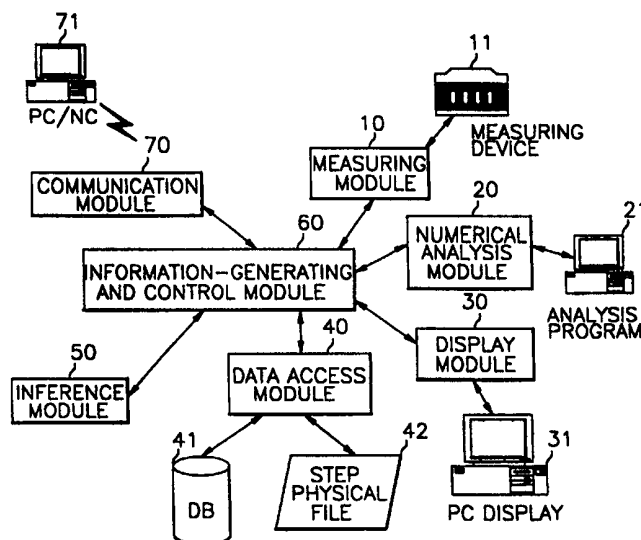




INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification ⁶ : B21D 5/00, 11/20	A1	(11) International Publication Number: WO 99/44764 (43) International Publication Date: 10 September 1999 (10.09.99)
(21) International Application Number: PCT/KR99/00093 (22) International Filing Date: 2 March 1999 (02.03.99) (30) Priority Data: 1998/7332 5 March 1998 (05.03.98) KR (71)(72) Applicants and Inventors: SHIN, Jong, Gye [KR/KR]; Samchang Golden Village 105-108, Banpo-4 Dong 586-3, Seocho-ku, Seoul 137-044 (KR). KIM, Won, DON [KR/KR]; Samho Garden Apartment, 2-1204 Woo-2 Dong 1104-1, Haewoodae-ku, Pusan 612-022 (KR). (74) Agent: LEE, Hwa, Ik; Young International Patent & Trade- mark Office, Daiheung Building, 4th floor, Suite 402, Youk- sam-dong 648-23, Kangnam-ku, Seoul 135-080 (KR).	(81) Designated States: CN, DE, DK, JP, US, European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE). Published <i>With international search report.</i>	

(54) Title: FORMATION METHOD AND DEVICE FOR CURVED PLATES



(57) Abstract

This invention includes the generation of forming information and its manipulation scheme as a method to form curved plates in ship hull-pieces. This invention consists of three components as follows: one is to construct and utilize a database which includes data about flat plates, objective curved plates, plates which are being formed, and their forming information, another is to infer new forming information with an artificial neural network system, and the third is to obtain forming information through calculating in-plane and bending strains. In the third, initial forming information is obtained by calculating strains from relationship between flat plates and objective curved plates. And new forming information is yielded through calculating the strains from relationship between partially formed curved plates and objective curved plates. Final objective plates are reached by repeatedly performing the measurement of the difference between plates in the proceeding steps and final objective plates and the calculation of the new strains in each process. Therefore, through this invention standardization and automation can be realized in the formation of curved plates.

FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AL	Albania	ES	Spain	LS	Lesotho	SI	Slovenia
AM	Armenia	FI	Finland	LT	Lithuania	SK	Slovakia
AT	Austria	FR	France	LU	Luxembourg	SN	Senegal
AU	Australia	GA	Gabon	LV	Latvia	SZ	Swaziland
AZ	Azerbaijan	GB	United Kingdom	MC	Monaco	TD	Chad
BA	Bosnia and Herzegovina	GE	Georgia	MD	Republic of Moldova	TG	Togo
BB	Barbados	GH	Ghana	MG	Madagascar	TJ	Tajikistan
BE	Belgium	GN	Guinea	MK	The former Yugoslav Republic of Macedonia	TM	Turkmenistan
BF	Burkina Faso	GR	Greece			TR	Turkey
BG	Bulgaria	HU	Hungary	ML	Mali	TT	Trinidad and Tobago
BJ	Benin	IE	Ireland	MN	Mongolia	UA	Ukraine
BR	Brazil	IL	Israel	MR	Mauritania	UG	Uganda
BY	Belarus	IS	Iceland	MW	Malawi	US	United States of America
CA	Canada	IT	Italy	MX	Mexico	UZ	Uzbekistan
CF	Central African Republic	JP	Japan	NE	Niger	VN	Viet Nam
CG	Congo	KE	Kenya	NL	Netherlands	YU	Yugoslavia
CH	Switzerland	KG	Kyrgyzstan	NO	Norway	ZW	Zimbabwe
CI	Côte d'Ivoire	KP	Democratic People's Republic of Korea	NZ	New Zealand		
CM	Cameroon	KR	Republic of Korea	PL	Poland		
CN	China	KZ	Kazakstan	PT	Portugal		
CU	Cuba	LC	Saint Lucia	RO	Romania		
CZ	Czech Republic	LI	Liechtenstein	RU	Russian Federation		
DE	Germany	LK	Sri Lanka	SD	Sudan		
DK	Denmark	LR	Liberia	SE	Sweden		
EE	Estonia			SG	Singapore		

FORMATION METHOD AND DEVICE FOR CURVED PLATES

Technical Field

This invention relates to formation method and
5 device for curved plates.

Background Art

Generally, two methods are being widely used in forming ship hull pieces: hot forming and cold forming.
10 Since mechanical cold forming can be easily controlled due to using a press or a roller, it is mainly used a method to form slightly curved plates or simple plates with constant curvature overall their area and a preceding method in forming doubly curved plates. Hot
15 forming method, which uses residual thermal elastic-plastic deformation to be caused in heating, is mainly used as a second method to form doubly curved plates or a method to remove residual welding deformation in ship blocks.

20 Hot forming method has been called line-heating process as plates are heated up in constant direction. This line-heating process needs a lot of forming information such as heating positions, heating speed, cooling positions, cooling speed, etc. In the former
25 process, skillful workers have decided this forming information. To make things worse, some technical systems and some databases have not yet been built in relation with this process.

To simulate mechanism of line-heating process and
30 to systematically provide forming information, some 3-dimensional thermal elastic-plastic analyses have been studied and published. But such analysis methods are not

adequate as a practical usage in production shops due to their long calculating time.

Some researches are implemented to improve this defect. They are roughly divided into two categories. One is to derive simple formula from relationship between heat input and the corresponding residual deformation, which is obtained from many experimental data. This has advantages in not spending much time compared with the thermal elastic-plastic analysis. The other is to use a simple model in the thermal elastic-plastic analysis. Recently in the simplified analysis, to improve an initial beam model some models are developed: there are a 2-dimensional strip model, a 2-dimensional elastic-plastic theory for a round plate under spring constraint, and a modified strip model. This approach has some difficulties in assuming the accurate structural behavior and this also spends much time in practically simulating the line-heating process.

Moreover, simplified formula and simplified analyses have fatal faults in offering exact forming information since shrinkage, in other words, the in-plane strain is not taken into consideration in them. But arbitrary curved plates have both in-plane strains and bending strains. In-plane strains and bending strains are indispensably yielded in the forming process. If only bending strains are considered in generating the forming information, the basic errors cannot be resolved.

