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DEVELOPMENT AND FIELD EXPERIMENTS WITH A FULLY AUTOMATED REBAR CAD/CAM SYSTEM

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ABSTRACT

The paper describes the development of a fully automated rebar manufacturing machine, using current technology of computerized numerically controlled machines. The development involved a graphic simulation system. The resulting machine receives the raw material in a discrete form and finite lengths. The raw material is fed to the machine, bent, cut to size and collected - all done automatically. The paper also describes an actual field experimentation with the fully automated CAD/CAM system in a large rebar manufacturing plant. The experimentation was based on the integration of the CAD/CAM system with the existing setup of the plant. A communication link was developed to enable the data to be transferred after being extracted and processed by the CAD/CAM system.

1. INTRODUCTION

A rebar CAD/CAM system, which enables data extraction and transfer from the design graphic database to the CNC rebar manufacturing machine was developed [11]. The system has two modules - a semi-automated design and an NC interface, which, in turn, has two sub-modules. The first extracts the data and the second sorts it, plans the production, and processes the data into a format that can be transferred to the NC machine and be understood by it.

The classification of NC rebar cutting and bending (RCB) machines depends on their raw material supply system, their operating principles, the range of rebar diameters that they process, and the length of the final product or its type (stirrup or shaped), as follows:

A. Machine type A produces **short** shaped rebars and stirrups of up to 16 mm diameter. The raw material is **continuous** and supplied to the machine in coils.

B. Machine type B produces **long** rebars of up to 16 mm diameter. The raw material supply system is identical to that of machine type A.

C. Machine type C has a supply system for **discrete** raw material and produces rebars larger than 16 mm diameter. The raw material, in the form of bars which have already been cut to their desired length, is fed manually into the machine.

Machines type A and B have satisfactory technological options for CAD/CAM integration and to permit the full automation of production. Machines type C, on the other hand, only bend rebars automatically. The rest of the operations, such as the raw material supply cutting and assembly of the finished product, is done manually. Thus, it is necessary to develop a fully automated machine resembling machine type C.

This paper, which is a follow-up to the one presented last year in Brighton, describes (1) the development of such a machine with the aid of a graphic simulation system, and (2) a field experimentation with the fully automated CAD/CAM system in a rebar manufacturing plant. The latter was also documented on tape [12].

2. FULLY AUTOMATED REBAR MANUFACTURING PLANT

An automated machine of type C was designed and developed. This machine, which receives the raw material in discrete form, inputs the bars for processing, cuts them, bends them, handles excess bars (the bar that remains from the raw material and has to be disposed of), and deals with the temporary storage of the finished product. The machine was designed and modeled with the aid of ROBCAD by Technomatix, which is an advanced software package for modeling mechanical systems and simulating their operation, taking into account their kinematic structures. Thus the system enabled the machine to be "built" in a 3D environment and the logic of the material flow to be checked; it provided the production methodology, the relative locations of the sub-systems and interference tests and, most importantly, it permitted to measure the system's productivity. More about machine development with graphic simulation can be found in [9,10,13].

2.1 Raw Material Feeding System

The raw material feeding system was designed for the continuous flow of raw material into the machine, in spite of it being supplied to the plant as discrete bars of a finite length. The bars are stored in containers according to size and length, and moved from them into the cutting and bending machine. Batches of the raw material are introduced into the container with a forklift[a]. The containers are tilted (about 20^{o}) to assist the bars in their slide towards the exit.

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a The forklift can be automated or manually operated - this question is beyond the paper's scope.

The machine's controller receives the production plan, which includes the order by which the bars are to be produced, from the preceding stage in the CAD/CAM process - the NC interface. The raw material flow starts with the command for a bar from a specified container to be taken and moved towards the machine. The raw material moves on a conveyor until it falls on supporting columns. At the machine's feeding port there is a system of two wheels that pulls the bars, borne on the supporting columns, into the machine.

As soon as that bar reaches the support system and the two-wheel pulling arrangement the wheels grip the bar and start rotating. The rotation moves the bar linearly into the feeding port. The pulling system includes encoders which count the wheels' rotation for a rough measurement of the bar's linear motion. A more accurate measuring system, which is based on free-motion wheels, is located inside the machine. The pulling system provides only part of the bar's linear motion, as will be explained in the next section. It can also move a bar in the opposite direction for excess disposal.

