Journal of Applied Sciences

ISSN 1812-5654

science alert

ANSInet
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Journal of Applied Sciences 14 (3): 279-284, 2014
ISSN 1812-5654 / DOI: 10.3923/jas.2014.279.284

High Speed On-Off Valve Self-adapting Clamping System

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Abstract: The high-speed switch electromagnetic valve was a new type of element in the electro-hydraulic control system. The study aimed at the functional requirements and technical specifications of the turbine governor system for high speed on-off valve, designed the new Pulse Width Modulation high speed on-off valve. The high speed on-off valve could control fixture clamping force. Through the analysis of the working characteristics of the hydraulic actuator and high speed valve, the fixture optimization could analyze the clamping force of each point. Variable clamping force fixture could adapt to the change of cutting force, reduce the cutting deformation of machining system. Adapting high-speed on-off valve control fixture, it could effectively reduce work piece deformation, had some use value and a wide range of application prospect.

Key words: Self-adapting clamp, high speed on-off valve, pulse width modulation

INTRODUCTION

High-speed switching high-off valve element has the advantages of simple structure, low price, fast response, resistance to pollution. Ability strong advantages, such as Wu *et al*. (2003), Li *et al*. (2002) and Liu *et al*. (2003). Its performance is typically used to open and close time to describe. Only two limit working form, on and off. The raw switch digital signal can be converted directly into the fluid pulse signal, is the combination of computer control technology and hydraulic fluid technology.

Abroad had began in the late '50 s and the development of the digital valve, but previous research laboratory in 1975. In 1976, Japan digital valve first hit the market and won. Later, some American companies have been also developed some specifications of the Numbers Valve and achieved the commercialization level (Liu *et al*., 1998). In view of its many advantages, high speed valve has many potential application values. In foreign countries it has become successfully used in construction and agricultural machinery etc.

High speed open sprawling basic idea is to control valve core of the open and close according to the pulse signal of high and low level. By changing the pulse signal modulation frequency, export duty ratios of regulating pressure or average flow rate. High speed switch cabinet wide mouth only has two working position, open or close from digital signal directly into a fluid Pulse signal. There is not sensitive to oil pollution, strong anti-jamming capability, etc (Xu *et al*., 1994). Due to the high speed switch valve when the wide mouth of work is in a state of high speed switch, the service life of the rich is the current problem to be solved.

Machine tool's fixture is a significant processing equipment in machining. In the conventional design project of machine tools fixture, there is a lot of research about stoical position error and clamping error. However, there is less research about dynamic error caused by the changes of cutting force and other factors during machining and its erasing methods. Figure 1 is a block diagram of component part of fixture which controlled by high speed on-off valve and the main components are mechanism, hydraulic pressure system, electrical control system and control software etc.

Along with the popularization of Numerical Control Technology, more and more parts produced by numerical control machine. Parts are processed by machining center, the feature of which is through one-step installation it can complete several rough and finish machining process steps. In order to guarantee parts can be processed steadily under different cutting force, the clamping force of fixture must be determined by the maximal cutting data, but usually that causes clumping deformation of low stiffness and delicate parts.

During machining, alterable clamping force fixture of this study can correspondingly adjust clamping force. According to cutting force, clamping force can suit with cutting force and minimize the deformation which caused by clamping force. At the same time it can adopts CNC technology to achieve the function of self-adapting clamping.

