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INCREASED ENERGY EFFICIENCY IN A SWEDISH IRON FOUNDRY THROUGH USE OF DISCRETE EVENT SIMULATION

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ABSTRACT

There is a long lasting debate concerning the rapidly increasing energy prices in Sweden. For industry the prices has increased by roughly 100 percent the last 5 years. This situation has resulted in an extensive energy research and the work of this paper is part of that development. The paper presents a methodology to analyze and reduce the energy use within energy-intensive companies where the Swedish foundries are the main targets. The methodology is tested on a Swedish iron foundry. The paper shows that using specially built simulation models companies can lower their energy costs by planning the production in a more efficient way. The methodology described helps breaking down energy parameters into groups and gives examples of how the simulation model can be built to take energy use into consideration.

1 INTRODUCTION

As described in a numerous papers manufacturing simulation have become a tool that today is used within several areas of business and applied on a wide range of applications. The applications and simulation types are expanding continuously. This paper is yet another step in that development. Most often the simulation models are built around the aspect of optimizing or at least decreasing the important times in a manufacturing system. Time and its corresponding cost are generally the most important factors. In our approach energy is another key factor and is modeled and analyzed with the aim of helping the company reduce its energy use. One of the key drivers for this is the cost connected to the energy use but side effects such as environmental issues are not to be underestimated.

The results and the description of the concepts in this paper are described from one specific foundry's point of view. The ideas are however applicable in many areas so it is not exclusively a method applicable to this foundry or the foundry industry itself. The ideas may thus also be used in other energy-intensive industries with minor adjustments.

1.1 Energy Use and Prices

The worlds aggregated energy use is increasing steadily and Sweden is no exception. The total energy use 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 2004).

The use of energy also affects the environment in a negative way. A report from OECD (OECD, 2004) states that energy use is the largest cause of environmental problems in the world. As a result of that the European Union has signed to decrease the total carbon dioxide discharge by eight percent to the years 2008-2012. The Kyoto protocol was also an attempt to decrease the extent of global heating.

The deregulation of the European electricity market will cause electricity prices to increase in Sweden, For Swedish companies this has become a particularly difficult situation since Swedish energy prices are, and have been for the last decades, among the lowest in Europe. (EEPO 2003). Moreover, the introduction of the carbon emission trading system will cause prices to peak even further. The Swedish foundry industry is, together with other energy-intensive industries, particularly sensitive to higher electricity prices due to their large electricity consumption, their large relative use of electricity compared to the aggregated energy use (see figure 1) and very high shares of energy costs, 5-15 %, in relation to the added value (Thollander et al. 2005).

