Design of DEH Test Platform for Steam Turbine's Hydraulic Actuator Valve Use

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Abstract. Digital Electro Hydraulic (DEH) control System, a key element including the nonlinear aspects, is an important control component of the steam turbine control system. The changes in parameters of DEH affect greatly on dynamic characteristics and quality of electricity produced by steam turbine. This paper study the parameter identification on DEH, propose a multi-particle swarm optimization method (MPSO) to increase the accuracy of DEH parameter identification. Then a test platform was designed for DEH with MPSO model. Performance test gives out detail performance parameters of hydraulic actuator which verify the veracity of DEH parameter identification based on MPSO.

Introduction

Steam turbine's DEH control system is a key component including nonlinear aspects. Its adjusting function's degradation and fault may lead to parameter changes on nonlinear aspects. Thus, parameter identification is used to check the condition of DEH in real time in order to predict fault on DEH system.

Li studied the electro-hydraulic servo system for steam turbine by correlation analysis and the least square method [1]. Dai applied the parameter identification to steam turbine speed governing system, gave simulation text and field test on turbine governing system. The test successfully got quite good time constant and other parameters of governing system which provided basis on online identification and condition monitoring [2, 3, 4].

The second part discusses the design MPSO model and gives mathematical model of DEH. The third part gives design of DEH performance test method. The forth part gives experimental test of DEH parameter identification and hydraulic actuator. The fifth part is conclusion.

The DEH Parameter Identification Based on Multi-particle Swarm Optimization (MPSO)

DHE is usually regarded as typical nonlinearity. The parameter Te in hydroelectric converter, Tc in hydraulic actuator part and Dz in nonlinear part usually drift over time. Thus it is important to calibrate these parameter regularly by using parameter identification. The nonlinearity is simplified as dead zone. Its math expression as (1) and Fig.1(a). Dz range from 0 to 1.0. The DEH system diagram with dead zone is shown in Fig.1(b).

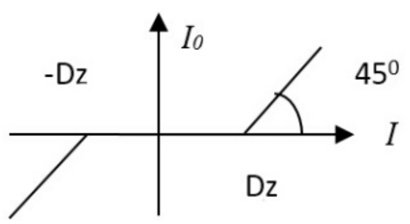


Figure 1(a) Description of Dead zone

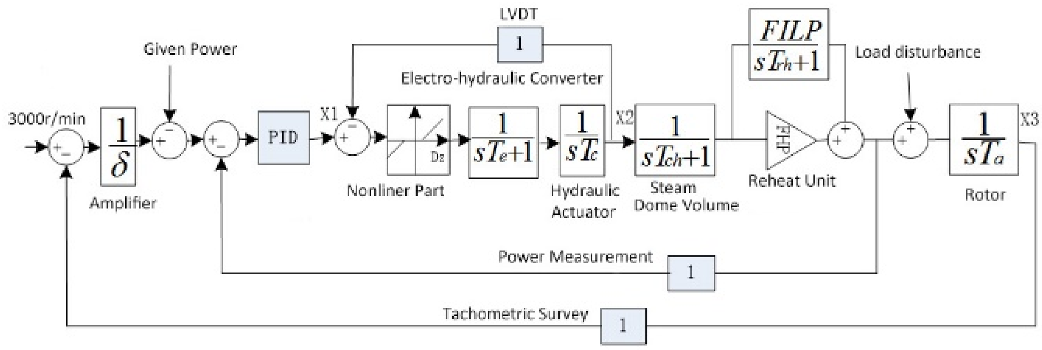


Figure 1(b) Steam turbine DEH control system block

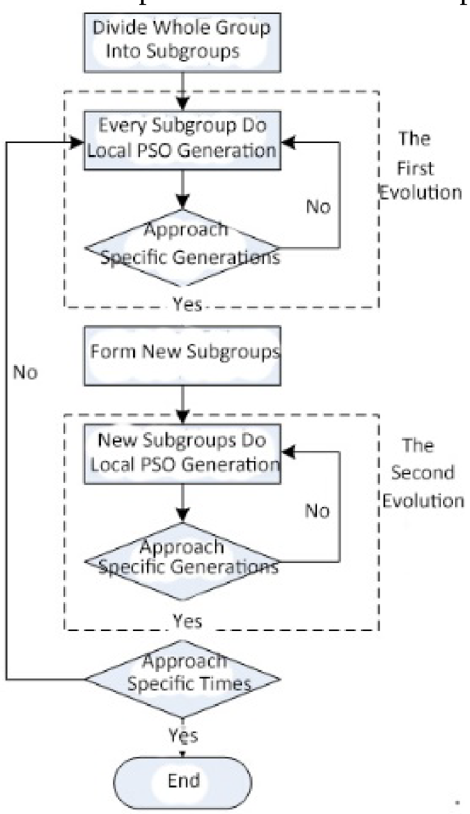
$$I_o = \begin{cases} I + Dz, & I < -Dz \\ 0, & -Dz \le I \le +Dz \\ I - Dz, & I > +Dz \end{cases} \tag{1}$$

