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RESEARCH ARTICLE

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ARTIFICIAL BEE COLONY TUNED PID CONTROLLER FOR VIBRATION CONTROL IN TWO MASS DRIVE SYSTEMS

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ABSTRACT

A drive system consists of a motor and a load machine which are connected through a shaft. In most cases, this shaft is assumed to be fixed but actually it is not fixed but possesses a certain degree of elasticity in it. This elastic nature of the shaft can cause speed difference between motor and load machine. This speed difference has a negative impact on the overall performance of the system. Owing to this speed difference, oscillations are produced and they make the system unstable. Hence some kind of control action is needed to reduce these oscillations as far as practicable. In this paper, I have taken up a recently developed algorithm which is based on the swarm behavior of birds known as Artificial Bee Colony (ABC) algorithm for fine tuning of PID parameters. The simulation result thus obtained is compared with that of a conventional PID controller depicting the improved control action of ABC tuned PID controller over the conventional one.

Key Words: ABC, elasticity, oscillations, PID controller, pole placement method, Two-mass drives system.

I. INTRODUCTION

Oscillations are present in all mechanical systems. By oscillation we mean the continuous change in the position of any object following a regular path. In a two mass drive system since there are two different inertial sides - motor side and load side, production of oscillations are very common. These oscillations arise from the fact that the speed of motor and load are never ideally equal as they are connected through an elastic joint/shaft. These oscillations hinder the performance of a system in many ways such as, they deteriorate the efficiency of the system, decreases the speed of response and, in the worst case they may even lead to complete failure of the system. Hence it becomes an utmost priority for designers to reduce these oscillations in the maximum possible way. Different controllers are available which can be implemented to reduce these oscillations out of which PID controllers are mostly used as they offer great simplicity in implementation and distinct functionality. A PID controller involves three different parameters, and hence called the three-term control: the proportional (P) control, the integral (I) control and the derivative (D) control. The proportional (P) control determines the current error, the integral (I) control determines the accumulation of past errors, and the derivative (D) control predicts the future error. The weighted sum of these three control parameters is used to provide optimum control structure of the system.

The main thing that is to be kept in mind while using a PID controller is to find the optimum or best parametric gain values of the controller namely Kp- proportional control, Ki- integral control and Kd- derivative control. For fine tuning of these constant parameters, there are again several methods that can be employed. Trial and error method, pole placement method, Ziegler-Nichols method are some of the tuning methods that can be mentioned. Here in this paper, I have studied the control action of the PID controllers tuned using pole placement method. Moreover for optimum tuning of these gains, different optimization algorithm can also be used. In this regard, I have selected Artificial Bee Colony optimization algorithm to obtain the gain values.

II. Related Work

F.Qiao et al. [1] studies the vibration suppression and the disturbance rejection of the two-mass drive system in rolling mill of a steel works with Kalman filter improved state feedback pole placement controller. In this paper, it is shown that the proposed controller improved the transient behavior of the system to the conventional PI controller. S.Thomsen and F.W. Fuchs [2] presents the design, analysis and comparison of the conventional PI-control to two state space controllers for the control of speed of drive systems with elastically coupled loads. Slobodan N. Vukosavi´c and Mili´c R. Stoji´c[3] in their paper deals with the problem of mechanical resonance in modern servo drive systems having the speed control loop =bandwidth and resonance frequency above 100 Hz. Kumaran Rajarathinam et al. [4]investigated Standard genetic algorithms (SGAs) to optimize discrete-time PID controller parameters for a multivariable glass furnace process with loop interaction by three tuning approaches. Initially, standard genetic algorithms (SGAs) are used to identify the control of the plant which is subsequently used for optimization of the controller.

The first tuning approach is considered to categories the cost functions, genetic operators and improves searching boundaries to obtain the desired performance criteria without loop interaction. The second tuning approach with loop interaction and individual cost functions considers optimization of the controller parameters. While, the third tuning approach utilizes a modified cost function which includes the total effect of controlled variables, glass temperature and excess oxygen. This modified cost function is found to produce improved disturbance rejection and control robustness and under loop interaction.

