Case Study and Analysis of the Production Processes in a Steel Factory in Jordan

Jamil J. Al Asfar[1,*] and Ashraf Salim[2]

[1] *Assistant Professor, The University of Jordan, Amman, Jordan*
[2] *Assistant Professor, Philadelphia University, Jarash, Jordan*
* *Corresponding author. Tel : +962 79 5568 716, E-mail: jasfar@ju.edu.jo*

Abstract: This work represents a true case study and analysis of the technical and energy managerial aspects of recommended designs of the production lines of a steel factory in Jordan. A modern structure of a control system based on SCADA (Supervisory Control And Data Acquisition) technology is proposed. Furthermore, the mechanical and electrical maintenance sections in the factory were reviewed due to their major effects on the production cost and energy consumption of the factory. This study was performed in two main phases: The first phase contains the collected data and process assessment that were undertaken by traditional direct observation and activity categorization, while the second phase gave details on the proposed control methodology in terms of design and architecture.

Moreover, a proposal on maintenance planning and procedure program was also included in this study in order to reduce the time and accordingly the cost of maintenance. The steel factory studied produces various steel products such as: Concrete Reinforcement Steel Bars (Rebars), Flat & Square Bars Section which includes standard flat bars, standard square bars, and plane round bars, in addition to Wire mesh in different sizes and steel billets. In steel production industries, two automation levels can, in general, be identified. The first level involves the electromechanical actuation of the devices in the production plant; this level of automation is currently available in every plant. The second level involves the supervision of the production process; this level of automation is less frequent and is generally only partial. In fact, steel production involves a variety of complex physical phenomena, described by sophisticated mathematical models which are rarely usable to derive real-time advice for process supervision and control. Most operators' support systems for steel production are represented by simple technologies such as microprocessor-based systems.

Based on the outcomes of this study, the factory purchased a new melting furnace of (60) tons capacity instead of the (30) tons capacity melting furnace used in the factory before the study. The factory is considering also the purchase of a scrap press in its new budget in order to improve scrap quality before melting it; in order to reduce the rate of consuming the furnace electrodes. Also, the maintenance section will be restructured by merging electrical and mechanical maintenance sections into one section headed by the deputy of the factory manager.

Keywords: *Steel Production Line, SCADA System, Maintenance Structure, Efficiency*

1. Introduction

To maintain an efficiently operating unit and avoid failure of critical equipment, especially modern steel industry equipment, the focus has clearly shifted over the years, from Breakdown Maintenance, i.e. repairing the equipment after its malfunctions, to Preventive Maintenance, i.e. fixing the equipment according to planned maintenance schedule. The next trend was Computerized Maintenance Management Systems (CMMS), and the latest trend encompasses asset management and maintenance, supported by various methods of Condition Based Maintenance Systems (CBMS) and in-service inspection processes. CBMS or Predictive Maintenance methods are an extension of preventive maintenance and have been proved to minimize the cost of maintenance, improve operational safety and reduce the frequency and severity of in-service machine failures. The basic theory of condition monitoring is to know the deteriorating condition of a machine component, well in advance of a breakdown, for proactive maintenance. A conventional integrated steel plant has a vast array of equipment. The plant is a conglomeration of smaller units, each in itself complete and self-contained. These constitute Coke Ovens, Coal Chemicals, Sinter Plants, Furnace, Steel Melting Shops, Continuous Casting Machine, Tonnage Oxygen Plants, Plate Mill, Hot Strip Mill, Cold Rolling Mill, other secondary mills, Captive Power Plants and a host of other departments. Every piece of equipment needs special care and attention, characteristic to it. The Coal Chemicals unit has Gas Boosters and Exhausters that handle coke oven gas, a highly inflammable commodity, whereas Sinter Plant Blowers and Waste Gas fans handle air containing highly abrasive sinter dust. The Turbo Alternators of Captive Power Plant require round the clock vigilance involving a variety of parameters. Seemingly innocuous Forced Draft & Induced Draft fans of the Reheating Furnaces also assume significance because of their criticality in application. Failure of these fans may lead to cut down of Hot Strip Mill/ Plate Mill production by 33 - 50 percent. Under the current business environment, cost competitiveness of steelmakers has assumed a priority role. As a global phenomenon, effective maintenance management has been accepted as the key to corporate strategy for reduced costs. This has led to integration of maintenance management function with production and business problems, not just equipment problems. With this realization that maintenance management can cost 35 - 40 percent of revenues and, in most cases up to 15 percent of unit production cost, steel companies are increasingly opting for new maintenance technologies which can be effectively and relatively easily implemented for reduced costs and increased profitability. According to industry estimates, a 10 percent reduction in maintenance costs translates to a 30 percent increase in profitability.

