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Development of a Control System for Automated Line Heating Process by an Object-Oriented Approach

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Abstract

A control system for an automated line heating process is developed by use of object-oriented methodology. The main function of the control system is to provide real-time heating information to technicians or automated machines. The information includes heating location, torch speed, heating order, and others.

The system development is achieved by following the five steps in the object-oriented procedure. First, requirements are specified and corresponding objects are determined. Then, the analysis, design, and implementation of the proposed system are sequentially carried out.

The system consists of six subsystems, or modules. These are (1) the inference module with an artificial neural network algorithm, (2) the analysis module with the Finite Element Method and kinematics analysis, (3) the data access module to store and retrieve the forming information, (4) the communication module, (5) the display module, and (6) the measurement module.

The system is useful, irrespective of the heating sources, i.e. flame/gas, laser, or high-frequency induction heating. A newly developed automated line heating machine is connected to the proposed system. Experiments and discussions follow.

Keywords: Automated line heating machine, heating control system, heating information, Plate Product Model DataBase

1 Introduction

Line heating is a method used in the production of curved shells at the bow and stern of a ship. The process is generally regarded as one of the outdated technologies in the modernized and automated shipbuilding process. Only a few chief technicians at a shipyard are able to provide limited heating information, which is based on their long experience. Other workers simply apply heat to a plate along lines, as requested by the chief technicians. No reliable data can be obtained from shipyards, since measurement of input and output quantities is not practical. Basic questions may arise as to which quantities should be measured in order to use them in succeeding jobs.

Since the line heating has been introduced, numerous studies have concentrated on how to determine the heating paths. In practice, the heating paths are determined in an obscure manner by skillful workers. Thermo-elastic-plastic mechanics(Moshaiov and Shin 1991), geometry analysis(Letcher 1993, Yoo et al 1995, Ryu 1998), finite element methods(Shin et al 1995), inherent strain concepts(Ueda et al 1994, Jang and Moon 1998), as well as other approaches have been applied to the understanding of line heating. Most have commented on the automation of line heating in their research on heating paths. However, in order to achieve the automation of line heating, a control system needs to be developed. The system should be able to integrate the large amount of forming information and to create a seamless data flow. In addition, it should be easily updated or revised as the relevant technology improves.

The objective of this paper is to develop a control system for an automated line heating process. Object-oriented methodology is employed to develop the system efficiently. The methodology can be useful for the development of a system having large data, complex information flow, and which requires frequent revisions. The major concept on the automated process is presented, followed by methodology and implementation. For verification of the system, a corresponding machine has been designed and tested. Since the system produces the forming information, it can be useful for individual workers as well as for any automated line heating machine.

2 Current line heating process

In shipyards, the current process has already been investigated in (AESA 1992). The process is almost the same in most shipyards in the world. Figure 1 shows the current line heating shop in a shipyard.

