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Application of press control based on infrared self-induction

Xiaoxu Xu[1], Hongbo Wang[1]

Abstract. To improve the control effect of press, a kind of press control algorithm based on infrared self-induction crankshaft and detection of slider position is put forward. First, design the hardware for master-slave module of infrared communication, infrared wireless communication principle and network communication protocol to realize the data collection of infrared self-pressure control system; second, construct the control framework for single servo motor driving servo mechanical press and detect the crankshaft and slider position to have realized the high-accuracy control of press system; finally, by simulation experiment, the effectiveness of the proposed method is verified.

Infrared, Self-induction, Press, Servo control
Key words.
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1. Introduction

The traditional mechanical press is driven by common AC asynchronous motor, designed with large-inertia flywheel storage to store and release formed energy and provided with the characteristics like low-capacity of motor and easy control. However, due to the non-adjustment of its slider motion, low energy efficiency of equipment, large impact vibration and other defects, it is hard to adapt to the requirements of flexibility, energy conservation and humanity in modern stamping, while the servo mechanical press adopts the AC servo motor whose motion is controllable as the drive element, removes the flywheel in order to simplify the transmission chain and adopts digital motion control technology, which makes it be part of a typical "numerical control generation" mechanical product. Its hard core control content is to control the slider to realize the motion needed in stamping period in accordance with the requirements of different stamping process. The design for control system of servo mechanical press directly affects the function and performance of products.

[1]School of mechanical and electrical engineering, Inner Mongolia Agricultural University, the Inner Mongolia Autonomous Region, 010018, China

At present, the controller adopted by the servo mechanical press includes PLC, PC and stand-alone motion controller.

2. Analysis on control requirements

Different controllers have their own advantages on the aspect of technology, performance, price and so on. The multilink servo mechanical press is taken as an example in the Paper. On the basis of analyzing its control requirements, the control system of servo mechanical press based on the controller of PC as the platform has been developed. According to different methods of drive and transmission, the servo mechanical press can be roughly divided into combination drive, parallel drive, single servo motor drive and other several drive methods. The combination drive method needs to control asynchronous motor and servo motor at the same time and the parallel drive method needs to realize the synchronous control of multiple servo motors, the control requirements of which are all rather special. The press driven by single servo motor is mainly discussed in the Paper. A press driven by some single servo motor is shown in Fig. 1. The servo motor is connected by shaft sleeve and pinion shaft. After the gear is decelerated, the crankshaft of drive rotates and the triangle connecting rod and top and bottom toggle rod transform the rotation of crankshaft into the linear reciprocating motion of slider.

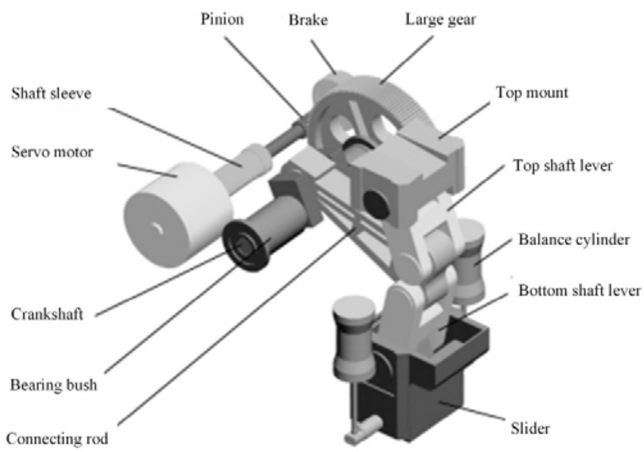

Fig. 1. Machine driven system

To obtain abundant equipment functions and advanced equipment performances, the following problems for control of servo mechanical press shall be considered.

