# PREDICTIVE MAINTENANCE OF FORGING PRESSES

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## Introduction

Well-timed identification of forging press failure is quite often dependent on a notification from an experienced maintenance technician. He is the one who can, in most of the cases, detect the noise caused by increased vibrations during the failure development of one of the machine's components. However, this method of machine condition diagnostics is not efficient. The human ear has certain limitations and the number of experienced and skilled maintenance technicians is decreasing. That is why technical diagnostic tools, which enable thorough machine's condition monitoring, are being used. Using the right technology together with good maintenance practices and processes, advantages of predictive maintenance can be leveraged.

Predictive maintenance is a method of proactive maintenance where the machine's maintenance is undertaken based on the real technical condition of the machine. In comparison to preventive maintenance, where the maintenance interventions are done based on a schedule created by the machine OEM, both time and financial resources can be saved.

It is said that predictive maintenance can decrease the number of machine failures by up to 70 % and decrease maintenance costs up to 12 %. But what about predictive maintenance of forging presses?

## Predictive maintenance of forging presses

Forging presses are one of the most critical machines in every forge plant. Considering the sheer physical size of the critical components, their failure leads to a difficult and costly repair. In the forging plants, technical diagnostic for the monitoring of rotational parts of crankshaft presses' drives is usually being used. Condition of the main motor, belt pulley bearings, countershaft bearings, main shaft bearings as well as bearings of the clutch and brake are being monitored. For example, increased vibrations caused by the damage of the countershaft's bearings can damage the bearing's housing, the countershaft itself and other components of the press. Such failure can create service cost up to tens of thousands of euros.

Condition monitoring of the press drive is usually done by the following means:

- listening to the machine noises by an experienced technician,
- measuring the temperature of the components,
- vibration analysis.

Most of the forge shops rely on the first-mentioned means. This method is limited by the capabilities of the human ear. Even though the nonstandard operation of the press can be identified just by listening to it, if the technician is experienced enough, it is not possible to localize the problem precisely and on time. Furthermore, considering the situation of the labor market, the number of technicians who have such skills is decreasing.

The most common condition monitoring method is monitoring of the components' temperature. Most of the forging presses are usually already equipped with the temperature sensors for monitoring of the bearings from the OEM. Increased temperature of the bearing indicates worsening of the bearing's condition which is usually caused by poor lubrication or by slipping rolling elements in the bearing. The bearings' temperature is being read by the press operator or maintenance technician directly from the control panel. When the increased temperature of the bearing is detected, visual inspection of the bearing and lubrication system is done. When the temperature increases by a small margin, the inspection is usually done after the current production batch is finished. When the temperature is rising drastically, the machine has to be stopped immediately.

Condition monitoring of the bearings by monitoring the temperature has its limitations as well. In the real conditions, the fluctuating temperature inside the forge shop can negatively influence the ability to determine the absolute condition of the bearing. The temperature of the bearing increases when the lubrication system fails when rolling elements slip, or when fatigue of the material occurs (for example pitting). Even though the lubrication systems are equipped with a system for verification of the system operation, blockage of the lubrication distribution system can occur near the bearing itself which does not have to be recognized by the system on time. Nevertheless, the main limitation of this method is that the temperature of the bearing usually increases only in the last stages of the failure process. Although this method is the most commonly used one, it does not allow for the identification of all failure modes that can occur on the forge press drive. That is why vibration analysis is the most convenient.

## Vibration analysis of the forging presses

Vibration analysis is probably one of the most important and progressive methods of technical diagnostic. It can be used for diagnostic of not only the rotational components, but also non-rotational components that create vibrations. In general, there are two types of vibration analysis diagnostic systems. The first one is offline monitoring where portable mobile devices for data collection are being used. The other type is an online monitoring system where the sensors are permanently mounted on the machine and connected to a monitoring unit.

Using the offline monitoring system, the data is being manually collected by a technician regularly, what can vary from days up to weeks. Small packages of the data do not allow for monitoring of the vibration trends (development of the vibrations in time), which are crucial for the prediction of the residual lifetime of the component. Furthermore, a skilled and qualified technician is needed to process the data.

Considering the increasing demand for the digitization of the production, online systems are being implemented. In this case, the data is being collected continuously to monitor the vibration trends and thorough analysis. Collected data can be processed either on a local computer or a distant server – cloud. The advantage of the cloud solution is higher computing power, which is essential for processing the data from complex machines, such as forging presses.


