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(54) Title: BENDING DISPLACEMENT WITH UTILIZATION OF AN ARTIFICIAL NEURAL NETWORK

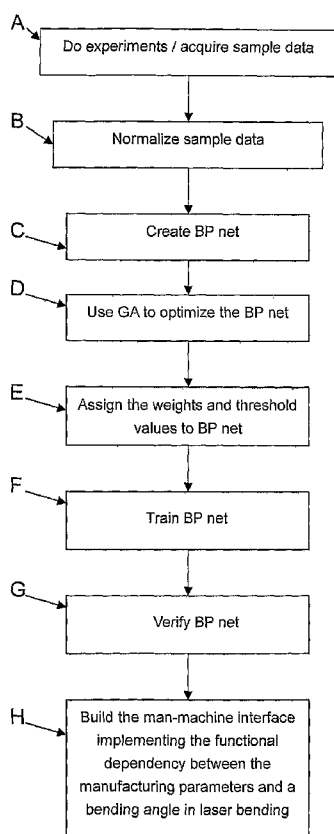


Fig.1

(57) Abstract: The invention relates to a method for estimating a functional dependency between manufacturing parameters and a bending displacement by means of an Artificial Neural Network in a bending process, the method comprising the steps of pre-calculating weights and threshold values of the Artificial Neural Network by means of a Genetic Algorithm, assigning the weights and threshold values to the Artificial Neural Network and training the Artificial Neural Network. Further, the invention relates to a bending process using a heat source, e.g. laser, electron or arc beam, and an interface implementing such a method.



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Bending displacement with utilization of an Artificial Neural Network

Field of the invention

The present invention relates to a method for estimating a functional
5 dependency between manufacturing parameters and a bending displacement in a bending process by means of an Artificial Neural Network.

Background art

Bending by a heat source, e.g. a laser, electron or arc beam or a ultraviolet
10 lamp, is a highly flexible process technology. It is a non-contact forming process in which a heat source is used as a forming tool for forming a workpiece, e.g. a sheet material, without any dies. The technology is applicable to a plurality of fields, especially in the ship, automobile and aerospace industry.

As the bending process by e.g. a laser, electron or arc beam is a very
15 complex non-linear thermo-physical process, it is difficult to predict and control the bending displacement, e.g. the bending angle, under the condition of a non-melted material surface.

Summary of the invention

20 The object of the invention is to provide a method in the field of bending for achieving an improved controllability of the bending results.

This object is solved with the method according to the independent claim.

Advantageous further developments are subject of the dependent claims.

For controlling and improving the achieved results in a bending process, an
25 Artificial Neural Network (ANN) can be utilized, which is a mathematical model or a computational model based on biological neural networks. With an Artificial Neural Network, a complex relationship between inputs (the so called input nerve cells) and outputs (the so called output nerve cells) can be modeled. The Artificial Neural Network is advantageous in carrying out a mapping from a space R^n (n is the
30 number of input nerve cells) to another space R^m (m is the number of output nerve cells) without the need of setting up the mathematical model of the whole system. In the Artificial Neural Network a plurality of nerve cells are interconnected based

on certain functions or regulations in order to form a network. Combining the single nerve cells which constitute rather simple functions results in total in a network having complex properties which can very exactly simulate the complicated non-linear process of bending by a local heat source, e.g. a laser beam.

5 A Back-Propagation Network (BP net) is a multilayer feed-forward neural network the mapping precision of which is ensured by using samples for training the BP net. During training, the system is provided with a feedback on the quality of outputs obtained so far with certain inputs. In general, neural networks are constructed in plural layers, i.e. an input layer to which the input nerve cells are
10 assigned to, an output layer to which the output nerve cells are assigned to and one or more hidden layers in between. It is to be noted that the Back-Propagation Network with one hidden layer can map any function in theory. Thus, a three-layer (one input, one hidden and one output layer) Back-Propagation Network is sufficient according to an embodiment of the invention.

15 With respect to the adaptation of the Back-Propagation network to the bending process, the determination of optimized results with this network has a drawback. Namely, the Back-Propagation Network uses a local search approach with a squared error function. This has the drawbacks of a high risk of running into a local minimum value, a slow constringency speed and a long training time.