Formerly, forming information has been also obtained in only relationship between flat plates and their objective curved plates. The objective curved plates are formed through some stages. Such former methods have not considered these stages to again form

the plates which are partially formed into the objective curved plates, so these cannot realize the practical line heating process.

Though forming information was obtained on basis of
5 an inaccurate theory or was generated by intuition of the skillful workers, a systematic database has not been built about such forming information. An information model must be examined on this manufacturing process as closely as possible. But such information model has not
10 been investigated until now. So data which has been known little and that are never being used.

Conclusively, in former techniques for the formation of curved plates, forming information depends on workers' experiences, the information is subject to
15 errors due to its inaccurate bases, and its flow has not been examined and its manipulation has not been systematic. That is, they are in a state that there are no techniques to obtain the computerized and structured data from the existing forming information.

20

Disclosure of the Invention

In this invention, it is intended to improve the productivity in shipbuilding and automae a formation process of curved plates, specially, a line-heating
25 process by establishing a new forming process to make better former ones in which inexact forming information is used only considering bending strain and developing some techniques corresponding to this process. Such techniques are divided into two: one is a component
30 technique to yield accurate forming information and the other is a system technique to utilize the information efficiently.

This invention is made to provide workers with accurate forming information and to form curved plates more close to their objectives specially in the hot forming process, e.g., line-heating in which curved plates are formed by locally heating one side of plates with a torch. Moreover, this invention makes forming process be automated. Such purposes are accomplished by constructing a database on various data and forming information systematically, which are formerly experiences of workers, by inferring new information from this database through the artificial neural network method, and by calculating in-plane and bending strains from relationship between initial flat plates or any initially-curved plates and their objective plates.

This invention adopts three main component techniques to obtain an accurate forming information. One is to calculate in-plane and bending strains. Another is to simulate the formation process of curved plates by developing a numerical model. And the third is to calculate and infer the forming information.

To efficiently utilize forming information produced through these three techniques in practical manufacturing, this invention includes the following techniques:

- to computerize the formation process of ship hull pieces systematically,
 - to establish its product model on a basis of the object-oriented concept to integrate various data,
 - to build a product database on a basis of this product model, and
 - to provide new information to form the plates which is partially formed into their objective curved plates.
- This new information helps plates to converge to their

objectives.

According to one aspect of this invention, there is provided a ship hull-piece forming method including steps
5 of (a) constructing a product database by using a relational database management system and by building product model on a basis of information modeling about formation data and processes; (b) measuring the shape of a plate and processing data; (c) performing numerical
10 analyses on a basis of thermal elastic-plastic theory, which have forming information on the above measured plate and information on heating position as a off-line training or programming; (d) inferring forming information that is applied to new plates with multilayer
15 artificial neural network from the product database which has many data obtained by numerical simulations and measured in the previous works; and (e) generating information on heating paths and heat condition by calculating in-plane and bending strains from
20 relationship between flat plates and the objective curved plates and from relationship between the objectives and plates partially formed in the middle of formation; wherein said method can measure the difference between any shaped plate partially formed in the middle of
25 formation and their objective plates during the process and numerically calculate the in-plane and bending strains with that difference to provide the forming information; wherein said formation step is completed by repeatedly making this measurement and calculation at
30 each processing step.

According to another aspect of this invention, there is provided the ship hull-piece forming method

having abilities of offering forming information to workers through monitors and worksheets, sending it to the automatic device for line-heating process, and storing intermediate forming information from this device to the product database.

According to another aspect of this invention, the information-generating step (e) has abilities of providing heating paths for the transverse formation, which are determined perpendicularly to maximum principal directions of bending strains by calculating the ratio between maximum principal bending strains and minimum ones, and providing heating paths for the longitudinal formation, which are determined perpendicularly to maximum principal directions of in-plane strains by calculating the ratio between maximum principal in-plane strains and minimum ones.

According to another aspect of this invention, the numerical analysis step (c) comprises steps of (c-1) setting up parameters such as sizes of plates, initial curvature of plates, speed of a torch, the clearance between a torch and a cooler, film coefficient, the number of finite elements; (c-2) setting up material properties like conduction coefficient and specific heat quality, to model a heat source and a cooling method, calculating temperature distribution in each time step, and making post-process to show the calculating results effectively; and (c-3) setting up material properties like conduction coefficient, elastic coefficient, thermal expansion coefficient, yield stress, determining boundary conditions, calculating strains and stresses with temperature distribution, and making post-processing to effectively show calculating results.

According to another aspect of this invention, the database-construction step (a) has a relational product database and having steps of (a-1) information modeling containing the flow of data in formation process of ship hull-pieces on a basis of the object-oriented concept; (a-2) definition of product model about formation process of ship hull-piece on a basis of the object-oriented concept, in which product model data cover all information over total life cycle - design, production and waste - of specific product such as phase 1, phase 2, phase 3, and phase 4 wherein the phase 1 is the selection of objects that is Hull piece and kinematics, Bending strain and in-plane strain, Principal curvature and piece forming method, Rolling and rolling condition, Line-heating and heating condition, Material property and NURBS surface, Offset table and surface measuring, Measuring points and measuring sequence, Heating line set and heating sequence, and Communication method and ANN model, the phase 2 is the definition of their attributes and their relationship, the phase 3 is the setup of their constraints, and the phase 4 is the model integration of these objects; and (a-3) construction of the product database which some forming information is saved to and retrieved from on a basis of such product model.

According to another aspect of this invention, there is provided an information-generation system for ship hull-piece formation consisting of measurement module in which the shape of plates in process and forming information is measured with some devices; numerical analysis module in which heating conditions are calculated and verified, and this process is simulated, using a numerical program for thermal elastic-plastic

analysis; display module in which much information is displayed in a monitor of a personal computer (PC) and is printed out through a printer; data access module in which measuring and forming information is stored to and
5 retrieved from a product database and a STEP physical file that has measuring and forming information is available; inference module in which forming information and heating conditions about a plate to newly form are predicted from data of the product database by an
10 artificial neural network method; information-generating and control module in which each module previously described is controlled by a program of this module and forming information is obtained through calculation of in-plane and bending strains in the processing stages,
15 wherein heating paths or locations to heat on are determined, comparing in-plane strains and bending strains with each other; communication module through which the information-generating and control module transmits forming information, heating conditions and
20 heating paths to numerical control machine based on PC (PC/NC) and through which the measured and the formation results are transmitted and stored to the product database.

25 **Brief Description Of The Drawings**

The present invention will become more fully understood from the detailed description given hereinbelow and the accompanying drawings which are given by way of illustration only, and thus are not limitative
30 of the present invention, and wherein:

Figure 1 is a diagram which shows the system of a formation method of curved plates suggested in this

invention;

Figure 2 is a chart which shows some kinds of information and their manufacturing flow on data production, handling and storage suggested in this
5 invention;

Figure 3 is a diagram which shows a method to generate forming information from any flat plate suggested in this invention. In other words, this is kinematics between any flat plate and the corresponding
10 objective plate; and

Figure 4 is a drawing which shows a method to generate forming information from any partially-formed plate suggested in this invention. In other words, this is kinematics between any initially-curved plate and the
15 corresponding objective plate.

