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APPLYING ENERGY ASPECTS ON SIMULATION OF ENERGY-INTENSIVE PRODUCTION SYSTEMS

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ABSTRACT

The electricity market within the European Union was liberalized in 2004, which means that Sweden, together with other countries with generally low electricity prices, will face higher electricity prices. This has triggered research with the aim to help energy-intensive companies reduce their electricity usage and total energy usage as well. This paper introduces a new concept for simulating energy-intensive production. Using specially built simulation models helps companies take more than the time aspect into consideration when planning their production. Often energy and power utilization is an important aspect to consider when planning, since the cost for energy and power usage can be high, especially if a "load subscription" is used and the usage is above the company's subscribed level. The methodology described helps breaking down energy parameters into three groups and gives examples of how the simulation model can be built to take energy and power into consideration.

1 INTRODUCTION

The advances of manufacturing simulation have made it a tool that today is used within several areas of business and applied on a wide range of applications. The usage areas and the types of simulation vary and are spreading all the time. This paper is another step in that development. Not often is more than the time or cost aspects taken into consideration in Discrete Event Simulation (DES) models. In our approach the energy consumption is also modeled and analyzed with the aim of helping energy-intensive manufacturing companies reduce their energy consumption.

The results and the description of the concepts in this paper are described from a foundry's point of view. Most of the ideas can also be used in other energy-intensive industries with minor adjustments and with focus on other processes.

1.1 Energy Consumption and Prices

The world's countries total energy consumption is increasing steadily and Sweden is no exception. The total energy consumption in Sweden increased from approximately 450 TWh per year in 1970 to approximately 625 TWh per year in 2003, of which Swedish industry today uses approximately 155 TWh annually (STEM 2004a).

The usage of energy gives negative stress on the environment. According to a report from OECD (OECD 2004) energy usage is the thing that gives rise to the most environmental problems in the world. During the last decades researchers have agreed to the fact that the threat from global heating is increasing. In an attempt to decrease the extent of global heating the Kyoto protocol was signed in 1997. The EU has signed to decrease the total carbon dioxide discharge by eight percent to the years 2008-2012.

Liberalization of the electricity market is one of the means of control that is introduced in the European Union. Together with increasing fuel prices this will probably lead to increasing energy prices. This is a risk for Swedish companies because Swedish energy prices are among the lowest in Europe. (EEPO 2003). A way to decrease this risk is to make the energy consumption more efficient in the companies. But there is a resistance to new technologies in several Swedish companies and simulation as well as other tools and methods are difficult to introduce. Obstacles and driving forces for making production more energy effective as well as guidelines for improvements are described by Persson et al. (Person et al. 2005) and Thollander et al. (Thollander et al. 2005). The result from their studies shows a great ignorance of the potential of energy saving investments and that the main driving forces are the engagement of one or more key persons in the organization and the existence of a long-term energy strategy.

2 SIMULATING ENERGY CONSUMPTION

Simulation studies have been carried out in various environments and in various industries with different objectives and goals. It can be analyzing bottlenecks in an existing manufacturing plant, verifying investment analysis, or creating an easy-to-use planning tool. Up until now the main aspects on which one look at the manufacturing is money or time (which often also is equal to money in some way). Optimization and planning of the daily production is also done from the aspect of time or money.

Including energy consumption into the simulation model breaks new ground for making the simulation tool a life-cycle-analysis tool. The simulation model can now include also the cost of investment of non-producing equipment such as ventilation and lighting, things that before have been looked at as only a yearly cost. Also more aspects of the cost of running this equipment can be taken into consideration. Examples of such non-producing equipment are:

- Ventilation systems, of which some parts have to be changed relatively often in some foundries, depending on material used in the process.
- Local comfort equipment, such as space heating as well as lighting. These things may be seen as small costs but in large factories with lots of space these can be important factors as well, when most of the excess heat from the melting and cooling processes are ventilated away because of difficulties faced when heat exchanging contaminated air, work environment specifications, and the fact that many companies don't have tools to reuse that excess heat.
- Compressed air, which is widely used and generally has low energy utilization rates.

Energy cost can't be excluded when a high percentage of the total refining cost is different energy costs. Using simulation in these environments to analyze or optimize without including energy costs means that only parts of the total cost can be optimized. Since extra costs are applied when the electricity load is high this influence will be lost if only the time aspect is considered.

There are three principal ways to reduce energy cost in plants:

- reduction of energy use.
- load management measures.
- changing energy carriers.

