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Intelligence Fusion Based Control Strategy for Hydraulic Pressure System of AGC

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Abstract: The hydraulic AGC system is a very important part of modern strip and plate mill, the dynamic and steady quality of control is the key factor to directly influence the product quality in this system. Aimed at the control puzzle resulted from nonlinearity, time lag, uncertainty and interference, this paper proposed a sort of intelligence fusion based control strategy for hydraulic AGC system. In this paper, the influence factors of the parameter has been comprehensively studied, the cybernetic characteristic of hydraulic system has been thoroughly discussed, and the control strategy of system and the algorithm based on intelligence fusion have been studied and designed. Under the condition of laboratory, the comprehensive comparisons have been made between the proposed fusion control strategy and other different control algorithm, and the simulation results demonstrate that the fusion control strategy is faster in response speed, higher in control precision and there is no overshoot as compared to the other control strategies. Therefore, the intelligence fusion based control strategy is an appropriate and feasible approach for the hydraulic AGC system.

Key words: hydraulic AGC, fusion based control strategy, robustness

1. Introduction

The hydraulic mill is a multivariable system, and its rolling process is very complex. By means of electrohydraulic servo valve, the flow rate and pressure of hydraulic cylinder could be regulated and the travel distance of hydraulic cylinder could be controlled in upward and downward direction. Therefore, the gap of nip roll could be easily adjusted. Through adjusting the displacement of hydraulic screwdown and the rolling pressure, the tolerance of wall thickness for plates and belt materials could be controlled. In view of the characteristic in strong coupling among variables, nonlinearity, uncertainty and so on, it is difficult to build accurate mathematical model of this system. Therefore, the system error would be much large if the routine control method is adopted. Even if under the condition of constant roll-gap rolling process, it could make the target value of outlet thickness beyond the allowable tolerance due to the variable rolling speed, thickness of belt materials entrance, cooling and bias-adjustable deviation and so on. Generally, there are three kinds of control, i. e., roll gap control, pressure control and pressure AGC control. The roll gap control is the basic inner ring of AGC control, and the pressure control is the second basic inner ring of AGC control. They are applied to adjust the upward movement of hydraulic cylinder and make the deviation to be zero by driving servo valve of deviation value. However, the pressure control is mainly used for AGC control of pressure-tension speed and so on. The pressure AGC control

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can effectively increase the rigidity of rolling mill, and make the equivalent rigidity of rolling mill be much greater than the nature rigidity of rolling mill. Therefore, it could make the rolling mill produce a constant outlet thickness and obtain the optimal performance of rolling mill. The characteristic of hydraulic servo system is nonlinear in pressure, flow rate, threshold, lag, friction, servo amplifier and so on. In addition, the load of actuator always results in change of loop gain and hydraulic tamping, and it makes the control of hydraulic AGC system become more complex. Therefore it is necessary to study the cybernetic characteristic of control process in hydraulic AGC system before the control puzzle is comprehensively discussed.

2. Cybernetic characteristic and control puzzle

Along with speedy development of science and technology, the hydraulic AGC is used to replace power-driven AGC due to its superiority of fast response speed and high control accuracy. So far, it has become the first choice of technology for new-built rolling mill and desired alternative for the reforming rolling mill. The production of plates and belt materials is a typically complex process, and it is hard to make accurate mathematical description because it is related and coupled by many variables such as nonlinearity, time varying, randomness, fuzziness, instability and uncertainty. Generally speaking, the characteristic of rolling process could be simply summarized as the follows: ① unknown, time varying, randomness and distribution in parameter of rolling process, ② unknown and time varying in time lag of process parameter, ③ serious nonlinearity of whole rolling process, ④ strong correlativity and coupling among process parameters, ⑤ unknown, diversity and randomness in environment disturbance of the rolling process. Due to its characteristics mentioned above, it is difficult to conduct an effective control during rolling process through conventional routine control strategy such as PID. The conventional control method is based on an accurate mathematical model, and its control algorithm is the quantitative computation under strict mathematic meanings. However, since the rolling process is very complicated and it involves some uncertainties and nonlinearities, it is almost impossible to make an appropriate mathematic description and construct an accurate analytical model. Furthermore, even if a complicated mathematical model could be obtained, it is still difficult to apply in a real engineering application. Therefore, it is necessary to explore the control strategy and corresponding algorithm and it becomes a difficult problem in the control engineering.