Best Mode For Carrying Out The Invention

Figure 1 is a diagram which shows the system of a formation process of curved plates suggested in this
20 invention. As shown in Figure 1, this formation process is composed of seven parts: a main module and six sub-modules. In the measurement module (10), the shape of plates in process and forming information is measured with some devices (11). In the numerical analysis module
25 (20), heating conditions are calculated and verified, and this process is simulated, using a numerical program (21) for thermal elastic-plastic analysis. In the display module (30), much information is displayed in a monitor of a personal computer (PC) (31) and is printed out
30 through a printer. In the data access module (40), measuring and forming information is stored in a product database (41) and retrieved from it, and this data is the

existing or the new. A STEP (STandard for the Exchange of Product model data) physical file that has measuring and forming information is available. In the inference module (50), forming information and heating conditions about a plate to newly form are predicted from data of the product database by an artificial neural network method. In the information-generating and control module (60), each process previously described is controlled by a program of this module and forming information is obtained through calculation of in-plane and bending strains in the processing stages. Also heating paths or locations to heat on are determined, comparing in-plane strains and bending strains with each other. This module (60) transmits forming information, heating conditions and heating paths to numerical control machine (71) based on PC (PC/NC) through the communication module (70). Also through the communication module (70) the measured and the formation results are transmitted and stored in the product database (41).

Figure 2 is a chart which shows some kinds of information and their manufacturing flow on data production, handling and storage suggested in this invention. As shown in Figure 2, this formation process is composed of four sub-processes as follows.

- CAD (Computer-Aided Design) process (S100 - S104) in which necessary data like surface model and expanded shapes are calculated on a basis of objective plates and they are stored in the product database (41)
- Roller bending process (S201 - S205) in which that rolling information such as the rolling quantity and the measuring information is retrieved from the database (41), roller bending is implemented, and

measured results are stored to database (41)

- Inference process (S301 - S302) in which forming conditions are inferred for roller bending and line heating by an artificial neural network method
- 5 • Line-heating process (S401 - S405) in which heating and measuring information are retrieved from the database (41), line-heating is implemented, and measured results are stored in the database (41)

10 Offset data of objective plates that are obtained from the ship design step are modeled into NURBS (Non-Uniform Rational B-Spline) surfaces (S101) in order to calculate bending and in-plane strains in this system and then the modeled surfaces are stored in the product model
15 database (41). In the development process (S103), developed shapes of the objective curved plates (S104) are calculated with such data and are also stored in the product database (41).

As the cold forming is adopted as the first process
20 (S201 - S205) in forming curved plates, the roller bending is carried out on a basis of rolling information (S201) obtained from relationship between objective plates and their developed plates. And then the bent plates are measured through the measurement module in
25 Figure 1. Through this measurement, we make sure how much the bent plates differ from the designed shapes. If their shapes are obtained as desired, information that occurs in this process is saved to the database (41) and next process is made.

30 Line-heating process (S401 - S405) can be adopted as the first without roller bending or as the second after roller bending. Therefore, in adopting line-heating

as the first process the forming information is determined to fabricate flat plates or plates that has initial curvature (S302). If the plates are pre-fabricated by the cold forming, the line-heating will be applied to curved plates as the second process. The forming information for line heating (S401) is yielded in the same way as that of roller bending. That is, it is obtained from relationship between the objective curved plates and the initial plates. After the line heating is proceeded (S402), the formed plates are measured (S404) and it is evaluated whether the desired shapes is got. If the desired shapes are not made, the previous steps are repeated. And the information which occurs in this process is continuously stored in the product database (41).

Inference devices, e.g., an artificial neural network method are adopted to estimate forming information in roller bending and line-heating. In the inference process (S301 - S302), the new information is determined through the database (41) in which many data have been accumulated.

Each part of Figure 1 is implemented by a software in this invention. We can constitute some softwares for each part to do the following steps in accordance with the information-generating and control module (60).

- The measuring step in which plates and information are measured through the measurement module (10) at the processing;
- The numerical analysis step in which forming information is predicted and verified on a basis of the thermal elastic-plastic theory of the numerical analysis module (20);

- The displaying step in which much information and measuring results are viewed in PC monitors (31) through the display module (30);
- The data manipulation step in which the designed data of plates and forming information is saved to and retrieved from the product database (41) through the data access module (40);
- The inferring step in which new forming information to be applied to new fabrication is predicted from data that exist in the product database (41) by using an artificial neural network method through the inference module (50);
- The communication step in which fabrication information is sent from the database (41) to the forming device, or PC/NC machine (71) through the communication module (70) and the proceeded data are transmitted from PC/NC machine (71) to the display module (30) and the data access module (40);
- The information-generating step in which bending and in-plane strains are calculated to generate initial forming information and intermediate information, and to decide locations of heating lines through the information-generating and control module (60).

From now on, the steps previously mentioned will be described in details.

(1) The measuring step

Using the measuring devices, the shapes of plates in process and the process information are measured. After that, the above information is inputted into the database (41) through the measurement module (10). The

information of the interim shapes during process is used to produce new fabrication information in '(6) The information-generating step'.

5 (2) The numerical analysis step

To find the fabrication information on heating paths, heating velocity, heat input, etc., a numerical analysis is efficient. The plates show a complicated thermal elastic-plastic behavior under line-heating
10 process. To analyze the thermal elastic-plastic problem, first one should find the time-dependent temperature distribution of a heated plate. As thermal deformation of a material under heating and cooling is not so large, heat transfer problem and thermal deformation problem can
15 be considered to be uncoupled in this analysis. So, the thermal elastic-plastic problem can be simplified somewhat. During this analysis, material properties such as yield stress, elastic coefficient, thermal expansion coefficient, etc., are dependent on temperature.

20 Numerical analysis process can be largely categorized into three parts.

In the first step, a numerical model is composed. It involves the shape information like sizes and initial curvature of a plate, the forming information like
25 velocity of a torch, cooling conditions, heat input, etc., and the meshes of the plate that affect on the numerical analysis.

In the second step, the heat transfer problem is solved. In heating, the plate has the temperature
30 distribution caused by the heat conduction in the transverse and longitudinal direction and in cooling, the plate gets cooled only by heat convection ignoring the

cooling by radiation.

In this invention the heat source is treated as the shape of Gauss distribution, moving over the plate with fixed velocity. The heat source is modeled as the
5 following equation.

$$q''(r) = q_{\max} e^{-\gamma^2 r^2}$$

where $q''(r)$ is heat flux, q_{\max} is maximum heat flux, γ
10 is concentration coefficient, r is a distance from the center of the heat source. Also the cooling process is expressed as convection heat conduction formula as below, known as Newton's law of cooling.

15

$$q_c'' = h(T_{\infty} - T_s)$$

where q_c'' is convective heat flux, h is film coefficient, T_{∞} is the temperature of a coolant, T_s is the temperature on a surface of the plate. The
20 temperature distribution is found by numerically solving the partial differential equations of this heat conduction problem caused by movement of the distributed heat source.

The third step is the procedure in which the
25 thermal elastic-plastic analysis is preformed with the temperature distribution which is found in the second step. The yield stress of a plate decreases as the temperature of the plate increases. The heated surface has the compressive stress as the surface expands in
30 heating. If this compressive stress gets lower than the yield stress, the material yields locally. Owing to that,

the plate has the bending effect during the cooling process. The heated surface has the tensional stress as the surface contracts in cooling.