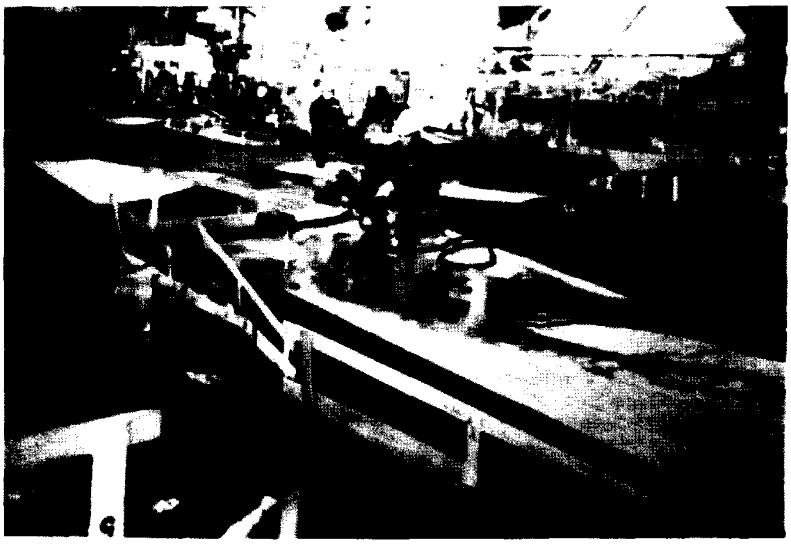

Figure 1: A typical line heating shop

The shop is very hot and noisy. A set of several wooden or recycled-paper templates per each plate are used as tools for checking the surface of a formed plate. The templates are discarded after checking a plate piece. Heating paths are drawn by one of the chief technicians. The paths are the result of the experience and intuition of an expert. It is said that at least several years' experience is required for a technician to draw heating lines with confidence. In addition, in the middle of the formation process, the templates do not exactly match the surface of a plate. The workers then determine the new heating paths by qualitative differences between the templates and the plate. In conclusion, every information in the line heating shop is not quantified, nor computerized.

Based on the shipyard practices, the information flow of the current forming process is illustrated in Figure 2. It can be seen that the design and production processes are separate in terms of information and participating personnel. Usually the design is carried out by engineers, while the actual production by technicians.

To overcome this, a new automated line heating process would be desirable. The process should be based on quantitative heating information, compared to the qualitative one in current shipyard practice. The information is not only concerned with heating paths but also others, such as torch speed, cooling, and torch height. For example, a heating path is determined by coordinates of two ends. All data should be stored in a computer so that it can be used in the next job. Since there is considerable data, the relation of which is very complicated, a systematic approach is inevitable in the development of a control system of the new process.