3. Control strategy and control model

3.1. Intelligence fusion based control strategy

By means of routine control strategy (i. e., PID) and method of modern control theory, it is hard to obtain better control quality during rolling process of plates and belt materials for hydraulic mill. The existent difficulties could be summarized as the following five aspects: ① complexity of system in parameter and structure, ② semi-structured and non-structured system, ③ high nonlinearity among parameter relations, ④ uncertainty of rolling process, ⑤ reliability. The existent puzzle of cybernetic characteristic mentioned above could make the rolling process can not be effectively controlled by the conventional control strategy, therefore it is necessary to further study the control strategy. Although there exist lots of control strategies that are available to be chosen, a lot of difficulties need to be solved for the rolling process.

The expert control system is based on the knowledge. Because it is difficult to collect and express the characteristic information of rolling process, and to build the maturity repository, the expert control system is also difficult to realize the whole control of rolling process. NN control needs lots of definite experiment samples to obtain the weight training. Due to the influence of uncertainty, it is very hard to obtain the experimental samples from the known experience and a forehand experiment. In view of the method limitation, it is also difficult to generally realize effective control. The hominine control experience can carry through the summarization and description by means of hominine language, it can be depicted to fuzzy language by means of fuzzy set in fuzzy mathematics, and also it can be realized by the sentence of "If condition Then action". However, since the number of uncertainty factors is too many, the fuzzy control is not a good choice for the rolling process of hydraulic mill. It is worthy to pay attention to the characteristic of robust controller. It is always used for that whereas it contains the uncertainty factor in the process model, but it could still obtain better control performance for controlled system. The robust control emphasizes to research on reliability of control algorithm in design method of controller. Its design target is to find that the control system must at least satisfy performance demand in actual environment to ensure security. Once the controller design is completed, its parameter can not be changed, but it can ensure the system performance to reach the design target. For hydraulic mill, its target is to make the rolling for plates and belt materials, and ensure the tolerance of wall thickness of plates and belt materials to be within allowable range. The basic characteristic of HSIC (i. e., Human Simulated Intelligent Control) can satisfy the demand of robust controller. The control strategy of HSIC is to simulate the control behavior of control expert. Therefore, its control algorithm is multi-modal control, and the mathematical method is to execute alternate use among multi-modal control. Such a characteristic of HSIC can make contradictions of control quality demand be perfectly harmonized for control system. Therefore, it is a sort of wiser choice. In this paper, starting from strategy optimization, it presents a sort of fusion control strategy based on expert control system and human simulated intelligent controller. The intelligence fusion based control strategy summarizes the control skill and experience of field operators, and it can be concluded as the engineering control algorithm based on HSIC. All the simulation and field debugging results show that the fusion control strategy is feasible and valid for real industrial applications.

3.2. Structure of control model

Based on the fusion of human simulated intelligent control and expert control technique system, the structure of control system is shown as in Fig. 1.

