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FACALITYOFELECTRICAL AND ELECTRONICS TECHNOLOGY INFORMATION AND COMMUNICATION TECHNOLOL (DEPARTMENT OF ELECTRICAL AND ELECTRONICS TECHNOLOGY)

Performance Comparison of Particle Swarm and Transit Search Algorithm for Position Control of Electrohydraulic Actuator

MSc Thesis for the Partial Fulfillment of Masters of Science in Electrical Automation and Control Technology Management

by

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January ,05, 2023

ADDIS ABABA, ETHIOPIA

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DECLARATION

This thesis is to certify that the entitled to "Performance Comparison of ParticleSwarm and Transit Search Algorithm for Position Control of Electrohydraulic Actuator is my original work and has been presented for a degree in this or any other university and that all sources of material used in this work have been fully organized

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TECHNICALANDVOCATIONALTRAININGINSTITUTE(TVTI)

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Thesis on

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Abstract

Electro-hydraulic servo actuator system is widely used in process industries due to their strong power-to-weight ratio, stiffness response, high and good speed, and substantial drive system The electro-Hydraulic actuator system's nonlinearities time-varying features, and uncertainties have made it difficult to regulate the system precisely. The best controller would be highly resistant to parameter fluctuations and result in improved performances. This thesis work studies the position control of electrohydraulic actuator system. In this thesis, Fractional order proportional integral Differential controller is employed for the position control of the electrohydraulic actuator system. In the study, the electrohydraulic servo actuator system is divided into different components, which are the spool displacement, flapper valve, and electromagnetic torque motor. A separate parameter calculation is done for each components. Initially, the conventional tuning method used for the tuning of parameters of the FOPID controller. To improve the system's performance and attain anticipated time-domain specifications, the Evolutionary algorithms such particle swarm optimization algorithm and TSCO are used for tuning of FOPID controller parameters. The FOPID controllers parameters are found in this work by calculating the performance index such as rising time (0.0327), (0.0183), (0.0175) and settling time (0.0875), (0.0310), (0.0290) on working parameter in case of conventional FOPID controller, Particle Swarm Optimization algorithm and Transit Search Optimization algorithm respectively and comparing these tuning methods by validated in MATLAB-Simulink software. The objective function values must be 0.0046 and 0.0044 on 0.03 cm set point in case of using PSO and TSCO tuned FOPID controller in 0.03 cm set point .Finally, the PSO and TSCO tuned FOPID controller performance compared with the conventional FOPID controller using numerical and graphical simulation results. The simulation outcomes confirm that the TSCO tuned the FOPID controller is performing better than PSO tuned FOPID and the conventional FOPID controller.

Key words : Particle Swarm Optimization (PSO), (ITAE) ,(EHAS), conventional FOPID controller, (TSCO)

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Acronyms and Abbreviations

TSCO	Transit Search Optimization Algorism
PSO	Particle Swarm Optimization
FO-PID	Fractional Order Proportional Integral Derivative
EA	Evolutionary algorithms
PID	Proportional Integral Derivative
MIMO	Multi Input Multi Output
SISO	Single Input Single Output
FLC	Fuzzy Logic Control
EHAS	Electrohydraulic Actuator System
EHSAS	Electrohydraulic Servo Actuator
LTI	Linear Time-Invariant
ITAE	Integral Time Absolute
OF	Objective Function

CHAPTER ONE

INTRODUCTION

1.1 Background

The majority of engineering operations use the electro-hydraulic servo actuator (EHSA) system because of its strong power-to-weight ratio, stiffness response, high and good speed, and substantial drive system. In numerous applications, including industrial systems, materials testing equipment, active hold up systems, mining equipment, fatigue testing, flight simulation, ships and electromagnetic marine engineering, injection molding equipment, and a variety of other fields, hydraulic control technology has recently developed and become widely used. Due to their functions, electro-hydraulic actuators must have the best position, force, or pressure performance. The difficulty in determining the precise model of the electrohydraulic actuators, their inherent nonlinearity, and parameter variations with changes in the working environment are the key difficulties in building a correct controller for the electrohydraulic actuators. In the past ten years, researchers have tried a variety of control design approaches, such as nonlinear model-based control or artificial intelligence (without modeling the system). Because of its excellent positioning and force feedback capabilities, electrohydraulic actuators have been employed in a variety of applications, including aerospace, machine tools, and industrial robots. These actuators don't require a pump or an external reservoir. These actuators can be utilized in a variety of applications, including damper drives, rotary torque arm actuators, coal mine diverter shuts, and valve actuators and position controllers[1].

In this paper, we focus on electro hydraulic actuator which controlled by optimal TUNED FO-PID controllers, structure based on the principle of IMC will be proposed, which can make the robustness and dynamic performance of the system decoupled from each other, the adjustable parameter of the FO-PID controller is directly related to the robustness of the closed-loop system, and the analytical expressions is given between optimal TUNED FO-PID controllers and the parameter of FO-PID controller. According to the dynamic performance requirement of practical system the parameters will be selected . Therefore, the best-tuned fractional order PID controller for position control of the electrohydraulic

actuator (EHA) system is suggested in this work. The optimal TUNED FO-PID controller parameters tuning can rely on the performance of the set-point tracking or robustness independently and monotonously controlled. Finally based on control system the simulation results will be done.

1.2 statement of the problems

Electro-hydraulic actuator (EHA) is known as by its strong nonlinearities, uncertainties, and time-varying characteristics that characterize an EHSA system's natural behavior make the research difficult. The challenging control process is primarily caused by the nonlinear characteristics of the EHA system. The position tracking accuracy of the system is assured by accurate control of the Electro-hydraulic actuator system (EHAs) . Till now, several advanced control approaches are proposed in to position control of based on literature, still, it needs the same advanced control approaches for position control of the electro-hydraulic actuator.

1.3 Objectives

1.3.1 General objectives

The main objective of this thesis is to compare the performance of PSO and TSO tuned fractional order PID controller for the position control of electrohydraulic actuator of servo system

1.3.2.Specific objectives

- To simulate the mathematical model of electrohydraulic actuator system using MATLAB – Simulink software.
- To apply FOPID controller for the position control of electrohydraulic actuator
- To apply the PSO algorithm for tuning of FOPID controller parameter for the position control of electrohydraulic servo actuator.
- To apply the TSO algorithm for tuning of FOPID controller parameter for the position control of electrohydraulic servo actuator.
- To analyze and compare the performance of the PSO and TSO tuned FOPID controller with conventional FOPID controller.

1.4 Significance of thesis work

Due to their dynamic properties, electro-hydraulic actuator (EHA) systems are known to be extremely nonlinear. These nonlinearities and uncertainties lead to a constraint in the control of EHA systems, which affects the accuracy of position tracking and the occurrences of leakage and friction in the system. Consequently, researchers must develop sophisticated control systems for the position control of electro hydraulic servo actuator system, a well-known nonlinear system

1.5 Scope of this thesis work

- To learn and get exposure in the design of advanced controllers for the mathematical model EHA using MATLAB simulation.
- To learn about the application of optimization algorithms for tuning of controller parameters for obtaining better performance of the controller.

1.6 Limitation of research

The finding of this thesis is limited to the simulation study. It is not precisely applicable for real-time application because certain assumptions and linearization procedures were considered for obtaining a mathematical model of EHA.

1.7 Organization of this thesis

This thesis is structured as follows; Chapter one : description of the overall background of the study. The main part of study such as problem statement, thesis objective (general and specific), significances of thesis work, Scope of this thesis work, Limitation of research. Chapter Two : describes literature review and summary of the literature. Chapter Three: Mathematical modeling of the system of the thesis work. Chapter Four: controller design, Chapter Five : simulation result and discussion Chapter six : conclusion and scope for future work.