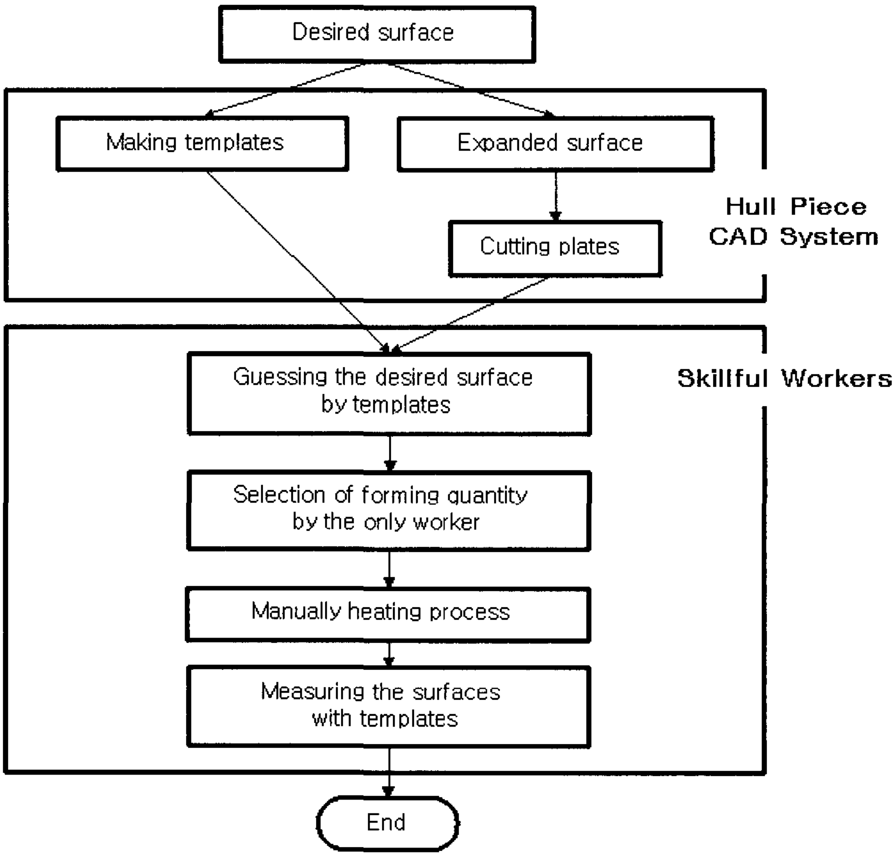

Figure 2: The current line heating process

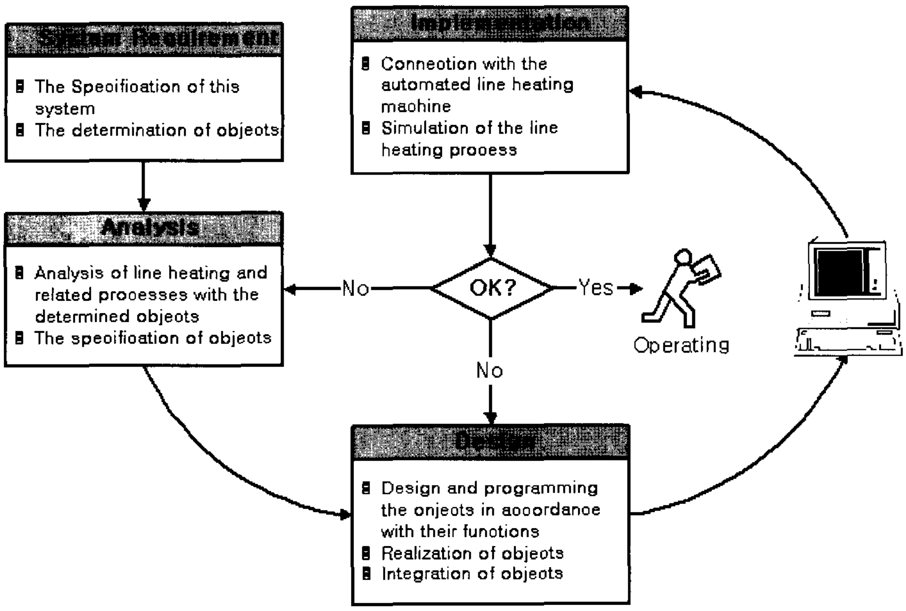

Figure 3: Developing steps of a control system for an automated line heating process

3 An object-oriented control system for an automated line heating process

In order to develop the control system for an automated line heating process, object-oriented technology is employed in this paper. The five steps in object-oriented technology, shown in Figure 3, are system requirements, selection of system objects, analysis, design, and implementation of the system.

In the system requirement step, the automated line heating process is identified in detail. The objects of the machine and the control system are then determined. In the analysis step, the line heating process and the related processes are analyzed with the objects. At this point, the specifications of each object are determined with attributes (or data) and methods (or functions). In the design step, the objects are designed and programmed corresponding to their functions. The objects are realized by use of proper developing tools in this step, following which they are integrated into a single system. In the implementation step, the developed control system is connected with the virtual machine and the hull forming process, i.e. the line heating is simulated with this integrated line heating system. The details of each step are as follows.

System Requirement and Determination of System Objects

The system requirements are specified and the modules of this system are determined in this step. The new automated line heating process should be computer-controlled in order to:

- serve as input for the computerized data
- form the hull pieces with high accuracy,
- reduce man-hours required

