failures or resulting component failures leading to costly production downtimes or rework.

These criteria should therefore be taken into account both in the process and tool identification as well as in the subsequent identification of the tool and component failures that occur. In particular, failures that have a high financial impact on the life cycle cost of the tool provide considerable potential for savings and should be analyzed in detail.

This selection process including failure definition is followed by the preparation of the forecast system. It is necessary to record the holistic interdependencies between failures and the associated maintenance measures in order to generate a detailed understanding of the process and the tool (**Fig. 2**). For this purpose, each failure image is assigned certain characteristics, relevant measurements, sensors for recording these measurements, causes of damage and resulting measures.

Based on the determined interdependencies, suitable control and warning limits are defined for the relevant process parameters. These must be logically specified for all previously defined measured variables and are necessary for the subsequent monitoring and prediction of future process conditions.

Design Phase: Service Concepts, Sensor Technology and Digital Infrastructure

In the design phase, the maintenance solution is specified, and service concepts are developed between the serial producer and the toolmaking company. To achieve this, in a first step, the needs of both sides are identified and prioritized. Based on the prioritized needs, specific direct and indirect services are developed and their relevance for both the serial producer and the toolmaking company is evaluated.

In the subsequent step, appropriate sensor technology is selected and integrated. By linking process parameters to occurring failures, the type and number of sensors can be determined. Suitable sensors and their positions on the tool are then identified. To pass on the data gathered by the sensors, a so-called IoT gateway is required. This is a central device that bundles data streams from different sensors and sensor types, pre-processes them and stores them in a cloud or on a central server of the customer.

For analysis and use, the data must be converted into a suitable data model that formally reflects all data to be described and processed as well as their rela- »

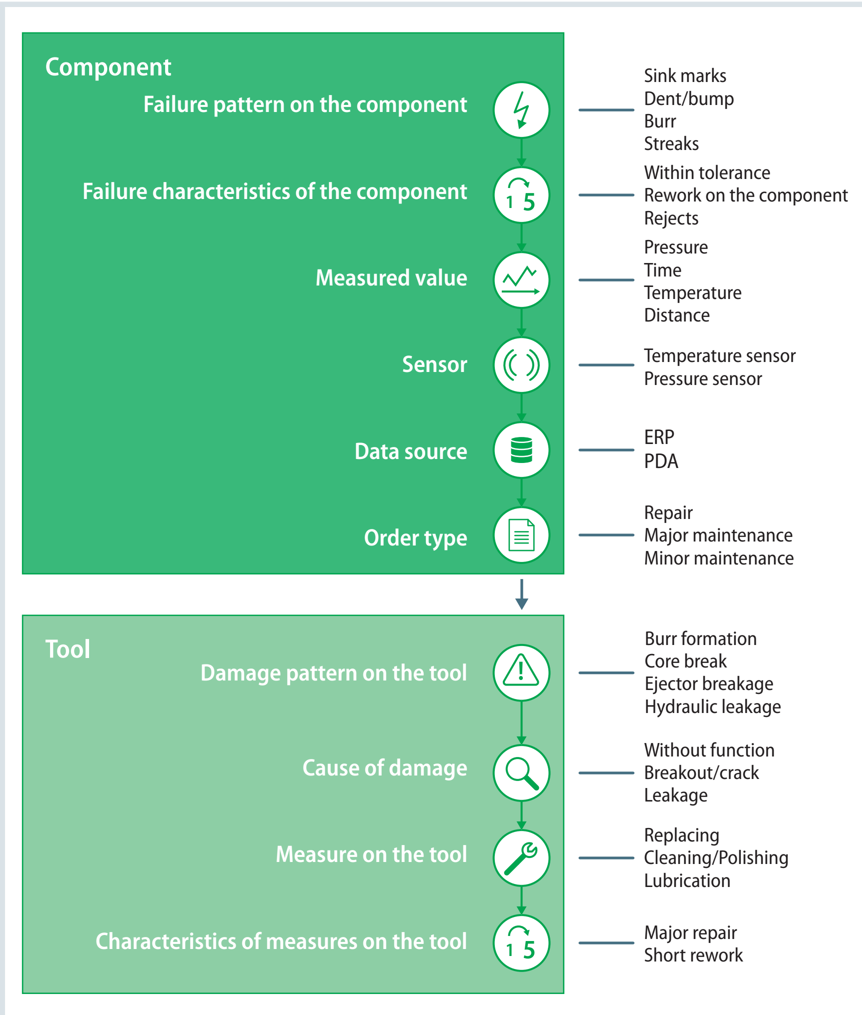

Fig. 2. A systematic procedure, here using injection molding production as an example, allows conclusions to be drawn from defect patterns on the component to damage patterns on the tool and corresponding maintenance measures Source: WZL; graphic: © Hanser

tionships to each other. In parallel with sensor integration and data acquisition, the requirements for a comprehensive data platform must be recorded. Furthermore, corresponding sub-goals for technical implementation are defined and formulated in a specification sheet. Subsequently, the development of the data platform can begin, enabling the visualization of the analysis results for serial producers and toolmaking companies (**Fig. 3**). In the subsequent implementation phase, predictive maintenance is finally established.

