The Conversion of a Zimbabwean Processing Plant from Manual to Smart Operation

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Abstract—**The automation of several key processes in a factory in Zimbabwe is described. The plant is a producer of bolts and nails for the southern Africa region. Being built in the 1950s, the equipment was intended for manual operation. To improve efficiency and reduce overhead costs, this project was commissioned to add electronic intelligence to some of the processing equipment. In particular the conversion of forging furnaces to computer control and the intelligent implementation of heat-treatment processes are described. Results of the project in economic and quality terms are presented.**

***Keywords*—ARMA model; automation; manufacturing; microcontroller; Zimbabwe.**

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1 Introduction

During the last decade Zimbabwe's industry has undergone a major shift, owing to the significant political, economic and social changes taking place in the country. The strong manufacturing base developed over the previous thirty years has been under pressure from lack of foreign currency and import restrictions. At the same time there existed an urgent need to maintain, upgrade and improve plant and information systems. As a result, attention has been given to greater utilisation of local expertise in the development of more sophisticated manufacturing methods, and companies are turning to local academic and professional organisations for the necessary innovation [1]. One area where this trend is particularly apt is the application of microcontrollers in production systems [2].

The project described in this paper concerns a company which is a well-established manufacturer of precision bolts, nails and screws, with a sizeable plant in Bulawayo. The operation involved improving two major production processes. The analysis, design, installation and testing were carried out by members of the Department of Electronic Engineering at the National University of Science and Technology in Bulawayo.

Preliminary results for some aspects of this project have already been reported [3, 4], but this paper seeks to present an overview of the whole operation and its impact on the Zimbabwe scene.

2 The bma fasteners company

The company, located in Zimbabwe's second city of Bulawayo, is a major supplier of ferrous fasteners for the construction industry in the country and its neighbours. The work-force totals 270, and the plant produces an annual output of 80,000 tons of nails, 4000 tons of bolts, 600 tons of roofing fasteners and 700 tons of rock-fixing bolts. Surface hardness is of major importance in many of these items, and the finishing process plays a significant part in maintaining product quality. Because of the large consumption of electricity, the efficient utilization of power is of paramount importance at this time. Fig. 1 shows the factory layout.

Figure 1 Aerial view of BMA Fasteners factory

3 ELECTRONIC FUEL CONTROL OF FURNACES

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3.1 Efficient use of fuel

The forming of large bolts and specialised fixtures is done through hot-forging. Heating is carried out in clay-brick furnaces with metal supporting structures. The sides are perforated to allow entry of the metal items being treated, and the top is open to allow free air outflow. The flame is produced by a mixture of air and liquid fuel, which combine in a burner unit installed into the furnace. The products to be formed are inserted through holes in the walls of the heated area, and maintained in position for specific times. Fuels used are paraffin, coal tar and industrial burning oil.

Before the implementation of this project, the operators in the factory used manual adjustment of the individual valves to achieve the desired flame colour and characteristics, the criteria of which were based on the experience of the operators who ran the system. Because of the rather unscientific nature of the means of measurement, it had been noted that there was excessive fuel wastage.

3.2 The Design of the Control System

It was decided to implement the control of the fuel system electronically, utilising embedded microcontrollers. The system uses closed-loop control [5], in which sensing by a thermocouple in the furnace provides feedback to the microcontroller, whose output feeds a stepper motor adjusting the mechanical opening of the liquid fuel valve. The operation of the system can be undertaken either from the shop-floor or by computer-communication from remote offices. The temperature set-points can be entered, and a real-time display of measured temperature then becomes available to both operators and management. The block diagram of the complete system is given in Fig. 2.

The monitored parameter is the temperature reading as determined by the thermocouple, which is then compared in the microcontroller with the set-point value entered from the key-pad or computer keyboard. The result of the comparison is the generation of a sequence of pulses on the coils of the stepper motor, causing movement in the appropriate direction to reduce the error. Inaccuracies in the system can stem from the miscalibration of the thermocouple, stepper motor overshoot, backlash in the gearbox or valve misalignment in the burner unit.

3.3 Electronic aspects of the system

The intelligent heart of control is an 8031 microcontroller which uses a Peripheral Interface Adapter to communicate the various parameters. Its inputs include the user-interface for entering temperature data and the signal from the thermocouple, whereas the outputs comprise the control signals for the stepper motors and signals for the LCD module.

The program for the microcontroller is stored in a separate EPROM, and serial connection to a personal computer is achieved by use of a MAX232 interface chip.