From the previous discussion, the need for introducing new technologies to the steel production is definite. This study provided the factory with some state-of-the-art technologies which can be adopted into the steel production processes in order to improve the product quality, minimize the need for electrical energy and human resources, reduce maintenance time and cost, and increase reliability and real-time data accuracy. The Jordanian factory is located in Zarqa area, and employs (324) technicians, engineers and administration employees. The main function of the factory is to melt Scrap (collected used steel pieces) in an electric furnace of (30) tons capacity, then cast molten iron in moulds to obtain steel billets. The steel billets are then manufactured in a sister company factory to produce concrete reinforcement steel bars (Rebar) in different sizes using rolling and extrusion, flat and square bars, and wire mesh. This factory, which was manufactured by a Turkish company, is a new one that started production in 2008. The current production capacity is around 10,000 tons of steel billets per month.

Employing SCADA system into the melting and casting processes has a good impact on the product quality, minimizing the need for human resources, reducing maintenance time and cost; increasing reliability, and real-time data accuracy. This technology should provide the following:

- Continuous (momentarily) monitoring of the state of the process and of the plant;
- Displaying warnings and alarms, at a sufficiently high level of abstraction;
- Giving advice as needed to the metallurgical management of the process.
- Generating historical reports.

Nowadays, there are two main industrial processes to produce steel: The first one, which is known as integrated steel plant, produces steel by refining iron ore. This ore-based process uses a blast furnace. The other one, which is steel-making from scrap metals, involves melting scrap metal, removing impurities and casting it into the desired shapes. Although, originally the steel production in the electric arc furnaces (EAFs) was applied mainly to the special steel grades, the situation has changed with tap's size increase, and the high productivity that has been reached progressively. This has allowed significant cost reduction, diminishing consumption of energy, electrodes and refractory. At present, electric furnace combined with chemical additives, allows to make a very important part of the worldwide steel production on the basis of the massive recycling of the iron scrap. Under the current business environment, cost competitiveness of steelmakers has assumed a priority role. As a global phenomenon, effective maintenance management has been accepted as the key to corporate strategy for reduced costs. This has led to integration of maintenance management function with production and business problems, not just equipment problems. With this realization that maintenance management can cost 35 - 40 percent of revenues and, in most cases up to 15 percent of unit production cost, steel companies are increasingly opting for new maintenance technologies which can be effectively and relatively easily implemented for reduced costs and increased profitability. According to industry estimates, a 10 percent reduction in maintenance costs translates to a 30 percent increase in profitability [1-3].

2. Methodology

This study reviewed the structure of the maintenance section in the factory in order to improve and develop the existing maintenance processes and reduce running production costs of consumed electrodes and electricity. The current bill of electricity consumption per month by the factory is around $0.5m, which is relatively high for a factory in a developing country. As mentioned above, the automatic control system and measures used to control the process of melting iron and steel scrap, was analyzed and reviewed in order to evaluate its effect on the mechanical and electrical maintenance of the factory. Many machinery parameters can be measured, trended and analyzed to detect imminent failure or onset of problems. Common among them are: Machinery vibration, Lube oil analysis including wear debris analysis, Infrared thermograph, Ultrasonic testing, Motor current analysis, Shock pulse measurement, …,etc. Additionally, operational characteristics such as flow rates, heat, pressure, tension, speed and so on can also be monitored to detect problems. In case of machine tools, product quality in terms of surface finish or dimensional tolerances is often an indication of problems. As all these techniques have value and merit, the application of any particular technique depends on the suitability and ease of implementation [1-4].