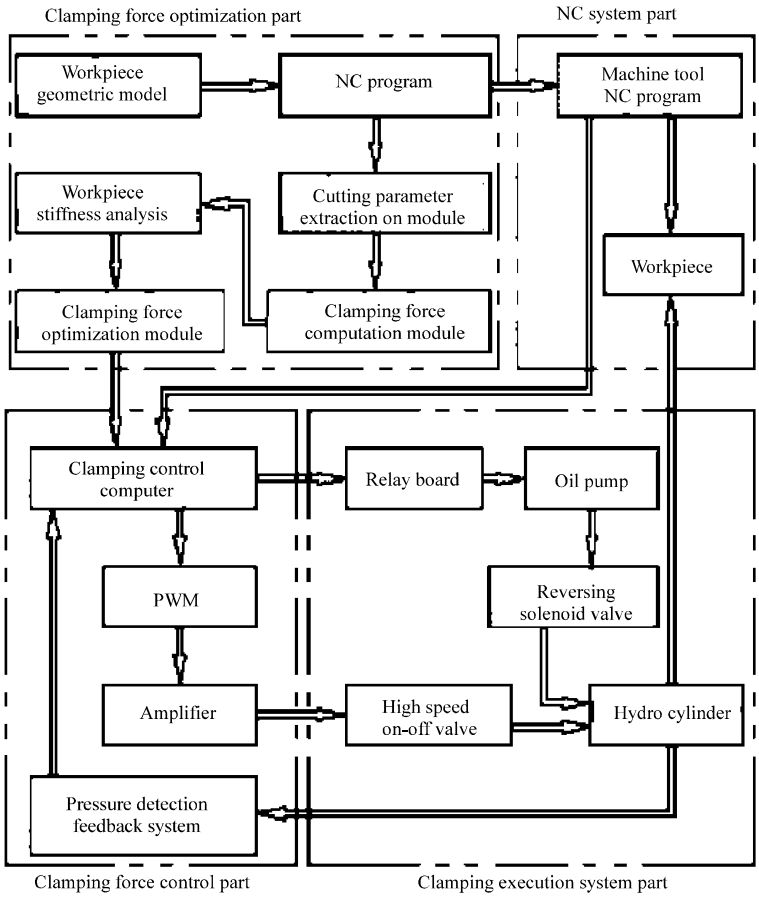

Fig. 1: Block diagram of component part of fixture

ALTERABLE CLAMPING FORCE FIXTURE SELF-ADAPTING SYSTEM

Materials and methods: Clamping force adaptive control system receives the clamping force optimization system input data and output controlled by pulse width modulation letter number. Pressure test feedback system detects the actual pressure of oil cylinder, by calculation machine to modify the PWM signal. Clamping force execution system completes the work piece clamping function design and adopt the hydraulic system control scheme.

Before machining, three-dimensional modeling should be conducted and analyzed on work piece three-dimensional entity model. With the finite element software identify the weaknesses of work piece stiffness and optimize analysis the best clamping points and the clamping force of each point. The force parameters of stiffness analysis computation from work piece NC (numerical controlling) work program (Man *et al*., 2010). Cutting parameters extraction module extracts machining amount from NC program and can compute the cutting force numerical value make use of the equation as follow:

$$F_z = \frac{a_p \cdot h_m \cdot C_S}{\sin \gamma_0} \quad (1)$$

While α_p is cutting depth, h_m is cutting thickness, γ_0 is tool orthogonal rake, C_S is cutting force of unit transverse section (N mm^{-2}) and obtained by experiment. Clamping force self-adapting control system accept the clamping data which inputted by clamping force majorization system. Pressure testing feedback system detects the actual pressure of oil cylinder and the PWM (pulse width modulation) signals amended by computer.

Clamping force execution system can accomplish the function of clamping. Hydraulic pressure system was adopted to control project to design the system, which, use with the high speed on-off valve, accomplish the execution and control of pressure according to the clamping force measurement provided by control system.

