Tool Monitoring and Electronic Event Logging for Sheet Metal Forming Processes

Gerd HEISERICH, Andreas JUNGK, Ludger OVERMEYER
Institute of Transport and Automation Technology, Leibniz University of Hannover
An der Universität 2, 30823 Garbsen, Germany

ABSTRACT

This contribution describes some innovative solutions regarding sensor systems for tool monitoring in the sheet metal industry. Autonomous and tamper-proof sensors, which are integrated in the forming tools, can detect and count the strokes carried out by a sheet metal forming press. Furthermore, an electronic event logger for documentary purposes and quality control was developed. Based on this technical solution, new business models such as leasing of sheet metal forming tools can be established for cooperation among enterprises. These models allow usage-based billing for the contractors, taking the effectively produced number of parts into account.

Keywords: Tool Monitoring, Event Logging, Sheet Metal Forming, Production Control, RFID, Wireless.

1. INTRODUCTION

The producing enterprises in the sheet metal forming sector are part of a closely merged supply network with very high requirements regarding adherence to schedules and quality of products. This is especially true for automotive component suppliers, but also for other areas of industrial production. There is considerable pressure to continuously adopt technical and commercial innovations in order to remain capable of persisting in global competition. An essential part of added value is generally created by specific know-how inside the production processes. The forming tools used for sheet metal forming are highly complex devices which are usually developed by specialized companies owning the necessary knowledge and experience (figure 1).

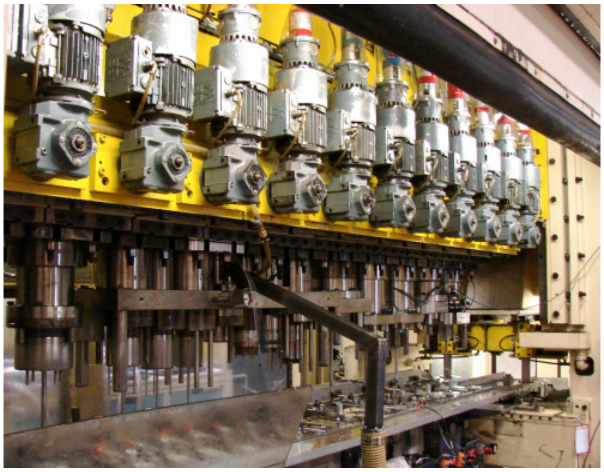

Figure 1: Sheet metal forming press (source: PWO)

Single sheet metal forming companies may face situations in which their production capacity is not sufficient to provide ordered quantities on time or to meet high quality standards. In this case, a relocation of capacities may be considered. In this context, relocation of production capacities specifically denotes the transfer of a forming tool for producing a certain product on another machinery. To do this, the order has to be assigned to another production site of the same enterprise or to an external contractual partner such as another sheet metal plant or a manufacturer of forming tools. In any case it is necessary to provide the internal or external contractual partner with the forming tool, which involves fundamental changes of logistic processes and creates new risks due to possible damages of the tool and possible loss of specific knowledge. By integrating tamper-proof sensors in the forming tools, which are capable of detecting the tools' output, these risks can be minimized, because the contractually agreed utilization of the tool appears to be well checkable.

Another important aspect is the demand for actively documenting important events during a tool's lifetime such as assembly/disassembly on machinery or date and type of maintenance work carried out.

This article is organized as follows: In section 2, an overview of related work and current focuses of research regarding monitoring of machines and tools is given. Section 3 describes the requirements and the system components which were developed. Different application scenarios and corresponding modes of operation are explained in detail in section 4. Furthermore, section 5 gives an extension of the work regarding active wireless transmission of sensor data to a host system rather than storing them in a memory. Results and limits are shown, before the article is concluded in section 6.

2. RELATED WORK

Monitoring of tools or entire machines in production environments has become more and more common due to the increasing availability of sensor technologies and signal processing devices [1, 2]. Research and development focuses on new robust and precise sensor systems which are capable of operating in raw environments on one hand, and on signal processing and evaluation mechanisms for state estimation of the monitored system on the other hand. Approaches based on neural networks [3, 4] as well as fuzzy techniques [4, 5] have been shown to yield useful results.