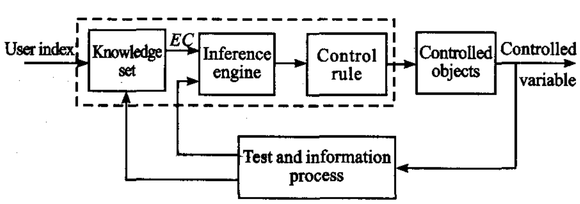

Fig. 1 Structure of control model based on fusion strategy

After the expert system technique is introduced into control system, it could make the structure of control model be simplified. The expert system is an intelligent program system that can solve the problem only solved by expert in special field in terms of knowledge base and inference machine. All the knowledge base, inference machine and rule set could be integrated into the human simulated intelligent controller that is excellent in performance, and simple in system structure, therefore it can excellently control the wall thickness outlet of plates and belt materials and input appropriate amount in plates and belt materials. The system of intelligence fusion based control strategy can realize multi-modal control by use of expert technique system in flexible mode since the control strategy is based on the basic characteristic combined open-loop and closed-loop control. Therefore, it is enhanced to the performance of the judge and inference. In fact, to establish knowledge set is how to express the obtained known-knowledge. The control system always adopts production rule to establish the knowledge set, its basic structure could be expressed as If < condition > Then < action >. Based on fusion strategy constituted by production rule, its outstanding advantages of system structure of control model are that it is good in modularity, it could be independent in addition, deletion and modification for each piece of control rule, and it is not direct affiliation among each piece of control rule. And also it is good in naturalness and suitable for the peculiarity of rolling process control.

4. Discussion about control algorithm

The control algorithm adopts improved prototype algorithm of human simulated intelligent controller based on semi-proportion adjustor.

$$u = \begin{cases} K_p e + kK_p \sum_{i=1}^{n-1} e_{m,i} & , e \cdot \dot{e} > 0 \cup e = 0 \cap \dot{e} \neq 0 \\ kK_p \sum_{i=1}^{n-1} e_{m,i} & , e \cdot \dot{e} > 0 \cup \dot{e} = 0 \end{cases}$$

In which, u is the control output, K_p is the proportional coefficient, k is the constraint coefficient, e is the system error, $e_{m,i}$ is i^{th} the system error rate of change, $e_{m,i}$ is i^{th} error peak value. The algorithm is to run the control at unit level. In the control algorithm, firstly the fusion controller identifies two sorts of simple characteristic relation of error and error rate of change, then it judges two sorts of different motion state of dynamical system, finally the controller adopts two sorts of different control modal respectively, so as to implement the control for rolling process. The output of quantitative control operation is decided by the relation among error peak value of characteristic memory and experienced knowledge (i. e., proportional coefficient K_p and constraint k) and current error value. Therefore, the algorithm not only has qualitative decision process (i. e., identification of motion state and selection of corresponding control modal), but it also has quantitative control (i. e., output of material control modal). According to the algorithm of human simulated intelligent controller based on semi-proportion adjustor, it could form a simplified algorithm and engineering algorithm as follows.

1) Simplified algorithm

The simplified algorithm can be described as the following.

Pattern 1 If $e_n \cdot \Delta e_n > 0$ or $e_n = 0, |e_n| > 0$,
Then $u_n = u_{n-1} + k_+ \cdot e_n$

Pattern 2 If $e_n \cdot \Delta e_n < 0$ and $|e_n| \geqslant M$,
Then $u_n = u_{n-1} + k_- \cdot e_n$

Pattern 3 If $e_n \cdot \Delta e_n < 0$ and $|e_n| < M$ or $e_n = 0$, Then $u_n = u_{n-1} + k \cdot e_{m,n}$

In which, e_n is n^{th} error, $e_n = e_n - e_{n-1}$, $e_{m,n}$ is the extreme error of n^{th}, k_+ is a quickening scale coefficient and $k_+ > 1$, k_- is a suppression scale coefficient and $0 < k_- \leqslant 1$, k is a hold scale coefficient and $0 < k < 1$, M is the setting error boundary, n represents the order number of control cycle, u_n is the amount of current control output, u_{n-1} is the amount of control output before the n^{th} cycle.

2) Engineering control algorithm

According to the prototype algorithm of human simulated intelligent controller and further summarize the hominine control experience, it can form the control rule set of rolling process to be suitable for different characteristic status. The material control rules are as the follows.