Our approach can help reducing the overall energy use by helping the load management work. Changing energy carriers is not a goal in itself to reduce the cost, but such scenarios can be analyzed as well.

3 APPLIED THEORY

3.1 Simulation Methodologies and Usage Areas

There is no doubt that there are several different methodologies available for simulation studies. What this paper will do is not invent a totally new method but instead apply common knowledge into a new area and add some concepts into it. Simulation project methodologies such those described by Law and Kelton (Law and Kelton 2000, Law 2003), Banks (Banks 2000), Robinson (Robinson 1994), Musselman (Musselman 1994) and Jägstam (dAISy 2003) and several more are applicable with the theories in this paper.

A little more effort has to be made to adopt the energy usage into the simulation model. Mainly in the conceptual modeling phase there has to be more efforts put in analyzing the material flow to identify additional energy consuming apparatus together with the producing machines and material handling systems. An energy mapping has to be carried out to be able to set the right usage levels to the right process. An energy mapping can be time-consuming and therefore costly but has been proven to be a procedure worth its cost since a lot can be learned about the system more than just using it as a feeder to the simulation work.

The input and output is preferably stored in a database or integrated into the company's ERP system if possible. But Microsoft Excel sheets or equivalent work as well and that issue is not dealt with in this paper.

3.2 Planning Levels

In every simulation case it is important to look at the usage possibilities along with the abstraction level, which is closely related to the planning level, in which the simulation model is used. Starting with the three common planning levels described in today's literature (Das et al. 2000, Dewhurst et al. 2001, Landeghem et al. 2002):

- Strategic planning.
- Tactical planning.
- Operational planning.

An energy consumption is useful mainly at the tactical level but also at the operational planning level. The most useful usage areas are probably when the companies need to restructure and rethink about the overall planning, for example when the ovens should be started in the morning, related to each other and to other heavy energy consuming equipment, so that the maximum electricity load isn't reached. This is a tactical planning problem but if very detailed information is available this could also be done continuously. It is also possible to see application areas within strategic planning such as those of analyzing investments in new ovens etc.

4 INTERESTING PARAMETERS

When mapping the energy consumption within a manufacturing company it is obvious that there are several different parameters that play an important role in the total energy system. What isn't obvious is what energy which process uses. It is easy to measure how much power different machines and other equipment use and the marked power and maximum power levels are often mentioned in the specifications. This information is useful and can be used when making an energy analysis and making overall assumptions of the system. But how this information can be used in a simulation model is not as obvious.

4.1 Modeling Different Parameters

Adding parameters into a simulation model isn't often a positive thing but using them in the right way reduces the potential extra work. Three different categories have been found that can express the behavior of energy consuming equipment:

- Overhead – The overhead parameters are modeled as constant or fluctuating values over time. Examples are:
  - Ventilation.
  - Space heating.
  - Lighting.
  - Sand preparation.
  - Knockout (also possible to use as direct if the usage is described in enough detail).
  - Shot peeling (also possible to use as direct if the usage is described in enough detail).
  - Grinding (also possible to use as direct if the usage is described in enough detail).
- Direct – The direct parameters are the ones that are caused and can be related to one specific process. Examples are:
  - Melting.
  - Holding.
  - Compressed air.
  - Molding.
  - Ladle heating.
  - Hot tap water.
  - Knockout (Overhead if not detailed enough).
  - Shot peeling (Overhead if not detailed enough).
  - Grinding (Overhead if not detailed enough).
  - Lab and office processes.
- Indirect – The indirect parameters are the ones either a direct process or an external process causes, but where the cause is not specified, such as transformation losses.

It is important to keep these parameters apart when modeling to be able to make an accurate model. It is important in this kind of modeling to be able to accurately identify the total energy and power usage at each specific moment since it varies over time. It is important both from the system analysis point of view but also to be able to see at what moments the power usage hits the maximum load for that specific company. Especially since most foundries pay extra for power loads above that top subscription level.

The direct parameters are the ones that can and must be used in direct connection to the actual process. These are also the most difficult to get right since they can vary over time even if the process stays the same. For example, the energy consumption while holding depends on the amount, sort, and quality of the metal.

Some parameters, such as shot peeling and grinding, can and may be used in different categories depending on detailed description of the process that is available.

4.2 Examples of Data and Codes

Besides the usual static and operational data used in the simulation model some additional data is necessary based on the parameters mentioned in the previous chapter. Below are examples of how the parameters are used in the simulation model. The examples are conceptual codes and shows only the parts related to the energy consumption, excluding other operating codes.