CHAPTER TWO

LITRATURE REVIEW

2.1 Introduction

Position control of electro-hydraulic servo actuator systems have different approaches and procedure includes the selection of the controller setting of the controller parameters and the realization process. In this section, the authors have discussed in detail the work done by the authors on the control of electro-hydraulic servo actuator position on the nonlinear system, the controller tuning method, and the implementation schedule, in order to know the areas that need to be improved for improve stabilize nonlinear position of actuator of electrohydraulic system.

Dyah Atsari, ErinnaHalim, Abdul ,proposed in his research, PID controller used to tune the position control of electrohydraulic actuators which decrease maximum overshoots, eliminate offsets, and accelerate the accomplishment of prescribed output values In contrast to traditional control system , which have three parametres (Kp, Ki, and Kd) parameters were chosen using the Ziegler Nichols method with a 1st order approach and a delay interval. Meanwhile, the optimal value for the parameters was chosen to improve the system's reaction. To evaluate the outcomes of the Fractional Order PID controller design, Matlab simulation was employed[2].

Wang, NingWang, JianmeiLi, ZhixiongTang, XuefengHou, Dingbang During his investigation, A Fractional-Order PID controller is proposed as a control solution for a hydraulic loading system of an electro-mechanical plat form, which is utilized to drive the loading system of a mechatronic journal test rig. The control system's mathematical model is established using the electro-hydraulic system's principle. Because model parameters are indeterminate, the method of parameter identification was utilized to validate the theoretical model's rationality. Traditional PID and fractional-order PID controllers are meant to improve the control precision of the hydraulic loading system by selecting appropriate tuning parameters. Their control performance is evaluated in both the frequency and time domains. The fractional-order PID controller offers greater control, according to the results[3].

Jusoff, Kamar uzaman Rahmat, MFMd Rozali, SAbdul Wahab, MATLAB's System Identification Toolbox was used to estimate a mathematical model of an electro-hydraulic system that the researcher had proposed as part of his research.. The model's PID controller was created using SIMULINK simulation. The Ziegler-Nichols approach is used to tune the controller. To attain the optimal performance of the system, the simulation work was confirmed by applying the controller to the real system result : The result showed that the output of the system with controller in simulation mode and experimental works were improved and almost similar[4].

Shern et.al (2019.) proposed in his research A comparison analysis of the Ziegler-Nichols tuning method, traditional Particle Swarm Optimization (PSO) approach, and Priority-based Fitness Particle Swarm Optimization (PFPSO) strategy for the selection of PID parameters will be undertaken in this paper. PFPSO is a more advanced variant of the traditional PSO method. A nonlinear Electro-Hydraulic Actuator (EHA) system will be used in the simulation. In terms of actuator internal leakage, a basic robustness test on the PID controller will be examined. The PID performed better when the controller's parameters were chosen using the PFPSO methodology rather than the Ziegler-Nichols method or the traditional PSO technique, according to the results[5].

Alqadasi et.al (2019), proposed in this research, Create a mathematical model of an industrial electrohydraulic actuator, then build a controller by optimizing the parameters with Particle Swarm Optimization-Gravitational Search Algorithm and proportional-integral-derivative (PID) (PSOGSA). Several controllers, including model reference adaptive control and standard PID (CPID), are available for comparison (MRAC). The performance of PID, PID-PSOGSA, and the current controller MRAC will be compared in order to choose the most effective controller. All controllers have the potential to deliver good performance, however PID-PSOGSA control systems deliver better positioning responses than PID and MRA[6].

Soon, C. C.Ghazali, R.Jaafar, H. I.Hussien on the basis of this research, For motion control procedures, the dynamic parts of an electro-hydraulic actuator (EHA) system are frequently utilized in the industrial sector. To achieve accurate motion generated by these dynamic elements, a suitable controller will be needed. The sliding mode control variables were optimized using the Particle Swarm Optimization (PSO) method (SMC). The Lyapunov theorem is used to confirm the stability of the control system, which is generated from the deduced dynamic equation. The simulation results showed that the PSO approach of SMC controller variable tuning outperformed the traditional proportional integral-derivative PID controller.[7].

Ishak et.al (2012) he proposed the For an electro-hydraulic position control system, Nelder-Mead (N-M) is compared to a self-tuning fuzzy technique. Tuning the parameters to their ideal values is the main challenge in PID application. An Auto-regressive with Exogenous Input (ARX) model structure produced from the MATLAB System Identification Toolbox was used to represent the electro-hydraulic system. The system's second and third order models had been evaluated. The output achieved the best response in terms of transient speed and Root Mean Square Error (RMSE) performance standards, according to simulation and real-time experiments.[8].

Do,Tri CuongTran, Duc ThienDinh, Truong QuangAhn, Kyoung Kwan This paper presents for controlling an electro-hydraulic rotary actuator's (EHRA) trajectory under a variety of operational conditions. The suggested controller is based on a fuzzy logic system and a fractional order PID controller. In particular, the PID serves to increase tracking, resilience, and stability of the control system by extending integral and derivative functions from integer to non-integer order. The PID parameters are adjusted using a fuzzy logic control system in response to time-varying working conditions. Co-simulations (using AMESim and MATLAB) and real-time experiments were used to assess the suggested controller. The results suggest that the proposed technique is more successful than other common controllers[9].

Xu, Bing Shen, Jun Liu, ShihaoSu, Qi Zhang, Junhui suggested in this study This report reviews the state of the art for relevant technologies and electro-hydraulic control actuators. In this review, three state acquisition methods—sensors or indirect acquisition technologies—control tactics—along with digital controllers and innovative valves—as well as online maintenance—through data interaction and problem diagnosis—are discussed.[10].

Ling, T. G.Rahmat, M. F.Husain, A. R. proposed in this research The technique of obtaining an EHA system's model utilizing a system identification approach is described in this work. Because it just takes input and output data pairs from the system, the system identification procedure has merit in obtaining system models. The model is validated by comparing its performance to that of the actual EHA system. Following that, a PID controller is constructed based on the model for accurate position tracking of the system. The system that is used with the suggested controller is able to execute position tracking with high precision, according to simulation results and real-time experiments[11].

Ghosh, Bibhuti BhusanSarkar, Bikash KumarSaha, RanaIn A motion simulator platform for electro-hydraulic actuators with two degrees of freedom (DOF) has been created. A real-time controller has been used to control the platform's heave movement. The current project The proportional integral derivative (PID) controller, the hybrid fuzzy-PID controller, and the self-tuning fuzzy-PID controller are the three different types of controllers that have been developed. For step demands of 0.05m, 0.1m, and 0.15m, the real-time control performance of the controllers has been investigated. The appropriate values for the control parameters are tuned in a different way for the various controllers in order to achieve the needed performance of the controller. Compared to PID and hybrid Fuzzy PID controllers, the self-tuned Fuzzy-PID controller exhibits the best control response[12].

Chong Chee Soona, Rozaimi Ghazalia Gradient Descent (GD) and Particle Swarm Optimization (PSO) approaches are suggested as the fundamental knowledge in proportional-integral-derivative (PID) controller optimization. The Ziegler-Nichols (ZN)

tuning method's PID parameters were optimized using the GD method and contrasted with the PSO optimization approach using MATLAB/Simulink software. Applying the established optimization technique results in a noticeably improved location tracking performance, according to the results. Therefore, the issues degrading the EHA system performance have been reduced[13].

Z. Has · M. F. Rahmat (B) · A. R. Husain · M. N. Ahmad · Y. M. Sam He suggests a variable boundary layered sliding mode control strategy to create a more effective and reliable position controller for the electro-hydraulic actuator system. The proposed approach has the capacity to enhance the actuator's position-tracking performance when friction and internal leakage are present. While the latter is depicted as a turbulent flow, the former is represented using the Lu Gre model. MATLAB simulations are run with friction and leakage effects to assess the viability of the suggested approach. Its effectiveness is evaluated in comparison to fuzzy PID (FPID) and traditional PID approaches. In order to validate the suggested concept, an experimental rig composed of a single-rod and double-acting hydraulic cylinder is put up. On a TMS320F240 digital signal processor in the D Space 1104 environment, software development is being done. Results from simulations and experiments demonstrate the suggested method's advantage over the PID and FPID in terms of tracking location[14].