20 A Genetic Algorithm (GA) is substantially similar to the process of biological evolution. A Genetic Algorithm uses techniques inspired by evolutionary biology such as inheritance, mutation, selection and crossover. It is helpful in searching for approximate or exact solutions for certain problems by evolving a population of abstract representations (the so-called chromosomes) of candidate solutions in
25 order to find an optimized solution for a specific problem. The evolution process of a Genetic Algorithm usually starts with a population of individuals and evolves generations from there. In a colony of each generation, the adaptability of each individual is calculated after coding, replication, overlapping and variation are carried out. Then, each individual is used to determine a group of new individuals
30 according to a certain condition.

The Genetic Algorithm utilizes a random search approach. When adapting the Genetic Algorithm to the bending process, it comes along with shortages such

as an early convergence, an inferior local search ability and a slow constringency speed.

According to an embodiment of the invention, there is provided a method for estimating by means of an Artificial Neural Network a functional dependency
5 between manufacturing parameters and a bending displacement, preferably a bending angle, in a bending process, the method comprising the steps of pre-calculating weights and threshold values of the Artificial Neural Network by means of a Genetic Algorithm; assigning the weights and threshold values to the Artificial Neural Network; and training the Artificial Neural Network. The basis for
10 this method is an Artificial Neural Network; however, this algorithm is improved by combining the Back-Propagation Network and the Genetic Algorithm. The method can avoid the slow constringency speed of a Back-Propagation network and the defective training ability of a Genetic Algorithm, and ensure stability and precision in optimally predicting the inputs and/or outputs in a bending process. Thus, the
15 advantages of a Back-Propagation network and a Genetic Algorithm are combined resulting in an improved Back-Propagation network. As a result, the bending process can be conducted with optimized manufacturing parameters for a desired bending displacement or the bending displacement can be predicted having certain manufacturing parameters. For example, this method enables to estimate or
20 determine the necessary manufacturing parameters (e.g. laser beam output power, scanning speed, spot diameter and sheet thickness) in order to obtain a desired bending displacement such as a bending angle. It also enables the functionality that a desired bending displacement and the sheet thickness are known and based on the method, the remaining manufacturing parameters e.g. laser output power,
25 scanning speed, spot diameter are determined. Also, the values can be estimated vice versa, i.e. the bending displacement is predicted based on known manufacturing parameters.

Further, a bending method for bending a workpiece by means of a heat source, e.g. a laser, electron or arc beam, is provided. The optimization of the
30 prediction of the manufacturing parameters and/or the bending displacement can impel the application of the bending technology in the actual production.

Moreover, an interface for determining manufacturing parameters and/or a bending displacement in a bending process is provided. This provides a man-machine conversation interface which is friendly and conveniently to use. The prediction of the manufacturing parameter and/or the bending displacement is optimized and the deformation displacement is predicted in the bending process. Predicting "the manufacturing parameters and/or the bending displacement" means that several implementations are possible. For example it is possible that a desired bending displacement is known and the interface outputs the necessary manufacturing parameters e.g. laser output power, scanning speed, spot diameter and sheet thickness. In another example a desired bending displacement and the sheet thickness are known while the interface outputs the remaining manufacturing parameters e.g. laser output power, scanning speed, spot diameter. In another example it is possible that the manufacturing parameters, e.g. laser output power, scanning speed, spot diameter and sheet thickness are known and the interface outputs a bending displacement which will be obtained with these manufacturing parameters.

Brief description of the drawings

Fig.1 shows an overview flow diagram of a method according to an embodiment of the invention;

Fig.2 is a flowchart illustrating part of the flow diagram of Fig. 1 in more detail;

Fig.3 is a diagram illustrating the difference in constringency speed of the method according to an embodiment of the invention and a Back-Propagation Network;

Fig. 4 shows a diagram in which output data of the Artificial Neural Network and sample data are compared;

Fig. 5 illustrates the comparison of sample data and the output data predicted by the trained Artificial Neural Network; and

Fig.6 is a picture illustrating the user interface according to an embodiment of the invention.