- Overhead – First, a machine that is working with a specific power usage a specific time represents the overhead parameter. Then the total cost of the parameter can be calculated by multiplying the simulation time by the power usage and the factor of number of worked hours, extracted from a schedule:

```
routine vent_tot_cons():real
var
    tot_energy_cons : real
begin
    tot_energy_cons = sim_time*ave_vent_power
    return tot_energy_cons
end vent_tot_cons
```

  If the instantaneous power usage is needed it can be extracted from the stored data in the database.

- Direct – For the direct processes the energy consumption must be calculated from every cycle the process executes, as in the following example of code where the total power usage is accumulated and stored:

```
procedure grind_work_cycle()
var
    temp_time, time_used : real
begin
    temp_time = sim_time
```

```
    work_grind_process()
    time_used = sim_time - temp_time
    grind_tot_energy_cons=grind_tot_energy_con
    s + time_used*grind_power_factor
end grind_work_cycle
```

See table 1 for typical input data applied to a specific grinding process.

- Indirect – The indirect consumption can be applied on different levels depending on the cause. If a transformation loss originates from a specific process and can be identified and measured it should be applied directly to that process. But if the loss can't be specified it may be treated as an overhead parameter.

Table 1. Typical Input Data Applied to a Specific Grinding Process

Cycle time (min)	Normal(2.9,0.40)
MTBF (min)	Normal(154,47)
MTTR (min)	Exp(7.2)
Average power usage when in use(kW)	82

Of course these examples may vary depending on the case and the codes depending on the simulation software, programming technique and language.

4.3 Other Interesting Aspects

The foundry process can be quite complex in some plants depending on the great variety of products that some foundries have. The things that most commonly vary are the product sizes and shapes, batch sizes, alloy variations. Different products have different requirements on the temperature on the melted material. This means that the melted metal that isn't used sometimes needs to be reheated or cooled depending on in what sequence the products are planned to be produced, resulting in large energy wastes. You also want to reduce the overheating and the holding times. An overheating of 2 degrees requires 1 kWh per ton melted metal. (Svensson and Svensson 2004) These things can be reduced using a simulation based planning model with the holding time as steering or optimizing factor.

Interesting is also that the melted metal that is poured into the moulds contains a large amount of energy that is freed while the metal cools down. Mostly this freed energy can be captured and recycled into for example the heating system or to heat tap water reducing the total energy consumption. Even though it is possible to do it isn't done in many plants today.

Changing or combining different energy carriers are in some systems possible. Combining these in a good way may help reducing the electricity levels thus also the power levels. It is not said that other energy carriers are cheaper than electricity and together with some casting methods other carriers are not possible or suitable. But it is predicted that prices of other carriers will not change as much as electricity prices in the near future, something that is important to keep in mind.

4.4 Breaking New Ground in Life Cycle Simulation

The hardening market and the customer's increased awareness as well as the engagement from environmental groups and unions etc. sets the standard for today's production. Keeping focus only on utilization as a means for generating profit is not enough anymore. There must be focus also on quality, ethics, environmental aspects, work environment etc. The simulation models must follow in that development, complicating the simulation models as well. But breaking down a simulation model into more details with more aspects taken into consideration is a good thing. If the usage of a simulation model increases the benefits from it increase as well. Energy and power consumption is one of these aspects that enriches the use of simulation helping it become a tool for LCC (Life Cycle Cost) analysis. If a machine or even an entire plant can be analyzed from its total cost in terms of utilization, energy consumption, influence on work environment (leading to sick leaves), influence on the environment (leading to fines) etc. the total picture will be much easier to understand. Before all these aspects can be built in the simulation softwares must be developed to be adopted to these circumstances and a more structured approach to modeling must be adopted.

There is much to further develop before one simulation model can have that wide range of usage areas. But the energy aspect is one of those important aspects that can't be forgotten.

5 FUTURE WORK

Two simulation cases are currently being solved with the described method at two different sized foundries in southern Sweden. Results will be presented with more details later but indications are that the working method works as hoped and the interest from the involved companies is great, indicating the need for this type of energy saving activities.

6 CONCLUDING REMARKS

This paper has described a new area and application of simulation methodology, the energy consumption within a foundry. The basics in the method described are generated from general methods used within the simulation community and applied in the specified area adding the special requirements needed. Focus has been on how the additional data connected to energy consumption are broken down and categorized for use in a simulation model.

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