Zulfatman, Zulfatman and Rahmat, he proposed actuator's capacity to track its position in the presence of friction and internal leakage can be enhanced. While the latter is depicted as a turbulent flow, the former is represented using the Lu Gre model. MATLAB simulations are run with friction and leakage effects to assess the viability of the suggested approach. Its effectiveness is contrasted with that of fuzzy PID (FPID) and traditional PID techniques. In order to validate the suggested concept, an experimental rig made consisting of a single-rod and double-acting hydraulic cylinder is put up. On a TMS320F240 digital signal processor in the D Space 1104 environment, software development is being done. Results from simulations and experiments demonstrate the suggested method's advantage over the PID and FPID in terms of tracking location[15].

2.2 Summery of Literature Review

From the literature review, it has been observed that various techniques have been employed to improve the performance of for the position control of electro hydraulic actuator such as a conventional PID controllers, traditional PID controller, mathematical model using system identification technique, Ziegler-Nichols tuning method, Priority-based Fitness Particle Swarm Optimization (PFPSO) approach, and standard Particle Swarm Optimization (PSO) technique are all used to tune the controller. PFPSO is an acronym for Particle Swarm Optimization-Gravitational Search (PSOGSA). A few controllers, including traditional PID (CPID) and model reference adaptive control (MRAC), variables of sliding mode control (SMC) by using the particle swarm optimization (PSO) algorithm, and optimization of PID parameters using the Nelder-Mead (N-M) compare with self-tuning fuzzy approach system identification technique or theoretical mathematical analysis Experiments, a PID controller, and a fuzzy logic system are used to calibrate unknown static and dynamical model parameters. sensors or indirect acquisition, system identification approach, hybrid fuzzy-PID controller, self-tuning fuzzy-PID, and fuzzy derivative (PID) controller The position control of electro hydraulic actuator system is difficult to fulfill the control requirement due to the inherent limitations of control techniques. The proper tuning of controller parameters is a critical problem in the PID and FOPID controller. To solve this problem, several optimization techniques have been reported in the literature. Still needs some improvement in the area of controller tuning. Therefore, in this thesis work, the TSCO and PSO algorithms are proposed for the optimal tuning of the FOPID controller for the position control of electrohydraulic actuator system.

CHAPTER 3

MATHEMATICAL MODELING OF ELECTRO-HYDRAULIC ACTUATOR

3.1 Methodology

The methodology of the thesis includes a variety of tasks that must be completed in order for the job to be finished. The problem statement and the purpose of the investigation were both described in the first task. This was followed by an extensive review of literature, books, and journals. The performance of electrohydraulic servo actuators (EHSAs) was thoroughly examined, and all relevant information was acquired. After that, the characteristics, performance modeling, and examination of the electrohydraulic servo actuators' static and dynamic performance were studied. The steady-state performance of these components— in particular, the spool displacement, the flapper valve, and the electromagnetic torque motor. A mathematical model of the entire system of electrohydraulic servo actuators' dynamic behavior (EHSAs). In this thesis, the performance of electrohydraulic servo actuators is controlled by a fractional-order PID controller (EHSAs).The PSO and TSCO optimization algorithms are used in this thesis work for tuning the FOPID controller's parameters. The simulation study is carried out by using the MATLAB-Simulink software package. The benefits of the PSO and TSCO tuned FOPID controller over the traditional PID controller are demonstrated through simulation tests conducted under various operating situations. A conclusion based on the research findings is the last step.

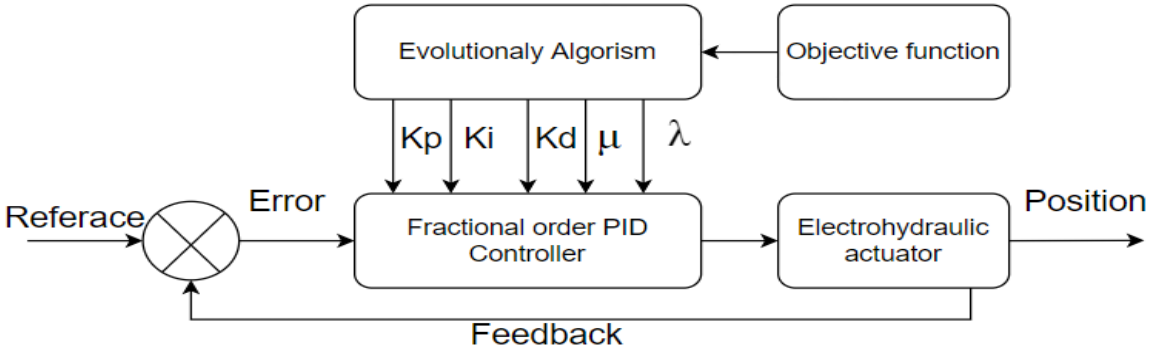


Fig3. 1 Block Diagram and System Design of the study

3.2 Principle and operation of the system

In this research, the mathematical model of the electrohydraulic actuator system is represented as a transfer function model. It is the ratio of the output of a system to the input of a system in the Laplace domain under zero initial conditions. The function helps to analyze the performance of a system theoretically. The important property of the transfer function is that it cannot be formulated for nonlinear or time-varying systems but only can be formulated for Linear Time-Invariant systems. The processes considered for the study are nonlinear systems. The systems can be characterized as different LTI systems in each operating position. Each position has a separate transfer function model.

3.3 Applications For Electro-Hydraulic Actuator Systems In Industry

The advancement of electro-hydraulic servo actuator technology has been driving the production of hydraulic actuators. Assuring effective machine operations, electro-hydraulic actuators incorporate servo valves and are electronically controlled to change rod position feedback. Accuracy is increased, utility is improved, usability is advanced, and enactment is better controlled thanks to its inclusion. Industries that are confident in their ability to manage the speed and positioning of loads include material handling, steel mills, nuclear power facilities, and lifter makers. In the near future, it is anticipated that these electro-hydraulic actuator properties will become more significant and in demand.[16]