The shop-floor indicator unit uses seven-segment displays to output information, and switches for input of configuration data. This unit can be used for temperature reading, setting of set-points, and the configuration dialog.

3.4 Mechanical features

The burner unit which mixes the fuels and injects the flame into the furnace is shown in Fig. 3. The original manually-operated knob has been replaced by a small gearbox, which is driven by stepper motor.

Temperature sensing is achieved by an R-type thermocouple in a tubular shield, which is inserted into the heart of the oven

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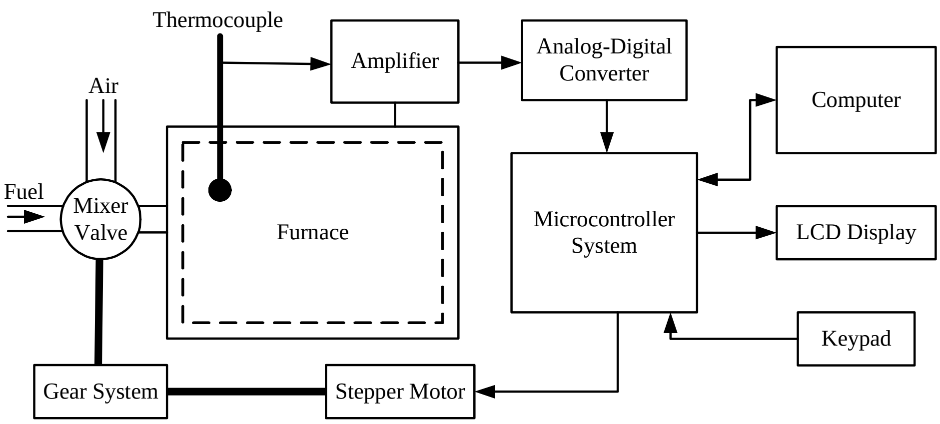

Figure 2 Block diagram of furnace fuel control system

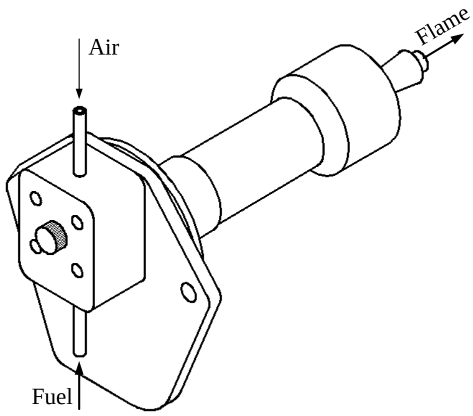

Figure 3 The furnace burner unit

3.5 Control system software

The microcontroller, which handles all decision-making for the control process as well as the input/output operations, is programmed in the ASM51 language.

When the microcontroller unit communicates with the personal computer via the RS232 serial cable, the signals are processed by a package written in C-language. This produces a windowed display of results and data entry forms, which allow both monitoring of the furnace conditions and control of the burner from a remote location. However, it is anticipated that the major use of the remote facility will be for management information purposes, and that the operation of the system will normally be carried out at shop-floor level

4 Intelligent heat-treatment processing

4.1 The previous treatment system

The heat-treatment workshop contains several furnaces for handling various types of steel products. These are of the salt-bath type, which are heated by passage of current through the solution. Previously these were semi-manually controlled by two Commander 50 control units which displayed the temperature of the furnaces derived from thermocouple readings. For a number of years the heat-treatment department had been plagued by problems with the effective control of their furnaces, arising from the following problems:-

1. Large deviations of temperature from the specified set-points, resulting in warping and cracking of materials.

2. The difficulty of setting the main Commander 50 controller with consistent accuracy, since the operators were required to adjust in excess of a dozen parameters before proper operation.

3. The uncertainties inherent in the use of the existing analogue controller, which did not include a temperature display panel, thus causing the control to be largely a mixture of experience and guesswork.

4. The maintenance and calibration of both the Commander 50 and analogue equipment, which was costly and often required the services of an expert from outside the company, if not the country.

4.2 The Computer Control Configuration

The solution to these problems was found by providing a degree of integrated furnace control, using a central computer and microcontroller system. The controlling station for the heat-treatment process was moved out of the noisy, smoky and somewhat hazardous environment of the factory floor into a supervisor's room, insulated in terms of noise and temperature from the main workshop. The computer provides a display of all the furnace temperatures, and includes the operator's interface for adjustment of furnaces and setting up of complete treatment cycles using a database of Bohler steel constants [6]. The complete electronic system is shown in Fig. 4. The existing thermocouples are retained and connected directly to the amplifier circuits which give an overall voltage gain in the region of 300 before input to the programmable Analogue-to-Digital converter. This A-D converter has eight inputs which are individually addressable, and uses a Peripheral Interface Adapter to interface to the microcontroller. On the actuator side the existing 3-phase contactors are used to energise the heaters in the furnaces, with the control signals for these being derived from the microcontroller outputs through a cascade of transistor switches, 12 V and 220 V relays.