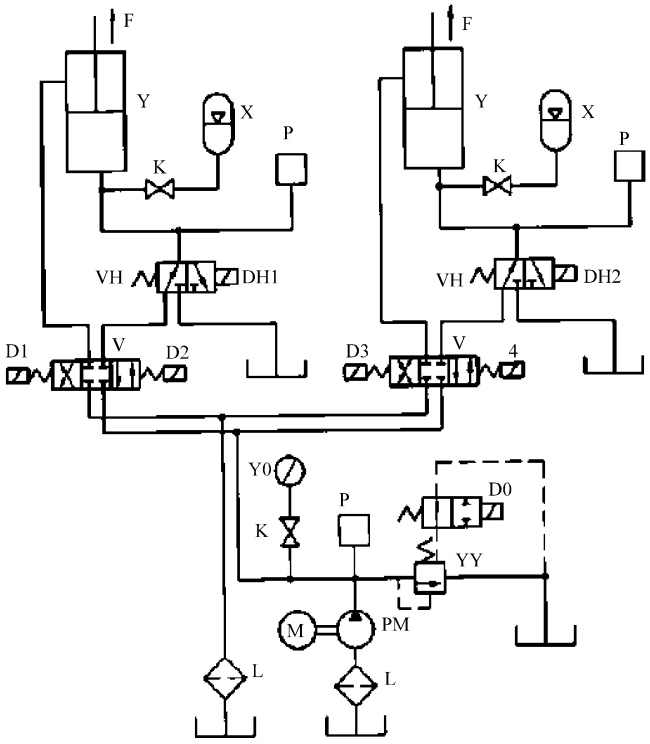

Fig. 2: Hydraulic pressure system key diagram of fixture, Y: Hydraulic cylinder, X: Accumulator P: Pressure transmitter K: Hand-operated switch, VH: High speed on-off valve, V: Three-position four-way solenoid directional valve, YV: Electromagnetic relief valve, PM: Hydraulic pump, M: Electric motor, YO: Pressure gauge, L: Purolator

Table 1: Table of the electromagnet and hydraulic cylinder motion state

	Hydraulic cylinder motion state			
Electromagnet	Advance	Clamping	Return	Stop
D0	+	+	+	–
D1	–	–	+	–
D2	+	+	–	–
D3	–	–	+	–
D4	+	+	–	–
DH1	PMW	PMW	PMW	–
DH2	PMW	PMW	PMW	–

D0-DH2: Code name of the electromagnet in Fig. 1, PMW: Pulse Width Modulation

RESULTS

Figure 2 shows hydraulic pressure system key diagram of fixture. This fixture system can control 5 independent oil cylinders ways. The figure has drew up 2 ways. The oil pressure of oil cylinder is controlled independently by high speed on-off valve VH. In order to improve pressure stability, accumulator X. Oil source circuit can be adopted to open circuit of constant rate pump and pressure control oilway adopts unloading spillover valve to control circuit. Table 1 shows the major components list of hydraulic pressure system.

In order to easy to use, two computed modes were set including hand drive and automatic while designing. Hand drive mode is used for adjust and determine system parameters. After the parameters are determined, the system work under automatic mode and its cycle of motion is advance→clamping→return→stop. The electromagnet action state is shown in Table 1.

HIGH SPEED ON-OFF VALVE-BASED FIXTURE KINETIC CONTROL

High speed on-off valve is one of quick-response switching mode digital electromagnetic valve and is a perfect interface element between electronic device and hydraulic pressure device. The most prominent feature of high speed on-off valve is it can directly accept the pressure or flow of digital signals to fluid system and carry out PWM. Compared to hydraulic pressure servo and proportional control system, the quick-response and antipollution competences of high speed on-off valve control system reflect to more outstanding engineering adaptability.

In view of the feature of high speed on-off valve, the fixture system adopts HSV-3202C7 open high speed on-off valve serve as kinetic control element. The fixture system dynamic response time is vopen less than 2.5 m sec and close less than 3.5 m sec. The biggest

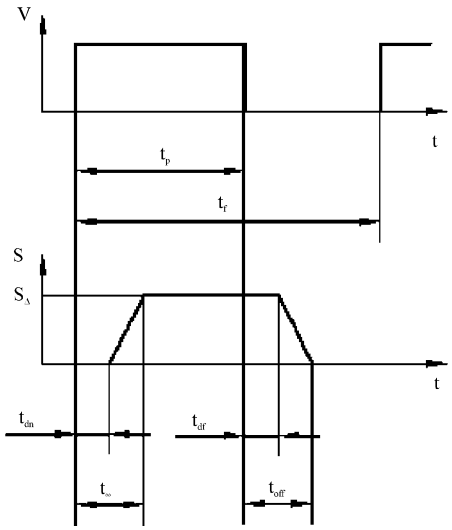

Fig. 3: Dynamic response control and the response process

working band is more than 200 Hz and the designed life is never less than 10^9 times. Combine to the fixture work condition, the control flow under 9 L min^{-1} was confined.