3.4 Description electrohydraulic servo actuator system

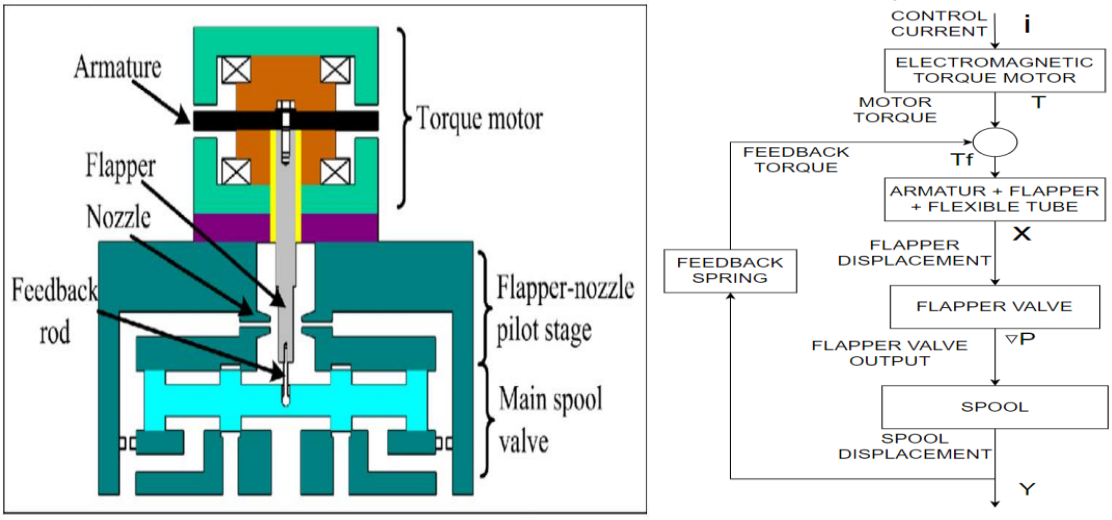
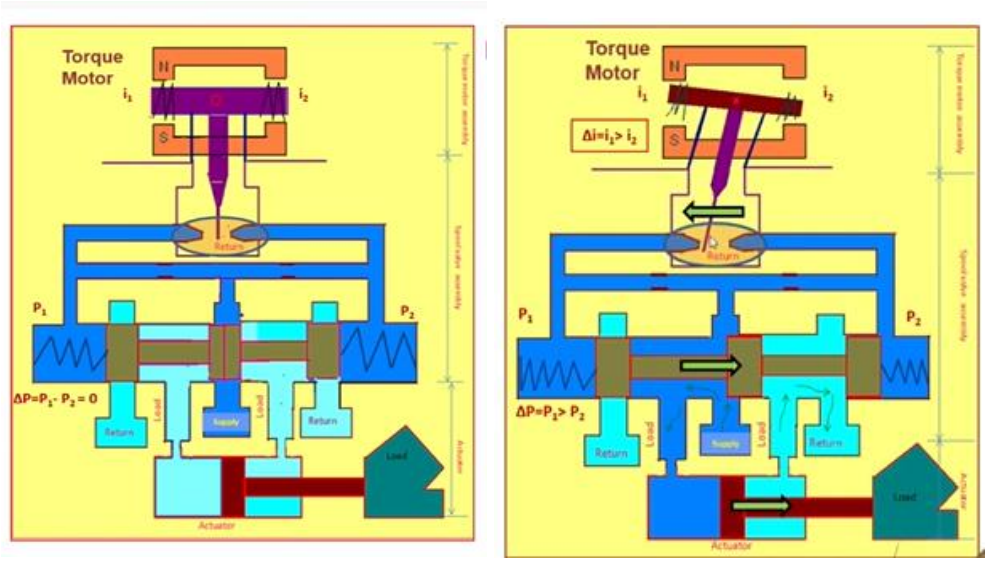


Fig3. 2Schematic diagram of electrohydraulic servo actuator **[17]**

An EHA system is electrical and hydraulic operation system that works a valve via pressured hydraulic fluid however, its main driving energy is solely electric power. The source of electric power is used to energize a motor that rotates a hydraulic pump which then purchases the pressurized fluid to function a hydraulic actuator for the control gate.

The applied current I_1 and I_2 on the armature of the torque motor . The applied input current and the torque generated by the electromagnetic torque motor is directly proportional. ,which is equal to force x displacement . during the rotation of armature the flapper starts to move left and right position depend on the rotation direction of the armature and also the rotation direction of armature is depend on the values of difference (ΔI) of $I_1$and I_2 .

If $I_1 > I_2$ the flapper move to left and closes the left side nozzle , If $I_1 < I_2$ the flapper move to right and closes the right side nozzle. Due to this effect the pressure (P_1) on the left end of the spool became higher than pressure(P_2) as the result of tis the spool move to the right direction then then the feedback spring return the spool to original position (null position) by return spring torque which is equal to armature motor torque and opposite (restoring torque).based on the movement of spool valve feeds to the control valve and the control valve control the inlet fluid by fully opened, partial opened and changing the direction of flow to the actuator to keep the actuator in desired position. The complete system is self-sufficient which eliminates the need for external hydraulic power unit, simplifying the system construction and improving safety and reliability this relationship self-contained electro-hydraulic actuator can be used with linear and rotary valves. It has been used with control valve and gate valves for various manufacturing applications.



A. Null position of armature($I_1 = I_2$) B. Deflected position($I_1 > I_2$)

Fig3. 3 position of armature. [18]

3.5 Component Of Electrohydraulic Servo Actuator

3.5.1 Electro Magnetic Motor

An electromagnetic torque motor is a device that moves by using the forces generated by an electromagnetic system created by a wire carrying live electricity. Every electric motor relies on electromagnetic principles to function. Using electromagnetic motors, the electric control signal is transformed into a proportional mechanical signal., which come in a variety of kinds. Single acting and double acting proportional solenoid – proportional solenoids[19]

I. Electro dynamic motor of moving bobbin/coil – moving coil

II. Electromagnetic torque motors – torque motor

III. Linear force motor – force motor

TABLE3. 1RELATIVE COMPARISON OF ELECTROMAGNETIC MOTOR

Electromagnetic Motor(Actuation mechanism)	Power input(W)	Stroking energy(N mm)	Linearity deviation(%)	Frequency range(Hz)
Proportional Solenoid	5-40	20 - 1000	0.5 – 0.6	10 -150
Moving coil	0.2 - 5	8 - 80	1 - 7	100 – 200
Torque Motor	0.02 - 4	2 - 40	1 - 2	100 – 300
Force Motor	10 - 40	400 - 2000	0.5 - 6	10 - 200

As in the above shows the electromagnetic torque motor shows better characteristics on measured parameters, due to this characteristics electromotive torque motor are usually used in electrohydraulic servo actuator system. An electronic or digital controller is used to operate the electrohydraulic actuator system. A component that transforms a low-power electric control signal into a proportional mechanical signal that activates the spool valve on the hydraulic actuator should connect the hydraulic and electronic subsystems in this system. An electromagnetic motor converts the low-level electric input signal into proportionate torque on the armature.

3.5.2 Armature

The armature is made of soft ferromagnetic material, which lessens magnetic hysteresis' effects, and it is mounted on a thin-walled spring tube known as a flexural tube, which is rotationally stiff. This tube functions as a dividing element between the hydraulic and electrical parts as well as a carrier and centering spring for the armature and flapper.

3.5.3 The Air Gap

The air gaps are uniform in four direction before supply of electric current . In one scenario with in time duration cannot be adjusted; but, in other scenarios, it can

3.5.4 Permanent Magnet

The air gaps are symmetrically positioned with regard to the permanent magnets, and their magnetic fields are set in the gaps. The four air gaps have similar diameters when the armature is in its neutral state. The magnetic flux is the same in all four air gaps. As a

result, there is no mechanical attraction between the armature extremity and the upper or lower pole component. The torque of the torque motor is zero under these circumstances.

3.5.5 Flapper valves

The flapper technically belongs to the hydraulic amplifier even though it is physically a part of the motor. When electrohydraulic servo actuator valves (EHASV) are used, the flapper valve serves as a hydraulic amplifier. It is triggered by the flapper's extremely modest displacement, which is typically under 30 m. In proportion to the flapper displacement, it generates a pressure difference that is noticeably large.

