Automated EDM-Based Center-Punching Systems for Pipe Production Lines

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Abstract. In this paper a control system that automatically detects the center and makes hole is presented. This control system comprises two subsystems: the Master Subsystem and the Control Subsystem. The Master Subsystem is mainly used for data processing including least squares analysis and then the result will be return to the Control Subsystem in addition to monitor the whole system in case of system errors or warnings. S7-300 PLC of the Control Subsystem is used for motion control, collecting all data, transmitting data to Master Subsystem, and executing commands that is received from Master Subsystem. By experiments we have proved the conventional manual operation can be effectively replaced by the developed system.

Introduction

In industry, seamless steel pipe plays an important role in many fields. However, the low efficiency and high cost of traditional manual centering perforation process make it difficult to meet the requirement of the seamless steel pipe. Due to the bad condition of high temperature and big noisy, it’s hard to make people adapt to the work. If unmanned automatic process of centering and perforating is used on this productivity, the quality of the perforation and the seamless steel pipe will be greatly approved.

Usually there are two steps during the steel pipe process. The first is EDM called electronic discharge machining. The main point of this step is to find the center of the round steel rod and make a mark that is 40mm deep with electrode. The second step is high temperature forging with the reference center found in the first step. The whole process is shown as Fig. 1.

Traditionly, the manual method is used for the first process. The precision is not good and the efficiency is not substantial. Besides, it’s quite danger to people. In order to solve these shortcomings that exist in the first step, a machine that can automaticly find the center and mark the steel rod is presented in this paper.

The System Structure

The Control System comprises two subsystems: the Master Subsystem and the Control Subsystem. The Master Subsystem makes it possible to keep men faraway from live situation through remote operation. The control system can automatically detect center and perforate. Two laser distance sensors are used to obtain the outline section of the seamless steel. The Master Subsystem and

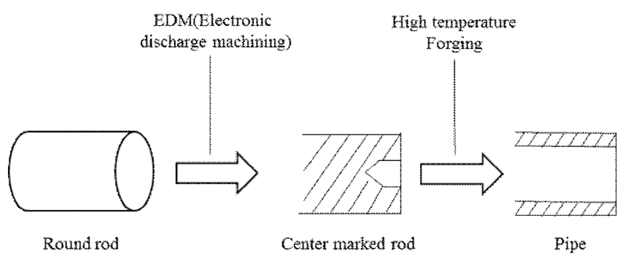

Fig. 1 seamless steel pipe processing

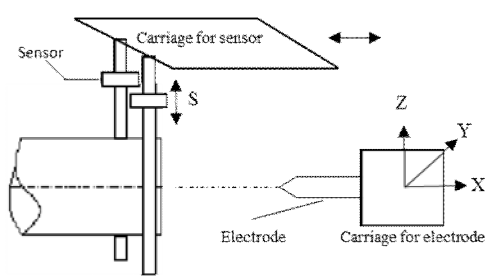

Fig. 2 System’s execiuite unit

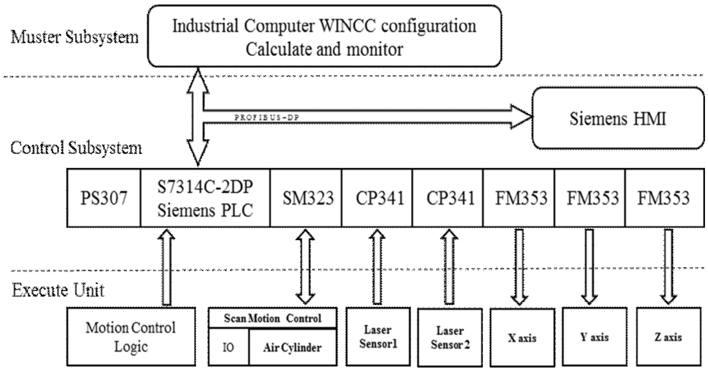

Fig. 3 The Control System Structure

Fig. 4 Operating UI

Control Subsystem that is implemented by S7-300 PLC are described in this paper.

Because of the existence of the high temperature and nosy especially for the electric arc interference, the whole system should be reliable at any circumstances. The Control Subsystem should be industry CPU instead of micro CPU. Laser sensor is adopted to collect critical data due to the good stability, instead of CCD camera. What's more, the working condition is quite danger for people, so the PROFIBUS-DP makes it possible to keep the operator far from the live working space through remote access operation. In case of system errors or warnings, the Master Subsystem has a variety of mechanisms to deal with the unexpected situations, and that is one of the reasons why the Master Subsystem is necessary in the machine.