5 Results of the project

5.1 Furnace fuel control results

5.1.1 Temperature regulation

To assess the response of the furnace to the automatic control system, the set-point temperature was changed from 860 ^{o}C to 1000 ^{o}C. Fig. 5 shows the regulation of temperature with time. The graph shows a heavily-damped response with a slight overshoot and a settling time of about 30 minutes, all being consistent with a brick oven of high thermal inertia

5.1.2 Fuel usage statistics

The average fuel consumption in the forging shop was recorded for the first year of operation, shown in Fig. 6.

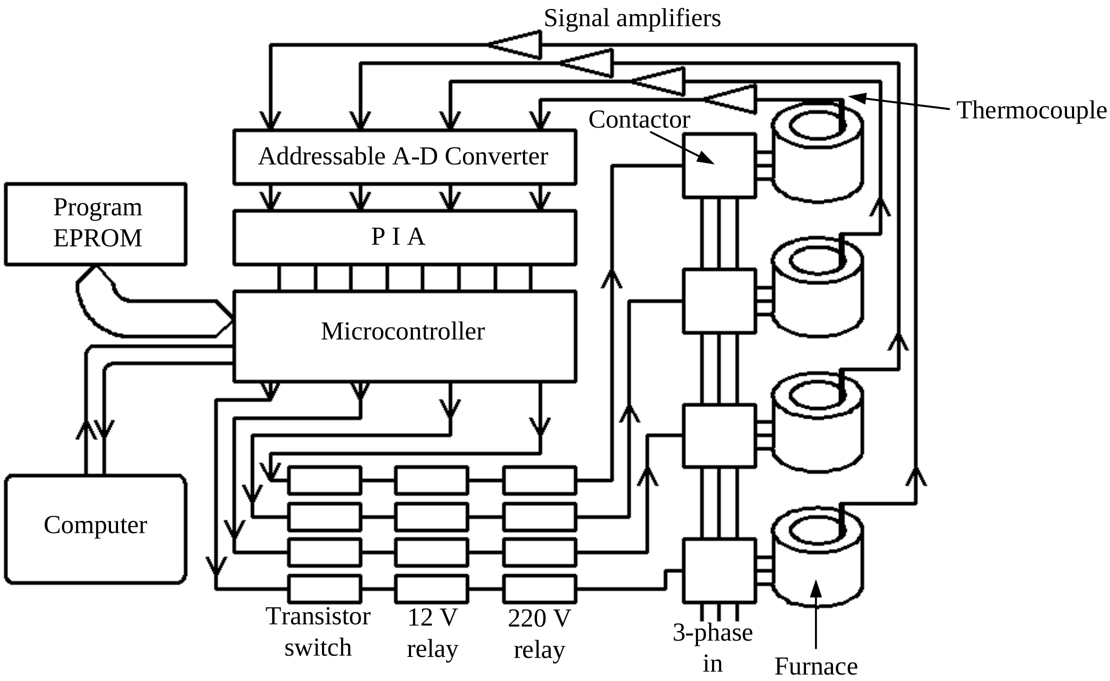

Figure 4 Block diagram of the complete heat-treatment system

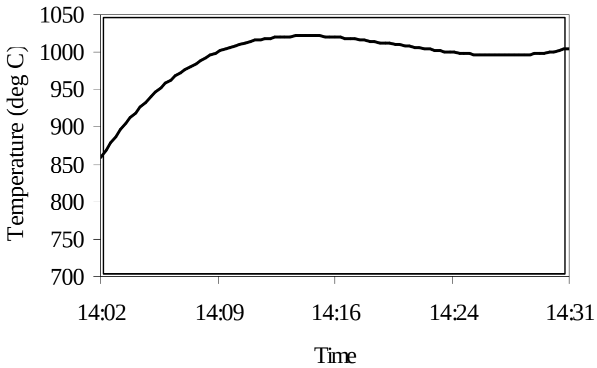

Figure 5 Response of furnace to step change of set-point

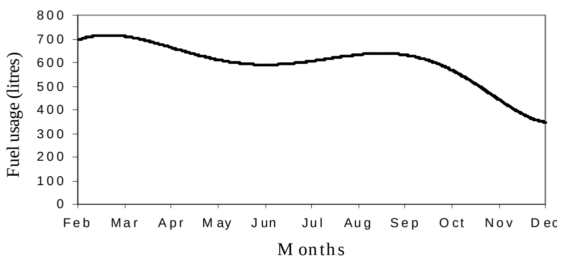

Figure 6 Fuel usage for the year

The electronic control system was installed in October, and was considered to have contributed to the decrease in fuel usage in the succeeding two months. The slight improvement in the months of May and June may be attributable to the fact the consumed fuel had been reduced by about 50%, indicating that the efficiency of the process had, to some extent, been improved.