3.5.6 Actuator

A hydraulic force that is continuously controlled by feedback from system sensors is used by an electrohydraulic actuator to provide switching or actuation for a range of systems. Systems with continuous demand changes require this level of actuation control. A servo system that integrates sensor inputs and monitoring the movement of hydraulic liquid to the actuator enables actuator control. Beyond this characteristic, the electrohydraulic actuator works similarly to other fluid-driven actuators and comprises a piston inside a tube or sleeve that is propelled forward or backward by fluid pressure. Typically, this kind of actuator is offered in linear, quarter-turn, and multi-turn variants.[20]

3.6. Mathematical Analysis of Each Parameters

3.6.1 Magnetic Circuits

A circular coil with a ferromagnetic core that is L in length and A in cross-section in which a magneto motive force generated when the electric current passes in side the iron core. A magnetic flux is provided by this force. The flux per unit area is used to compute the magnetic flux density B. Electromotive force (EMF) is necessary to drive the magnetic flux in a magnetic circuit, just as it is due to MMF that current flows in an electric circuit. The Magneto motive Force is the name given to the magnetic pressure that drives the magnetic flux in a magnetic circuit. The Ampere-turn is the MMF's SI unit (AT),

The force produced by current through a coil of wire is called magneto motive force (MMF)[19]

$$\lambda = NI \quad (1)$$

$$B = \phi / A \quad (2)$$

Where, λ = Magneto-motive force, A ϕ = Magnetic flux, Vs (1Vs = 1 weber)

A = Cross-sectional area of the core, m2 N = Number of turns of the coil

B = Magnetic flux intensity, Vs/m2 i = Electric current, A

The magneto motive force per unit length (H = B/L), This explains the characteristics of magnetic materials and is the relationship between the magnetic flux intensity (B) and the magnetizing force (H). Simple magnetization and demagnetization define a soft ferromagnetic material. This material has a single-valued curve connecting B and H, meaning that (B = 0) occurs when (H = 0). H and B are proportionate to one another. The hard ferromagnetic materials show a hysteresis loop when H is cycled.. The B(H) relation's initial slope is a parameter that describes the material. Permeability is it. The permeability of the empty space is o. Relative permeability, denoted by the symbol _r, is sometimes used to express magnetic permeability.

$$\mu = \mu_o \mu_r \quad (3)$$

$$\mu = BH \quad (4)$$

It defines the coil reluctance. To create a unit magnetic flux in the medium, one needs a certain amount of magneto motive force. The reluctance R for the entire coil is calculated using the $\phi(\lambda)$ relation,

Where, $R = \frac{\lambda}{\phi} = \frac{HL}{BA}$ or $\frac{L}{\mu A}$ (5)

Magneto motive force are sometimes comparable to electric current and Reluctance, R, is compared to electric resistance, which indicates that flux. This is merely an analogy in

mathematics. It can be applied to the steady-state computation of magnetic circuits. However, from an energetic perspective, it is unsatisfying. While magnetic reluctance saves energy, an electric resistor dissipates it. The relationship given below describes the reluctance:

$$\lambda = R\phi \tag{6}$$

Actually, electric capacitance and magnetic reluctance are similar. The same mathematical relations can be used to characterize both of them as energy stores. The permeance P is a magnetic material's reciprocal of its reluctance. where

$$P=\frac{\phi}{\lambda}=\frac{1}{R}=\frac{\mu}{AL} \tag{7}$$

The attraction between two magnetic poles separated by a cross-sectional area-sized air gap A is expressed as follows:

$$F=\frac{\phi^2}{2\mu oA} \tag{8}$$

Where, F = Force, N H = Magneto motive force per unit length ,A/m

L = Length ,m P Magnetic permeance Vs/A

R= Magnetic relactance ,A/Vs λ = Magneto motive force. A

μ = Permeablity Vs/Am μ_0 = Permeability of free space Vs/Am

μ_r = Relative permeability

An electromagnetic torque motor's magnetic circuit the two polar parts serve as the armature's framework and as conduits for the magnetic flux. In the four air gaps between the polar sections and the armature's extremities, the permanent magnet creates a permanent magnetic field. The magnetic field is changed in two diagonally opposed air gaps and two other air gaps when current is applied to the armature coils.. As a result, the armature experiences a torque that causes it to angulate. The torsion spring-like property of the flexible tube makes the rotational angle proportionate to the torque. The electromagnet's field has no effect on the permanent magnets because they are positioned outside of it. The two pairs of air gaps make up the majority of the reluctance in the torque motor's magnetic circuit. In comparison to the resistance of the air gaps, the

magnetic components of polar pieces exhibit negligible resistance. The magnetic flux in the air gap can be calculated by contrasting the effects of the permanent magnet and the electric current on their own. The length of the diagonally opposed air gaps is equal because of the symmetry of the torque motor; their reluctances are determined by:

$$R_1=\frac{x_o - x_a}{\mu_o A} \quad (9)$$

$$R_2=\frac{x_o + x_a}{\mu_o A} \quad (10)$$

$$x_a=\vartheta L/2 \quad (11)$$

Where, x_0 = Length of the air gap in the neutral position of the armature, m

x_a = Displacement of the armature end, m A = Areas of the air gapm^2

L = Armature Length , m ϑ = Armature rotational angle, rad

P = the permanent magnet's magnetic motive force, and A

The electromagnetic torque motor's of magnetic circuit

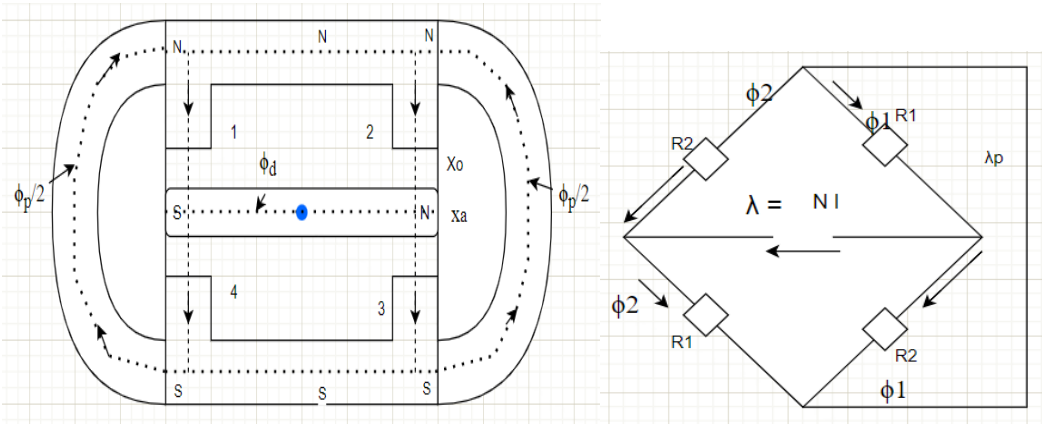


Fig3. 4 electromagnetic torque motor's magnetic circuit

Fig. 3.4 depicts the electromagnetic torque motor's magnetic circuit. This circuit is symmetrical, so the magnetic fluxes in the diagonally opposed arms are equal. The magnetic circuit and the electric circuit can be compared mathematically. Each loop's magneto driving force must be zero. In this example, magnetic reluctance and electric resistance are compared. [21]

$$-iN+R_1\phi_1-R_2\phi_2=0 \quad (12)$$

$\lambda_p+R_1\phi_1+R_2\phi_2=0$ (13)

$$\varphi 1 = \frac{\lambda p+iN}{2R1} \text{ and } \varphi 2 = \frac{\lambda p+iN}{2R1} \quad (14)$$

By handling Eqs. (09) through (17), we can derive Eqn (15)

$$\varphi 1 = \frac{(\lambda p+iN)\mu oA}{2(xo-xa)}, \qquad \varphi 2 = \frac{(\lambda p-iN)\mu oA}{2(xo+xa)} \quad (15)$$

The following mathematical formulas are used to determine the torque on the armature as a result of the mechanical forces occurring on its extremities.