In the first step previously described, various
5 parameters are established. These parameters involves the size of the plate, the initial curvature of the plate, the velocity of the torch, the distance between the torch and the cooling device, film coefficient, the number of the finite element, etc.

10 As the second step previously described, four procedures are performed in the heat conduction problem. The first is setting the conduction coefficient and specific heat quantity. The second is modeling the plate, a torch, and a cooling. The third is calculating the
15 temperature distribution in each time step. And the fourth is post-processing which shows the results efficiently.

As the third step previously described, four
procedures are also performed in the thermal elastic-
20 plastic problem. The first is setting up the material properties like the transfer coefficient, the elastic coefficient, the thermal expansion coefficient, the yield stress, etc. The second is applying the boundary condition. The third is calculating the deformation and
25 the stress from the temperature distribution which is obtained in the second step. And the fourth is post-processing which shows the calculation result efficiently.

(3) The displaying step

30 This is the step of showing determined information through a monitor.

(4) The data manipulation step

In this step, we build and use the design data on the shapes of curved plates and the forming information. The information contains measuring values and the results of the numerical analysis. For that, this invention carries out a information modeling using an object oriented concept in the forming process on ship hull pieces and defines a product data model. This product model defines all information generated during a whole lifetime from the design and production of a specified product to the waste. Using a relational database management system (RDBMS), we build the database on a basis of the product model of a ship hull plate. The necessary objects are defined and the database is organized with these objects. The principal objects are as follows:

Hull piece,	Kinematics,
Bending strains,	In-plane strains,
Principle curvature,	Piece forming method,
Rolling,	Rolling condition,
Line-heating,	Heating condition,
Material property,	NURBS surface,
Offset table,	Surface measuring,
Measuring points,	Measuring sequence,
Heating line set,	Heating sequence,
Communication method,	ANN model.

A product database, shown in Figure 2, is constructed on the basis of the definition and constraints of the attributes and relationships of these objects.

(5) The inferring step of the forming information

The fabrication information can be obtained though a multilayer artificial neural network (ANN) with a backpropagation algorithm, which requires the information database built by the simulation of the numerical analysis and the measurement.

The ANN consists of the input layers, the hidden layers and the output layers.

$$Q = \sum_{i=1}^n I_i w_i$$

$$R = f(Q)$$

where I_i are the values of the input layers, Q is the value of hidden layers, R is the value of output layers, w_i are the weights, and f is the active function. For the active function f , the sigmoid function is adopted as follows.

$$f(Q) = 1/(1 + e^{-Q})$$

And the next equation is valid to control the weights.

$$w_i^n = w_i^0 + \eta \times \delta \times R$$

$$\delta = f' \times (T - R)$$

where w_i^n are updated values of the weights, w_i^0 is the old values of the weights, R is the output values of the correspondent variables, η is the training rate, f' is the derivative of the active function f , and T is the target value. The training rate η is a constant between 0.01 to 1.0.

In the case of the sigmoid function as f , f' is simply obtained as $f' = R(1-R)$. After the weights are

controlled in the connection between the hidden layers and the output layers, the weights between the hidden layers and the input layers are also controlled in the similar way. And then, with the newly updated weights,
5 ANN system calculates the output. If that result is within the tolerance range, it ceases the training, but if not, continues the training until the accuracy of output enters the tolerance range.

In this invention, the training is performed with
10 the variation in the number of the hidden layers and of neurons in each hidden layer. From the results, if ANN system has enough neurons in two hidden layers, it studies the example problems with ease. The inference from the training gives reasonable solutions, which
15 presents relatively small error. This means that when the rich data sets are examined and trained in the problem domain, the ANN system will serve the results close to the real practice. And it will efficiently utilize the results of the structural analysis.

20 To verify this possibility, examples are shown for the implementation of the numerical analyses and the inference of new information. The numerical analyses are performed with variation of the thickness, initial curvature of plates and the moving speed of the heating
25 torch. When the results of the examples are regarded as the training set, ANN system infers the maximum deformation for new inputs.

In Table 1, the results of numerical analyses are shown. The input values are initial curvature and
30 thickness of plates, and the output value is deformation.

Table 1

Initial curvature (ρ :mm)	Thickness (t :mm)	Speed of torch (s :mm/sec)	Maximum deflection (δ :mm)
1000	20	7.5	3.654
1000	20	10	2.413
1000	20	12	1.917
1000	25	10	1.958
1000	25	12	1.71
2000	20	7.5	3.328
2000	20	10	2.465
2000	20	12	2.04
2000	25	7.5	2.169
2000	25	10	1.981
3000	20	7.5	3.219
3000	20	10	2.471

With respect to the radius of initial curvature, thickness and the speed of torch, the two following cases
 5 give the maximum deformations inferred by the ANN system in Table 2.

Table 2

ρ	t	s	δ (exact)	δ (1)	δ (2)
1000	25	7.5	2.406	2.56 (+6.4%)	2.868 (+19.2%)
2000	25	11	1.89	1.896 (+0.33%)	1.838 (-2.75%)

10 In this table, (1) is obtained from the ANN system with 2 hidden layers and 4 neurons in each layer and the training is performed 162900 times. (2) is done with the system with 2 hidden layers, 6 neurons in each layer and 227700 times training.

15 As seen in Table 2, when the number of neurons increases in each layer, the time needed for training also increases with the remarkable error. This means that adequate number of hidden layers and neurons should be

selected with caution.

(6) The communication step

TCP/IP is adopted as a protocol for the
 5 communication of manufacturing data between physical
 devices and the database management system. This is
 currently being used as an internet protocol.

(7) The information-generating step

10 Strains are adopted as a primary factor to
 determine the heating paths and forming conditions to
 apply initial plates. In this step, such fabrication
 information is generated through the calculation of in-
 plane and bending strains. The Green-Lagrangian strain
 15 tensor is in main use as follows.

$$\varepsilon_{ij} = \frac{1}{2} \left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} + \frac{\partial u_k}{\partial x_j} \frac{\partial u_k}{\partial x_i} \right)$$

where ε_{ij} is the strains and u_i means the deformation
 20 in x, y, and z direction.

The method 1 is shown about the information generation
 for flat plates in Figure 3, which shows kinematics
 between any flat plate and the corresponding objective
 plate.

25 When you consider an infinitesimal element
 $h(x,y)dxdy$ in Figure 3, the corresponding strains are
 formulated as,

$$\begin{aligned}\varepsilon_{xx} &= -z \frac{\partial^2 w}{\partial x^2} + \frac{\partial u}{\partial x} + \frac{1}{2} \left(\frac{\partial w}{\partial x} \right)^2, \\ \varepsilon_{yy} &= -z \frac{\partial^2 w}{\partial y^2} + \frac{\partial v}{\partial y} + \frac{1}{2} \left(\frac{\partial w}{\partial y} \right)^2, \\ \varepsilon_{xy} &= -z \frac{\partial^2 w}{\partial x \partial y} + \frac{1}{2} \left(\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x} + \frac{\partial w}{\partial x} \frac{\partial w}{\partial y} \right)\end{aligned}$$

When the total strain tensor is denoted by ε ,

$$\varepsilon = \varepsilon^b + \varepsilon^m.$$

5

The total strains are divided into the bending strains ε^b and in-plane strains ε^m .

