INTEGRATED-PRODUCT-MODEL-BASED AUTOMATIC REBAR PRODUCTION

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ABSTRACT

A CAD/CAM system which automates the design and manufacturing of rebars is described. The CAD-based design module of the system permits a semi-automated design alongside the conventional one. The uniqueness of the system resides in its ability to extract automatically the data needed for manufacturing from the graphic design database, process this data, and transfer it to the rebar manufacturing machine. Thus all the manual data manipulation stages of traditional rebar design and production (detailing, documentation, data extraction, etc.) are avoided. In many cases the multi-stage manual data manipulation is a source of errors and is moreover labor-intensive. Consequently, the CAD/CAM system described here leads to cost reduction together with increased quality. The paper describes the principles underlying the development of the system and the system's structure. The paper also describes an actual field implementation of fully automated rebar production in a large rebar manufacturing plant. The implementation 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.

INTRODUCTION AND BACKGROUND

The recent development in reinforcement manufacture started in the mid-1980s (Schwarzkopf 1991), with the appearance of Numerically Controlled (NC) rebar production machines appeared, where a computer controls the cutting and bending locations as well as the bending angles and bending directions. The data is preprogrammed by the operator according to the details in the shop drawings, which are normally prepared at the fabricator's main office.

The rebar production process begins at the consulting firm with the computer-aided design (analysis and graphic programs) of reinforced-concrete element design. The rebars are detailed either at the same place or by the constructor, after which production plans are prepared. These plans give the complete information needed to produce the bars, either manually or by CNC machines. If the rebars are produced manually, the production plans are given to the worker. Production by CNC machines also has two stages - the shop drawing preparation and the programming - which are done by the machine's operator.

The basic question underlying this research is: why data needed for the operation of the CNC machine cannot be taken directly from the design database. After all, the data is stored in electronic format, and all the subsequent data manipulation seems redundant. Moreover, every stage of the process involves human read-and-write or process operation, which means that at

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each stage there are two sources for mistakes. Additionally, data manipulation is very costly because it is performed by the most expensive manpower of the industry (engineers). This problem of paying more for lower-quality data can be avoided if a different approach is adopted. Certain technological problems had to be overcome for this purpose, as will be explained below.

This paper describes a system that automatically extracts data from the design graphic database, sorts it according to various criteria, processes it, and transfers it into machine language files. These files are then transferred automatically to the CNC machines for production.

SYSTEM OVERVIEW

The Rebar CAD/CAM System (RCCS) is totally automated. This is achieved by the automatic flow of data from the design stage to the actual production, and by automating the production itself. A schematic view of the system is depicted in Fig. 1.

The first module is for the design of the reinforced concrete element and the detailed design of rebars. The graphic driver selected for this purpose is AutoCAD, because it is an industry standard and it is an open and flexible system. The graphic part of the element design is performed in exactly the same manner as in present-day design firms. The rebar is designed with a dedicated commercially available program called 2BARS, for which a permission was granted to adapt it to our purposes. Changes were needed, because the original 2BARS is a purely design-oriented program without any possibilities to retrieve production data.

The documentation module produces plans, sections, elevations, etc., in a hard copy format, simply by means of the plotting or printing function of AutoCAD. The rebar schedules are produced automatically by 2BARS and the plotting or printing function. This is not necessary for the automated rebar production process, but is used for the rebar scheduling and placement on-site.

The data extraction module searches through the graphic database (PROCESSOR I) produced by the design module. It systematically checks every item, identifies it and, if it is found to be a rebar element, writes all its graphic details into a separate file (RDF). These details include linear information relating to the cutting and bending locations, the bending angles, general data relating to the required quantity and the bar type, and the serial number. The data does not include topological or construction-related information, as the system relates to rebar production alone.