Particle swarm optimization (PSO) has several steps. Firstly initialize a group of random particles whose position is Xi. Then these particles find the optimal solution by iteration. During the updating process particles update their position to local optimum. Step size is Vi. The iterative process should meet practical problems. Standard PSO with inertia weight w is shown as follows

$$v_{id}^{t+1} = w * v_{id}^{t} + c1 * rand_1^k * (p_{id} - x_{id}^t) + c2 * rand_2^k * (g_d - x_{id}^t) \tag{2}$$

$$x_{id}^{t+1} = x_{id}^{t} + v_{id}^{t+1} \tag{3}$$

In the equation (2) and (3), i=1，2，…，m； d=1，2，…n；c1，c2 value from 0 to 2; rand1, rand2 are random numbers value form [0, 1] and independent of each other. t =1，2，…， is current iterations. W: inertia weight. PSO has two disadvantages: One is its easily running into prematurity, the other is low convergent speed [6]. Running into prematurity is that particles get into local optimum that is not global optimization solution and will not evolve any more. Low convergent speed happens because PSO could not obtain all information of each particles and could not remove particles that is poor in evolution. These poor particles cause bad solution.



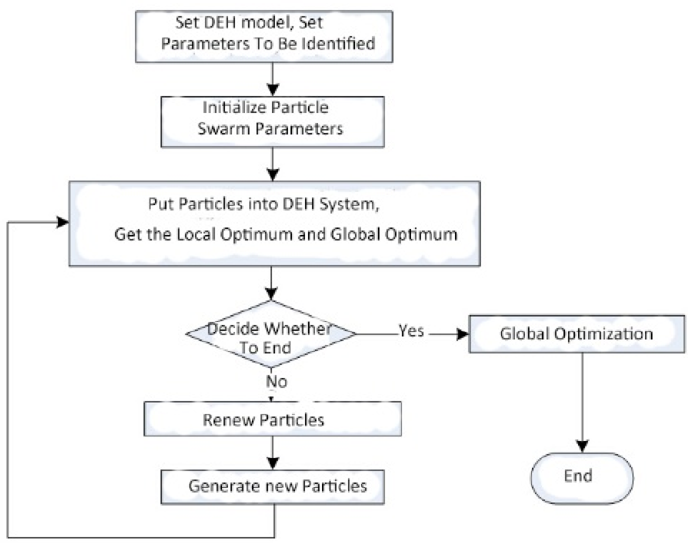


Figure 2(a). The basic process of MPSO Figure 2(b) Flow chart showing identification of the model parameters of the electrical hydraulic turbine governing system

In this paper, the multi-particle swarm optimization (MPSO) method is used to achieve the process as shown in Fig.2(b). The former double evolutions make up the first round evolutions. Put the particles values into former local model and then local optimum continue to evolve. The evolution process acts in loops. Eventually, evolution loops achieve certain amount or the solution can fulfill the requirement of actual question. Then we can get the global optimization solution.

By using the MPSO process to identify the parameter in DEH system, the process have six specific steps, as follows.

(a.) Set simulation models of DEH system include unknown parameters by Matlab/Simulink. Set parameters that need to be identified and their ranges.

(b.) Initialize parameters value of MPSO process. This step should include set group size, maximum iterations and inertia weight.

(c.) Initialize particles' positions and acquire a group of random value of parameters need to be identified. Get model responses by Matlab/Simulink simulation.

(d.) Compare the simulation response to the system actual response. Constructing error function:

$$e = \sum_{i=1}^{n}(|\emptyset - \emptyset_0|) \quad (4)$$

In the equation (4), $\emptyset$ is the position output of hydraulic actuator in DEH system. $\emptyset_0$ is the actual output of hydraulic actuator in DEH system. When the value of e is smaller, it means that the model parameters are better.