$F_1=\phi_1^2/2\mu_oA$ (16)

$F_2=\phi_2^2/2\mu_oA$ (17)

$F=F_1-F_{2=}\phi_1^2-\phi_2^2/2\mu_oA$ (18)

T=FL (19)

$$T=\frac{L}{2\mu_oA}\left[\frac{(\lambda_p+iN)^2\ \mu_o{}^2A^2}{4(x_o-x_a)^2}-\frac{(\lambda_p-iN)^2\ \mu_o{}^2A^2}{4(x_o+x_a)^2}\right] \quad (20)$$

$$T=\frac{2\mu_oAL}{8(x_o-x_a)^2}[(\lambda_p+iN)^2(x_{o+}x_a)^2-(\lambda_p-iN)^2(x_o-x_a)^2] \quad (21)$$

$$T=\frac{\mu_oA_L}{8x_o{}^4}[4x_ox_a\lambda_p{}^2+4\lambda_piNx_o{}^2] \quad (22)$$

$$T=\frac{\lambda_p{}^2\mu_oA_L}{2x_o{}^3}x_a+\frac{N\lambda_p\mu_oA_L}{2x_o{}^2}i \quad (23)$$

Hence, $T=K_xx_a+K_aI$ or $T=K_\vartheta\vartheta+K_ii$ (24)

$$\text{Where, } \vartheta=\frac{2x_a}{L}, K_x=\frac{\lambda_p{}^2\mu_o AL}{2x_o{}^3},\ K_i=\frac{N\lambda_p\mu_oAL}{2x_o{}^2}i,\ K_\vartheta=\frac{\lambda_p{}^2\mu_oAL^2]}{4x_o{}^3} \quad (25)$$

$$T = K_i i \quad (26)$$

3.6.2 Torque Motors

The electromagnetic torque motor converts an electric input signal of low-level current (usually within 10 mA) into a proportional mechanical torque. The motor is usually designed to be separately mountable, testable, interchangeable, and hermetically sealed against the hydraulic fluid. The net torque depends on the effective input current and the flapper rotational angle. Neglecting the effect of the magnetic hysteresis, the following expression for the torque can be deduced:

$$T = k_i i_e + k_\theta \vartheta \quad (27)$$

Where i_e = Torque motor input current, A

T = Torque of electromagnetic torque motor, Nm

The motion of the rotating armature and attached elements is governed by the following equation:

$$T = J\frac{d^2\vartheta}{dt^2} + f_\vartheta \frac{d\vartheta}{dx} + K_T\vartheta + T_L + T_P + T_F \quad (28)$$

$$T_p = \frac{\pi}{4} d_f^2 (p_2 - p_1) L_f \quad (29)$$

J = Moment of inertia of the rotating parts, Nms2

T_L = Torque due to flapper displacement limiter, Nm

f_ϑ = Damping coefficient, Nms/rad

K_T = Stiffness of flexure tube, Nm/rad

T_F = Feedback torque, Nm

T_P = Torque due to the pressure forces, Nm

The feedback torque depends on the spool displacement and the flapper rotational angle as given by the following equations:

$$T_F = F_s L_s$$

$$F_s = K_s\ (L_s \vartheta + \mathrm{x})$$

$$T_F = K_s\ (L_s \vartheta + \mathrm{x})\ L_s$$

Where, K_s = Stiffness of the feedback spring, N/m

L_S = Length of the feedback spring and flapper, m

x = Spool displacement, m

F_S = Force acting at the extremity of the feedback spring, N

3.6.3 Flapper Position Limiter

The flapper displacement is limited mechanically by the jet nozzles. When reaching any of the side nozzles, the seat reaction develops a counter torque, T_L, given by the following equation:

$$T_L = \begin{cases} 0, & |x_f| < x_i \\ R_s\ \frac{d\vartheta}{dt} - (|x_f| - x_i) K_L\, L_f\ sign x_f & |x_f| > x_i \end{cases}$$

where K_{Lf}= Equivalent flapper seat stiffness, N/m

R_S = Equivalent flapper seat damping coefficient, Nms/rad

Equation of Motion of the Spool

$$A_s\ (P_2 - P_1) = m_s \frac{d^2x}{dt2} + f_s \frac{dx}{dt} + + F_s$$

f_s= Spool friction coefficient, Ns/m

F_s= Force acting at the extremity of the feedback spring, N

m_s = Spool mass, kg

3.6.4 Flow Rates Through the Spool Valve

Neglecting the effect of transmission lines, connecting the valve to the symmetrical cylinder, the flow rates through the valve restriction areas are given by the motion of the spool is described by the following equations:

$$Q_a = C_d A_a(\mathrm{x}) \sqrt{\frac{2}{\rho}(p_A - P_B)} \tag{44}$$

$$Q_c = C_d A_b\ (\mathrm{x}) \sqrt{\frac{2}{\rho}(p_S - P_A)} \tag{45}$$

$$Q_c = C_d A_c\ (\mathrm{x}) \sqrt{\frac{2}{\rho}(p_S - P_B)} \tag{46}$$

$$Q_d = C_d A_c\ (\mathrm{x}) \sqrt{\frac{2}{\rho}(p_S - P_T)} \tag{47}$$

$$A_a = -A_c,\ A_b = A_d = \omega\sqrt{(x^2 + c^2)} \} \text{for } \mathrm{x} \geq 0 \tag{48}$$

$$Q_a = -Q_c = \omega\sqrt{(x^2 + c^2)}, A_b - A_d \omega c \} \text{for } \mathrm{x} \leq 0$$

Continuity Equations Applied to the Cylinder Chambers Applying the continuity equation to the cylinder chambers, considering the internal leakage and neglecting the external leakage, the following equations were obtained

$$Q_b - Q_a - A_p \frac{dy}{dt} - \frac{p_A - P_B}{Ri} = \frac{V_C - A_p y}{B} \quad \frac{dp_A}{dt} \tag{49}$$

$$Q_c - Q_d + A_p \frac{dy}{dt} + \frac{(p_A \pm - P_B)}{R1} = \frac{V_c - A_p y}{B} \quad \frac{dP_B}{dt} \tag{50}$$

3.6.5 Equation of Motion of the Piston

The motion of the piston under the action of pressure, viscous friction, inertia, and external forces is described by the following equation:

$$A_p\ (P_A—P_B)=m_p\ \frac{d^2y}{dt2}+f_p\ \frac{dy}{dt}+K_{by} \quad (51)$$

Feedback Equation

The piston displacement is picked up by a displacement transducer and fed back to the electronic controller, which generates the corresponding error signal. The feedback loop can be described by the following equations:

$$i_e=i_c\text{-}i_b \quad (52)$$

$$i_b=K_{FB}\,\mathrm{Y} \quad (53)$$

3.7 Modeling and Simulation of EHSA

This appendix presents mathematical models of an electrohydraulic servo actuator and its subassemblies—mainly the electromagnetic torque motor, the single-stage servo valve, and the two-stage servo valve. The effect of armature magnetic hysteresis and flow forces are neglected in this study. The deduced mathematical models were applied to develop computer simulation programs using SIMULINK. The step response of the systems is calculated and presented. The simulation programs are built considering the following numerical values of a typical electrohydraulic servo actuator incorporating a two-stage servo valve.

Tork Motors = Current tork gain, k_i= 0.556Nm/A

Armature damping coefficient ,f_∂ =0.002Nms/rad

Momentum of inertia of the armature-flapper assembly,J=5*10^{-7}kgm^2

Armature rotational angle torque gain,k_θ= 9.45*10^{-4}

Servo actuator feedback, k_{FB} = 3A/m

Flapper valves = Length flapper, l_f = 9mm

Flapper length L_s = 30mm

Flapper displacement, x_i 30μm

Diametre of flapper nozzle, d_f = 0.5mm

Equivalent flapper seat material damping coefficient,R_s = 5000Nsm/rad

Flapper seat equivalent stiffness,k_{lf} = 5*106N/m Hydraulic amplifier nozzlesN_1 andN_2 diameter. d_f = 0.5mm Diameter of return orifice (N_5) , d_5 = 0.6mm

Hydraulic oil : Oil density, ρ = 867kg/m^2

huge pressure of oil , B = 1.5GPa

Spool valve = Spool diameter, d_5 = 4.6mm System pressure **:**

Supply pressure, Ps = 250 bar

Return pressure, PT = 0 bar

Hydraulic cylinder: Piston area, A_p=12.5cm^2

Chamber, Vc =100 cm^3

Resistance to internal leakage, Ri= 1014 pa s/ m^3

Pisten mass, m_p = 10kg

Friction coefficient on piston , f_p =1000Ns/m

Piston loading coefficient ,Kb = 0N/m the piston is unlocked.