Detailed description of a preferred embodiment

The method for estimating by means of an Artificial Neural Network a functional dependency between manufacturing or technical parameters and a bending angle in a bending process is explained further with reference to the accompanying diagrams Fig.1 to Fig.6.

Fig.1 shows an overview flow diagram of a method according to an embodiment of the invention.

First, in step A, experiments for acquiring sample data are conducted. The sample data can be divided into two parts, an input part and an output part. The input part includes in this embodiment the laser output power, scanning speed, spot diameter and sheet thickness of the workpiece, while the output part includes the sheet bending angle which is achieved with the respective inputs. All these data are gained from experiments.

The laser beam is chosen as a Nd:YAG laser with a wavelength of $\lambda = 1064$ nm and 3500 W of maximum power. The sheet material is the Aluminum alloy AA6056 having the dimensions of 150mm in length, 100mm in width and 2.5mm in thickness. The sheet material is clamped at one end like a cantilever sheet. Then, the laser output power, the scanning speed and the spot diameter are set accordingly. Afterwards, the laser beam starts to irradiate continuously along the center line in the width direction of the workpiece. Then, the bending angle is measured. In this way, 30 groups of sample data are gained, wherein one group is a pair of manufacturing parameters (including laser output power, laser scanning speed, laser spot diameter and sheet thickness of the workpiece) and the corresponding bending angle.

Thereafter in step B, the sample data are set and normalized in order to be used as data for training the Artificial Neural Network. This means, a proper range and amount of sample data is set. The 30 groups of sample data derived in step A are set and normalized to the range of $[-1, 1]$, in order to establish the corresponding relationship with the input and output values of the Artificial Neural Network, i.e. to level the sample data to the range of the input and output values. In this embodiment the computing environment and programming language MATLAB ® is used. In order to implement step B in MATLAB ®, the premnmx-function is

chosen. The premnmx-function is an existing software function which preprocesses the sample data by normalizing the inputs and outputs so that they fall in the interval [-1, 1].

In the following step C, the Artificial Neural Network is created as a three
5 layer Back-Propagation network having one input layer, one hidden layer and one output layer. The number of nodes of the input layer is set to be four, the hidden layer is set to include 15 nodes, and the output layer is set to comprise one node. Further, the tansig function is chosen as neuron transfer function between the middle layer and the output layer. The tansig function is a hyperbolic tangent
10 sigmoid transfer function for calculating a layer's output from its network input. It is also an existing function in MATLAB®.

Thereafter, in step D, the Artificial Neural Network is pre-trained or optimized by using the Genetic Algorithm shown in the left column of Fig. 2 in more detail. Thereby, the steps S100 to S107 of Fig. 2 are executed in step D of Fig. 1. In other
15 words, weights and threshold values for defining the Artificial Neural Network are pre-calculated with the Genetic Algorithm. In this Genetic Algorithm, an initial population is created in step S100 by setting the population size to 50, the number of hereditary generations to 100, the crossover probability to 0.1 and the mutation probability to 0.05. Thereby, a population comprises a group of weights and
20 threshold values. Then, in step S101 the fitness of the population is determined and it is verified whether the population meets the desired requirements (step S102). If this is the case, the flow diagram of Fig. 2 proceeds to step S107 which ends the Genetic Algorithm and forwards the achieved results, namely the weights and threshold values for the Artificial Neural Network, to step S108 which is executed
25 during the later described step E of Fig. 1. If the result in step S102 is negative, the flow diagram of Fig. 2 proceeds with steps S103, S104, S105 and S106 which are known functions of a Generic Algorithm in order to create a new population. After a new population is created, the process returns to step S101. In this embodiment, the described step D is implemented by employing the GAOT-function to pre-train
30 the Artificial Neural Network (i.e. to pre-calculate the weights and threshold values for the ANN). The GAOT-function (GAOT = "Genetic Algorithm Optimization Toolbox") is a toolbox of MATLAB®. Finally, in step D, weights and threshold

values for the Artificial Neural Network are achieved, which are optimized by using a Genetic Algorithm (being the GAOT-function in this embodiment).