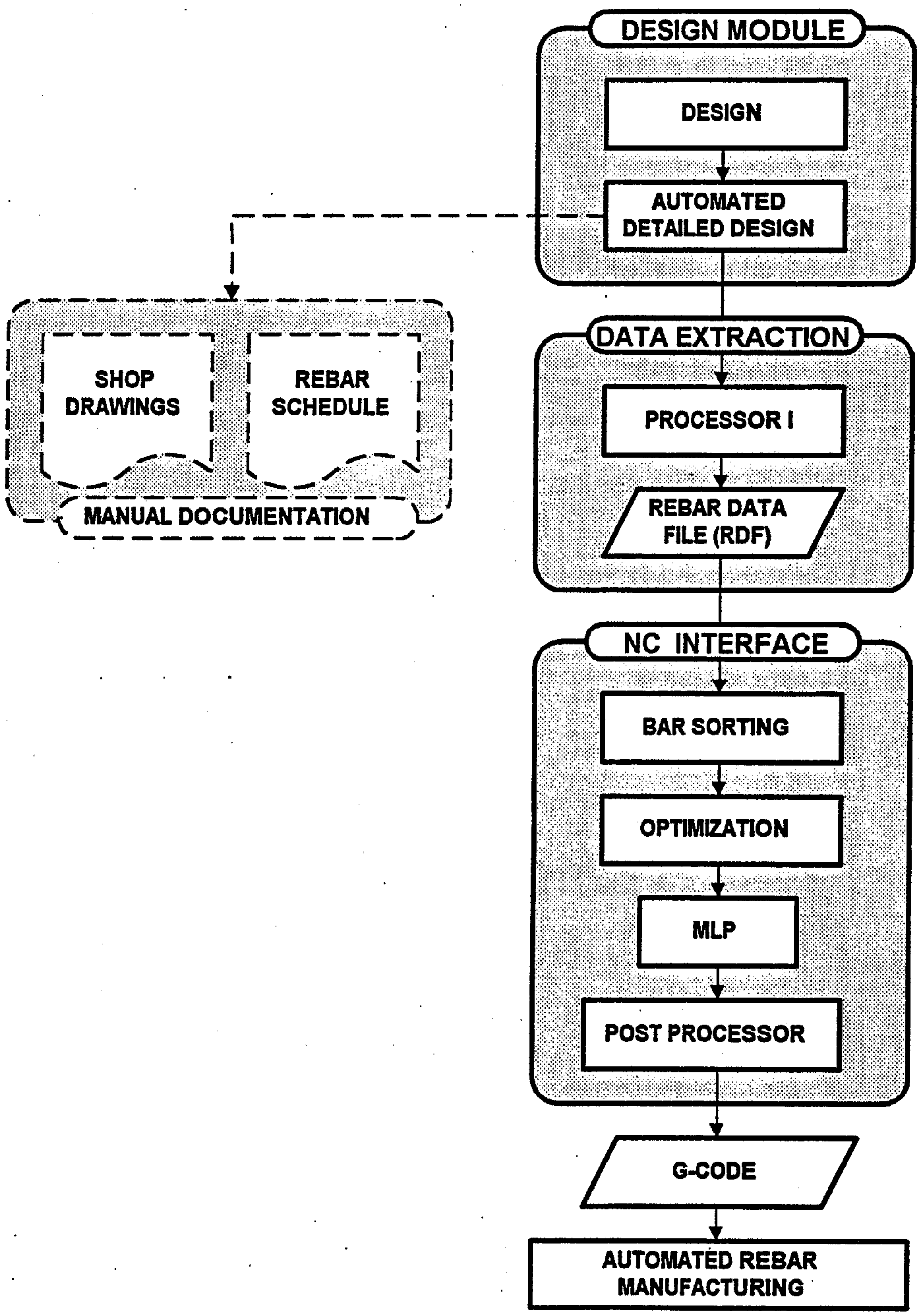

Fig. 1: Schematic view of the CAD/CAM Rebar System.

The NC INTERFACE module uses the above data to produce a machine language file which is fed into the AUTOMATED REBAR MANUFACTURING machine (ARMM). To do so it sorts the bars according to their type, diameter, and serial number. The NC INTERFACE module then runs an optimization process, determining which rebars are to be produced from which bar of the raw material and in what sequence. Finally, a machine language program is produced by the machine language processor (MLP). The automated rebar production module receives the program from the preceding module and automatically produces the bars.