5.2 Heat-treatment system results

operators were aware of the upgrade, and therefore were more conscientious in reducing fuel wastage.

5.1.3 Non-Product Output statistics

Non-Product Output (NPO) refers to either items which are faulty because of incorrect process conditions, or to waste material resulting from the trimming process. Statistics for the year are shown in Fig. 7, and it is considered that the electronic process contributed to the improvement. The discontinuity in March is attributed to socio-economic factors beyond the technical sphere.

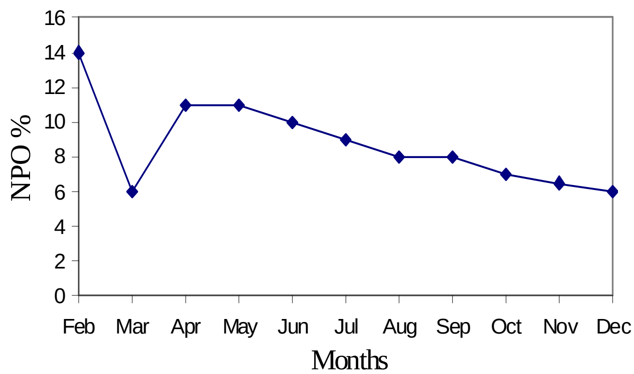

Figure 7 Non-product output for the year

5.1.4 Fuel consumption

Measurements in the months following the installation of the new system indicate that the

5.2.1 Product quality

Following the concept of a "merit index" for process controllers suggested by Safiuddin [7] statistics were studied from the quality control department for the periods before and after the introduction of the computerised system. A summary of the number of items not conforming to specification because of warping or cracking during heat-treatment is given in Table 1. The new system was installed in 2001.

TABLE 1 ITEMS NOT CONFORMING TO SPECIFICATION

Year	Number of non-conformance items
1998	11
1999	9
2000	8
2001	0

To ascertain the effectiveness of the system for a full heat-treatment process, a batch of wedge NUT bottom dies was treated at 1020^0C to produce a specific hardness. The targeted Rockwell value was 52 HRC. Before tempering, the value was measured as 54 HRC, and after the tempering stage came out as 52 HRC.

5.2.2 Temperature measurement accuracy

An important consideration was the consistency with which the temperatures in the salt bath were recorded by the computer. This effect was calibrated by the use of a pyrometer directed at the surface of the salt solution during heat-up.

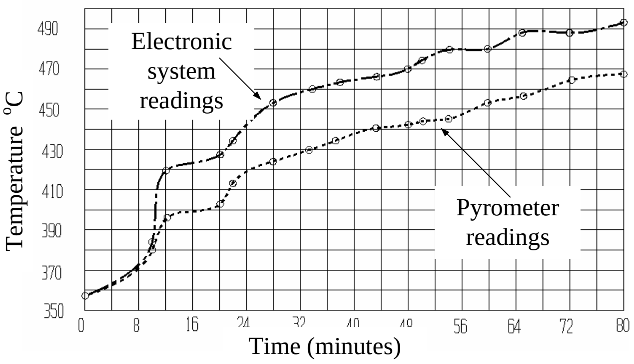

Figure 8 Calibration of temperature readings

Fig. 8 shows the comparative readings. In view of the difference between surface and mass temperature of the liquid it was considered that accuracy was sufficient for meaningful heat-treatment to be undertaken.

6 Conclusion

The electronic control systems described above have been installed and tested over an extended period. The overall picture is that the reliability of both production processes has been improved, and the quality of products has been enhanced as evidenced by reduction in faulty items. Fuel reduction has also had a significant economic impact on the company's ability to be competitive, particularly in view of the country's current energy crisis.

In the light of current economic trends and conditions in Zimbabwe, this type of project illustrates the contribution that local expertise can make in upgrading operations in the manufacturing sector. The alternative would be the importation of equipment and specialists from abroad at high cost. Customisation and maintenance of the system is also simplified because of its local design and fabrication.

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