Then, in step E, the weights and threshold values derived in step D are assigned to the Back-Propagation Network which was created in step C. For this purpose, the gained weights and threshold value matrix is decoded and assigned to the Back-Propagation Network. This step E of Fig. 1 corresponds to step S108 in Fig. 2.

In the following step F, the Back-Propagation Network is trained. The training times are set to be 1000 and objective squared error as 0.0001. The training process will stop when the training times is over 1000 or when the squared error reaches 0~0.00001. This step F of Fig. 1 corresponds to the steps S109 to S113 of Fig. 2 in which the training is repeated until the desired squared error is met in step S113. For training the Artificial Neural Network, the known Levenberg-Marquardt algorithm is selected.

Fig.3 is a diagram illustrating the difference in constringency speed of the method according to the embodiment of the invention and a Back-Propagation network. This Fig. 3 is plotted wherein the abscissa represents the epochs and the ordinate represents the squared error. As can be seen in Fig. 3, the desired goal which is the straight line at a squared error of 0,0001 is already reached after 10 epochs with the present embodiment (continuous line) in which the Generic Algorithm is utilized for pre-calculating the weights and threshold values for the Back-Propagation Network, whereas it takes 28 epochs when only the Back-Propagation Network without the Generic Algorithm is used (dotted line). The constringency diagram of Fig.3 clearly shows that the method according the present embodiment has an efficiently enhanced constringency speed.

Fig. 4 shows a diagram in which the output data of the trained Artificial Neural Network (the network derived after executing step F) and the sample data derived in step A are compared. As can be seen, the two curves are almost matching.

Referring back to Fig. 1, in step G, the Artificial Neural Network is verified. For this purpose, new sample data are derived by conducting experiments as described in step A. The newly derived sample data cover all the possible sample

cases in order to verify the performance of the ANN completely. In total, 14 groups of sample data are determined and their outputs will be predicted with the trained Artificial Neural Network present after conducting step F. Step F of Fig. 1 corresponds to step S114 of Fig. 2.

5 Fig. 5 illustrates the comparison of the newly derived sample data and the output data, namely the bending angle, predicted by the trained Artificial Neural Network. It can be seen that the curves are almost the same. This proves that the relationship or dependency between input values (the manufacturing parameters like laser output power, scanning speed, spot diameter and sheet thickness) and
10 the output value (the bending angle) is calculated correctly. The method according to the present embodiment can predict the output nearly exactly and the stability and feasibility of the method is proven.

Finally, in step H, an optimization program is written by combining the programming environments of MATLAB® and Visual C++ (VC++). First, the above
15 described method is implemented as codes in MATLAB®. Then, the command comtool is used to open a comtool dialog (function in MATLAB®). The codes are added to a project, then the codes are compiled and executed and their corresponding C++ source files and C++ header files are created. Second, a MFC project is created in VC++, and the C++ source and header files are added to the
20 project created in the first step. Then a friendly and convenient man-machine conversation interface is designed and developed as the one shown in Fig.6. With this interface the laser bending process can be simulated and the bending results can be predicted as depicted in step S115 of Fig. 2.