THE DESIGN MODULE

Designers still use CAD programs mainly as 2-D drafting tools, which, to a large extent, merely mimic manual drafting. They use a few basic graphic primitives (dots, lines, polygons, circles, icons, characters, etc.) to draw even the most complicated drawings, which is useful enough for their purposes. When a professional examines these drawings, he/she interprets the collection of the graphic primitives using knowledge, intelligence, and experience in order to comprehend the designer's intent. No computer program can do that yet, and consequently a different approach to design is presented here.

RCCS uses a modeling approach, based on components, or entities, which are symbolized graphically. The graphical symbols are different images for plans, elevations, sections, details, etc. For rebar representation, RCCS uses an entity called POLYLINE in the AutoCAD environment. This is an entity combined of lines and arcs broken into a number of sections.

The rebars are drawn either "conventionally" or semi-automatically. In the "conventional" option the designer draws the rebar in exactly the same way as he/she used to do it before - with one difference, viz. that instead of drawing separate lines for each of the rebar's sections, the rebar is drawn as one POLYLINE. The semi-automated rebar design (SARD) uses a rebar library, which contains different rebar shapes, each of which is a parametric component and an independent entity. There are several options to do so: the designer either selects the rebar shape from a library and "places" it in the concrete element, or just indicates the limits of the concrete element in which the rebar is to be placed, and the system does that automatically according to codes (SII 1987).

THE NC INTERFACE

The DATA EXTRACTION and the NC INTERFACE link the design module with actual production. They are connected to the graphic database of the design module, extract the relevant data from it, and produce the machine language file.

Data Extraction

After being designed according to the principles outlined above, the rebar data in the graphic database is now in a format suitable for extraction (Besant and Lui 1986). Consequently, it is possible to systematically scan the database and check each graphic entity separately. The data extraction module was developed in the AutoLISP Language. Data is extracted in 3 stages:

- Every entity in the database is scanned. If the entity is identified as a rebar, all the data associated with it is written into a separate file.
- When the bar identification is completed, the system takes each bar separately and extracts all the relevant data: Number of identical bars, diameter, type, etc., as well as detailed geometric data, consisting of the length of each section, bending points, bending angles, and total length.

- In the last stage this data is written into a rebar data file (RDF) in a format that allows its subsequent processing.

NC Interface

The NC INTERFACE module sorts the data in RDF, plans the process for optimal performance, and translates the data into machine language (G-code) (ISO 1981). This module was written in Turbo Pascal - it receives an ASCII file (RDF) and produces another ASCII file (G-code) readable by the ARMC. The order of appearance of the data in RDF is determined by the structure of the graphic database (which in turn depends on the order of design). Process planning has a logical structure, and the data input must reflect this logic. The data in RDF must therefore be sorted before it can be processed. The sorting is done in two stages: by serial number and by bar type, diameter, and length.

As the whole data exchange is computerized, it was possible to develop a module that would automatically optimize the production to minimize raw material waste. Optimization in this case is a linear integer programming (LP) problem. The module reads the relevant data from RDF and translates it into an LP model, which creates the target function and defines the constraints. This LP model is fed into an LP solver - LINDO.

A machine language processor (MLP) performs the actual process planning. Determining the machine's operating sequence requires the knowledge of all the geometric data pertaining to the rebar as extracted by the data extraction module. The operating sequence is process-dependent and therefore takes account of the production method. The main production characteristic that influences MLP is the bending and cutting method. A post-processor translates the data into a machine language. The MLP's output is in fact a series of instructions to the machine, but it is in a higher-level language. Every instruction in higher-level language must be broken down into a series of lower-level instructions in a machine language. The post-processor translates the data into a generic machine language called G-code, which is a language popular in the CNC milling-machine environment. The instructions in G-code had to be adapted to the particular purposes of rebar production. Examples of such adaptations are: selection of the raw material bar diameter is made in the same way as the tool is selected in milling; or an instruction to advance the bar inside the machine is the same as that for moving the tool, etc.