The control systems of the Electrical Arc Furnace (EAF) used in the factory need the following improvement and development in order to reduce the final product cost. In order to achieve this aim, analytical methods were followed to improve steel production process in the EAF. In order to do so, the study was divided into two phases that are sequential yet synergistic. The first phase used traditional methods of work measurement drawn from industrial engineering practice, such as process definition, development of flow charts, and data collection via time-and-motion studies, to obtain a complete, quantitative understanding of current system operational procedures, workflow patterns, and location of productivity constraints. The second phase was built upon the understanding gained during the first phase. In the second phase, opportunities to improve throughput was identified, with particular attention to those opportunities requiring relatively low capital investment. The principal analytical tools to be used for this phase were the operations research techniques of project management, to identify both critical paths within work flow and utilization imbalances among system resources.

2.1. Improving Maintenance Management

A working definition for various types of maintenance actions is as follows:

- Failure Maintenance: This relates to the policy of repair or replacement of a part or subsystem only upon failure of the named part or assembly.
- Block Maintenance: This relates to the policy of repair or replacement of all parts on subsystems (block) at a predetermined interval of time.

- Preventive Maintenance: This relates to the policy of repair or replacement of a subset of parts or subsystems, when another part of subsystem fails or is repaired/replaced after a certain length of service [5, 6].

Proper maintenance is essential to keep production equipment and capital assets at a state conducive to its output role in maintaining a level of production at a predetermined quality and quantity. Maintenance costs typically average from 5% to 7% of the value of fixed capital assets, hence the economic implications of reducing maintenance costs are very vast. Data can be collected on costs of repair, downtime and availability percent statistics, usage of spares inventory, etc. This information can be used to set budgets, make historic comparisons and in general be used as control information. A sensible combination of failure maintenance and preventive maintenance will ensure that these objectives are met. The equipment failure characteristics often determine the worthwhileness of preventive maintenance activities. Equipment that fail randomly due to unexpected and inexplicable ove rstress, generally do not lend itself to preventive maintenance. Equipment that fails due to wear and tear may lend itself to preventive maintenance. Thus the 1st step in maintenance planning consists of analysis of failure characteristics of the subsystems comprising the total system. Forecasting of equipment failures in a stochastic system (probabilistic) is based on studying the past performance of the equipment and its subsystems, and assuming that these characteristics will hold in the future. Past data of equipment failures like time to fail are analyzed with a view to find a statistical distribution which closely resembles with a confidence limit of 90% or more the actual failure distribution of the subsystem. Once this is determined, methods of statistical sampling can be used to predict times to failure in any analysis. Among the most common failure distribution applicable to electromechanical systems are the Exponential distribution, Normal distribution, Log Normal distribution, Gamma distribution and Weibull distribution.

Maintenance Procedure Program (MPP) system is a s eries of dynamically linked programs, each of which plays an important role in the effectiveness of the maintenance program. The system applies to both electrical and/or mechanical maintenance in the steel production line and provides the process of equipment inspection as well. The MPP is a manner of applying several maintenance concepts into a co mplete program. This program fully utilizes each concept while combining the efforts of all. Each program element can stand alone in its own right, yet together their strength is multiplied. The need of such a program came about after many attempts of installing only one concept of preventive maintenance. It became apparent that no one method would cover all the bases at any one time. Thus, building a structure which would take into account each facet of maintenance and combine the efforts of each into a master program became a reasonable task. In Maintenance Job Order System, information is fed into this system from the crew inspectors, the department inspectors, the nondestructive testing group, the operations department, and the electrical/mechanical maintenance group. This information is in the form of necessary work to be done as a result of inspections from the various sources. The equipment history files are also important inputs into the job order system. This history helps coordinate the jobs to be completed during planned outages. The next step is to open the job order. The job order can be opened or directed to the maintenance foreman or the departmental planner. If the order is directed to the foreman, the work is assigned to a crew for completion. Normally, work assigned to the foreman would be of a nature which could be completed with the line running or which would be done during an unscheduled interruption in the operation. If the job order is opened to the departmental planner, he will coordinate the job order with the central shops crafts department using a shops job priority system, the maintenance foreman, and the maintenance spares man. These people act as a team in organizing the manpower, spares, and other factors necessary to complete the required job during the planned outage. After the completion of the job, the job order is closed.

