SENSE & REACT

A context-aware and user-centric approach for information distribution system in manufacturing

Energy Efficiency White Paper

Challenges

Raising energy prices intensify market requirements and globalization of markets forces enterprises to change their actual views to energy consumption. The pressure from environmental regulations on consumers and companies to save energy increases. Industry is a major producer of greenhouse gases witch has to be reduced by 80-95% in 2050. This is one EU target to reduce the greenhouse gases. The Global energy demand is constantly growing and prices for electricity and fuel are and will maintain to increase in the future. Furthermore a variety of environmental regulations on the consumption and the production of energy exist. All these influences put a high pressure on industry regarding efficient energy consumption. The European industry sector accounts for 25% of end energy consumption, out of which about 30% of total energy consumption can be saved by technical improvements. In order to realize these potential savings, different solutions were introduced by many manufacturing companies. The detection of wear on machine tools is an essential issue for saving energy and preventing wastage.

Machine tools are one of the biggest industry sectors in the world. Due to the fact that machine tools are used nearly in every manufacturing enterprise, the energy efficiency aspect is elementary. Machine tools work with electricity, pneumatic systems, heat, water and cooling fluids. All these substances have to be produced witch costs energy. These energy flows can be measured by sensors. In This paper the energy form of electricity is the most important one. An energy efficiency concept on company level contains the following key parts:

1. Target function
2. Measuring and determination of energy efficiency
3. Measures to increase energy efficiency

Within Sense & React, the target function is to maximize the energy efficiency of manufacturing machines and production lines and to minimize the machine downtimes in enterprises. More precisely, the area to which the detailed energy efficiency concept should be applied to has to be specified. An electricity sensor measures the energy consumption of machine tools. In order to detect energy wastage and wear these measured data has to be compared with target values. These values have to be charged and saved in some kind of database. Variance analysis is used to recognize energy wastage and wear on machine tools. According to describe what wear is and how this refers to energy consumption, the model of wear detection is presented. In Sense & React energy consumption is measured to analyze how far wear has proceeded. Whereby knowledge about wear it is possible to save costs for machine downtimes and maintenance. These benefits will be presented in this Paper. To realize this model and gain these benefits a test environment has to be set up. This environment is provided by FIR at RWTH Aachen. In the DFA factory the model will be implemented and tested.

Background

Wear

Wear is defined as the loss of substance from the operator surface of a body occurring as a result of relative motion at the surface. Studies of wear show increasing energy over time. Wear is not only a phenomenon leading to an increase in energy consumption but also affects accuracy and product quality as well as safety issues depending on the machinery. Once identified, the affected components should be exchanged or repaired. Depending on the amount of energy wasted and the specific energy cost, there is a critical degree of wear when the exchange or repair becomes economical reasonable or favorable. Malfunction is the failure of a component or a machine to function normally or properly. Malfunctioning manufacturing system does not only lead to unnecessary costs but also to unnecessary energy consumption. Once identified energy wastage caused by malfunctioning components can be prevented by repairing or exchanging the component. Wear and malfunction goes hand in hand. In this paper it is only referred to the term wear. Wear is a failure causing process witch accompanies with increased friction. This increasing friction leads first to rising energy consumption. Afterwards it leads to a machine downtime because of some broken component of machine tools. Previously it was common to prevent breakdowns by changing components in determined periodic maintenance. In order to save costs for maintenance Sense & React developed a model to identify wear on machine tools before break downs and periodic changes. The functional chain of the wear process

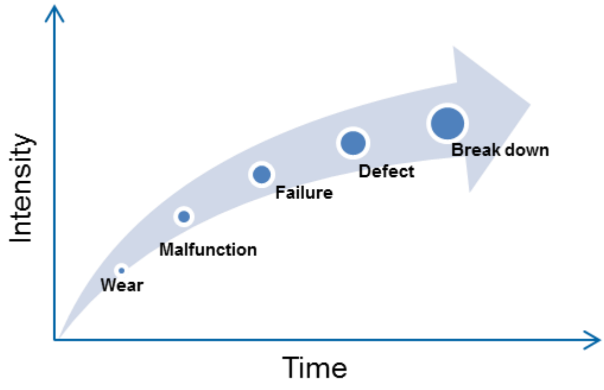

Figure 1: Wear development

shows that failures and break downs can be prevented if wear is precociously detected.