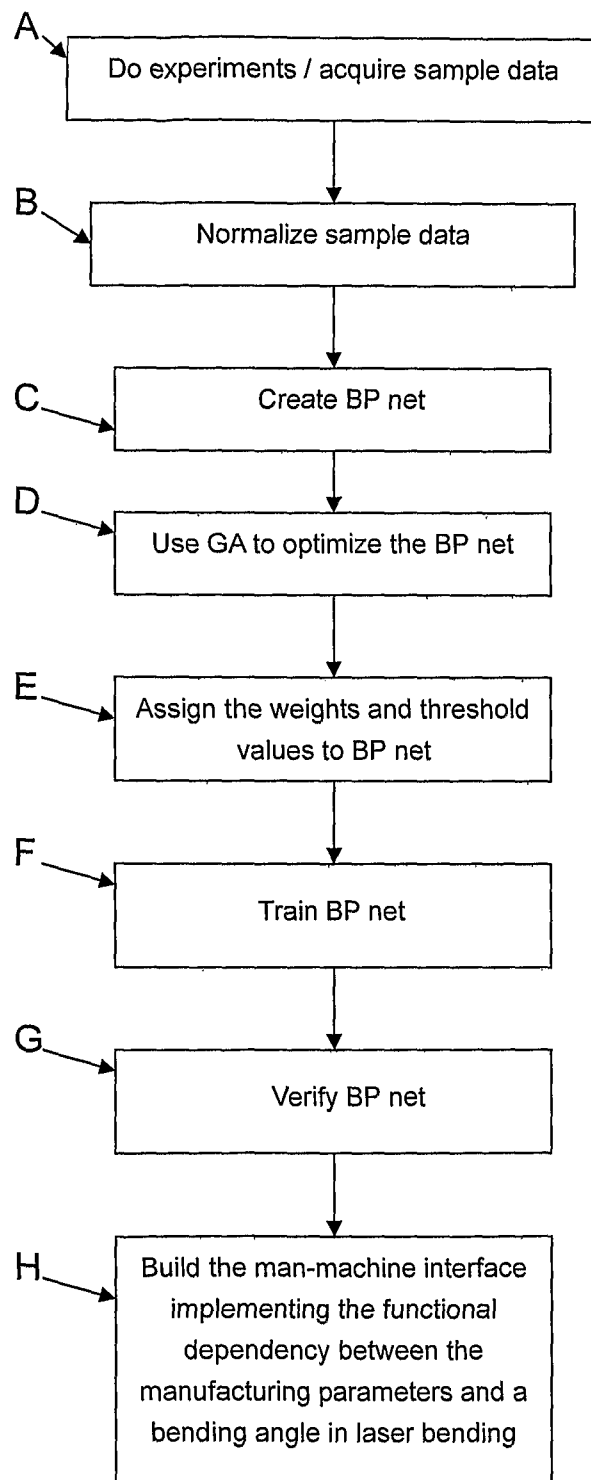
In the network training part of the interface, the hidden layer and the
25 objective error can be input via respective buttons. Also, the sample data (including the input part and output part) can be input by pushing respective buttons. Then the Artificial Neural Network is trained and saved by pushing respective other buttons. There is also a button for starting the parameter prediction. When inputting the laser output power, scanning speed, spot diameter and sheet thickness, the
30 interface calculates the bending angle which can be read directly.

Above, only one embodiment is described in detail and it is not intended to restrict the invention to this embodiment.

Claims

1. A method for estimating a functional dependency between manufacturing parameters and a bending displacement by means of an Artificial Neural Network
5 in a bending process, the method comprising the steps of:
pre-calculating weights and threshold values of the Artificial Neural Network by means of a Genetic Algorithm;
assigning the weights and threshold values to the Artificial Neural Network;
and training the Artificial Neural Network.
10
2. The method according to claim 1, further comprising, prior to the step of pre-calculating the weights and threshold values, the steps of:
acquiring sample data of the functional dependency by conducting experiments wherein the sample data comprises pairs of manufacturing
15 parameters and corresponding bending displacements; and
normalizing the sample data.
3. The method according to claim 2, further comprising the step of:
verifying the Artificial Neural Network by using further sample data.
20
4. The method according to one of the preceding claims, wherein the Artificial Neural Network is a three layer Back-Propagation Network, including one input layer, one hidden layer and one output layer.
- 25 5. The method according to one of the preceding claims, wherein the manufacturing parameters comprise at least one of a heat source power, heat source scanning speed, heat source size and a workpiece sheet thickness.
6. A bending method for bending a workpiece by means of a heat source in which
30 manufacturing parameters and/or a bending displacement are determined according to one of the preceding claims.

7. An interface for determining manufacturing parameters and/or a bending displacement in a bending process, wherein the interface is adapted to execute the method according to one of claims 1 to 5.