2.2 Cutting and Bending System

The cutting and bending system is basically a machine type C, as defined in the Introduction. The machine has two bending heads, which comprise means for longitudinal motion; a table; a pulling system; and a cutting head.

Two options for the cutting head were considered, the first operates like a guillotine. It is not clear at the time of writing what the bar's limit diameter is for such a system, and the decision therefore is left open for the detailed design. The second option is based on a rotating disk. As the bar moves into the machine, it is being measured. When the bar's total length is reached the motion is stopped, and the bar is cut.

The table is the main structure of the system. It has an open track in the middle for the bending heads' motion. The table has two principal tasks, the first being to support the bar during the bending operation and keep it in one plane, the second, to serve as a sliding surface for the finished product on its way to the temporary storage. This is why the table is tilted (about 35^{o}).

The actual bending operation is done with the bending heads. The bar enters the bending head, a stator grips it and a rotor starts rotating - the direction and rotation angle being determined by the desired bar shape. The bending operation is inaccurate because of the "spring-back" effect, which is the major obstacle to the accurate bending of a rebar [2]. The spring-back problem can be solved with an intelligent control system, such as the one being developed in North Carolina State University [6].

The bending operation is carried out in two stages, firstly, the bar is moved into the first bending head, and the first bend is applied. The bar is then released and moved to the next bending position, where another bending takes place in the opposite direction. To complete the first stage, the bar is moved to the cutting position and cut to the desired length. The second stage, which is performed by the second bending head, begins with the bar being moved to the next bending position. As the bar is already cut, its motion can no longer be caused by the pulling system, consequently the task devolves on the first bending head while the bar is still clamped. The bar is bent and from this stage onwards it no longer moves, but rather the second bending head does. When the bending operation is finished, the bar is released, and the two bending heads are lowered beneath the surface of the table. As a result the rebar slides down into temporary storage.

2.3 Excess Bars Handler

Machines type A and B receive a continuous raw material supply from coils. As a result there is no excess-bars problem with those machines, like there is with machine type C. The reason for this problem is that a number of rebars of finite lengths have to be cut and bent from each standard-length bar. In most cases, after cutting all the rebars from a raw-material-bar there is an excess bar remaining, which is shorter than the desired length for the next rebar.

An attempt to solve this problem by welding the end of a bar, before it reaches the machine's feeding port, to the beginning of the next bar, failed. The suggested welding method was friction welding [4 223:225]. The welding attempt failed because the Israeli code (IC # 466 [14]) limits rebar welding.

The solution for minimizing excess bars was to optimize the sequence of rebar production at the CAD stage, before the data transfer (explained in [11]). Although the optimization significantly reduces the problem, excess bars remain and have to be removed. After the last rebar has been cut, one end of the excess bar remains in the pulling system. The other end rests on the supporting columns. Before being removed the excess bar is slid backwards until it completely rests on the supporting columns. From there it is removed by the excess bar handler.

The present study does not consider recycling of the excess bars - this is planned to be done in the future. The idea here is that, at any given stage, the optimization algorithm can take into account the excess bars from previous stages and consider their use. The major problem in implementing it is how to develop a storage and handling system for recycling. Alternatively, storage and handling can be done manually. The whole question has to be checked also from the economic point of view.

2.4 Temporary Storage of Finished Products

In existing machines the finished product is collected by the machine's operator or by semi-automated methods. As long as the collection of finished products involves humans, it will be the bottleneck of the production process and there will consequently be no point in increasing the machine's productivity [5]. The machine developed in this research has temporary storage means for finished products (FPTS), collection being mechanized.

The FPTS is mounted on tracks, which enables it to move from the empty trolley stack, to its location underneath the cutting and bending machine. When a rebar is finished it slides down onto the FPTS. The machine controller determines the location of the rebars fall. When a trolley is full, it is automatically moved to the stack of loaded trolleys, and is replaced by an empty trolley from the empty-trolley stack.

3. FIELD EXPERIMENTS

The rebar CAD/CAM model, which was presented in [11], is based mainly on two modules, the first automatically extracts data from the design phase, the second renders the extracted data into a production-oriented format. It also plans the production and translates the data into a machine language - G-CODE.

The model assumes that the machine-language file is transferred to the numerically controlled (NC) machine. Thus, no human intervention is needed from the design stage to the actual production of the rebar, the system being fully automated. But does it really work? What are the actual implications of transferring the data to the machine and making it work? How do the two computers (one for the design and data transfer, the other - the controller of the machine) converse?