Response and speed control of fixture: The system uses PWM method of high speed on-off valve to carry out dynamic response control and the response process shown as Fig. 3. In a control period t_f, t_{dm} is the delay time when valve open, t_{on} is open time, t_{on}-t_{dn} is movement time of spool from beginning movement to complete open, that is starting signal response time. t_{df} is close response time, t_{off} is close time, t_{off}-t_{df} is the time of spool from beginning close to complete close, that is finish signal response time. Delay time is the key factor of determination response speed, delay time t_{on} and t_{off} more less the dynamic response dynamic response characteristics more better. Delay time is mainly caused by spool inertia and friction etc. Because the control coil is a lagging load and its electric current addition has a process, the force just begins to set spool in motion. When the electric current reach a certain value, spool motion needs some time so the delay phenomenon can't be avoided. The delay phenomenon will lead to zero dead-zone and saturation phenomenon when valve working.

In order to eliminate the valve time delay, the system should compensate the delay time. First and foremost measure actual delay time of valve in hydraulic pressure system and consider the delay time when decide the duty factor after that giving the impulse amplitude in modulation a certain widened to eliminate the influence by delay time beforehand.

In the fixture system of the study, inside diameter of hydraulic pressure oil cylinder is D and piston rod diameter is d. Then when the system works, the travel speed of the piston rod is:

$$v = \frac{4Q}{\pi(D^2 - d^2)} \quad (2)$$

Therefore, Q is the flow rate feed in the oil cylinder. Setting the average flow-rate which flows through the high speed on-off valve is $\bar{Q}$ and its formula as follow:

$$\bar{Q} = \tau CA\sqrt{\frac{2\Delta P}{\rho}} \quad (3)$$

While, τ is pulse signal dutyfactor:

$$\tau = \frac{t_p}{t_f}, t_f$$

is pulse signal period, t_p is pulse width, C is flow coefficient. A is the flow sectional area of valve, Δp is the pressure difference between inlet opening and control opening of valve. ρ is fluid density. If ignore the influence caused by leakage etc, then $Q = \bar{Q}$ from Eq. 2, that flow rate outputted by high speed on-off valve is linearly related to duty factor τ. Therefore, in clamping process of the system, adjust clamping speed if only through control the duty factor of PWM.

The system is controlled by Siemens PLC. The Siemens PLC is composed of CPU226 module, EM222 relay output module and EM231 analog quantity input module. The output side Q 0.0 and Q 0.1 of CPU 226 can produce impulse, its highest frequency can reach 20 kHz, to form PWM wave in form of envelope card. Each relay output side of EM222 module separately connect with the electromagnet of electrical motor relay, of electromagnetic relief valve and of three-position four-way valve.

Generally, the frequency of high speed on-off electromagnetic valve is 200 Hz (period is 0.005 sec). Make use of PLC high speed impulse output side to input PWM signals with period 0.005 sec and different duty factor τ to high speed on-off electromagnetic valve and at the same time the high speed on-off valve working in the manner of PWM when the pulse-width-modulated signal working. Setting the dutyfactor τ between 15-85%, then the flow rate control range of high speed on-off valve is 1.35 ~7.65 L min^{-1} and using 5 oil cylinders at the same time, then clamping speed can be controlled between 14.1~80.3 m sec^{-1} (Chen *et al*., 1993).