**Fig.1**

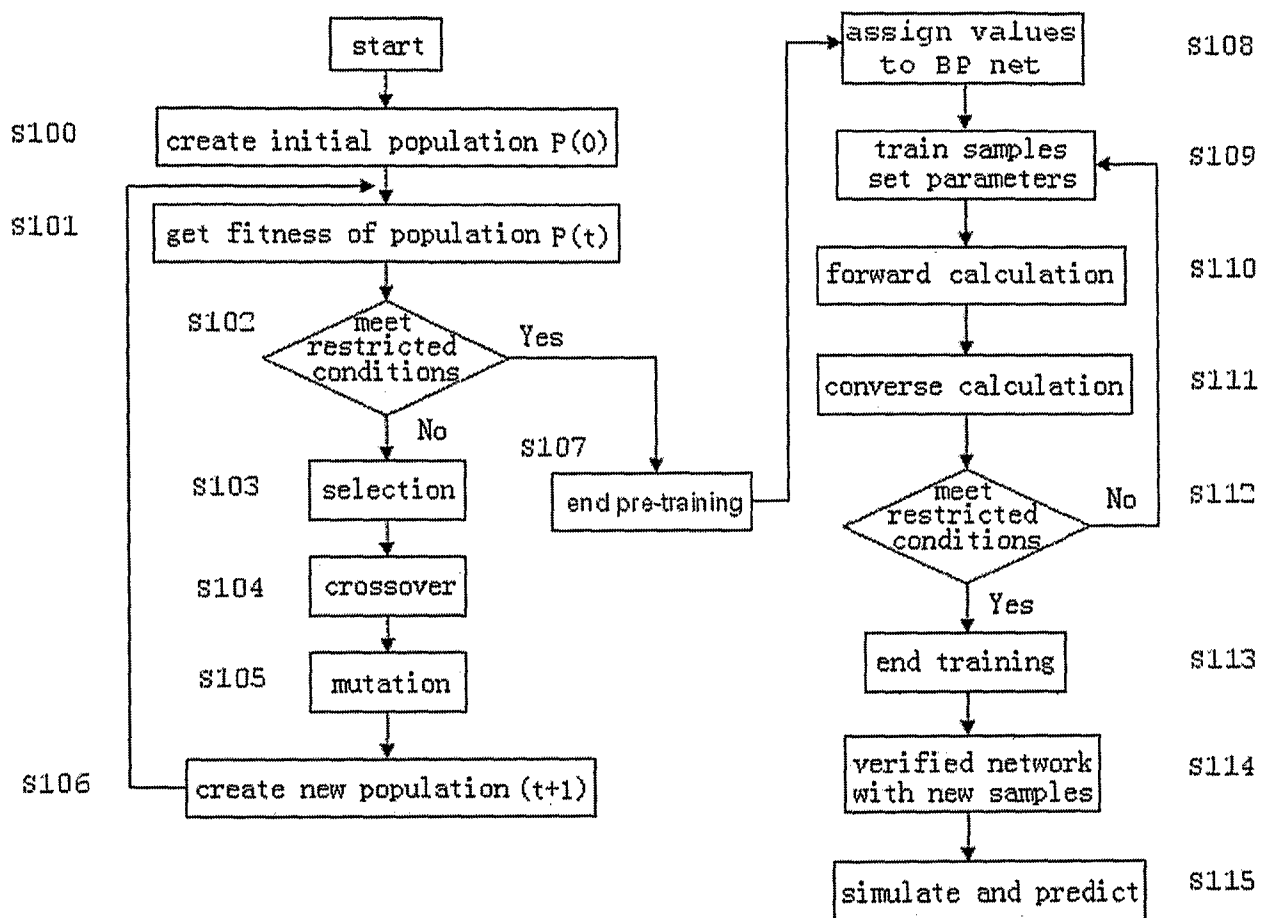
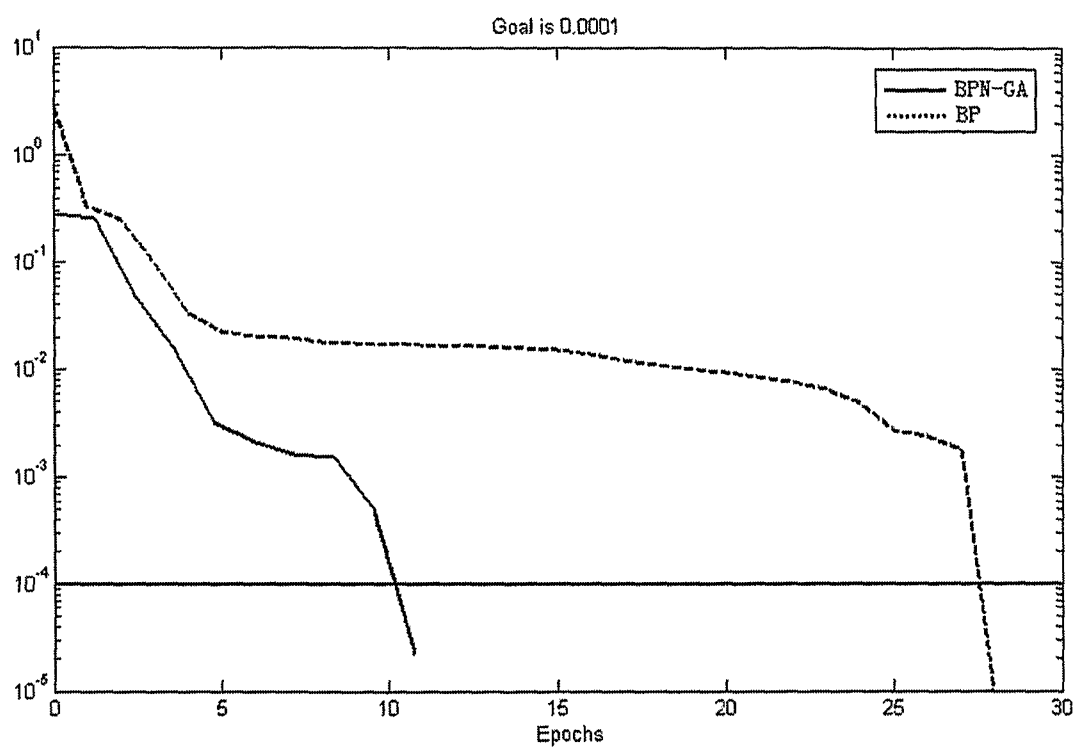
