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Maintenance Support Wireless System for Ram of Forming Presses

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***Abstract* – In the paper, an innovative wireless system for press ram stress monitoring will be presented as component of a decision support system for predictive maintenance. This system involves low power consumption wireless nodes and energy harvesting techniques to gain autonomy for the whole solution. The monitoring systems output signals serve to extract and generate "virtual sensor" signals. These represent actual load and stress situations on locations that are crucial for machine stability but are inaccessible for real measurement or even buried inside the frame structure. In addition, the monitoring system is embedded into a networked environment of an e-maintenance cloud, linking a variety of information sources like enterprise resource planning.**

Keywords – condition monitoring, maintenance, forming, fatigue, simulation, wireless.

I. Introduction

Breakages at highly stressed components of forming presses like frame, crown, table, and plunger often cause very high direct and indirect costs for the machine owner. To prevent or minimize this, the monitoring of mechanical stresses is a very important field of research. Although the facility manufacturers are trying to prevent crack formation by oversizing of highly stressed parts, the high number of failure cases high-lights the relevance of this problem. An example of a repaired fatigue breakage of a press crown is shown in Fig. 1.

A promising approach to solve this problem is the monitoring and evaluation of stresses in production presses and its embedment into a preventive maintenance strategy. To reach this goal, three main challenges have to be solved:

- development and integration of embedded in-formation devices with data pre-processing capabilities in order to capture relevant information like loads, strains and stresses
- definition of new algorithms and techniques in order to provide intelligent data processing and knowledge extraction from production equipment
- development of reliability & maintainability de-sign practices/methods to predict and assess the availability of equipment already at an early de-sign stage

Fig. 1. Repaired fatigue breakage at a press

A basic technology – the monitoring of mechanical stresses – actually is not applied to industrial forming machines, but is well-known from a number of different industries. One important example is the ship building industry, where the strain of ship hulls [1-2] and motor shafts is measured. Also concrete buildings are equipped with strain sensors in order to obtain data concerning their structural health [3]. But the direct measurement of strains or stresses can be done only locally and at the previously identified critical places. The estimation of the stresses in the whole geometry corresponds with the need of a high number of sensors or relatively uniform stress gradients that allow a mathematical description of the non-sensored areas. That's why – on the one hand – it is done mostly on relatively simple geometries like bars, drive shafts or plates.

In conclusion, the stress monitoring in forming presses with its complex mechanical structures like welded parts or ribbed frame components and under varying load conditions is a core challenge of the project. The reasons are the partial inaccessibility of the required measurement locations, the high number of potential fracture critical locations and their dependence on varying load conditions based on the ram stroke or tool geometry.

On the other hand, mostly fatigue breakages are the reasons for press breakages, while static overloads normally can be avoided by overload protection units.

The common strategy to avoid fatigue breakages is to operate forming machines below the fatigue limits. These limits are estimated by static simulations (e.g. finite element methods) during the design stage, based on pre-defined load scenarios. But in practice the high numbers of breakages show that not every critical load scenario can be considered during design stage, not least because of the unknown future production spectrum and the resulting real loads.

To learn more about real mechanical loadings and the reasons of breakages, and to minimize future failures in forming presses, in the iMAIN project a novel stress and condition monitoring system is in development, embedded into a cloud-based maintenance concept. In chapter 2 this overall concept will be introduced and in the following chapter 3 the Wireless system concept will be explained.

II. iMAIN SYSTEM CONCEPT

To address the maintenance challenges listed above, a novel concept has been developed, that is based on intelligent information agents. These agents combine different data and information sources like control-inherent sensors, additional real sensors and model-based virtual sensors, that allow continuous, real time, remote, and distributed monitoring and analyzing of forming machinery. The chosen approach to get knowledge from data and information is planned to be demonstrated on forming machines, but can be applied also to other industries with highly and dynamically loaded systems, e.g. power plants, transportation sectors or aircraft industries.