(e.) Till the function value e becomes the minimum or the iterations achieves preset number, the PSO process of parameter optimization stop. At this time, the position of parameters can be regarded as the global optimization solution.

Test Method Design of Hydraulic Actuator DEH System

Test Methods.

How the hydraulic actuator works is shown in Fig.3. When the solenoid valves L1 and L2 are powered, cartridge valves A and B are not connected. The pathway between piston intake and tank is disconnect. When the servo valve get control signals of turn on valve, the valve core of servo valve turn right. The hydraulic fluid flow through throttle valve 12 and 13, then enter oil cylinder which make the cylinder pressure increase. The hydraulic fluid overcome resistance of spring force and friction force. At last, the valve move with help of piston rod. In case of the emergency, for instance, the solenoid valve should be turned off L1 or L2 or both of them to load rejection.

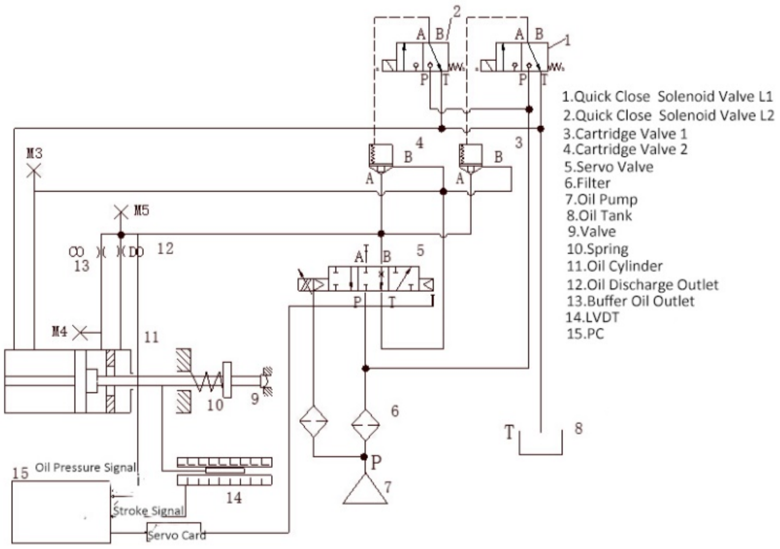


Figure 3. The working principle of hydraulic actuator.

The test aim to measure the closing performance of hydraulic actuator. Before the load rejection test, the time between switch off and valve closing to no load should be measured. The load rejection test should be recommended test after overhauling. Oil pressure test can make sure the spring force and friction force. In the process of oil pressure test, we can easily know the assembly accuracy and manufacture precision of hydraulic actuator. That is meaningful in its manufacture process. Open and close test: made the hydraulic actuator running back and force, and measure the time of open process and close process. These two parameters can be used to judge the actuator's working performance. Step response test: Some actuator has servo board with typical proportional component. So we should measure the overshoot and overshoot time of sudden upgrade and downgrade process.

Algorithm of Hydraulic Actuator.

We can get several performance parameters of hydraulic actuator after tests. The Fig. 4(a) shows the sketch of valve stroke. Fig. 4(b) shows ideal quick close stroke curve.

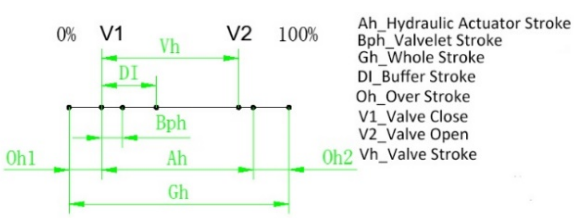


Figure 4(a) Sketch of valve stroke.

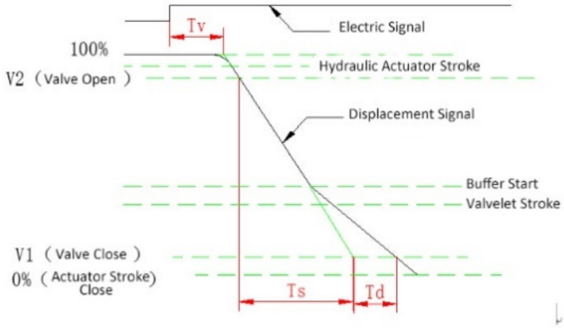


Figure 4(b) Ideal quick close stroke curve.