(1) Determination of control object. The control object is the physical quantity needed to be controlled by controller, which can be the displacement of slider and also be the angle of crankshaft. If the slider is taken as the control object, because it is non-linear relationship between the angle of crankshaft and the displacement of slider, for example, when the motion of control slider is of uniform speed and orientation, the variable motion with pretty high acceleration shall be carried out

for crankshaft or servo motor, which is unfavorable to the operation of servo motor and energy conservation of equipment. In fact, most of servo stamping processes have no strict accurate requirements for the speed of slider but only generally require the slider to have higher average speed in idle stroke, while to have lower average speed in operating stroke. If the angle of crankshaft is chosen to be the control object, the crankshaft shall be controlled to carry out uniform motion within each angle scope and variable motion within different corner scope, which can not only satisfy the requirements of most servo stamping process for the speed of motion of slider, but also make it easier for the control of servo motor.

(2) Planning on motion track. Different servo stamping processes need to be planned for different motion track of slider. From the point of designers for servo stamping process, to input the speed of slider on several stroke stages on human-computer interface can more conveniently and directly plan the motion track of slider than to input the rotation speed of crankshaft in several angle scopes. Essentially, the motion of slider in servo mechanical press belongs to multi-point variable motion, that is to say, within the shorter stamping period, the multi-stage motion is carried out for slider. The motion track parameter of slider includes the number of stages in variable speed, position of variable-speed points, operating speed, motion direction and pause time, etc. However, because the control object is the angle of crankshaft, the motion position, speed and direction of slider in the human-computer interface need to be conversed to the angle of motion, rotation speed and diversion of crankshaft. Hence, the controller with higher function computing power or quick lookup power is needed.

(3) Detection of crankshaft angle and slider stroke. To plan and control the motion track of slider to carry out linear reciprocating motion on one-dimensional axis, zero point shall be established for motion axis of slider, which can generally be chosen as top dead center or bottom dead center position. For servo mechanical press whose operating mechanism is crank slider or toggle rod mechanism, its characteristic is: the operating speed of slider is slow, while the rotation of crank is faster around the top dead center or bottom dead center position. Hence, to accurately establish the origin, the angle of crankshaft and position of slider need to be detected.

(4) Treatment of multiple control signals. Besides handling the general switch quantity signals, the control system also needs to handle the analog quantity, pulsed quantity signals and even communication signals. For example, when the strain gage pasted on the side plate of motor is adopted to monitor the stamping tonnage, the amplified signal needs to be received; to control the speed and pressure of ejector hydraulic cylinder, it is necessary to output the current signal to control the proportional solenoid valve; if the optical-electricity encoder and grating ruler are adopted to detect crank angle and position of slider, it is also necessary to handle input pulse signal or communication signal; besides, on the occasion where servo feed needs to be adopted, it is also necessary to output pulse signal to control pulsed servo driver or adopt industrial Ethernet bus to control bus servo driver.

(5) Outside information interaction based on Ethernet. With the integration of industrialization and informatization and transition from manufacturing to intelligent manufacturing, the servo mechanical press should not be like the common

mechanical press to be the information isolated island anymore but should be provided with the power to carry out information interaction and information share with the outside manufacturing system. Meanwhile, to decrease the cost of remote maintenance and breakdown maintenance for equipment, the servo mechanical press should also be provided with the remote breakdown monitoring and diagnosis power. These all need the control system to be provided with the corresponding openness and Ethernet interface technology.

3. Infrared self-pressure data collection

3.1. Hardware design for master-slave module of infrared communication

The singlechip used by master-slave module of infrared communication is C8051-F350, which is the enhanced series 51 singlechip produced by SILIConLAb company. Its speed can reach 50MIPS and the integration includes UART, HC, SPI, ADC, DAC, TIMER and other functional unit circuits. 8-channel 24-bit ADC with PGA can finish the high-accuracy analog acquisition, 2-channel current output DAC is used for the output of analog quantity and the asynchronous serial interface UART is used for the communication of host node and upper computer. There are 4 timers and a PCA circuit, where timer 1 is used to generate UART clock signal, timer 4 is used to generate 38kHz modulating pulse signal transmitted by infrared ray and timer 3 is used to receive and time infrared ray. The transmission of infrared ray is realized by $P_{1,4}$ pin driving transistor 9013. The resistance R1 connected with transistor is 510Ω and R2 is 10Ω. Most products are available for infrared transmitting tube in the mark. Integration receiver module TOP8138 is adopted in infrared receiver, which only needs to be connected with $P_{1,5}$ of singlechip. The connection of infrared transmission and receiving circuit is shown in Fig. 2.