Thus wear is the initial point for break downs and machine downtimes.

Inefficient operations mode

The energy wastage type standby describes the energy that is wasted while a machine has no production order and resides in standby or idling mode. Standby mode is a typical operating mode of a manufacturing machine, in which those functions, that allow a quick transition into primary operating mode, are active and other functions are turned off in the interest of energy savings.

To prevent energy wastage during standby mode, the machine has to be completely shut down. Being completely shut down, a manufacturing machine needs more time and consumes more energy to reach the primary operating mode than the transaction from standby mode. Therefore a complete shut-down is not useful in every instance. Using the data from production planning, the production-free time can be determined. Analyzing the energy consumption for switching off and on process, a critical timespan can be defined meanwhile a complete shutdown is not profitable.

Use Cases

The goals of Sense & React are to save energy, maximize the energy efficiency of machine tools and stabilize the production processes of manufacturing enterprises. To achieve these goals, in the following two uses cases are presented. Theses use cases describes how energy can be saved and how wear can be detected by measuring and analyzing the energy consumption of machine tools. The analysis follows the variance analysis. Empirical values will be compared with actual values, so called real-time-data.

Use Case 1: Wear Detection

In order to save energy, costs for maintenance and reduce greenhouse gases Sense & React developed a model to identify and recognize wear on machine tools in manufacturing enterprises. The model is built up in four phases:

1. Measure energy consumption
2. Value patterns development
3. Warning and control limit
4. Variance analysis and wear detection

While manufacturing a product electricity is necessary for the machine tool. Every product has its specific energy consumption while manufacturing process.

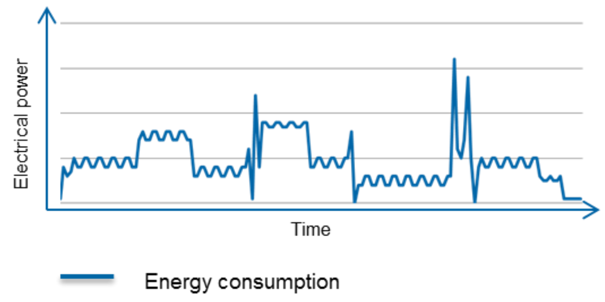

Figure 2: Energy consumption

This energy consumption has to be measured while producing the products for the first time. These data has to be deposit in the production plan for each product. The production plan is a schedule where the manufacturing process is accumulated. When the energy consumption is measured and compared to the product the value patterns can be constructed. This development requires that the energy consumption is segmented in phases.

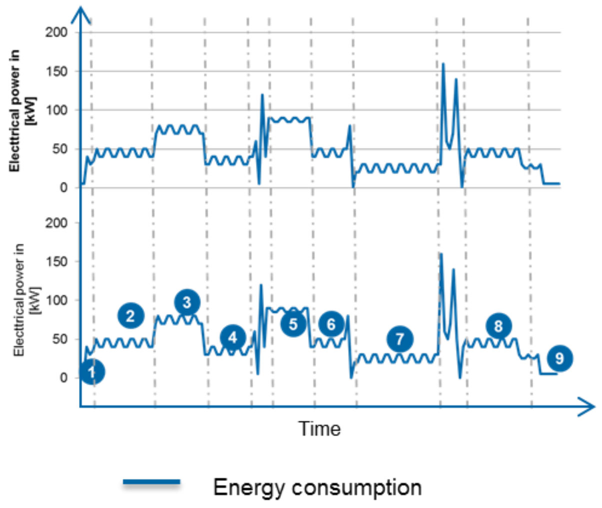

Figure 3: Phase definition

These phases are parts of the production process. For example milling or finishing. Thereafter the upper limit value has to be defined. Every production phase has an upper limit which has to be determined.