The in-plane strains are obtained by

$$\begin{aligned}\varepsilon^m_{xx} &= \frac{\partial u}{\partial x} + \frac{1}{2} \left(\frac{\partial w}{\partial x} \right)^2, \\ \varepsilon^m_{yy} &= \frac{1}{2} \left(\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x} + \frac{\partial w}{\partial x} \frac{\partial w}{\partial y} \right)^2, \\ \varepsilon^m_{xy} &= \frac{\partial u}{\partial y} + \frac{1}{2} \left(\frac{\partial w}{\partial y} \right)^2\end{aligned}$$

10

And the bending strains are by

$$\varepsilon^b_{xx} = -z \frac{\partial^2 w}{\partial x^2}, \quad \varepsilon^b_{xy} = -z \frac{\partial^2 w}{\partial x \partial y}, \quad \varepsilon^b_{yy} = -z \frac{\partial^2 w}{\partial y^2}.$$

15

Also, the information generation for partially formed plates, namely the plates which are initially deflected is shown as the method 2 in Figure 4, which is kinematics between any initially-curved plate and the corresponding objective plate.

20

When we consider an infinitesimal element $h(x,y)dxdy$ with initial shape ξ , which occurs by the partial fabrication in Figure 4, the corresponding strains are obtained as,

$$\begin{aligned}\varepsilon_{xx} &= \frac{\partial u}{\partial x} + \frac{1}{2} \left(\frac{\partial w}{\partial x} \right)^2 + \frac{\partial \xi}{\partial x} \frac{\partial w}{\partial x} - z \frac{\partial^2 w}{\partial x^2}, \\ \varepsilon_{xy} &= \frac{1}{2} \left(\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x} + \frac{\partial w}{\partial x} \frac{\partial w}{\partial y} + \frac{\partial \xi}{\partial y} \frac{\partial w}{\partial x} + \frac{\partial \xi}{\partial x} \frac{\partial w}{\partial y} \right) - z \frac{\partial^2 w}{\partial x \partial y}, \\ \varepsilon_{yy} &= \frac{\partial v}{\partial y} + \frac{1}{2} \left(\frac{\partial w}{\partial y} \right)^2 + \frac{\partial \xi}{\partial y} \frac{\partial w}{\partial y} - z \frac{\partial^2 w}{\partial y^2}.\end{aligned}$$

Total strain tensor ε is obtained, adding two strain tensors ε^m and ε^b like the case of the flat plate.

5

$$\varepsilon = \varepsilon^b + \varepsilon^m.$$

So it is seen that ε_{ij} represent components of the strains, divided into in-plane strains ε_{ij}^m and bending strains ε_{ij}^b .

10

In-plane strains are denoted by

$$\begin{aligned}\varepsilon_{xx}^m &= \frac{\partial u}{\partial x} + \frac{1}{2} \left(\frac{\partial w}{\partial x} \right)^2 + \frac{\partial \xi}{\partial x} \frac{\partial w}{\partial x} \\ \varepsilon_{xy}^m &= \frac{1}{2} \left[\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x} + \frac{\partial w}{\partial x} \frac{\partial w}{\partial y} + \frac{\partial \xi}{\partial y} \frac{\partial w}{\partial x} + \frac{\partial \xi}{\partial x} \frac{\partial w}{\partial y} \right] \\ \varepsilon_{yy}^m &= \frac{\partial v}{\partial y} + \frac{1}{2} \left(\frac{\partial w}{\partial y} \right)^2 + \frac{\partial \xi}{\partial y} \frac{\partial w}{\partial y}\end{aligned}$$

and bending strains are by

$$\varepsilon_{xx}^b = -z \frac{\partial^2 w}{\partial x^2} \quad \varepsilon_{xy}^b = -z \frac{\partial^2 w}{\partial x \partial y} \quad \varepsilon_{yy}^b = -z \frac{\partial^2 w}{\partial y^2}.$$

15

The effect of the initial deflection appears in terms of ξ in the in-plane strains.

The strains can be calculated numerically on a basis of derived equations in each method. Bending strains represents curvatures at that point. Thus, they can be replaced with the curvature of the interpolated surface. And in-plane strains can be calculated by an iso-parametric finite element formulation. In this

20

formulation, a plate element is utilized for obtaining in-plane strains.

After obtaining such in-plane strains and bending strains, the forming information like heating paths and heating order, etc., is determined. Firstly, the ratio of the maximum bending strains and the minimum bending strain is calculated and then heating paths for the transverse formation are determined perpendicular to maximum principal bending strains. Secondly, the ratio of the maximum in-plane strain and the minimum in-plane strain is calculated, and then heating paths for the longitudinal formation are determined perpendicular to maximum principal in-plane strains.

In this step, we construct a forming technique to diminish the errors that naturally occurs in the formation process by repeatedly calculating new forming information from the relationship between the objective curved plates and intermediately formed plates.

As minutely mentioned, this invention, in the formation process of ship hull pieces, makes a database with forming information, inferred new information by an artificial neural network system, and fabricates the optimal plates by continuously comparing with the objectives during process.

So it can be possible to fabricate a flat plate into the correspondent objective even if not best workers and actually all processes can be automated in the formation of ship hull pieces.

Although the preferred embodiments of the present invention have been disclosed for illustrative purposes, those skilled in the art will appreciate that various modifications, additions and substitutions are possible,

without departing from the scope and spirit of the invention as recited in the accompanying claims.

What Is Claimed Is:

1. A ship hull-piece forming method including steps of:
 - (a) constructing a product database by using a relational database management system and by building product model on a basis of information modeling about formation data and processes;
 - (b) measuring the shape of a plate and processing data;
 - (c) performing numerical analyses on a basis of thermal elastic-plastic theory, which have forming information on the above measured plate and information on heating position as a off-line training or programming;
 - (d) inferring forming information that is applied to new plates with multilayer artificial neural network from the product database which has many data obtained by numerical simulations and measured in the previous works; and
 - (e) generating information on heating paths and heat condition by calculating in-plane and bending strains from relationship between flat plates and the objective curved plates and from relationship between the objectives and plates partially formed in the middle of formation;
- wherein said method can measure the difference between any shaped plate partially formed in the middle of formation and their objective plates during the process and numerically calculate the in-plane and bending strains with that difference to provide the forming information;
- wherein said formation step is completed by repeatedly making this measurement and calculation at each processing step.

2. The ship hull-piece forming method according to the claim 1, said method having abilities of offering forming information to workers through monitors and
5 worksheets, sending it to the automatic device for line-heating process, and storing intermediate forming information from this device to the product database.

3. The ship hull-piece forming method according to
10 the claim 1, wherein said information-generating step (e) has abilities of providing heating paths for the transverse formation, which are determined perpendicularly to maximum principal directions of bending strains by calculating the ratio between maximum
15 principal bending strains and minimum ones, and providing heating paths for the longitudinal formation, which are determined perpendicularly to maximum principal directions of in-plane strains by calculating the ratio between maximum principal in-plane strains and minimum
20 ones.

