Measurement and Control Methods of 3-D NC Press Machines for Forming Springback of Ship Steel Plates

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***Abstract* — Aiming at the problems of ship plate forming spring-back in theory and experiment, combining the law of sheet metal forming, this paper puts forward a measurement and compensation method of spring-back outside plate of a ship based on the three dimensional NC (numerical control) pressing machine. First, we use Dynaform software for finite element analysis of spring-back prediction, and then establish the model in the UG to generate the initial surface data, after those we make the first time stamping. After forming, we measure the surface shape of the work piece by a self-developed non-contact measurement of 3D laser rebound measuring device, and then analysis the spring-back. According to the spring-back data measured by body, we can use least squares fitting approximation mould surface, then adjust the lower mould basic body group tool surface shape to make stamping one more time. After 1~2 times prediction, basic body surface shape modify and stamping, it finally realize the purpose of controlling spring-back and forming well. Finally, examples show that the method is feasible, and the rebound quantity can be controlled to the allowed precision, the complex problem of plastic forming spring-back ship surface is effectively solved.**

Keywords – spring-back measuring ;surface compensation;the least square method

I. INTRODUCTION

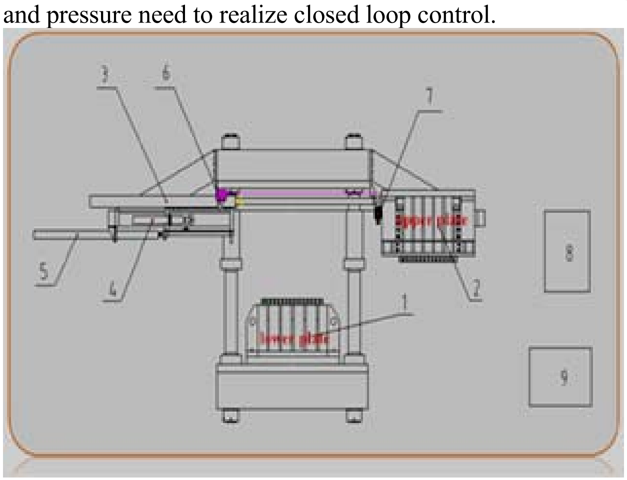
At present, in shipbuilding industry, a hull plate component is a three-dimensional curved surface, and the size, shape of each piece of planking are not identical, ship hull plate is difficult for mass production and hard to use the three-dimensional curved surface forming Integer Mould that forms accurately but high cost in processing. The universal processing method in shipyards all over the world is one-way roller bending integrate with line heat forming, that is, local heating by heat source and cooling by water at heating area so the ship hull plate local deformed for thermal expansion and contraction. However, this method is of poor quality and the low production efficiency, and the intensity of labor is great. Such problems become the essential challenges for restricting the ship manufacturing quality and shipbuilding cycle.

Since in year 1942, Walters in United States firstly put forward the conception that discretize traditional whole mould and transform it into shape can changed and flexible reconfigurable one, the flexible sheet metal forming method of multi-point mould became an important research direction of solving small batch complex curved surface shape of hull parts forming in shipbuilding industry all over the world [1]. After years of research and practice, the reconfigurable mould hull plate forming method has become one of the ways that bulk forming the three-dimensional planking component. But in the plastic deformation process of pressing plate, the prevention of defects such as springback control, plate produce indentation and fold is very difficult, has not been fully and effectively solved.

The continuous improvement of the sheet metal stamping CAE simulation technology provides the necessary foundation for the springback prediction and control research. Springback control of forming component generally proceeds from two aspects. One is reduce the springback by changing the boundary conditions of forming process, such as sheet metal, blank holder force, mold the rounded shape, friction condition, this kind of method can be referred to process control [2]. Another way is predict or measure the size of the springback in certain technological conditions, and then fixed the mold shape so the size of springback components exactly meet with the design requirements, this way namely mould surface compensation method. In the actual production process, in the field of controlling springback, mould surface compensation method is most popular. In early times, the research of mould surface compensation method is mainly based on the theory of analytic method to the springback prediction. Later, some scholars began to integrate the CAE simulation technology, rapid mould making and experimental iterative correction method into the compensation method, to realize optimization design of the mould, and made a lot of progress [3]. At present, a square head adjustable mould plate surface forming device based on reconfigurable-technology has been developed, and based on this device, a multi-head 3-D CNC bending machine prototype for shipbuilding has been developed. The biggest advantages of the machine prototype are that, it can avoid the buckling in planking forming, and the forming quality is very good. So, it is quite accord with the development tendency of modern digital shipbuilding, green shipbuilding and lean shipbuilding.