The main purpose of the field experimentation was to see for ourselves (seeing is believing) that data can flow automatically from the design to the production without problems. Additionally we wanted to see that, upon the arrival of data, the machine produces the intended rebar exactly as designed.

It was very tempting to try to find the answers to the above questions and many others. Fortunately, the industry seems to be ready for such a development, and a manufacturer willing to cooperate was easily located. This was an opportunity to carry academic research further and achieve real cooperation between academia and industry for the benefit of both. A system implementing the method developed was set up at the manufacturer's plant. The system, which is shown in Fig. 1, included three physical elements:

- A Structural Design Office - a computer for the semi-automated design of rebars, data extraction, data transfer, and communication management (the latter will be explained below).
- The physical link(s) - cables with RS232 connectors.
- The NC rebar production machine - an existing machine which, in its conventional form, served the day-to-day production of the manufacturer. Normally, in order to produce rebars, the operator had to program the machine in real time (which means that the machine does not produce while being programmed). Programming included keying-in detailed rebar production data.

The end product of the design and the subsequent data extraction, processing and transfer (NC interface) is a machine-language file (G-CODE), which contains all the data needed for each purchase order. In the experimentation described herein one computer was used for both the detailed design, the NC interfacing, and the communication link functions.

The machine-language file has much more data than the machine controller can store or process at any given time. Consequently, a communication link (CmL) was developed to manage and control the data transfer process. The development followed the Open System International (OSI) Reference Model [1, 7, 8]. That model is based on seven control levels, or layers, arranged in a pyramid form. Instructions given at the higher level are translated into more detailed instructions and transferred to the lower level in the hierarchy. Modules at each level make decisions based on instructions given by the higher level and the reactions of the lower level. There are master/slave relationships between the levels as data flows up and down the hierarchy levels. The actual physical link is made at the lowest level.

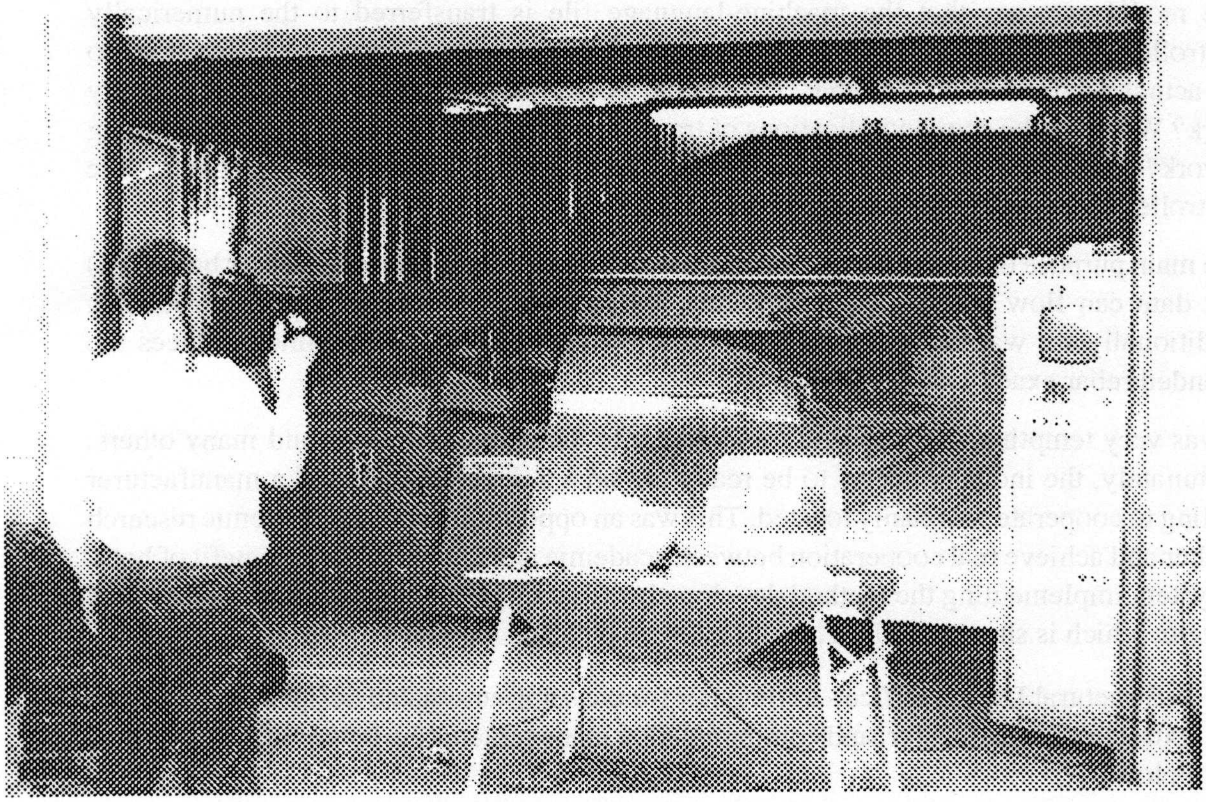

Figure 1: The Experimentation Setup.