4. The ship hull-piece forming method according to the claim 1, wherein said numerical analysis step (c) comprising steps of:
25 (c-1) setting up parameters such as sizes of plates, initial curvature of plates, speed of a torch, the clearance between a torch and a cooler, film coefficient, the number of finite elements;
(c-2) setting up material properties like conduction
30 coefficient and specific heat quality, to model a heat source and a cooling method, calculating temperature distribution in each time step, and making post-process

to show the calculating results effectively; and

(c-3) setting up material properties like conduction coefficient, elastic coefficient, thermal expansion coefficient, yield stress, determining boundary
5 conditions, calculating strains and stresses with temperature distribution, and making post-processing to effectively show calculating results.

5. The ship hull-piece forming method according to
10 claim 1, said database-construction step (a) having a relational product database and having steps of:

(a-1) information modeling containing the flow of data in formation process of ship hull-pieces on a basis of the object-oriented concept;

15 (a-2) definition of product model about formation process of ship hull-piece on a basis of the object-oriented concept, in which product model data cover all information over total life cycle - design, production and waste - of specific product such as phase 1, phase 2,
20 phase 3, and phase 4 wherein the phase 1 is the selection of objects that is Hull piece and kinematics, Bending strain and in-plane strain, Principal curvature and piece forming method, Rolling and rolling condition, Line-heating and heating condition, Material property and
25 NURBS surface, Offset table and surface measuring, Measuring points and measuring sequence, Heating line set and heating sequence, and Communication method and ANN model, the phase 2 is the definition of their attributes and their relationship, the phase 3 is the setup of their
30 constraints, and the phase 4 is the model integration of these objects; and

(a-3) construction of the product database which some

forming information is saved to and retrieved from on a basis of such product model.

6. An information-generation system for ship hull-piece formation consisting of:

5 measurement module (10) in which the shape of plates in process and forming information is measured with some devices (11);

numerical analysis module (20) in which heating

10 conditions are calculated and verified, and this process is simulated, using a numerical program (21) for thermal elastic-plastic analysis;

display module (30) in which much information is displayed in a monitor of a personal computer (PC) (31)

15 and is printed out through a printer;

data access module (40) in which measuring and forming information is stored to and retrieved from a product database (41) and a STEP physical file that has measuring and forming information is available;

20 inference module (50) in which forming information and heating conditions about a plate to newly form are predicted from data of the product database by an artificial neural network method;

information-generating and control module (60) in which

25 each module previously described is controlled by a program of this module and forming information is obtained through calculation of in-plane and bending strains in the processing stages, wherein heating paths or locations to heat on are determined, comparing in-

30 plane strains and bending strains with each other;

communication module (70) through which the information-generating and control module (60) transmits forming

information, heating conditions and heating paths to numerical control machine (71) based on PC (PC/NC) and through which the measured and the formation results are transmitted and stored to the product database (41).