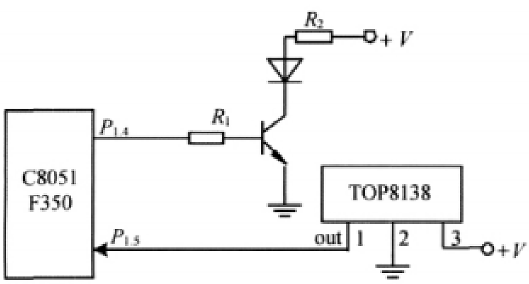

Fig. 2. Infrared transmission and receiving circuit of C8051F350 singlechip

3.2. Infrared wireless communication principle and network communication protocol

The timing of infrared data communication is shown in Fig, 3. The activation code is composed of $a + b$ where A = 9MS and b = 4.5MS. The binary 0 is composed of $c+c$ where $c = 0.56$MS; 1 is composed of $C + D$ where $D = 1.68$MS. To decrease the power dissipation and increase the communication distance, binary 0 and 1 sent are adopted in infrared communication to carry out coded modulation, the high level is modulated on the 38kHz carrier and after the current amplifies the circuit, the infrared LED is driven to transmit. The coded signal shall be recovered on the receiving end for CPU decoding. Attention shall be paid to the fact that the signal on the receiving end is opposite to transmitting end. The integrated infrared receiver widely adopted at present can directly output demodulation signal. In fact, this receiver module is an integration circuit, which has encapsulated infrared photocell, pre-amplifier, limiting amplifier, band-pass filter, detection as well as comparison, integrator and waveshaping circuit. The data format of this infrared communication system is shown in Fig. 4, which is composed of 4 -byte and 32-bit binary code where high 4 bits of the 1^{st} byte is the device code and low 4 bits is the radix-minus-one complement of device code. There are 16 kinds of coding for 4 bits, where coding 0 is the radio code and the rest 15 kinds are assigned to 15 slave units. The radix-minus-one complement of device code is used to verify the device code. High 4 bits of the 2^{nd} bite is the command code, which is as the command of swap data between master computer and slave. The high and low two bytes of analog quantity are not only the data collected by slave ADC but also the analog quantity that the master computer transmits to slave DAC.

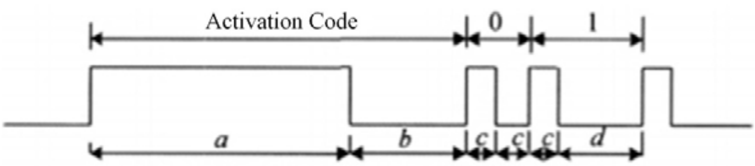

Fig. 3. Infrared communication timing

4. Control system design

4.1. Selection of controller

In the "numerical control generation" industrial machinery, the use of high-power servo driver and servo motor becomes wider and wider, while most suppliers for motion control system might not be provided with the manufacturing capability for high-power servo drive system and there are problems like various types of servo driver interface and communication difficulties due to different PLC, NC and HMI brand, etc. The PC controller in Germany Beckhoff Automation Company is an openness control system based on industrial PC hardware and Windows software platform, which is provided with strong operation, storage capability, abundant types of peripheral interface, flexible and diverse modular construction, efficient remote monitoring and diagnosis capability; EtherCAT true-time industrial Ethernet bus equipped with it can be totally compatible with Ethernet, which is provided with highly open, flexible extension, lower cost and other characteristics; TwInCAT software carried by it can convert any system based on PC to a true-time control system integrated with PLC, NC and HMI and can support almost all servo driver interface. Based on this control platform, not only can it conveniently realize HMI, PLC and NC as well as all kinds of "ALL-In-One" controls of controlled quantity and can have bigger selection freedom for high-power servo driver and servo motor, but also can efficiently realize the computing of complex function, treatment of mass data, information interaction with outside Ethernet as well as remote breakdown diagnosis and other functions.