II. CONTROL DEVICE AND PRINCIPLE OF MOULD SURFACE COMPENSATION METHOD

In this paper, a kind of no-pair reconfigurable mould device for ship hull plate 3D CNC bending machine was provided. This device used the rule of springback of sheet material and based on mould surface compensation method and surface fitting based on the method of least-squares which iterates to target. The device is made up of the reconfigurable modular group under pressure with adjustable height driven by a servo motor , mobile group of upper mould driven by oil cylinder, mould device of push and pull, lifting device, feeding device, radiotherapy rope displacement transducer, laser displacement sensor, electric control cabinet and hydraulic station, etc. By using Dynaform software analyzed the surface springback of theory design of parts mould and get mould surface after repairing mold in UG, reconfigurable tooling control data was generated. With this data, the device pressed sheet material once. After that, measured the actual forming surface point cloud data after unloading and registered the data, and then using the theory of least squares to approximate theory surface and analyzed the springback. Finally, the modular group basic adjustment data that is reconfigurable was gotten, then fixed mold surface and pressed secondly. To make the error of the plank curvy and theoretical within the range of machining and conform to the requirements of the precision, the measure, unload, revising and pressure need to realize closed loop control.



1 - reconfigurable lower plate;2 - mobile upper plate;3 - mould device of push and pull;4 - lifting feeding device;5 - feeding device;6 - rope displacement sensor;7 - laser displacement sensor;8 - electric control cabinet;9 - hydraulic station

Figure 1. schematic diagram of ship hull plate 3D CNC bending machine

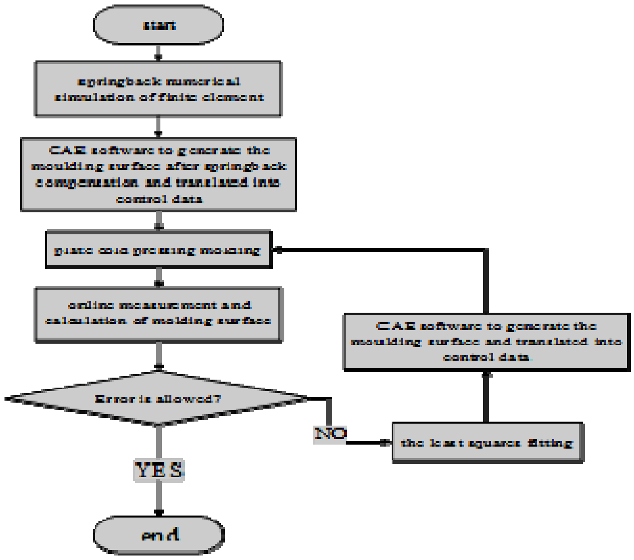


Figure 2. Work flowchart of ship hull plate 3D CNC bending machine

In this paper, principle of molded surface compensation method was shown in the Fig3. Assumes the target parts shape is Z_0 and springback deformation is Z_1, the springback amount is Z_{b1}, there have $Z_{b1} = Z_0 - Z_1$.Then add the springback amount of reverse to the Z0 and get Zf2, there have $Z_{f2} = Z_0 + Z_{b1}$.