Krzysztof Szabat and Teresa Orlowska-Kowalska [5] present the analytical design procedure of a speed control system with PI and PID controllers with different additional feedbacks for a drive with elastic joint. The comparative analysis based on the location of closed-loop system poles is presented. Ruicheng Zhang et al. [6] proposed that the state feedback control can be effectively used to suppress the torsional vibration of the main drive system in a rolling mill. In this paper, a new observer known as extended state observer (ESO) is proposed to estimate the unknown states and the disturbance torque of the load. ESO based speed controller with an integrator and load torque feed forward compensation for torsional vibration reduction in two-mass main drive system of rolling mill is proposed.

Mohammed E.El-Telbany [7] in his paper, he uses Artificial Bees Colony (ABC) optimization algorithm for regulating the parameters of PID controller of DC motors. The aim of this paper is to improve a DC motor in terms of its tracking performance. At the end of the study, he successfully showed that ABC algorithm produce better performance.

T. Ananthapadmanaba et al. [8] presents the design and analysis and also the comparison of the conventional PI-controller to control structure using PI aided by various feedbacks for improving the performance of the Industrial drives system.

Some studies related to Artificial Bees colony algorithm can be found in the literatures [9, 10 and 11].

III. Mathematical Model of The Drive System

In this paper, a two mass drive system with whippy shaft is considered. There are many mathematical models that can be used for the study of the plant with elastic/flexible couplings. In many cases, the drive system can be approximated as a two-mass system, where the first mass refers to the moment of inertia of the drive and the second mass represents the moment of inertia of the load side.

The damping of the two-inertia system is very low, and friction can be neglected without affecting analysis accuracy [5].The schematic model of the two mass drive systems can be represented by the following figure 1.

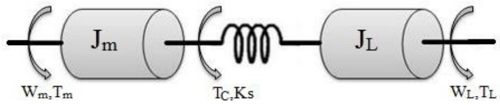

Fig.1: Schematic diagram of two mass systems.

The equations describing the model of our system after neglecting the nonlinear friction is given by

$$\frac{d}{dt}\begin{bmatrix}\omega_m(t)\\ \omega_L(t)\\ t_s(t)\end{bmatrix}=\begin{bmatrix}0 & 0 & \frac{-1}{T_1}\\ 0 & 0 & \frac{1}{T_2}\\ \frac{1}{T_C} & \frac{-1}{T_C} & 0\end{bmatrix}\begin{bmatrix}\omega_m(t)\\ \omega_L(t)\\ t_s(t)\end{bmatrix}+\begin{bmatrix}\frac{1}{T_1}\\ 0\\ 0\end{bmatrix}[t_m]+\begin{bmatrix}0\\ \frac{-1}{T_2}\\ 0\end{bmatrix}[t_L] \quad (1)$$

Where

ω_m – speed of motor

ω_L – speed of load

T_1–mechanical time constant of motor

t_s – shaft torque

T_2 – mechanical time constant of load

t_m – motor torque

T_C– stiffness time constant

t_L – load torque

For simulation purpose, the parameters of the drive system are taken as T_1=203 ms, T_2=203 ms and T_c=2.6 ms[5].

IV. PID Control Structure And Design

The classical control structure of a two mass drive system is given in figure 2 shown below comprising of a power source, converter-fed motor, a load and a control system comprising of sensing unit and control unit.

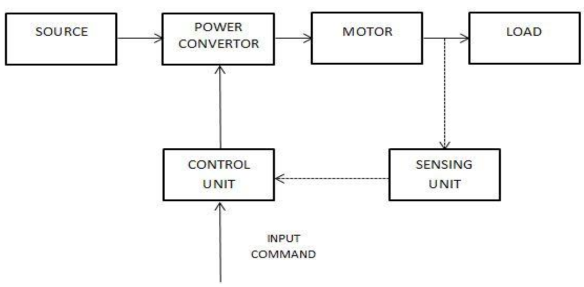

Fig.2: The classical control structure [5]