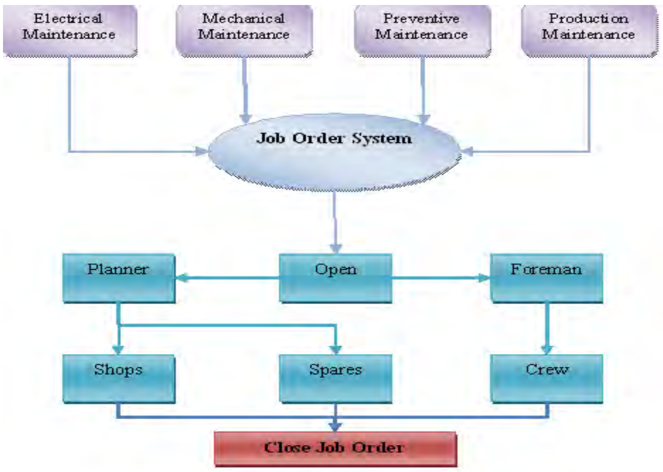

Fig 1: Maintenance Job Order System [5].

2.2. System Modelling

Fig.'s 2 and 3 show physical and electrical models of the existing EAF. In these models, three electrodes are moved vertically up and down with hydraulic actuators. Each of these electrodes weighs 0.4 tons and is 1.5m long. The ore is melted with a huge power surge from the electrodes. The actual product is denser than the scrap and thus falls to the bottom of the furnace creating the matte. Above the matte lies the slag where the electrode tips are dipped. The tremendous heat created by these electrodes causes the ore to liquefy and separate. Thereupon, more raw materials are placed in the furnace and the process repeats itself.

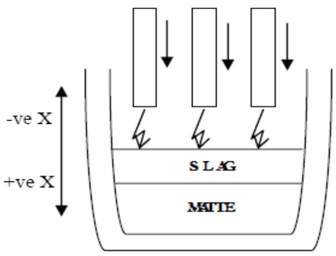

Fig. 2: Physical Model of the EAF [2].

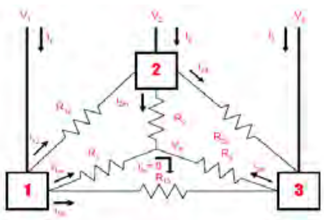

Fig. 3: Electrical Model of the EAF [2].

3. Results

The EAF operates on the principle of direct arc heating. Three graphite electrodes carry the three phase current into the furnace. An electric arc is generated between the electrodes and the metal charge which gives out heat. The charge gets melted by the direct impingement of the arc and also by the radiation from the roof and walls. A proper length of arc is to be maintained throughout the melting cycle. The furnace consists of a cylindrical steel shell mounted on supporting rockets. There is a tapping spout for drawing molten metal and a slag door at the back for slag removal. A removable roof covers the shell. The three electrodes enter the shell through the holes on the roof and are carried by electrode holders on the electrode arm. The position of the electrodes is controlled by moving the mobile carriage over the electrode post which- is done by electrode hydraulic cylinders. The electrodes are water cooled at the point of entry into the furnace. A separate water storage tank with a centrifugal pump is provided for circulating cooling water for the shel1, electrode holder, roof and the slagging door. A control panel is provided for controlling power input to the furnace, for forward and backward tilting, to indicate the currents and voltages and for accurate lifting and lowering of the electrodes. The hydraulic cylinder used for electrode movement is controlled by PLC (S7 400) to maintain the arc impedance a constant for a given voltage, the charging of furnace is done by opening the roof by swinging it to one side. One of the main objectives of the three-electrode control study is to have the electrodes maintain constant power consumption. This is achieved by moving the electrodes to a given depth, obtaining the desired resistances (or conductance), which leads to a constant power consumption. To attain this goal, the open-loop system must be closed in order to create an error signal. The control principle is accomplished by minimizing this error signal with specific controllers. PID controller can be designed and optimized for best performance. For this system, controlling the current will lead to power control; since the power magnitudes are scalar multiples of the electrode currents. Employing SCADA system into the melting and casting processes has a good impact on t he product quality, minimizing the need for human resources, reduction maintenance time and cost, increasing reliability, and real-time data accuracy. This technology should provide the following:

- Continuous (momentarily) monitoring of the state of the process and of the plant;
- Displaying warnings and alarms, at a sufficiently high level of abstraction;
- Giving advice as needed to the metallurgical management of the process.
- Generating historical reports.