The Master Subsystem with an industrial computer inside is used for least squares analysis, while motion control and data collection are finished in the Control Subsystem. The laser sensors, arc perforated electrode and execute unit are initialed at the reset original location. The execute unit's structure is shown as Fig. 2. The system structure is shown as Fig. 3. While there is a mission the machine works according to the following orders:

1) The laser sensors are move to the initial etecting location by the air cylinder. Then the PLC starts to collect data while the laser sensors move up to down, at the same time the data is sent to the Master Subsystem through PROFIBUS-DP.
2) While data collection is finished, the sensors are returned to the original place. The Master Subsystem will calculate the center of the kernel of section in least squares analysis, and make arc electrode aim at the center of the kernel of section by adjusted mobile device automatically.
3) Power on the perforation unit and punch about 40mm deep at the center of the kernel of section automatically. Then reset all executing units for the next operation. The whole process takes 15s average.

The Master Subsystem

The Master Subsystem makes it possible to keep operator far away through remote access due to the danger and bad working environment. The Siemens industrial control configuration software is used to monitor the whole system's dynamic statuses, operations and deal with the error and warning messages. The industrial control configuration software comprises four main parts: initialization, configuration, error log and operating UI shown as Fig. 4.

While data collection is finished, least squares analysis is used to calculate the center of the kernel of section. The circle formula can be express as:

$$\begin{bmatrix} x & y & 1 \end{bmatrix} \begin{bmatrix} a \\ b \\ c \end{bmatrix} = -x^2 - y^2 \qquad (1)$$

If n ($n \geq 3$) points are collected, then there will be

$$\begin{bmatrix} x_1 & y_1 & 1 \\ \vdots & \vdots & \vdots \\ x_n & y_n & 1 \end{bmatrix} \begin{bmatrix} a \\ b \\ c \end{bmatrix} = \begin{bmatrix} -x_1^2 - y_1^2 \\ \vdots \\ -x_n^2 - y_n^2 \end{bmatrix} \qquad (2)$$

Suppose

$$A = \begin{bmatrix} x_1 & y_1 & 1 \\ \vdots & \vdots & \vdots \\ x_n & y_n & 1 \end{bmatrix}, \mu = \begin{bmatrix} a \\ b \\ c \end{bmatrix}, B = \begin{bmatrix} -x_1^2 - y_1^2 \\ \vdots \\ -x_n^2 - y_n^2 \end{bmatrix}$$

Equation (2) can be written as $= B$, so,

$$\mu = (A^T A)^{-1} A^T B \quad (3)$$

In this paper, 120 points are collected in this system. Specially, after the first calculation ten points are abandoned, the nearest five points and the farthest 5 points from the center. Then the calculation will be proceeded once more.

The Control Subsystem

The Control Subsystem comprises eleven elements' signals : limit switch, laser distance sensor, control panel, cylinder home, ingot detected, error and warning, indicator, servo motor motion, cylinder motion and laser sensor carrier. All end effectors are connected to PLC and its additional modules. The laser sensors and electrode are carried by servo motors and cylinders, at the same time, the laser sensors and other signals are collected by the Control Subsystem and critical data is respond to the Master Subsystem in order to monitor the whole system's working status. The Control Subsystem's IDEF (ICAM Definition method) is shown as Fig. 5.

While automatic task begins, the Control Subsystem waits the ingot to be delivered to the proper location. Once this step is done the No.6 cylinder moves until the laser sensors reach the initial location by reading limit switch signal. Once laser sensors trigger the limit signal, the laser sensors move from up to down carried by servo motor, and at the same time, the sensors' data is upload to the Control Subsystem, meanwhile, the coordinates of this servo motor are upload to the Master Subsystem together with the compatible laser sensors' data. After all operations mentioned is finished, the Control Subsystem resets all the end effectors and waits for the Master Subsystem's respond, which is the coordinate of the circle center. When the coordinate is received, the Control Subsystem moves the electrode to the center of the ingot, then power on the heating device and start to make a hole on the ingot about 40mm deep. Till this step, the whole process comes to an end and all the end effectors are reset to an initial status and wait for next process. The main program flow chart of the Control Subsystem is shown as Fig. 6.

Simulated Result and Experimental Result

In order to test the system, we pick up one kind of ingots (R0 = 134.9 mm) as experiment object. The results of the system calculated are shown as Fig. 7, and the actual perforated ingot is shown as Fig. 8. The kernel of the tested steel ingot is (319.9, 114.2).