As an objective, optimized maintenance strategies for critical parts are desired. This is denoted as Condition Based Maintenance (CBM) and is an active area of research in machine engineering, industrial production as well as automotive and aeronautical engineering [6, 7, 8]. For implementing such strategies, systems for gathering reliable information about the tool state are necessary. In comparison to traditional maintenance strategies such as preventive maintenance (i.e. based on fixed maintenance intervals) or corrective maintenance, CBM methods are expected to cut down maintenance costs and to improve the operational availability of equipment.

Even more generally, there is a trend towards integrating intelligent components in machine parts to collect information using integrated sensor structures. These components also have to be able to communicate with each other using electrical or optical signals or even wirelessly using electromagnetic waves [9]. A method to integrate optical communication structures in metallic surfaces has been developed in [10].

3. ELECTRONIC EVENT LOGGING

Application Scenario and Requirements

In this work, a system for automatic detection of the strokes of a sheet metal forming press was developed. The objective was to create an autonomous and independent counter for control and billing purposes. On the other hand, an integrated event logging facility for storing information about a tool's life cycle was desired. This has many advantages regarding maintenance and quality management. These technical systems have to operate under raw industrial environment conditions such as high temperature and mechanical stress (vibration).

Components

The event logging system, which was developed, consists of the following parts: a sensor element for detecting the performed strokes by the forming press; a memory element to store the information gained by the sensor; a battery for the internal electronics and an RFID (Radio Frequency Identification) interface for accessing the memory. For a detailed description of RFID-based data transmission see [11]. The system architecture is shown in figure 2.

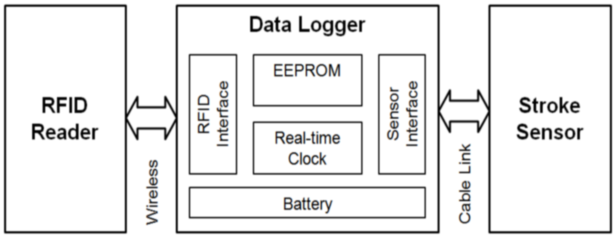

Figure 2: System architecture

Stroke Sensor: Detection of strokes is based on measuring the solid-borne sound inside the tool, utilizing the piezoelectric effect to convert oscillations into electric signals. By appropriate positioning of the sensor, a process cycle of the machine can be detected with very high reliability. A cylindrical shape with a diameter of 25 mm and a height of 5 mm could be realized (figure 3). This small overall size allows the sensor to be mounted and sealed in the tool to become an integral tool component.

Data Logger: The data logger contains an EEPROM and an RFID interface with a carrier frequency of 13.56 MHz for wireless access to the memory. The data logger was implemented separately from the sensor in another casing. Manipulative changes, i.e. disconnecting the cable between sensor and data logger are detected and recorded. The memory is organized as follows: A read-only section contains master data such as tool identification number, description, type, and manufacturer. A read-write section contains all life-cycle-related information, which will be explained in detail in section 4 of this article. The memory can be accessed by authorized users by using a standard mobile reader device, e.g. a PDA with an RFID interface, which can be integrated on its part to a higher level data processing infrastructure.

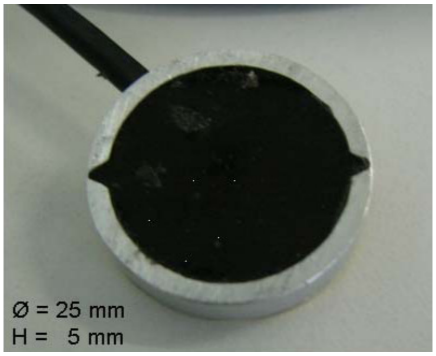

Figure 3: Stroke sensor (source: Schwer+Kopka)

Battery: The system is dimensioned for a lifetime of > 10 years, which is a typical service life of a forming tool. A technically limiting factor is the lifetime of the battery. Due to low-current technology employed, requirements to the battery capacity are easily met. However, self-discharge over time and the expected exposure to mechanical and thermal stress in an industrial production environment are considerable challenges. Laboratory experiments that were carried out during the investigations suggest that most available high quality batteries do meet these requirements. Methodologies of battery condition estimation can be found in [12, 13].