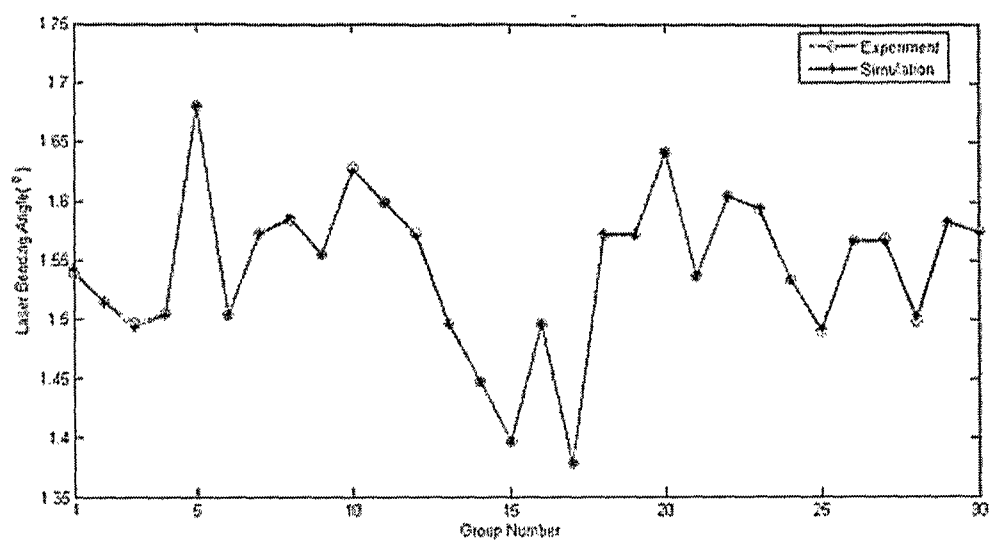
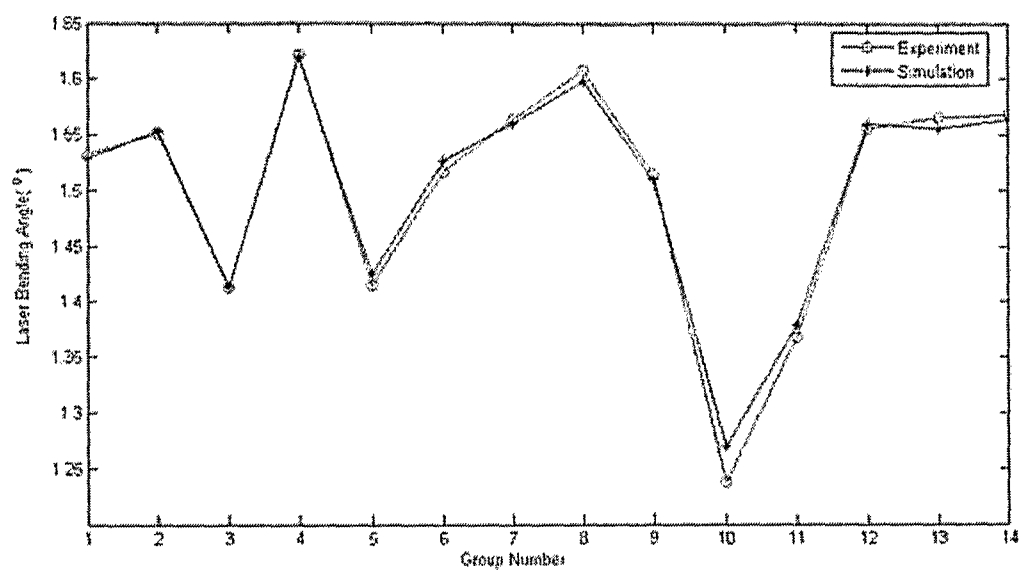