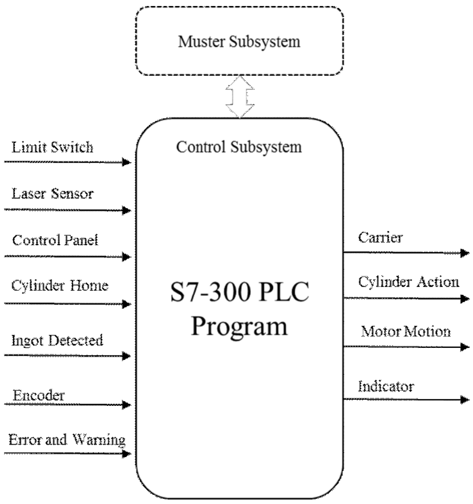

Fig. 5 Control Subsystem block diagram

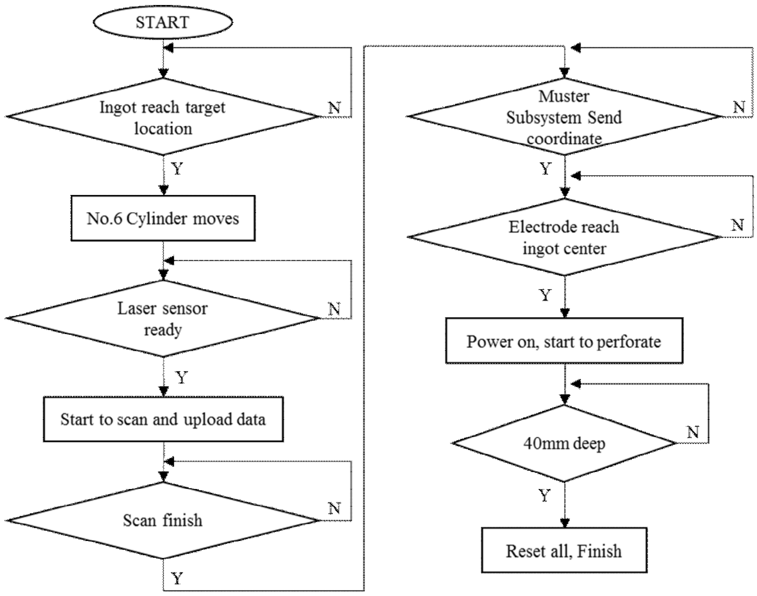

Fig. 6 Control Subsystem program flow chart

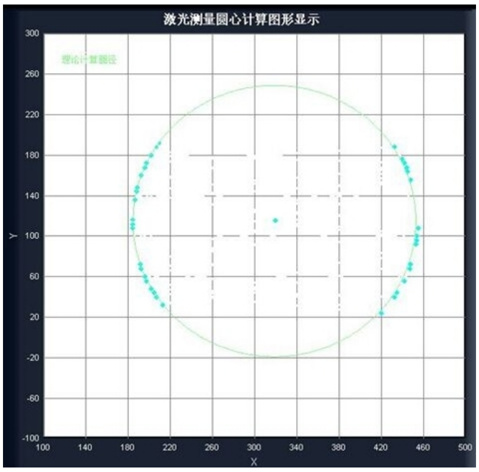

Fig. 7 Experiment Result

Fig. 8 Experiment Result

We have 10 experiments with the same object, and the data of these 10 experiments calculated by this system gives the result as Table 1 and shows that this system is quite effective and has high accuracy with a required average error within 1mm that meets the requirement of the steelworks. What's more, a whole operation takes the system only 15s, which is 50% discount of that cost by manual.

Table 1. Experiment Result [mm]

	1	2	3	4	5	6	7	8	9	10	σ
2*R0	269.4	269.8	270.0	270.1	269.3	270.0	269.9	269.5	270.4	270.0	0.3438
X0	319.5	319.8	319.7	320.3	320.1	319.5	319.7	320.0	319.9	320.0	0.2593
Y0	114.0	113.6	114.2	114.5	113.9	114.0	113.8	114.0	114.2	113.9	0.2470

Summary

In this paper, a control system that automatically detects the cross-sectional center of steel rods and makes mark, which is used in high-temperature forging process for seamless pipes. The control system comprises two parts: the Master Subsystem and a Control Subsystem. The laser sensors are used to detect the profile of the steel rods, which is used to fit to a circle by the least squares analysis. The sensor data gathered from the Control Subsystems are sent to the Master System by PROFI-BUS, which is proved to be effective under the severe working environment, like high-temperature and electric arc. Experiments show that this system is of rapid response, precision and reliability.

References

[1] Yan Bei, Wang Bin, Li Yuan, "Optimal ellipse fitting method based on least-square principle", Journal of Beijing University of Aeronautics and Astronautics, June, 2007.

[2] ZUO Shi-hui, "Application of FM357-2 Multi-Axis module for servo and robot", Manufacturing Automation, October, 2008.

[3] William Robson Schwartz, Aniruddha Kembhavi, David Harwood, Larry S. Davis. Human Detection Using Partial Least Squares Analysis, University of Maryland, A.V.Williams Building, College Park, MD 20742