A second-order transfer function was employed to identify the servo system from the transient response that was derived using the simulation program. The identifying transfer function's parameters are gain = 0.0202, ωn = 112 Hz, ξ = 1.34.

$$\frac{0.0202}{0.000002s^2+0.0038s+1}$$

By using this given parameters value it can be calculated transient response of the system by using simulation program

CHAPTER FOUR

CONTROLLERDESIGN

The controllers are designed to achieve the system's best performance when the transfer function model is derived. The controller parameters can be properly tuned to achieve this. The parameters of controllers can be tuned using a variety of methods. In this thesis, the electrohydraulic actuator system's position is controlled by a FOPID controller. The FOPID controller's parameters are tuned using the PSO and TSCO optimization techniques.

4.1 Proportional Integral Derivative Controller

The PID controller is essentially a tool used in a closed loop with the system or plant that has to be stabilized or whose parameters can be improved.. The PID controller was created in 1939, and since then it has remained indispensable and is virtually always utilized in the industrial sector. K_p, K_i, and K_d are the PID controller's three primary tuning parameters. [22]

$$\mathrm{U(t)} = k_p \mathrm{e(t)} + k_i \int_0^t e(t)dt + k_d \frac{de(t)}{dt} \qquad 4.1$$

Where, e is the Error (SP-PV), t is the instantaneous time, and is the variable of integration that takes on values from time 0 to the present t. K_p is the gain of proportionality, K_i is the gain of integral, K_d is the gain of derivative, and e is the error. Equation (1), the PID controller equation, is transformed using the Laplace method.

$$\mathrm{U(t)} = k_p + \frac{K_i}{s} + K_d \mathrm{s} \qquad 4.2$$

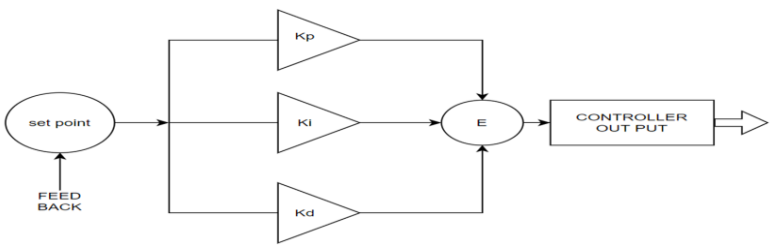


fig4. 1 PID controller system

4.2 Ziegler-Nichols Method

Ziegler and Nichols developed two empirical techniques in 1940 to get controller parameters: non-first order plus dead time situations and intensive manual computations . We employ the following process to calculate the tuning parameters: Integral and derivative activity must be eliminated for feedback loops or closed loops. Derivative controller (, T_d) must be set to 0, and integral time (T_i) must be set to 999 or more. Changes to the set point cause a slight disruption in the loop. Continue changing the proportional by until the oscillations have a common amplitude. increasing or decreasing the gain. The value of (K_u) and (p_u) must be recorded gain and period of oscillation respectively. The necessary tuning of the controller must be determined by finding the appropriate values in the Ziegler-Nichols value [23].

General block diagram of the control system of plant

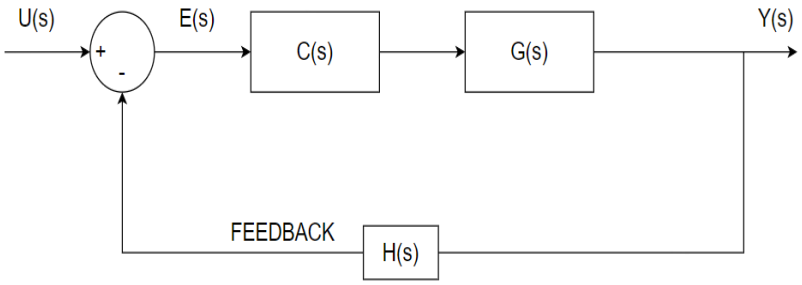


fig4. 2 General block diagram of the control system of plant

G(s) system is $\frac{Y(s)}{U(s)}$

$$E(s)= U(s) – H(s)\ Y(s) \quad (4.3)$$

$$Y(s) = E(s)C(s)G(s). \quad (4.4)$$

Now, we can calculate input output relationship from the graph

Substitute equation (1) in equation (2)

$$Y(s) = E(s)*C(s)*G(s)$$

$$Y(s) = (U(s) – H(s) *Y(s))C(s)*G(s)$$

Y(s) = (U(s) *C(s)*G(s)– H(s) Y(s)*C(s)*G(s)

Collect like terms,

Y(s) + H(s) Y(s)C(s)G(s) = (U(s) C(s)G(s)

Y(s)(1 + H(s)C(s)G(s)) = (U(s) C(s)G(s)

$$\frac{Y(s)}{U(s)} = \frac{C(s)*G(s)}{1 + H(s)*C(s)*G(s)} \qquad (4.5)$$

Substitute, H(s) = 1, unit feedback, C(s) = gain, K

G(s) = plant is equal to $\frac{0.0202}{0.000002s^2+0.0038s+1}$

Now, substitute the given values in equation (3)

$$\frac{Y(s)}{U(s)} = \frac{C(s)*G(s)}{1 + H(s)*C(s)*G(s)}$$

Transfer function F(s)= $\frac{Y(s)}{U(s)}$

$$F(s)= \frac{K\frac{0.0202}{0.000002s^2+0.0038s+1}}{1+K\frac{0.0202}{0.000002s^2+0.0038s+1}}$$

$$=\frac{0.0202K}{0.000002s^2+0.0038s+1} * \frac{0.000002s^2+0.0038s+1}{0.000002s^2+0.0038s+1+0.0202K}$$

$$= \frac{0.0202K}{0.000002s^2+0.0038s+0.0202K+1}$$

The characteristics of the system is the denominator D(s) = 0

D(s) = $0.000002s^2 + 0.0038s + 0.0202K + 1 = 0$

Calculate ultimate gain k_{cu} and ultimate period p_{cu} by using routh herwitz stability

$0.000002s^2 + 0.0038s + 0.0202K + 1 = 0$ (4.6)

s^2	a_0	a_1
s^1	b_0	b_1
s^0	c_o	c_1

The system to be stable the sign of the first column must be the same so $c_0 > 0$

$c_o = \frac{b_0 * a_1 - a_0 b1}{b_0} > 0$

s^2	0.000002	$0.0202K + 1$
s^1	0.0038	0
s^0	c_o	

$$c_o = \frac{b_0 * a_1 - a_0 b1}{b_0} > 0,$$

$c_o = \frac{0.0038 * 0.0202k + 0.0038 * 1}{0.0038} = 0$

$0.0038 * 0.0202k + 0.0038 * 1 = 0$

$0.00007676k + 0.0038 = 0$

0.00007676k = - 0.0038

K = $\frac{-0.0038}{0.00007676}$ = -49.5

K > -49.5 , let k = - 40 , -20 ,0 ,20,40 …….