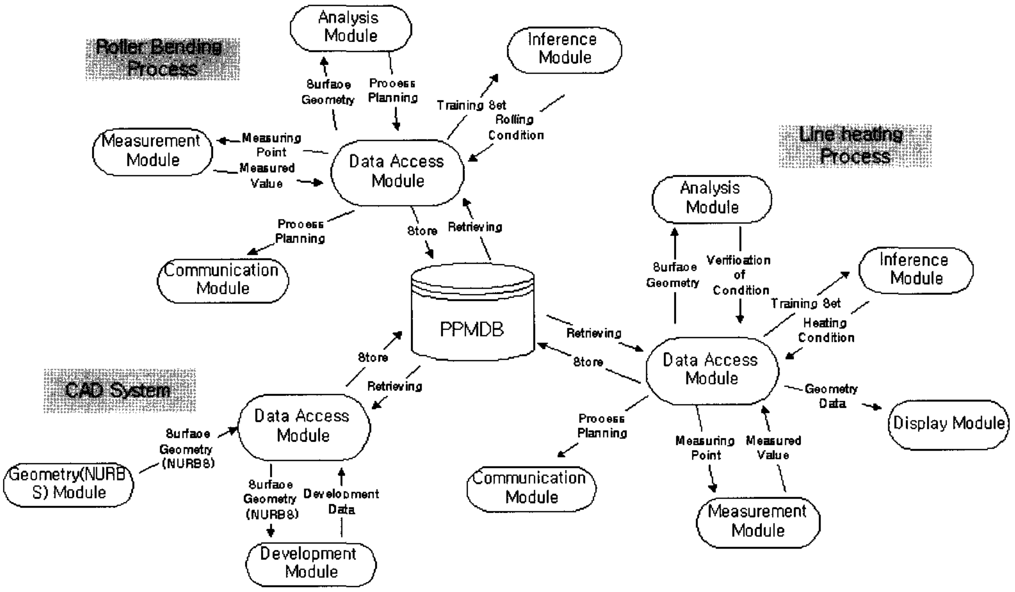

Figure 4: Global information flow and the objects in the hull forming system

- automatically generate the process planning in real time or in the off-line program
- manage this workshop in the integrated manufacturing system with other workshops and the information system.

The system objects are determined after focusing on the above requirements. Those are classified into two categories with six subsystems. The line heating process in Figure 4 shows the six modules and their basic relations.

The first category is the process information system which consists of the following three subsystems, or modules.

- Analysis module with use of Finite Element Method (FEM) and kinematic analysis
- Inference module with an artificial neural network algorithm (ANN)
- Data access module with the product database

The second category is the process control system which consists of the following three modules.

- Measurement module with measuring hardware
- Communication module with the machine and other workshops
- Display module with the computer monitor and printers

Following the approach by Schenck and Wilson(1994), basic objects for our system are defined such as Table1.

Table 1: Definition of basic objects in line heating system

Hull Piece, Kinematics, Bending Strain, In-plane Strain, Piece forming Method, Rolling, Line heating, Rolling Condition, Heating Condition, Material Property, NURBS Surface, Offset Table, ANN Model

Next, all analysis and design are carried out on the line heating process and the adjacent processes with these modules.

Analysis and Design of the Line Heating Process and the Related Processes

In this step, the subsystems of the line heating process are analyzed together with the adjacent manufacturing processes. Figure 4 shows the subsystems and the information flow with the adjacent processes. The Computer-Aided Design (CAD) process for the geometry of curved plates and the shell development is included. In addition, the roller bending process to obtain the cylindrical shells is included, since the rolling process is the pre-forming stage for line heating. These constitute the parts in the entire hull forming fabrication, that is, production design, cutting, roller forming, and line heating.

Each process requires input and output data, which are essential in the determination of the processing information and for the control of the forming process. For example, these are the geometry of an objective curved shell, forming conditions, and the measured data. The automated line heating process can obtain the geometry of the objective curved shell and its developed shape from the CAD system, and should obtain the measured data of the initially rolled plate from the roller bending process.

The six subsystems of the control system have their attributes and methods on the basis of such data in the line heating. The attributes and methods of each subsystem are shown in Figure 5. The functions of subsystems are summarized, along with their attributes.

1. *Analysis module*: to simulate line heating with the given conditions using the external FEM packages(Shin et al 1995) and to obtain the curvatures of the curved shell, the strains, and the heating paths from the kinematic analysis(Ryu 1998).

2. *Inference module*: to provide the forming input value, i.e. the heat quantity, torch gap, heating speed, gas pressure, and the like, by using ANN(Park et al 1997) and the experimental formula(Lee 1999).

3. *Data access module*: responsible for saving the implemented results into a database and retrieving the data by an application program corresponding to each access format. This includes the access to the Plate Product Model Database (PPMDB) and the packing of the data that are required by each module.