If $e > \beta R$ Then $u_n = u_m$
If $e < -\beta R$ Then $u_n = -u_m$
If $|e| < \delta_1$ and $|\dot{e}| < \delta_2$ Then $u_n = u_{n-1}$
If $|e| > m \cdot R$ and $e \cdot \dot{e} > 0$ Then $u_n = u_p$
If $e \cdot \dot{e} < 0$ and $|e/\dot{e}| > a$ Then $u_n = \alpha p_1$
If $e \cdot \dot{e} < 0$ and $|e/\dot{e}| > b$ Then $u_n = p_1 + K_d \dot{e}$
If $e \cdot \dot{e} < 0$ and $b \leqslant |e/\dot{e}| \leqslant a$ Then $u_n = p_1$
If $e \cdot \dot{e} \geqslant 0$ and $|e| \in (\delta_1, \theta_1)$, $|\dot{e}| \in (\delta_2, \theta_2)$
Then $u_n = P_1 + K_{p2} e + K_{i2} \sum e_j$
If $e \cdot \dot{e} < 0$ and $|e| \in (\delta_1, \theta_1)$, $|\dot{e}| \in (\delta_2, \theta_2)$
Then $u_n = P_1 + K_{p2} e$;
If $e \cdot \dot{e} \geqslant 0$ and $|e| > \theta_2$
Then $u_n = P_1 + K_{p1} e + K_{i1} \sum e_j - K_d \dot{y}$

In which, u_n is the n^{th} output of controller, u_m is an output holding value related to input variation ΔR, u_p is a constraint holding value, e and $\dot{e}$ are the system error and error rate of change, respectively. $\dot{y}$ is the object output rate of change. $p_1 = r \sum_{i=1}^{l} e_{m,i}$ is the latest holding value of control output, in which, $e_{m,i}$ is the j^{th} extreme error, r is an extreme weighting factor that can be modified on line. K_{p1}, K_{p2}, K_{i1}, K_{i2} and K_d are the gain coefficients of proportion, integral and differential coefficient, respectively. $\sum_j e_j$ is accumulative error when $e \cdot \dot{e} \geqslant 0$. Coefficient β is a switch factor. α, a and b are constants determined by experience rules in the knowledge set, respectively. R is a setting value. δ_1, δ_2, θ_1 and θ_2 are the allowable error and error rate of range, respectively.

5. Simulation experiment and its analysis

5.1. Simulation experiment

For convenience, here it only takes simplified control algorithm to conduct the simulation. To ignore the influence of various factors such as nonlinearity, time varying, uncertainty and so on, the robust controller could ensure the control quality of hydraulic mill, and therefore the simulated mathematical model is not so important. If the hydraulic mill system is considered as one order process with time lag, then its control process can adopt the model of inertia node with pure time lag to be described approximately.

$$W(S) = K e^{-\tau s} / (Ts + 1)$$

In which, τ, T and K are the pure lag time, time constant of rolling process and gain coefficient, respectively. Generally, three parameters in the formula can be determined by means of unit step response method. For convenience, here it takes $\tau = 2$, $T = 1.2$, $K = 1$, therefore the model could be written as:

$$W(S) = e^{-2s}/(1.2S + 1)$$

Under the condition of Matlab environment, adopting unit step input signal and Simulink tool box, it could build simulation system model to conduct the simulation of control process. The simulation adopts the PID and intelligence fusion based control algorithm (i. e., simplified as HSIC in the following figure) to be in charge of the same process, respectively, and the simulation curves are shown in Fig. 2.

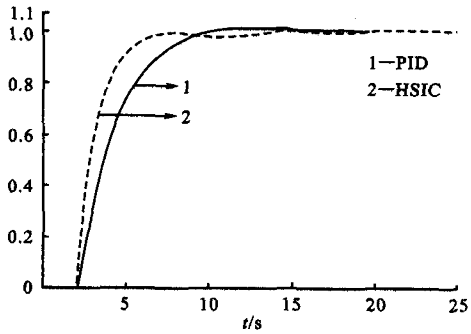

Fig. 2 Process response

In the Fig. 2, the curve 1 and curve 2 are the response curves by PID and HSIC, respectively. From Fig. 2, it could be seen that both PID and HSIC can not be in overshoot, however for the PID control the time of rising and regulating is lower than that of HSIC, therefore the HSIC owns better control effect.

5.2. Comparison of anti-interference capacity

At the time of $t = 4.5$ s, it imposes a pulse disturbance with 0.5 amplitude for the process, and the response curve is shown as in Fig. 3. From this Figure, it can be seen that the response of HSIC is better than that of PID in anti-interference capability.