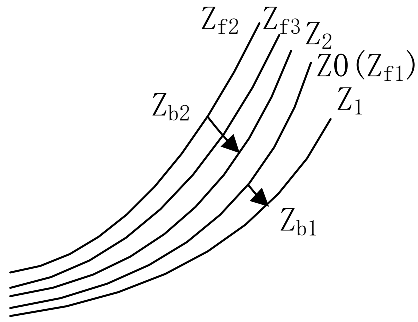


Figure 3. molded surface compensation method principle

If Zf2 is shape of formed parts, the springback amount is Z_{b2} and the springback properties for Z_2, there have $Z_{b2} = Z_{f2} - Z_2$. The shape of after springback is Z_2 and desired shape is Z_0. If add deviation between $Z_0 - Z_2$ to Z_{f2}, $Z_{f3} = Z_{f2} + (Z_0 - Z_{b2}) = Z_0 + Z_{b2}$ was gotten.

If Z_{f3} as after forming parts shape, and so on:

$$Z_{b3} = Z_{f2} + Z_3 \tag{1}$$

$$Z_{f4}=Z_{f3}+(Z_0-Z_3) = Z_0 + Z_{b3} \tag{2}$$

To: $Z_{f2} = Z_0$

Dynaform is the special package, which developed by ETA and LSTC companies jointly and used for sheet metal forming simulation. It can significantly reduce the mold design personnel mold development and design and test cycle time. It not only has good usability, but also has a lot of intelligent automatic tool, which can easily solve the problems of all kinds of sheet metal forming. Dynaform can predict the forming process of sheet metal, scratch, crack, wrinkle, thinning the springback, and assess the formability of sheet metal, which provide help for plate forming technology and model design[4].

Molded surface compensation method princess is based on the virtual mode iterative process of component shape design. First of all, according to the theory of shape design in the UG mold parts to get the initial shape, then using Dynaform to analysis parts springback with finite element. And the springback simulation results are obtained. The springback compensation under repairing mold quantity is reverse to get new type mould surface. Finally, determine whether this shape after springback parts products satisfy the precision. If meet, namely, repairing mold type surface geometry is obtained, otherwise need to repeat the steps until the simulation results meets the requirements.

The concrete implementation steps as shown in Fig4.

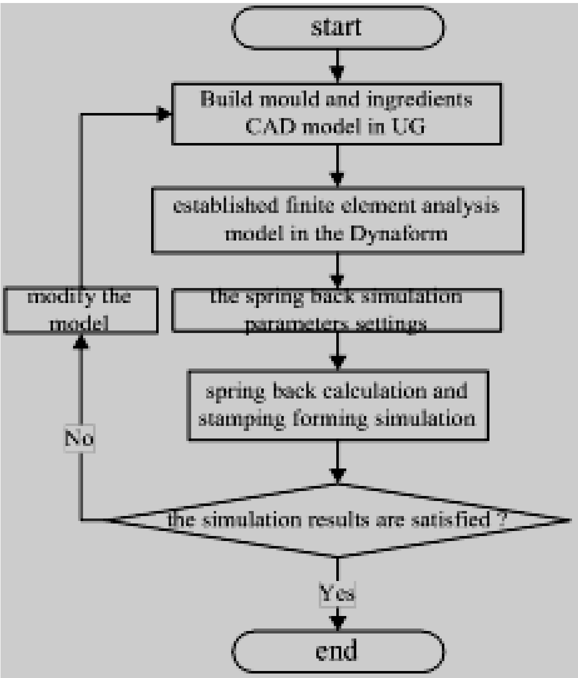


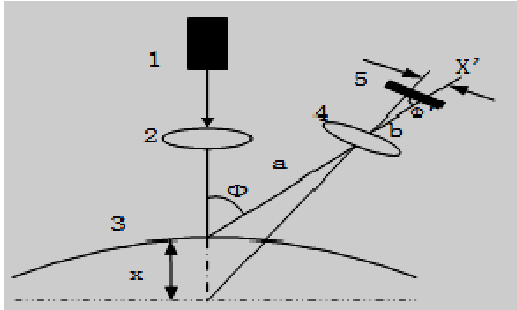
Figure 4. flow chart of molded surface compensation method software

III. REBOUND MEASURINGS

A. Springback online measuring device of three-dimensional curved surface forming

In this paper, the springback online measuring device of three-dimensional curved surface forming is made from laser displacement sensor, data acquisition card, X and Y direction screw nut transmission mechanism, computer, etc. LG10A65NU of Ban - Ner companies in the United States is chosen as laser displacement sensor, PCI6023 of NI in the United States is chose as the data acquisition.