4. *Measurement module*: to sort the measuring points, to send them to the measurement device and to obtain the results after measuring the formed plates.

5. *Communication module*: to transmit processing commands, information and status through machines and the other forming workshops. In choosing two physically separated computer's communication regulation, a standard communication regulation, or communication

module is appropriate. When the control system is some difference from the machine, this module enables the main control system to operate the remote machine.

6. *Display module*: to output the progress of calculation and processing to monitors and printers in a user-friendly manner.

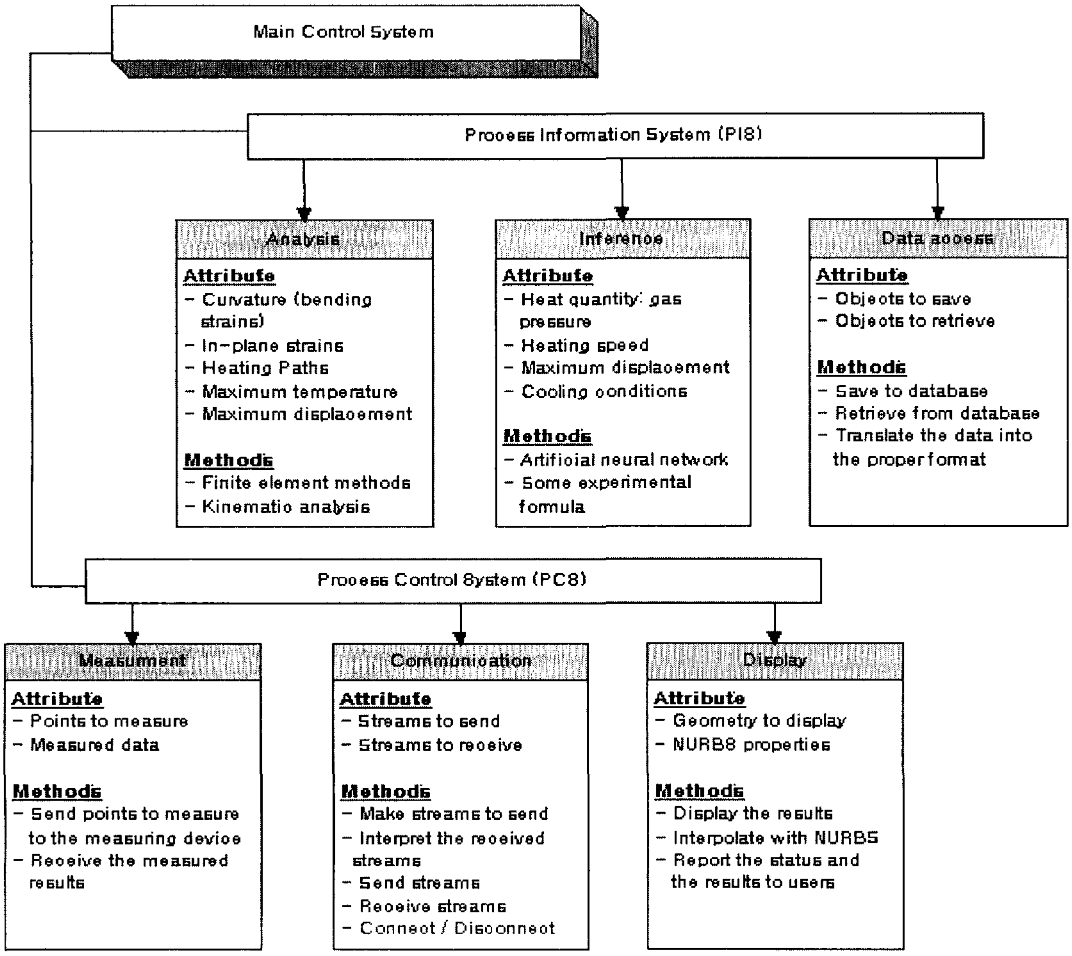

Figure 5: The attributes and the methods of each subsystem

Among data in each module and each process, persistent data must be stored in the database. For the automation of hull forming process, the processes and the data flow between them must be known. These constitute the basis of the product data model and is referred to here as the PPMDB(Plate Product Model DataBase). All persistent data used in overall system arises from the PPMDB. The measured data after forming and the forming conditions are stored in the PPMDB. In addition, for the case where the data are given in STEP (Standard for the Exchange of Product model data) file formats, the STEP file is available. The STEP formats are of two types: one is for the modeling of the products and the other for the production information.