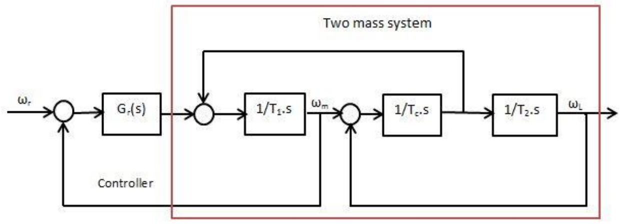

Fig: 3 control structure of the two mass systems

Among different controllers available, PID controller is one of the most commonly used controllers in industrial system. Its popularity is mainly because of the fact that PID controllers provide ease or simplicity in implementation; high efficiency and robustness. The PID control scheme is named after its three correcting terms, whose sum constitutes the output of the controller.

$$y(t) = K_p e(t) + K_i \int_0^t e(\tau)d\tau + K_d \frac{d}{dt} e(t) \quad (2)$$

Where

K_p = proportional gain

K_i= integral gain

K_d= derivative gain

$e(t)$ =Error

In a proportional controller the actuating signal (output) is directly proportional to the error signal.

$$P_{out} = K_p e(t) \quad (3)$$

In integral controllers the actuating signal (output) is directly proportional to the integral of the error signal.

$$I_{out} = K_i \int_0^t e(\tau)\, d\tau \quad (4)$$

In a derivative controller the actuating signal (output) is directly proportional to the derivative of the error signal

$$D_{out} = K_d \frac{d}{dt} e(t) \quad (5)$$

The transfer function of the control structure without additional feedbacks are given by

$$G\omega_m = \frac{G_r(s^2T_2T_C+1)}{s^3T_1T_2T_C+s^2T_2T_cG_r+s(T_1+T_2)+G_r} \quad (6)$$

$$G\omega_L = \frac{G_r}{s^3T_1T_2T_C+s^2T_2T_cG_r+s(T_1+T_2)+G_r} \quad (7)$$

Where,

$G_r = sK_d + K_p + \frac{Ki}{s}$is the transfer function of the speed controller.

The characteristic equation of the considered system is given by

$$S^4 + S^3\left\{\frac{T_2T_CK_P}{T_2T_C(T_1+K_d)}\right\} + S^2\left\{\frac{T_2T_CK_i+T_1+T_2+K_d}{T_2T_C(T_1+K_d)}\right\} + S\left\{\frac{K_p}{T_2T_C(T_1+K_d)}\right\} + \left\{\frac{K_i}{T_2T_C(T_1+K_d)}\right\} = 0 \quad (8)$$

The desired polynomial of the system is in the form

$$(S^2 + 2\xi\omega + \omega^2)(S^2 + 2\xi\omega S + \omega^2) = 0 \quad (9)$$

Where

ξis the damping coefficient

ωis the resonant frequency of the closed-loop system.

Solving the above equation we have,

$$S^4 + S^3(4\xi\omega) + S^2(2\omega^2 + 4\xi^2\omega^2) + S(4\xi\omega^2) + \omega^4 = 0 \quad (10)$$

Now comparing the coefficients of eqn. (8) and (10) we get

$$4\xi\omega = \frac{T_2T_CK_P}{T_2T_C(T_1+K_d)} \quad (11)$$

$$2\omega^2 + 4\xi^2\omega^2 = \frac{T_2T_CK_i+T_1+T_2+K_d}{T_2T_C(T_1+K_d)} \quad (12)$$

$$4\xi\omega^2 = \frac{K_p}{T_2T_C(T_1+K_d)} \quad (13)$$

$$\omega^4 = \frac{K_i}{T_2T_C(T_1+K_d)} \quad (14)$$

Solving the above four equations we get the values of K_p, K_i and K_d as follows

$$K_p = 2\sqrt{\frac{T_1+K_d}{T_C}} \quad (15)$$

$$K_i = \frac{T_1+K_d}{T_2T_C} \quad (16)$$

$$K_d = \frac{T_2}{4\xi^2} \quad (17)$$

V. ABC Optimization Algorithm

ABC is a nature-inspired technique which imitates bees' foraging behaviour. The major advantages of ABC algorithm over other optimization algorithms are:

- Simplicity in implementation, flexibility and robustness
- Use of lesser number of control parameters compared to other search techniques
- Has the facility to hybridize with other optimization algorithms.
- Ability to handle the objective function with stochastic nature
- Ease of implementation with basic mathematical and logical operations.