According to the Fig 4. We can calculate the parameters of sensitivity: Sen, delay time: tv, close time: ts, terminal velocity: Ev, buffer time: td. The Sen is shown as (5).

$$\mathrm{Sen} = \frac{I_{100\%} - I_{0\%}}{\mathrm{Gh}} \tag{5}$$

$$\mathrm{V1} = I_{0\%} + \mathrm{Sen} * \mathrm{Oh1} \tag{6}$$

$$\mathrm{V2} = I_{0\%} + \mathrm{Sen} * (\mathrm{Oh1} + \mathrm{Ah}) \tag{7}$$

During the valve stroke from 80% to 40%, take points from every 5% point. Than use these points to make curve fitting: L1. Than the straight slope K1 and zero point B1 can easily be calculated.

$$\mathrm{tv} = I_{100\%} - \mathrm{B1} \tag{8}$$

$$\mathrm{ts} = \frac{\mathrm{V1} - \mathrm{V2}}{\mathrm{K1}} \tag{9}$$

To get the terminal velocity: Ev, we need to get the intersections of stroke curve and V1 horizontal line to fit curve line L2. And straight slope of L2 can also be calculated as K2.

$$\mathrm{Ev} = \left|\frac{\mathrm{K2}}{\mathrm{Sen}}\right| \tag{10}$$

In the meantime, the buffer time should be as (11).

$$\mathrm{td} = \frac{\mathrm{V1} - \mathrm{B2}}{\mathrm{K2}} - \frac{\mathrm{V1} - \mathrm{B1}}{\mathrm{K1}} \tag{11}$$

In the oil pressure test, get stroke signal and oil pressure signal and match them one to one. Then get oil differential pressure between up stroke and down stroke. Find the maximum oil pressure and determine the spring force and friction force.

The software in PC was write by LabVIEW, working with the 6238 data sampling card of NI. Test platform mainly consist of electro-hydraulic converter, hydraulic actuator and LVDT.

Verification of DEH Parameter Identification and Hydraulic Actuator Performance Test

Test Program

To analyze the hydraulic actuator DEH system parameter identification, signal stimulus need to be imposed on the DEH system. Then we can get time field output response. Lastly, use these output and use software we have made to identify exactly parameters.

To verify hydraulic actuator's performance, quick close test, oil pressure test and open and close test should be carried out one by one.

Result Analysis of Parameter Identification

There are two parts in the parameter identification. The first part is using the simulation method to verify if it is correct to apply MPSO on the parameter identification. The second part is apply the parameter identification result on the DEH system and have a field test. Eventually, we can get the exact model of servo link.

In this paper, the multi-particle swarm optimization (MPSO) method's parameters as follows. Particle population 80, divide them into 8 groups. Every population has 10 subgroups. Every subgroup evolves 10 generations. Every group evolves 10 times. The result of Executive link parameters identification on DEH system is shown in Table1.

Table 1. Executive Link Parameters Identification Result

Model Parameters	Dz	Te/s	Tc/s
Nominal Value	0.1	0.03	0.6
Identification Value（MPSO）	0.1000242	0.029747	0.600871
Relative Error（MPSO）	0.0242%	0.843%	0.145%

On the Table 1, we can see relative error of parameter identification is around 1% which proved it effective.

Having proved the accuracy of MPSO, we use this algorithm to identify parameters in hydraulic actuator DEH system. Fig.5 shows a response curve towards 100% step signal input. The response curve was write down by LVDT as output voltage waveform.

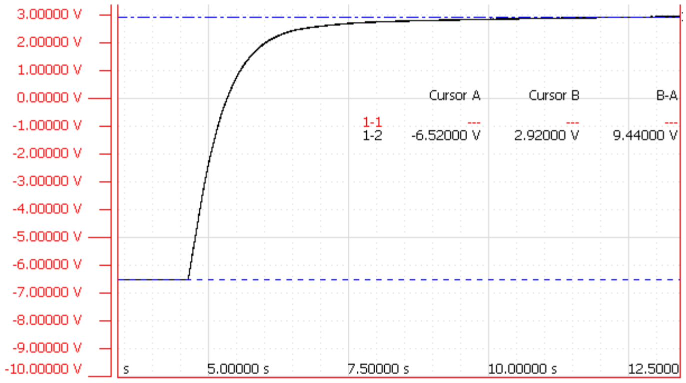


Figure 5 Step response 0f 0-100%

By using MPSO to identify parameters, the result is shown in Table2. (The result present 3 significant digits.)