The overall system is specified for an operating temperature of up to +50 °C. A prototype system consisting of a stroke sensor and a data logger is currently in operation on a forming press at Progress-Werk Oberkirch AG (PWO) for gaining long-term experience in an actual production environment.

4. MODES OF OPERATION

Minimal Model

Using the minimal model, only the total number of strokes is recorded in the electronic event logger's memory. Besides a cumulative counter, further counters on a day-to-day basis were implemented. Consequently, an evaluation of the number of performed strokes for each of the past 365 days is possible. Summaries for arbitrary periods of weeks, months or single assignments can be generated, too.

The typical application scenario of the minimal model is the sharing of free capacities between production sites as mentioned above. Using the counting functionality, the usage of the forming tool according to contract can be ensured, and usage-based billing is possible with the actual number of produced parts. From the ordering party's point of view, this is a crucial precondition for the capacity-sharing business model. Fraud attempts, for example illegal manufacturing of additional parts using the tool, are effectively obviated. The intention to maintain control over the tool even in a sharing scenario is emphasized in the minimal model.

Maximal Model

The maximal model uses the very same memory, which is now used to store additional information. Possible applications include the documentation of an entire tool history (such as repair work with points of time and performing department/person) or registration of maintenance intervals. Generally, any data of interest may be written to the memory by authorized personnel; applications are only limited by the size of the memory. The advantages compared to a traditional paper-based solution are the physical connection of object and memory medium and the availability of digital data, enabling the content to be transferred directly to higher-level data processing systems. Hence, the intention of the maximal model is mainly quality improvement by simplification of documentation processes.

5. WIRELESS REAL-TIME MONITORING

Advantages of Wireless Process Monitoring

In addition to the electronic logging of specific events as described above, there is also a demand for monitoring process parameters in detail. In sheet metal forming, characteristic sequences of analog signals such as solid-borne sound over time provide information about stability and faultlessness of the process. Today, process monitoring on sheet metal forming machines is carried out by placing a number of sensor elements on the tool. These measure process parameters at runtime, allowing an online evaluation of quality and stability of the process. The installation and connection to the machine controller however is a laborious procedure, which is a disadvantage especially in production areas where high flexibility is required and tools often have to be mounted to forming machines and to be dismounted from them. For this reason, another objective of the project was to transmit sensor signals over a wireless interface from the tool to the machine controller, avoiding the sensor installation and wiring process after every tool change.

Real-time Requirements

A system is considered capable of running in real-time if the reaction time to a signal or event never exceeds a given maximum (deadline). The reaction time is the time from acquisition of a metered value until the corresponding reaction of the system, such as an emergency stop of the machine. It is the sum of the latency time for data transmission and the controller's response time, plus additional delays, for example due to mechanical inertia of moving masses. The latency time is the period of time between sampling a measurement at the sender and the point of time of interpretation of the data in the receiver. The deadline depends on the specific process, ranging from very short times for safety systems (e.g. anti-lock braking systems / ABS) to several seconds for slowly changing physical quantities (e.g. temperature control)

If "hard" real-time conditions are to be met, the maximum reaction time must be guaranteed and may never be exceeded. This is necessary if exceeding the reaction time may lead to damages of equipment or even injuries of persons. In contrast, for meeting "soft" real-time conditions, the statistic average of reaction times is required to stay below a certain value.

Current wireless standards and protocols such as Wireless LAN or ZigBee do not guarantee a maximum transmission time due to their medium access strategy and are therefore not usable under hard real-time conditions. For industrial monitoring with time constraints, modifications on the medium access (MAC) layer of the protocol stack are necessary. Adapted MAC protocols for different applications in the field of wireless sensor networks have been developed by several research groups [14]. Approaches and considerations for protocol design are reviewed in [15]. A hard real-time MAC protocol for wireless sensor networks is described in [16].