In an ABC model, the colony is divided into three groups of bees:

a. employed bees
b. onlookers and
c. Scouts.

It is assumed that, for each food source, there is only one artificial employed bee which implies that the number of employed bees in a colony is exactly equal to the number of food sources available around the hive. Employed bees fly to their food source and returns back to hive and dance. Those employed bee whose food source has been abandoned becomes a scout and starts searching for a new food source. Onlookers are those bees that watch the dances of employed bees and choose food sources in accordance to their dances.

The main steps of the algorithm are given below:

Initialize the population
Evaluate the population
Cycle=1
repeat
employed bee phase()
{
new food source search the employed bees
Evaluate fitness and apply greedy selection
Calculate probabilities P_i for the i^{th} solution using(18)
}
onlooker bee phase()
{
onlooker bees selects a solution depending on P_i and evaluate them
Apply greedy selection process for the onlookers
}
if abandoned solution exists for the scout
then a new random solution replaces it
the best solution found so far is memorized
cycle=cycle+1
until
cycle=maximum cycle number

Fig: 4 ABC algorithm

The selection of i[th] solution for the employed bees and the onlooker bees is done based on the probability value of P_i given by

$$P_i = \frac{f(g_i)}{\sum_{m=1}^{s} f(g_m)} \quad (18)$$

Where

g_i – position of the i[th] solution and

$f(g_i)$ represents the quality of the solution

The new food position or the solution in the next iteration (k+1) is updated using (19)

$$g_i(k+1) = g_i(k) + \phi_i(g_i(c) - g_m(c)) \quad (19)$$

m: randomly chosen index different from i.

φ_i: a random number in the interval [-1, +1]

Now the quality of each solution in the colony is evaluated using the formula

$$f(i) = \frac{1}{1+J} \quad (20)$$

Where

J is the same cost function defined by authors in [5] which is given by

$$J = min \int_0^\infty (|\omega_{ref} - \omega_L|t)dt \quad (21)$$

VI. RESULTS AND DISCUSSION

The detailed information about the system responses is given in the following tables 1 & 2. It is quite clear from the response graph as well as from the table that the performance of the pole placement tuned PID controlled system has larger overshoot and longer settling time than that of the ABC tuned PID controlled system which means that ABC optimized PID controller has better performance

Table 1. Comparison of the load side responses

Type of Controller	Tp (sec) (Peak time)	Tr (sec) (Rise time)	Ts (sec) (Settling time)	%OS
PID (analytical method)	0.09420	0.03048	0.27297	60.84461
ABC tuned PID	0.07901	0.02954	0.18583	58.57351