The prediction of the remaining service life, as one of the core challenges of the project, needs information about the actual deterioration of components (deterioration history) and about future load scenarios. The deterioration is estimated by the monitoring of maxi-mum strain or stress values of every forming cycle under real process loads and its accumulation during the life cycle via cumulative damage hypotheses. For this, a load and deterioration history has to be stored, covering the whole lifecycle of the forming equipment.

Considering the challenges in stress monitoring, a special approach – the so-called “virtual sensor technology” – has been developed (Fig. 2). It extends the information of a limited number of real sensors (especially strain gauges and force sensors) by additional virtual sensor signals that are processed in real-time. These “live” calculations continuously derive how stress on virtual locations is determined by signals from the surrounding real sensors. The respective models that represent these relationships are developed by reduced-order finite elements (FE) models. This allows the observation of all potentially critical points of the press mechanics with minimized effort and even over-coming physical limitations. The crucial calculations are implemented as a part of the embedded condition & energy monitoring system (ECEM system). Stress monitoring on both real and virtual sensors together with the assessment of a wide variety of additional machine related sensors and data contributes to building an extensive history of machine life. The so-called Smart Service Life Prediction (SSLP) system will then combine data from load and deterioration history as well as actual sensor and production planning information and allow for intelligent and predictive maintenance strategies.

Based on the functionalities described above, such a monitoring and maintenance system consists of a number of distributed components that are networked for close cooperation (Fig. 3). These are:

- press machines to be monitored, which are each
- associated with an ECEM system, including a SSLP system
- multiple machines/ECEM

The ECEM systems are typically installed in close proximity to the associated machine. Such units in turn are distributed over a wide area industrial installation that can extend across a single facility or company and even across multiple sites, industrial entities, companies and even countries. The overarching networking structure of this setup is called the “eMaintenance Cloud”. It provides mechanisms and services to allow multiple clients to participate in the condition monitoring process. These clients can be:

- data center providing IT infrastructure, processing services and database information
- monitoring operators
- press manufacturer
- scientific experts

While operators typically control the process and selected machines in an interactive or automated way, manufacturers and scientific experts can also contribute in adding additional information and input in order to optimize the process.

III. FUNCTIONALITY AND STRUCTURE OF THE WIRELESS SYSTEM

The wireless network that has been thought for inter-facing with the ECEM system is intended for capturing temperature from the moving slide since this parameter has a direct relation with excessive friction due to its misalignment.

The press operation scenario considered in this case is a press’ running mode of 30 cycles per minute with a working period of 16 hours/day during 5 days per week (Monday to Friday). Moreover, a photovoltaic (PV) system was dimensioned in order to supply the wireless sensor nodes.

The system proposed comprises the wireless monitoring system with 4 "sensor nodes" that measure the temperature of each linear guiding rail. For this purpose, each sensor node should be able to measure two temperature points and send the information to the remote network system gateway. Furthermore, each wireless sensor node should be autonomous.