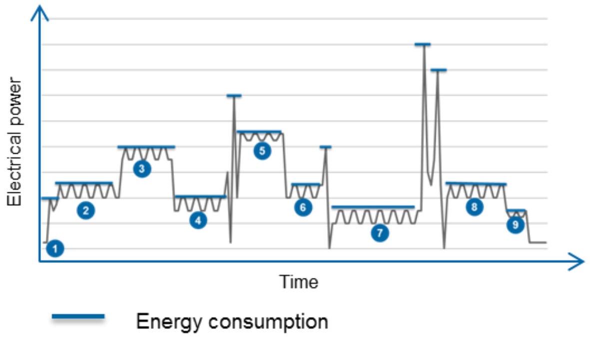

Figure 4: Determining of limits

Below the value patterns can be constructed.

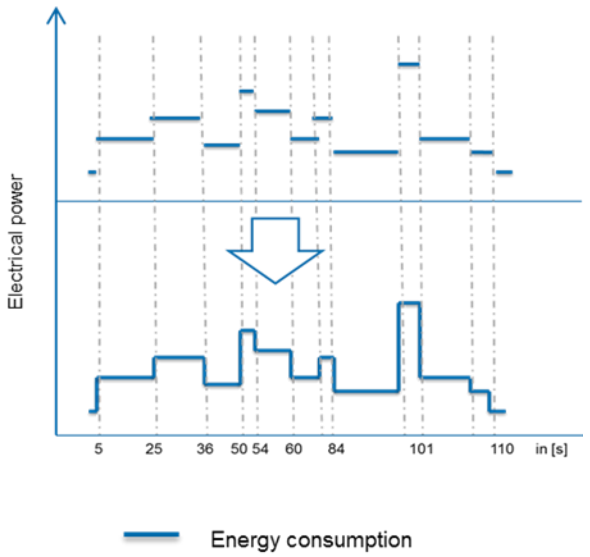

Figure 5: Construction of value patterns

In order to use this pattern it is necessary that warning and control limits are established. The creation of these limits follows the same procedure as the construction of the value patterns. In the end upper and lower control and warning limits are built.

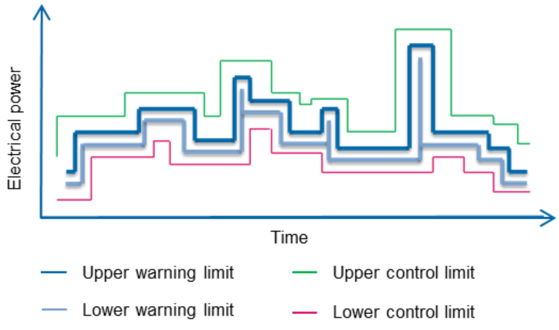

Figure 6: Upper and lower limits

The next and last step of this model is to analyze the energy consumption of each product while manufacturing in future. There are three input coefficients: Energy consumption measured by sensors, production plan data and historical data as saved measures. By the use of these factors production processes can be analyzed and wear detected. The variance analysis recognizes wear in an early stadium. The energy consumption will raises in some phases of the manufacturing process, if wear proceeds. The two types of limits are in the following described: By crossing the control limits wear is detected. The machine has to be turned off to avoid a defect. The worn component must be changed. By crossing the warning limit an irregularity is recognized. The model gives objective evidences of starting wear process.

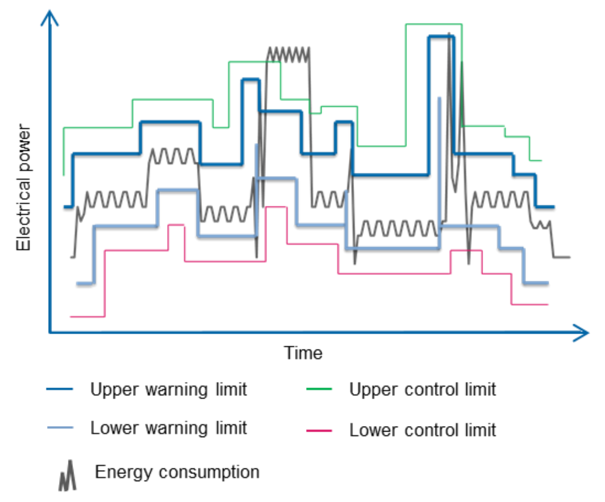

Figure 7: Variance analysis

On the basis of this figure it is obvious that the energy consumption passes the upper control limit. Consequently, wear is detected and maintenance activities must be realized. This output is presented in a wear and malfunction monitor. Therein is demonstrated which component of which machine tool is starting to wear out. This model offers the opportunities to save energy because wear is early detected and save maintenance costs. As discussed, periodic component changes were yesterday. This model represents a predictive maintenance system and furthermore methodologies to improve the energy efficiency of machine tools in manufacturing enterprises.