4.2. Construction of control framework

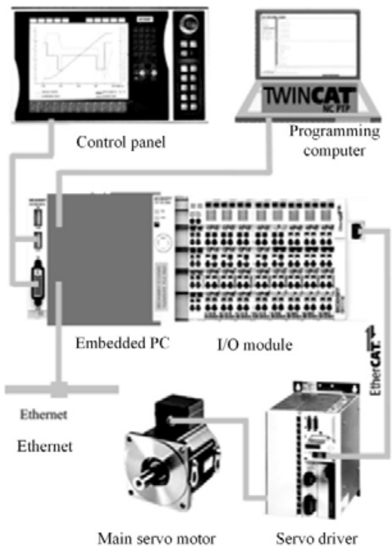

Fig. 4. Framework diagram of control system

Fig. 4 shows the control framework diagram of single servo motor driving servo mechanical press based on PC control technology in Germany Beckhoff Automation Company. The controller is the embedded PC, which is equipped with high frequency CPU with strong operational capability (being able to reach 1.8HZ) and adopts high capacity CF card (being able to reach 8GB) of non-rotating member as activation and storage medium. CPU module is connected with all kinds of I /O modules with standard width by PC /104 bus to handle all kinds of switch quantity, analog quantity, pulsed quantity and communication signal; connected with servo driver by EtherCAT industrial Ethernet bus to control the variable motion of multipoint in main servo motor; connected with touch control panel with simple keyboard by DVI and USB interface to realize human-computer interaction function; can be connected with programming computer installed with motion control software TwInCAT by RJ45 network interface or connected with other PC to construct linear topology structure or connected with Ethernet to carry out information interaction with the outside and remote breakdown diagnosis. This control framework can meet the control requirements of servo press driven by single servo motor.

4.3. Detection for position of crankshaft and slider

Not only can detection for position of crankshaft and slider be used to establish the zero point for the linear axis of slider and the rotation axis of crankshaft, but also can be used to convert the motion track parameter of slider to motion control parameter of crankshaft. The linear grating ruler is adopted to detect the linear displacement of slider and the interface terminal module EL5101 of incremental encoder is adopted to receive the differential pulse signal output by grating ruler in control system. The specific signal connection is shown in Fig. 5. The 5VDC voltage of grating ruler is provided by EL5101. To adopt differential signal is to improve antijamming capability. In a similar way, the absolute optical-electricity encoder is adopted to detect the angular displacement of crankshaft and interface terminal module EL5001 of SSI encoder is adopted to receive the synchronous serial signal output by encoder. The 24VDC voltage of encoder for specific signal connections is provided by EL5001 and SSI signal is also provided with higher antijamming capability.

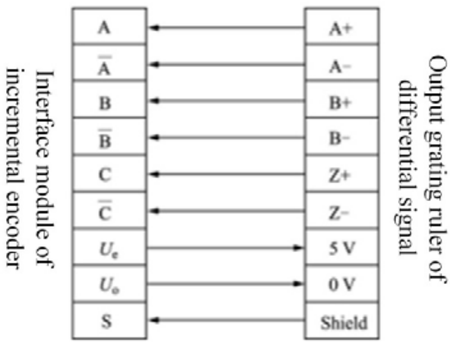

Fig. 5. Wiring diagram of slider grating ruler

5. Simulation experiment

Simulink has provided the non-linear electromechanical control system with strong simulation tools. According to the mathematical model of motion control system established above, the dynamic simulation model of electromechanical system in press driven by servo based on Simulink module has been established, including motor body and mechanical transmission subsystem. To verify the accuracy of no-load simulation model and effectiveness of motion curve of arbitrary slider, under the circumstance of constant speed and variable speed, the no-load simulation test is carried out. According to the actual prototype, the parameter of simulation test is given as shown in Table 1.