The output of the post-processing - the machine language files (G-code) - is automatically fed to the production machine. A more detailed description of RCCS can be found in (Coffler 1994, Navon et al. 1995).

FIELD IMPLEMENTATION

A system implementing the model presented above was set up at a rebar manufacturing plant. The system included three physical elements:

- A Structural Design "Office" - an IBM PC 486 compatible computer for the semi-automated design of rebars, data extraction, data transfer, and communication management (to be explained below).
- The physical link - IBM PC 486 compatible and cables with RS232 connectors.
- The NC rebar production machine - Concept 91 of MEP, which served for the day-to-day production of the manufacturer. Previously, in order to produce rebars, the operator had to program the machine on-line (the machine does not produce while being programmed). Programming included keying-in detailed rebar production data.

The structural design is almost invariably done in the offices of the design firm, while the detailed design of the rebars can be done by the design firm, the general (or sub) contractor, or the rebar manufacturer. The end product is a machine-language file (G-CODE) which contains all the data needed for each purchase order. In the implementation described herein one computer was used for both the detailed design 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 Interface (OSI) Reference Model (Amaranth, 1987; Melvin, 1986; Jones, 1988). That model is based on seven control levels, or layers, arranged in a hierarchy. 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 feedback from 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.

The CmL developed for the present application deals with one machine with 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.

A wide range of rebar shapes was produced automatically during a few sessions - all without any human intervention and all exactly as designed. At each session a range of rebars was designed with the semi-automated design tool. When data extraction was completed, the data transfer and communication link were initiated with one command. Immediately following the data transfer, the machine operator was prompted by a system message to approve production. The operator then gave the O.K., after which the rebars were produced. Thus, the actual program was prepared automatically off-line, and the machine was idle only for a minimal time of data transfer and production approval.

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.

SUMMARY

A rebar CAD/CAM system (RCCS), which totally automates rebar production, was presented. The system consists of a design module, a data extraction module and an NC interface. In this system the data flow, from design to actual production, is entirely automatic.

The design module is based on AutoCAD as its graphic driver and on a dedicated rebar design program called 2BARS. A data extraction module was added to AutoCAD, and 2BARS was changed to meet the needs of a production-oriented system. The design module is based on a modeling approach that uses components, or entities, rather than graphic primitives. The design module permits either conventional or semi-automatic rebar design (SARD). The latter is based on a parametric rebar library.

The NC interface is the electronic link between the design and the production. It automatically transfers data from the graphic database to the production machine. The first module of the NC interface scans this database, identifies the rebar components, and extracts all the relevant information into a rebar data file (RDF).

Traditional rebar design and production involves a multi-stage process of data manipulation. The stages include detailing, documentation, data extraction, processing, production planning and, in the case of CNC-based machines, programming. All this is done manually. Most of the stages include the reading, writing, and processing of data. Consequently, there are numerous sources of errors (Teicholz and Fischer 1994), the results of which may be very costly (Burati et al.1992). Moreover, the data manipulation is the task of the most expensive manpower in the industry - the engineers. RCCS eliminates all the above stages, saving the costs of data manipulation and preventing additional costs caused by reworking.

RCCS can be integrated with other construction-related software, such as scheduling, estimating, etc. It is possible to link RCCS to the schedules of the various projects to provide an automatic procurement system that will closely follow the updated progress of the project. This will make a just-in-time supply much more feasible. If RCCS is linked to the estimating system, it can automatically supply the quantities to the estimating system, saving the laborious task of quantity takeoff.

The concepts of CAD/CAM and fully automated rebar production were implemented in a large rebar production plant, which uses CNC machines. A temporary structural design facility was 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 data reached the machine, the screen of the machine's controller asked the operator to O.K. production. When permission was granted, the machine produced the designed bars with good accuracy. The main challenge in the implementation was the development of a communication link and of strategies for data transfer that actually enabled the automatic transfer of data.

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