For the purpose of showing that this model has the potential to detect wear, in the following an example is evinced. In a trial at the WZL at RWTH Aachen jammed balls in the linear guiding were detected by measuring the needed energy of the feed motor. 750h before the break down of the linear guiding the wear were recognized. Afterwards the balls were exchanged and a breakdown was prevented. This experiment demonstrates that the model of Sense & React has a high potential to detect wear by variance analysis and saves energy of machine tools. Furthermore costs for preventive and reactive maintenance will be saved.

Use Case 2: Inefficient Operations Mode

In order to save energy, a significant amount of energy is wasted in the standby or idling mode of a machine tool.

A certain amount of this wastage can be saved with an intelligent way to control the operation modes of the machines according to their production schedule. The schema of this control mechanism is illustrated in Figure 8.

It consists out of two blocks, one is the decision making layer, the other one is describing the information acquired from some kind of database. The overall process consists out of four steps. It starts on the left side with the identification of gaps within the production plan. Therefore, the production plan needs to be scanned and the timestamp of the gaps need to be determined. In a second step, this timestamp needs to be compared to the shutdown / power on time of the machine to check whether it is actually possible to shut down the machine within the production gap. If it is not possible, the machine will remain in standby and the decision making process ends. The information about the time needed to power off / on a machine can be collected from a database entry, since it is usually a fixed value. If the identified gap is large enough, a third step calculates the power that would be needed to keep the machine in standby mode during the identified gap. Thus, the information of the standby power consumption per minute needs to be stored in a database. Finally, the fourth and last step compares the power used for remaining the machine in standby with the power consumption during the powering on and off of the machine. As the example graph displays in Figure 8 (bottom, very right), the power consumption usually increases for a short period of time during the power off as well as during the power on process.

This data can also be stored in a database and used on demand. After comparing the power consumption of the two options, a decision can be made. For example, if the power consumption of turning off / on the machine lower than the power needed for keeping the machine in standby, powering off would be the right recommendation.