With in-line single point laser triangulation measurement, the principle measurement is shown in Fig 5.



1 laser; 2 convergent lens; 3 surface under test; 4 receiving lens; 5 the CCD light receiving element

Figure 5. the principle of direct triangulation measurement diagram

Among them, the displacement of the measured surface:

$$x = \frac{ax'}{b\sin\varnothing - x'\cos\varnothing'} \qquad (3)$$

In formula (3): a is the distance between the intersection of receiving lens optic axis and optical axis of the laser beam and front face of receiving lens; b is the distance between behind face of receiving lens and center of the imaging plane; Φ is the angle of between laser beam axis and receiving lens axis; Φ' is the angle of between receiving lens and the CCD light receiving element.

Initialized configuration parameters is the first thing, such as x and y scanning speed of the precision mobile platform and sampling frequency of the data acquisition card, when designing software. Then, completed the determination of surface boundary by controlling the x-y precision mobile platform moving around the surface determines an appropriate tolerance rectangle. At the same time, X and Y feeding in the measurement area with equal interval, Z to the location by the laser displacement sensor measurement and linear encoder. Carried on the point cloud data processing and surface reconstruction is the last thing [5].

The system software flow chart is shown in figure 6.

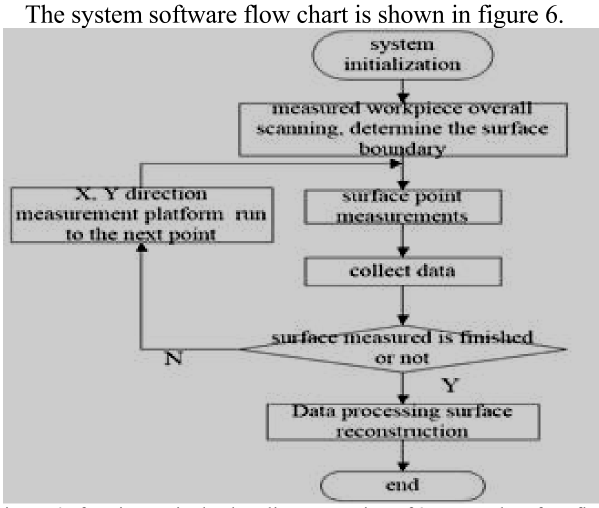


Figure 6. forming springback online measuring of 3D curved surface flow chart

B. Point cloud data registration

In order to get the complete data mode of measured surface, an appropriate coordinate transformation is needed to determine. It is used to transformation point cloud data got by the three-dimensional springback measuring device to the unified coordinate system. And, this is the registration of point cloud data. Point cloud registration work is mainly divided into two steps: determine couple point with the same name, solve the rotation matrix R and translation matrix T [6].

At present people have proposed many three-dimensional point cloud data registration method, the most widely used way is the nearest neighbor points iterative matching (ICP, Iterative Closest Point) algorithm. The whole implementation process of the ICP algorithm is a searching corresponding iterative closest point and the calculation (R, T) to finish point set registration process. On the search of corresponding points is a cycle iterative process from coarse to fine, from false to true (see Fig.7).

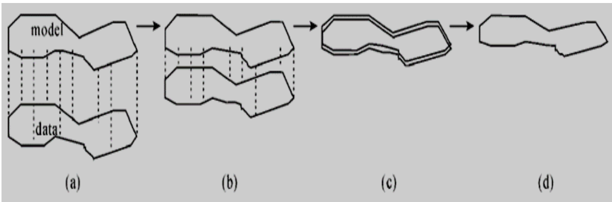


Figure 7. least squares iterative process diagram

It is a kind of iterative algorithm, has the very high matching precision. But the algorithm description shows that it has defects of large amount of calculation and the iterative process may not be able to converge to global optimal solution.