Integration of the six objects can lead to the development of a control system for the new automated line heating process, as illustrated in Figure 6. The control system computes the processing

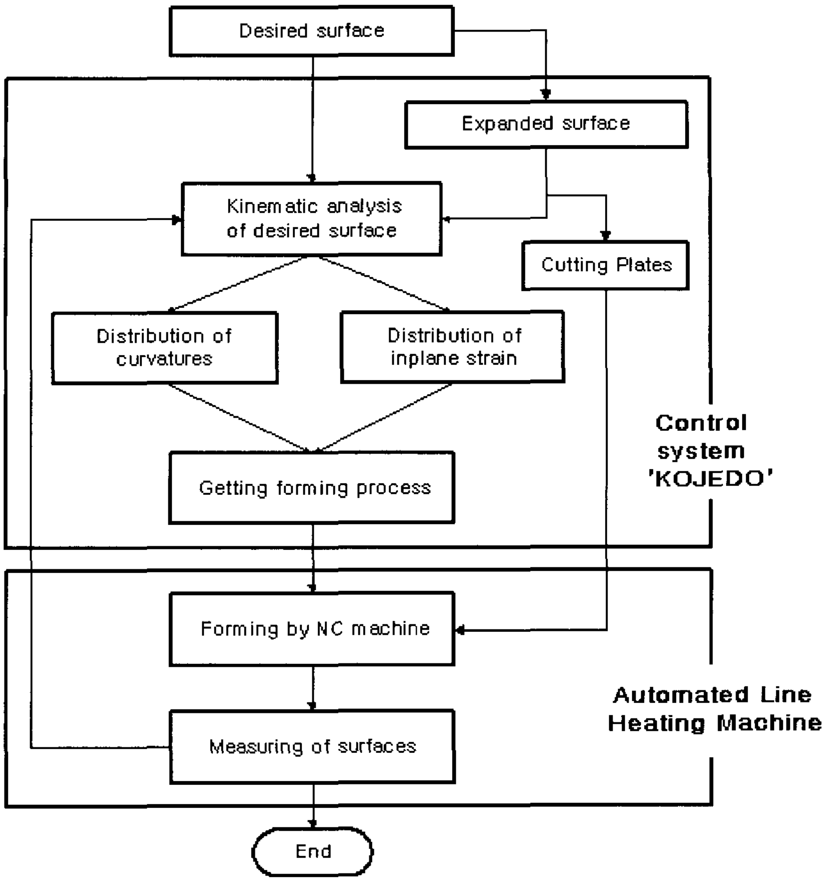

Figure 6: The new process for an automatic line heating

information with curvatures and strains, and connects other modules of system. The curvatures and strains are calculated from kinematic analysis(Shin and Kim 1997). Using the results, the information on heating paths of line heating(Ryu 1998) and on rolling process also can be obtained. The calculated data is input to the inference module and the display module, and the processing information is transmitted to the machine or technicians through the communication module. The measured points, torch speeds, and paths are controlled through the measurement module. All information is stored in the PPMDB through the data access module.

Implementation of the Control System

Based on the new automated line heating system, as shown in Figure 6, the control system is realized by implementing the objects. In this step, a virtual machine is developed instead of an actual machine for modifing an accurate calculation and to provide smoothly flowing information. Since this virtual machine cannot actually measure the curved shell, the measured displacement is generated with some assumptions. Figure 7 shows the template of the developed control system into which the six subsystems have been integrated. This virtual machine and the system can be used as an off-line teaching or programming tool. In this paper, EXPRESS and EXPRESS-G are used as lexical and graphical representation methods.