Real-time Behavior Evaluation

For implementing a wireless real-time monitoring device, a transceiver module based on the physical protocol layer defined in IEEE 802.15.4, which is also the base for the ZigBee protocol stack, was chosen. These hardware designs generally allow small and energy saving devices for battery-powered embedded devices. Components offer sleep modes with very low current consumption and can stay in sleep mode for long periods of time between communication events.

On the chosen transceiver module, a deterministic media access (MAC) protocol was developed for a star network topology, i.e. with *n* sensor nodes assumed to be connected to the same host system with no routing of packets involved. This protocol is based on a time division multiple access (TDMA) strategy using the host node as a coordinator (figure 4, see also [15]).

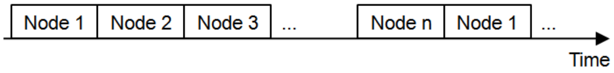

Figure 4: Principle of TDMA

Using this method, a guaranteed latency time of the wireless link of less than $n \cdot 5\ ms$ could be reached. Due to pre-scheduled time windows for each sensor node, the latency time increases linearly with the number of nodes per coordinator. By implementing a watchdog timer on the receiver side, a sender failure can be detected within the same time interval. Using this protocol, real-time requirements for many applications are met.

Energy Consumption and Battery Lifetime

The wireless real-time monitoring implies very different requirements to the sensor nodes' energy source than in the previously discussed event logging scenario. Current consumption of most currently available transceiver modules is roughly *40 mA* during packet transmission. For continuous data transmission at a sampling rate of *1 kHz* for a period of 20 days, a battery capacity of $C=20\ Ah$ is needed. This is equivalent to two standard "D" size cells, being just barely acceptable for an embedded module. When transmitting data continuously, ZigBee modules cannot display their strength of consuming only little energy in sleep mode. The technology is better suited for applications with a low duty cycle.

In the following table, three different monitoring scenarios with different sampling intervals are compared, showing the calculated battery lifetime in the far right column (assumption: two "AA" size Li-cells, $C=2000\ mAh$):

Scenario	**Sampling interval**	**Duty cycle**	**Average current cons.**	**Battery lifetime**
Solid-borne sound (continuous)	5 ms	1	41 mA	96 hours
Temperature (once per stroke)	0.6 s	0.033	1.42 mA	117 days
Wearout (every 10 strokes)	6 s	0.003	0.187 mA	29 months

As a result, energy consumption of the wireless transceiver modules can currently be considered the most important limiting factor to adoption of wireless modules in industrial monitoring applications. At present, only applications with fairly low duty cycles are possible with an acceptable battery lifetime.

An approach for further development is preprocessing the sensor data within the transceiver module rather than transmitting each and every sampled value for external processing. Then communication events are necessary only in case of extraordinary situations such as the detection of an error. This requires to run the corresponding evaluation algorithms on an embedded microcontroller-based device and will potentially be limited by the available computing capacity.

6. CONCLUSION

This contribution shows a concept and implementation for detecting events during a forming tool's life cycle using an autonomous sensor and data logger system. Within the development and research project described here, both a tool monitoring sensor system and an electronic event logger were developed. Autonomous logging of events provides the possibility to introduce new business models. An example is sharing forming tools between enterprises to handle capacity bottlenecks. This requires a mechanism to control the number of parts produced, which is provided by the described system. Furthermore, methods for wireless tool monitoring in real-time were discussed and constraints to their application in an industrial production environment were described.

The event logging solution is in principle also suitable for other fields of application, in which production equipment such as tools, machinery modules or transportation systems are shared between partners of a supply network. The innovative aspect is especially the autonomous detection and processing of events by object-inherent sensor and logging systems. In this context, RFID technology serves not only for identification, but in combination with sensor structures also as a control instrument for contracting and billing based on actual output or runtime.

7. ACKNOWLEDGEMENT

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