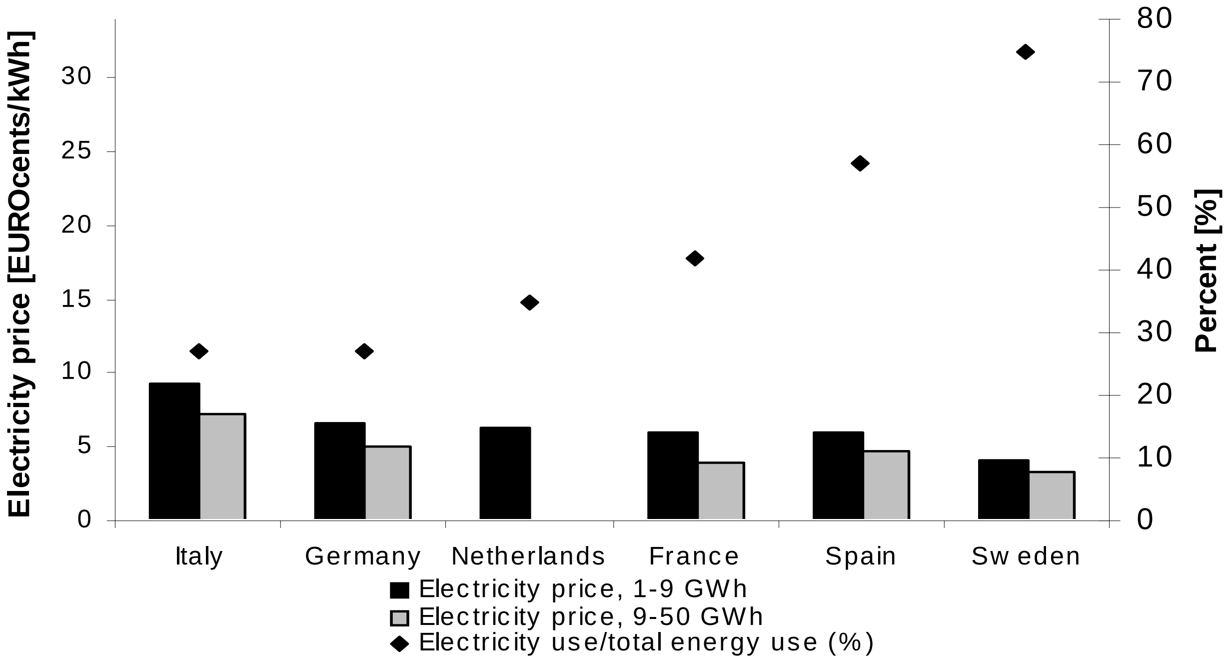

Figure 1: Foundry Sector's Average use of Electricity in Relation to the Total Energy Use [%] and Electricity Prices for 1-9 GWh and 9-50 GWh Enterprises in Some European Countries. For the Netherlands, too Few Observations Were Made in Order to State a Figure for Enterprises Using 9-50 GWh Annually (Orkas, 2000. Soultanian, 2003. Ravn et al. 1994. EEPO, 2003).

A way to reduce this threat is to decrease the companies' dependence of electricity and other energy sources. However, with some exceptions, the resistance to new technologies in Swedish foundries is significant. Not only new technology, but also new working methods and aids, simulation being one, are difficult to introduce. Obstacles and driving forces for making production more energy effective as well as guidelines for improvements are described by Rohdin et al. (2006a-b). These studies show 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.

1.2 Energy and Swedish foundry industry

With 130 companies and some 7 500 employees the Swedish foundry industry has an aggregate domestic turnover of 1.3 Billion Euro (Swedish Foundry Association. 2005). Swedish foundries produce some 320 000 tons of castings annually of which 74% is iron castings, 20% non-ferrous and 6% steel [ref]. The total annual energy use is about 1 TWh (Swedish Foundry Association. 2005).

The foundry industry is a large user of energy and in the majority of the foundries processing, and in particular melting and holding, are the major energy using processes (Thollander et al. 2005). The quantity of energy used to melt metal is approximately proportional to the amount of metal melted. The casting output may vary from 85-95 % for simple and heavy grey iron casting to 40-50 % for production of small ductile iron casting in mechanized volume production (DETR 1999). Increasing the yield (the total weight of good castings in relation to the total weight of metal melted) directly gives lower energy usage. To manage this focus should be on accurate production planning and good practice in general in key areas such as melting, pouring, molding and core making. The reduction of scrap is one important issue since it has a two-fold effect. Firstly, less energy is required for metal melting and secondly, materials, consumable items and labor are also reduced, thus increasing the foundry's capacity. Apart from melting and holding, energy usage in the supporting processes, such as ventilation, lighting, space heating and tap water, have often received less attention. Reasons for that are for example the history of low electricity prices (Trygg and Karlsson, 2005), limited access to capital, technical risks such as risk for production disruptions and lack of budget funding (Rohdin et al. 2006b).