Clamping force control: During fixture working, when clamping element touch with workpiece, the control mode

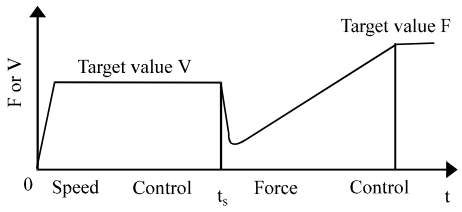

Fig. 4: Control process of self-adapting numerical control fixture

should change from speed control to pressure control, that is the pressure of hydraulic pressure system gradually rise until achieve setting value when touch the workpiece. As shown in Fig. 4 is the control process of self-adapting numerical control fixture. During beginning time t_s, clamping mechanism doesn't work.

Clamping force control: During fixture work, when calmping element touch with work piece, the control mode should change from speed control to pressure control, that is the pressure of hydraulic pressure system gradually rise until achieve setting value when touch the work piece. As shown in Fig. 4 is the control process of self-adapting numerical control fixture. During beginning time t_s, clamping mechanism don't touch with work piece and at the same time clamping element quickly approach part in the manner of speed control and when it soon approach the work piece, the control mode changes into force control, in order to prevent part be hitted by sudden pressurizing, clamping elements should slowly approach workpiece to carry out clamping and achieve setting value (Chen and Cao, 1994).

When carry out pressure control, the control opening of high speed on-off electromagnetic valve can alternately connect with inlet opening and return opening. If increase the pressure of control chamber, make the control opening connect with the inlet opening. On the contrary, make the control opening connect with return opening. achieve pressure control through control the time of control opening connect with inlet opening or return opening.

As shown in Fig. 5 is the relational graph of control pressure and dutyfactor p_m is system pressure. From the figure when dutyfactor is 20~80%, the relationship of control pressure and dutyfactor is generally linearized, when dutyfactor is less than 20%, because spool response lag behind PWM signals, it will appear linearity dead area and when dutyfactor more than 80%, it will get in saturation area and cause nonlinear phenomenon. And the pressure control experimental data is shown in Table 2.

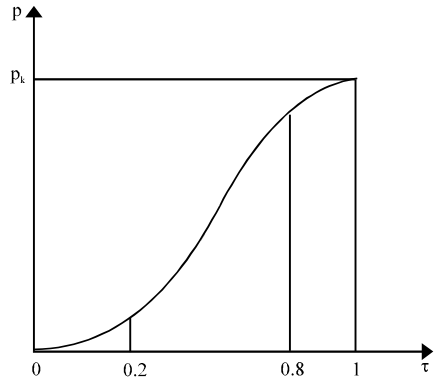

Fig. 5: Relational graph of control pressure and dutyfactor

Table 2: Experiment data table of two groups target pressure and real pressure control

	First group oil cylinder		Second group oil cylinder	
No.	Target pressure (N)	Real pressure (N)	Target pressure (N)	Real pressure (N)
1	1000	900-1035	900	831-971
2	1400	1370-1534	1300	1247-1338
3	1500	1414-1555	1600	1598-1605
4	1800	1832-1836	1800	1874-1868
5	2000	1971-2143	2000	1981-2006
6	2200	1950-2261	2200	2180-2319
7	2500	2459-2562	2500	2478-2589

Remark: Experiment conditions, spillover valve setting pressure is 10 Mpa, work frequency of high speed on-off valve is 31.25 Hz, oil viscosity is 32 mm sec^{-2}.

During real work, dutyfactor can be controlled between 15~85%, the rated working pressure of HSV-3202C7 high speed on-off valve is 20 Mpa, efficient area of oil cylinder is 3.16 cm^2 and single oil cylinder pressure control extent is 94.8~537.2 kg. All of above meet fixture real use requirement so this is a very practical control program.

After real test, the pressure control accuracy of the system can reach 4.5%.

CONCLUSION

Adopting alterable clamping force fixture can effectively decrease work piece clamping deformation and guarantee part machining accuracy so this method has actual significance for the machining of work piece with bad stiffness. The study adopts a new-type electro-hydraulic transition element named high speed on-off valve as clamping force control element in place of servo valve and proportional therefore it can decrease hydraulic pressure system cost and can be controlled directly by computer so it especially applied in bad working condition for convenient and flexible control mode.

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