4. Discussion and Conclusions

Unfortunately, we found that the SCADA system in the factory is only used for continuous (momentarily) monitoring of the state of the process and of the plant. Therefore; it is highly recommended to activate the other three facilities of the plant. Moreover, the SCADA systems which are employed for the EAF, Ladle Furnace, and the Continuous Casting Machine (CCM) are not networked, which is causing an extra burden and difficulty in the management process [2].

Based on above analysis, great deal of improvements is suggested in order to implement an active control and analysis in order to reduce the cost of production and maintenance in this factory, including scrap management; since economic and competitive pressures force industrial and process engineers to seek continuous improvement in industrial production processes [1]. In a complex industrial system, as in an EAF, the ways to improve this process are diverse, such as selection and treatment of materials, the redesign of the facilities and new kinds of energetic contributions to the process. The evolution of electric furnaces is reflected mainly in the progressive reduction of specific consumption of energy, tap-to-tap times and improvement of the metallic yield [2]. A deep study, comparing energy consumed currently in the production of steel with theoretically needed energy, was made by the Carnegie Mellon University (Pittsburg, USA) for the US Department of Energy [3-8]. The principal analytical tools used for second phase were the operations research techniques of project management and heuristic scheduling [6]. Though the direct comparison of different EAFs is difficult due to the operational differences, the disparity between the theoretical energy and the consumed energy contributes to the idea of potential improvement of these facilities which could be about 25% of the energy consumption. One of the pathways proposed to reach this yield improvement in EAF operation is the optimization of process sequencing by means of Programmable Logic Controllers (PLCs). Important effort has been directed towards further productivity improvements under EAF process. Much of this has focused on de veloping alternative energy sources to reduce the high cost of electrical energy, which means about 10-15% of EAF operation costs. Another two different types of costs that have impact on t he total cost of EAF operation can be identified: the cost of the feed materials and the cost implication of not reaching control objectives. Feed materials are very conditioned by the final quality of steel to obtain (scrap substitutes are mainly used in the production of higher quality products) and the steel cost due to materials is mainly determined by the price of scrap in the world-wide market. Processing control optimization is another very important way for the reduction of the energy consumption. Because of knowledge lack of a suitable plant model, the operations in the furnace are only based on empirical knowledge. There are a large number of traditionally manually controlled variables. The furnace operator, in accordance with his own experience and in his particular way of working, has been taking the decisions. For example, he was deciding if it was necessary to inject more or less oxygen, coal or HBI (hot briquetted iron), or even stopping the process and measuring the steel temperature. The automation of these variables ensures better operation in EAFs [7-13].