4 An computerized and automated line heating machine

According to the proposed concept of the automated line heating process, an automatic line heating machine is developed, as shown in Figure 8. The machine is based on PC-NC (personal computer operated-numerically controlled) logic. It contains the heating and cooling unit, a measuring unit, a communication unit, a control PC, and others. The control system, developed in this paper, is installed in the machine to automate the process.

5 Test of the system and verification example

A simple model was tested with this simulator. The simulation model is expressed in the following parametric mathematical form.

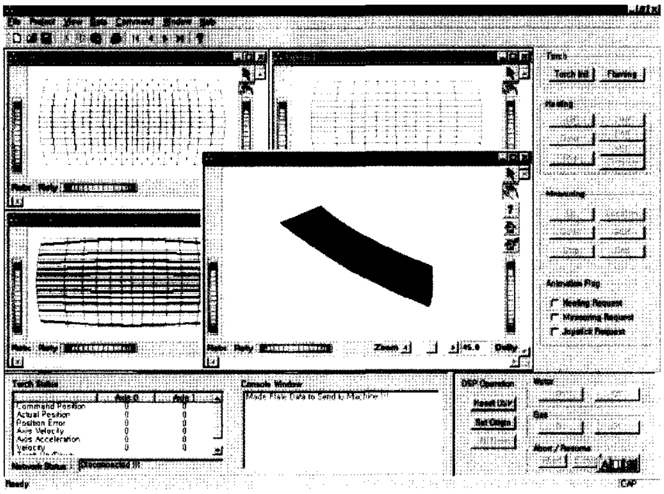

Figure 7: The proposed system template for the automated line heating process

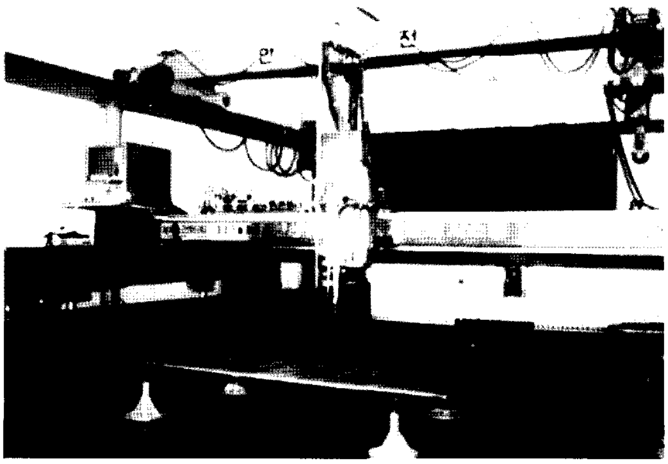

Figure 8: An automated line heating machine and experimental setup

$$S(u,v) = \left[a\frac{2u(1-v^2)}{(1+u^2)(1+v^2)}, b\frac{2v(1-u^2)}{(1+u^2)(1+v^2)}, c\frac{(1-u^2)(1-v^2)}{(1+u^2)(1+v^2)} \right] \tag{1}$$

$$a = 500, b = 300, c = 200, \qquad -0.2 \le u, \quad v \le 0.2$$

This model is one of the quadratic surfaces and is called the ellipsoid. The shape is shown in Figure 9.

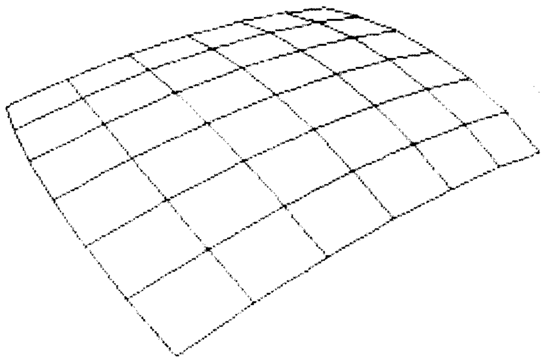

Figure 9: The shape of the simulation model

In the analysis module, the primary heating paths for transverse bending are obtained as shown in Figure 10.