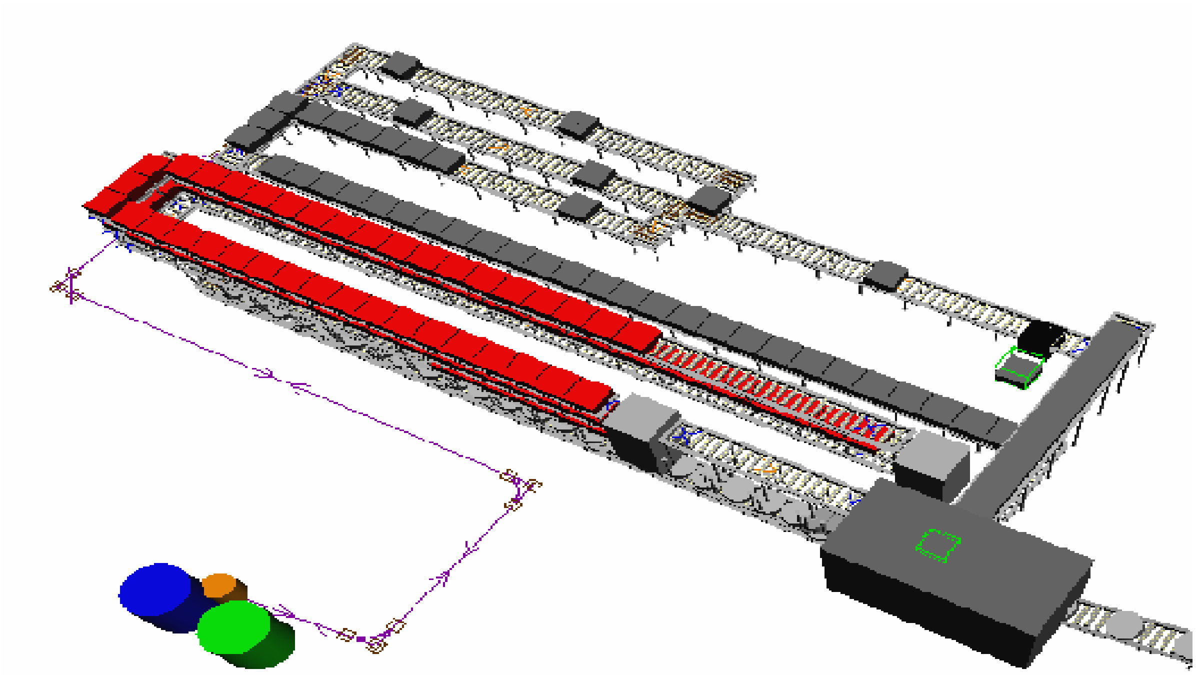

Figure 2: Overview of the Studied Foundry. The Picture Shows the Furnaces, the Molding Machine, the Pouring Conveyor, the Cooling Conveyors and the Knock Out Station.

2 METHOD

The results presented are derived from a handful simulation studies in the Swedish foundry industry. The case presented in this paper can characterize a general example of this group even though variations may occur.

The case study originates from the methods presented in Solding and Petku (2005), also presented here in a shorter version. The final results and final methodology will be presented at the end of the ongoing research program.

The studies are focusing on electricity use within the plant even though reductions off fossil fuels are of great interest too and especially its influence on CO_2 emissions. The substitution of fossil fuels to other energy carriers for heating and the work of recycling of heat does not in itself reduce the actual energy use hence these issues are not directly dealt with in the simulation studies. Also, other factors, outside the system boundary, i.e. the actual plant, like the percentages of ”green electricity” are of lower importance in this study.

Influences are also gathered from survey studies (Rohdin and Thollander 2006a, Rohdin et al. 2006b) and an interview study (Rohdin and Thollander 2006c) conducted during 2005 and 2006. These studies show what the drivers and the barriers are for introducing energy efficient technology and energy efficiency methodologies in the Swedish foundry companies.

Well-developed methodologies for the application of discrete event simulation to industrial processes exist. (Banks 2000, Law and Kelton 2000, Law 2003). Only the key model development issues pertinent to the application of energy use are presented here.