Steel scrap is the most important raw material for electric steelmaking, contributing between 60% and 80% of total production costs. In addition, the degree of which the EAF process may be controlled and optimized is limited by fluctuations in scrap quality. Therefore quick estimations of properties of different steel scrap grades are very important for improving the control and optimization of the EAF process. Most countries have national classification systems for steel scrap, but there is also a European classification system that the EU-countries use for international scrap trade [13]. Steel scrap is usually graded in terms of size distribution, chemistry, density, and origin, and processing method. Some melt shops have internal classification systems that further divide the standard scrap grades into subtypes, and also a number of internal scrap grades (scrap produced within the steel plant). However, the scrap grading systems are designed for commercial purposes and the variation in scrap properties within each scrap grade is high. In general, scrap properties may be divided into two main categories, physicochemical properties and process related properties. Physicochemical properties (chemical composition, density, specific surface area, size distribution and melting temperature, specific heat capacity, metallic/ organic/oxidic content) are only dependent on t he particular scrap grade and are best determined by controlled experiments in laboratories. Process related properties (yield coefficients, specific energy consumption, contribution to chemistry of steel and slag, contribution to basket and furnace filling degree, contribution to dust generation and off gas composition) depend on bot h the process conditions and the other materials in the scrap mix. Therefore, the process related properties for the same scrap grade may vary considerably between different melt shops. Chemical analysis, conductivity, metal content and size distribution may be measured or estimated for individual pieces of scrap and/or random samples but the fluctuation in scrap quality is often too large for these measurements to be representative for the whole population of a scrap lot on the scrap yard. Experimental design methods have been proposed to set up a series of experimental heating processes that can then be used to estimate the scrap thermophysical properties. However, because of the variation in process conditions and fluctuations in scrap quality each experiment would have to be repeated several times. The number of experiments needed to get estimations for all scrap grades can therefore be very high, depending on t he number of scrap grades that are used, rendering this approach unsuitable. An alternative to designed experiments is to firstly extract large quantities of data from process databases [3]. Advanced statistical methods can then be used to analyze the combined effect of scrap mix and process conditions on the end conditions, chemical analysis of the liquid steel, energy consumption and metal yield [2- 3, 13].

References

[1] Reeder, Thomas J. 1995. Take a Flexible Approach - Combine Project Management and Business Principles into Program Management. Industrial Engineering 27(3): pp. 29-35.

[2] E. Quation, Jose´ Manuel Mesa Ferna´ ndez_, Valeriano A ´ lvarez Cabal, Vicente Rodrı´guez Montequin, Joaquı´n Villanueva Balsera, Online estimation of electric arc furnace tap temperature by using fuzzy neural networks, Engineering Applications of Artificial Intelligence, 2007.

[3] Fruehan, R.J., Fortini, O., Paxton, H.W., and Brindle, R., 2000. T heoretical Minimum Energies to Produce Steel for Selected Conditions. Energetics, Inc., Columbia, MD, US Department of Energy Office of Industrial Technologies Washington, DC.

[4] Leu, B or-Yuh., 1996. Simulation A nalysis of Scheduling Heuristics in a Flow-Line Manufacturing Cell with Two Types of Order Shipment Environments. Simulation 66(2): pp. 106-116.

[5] McIlvaine, Bill. 1996. P lanning and Scheduling Gets the Job Done. Managing Automation 11(8): pp. 24-30.

[6] Morton, Thomas E. and David W. Pentico. 1993. H euristic Scheduling Systems with Applications to Production Systems and Project Management. New York: John Wiley & Sons.

[7] Mundel. Marvin E., and David L. Danner. 1994. Motion and Time Study Improving Productivity,7th edition. Englewood Cliffs, New Jersey: Prentice-Hall.

[8] Pegden, C. Dennis, Robert E. Shannon and Randall P. Sadowski. 1995. Introduction to Simulation Using SIMAN, 2nd edition. New York, New York: McGraw-Hill.

[9] Pinedo, Michael. 1995. Scheduling Theory, Algorithms, and Systems. Englewood Cliffs, .New Jersey:Prentice-Hall, Incorporated.

[10] Profozich, David M. and David T. Sturrock. 1995. Introduction to SIMAN/CINEMA. In Proceedings of the 1995 Winter Simulation Conference, eds. Christos Alexopoulos, Keebom Kang. William R. Lilegdon and David Goldsman: pp. 515-518.

[11] Raman, Narayan. 1995. Input Control in Job Shops. IIE Transactions 27(2): pp. 201-209.

[12] Seila, Andrew F. 1995. Introduction to Simulation. In Proceedings of the 1995 W inter Simulation Conference, eds. Christos Alexopoulos. Keebom. Kang, William R. Lilegdon, and David Goldsman, pp. 7-15.

[13] Seila, Andrew F. 1995. Introduction to Simulation. In Proceedings of the 1995 W inter Simulation Conference, eds. Christos Alexopoulos. Keebom. Kang, William R. Lilegdon, and David Goldsman, 7-15.