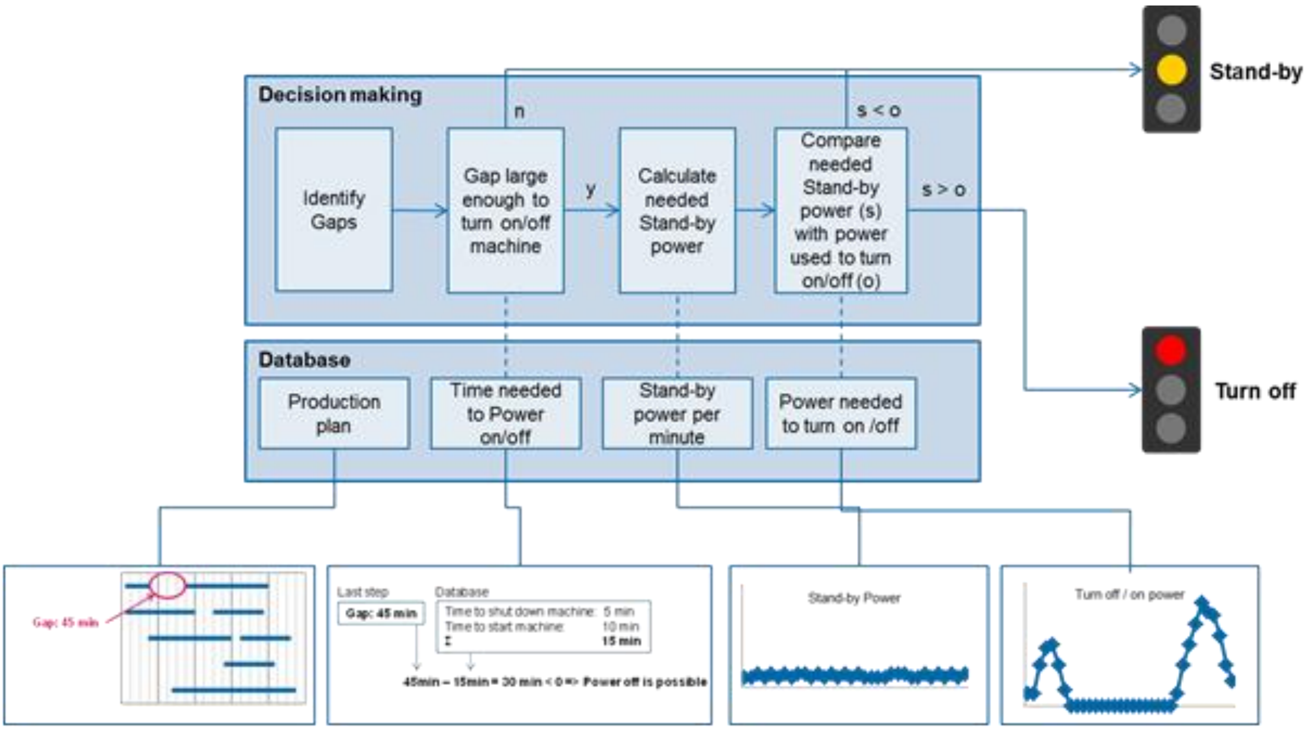

Figure 8: Use Case 1: Decision making process

Benefits & Costs

Benefits and costs can be calculated for prevention of wear and malfunction but also for inefficient operations mode. The expected benefit of the inefficient operations mode can be calculated by one machine that is still in the stand-by mode in not productive times. This case comparable to ENP where in average one machine is over night and over the weekend still in the stand-by ENP handles mostly with hand holding machines that consumes 5kW energy. The averages consumption in the stand-by mode is 10%. ENP calculates with 90.192h production free times per year (52 weekends and 14 hour night break). With energy cost of 13.16 ct/kWh the possible savings are 5.934 € per year.

The wear and malfunction use case will be calculated with a company that has an average energy consumption of 1 GWh. Different studies calculate with energy saving costs of 5%. Additionally this is a part of prevented maintenance which can also reduce unplanned breakdowns (s. Volvo case). The Potential can be calculate by 50 MWh. With energy cost of 13.16 ct/kWh the possible savings are 6.000 € per year per GWh. The benefit for prevented maintenance is temporary not able to quantify.

Prioriti-zation	Potential
A	Reduce waiting time due to current use of equipment
B	Decreased searching time for expert
	Reduced time for searching equipment
	Reduction of effort due to outdated plans
	Reduce errors in calculating working time
	Energy efficiency
C	Reduced time for searching material
	Reduced rework on lifting points
-	Reduced health risks
	Improve task reassignment

Figure 9: Potentials and prioritizations

If the wear detection model is implemented, prevented costs for maintenance will be quantified. In order to try quantifying the benefits of saved energy and prevented maintenance potentials are recognized. Potentials have different prioritizations:

1. A: Implementation recommended
2. B: Implementation depends on effort
3. C: No implementation recommended
4. D: Qualitative impact

These potentials are quantified and therewith the reachable benefits. Sense & React developed a tool to calculate how these potentials can be achieved by using functionalities. These functionalities are offered in two types, basics and optionally packages.

	Functionanlities	Choose	Number of Employees 1...*
Basics	Notification & Alerts Service	1 = yes	50
	Role MGT Authorization/Authentication	1 = yes	50
	Context & Data Services	1 = yes	50
	Context Engine Component	1 = yes	50
	Complex Event Processing	1 = yes	50
	Data Access & Database	1 = yes	50
	Legacy System Interface	2 = no	
	Proxy System	2 = no	
	Sensor System	2 = no	
Packages	Reactive Cognitive Load	2 = no	
	Maintenance Consultant Service	2 = no	
	State Model Analyzer & Query Tester	2 = no	
	S&R Shell	1 = yes	50
	Tool Finder	1 = yes	
	Material Handling	2 = no	
	Production Info	2 = no	
	User List	1 = yes	
	Context Aware Message Server	2 = no	
	Construction Supporter	1 = yes	50
	Daily Construction Plan	1 = yes	
	Assembly Supporter	2 = no	