Fig.2

**Fig.3**

**Fig.4**

**Fig.5**

laser

Parameters optimization system for laser bending

Network Training

Hidden layer Objective error

Input data

Output data

Train network

Save network

Results curve

Parameters forecast

Technical parameters

Laser power: Scanning speed:

Sheet thickness: Facula diameter:

Output:

Bending angle:

Switch to forecast section Edition Help Exit

Fig.6

INTERNATIONAL SEARCH REPORT

International application No.

PCT/CN2009/001273

A. CLASSIFICATION OF SUBJECT MATTER

See extra sheet

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)

IPC: G06N3/-,G06F17/-

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)

CPRS; CNPAT; WPI; EPODOC; PAJ: bend+, displacement, dependency, neural, network, ANN, pre-calculat+, weight?, threshold, assign+, train+, sample,

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	CN101320400A(UNIV GUILIN ELECTRONIC TECHNOLOG) 10 Dec. 2008(10.12.2008) See the whole document	1-7
A	JP2008249610A (ZH TETSUDO SOGO GIJUTSU KENKYUSH) 16 Oct. 2008 (16.10.2008) See the whole document	1-7

☐ Further documents are listed in the continuation of Box C.☒ See patent family annex.

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“A” document defining the general state of the art which is not considered to be of particular relevance	“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
“E” earlier application or patent but published on or after the international filing date	“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
“L” 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)	“&”document member of the same patent family
“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	

Date of the actual completion of the international search 17 Jan. 2010(17.01.2010)	Date of mailing of the international search report 25 Feb. 2010 (25.02.2010)
Name and mailing address of the ISA/CN The State Intellectual Property Office, the P.R.China 6 Xitucheng Rd., Jimen Bridge, Haidian District, Beijing, China 100088 Facsimile No. 86-10-62019451	Authorized officer HAN,Xianping Telephone No. (86-10)62411841

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Form PCT/ISA /210 (patent family annex) (July 2009)

INTERNATIONAL SEARCH REPORT

International application No.

PCT/CN2009/001273

A. CLASSIFICATION OF SUBJECT MATTER

G06F17/50 (2006.01) i

G06N3/02 (2006.01) i

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