The Manufacturing Messaging Service (MMS), an application of the OSI model, is a machine-independent process-to-process communication protocol which defines actions and syntax for the communication. It gives a wide range of services - the main ones relating to the present application are enumerated below:

- **Memory exchange** - enables the master to read or write in the slave's memory. This is not a trivial operation, because the read or write operation can be done either immediately, or, with a delay, after a specified event takes place. The memory address can be referred to either directly or by a logical name. More than one value can be read or written at once.

- **Operator communication** - this is a virtual terminal service. The master may ask for input from the keyboard, touch screen, bar code, or sensor. The master can also display information or instructions on a screen.

- Event manager - a wide range of event-driven activities can be defined. The application program can act one way if a specified event happens, or in another way if that event does not happen or another takes place.

The CmL developed for the present application (in the C++ language) deals with one machine only and consequently performs only the above 3 functions. The machine has 300 memory cells, each of them a record that stores a great amount of information: the exact bending locations and bending angles for each bar, and general parameters concerning the production (pin diameter, raw material diameter, advancement and angle compensation, total amount to be produced, the next bar to be produced, etc.). This means that the communication link has to manage 300 records at any given time. The input into the CmL is the machine language file, while the output comprises the instructions to the machine. The CmL is the master and the machine is the slave. The **memory manager** performs the following tasks:

- It asks the machine for the status of the various memory cells.

- In reply, the machine answers which memory cell is vacant and which is occupied. For each occupied memory cell the machine specifies one of the following options:
  - "in process" (means that data cannot be updated anymore).
  -"done" (means that information can be erased and the cell used for new information).

- The master decides which memory cell to send the information to - a vacant cell, or a cell in which the information can be erased ("done").

- The machine acknowledges the receipt of the information. If a "not acknowledged" signal is received the CmL will try to send the information later.

- The CmL informs the machine of the production sequence. This is done with the record field that specifies the number of the next cell to be produced. The same field can also specify if the production is to be done continuously or if it has to wait for the operator's instructions, or for the change of raw material (which implies changing of coils), etc.

The **operator communication function performs** tasks like:

- Prompting the operator to ask to O.K. the beginning of production.
- Instructing the operator to change coils of raw material.

The **event manager** performs tasks like:

- Receiving information from the operator that production is completed, or temporarily stopped.

- Receiving information that the system is jammed or inoperative for another reason.

The **journal** registers production information referring to production quantities, production rates, and the exact values of the production as received by the machine. This information can be used for statistical analysis, as a basis for future cost estimates, and for quality control purposes.

A wide range of rebar shapes was produced automatically during a few sessions - all without any human intervention and all produced exactly as designed. At each session a range of rebars were designed with the semi-automated design tool. When completed the data extraction, data transfer, and communication link were initiated with one command, and immediately a command was prompted on the screen of the machine's controller to O.K. production. The operator then gave the O.K., after which the rebars were produced.

The system worked very effectively and very fast, although no real conclusions could be drawn regarding the speed of the data transfer of more commercial amounts. This is because the application was for experimental purposes only, and we did not want either to interfere with the day-to-day production or to waste a lot of raw material.

4. CONCLUSIONS

The concepts of CAD/CAM and fully automated rebar production were experimented-with in a large rebar production plant, which uses CNC machines. A structural design facility was temporarily built for this purpose, and various shapes of bars were designed. When the design was completed, the designer initiated an automatic process of data extraction and transfer to the production machine. As the data reached the machine, the operator was asked to O.K. production. When permission was granted, the machine produced the designed bars with good accuracy.

The work described herein showed that an integrated CAD/CAM system for the fully automated production of rebars is technologically feasible, which was shown first with the aid of a graphic simulation system, by "building" a totally automated machine and implementing the CAD/CAM principles on site.

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