In this paper, the point cloud data registration method is an improved ICP algorithm. In the initial point cloud registration, the improved algorithm combined point matching method based on the boundary feature with ICP algorithm based on corresponding points weights and the M - estimates. Improved algorithm solves the efficiency bottleneck of classical ICP algorithm, effectively eliminate the influence of abnormal point on algorithm, improve the accuracy and reliability of the algorithm, and improve the matching ability of global optimization[7].

C. Surface fitting approach based on weighted least squares

Points got by 3d laser measurement device are discrete data and polluted by noise. If directly with these data to reconstruct surface, it is unable to get a smooth surface model. To regenerate the reflecting surface characteristics and meet the precision requirement of surface typed point, it is necessary to filter and sample processing the data.

Least squares method is a kind of approximation theory, and one of the most commonly used method in curved surface fitting with sampling data. Surface is generally not by known number, but according to minimize the sum of difference squares between the fitting surface at the sampling value and actual value. The message is deviation minimize the bias squares between test data and the real value [8]. That is:

$$E(f)=\sum_{i=1}^{n}(f(l_i)-z_i)^2=\sum_{i=1}^{n}\Big(\sum_{j=1}^{n}(a_j b^j(l_i)-z_i)\Big)^2 \tag{4}$$

In the formula 4, E (f) for calculating the sum of the squares of the error, to attain minimum E (f), must satisfy the following equation:

$$\frac{\partial E}{\partial a_j}=0 \quad j=1,2,...,n \tag{5}$$

By formula 4 reduction and linear transformation into a system of linear equations:

$$\begin{aligned} a_1\sum_{i=1}^{n}b_i^1b_i^1+a_2\sum_{i=1}^{n}b_i^1b_i^2+...+a_i\sum_{i=1}^{n}b_i^1b_i^n&=a_1\sum_{i=1}^{n}b_i^1z_i\\ a_1\sum_{i=1}^{n}b_i^2b_i^1+a_2\sum_{i=1}^{n}b_i^2b_i^2+...+a_n\sum_{i=1}^{n}b_i^2b_i^n&=a_1\sum_{i=1}^{n}b_i^2z_i\\ a_1\sum_{i=1}^{n}b_i^nb_i^1+a_2\sum_{i=1}^{n}b_i^nb_i^2+...+a_n\sum_{i=1}^{n}b_i^1b_i^n&=a_1\sum_{i=1}^{n}b_i^nz_i \end{aligned} \tag{6}$$

Formula 6 rewritten into matrix form: BBTA=BZ, in the formula:

$$B=\begin{pmatrix} b^1(l_1) & b^1(l_2) & b^1(l_N)\\ b^2(l_1) & b^2(l_2) & b^2(l_N)\\ & ... & \\ b^n(l_1) & b^n(l_2) & b^n(l_N) \end{pmatrix},$$

AT=(a1, a2, …an), ZT=(z1, z2, …zn),

In this formula B is n * n matrix, A, Z are n column. According to the matrix equation, a1, a2,...can the an accurate the solution by the method of general linear system of equations. There by fitting surface forming [9].

IV. SPRINGBACK CONTROL

Measuring the springback is for the purpose of the basic adjustment of tool surface based on springback amount. The tool surface was forming by the basic point matrix.

Zobj (x, y) is the goal of forming surface, Zk (x, y) for the k times fixed surface, and the error of the target surface is:

$$e_k(x,y)=Z_{obj}(x,y)-Z_k(x,y) \tag{8}$$

$$S_{k+1}(x,y)=S_k(x,y)+e_k(x,y) \tag{9}$$

In formula 9: Sk (x, y) is construction of the k times mold modification based on basic body.

Springback control process: first of all, get the goal of forming surface, namely the molding surface after mold, through the profile design based on compensation method. And S1 (x, y) = Zobj (x, y), the measurement of the first time stamping and corresponding to the springback. After unloading, calculated error between sheet forming after the springback and the target surface through formula 8. Then through formula 9 calculation error and continue to adjust the mould for amending the surface [10].