5

10

15

20

25

30

FIG. 1

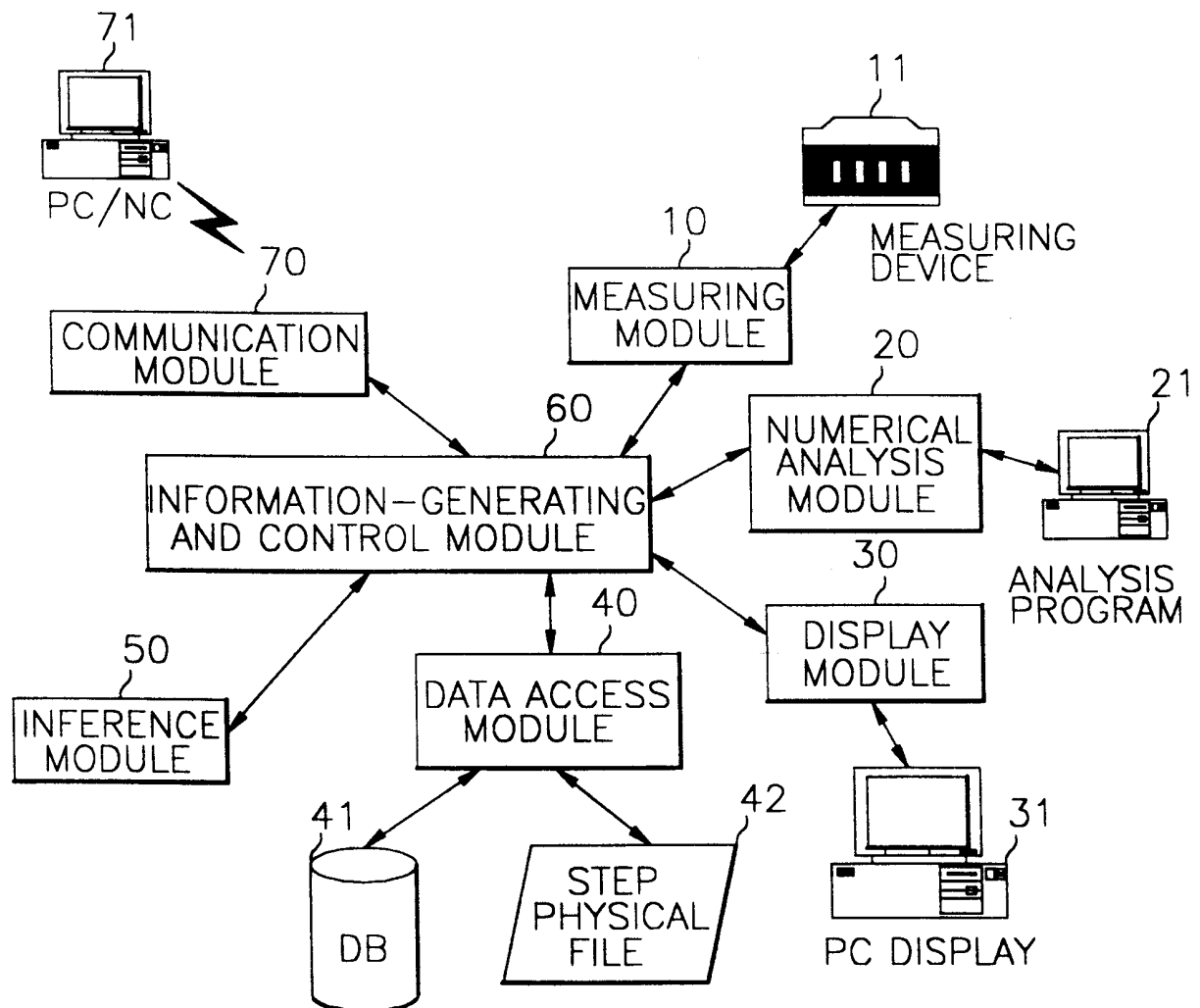


FIG. 2

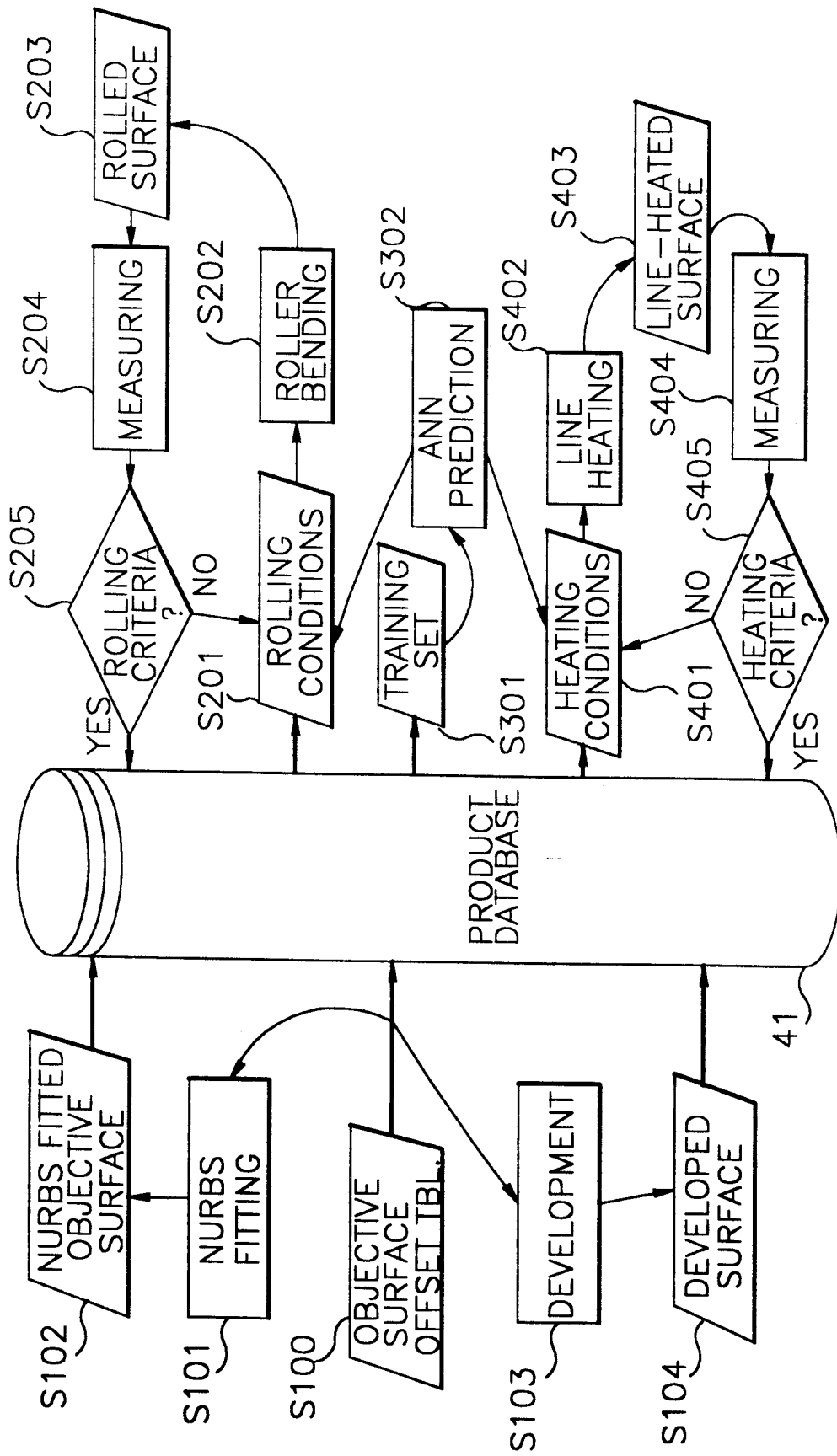


FIG. 3

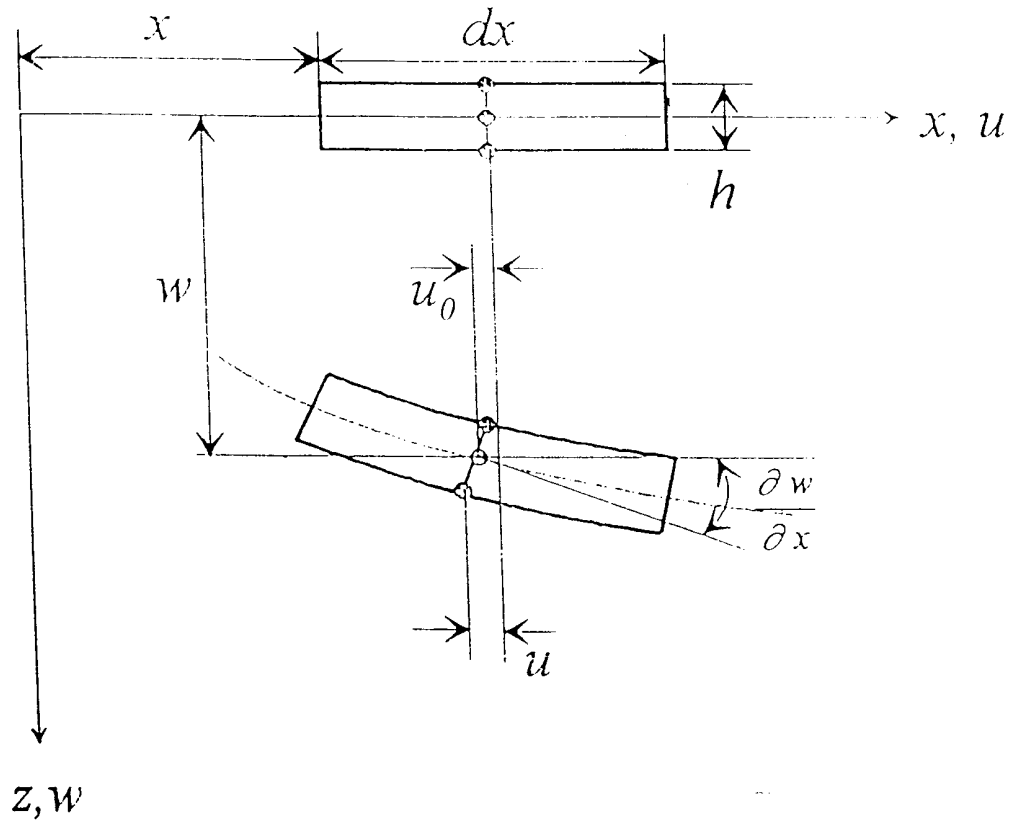
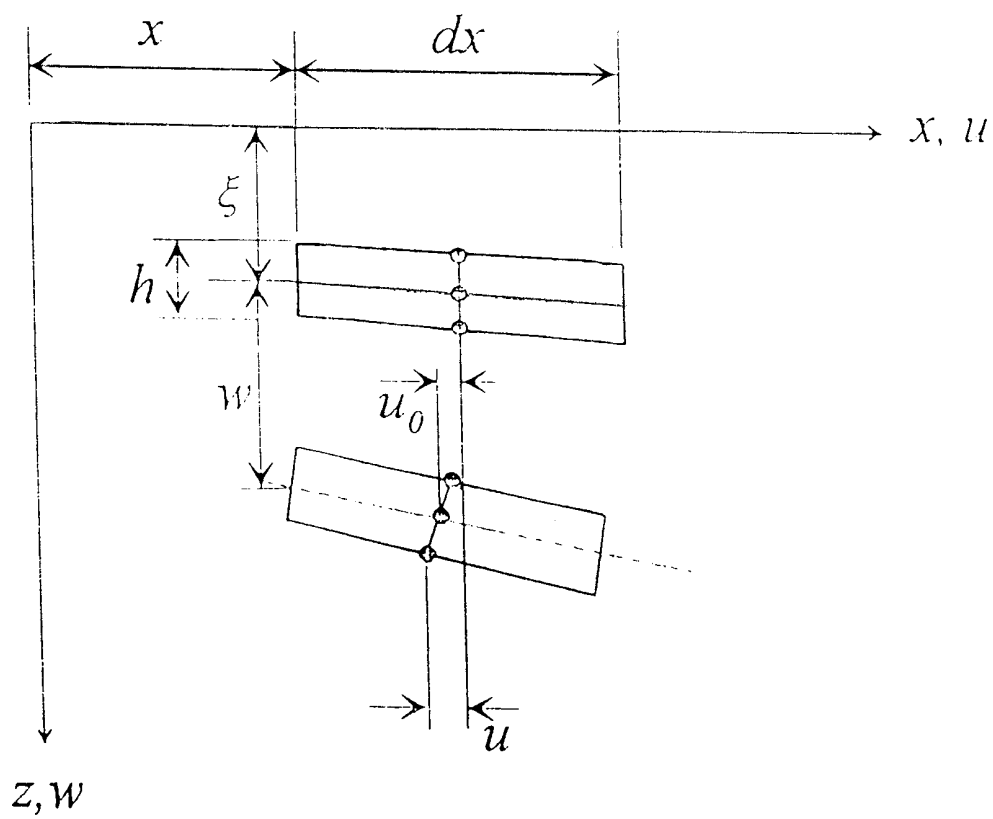