*Figure 1* 4dot Monitoring: the monitoring unit collects the data from sensors mounted on the machine and sends it to the cloud. The machine's condition can be monitored real-time in the 4dot application.

There is no prescribed method for condition monitoring of forging presses which would identify the problem, its urgency and the absolute real condition of the press. The data can be analyzed in the frequency or time domain. There are different types of analyses such as envelope method, peak value, crest factor effective value, and others. Each monitoring system then utilizes a different combination of these methods based on the machine type and its operating conditions.

Technical diagnostic of forging presses is a good example of an operating condition where common methods of vibration analysis do not work. The reasons are mainly big impacts from the forging process, clutch and brake engagement and quite often by high vibration caused by adjacent forging presses (low SNR – signal to noise ratio).

Another complication is the low-speed revolutions of the drive making the whole analysis to determine the condition quite a difficult task.

So, is it even possible? Yes, it is. Nonetheless, the right combination of hardware, analyses developed especially for forging presses and a good understanding of the machine is needed.

According to equation 1, the vibrations can be measured by three types of sensors: distance sensor, speed sensor and acceleration sensor.

$$m\ddot{y} + b\dot{y} + ky = F_b = M\ddot{x} \quad \text{(equation 1)}$$

Where:

| | | | |
|---|---|---|---|
| y – displacement | $\dot{y}$ – velocity | $\ddot{y}$ – acceleration | $\ddot{x}$ – mass acceleration |
| M – mass | k – stiffness coefficient | b – damping coefficient | $F_b$ – excitation force |

With a convenient choice of the *m*, *b* and *k* parameters, any of these sensors can be simulated. However, which one is the most suitable for the vibration analysis? Distance sensors do not possess the sensitivity and measurement range needed. And if they do, they are quite expensive and not suitable for the forging environment at all. Velocity sensors are used quite commonly, as there are several standards for vibration analysis in the time domain available. Induction sensors of the velocity possess low natural frequency (up to 10 Hz) and a measurement range up to 3,5 kHz, which is usually not enough for rolling bearing's condition monitoring. Another quite commonly used sensors are velocity sensors that measure the acceleration, which is afterwards integrated back to the velocity. The problem is that the signal is often distorted by the numerical integration, which makes these sensors inappropriate for application on forging presses (high process and other noise).

The most suitable are acceleration sensors – accelerometers (most often IEPE accelerometers). These possess high sensitivity, measurement range and also their natural frequency is around 30 kHz, which is frequency of most of the failure modes of rolling bearings. However, the natural frequency of the sensor varies according to the type of the sensor's mounting (magnetic, adhesive or stud).

*Figure 2* One-axis piezoelectric accelerometer with embedded electronics (IEPE) suitable for application on forging presses.

Vibration sensors are usually installed in the nearest location from the monitored bearing, usually right in the housing. The sensors installed to a forging press are usually screwed. With an appropriate combination of sensors and analyses, it is possible to measure indirectly the condition of components, where sensors cannot be mounted directly on them. As a result, condition of the clutch and brake bearings, as well as the wear of friction plates, can be monitored.

The monitoring unit used within 4dot Monitoring has a real-time operating system and extendable data storage. The unit has a modular design for the connection of different modules for signal processing and system connectivity. These modules are connected with the real-time application through embedded FPGA (field-programmable gate array). The modularity and resilience to the rough environment of forge shops make the 4dot unit suitable for the applications on forging presses. The data is being sent continuously from the unit to the cloud, where it is processed by appropriate algorithms. The raw data is also stored for further analysis and development.

4dot uses MUSA (Multiple Sensor Algorithm) analyses, which have been developed for condition monitoring of the forging presses' bearings. These analyses are also used for real-time monitoring of bolster condition, ram slide guides monitoring, process monitoring, etc. within 4dot Monitoring. The analyses combine data from more sensors at the same time to increase the accuracy of the monitoring. This enables the separation of the noise from the technological process in the signal from the information about the component's condition.

Further development of monitoring technologies is the utilization of AI (Artificial Intelligence). The AI will increase the accuracy and speed of detection of the abnormalities of the forging presses operation. 4dot collaborates with the Brno University of Technology on the implementation of AI into the monitoring system.