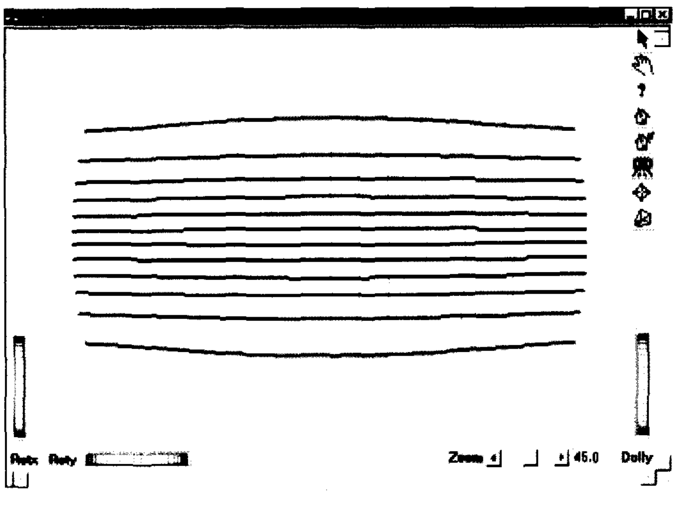

Figure 10: The heating paths for the first bending

After measuring the formed surface through the measurement module, the secondary heating paths for the longitudinal bending are calculated as shown in Figure 11. It is not the concern of this paper whether the heating paths are exact or not. The main goal is to develop an integrated system for the automated line heating process.

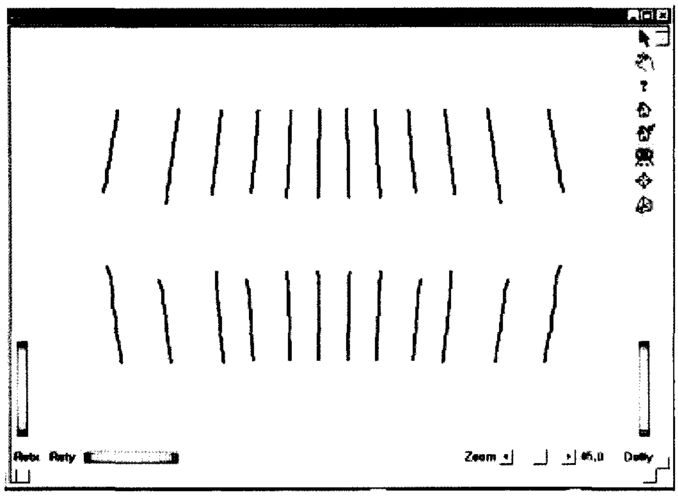

Figure 11: The heating paths for the longitudinal bending

6 Conclusions

In this paper, a prototype control system is proposed for an automated line heating process. In addition, an automatic line heating machine is developed, in order to make the system complete.

Since the amount of data is huge and the information flow is very complex, object-oriented methodology is employed for developing the system. By following the development steps of the methodology, a new automated process is realized. The proposed, automated system is compared with the current, experience-dependent system. The proposed control system consists of six sub-systems: the analysis, the inference, the data access, the communication, the measurement, and the display module. A product data model is constructed to store and retrieve all data in the automated process. By using the development system, data are accumulated in such a manner that highly precise forming conditions can be obtained.

This system is useful, irrespectively of heating methods, i.e. flame/gas, laser, or high frequency induction heating. In addition, the generated information is quantified, and thus useful for both technicians as well as other automated machines.

However, the automation system in this paper is not connected to the other systems, such as the design system, the roller bending system, and the process control system. This results in a problem of 'islands of automation' which are found in most shipbuilding processes. If these connections are considered in the future, the automation system suggested in this paper could be used more efficiently.

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