FIG. 4



INTERNATIONAL SEARCH REPORT

International application No.
PCT/KR 99/00093

A. CLASSIFICATION OF SUBJECT MATTER

IPC⁶: B 21 D 5/00, 11/20

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC⁶: B 21 D 5/00, 7/12, 11/20, 37/16

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

WPI

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	GB 2 259 877 A (OKUMA CORP.) 31 March 1993 (11.03.93), page 23, last chapter; fig.8.	1,2,3,5,6
A	FR 2 601 603 A1 (ARIPA) 22 January 1988 (22.01.88), page 6,7.	1,4,6
A	DE 41 31 765 A1 (SIEMENS AG) 25 March 1993 (25.03.93) claims 2,3,5; fig. 2.	1,5
A	US 4 120 187 A (MULLEN) 17 October 1978 (17.10.78), claims 1,8; fig. 1-4.	4

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents:

„A“ document defining the general state of the art which is not considered to be of particular relevance

„E“ earlier application or patent but published on or after the international filing date

„I“ document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

„O“ document referring to an oral disclosure, use, exhibition or other means

„P“ document published prior to the international filing date but later than the priority date claimed

„T“ later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

„X“ document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

„Y“ document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

„&“ document member of the same patent family

Date of the actual completion of the international search

27 May 1999 (27.05.99)

Date of mailing of the international search report

15 June 1999 (15.06.99)

Name and mailing address of the ISA/AT

Austrian Patent Office

Kohlmarkt 8-10; A-1014 Vienna

Facsimile No. 1/53424/535

Authorized officer

Bistrich

Telephone No. 1/53424/375

INTERNATIONAL SEARCH REPORT

International application No.
PCT/KR 99/00093

GB 2 259 877 A discloses a method of laser processing a sheet metal.

The portion to be deformed of a metal sheet 2 is heated by irradiating it with a laser beam L2 which is scanned at a high speed, and, when the portion to be deformed has attained a predetermined temperature, a force is applied to the portion to perform the bending. The metal sheet may be worked into an arc of 90° having a predetermined radius by progressively bending at spaced locations. Fig. 4 (not shown). The laser beam may be scanned along enclosed paths I_1 , I_2 , ----- I_6 , to progressively produce a convex form, Fig. 6. The process may be performed under numerical control.

A working information memory is used.

FR 2 601 603 A discloses a self-adapting folding-type bending method: the present method can be applied to various material-forming operations such as folding-type bending, curving-type bending etc.

This method is based on the strength-of-materials laws and consequently it takes into account the spring-back of materials, having undergone a forming operation by means of deformation. In order to do this, the system carries out a series of systematic measurements of the deformations and of the forces which have produced these deformations, which amounts to systematically analysing the mechanical properties of the material to be formed. Following this analysis, the system fixes the parameters of the operations. For example, for folding-type bending, the system records the forces and the displacements of the plate of the folding-type bending machine and then, after the calculation, it fixes the value of its descent in order to obtain the desired bend value.

DE 41 31 765 A1 discloses a method for improving operating parameters in an industrial installation of basic industry, for example in a rolling mill, wherein the operating parameters in working points are calculated beforehand with the aid of models, for example algorithms, and are then matched to the actual variables in the working points by adaptation and wherein the improvement of the operating parameters takes place by means of information processing based on neuronal networks, the input variables of which information processing are conditioned taking into account expert knowledge in respect of the scattering and distribution of process variables and measured values that occurs.

US 4 120 187 A discloses a forming method, whereby a large flat metal plate is formed to have a three-dimensional shape of compound curvature by locally heating to an elevated temperature along predetermined lines and then quickly cooling, as by using a torch which carries water spray nozzle. The heating extends completely through the thickness of the plate, and cooling causes significant shrinkage in the plane thereof in a direction perpendicular to the line of heating. Heating is carried out along lines in a geometric pattern and in a preselected sequence involving all quadrants of the plate so that it experiences a gradual transformation overall. The plate is normally supported upon an underlying cradle shaped to the desired compound curvature.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/KR 99/00093

Im Recherchenbericht angeführtes Patentedokument Patent document cited in search report Document de brevet cité dans le rapport de recherche	Datum der Veröffentlichung Publication date Date de publication	Mitglied(er) der Patentfamilie Patent family member(s) Membre(s) de la famille de brevets	Datum der Veröffentlichung Publication date Date de publication
GB A 2259877		DE A1 4228528	04-03-1993
		GB A0 9218294	14-10-1992
		GB A1 2259877	31-03-1993
		GB B2 2259877	21-09-1994
		JP A2 6114443	26-04-1994
		US A 5359872	01-11-1994
		JP A2 5177366	20-07-1993
FR A1 2601603	22-01-1988	keine - none - rien	
DE A1 4131765	25-03-1993	AT E 146287	15-12-1996
		DE C0 59207657	23-01-1997
		EP A1 534221	31-03-1993
		EP B1 534221	11-12-1996
		JP A2 5204408	13-08-1993
US A 4120187	17-10-1978	BE A1 867432	18-09-1978
		DE A1 2822825	07-12-1978
		DK A 2298778	25-11-1978
		ES A1 469995	16-03-1979
		FI A 781596	25-11-1978
		FR A1 2391788	22-12-1978
		FR B1 2391788	01-03-1985
		GB A 1588099	15-04-1981
		IT A0 7849465	19-05-1978
		IT A 1103292	14-10-1985
		JP A2 53146965	21-12-1978
		NL A 7805598	28-11-1978
		NO A 781774	27-11-1978
		NO B 152324	03-06-1985
		NO C 152324	11-09-1985
		PT A 68051	01-05-1978
		PT B 68051	19-11-1979
		SE A 7805877	25-11-1978
		SE B 433812	18-06-1984
		SE C 433812	27-09-1984