## 4dot Monitoring in MSV Metal Studenka

An appropriate example of how principles of predictive maintenance can be leveraged is the forging press Smeral LMZ 2500 in MSV Metal Studenka, where 4dot Monitoring has been implemented since 2017. The requirement from the customer was to monitor the condition of the countershaft's bearings, main motor, and bearings of the clutch and brake.


*Figure 3* Different types of products are forged on the LMZ 2500 press. There are also other forging presses (hammers) nearby, which influence the vibration of the press, thus influencing the vibration analysis.

For this application, the machine has been equipped with Mouflon Li486 monitoring unit, which allows for connection and simultaneous measurement of data from six piezoelectric acceleration sensors and up to eight temperature sensors. The monitoring unit pre-processes the data, sends it to the 4dot cloud, where the data is processed by the algorithms developed for forging presses, and subsequently being visualized in the online 4dot application.

As soon as any of the limits is exceeded, a notification is automatically sent to both the maintenance technician and 4dot engineer, who validates the data to avoid false alarms and unnecessary downtime. The engineer also provides technical support during the localization of the failure and analyzes the cause of the failure itself.

In this case, the vibration monitoring system has been extended with a temperature sensor for better identification of certain failure modes. The sensors are mounted on the mounting points, which are supposed to be as close as possible to the monitored component. Modifications of the bearing's housing needed for installation of the sensors are depicted in picture 4. Installation of the 4dot monitoring system can be completed within a one-day shutdown. Installation consists of mechanical modifications for mountings of the sensors, cable work and installation of the monitoring unit in the machine's distribution control box.

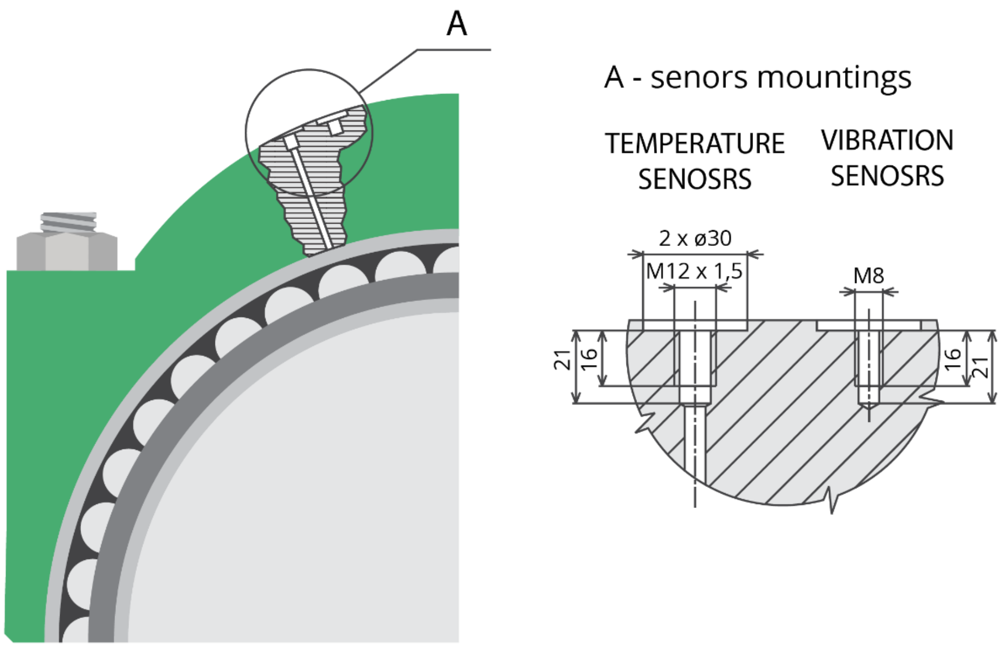


*Figure 4* Vibration sensors are mounted with M8 thread. The LMZ 2500 has been also equipped with temperature sensor for identification of wider spectrum of failure modes.

Since the installation of the monitoring system in 2017 several bearing failures have been eliminated thanks to appropriate processes within the MSV Metal maintenance management and communication with 4dot engineers. As a result, well-time service intervention has been done eliminating further damage of the press and reducing maintenance costs.