Table 1. Test parameter of simulation model

Parameter name	Numerical value	Parameter name	Numerical value
Rated voltage	220V	Connecting rod quality	77kg
Resistance of armature winding	0.014Ω	Slider quality	550kg
Inductance of armature winding	0.532mH	Crank radius	70mm
Coefficient of potential	$0.744\text{V}\cdot\text{rAd}^{-1}\cdot\text{s}^{-1}$	Connecting rod length	640mm
Torque coefficient	$1.58\text{N}\cdot\text{m}\cdot\text{A}^{-1}$	Coefficient of connecting rod	0.109
Connecting rod inertia	0	Gear ratio	10
Motor inertia	$0.0445\text{kg}\cdot\text{m}^2$	Friction coefficient of slider	0.04
Pinion inertia	$0.034\text{kg}\cdot\text{m}^2$	Crankshaft support neck radius	130mm
Larger gear inertia	$4.12\text{kg}\cdot\text{m}^2$	Crank web diameter	160mm
Crank inertia	$0.293\text{kg}\cdot\text{m}^2$	Bulb diameter of connecting rod	150mm

5.1. No-load constant-speed simulation test

The simulation result is shown is Fig. 6. The displacement and speed curve of slider conforms to the theories, which has indicated the correctness of constant-speed no-load simulation model.

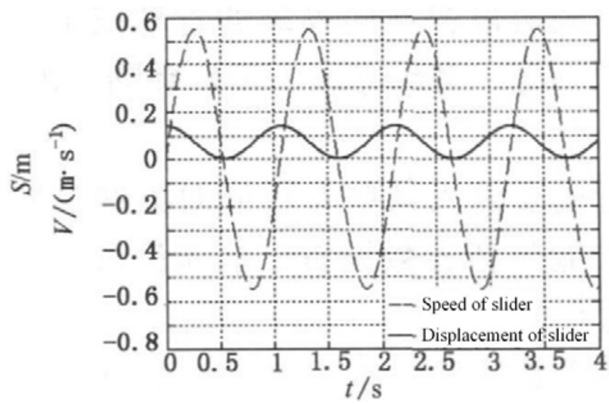

Fig. 6. Displacement and speed of slider under No-load constant speed

5.2. No-load variable speed test

Under the driving of servo motor, the slider can realize fast-slow-fast motion characteristics, as shown in Fig. 7. Hence, arbitrary motion curve can be realized under no-load circumstance.

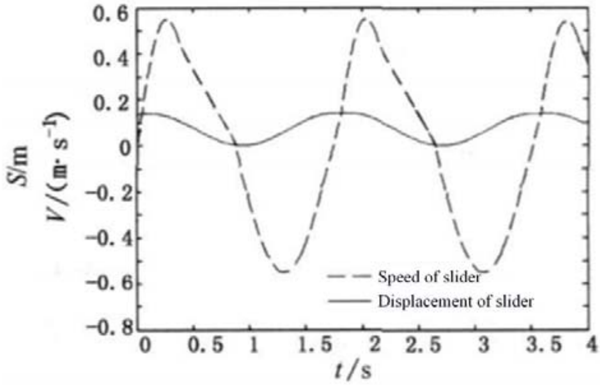

Fig. 7. Displacement and speed of slider under the circumstance of No-load variable speed

5.3. Load change test

It can be seen from Fig. 8 that the model constructed can realize the variable-speed load motion of slider and when it bears the continuous loading impact, the instant jitter occurs to the rotation of the motor, hence the instance decline of speed of slider also appears, but it can go back to normal within a short time.

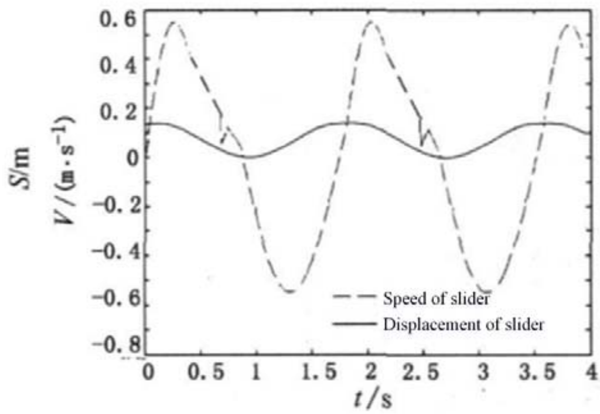

Fig. 8. Displacement and speed of slider under the circumstance of load variable speed

6. Conclusion

A kind of press control algorithm based on infrared self-induction crankshaft and detection of slider position has been put forward in the Paper to realize the data collection of infrared self-pressure control system and construct the control framework for single servo motor driving servo mechanical press to have realized the high-accuracy control. The next step is mainly to carry out in-depth study on the development of system application, especially to construct the simulation machine under the real experiment environment to carry out effect verification on algorithm.