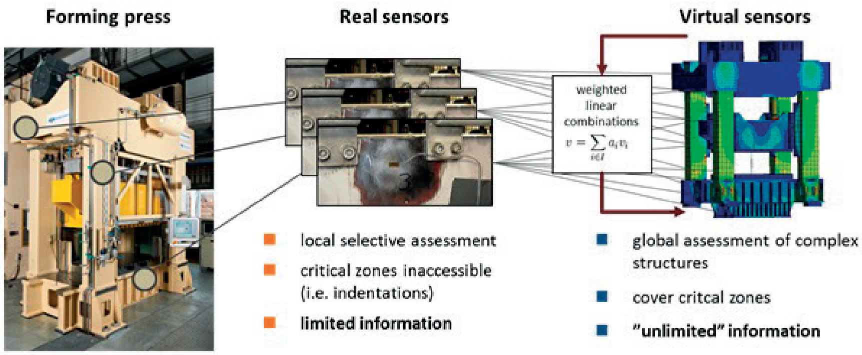

Fig. 2. Principle of using virtual sensor technology

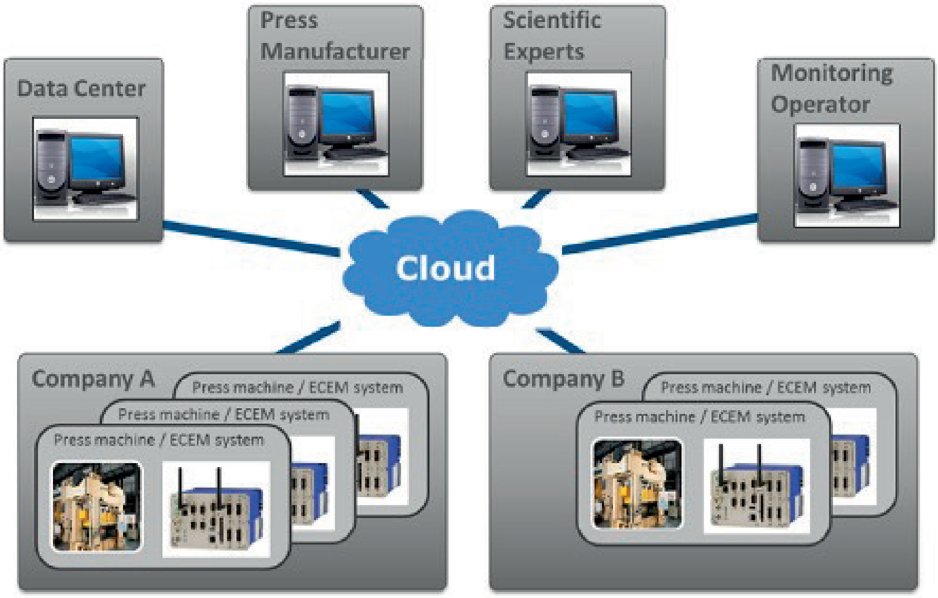

Fig. 3. Distributed condition monitoring environment

Therefore, in order to fulfil this aim, a mixed power supply system based on batteries and energy harvesting technologies is developed. Following the low power requirement, during the "ON mode" the sensor nodes are able to send frames to the data collector upon request. If there are no requests during this mode, the Sleep mode is set up.

Since the sensor node cannot identify when the press operation cycle begins, an automatic start up system by detecting movement in the press is implemented. The movement detection system consists of a high-sensitivity accelerometer that turns on the node when a press movement is detected.

A. System's blocks

The monitoring system is divided in the following functional blocks (Fig. 4):

- Power system
- Wireless Sensor node
- Wireless communication bridge
- Data collector and communication gateway

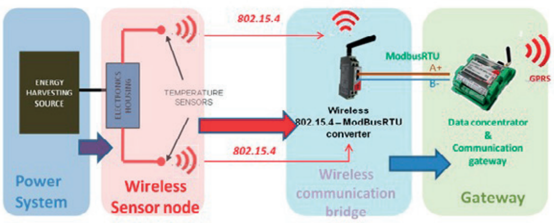

Fig. 4. Wireless system blocks

The power system is composed by an energy harvesting module based on a high-capacity capacitor. It is powered with

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a solar panel that recollects energy from the ambience light. Moreover, for ensuring that the wireless sensor node is able to work in case of insufficient light conditions it was also included a high-capacity battery. Using both energy sources it is possible to ensure a wireless sensor node life cycle up to a year. Moreover as an energy saving task, during the non-operation period two low consumption modes can be set up in the wireless sensor nodes: low-power mode (~uA) and ultra low-power mode (~ nA).

The Wireless Sensor node is an IEEE 802.15.4 compliant wireless sensor node based on the original open-source "TelosB" platform design developed and published by the University of California, Berkeley ("UC Berkeley"). The node has the following general characteristics:

- IEEE 802.15.4 WSN platform
- TI MSP430F1611 Microcontroller
- TI CC2420 Radio Transceiver
- TinyOS 2.x & ContikiOS Compatible
- Temperature, Humidity, Light sensors
- User & Reset Buttons
- 3xLeds
- USB Interface
- 2xAA Battery Holder

In order to transmit the information collected by the wireless sensor nodes to the communication gateway, wireless 802.15.4 to Modbus RTU is used. The selected device is the Advanticsys® DM-124 wireless communication bridge. The main function is to collect all the data sent by the wireless sensor nodes and transmit them automatically to the central gateway, which is in charge of the data and energy saving management, so the mote life cycle is optimized. Moreover, due to the use of the DM124 device it is possible to reduce the amount of cables needed in RS485 installations by bridging devices through IEEE 802.15.4 based wireless networks. This provides legacy industrial installations the versatility and ease of deployment of wireless sensor networks (WSN).