Surface modification method is as follows: according to the measurement of the springback amount give the basic body a given size contrary displacement, the contrary displacement expression is:

$$\triangle d = \lambda D \cos\Phi \tag{10}$$

In formula 10: λ as the coefficient of restitution, D measured for the springback, Φ is the angle between law vector of contact point and the basic body moving direction [11]. Stamped group of basic body after amendment and repeated the steps until the sheet forming precision meet the permissible error. At this point, the mold surface is corresponding to the theory of target surface before rebound, namely the initial mold surface. It is effectively solve the numerical control (NC) bending springback problem, ensure the forming precision of the 3 d surface planking.

V. Experimental Result

Run the ship plate three-dimensional numerical control press machines and process a hull plate. As shown in Fig.8 and Fig.9, through several times height adjustment of mould group under the head, automatic surface modification, can get curved surface which meet the requirements of the precision. Pressure plate machine based on type surface compensation design is effective and has high control precision. Thus sheet forming inside and outside surface is smooth, no buckling phenomenon.

Figure 8. 840 x 840 x 10 mm sail stamped form board (outside smooth surface)

Figure 9. 840 x 840 x 10 mm sail stamped form board (inside smooth surface)

VI. Conclusion

In this paper, the springback was predicted by using Dynaform finite element analysis software, and the initial profile data was generated in UG, then stamping forming for the first time. After forming, by using non-contact 3-D laser rebound measuring device to measure work-piece surface, and then analyzed springback surface. With the springback amount and the least squares fitting moulding surface, adjust the tools for basic body of curved surface shape. After 1 ~ 2 basic body surface measurement and shape changes and stamping, finally realizes the purpose of control of springback, forming better. The actual test results show that the method is feasible and the springback amount can be controlled to allowable precision. And this method solve the complex surface planking plastic forming springback problem simpler and effectively. For ship hull plate forming mechanization, automation and digital production, it provides a new solution.

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References

[1] Zhang Wei Yong. "Numerical Simulation On Hull Plate's NO-Pair Multi-Press Head Stamping Forming." Wuhan university of technology.2012

[2] Yin Li Xue. "Research on Springback Numerical Simulation of Automotive Panel Forming." Shandong university.2007

[3] Wang Xing. "The numerical simulation and experimental research on bending springback and mould surface compensation." Shandong university.2013

[4] DavidE.Hardt,Mary C.Boyce,Karl B.Ousterhout. "ACAD-Driven Flexible Forming System for Three-Dimensional Sheet Metal Parts." ComPut.-BasedFact.Autom, pp. 69-76, 1993.

[5] Yuan Jiang. "Research of Integration of Laser Displacement Sensor and Encoder Surface Profile Measuring Head." Chinese Journal of Scientific Instrument. vol. 31, No. 11, pp. 2489-2492, 2010.

[6] Z.T. Zhang,S.J. Hu. "Stress and residual stress distribution in Plane strain bending." Int.J.Meeh.Sei, vol. 40, No. 06, pp. 533-543, 1998.

[7] Wang Xin, Zhang Ming Ming, Yu Xiao and Zhang Ming Chao. "Improved iterative closest point method of point cloud data registration." Optics and Precision Engineering. vol. 20, No. 09, pp. 2069-2077, 2012.

[8] K.P.Li, W.PCarden, etc. "Simulation of springback." International Joumal of Mechanical Seienees, vol. 44, pp. 103-122, 2002.

[9] Li Er Tao, Zhao Guo Xuan, Zeng Hong. "A curved surface fitting method based on least squares." Journal of Hangzhou Dian zi University. vol. 4, No. 29, pp. 48-51, 2009.

[10] Yang Jian Ming,Hao Jie. "Numerical simulation of springback in sheet metal multi-point forming (MPF) and compensation research." Machine Tool & Hydraulics. vol. 32, No. 21, pp. 76-77, 2011.

[11] Yan Qin Guang,Li Ming Zhe,Cui Xiang Ji. "Research of multi-point forming springback amount of measurement and control method." Materials Science and Technology. vol. 14, No. 12, pp. 46-53, 2004.