Figure 11: Cost calculation application

The client can choose which functionality he wants to have in his enterprise. Each functionality has a smart background calculator. The client must fill in the relevant variables. In this section number of employees or size of the production hall etc. After the client passes all relevant information the tool releases a final impact. Thereby the achievable benefits are deducted with the costs of wanted functionalities.

The economization of the implemented models can be calculated by deducting the benefits and costs. In all Sense&React Use Cases the used Sensors are Weidmueller Power Monitors for each analyzed machine tool. Each sensor costs 500€. In our Use Cases four of these sensors were used for measuring the energy consumption of a machine tool. Costs for consulting, software and implementation are temporary unable to quantify.

These are four Weidmueller Power Monitors in our test environment DFA. Which is closer described in the next section.

Figure 10: Weidmueller Power Monitor

Saved costs for detected wear is calculated by 6.000€ per year per GWh and for an efficient operations mode by 5.934€ per year. Assumed that in the DFA 1 GWh energy is used in a year, the whole benefits by implementing both use cases are 11.934€. The total costs for sensors are 2000€.

The total benefits after 1 year are 9.934€. In less than one year, the investment is amortized.

Test Environment

The demonstration plant will be implemented at the RWTH Aachen Campus, which is an innovation of the RWTH Aachen University to create a link between University and industry. The cluster is a network of research institutes, enterprises and associations that pursue joint interest in a predetermined topic. Researchers from science and industry work closely together in content and location.

Part of the RWTH Aachen Campus is the Campus Cluster Logistics which is managed by FIR. The goal of the campus logistics is to make complex interconnection in logistics production and service visible and researchable. The cluster includes the “Enterprise Integration Center (EICe)”, which is composed of a demonstration factory, theme park with individual experimental constructions and experimental and collaboration areas.

The demonstration plant will be implemented in the Campus Cluster Logistics and will enable empirical research of the production management on the basis of a real production. Thereby, an interlocking of theory and empiricism in production management will be obtained between the elements research, advanced training, system testing and real production. The demonstration plant will be the hot-spot for providers of innovative production and IT-systems and offers an unique user-oriented education environment for future production manager. It allows an experiment-based research as well as training and education in a real production environment. Through the integration of intelligent information technology like sensors, movement data in real-time and scalable definition are provided. By means of the flexible production environment differing material flows can be shown as required.

The demonstration factory consists of six different areas: a storage area, a sheet forming area, a welding area, a mechanical production area, a paintwork area, and an assembly area. The mechanical production area comprises a large milling machine, four small milling machines, two turning machines and one sawing machine. In the sheet forming area there is one folding machine, one rounding machine, one sheet cutting machine and one drilling machine. In the welding area there are two MAG welding machines, two welding robots, one 2D-laser machine and one 3D laser machine.

The demonstration factory has a Wi-Fi network that can be used for testing localization solutions. Because of the testing character of the plant, other location technologies can be installed. As an example for part location at the edge of the six different areas, RFID gates can be installed, so the user knows in which area the needed part or tool is.

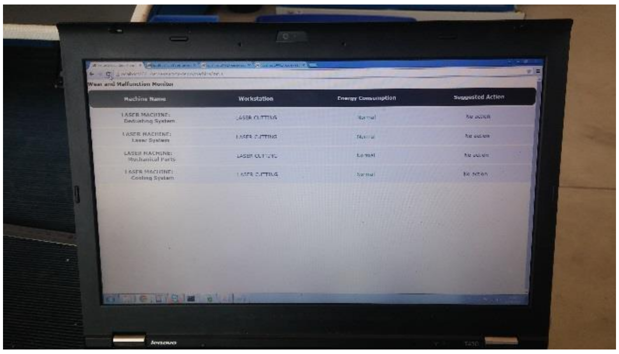

Figure 12: Test szenario

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