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References

[1] M. Barut, R. Demir, E. Zerdali, et al.: *Real-Time Implementation of Bi Input-Extended Kalman Filter-Based Estimator for Speed-Sensorless Control of Induction Motors*[J]. IEEE Transactions on Industrial Electronics *59* (2012), No. 11, 4197–4206.

[2] D. M. Herlach, B. Feuerbacher: *Non-equilibrium solidification of undercooled metallic melts*[J]. Advances in Space Research *11* (1994), No. 7, 255–262.

[3] P. Sonneveld, H. Goldschmidt, L. Rosiñol, et al.: *Bortezomib-based versus nonbortezomib-based induction treatment before autologous stem-cell transplantation in patients with previously untreated multiple myeloma: a meta-analysis of phase III randomized, controlled trials*[J]. Journal of Clinical Oncology Official Journal of the American Society of Clinical Oncology *31* (2013), No. 26, 3279–87.

[4] X. Du, J. Qi, Z. Zhang Z, et al.: *Efficient Non-doped Near Infrared Organic Light-Emitting Devices Based on Fluorophores with Aggregation-Induced Emission Enhancement*[J]. Chemistry of Materials *24* (2012), No. 11, 2178–2185.

[5] K. D. Rector, J. W. Jiang, M. A. Berg, et al.: *Effects of Solvent Viscosity on Protein Dynamics:? Infrared Vibrational Echo Experiments and Theory*[J]. Journal of Physical Chemistry B *105* (2013), No. 5, 1081–1092.

[6] H. Shin, B. D. Olsen, A. Khademhosseini: *The mechanical properties and cytotoxicity of cell-laden double-network hydrogels based on photocrosslinkable gelatin and gellan gum biomacromolecules*[J]. Biomaterials *33* (2012), No. 11, 3143.

[7] L. Shang, J. Hu: *Sliding-Mode-Based Direct Power Control of Grid-Connected Wind-Turbine-Driven Doubly Fed Induction Generators Under Unbalanced Grid Voltage Conditions*[J]. Energy Conversion IEEE Transactions on *27* (2012), No. 2,362–373.

[8] L. Assis, A. I. S. Moretti, T. B. Abrahão, V. Cury, H. P. Souza, M. R. Hamblin, N. A. Parizotto: *Low-Level Laser Therapy (808 nm) Reduces Inflammatory Response and Oxidative Stress in Rat Tibialis Anterior Muscle After Cryolesion*[J]. Lasers in Surgery & Medicine *44* (2012), No. 9, 726–735.

[9] G. Mouneimne, S. Hansen, L. Selfors, et al.: *Differential Remodeling of Actin Cytoskeleton Architecture by Profilin Isoforms Leads to Distinct Effects on Cell Migration and Invasion*[J]. Cancer Cell *22* (2012), *5*, 615–30.

[10] A. Wollenberg, L. M. Ehmann: *Long Term Treatment Concepts and Proactive Therapy for Atopic Eczema*[J]. Annals of Dermatology *24* (2012), No. 3, 253–260.

[11] J. A. Riveros, F. Barrero, F. Levi, et al.: *Variable-Speed Five-Phase Induction Motor Drive Based on Predictive Torque Control*[J]. IEEE Transactions on Industrial Electronics *60* (2013), No. 8, 2957–2968.

[12] M. C. Camp, K. P. Macpherson, L. Lederle, et al.: *Genetic strain differences in learned fear inhibition associated with variation in neuroendocrine, autonomic, and amygdala dendritic phenotypes.*[J]. Neuropsychopharmacology *37* (2012), No. 6, 1534–47.

[13] H. X. Guo, Z. Y. Niu, H. B. Guo, et al. *Infrared Image Edge Detection Algorithm Based on Improved Canny Algorithm*[J]. Fire Control & Command Control *90* (2014), No. 5, 1997–2001.

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