The difficulty of forging presses' rolling bearings monitoring is demonstrated in chart 1, which compares conventional analyses and MUSA analyses used by 4dot.

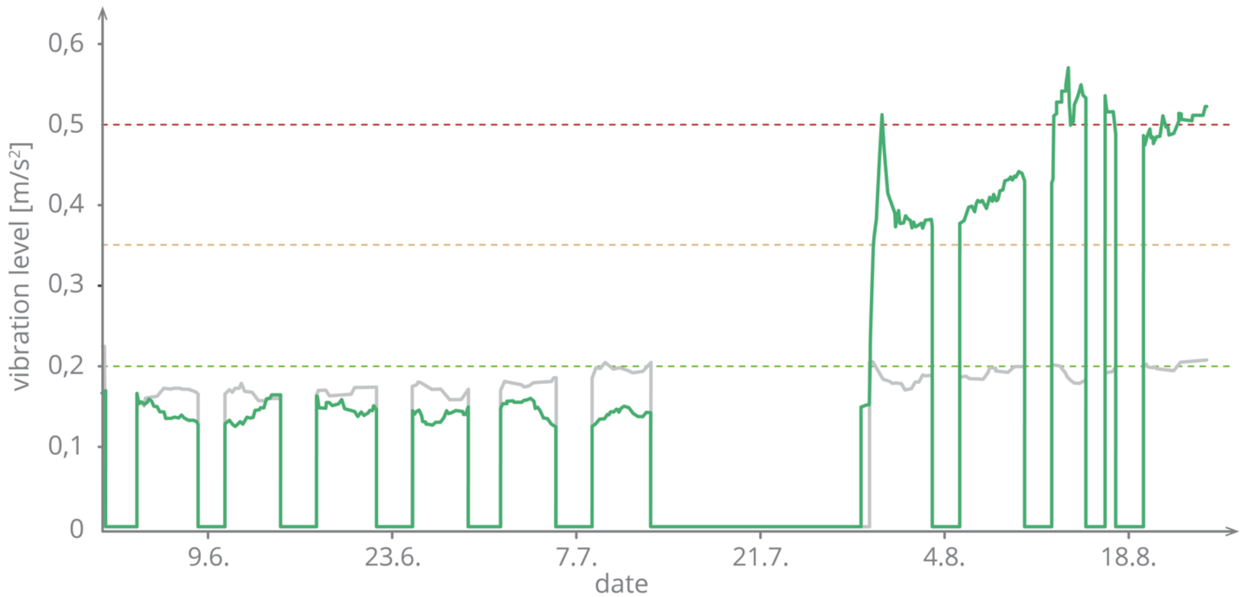


*Chart 1* Bearing's condition monitoring with MUSA analyses (green) in comparison to envelope analysis (grey). Dashed lines represent the limits: green – good condition, orange – alertness, red – high risk of failure.

Using the MUSA analyses, a significant increase in vibration level was detected on 27.8.2019 – green line. In contrast to the conventional envelope method usage, the increase can be hardly detected – grey line. Based on further data analysis by 4dot engineers, an inspection of the bearing had been undertaken and a failure of the lubrication system was detected. The level of the bearing's damage was evaluated as a serious one, hence it was replaced and the lubrication fixed.

Long-term trends in the bearing's condition can be monitored as well. These indicate deterioration of the bearing caused by gradual wear of the bearing's surfaces (pitting). Service interventions can be planned based on the trends, therefore the production schedule is interrupted as little as possible. An example of a long-term bearing's deterioration is depicted in the chart 2.


*Chart 2* Condition of a countershaft's bearing. By approximating the trend of vibration development, residual lifetime can be predicted.

As soon as the first limit (green) is exceeded, the data can be approximated with a curve that is extended to the limit which represents a high risk of the component's failure (red limit). The difference between the current date and the intersection represents an estimation of the residual lifetime.

The condition of the press can be monitored in online 4dot application, which enables real-time monitoring of each component. It also enables data history access, notes adding, an unlimited number of users and many more.

## Conclusion

Continuous condition monitoring of the forging presses' drives using vibration analysis allows for early failure detection. As a result, damage to other parts of the press as well as unplanned downtime can be eliminated. Despite the technical complexity of the vibration analysis of the forging presses' low-speed revolution bearings, this method is the most efficient one in terms of time, function and costs.


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