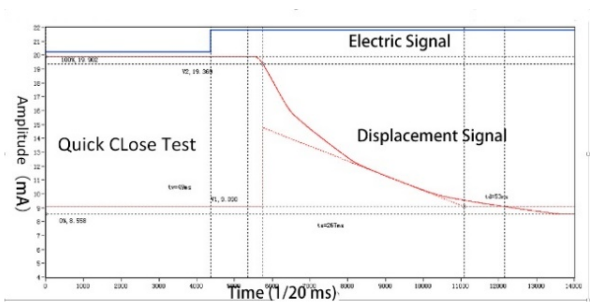
Table 2 Result of Parameter Identification

Parameters	100%	Nominal Value	Error
Dz	0.0771	0.1	2.29%
Te/s	0.0399	0.03	33%
Tc/s	0.585	0.6	2.5%

From the Fig.5 and Table2, We can easily find the result of parameter identification has high precision. The simulation curve is almost the same with the actual response curve.

Performance Test and Result Analysis

After several hydraulic actuator tests, some measure curves are shown in Fig.6. The performance details are also shown in the pictures.



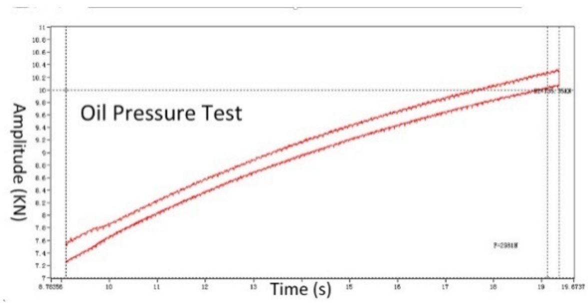


Figure 6（a）Measure curve of quick close test   Figure6 (b) Measure curve of oil pressure test.

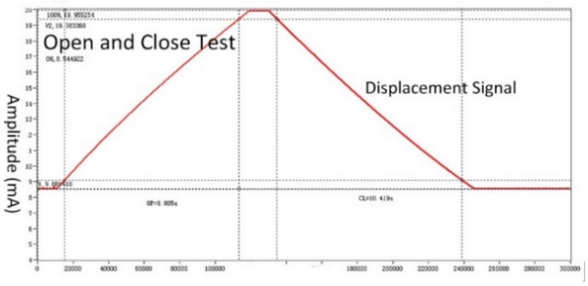


Figure 6（c） Measure curve of open and close test.

Conclusions

Multi-particle swarm optimization (MPSO) method is based on the particle swarm optimization (PSO) method. MPSO is applied on parameter identification of steam turbine's DEH system. Combine with dead zone feature we set up the mathematical model of DEH system. The simulation result indicates that MPSO method is accurate and the precision is around 1%. The field test also verifies the reliability of identification precision. The DEH system has variable parameters in nonlinear zone. Using MPSO to identify parameters can ensure DEH normal running.

References

[1] Yong Li, "Simulattion and Parameter Identification of DEH System on Steam Turbine", Zhangjiang University, 2005.

[2] Yiping DAI, Maozheng YU and Jiong LIU LI: Parameter Identification of Steam Turbine Governing System Based on Correlation Analysis, Turbine Technology, 43(5):276-279，297 (2001 05.008.)

[3] Yiping DAI, Maozheng YU and Jiong LIU LI: Experimental Study of Parameter Identification for a Correlation Analysis-based Steam Turbine Governing System, Journal of Engineering for Thermal Energy and Power ,17(3):248-250, (2002)

[4] Yiping DAI, Maozheng YU and Jiong LIU LI: Study on Parameter Identification for Steam Turbine DEH System Based on Genetic Algorithm, *Proceedings of the Chinese Society for Electrical Engineering*, 22(7):101-104. (2002)

[5] Yu PENG, Xiyuan Peng, Zhaoqing LIU: Statistic Analysis on Parameter Efficiency of Particle Swarm Optimization, *ACTA Electronica Sinica*, 32(2):209-213, (2004)