The simulation model has been created using the commercial discrete event simulation package AutoMod (BrooksSoftware 06). Supporting data is stored and transferred to and from Microsoft Excel.

3 THE CASTING PROCESS SYSTEM

The system which is described in this paper is a casting process in an iron foundry producing approximately 1 800 tons annually. Two melting furnaces support the system via a ladle transported along an aerial monorail from the melting facility to the mould line. The melting time depends on the amount of iron and the charge recipe. Being believed as the bottleneck the melting facility always tries to optimize the melting time.

The mold machine delivers molds to the system with a speed greater than the one of the melting facility to avoid holding losses. Molds, before and after pouring are transported on a system of conveyor belts. After knockout the parts are transported on a secondary conveyor belt in the basement for cooling to desired temperature before entering the shot blaster. The speed of this conveyor belt can be altered depending on the size of the goods and the time on the primary cooling conveyor belt, factors that are controlling the cooling demands. Finally the goods are transported to the fettling stations and stored before transportation. The cores are produced in a room right next to the melting furnaces.

3.1 Production planning

Production plans are made manually by a production planner. The plans are based on the incoming orders. The production planner then decides good mix based on experience. The fact that there are several hundreds of models that can be arranged in almost an infinite number of ways makes the situation even more complicated. The exact plans and the mix of models are not decided until the production list reaches the mould line. The models are there being placed in a mix possible on the mold flask, which has a length of 1 200 mm and a breadth of 1 000 mm.

During the main portion of the time the company only uses one of the two furnaces. The only times that two furnaces are used are when the most used one is rebuilt and sintered, something that happens about every ten days, and in rare cases when two different alloys are needed at the same time. The rebuilding of the furnace are planned in the way that the rebuilt furnace is loaded with an increasing amount of heat to sinter the material. While this is being done the other furnace is providing melted iron to the line. When the furnace is sintered it is charged with material and the melting procedure started. During this period two furnaces are used parallel. To avoid too high power loads one furnace goes with reduced intensity, manually adjusted from experience. Around 1 p.m. the rebuilt furnace is sintered and ready to deliver its first batch of melted iron. Not surprisingly it is during these periods that the peak loads occur.

3.2 The electricity and power subscription

The foundry's subscription of electricity consists of two parts. One part is the variable electricity cost, based on the actual electricity consumption during a period of time, here referred to as the variable cost. The foundry is, through the deregulated European electricity market, able to choose which company to buy electricity from. This may be done on the spot market or directly by the power company or by other actors on the market. The foundry is also being charged with another electricity cost, here refereed to as the grid cost. The grid cost is set by the owner of the grid and is thus not possible to change, as the market is a monopoly. The grid cost consists of three parts. One regards the power subscribed, one regards the three highest peak loads (hourly), during the previous year, which the company used and one regards the actual consumption of electricity and thus works like the variable cost, though charged by the owner of the local grid. It is therefore not only of interest to keep the electricity consumption low due to the variable price and the variable part of the grid cost but also to keep the peak loads to a minimum during the current year to decrease this cost for the following years. Another reasons for keeping the load low is that a usage of more power than the prescription amount is subject for a fine. This type of electricity subscription described is the most common among the Swedish foundries today.

As an addition to electricity the company uses a certain amount of oil for space heating and hot tap water and LPG (liquefied petroleum gas) for ladle heating. These amounts do not affect the electricity usage.

4 SIMULATING ENERGY USE

There is no doubt that discrete event simulation today can be applied in a wide range of disciplines. Simulation studies have been carried out in various environments and in various industries with different objectives and goals. Bottlenecks have been identified in existing manufacturing plants, investments have been analyzed and verified and production facilities have been thoroughly planned with the help of simulation tools. However, up until now the main aspects on which one look at the manufacturing are 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. It is time to break new ground for how and where to use simulation. Including energy use aspects into the simulation model in the Swedish foundry industry is one way of breaking that new ground. This also helps simulation grow even more into a life-cycle-analysis tool.