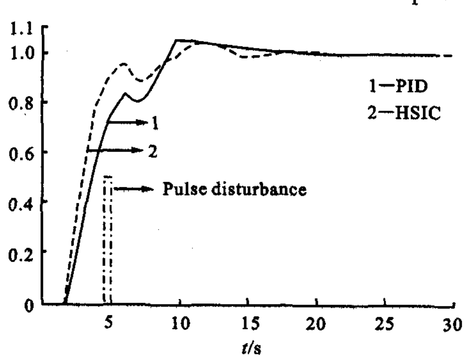

Fig. 3 Process response under disturbance

5.3. Comparison of robustness for parameter changing

The parameter consists of K, T and τ, and for simplification, here it would add an inertia node $1/(2S+1)$ for controlled object, namely when the transfer function of controlled object changes from $W(S) = e^{-2s/(1.2S+1)}$ to $W_1(S) = e^{-2S}/(1.2S+1)(2S+1)$ the response curve is shown as in Fig. 4. From the Fig. 4, it can be seen that the system response is almost not changed for HSIC control and there is no overshoot. However, the overshoot phenomena is comparatively clear for PID control.

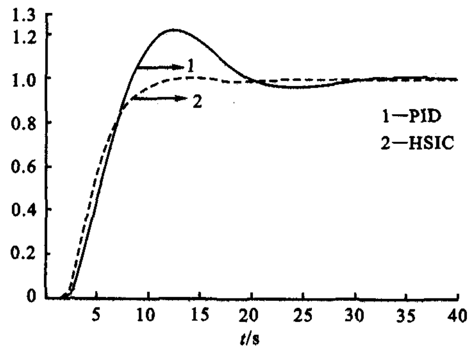

Fig. 4 Response of two-order process with pure lag

5.4. Analysis of simulation experiment

When there exits a disturbance, the HSIC owns better anti-interference capability than PID. When the system parameters get changed, the HSIC has very strong robustness than PID. In the controlled process of hydraulic mill, the PID control produces very obvious overshoot, and the rising as well as regulating time get slow, but those of HSIC are not changed. The simulation mentioned above shows that control algorithm of HSIC has much better control quality than that of PID.

6. Conclusions

The rolling process of hydraulic mill is continuously changed in the whole rolling process of plates and belt materials. In order to make the difference of wall thickness after rolling satisfy the specified output standard, this paper proposed a kind of fusion control strategy based on HSIC. By means of intelligence fusion based control strategy, the difference of wall thickness can be controlled within allowable tolerance range. The simulation results show that when the fusion control strategy is adopted the control quality of system is much better than that of PID. Furthermore, the fusion control strategy based on HSIC has much simpler system structure and better real time performance than those of conventional control strategy.

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液压 AGC 系统的智能融合控制策略

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摘要:针对液压系统存在的非线性、滞后、强耦合、不确定性及干扰等控制难题,提出了一种基于智能融合的液压 AGC 系统控制策略。论述了参数的影响因素,讨论了液压系统的控制论特性,研究了系统的控制策略,基于智能融合设计了控制模型与控制算法。在实验室条件下,借助不同控制算法作了仿真对比研究.仿真曲线显示融合控制策略响应速度更快,无超调,控制精度更高。研究结果表明所提出的控制策略是可行与合理的。

关键词:液压 AGC;融合控制策略;鲁棒性

中图分类号:TP273;TH137

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恒力铣削智能控制算法研究与仿真

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摘要:针对数控加工,建立了 2 种以切削力恒定为控制目标的在线智能控制系统。首先,利用 BP 神经网络对铣削过程进行了建模;然后,基于 BP 神经网络和模糊控制理论,提出了 2 种以切削力恒定为控制目标的在线铣削控制算法;最后,在变轴向切削深度条件下开展了仿真实验。相对于传统恒速切削,基于 BP 神经网络和模糊控制的在线智能控制系统分别节省了 13.9% 和 13.7% 的切削时间。

关键词:恒力铣削;智能控制算法;神经网络;模糊逻辑

中图分类号:TH116