Finally, an Advanticsys® controller MPC product line is used as data collector. It is mainly in charge of managing the information from the wireless sensor nodes and the integration with the iMain platform.

B. *Operation*

The temperature reached in the press linear guides must be supported by the wireless sensor node. According to the press documentation, the temperature range of this part of the press is from 0 degrees up to 250 degrees. The response time is also a revelant aspect as this parameter has influence on the "ON" time of the node (if the response time is big we have to power it more time to have a valid measure).

In order to achieve the aim of monitoring the press temperature during working cycles, it has been defined a system prototype according to the measurement requirements (Fig. 5). During the press working cycle the sensor node is switching from the ON mode to the Low-Power mode alternatively. In the low power mode, when the T_Threshold is reached, the node turns to Ultra-Low-Power mode and all the electronics power down except the energy harvesting module and the wake up accelerometer, which is the responsible of switching on the sensor node when motion is detected or several samples without motion are detected (time of inactivity, this is to avoid that the node never wakes up again in case of failure). In the next ON mode, all the peripheral should be initiated again (microcontroller, RF transceiver, accelerometer, RTC, flash memory, etc.).

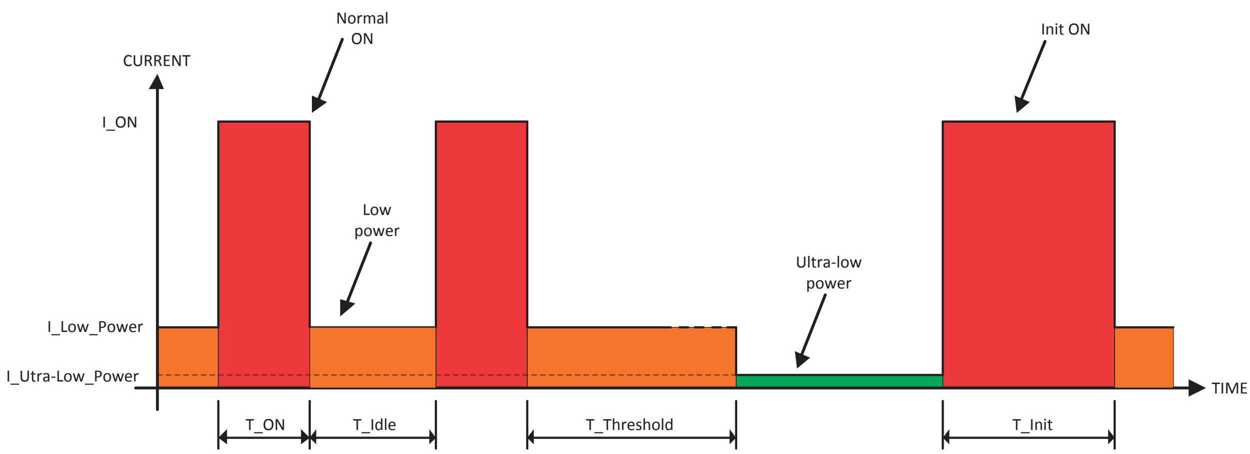

Fig. 5. . Continuous- operation Software/Hardware cycle

IV. CONCLUSIONS

Frequent occurrences of fatigue fractures and failures of forming machines have motivated the development of a novel strategy for stress monitoring and predictive maintenance of high-loaded mechanical components. The smart combination of advanced monitoring and knowledge-generation approaches like the virtual sensor technology, life cycle histories or the merging of location independent information sources requires the development of new IT infrastructures. In the paper, the high-level structure of such a system has been presented along with the concept of a wireless system for data acquisition. This structure will be the base of an advanced and modular condition monitoring and maintenance system for forming machines as well as other highly stressed systems from different industries.

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