When modeling energy using equipment it is useful to divide them into groups. Generally there are two main categories of energy consuming equipment - production processes and support processes (Trygg and Karlsson, 2005). Examples of production processes in a foundry are:

- Melting, together with holding the main energy using process in a foundry.
- Holding
- Molding, with intermittent energy usage
- Sand mixing, a fairly constant process
- Knock out, with fairly low energy use
- Shot blasting, which varies depending on machine type.
- Fettling, which, if needed, can be divided into different subgroups

Examples of support processes 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 heating and cooling.
- Lighting
- Compressed air, which is widely used for fettling and generally has low energy utilization rates.

It is also possible to make subgroup of support processes more similar to overhead processes with relatively constant energy use. Examples are transformers and pumps, processes that don't vary much over time.

Production- and support processes are being handled differently in the simulation model. The production processes are directly connected to the processes itself while the support processes are handled in different ways. If the support process is directly connected to a production process the working periods of that process can be used. That is the case in for example VAV (Variable Air Volume) driven ventilation, where the air volume is depending on for example the fettling taking place. Support processes can also be modeled more generally as a continuous flow where it is difficult or impossible to foresee the reasons for fluctuation.

The actual costs of supporting non-producing equipment such as ventilation, space heating and lighting, have previously been modeled, if included at all, as a yearly cost, but are now being included in the model with continuous impact on the whole system.

4.1 The simulation model

The simulation model was built based on the information from the production planner, technicians and shop floor workers. Information concerning business figures was received from the managing director. Information concerning energy use and energy sources was received from a previously made energy audit. Order lists were received from the planner and these were double checked with the actual outcome to make the best approximation.

The outcome of the simulations were validated and verified through interviews and continuous interactions with decision-makers, and via comparisons with output from the model and output from real system and energy mappings.

5 RESULTS AND ANALYSIS

The main goal with this simulation project and the research project as a whole is to find ways to plan the production in a more energy efficient way without losing output. Two main planning problems have been identified – reduction of the maximum power load and the reduction of the total energy use in the day to day production.

Since there is a considerable lack of detailed production data and the fact that the models are arranged in the forms at the last minute by the shop floor personnel it is difficult to make an accurate detailed simulation model. The fact that there are several hundreds of models that can be arranged in almost infinite number of ways made the situation even more complicated. Therefore it was decided that no detailed daily production planning should be made with the simulation model in this case.

However, it was early identified that there is a lot to benefit from reducing the maximum load. As described, the company normally only uses one of the two furnaces. The situations when one furnace is rebuilt and sintered play a role of the total energy cost. These courses of events were simulated and tests were made. It was shown that by sintering the furnace during the night and early morning, and not starting the other furnace at all during that time, the peak loads could be reduced by approximately 100 kW. With the current power subscription this reduction of load corresponds to annual savings of 4 500 Euro. In addition there is a reduced possibility of exceeding subscribed power limit in the future and its corresponding fines.

To the simulation model was added the cost of different energy carriers. It is also possible to apply different tariffs during different periods of a day or week if that is the case. By adding these factors different scenarios of future energy prices can be simulated and costs calculated, which can be helpful in a analysis of future investments or rearrangements in work hours etc.

During the modeling it was found that there were difficulties in deciding where the boundary lines between different states are, for example when melting ends and holding begins. The level of detail of energy data decides the level of detail of the simulation model.

6 CONCLUDING REMARKS

Finally, the conclusion of this simulation project is that discrete event simulation is a good tool for simulating energy use in addition to the traditional production planning. However, it is important to know that the method described in this paper not solely decreases the energy use of the company. To use the results there is a need for an understanding of the results as well as a willingness to adopt the ideas and results into the company. Without the engagement of the workers it is impossible to create a more energy efficient plant.

7 FUTURE WORK

Two simulation projects within the research project have been conducted. Following some further enhancements of the methodology two more will be carried out. The final results are scheduled to be presented in midyear of 2007.

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