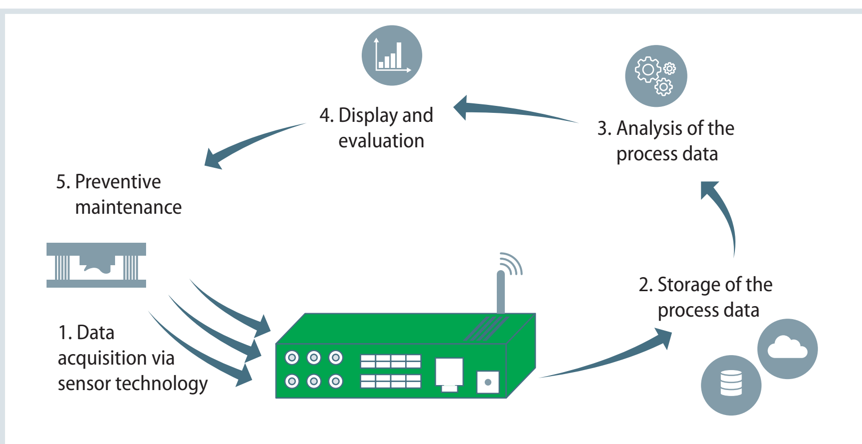

Fig. 3. Process monitoring is used to forecast preventive services and repairs from collected sensor data Source: WZL; graphic: © Hanser

Implementation Phase: Training of the Algorithm

The last phase includes the selection and training of a capable algorithm. The objective is to predict failures, i.e. violations of the predefined control limits, in order to be able to initiate corrective measures preventively (**Fig. 4**). Training of the algorithm is a key factor for ensuring a high prediction quality and thus for obtaining the desired functionality of the predictive maintenance solution.

In particular, the supervised learning approach is suitable for the training of the algorithm, since the training data includes not only the input but also the corresponding output values and is consequently predestined for forecasting tasks. During training, the algorithm learns the relationships between occurring failures and recorded process parameters based on historical data. It is thus possible to reproduce the interdependencies in order to be able to forecast occurring failures and potential maintenance cases even with new data sets.

Result: Improvements in All Significant Areas

The steps described in the guideline for the development of predictive maintenance systems have been validated in cooperation with serial producers and toolmaking companies. For both groups, improvements within the four target dimensions

- strategy,
- profitability,
- quality and
- time

were achieved (**Fig. 5**). Based on specific predictive maintenance applications, tailored services such as the prediction of failures including maintenance measures were developed. In this case, the service had a positive influence on all four target dimensions.

In general, the advantages for the serial producer, representing the service recipient, consist primarily in reduced

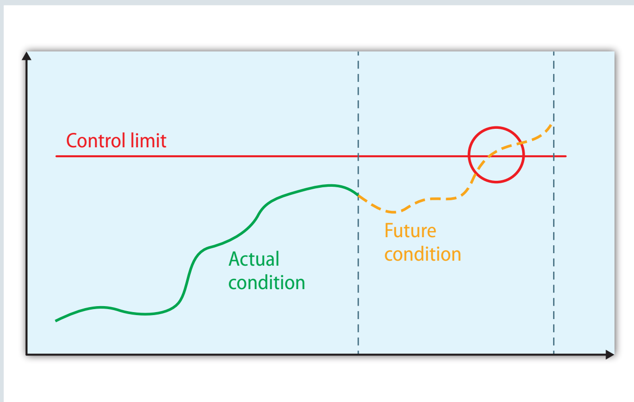

Fig. 4. A suitable algorithm calculates the imminent violation of previously defined control limits in order to be able to initiate preventive corrective measures Source: WZL; graphic: © Hanser

maintenance costs, improved production planning and process optimization. As a service provider, the toolmaking company benefits from the expansion of its service portfolio and the associated competitive differentiation.

An important result of the activities involving the collaboration of toolmaking companies and serial producers was the development of a predictive maintenance platform, which visualizes production and sensor data in conjunction with alert messages. Through different illustrations, the platform provides information about the condition of the production machines as well as the tools and allows for the prediction of necessary intervention in the production system based on the collected data. In addition to displaying information and warnings, it is also possible to manually analyze certain data.

Conclusion

The results of the study show that the use of predictive maintenance solutions offers high potential for increasing machine availability in injection mold production. This can be achieved by significantly reducing unforeseen downtimes. Because maintenance measures can be planned more efficiently (according to the condition), costs can be reduced drastically. By providing these services, toolmaking companies have the opportunity to expand their service portfolio, to effectively differentiate themselves from the competition and to increase their profitability. Through the cooperative development of proactive maintenance solutions, both serial producers and toolmaking companies can benefit equally from appropriate service concepts. ■

Serial producer
Tool making company

		Strategy		Profitability		Quality		Time	
		Breakdown risk	Number of maintenance orders	Maintenance cost	Revenue	Rejects	Complaint rate	Tool-related downtime	Lead time of maintenance task
	Direction of change in KPI	↓	↑	↓	↑	↓	↓	↓	↓
Direct services	Prediction of failures including service and repair	+	+	+	+	+	+	+	+
Direct services	Improved coordination of the maintenance process	○	+	+	○	○	+	+	+
Direct services	Optimization of the production process	+	+	+	+	+	○	+	○
Direct services	Optimization of the tool	+	+	○	+	+	○	○	○
Indirect services	Increase in process transparency	○	○	+	○	+	+	+	+
Indirect services	Generation of new tool knowledge	○	+	○	○	○	+	○	○

Fig. 5. The developed direct and indirect services largely have a positive influence on the key performance indicators (KPIs) within the four target dimensions Source: WZL; graphic: © Hanser

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The detailed guideline and the results of the study can be downloaded in German free of charge from the WZL website:
- **https://www.wzl.rwth-aachen.de/cms/WZL/Forschung/Forschungsumfeld/Forschungsprojekte/Projekte/~cxdqm/WerkPriMa/**

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