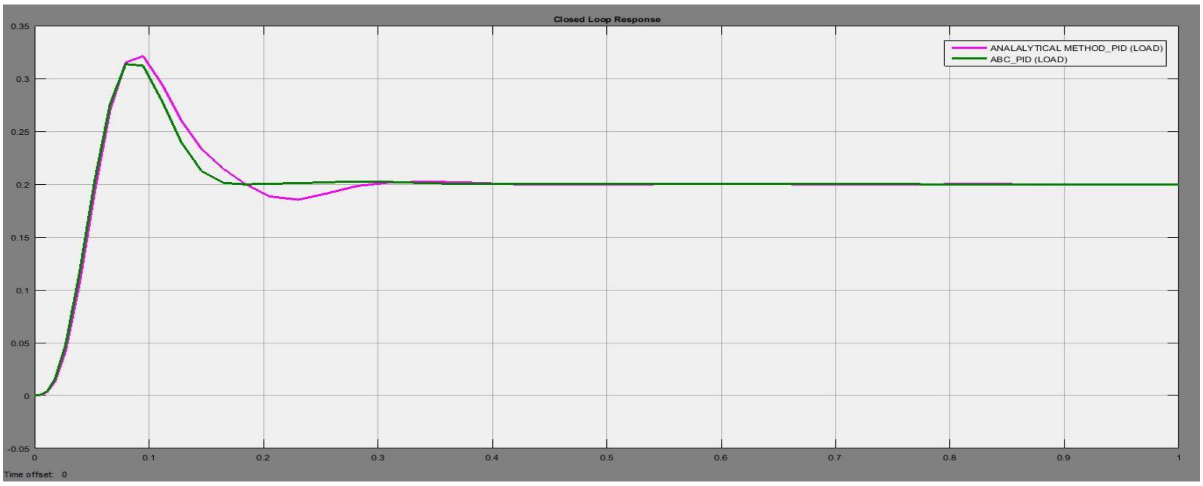

Fig:5 Comparison of the load speed response of PID-analytical method to ABC-PID

Table II. Comparison of the motor side responses

Type of Controller	Tp (sec) (Peak time)	Tr (sec) (Rise time)	Ts (sec) (Settling time)	%OS
PID (analytical method)	0.11083	0.06725	0.28729	41.33625
ABC tuned PID	0.11083	0.06748	0.17752	35.34292

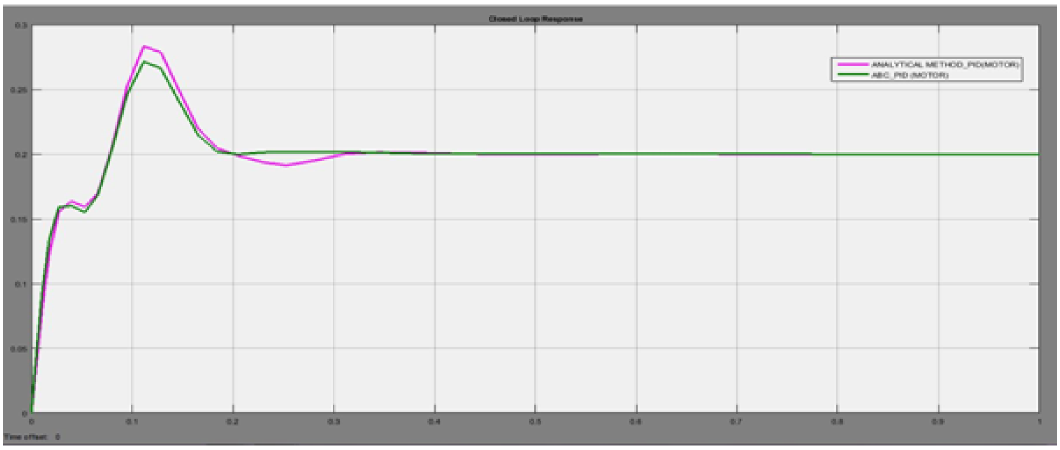

Figure: 6 Comparison of the motor speed response of PID-analytical method to ABC-PID

The figure showing the convergence of the fitness function described in equation no. (21) is given below:

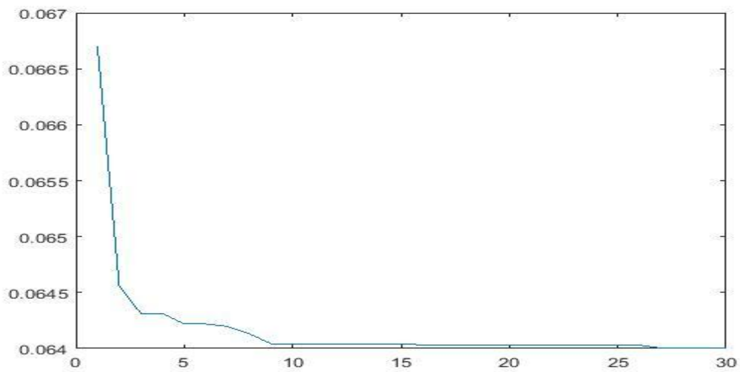

Fig: 7 Convergence of fitness function of ABC

VII. Conclusion

In this paper, torsional vibration suppression of a two mass drive system using PID controllers with parameters tuned using different methods are presented. First, a PID controller with parameters obtained using pole placement method was analyzed. In the next step a technique based on the swarm intelligence called ABC optimization algorithm was analyzed. In parallel, a comparative study between the analytical method and the ABC algorithm were investigated. The results clearly show that the response of the system controlled using ABC algorithm has better performance than that of the analytical method in terms of overshoot and settling time.

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