Suppose, k = k_{cu} = 40

Substitute k in equation (4) and calculate the values of ω

$0.000002s^2 + 0.0038s + 0.0202K + 1 = 0$

$0.000002s^2 + 0.0038s + 0.0202 * -40 + 1 = 0$

$0.000002s^2 + 0.0038s - 0.808 + 1 = 0$

$0.000002s^2 + 0.0038s + 0.192 = 0$ (5.7)

To calculate the ultimate period p_{cu} first find omega ω,

By substituting s = jω in equation (5)

$0.000002(j\omega)^2 + 0.0038j\omega + 0.192 = 0$

$(j)^2$ = -1

$-0.000002(\omega)^2 + 0.0038j\omega + 0.192 = 0$

Equate imaginary with imaginary term and real with real number

$0.0038j\omega = 0$ & $-0.000002(\omega)^2 + 0.192 = 0$

Calculate the value of ω

$-0.000002(\omega)^2 = -0.192$

$(\omega)^2 = \frac{0.192}{0.000002}$

$$\omega = \sqrt{\frac{0.192}{0.000002}} = \sqrt{904000} = 310$$

$$P_{cu} = \frac{2\pi}{\omega} = \frac{2*3.14}{310} = \frac{6.28}{310} = 0.020258$$

Now we can calculate the parameters of controller by using Zeigler and Nichols described methods of tuning a PID

Table 4. 1 calculation of K_p, K_i, K_d in closed loop

CONTROLLER	K_p	τ_i	τ_d	K_p	K_i	K_d
P	$K_U/2$	∞	0			
PI	$K_U/2.2$	$P_U/1.2$	0			
PID	$K_U/1.7$	$P_U/2$	$P_U/8$	$0.6K_C$	K_p/τ_i	$K_p*\tau_i$

Table 4. 2 calculated values of K_p, K_i, K_d in closed loop

CONTROLLER	K_p	τ_i	τ_d	K_p	K_i	K_d
P	$K_U/2$	∞	0			
PI	$K_U/2.2$	$K_U/1.2$	0	18.18	0.01688	
PID	24	0.01013	0.00254	24	2369.4	0.06077

In industrial control applications, a PID controller is a device that regulates temperature, flow, pressure, speed, and other process variables. PID (proportional integral derivative) controllers, which use a control loop feedback mechanism to control process variables, are the most accurate and trustworthy controllers. PID controllers are linear controllers because they work reliably and efficiently. PID controllers are frequently used in engineering to improve both transient and steady-state behaviors because of its simple control structure, high robustness, and high precision. It has been demonstrated that choosing the right PID parameters allows for both high controllability and quick response times. Many different control systems use PID controllers. A PID controller has three parameters: the integral parameter K_i, the differential parameter K_d, and the proportional

parameter K_p. K_p impacts the system's response time, K_d affects its dynamic performance, and K_i affects the steady state error. These three parameters have a significant impact on how well control systems perform. The continuous form and the discrete form are the two primary modes of the current PID controller.

4.3 FOPID controller

Since Podlubny 19 proposed the idea of the fractional-order PID controllers and demonstrated their efficiency in actuating desired fractional order system responses, dynamic systems based on fractional order calculus have been the subject of extensive research. FOPID stands for the fractional order proportional integral derivative. The FOPID's equation in the Laplace domain is,

$$u(t) = K_p e(t) + K_i D^{-\mu} e(t) + K_d D^{\lambda} e(t) \quad (4.8)$$

The continuous transfer function of FOPID is derived using the Laplace transform, which is provided by: The differential equation of the fractional order controller is thus defined as;

$$U(s) = \left(K_p + \frac{K_i}{S^{\lambda}} + K_d S^{\mu} \right) E(s) \quad (4.9)$$

$$\frac{U(s)}{E(s)} = K_p + \frac{K_I}{S^{\lambda}} + K_d S^{\mu} \quad (4.10)$$

K p stands for proportionality gain, K i for integral gain, K d for derivative gain, and and stand for the differential-integral order for the FOPID controller. The FOPID controller is used because has gain and phase cross over frequency, gain and phase margin, and robustness from changes in the phase cross over frequency and high frequency noise[24]. It also has no steady state error. Fractional Order Proportional-Integral-Derivative (FOPID) controller is based on integration and differentiation of non-integer order. It is usually denoted by μ, λ PI D $(0 < \mu < 1$ and $0 < \lambda < 1)$. In this work the gain values of the proportional, Integral, and derivative (i.e K_p, K_i and K_d , ,) as well as the values of μ and λ are obtained using Genetic Algorithms (GAs).The tuning procedure is based on the principle of model reference control. Illustrative example is presented in which FOPID controller is designed and compared with proportional integral derivatives (PID)

ones. It was shown that FOPID controllers gave more freedom in faithfully following the dynamics of the reference model.[25]

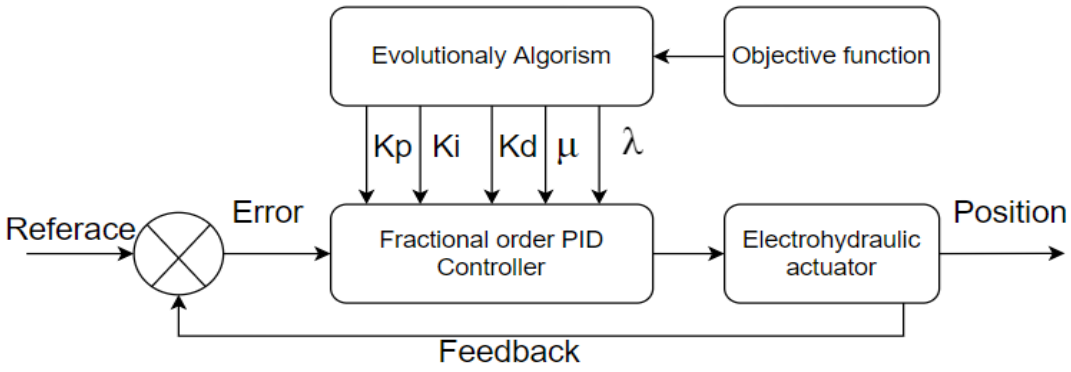


fig.4. 3 Design Of Electro Hydraulic Actuator System Tuned By FOPID Controller

4.4 Optimization Algorism

Finding the best overall solution in the search space for an objective function (its higher or lower values) is known as optimization. Both classical and meta-heuristic methods can be used to accomplish this. Although using these methods won't ensure you get the perfect answer, they can help you get close to the ideal solution at the right moment. One of the most crucial problems, optimization has numerous applications across numerous sciences[26].The Selection of algorithm based on No Free Lunch Theory, which indicates that there is no super-algorithm that can solve every machine learning problem better than every other algorithm. Every algorithm makes assumptions that create different types and levels of bias, thus making them better suited for certain problems. It does not mean that all algorithms are equal. In practice, all algorithms are not created equal. To find a good model for a problem, you may have to try different models and compare them using a robust cross-validation strategy.

4.4.1 PSO based tuning method

The adjustment strategy based on the PSO is one of the transformative computing techniques used to adjust the FOPID controller[27]. The PSO calculation was proposed by Kennedy and Eberhart in 1995. Compared with other expert-based random improvement methods, PSO provides better survey execution and a faster and more uniform mixing rate. In addition, the number of introductory calculation limits to be set is

not much compared to other natural calculations given in the document[28]. The PSO is slowly becoming famous for its worldwide ideal arrangement in many rooms. PSO is a population-based random improvement strategy that is activated through the social behavior of bird noise or fish lessons. The first PSO calculation was reformulated on the friendly model. It should first imitate birds looking for food and is characterized by cornfield carriers. This bird discovers food through friendly cooperation with various birds in the environment (within its area). Then expand it into multi-dimensional pillars (2008) Wang et al. This study examines the tuning of fractional-order PID controllers for a class of fractional-order MIMO systems using the particle swarm optimization (PSO) algorithm. This algorithm, which incorporates socio-cognitive human agents and evolutionary computations, is motivated by the biological behavior of fish schooling and bird flocking. It can solve optimization problems with good numerical convergence. Some simulation results are provided to demonstrate the viability of the PSO-based FOPID and PID controllers. This study presents the design of FOPID controllers for a type of fractional-order MIMO systems using a PSO technique. The design of the PSO-based FOPID control is provided in this work. [29]

4.4.2 TSCO Based Tuning Method

In this thesis I have used a very recent tuning algorism which is called Transit search optimization algorism(TSOA) which is based on the most effective way for finding exoplanets. Some are far larger than others, like Jupiter, yet they orbit their host star much more closely than Mercury does our Sun. Two parameters employed in the suggested technique, and their product is the same as the initial population value in earlier algorithms. The signal-to-noise ratio (SNR) and the number of host stars (ns) are two factors that are defined in the algorithm structure (SN). [26].

Flow chart of TS Algorism

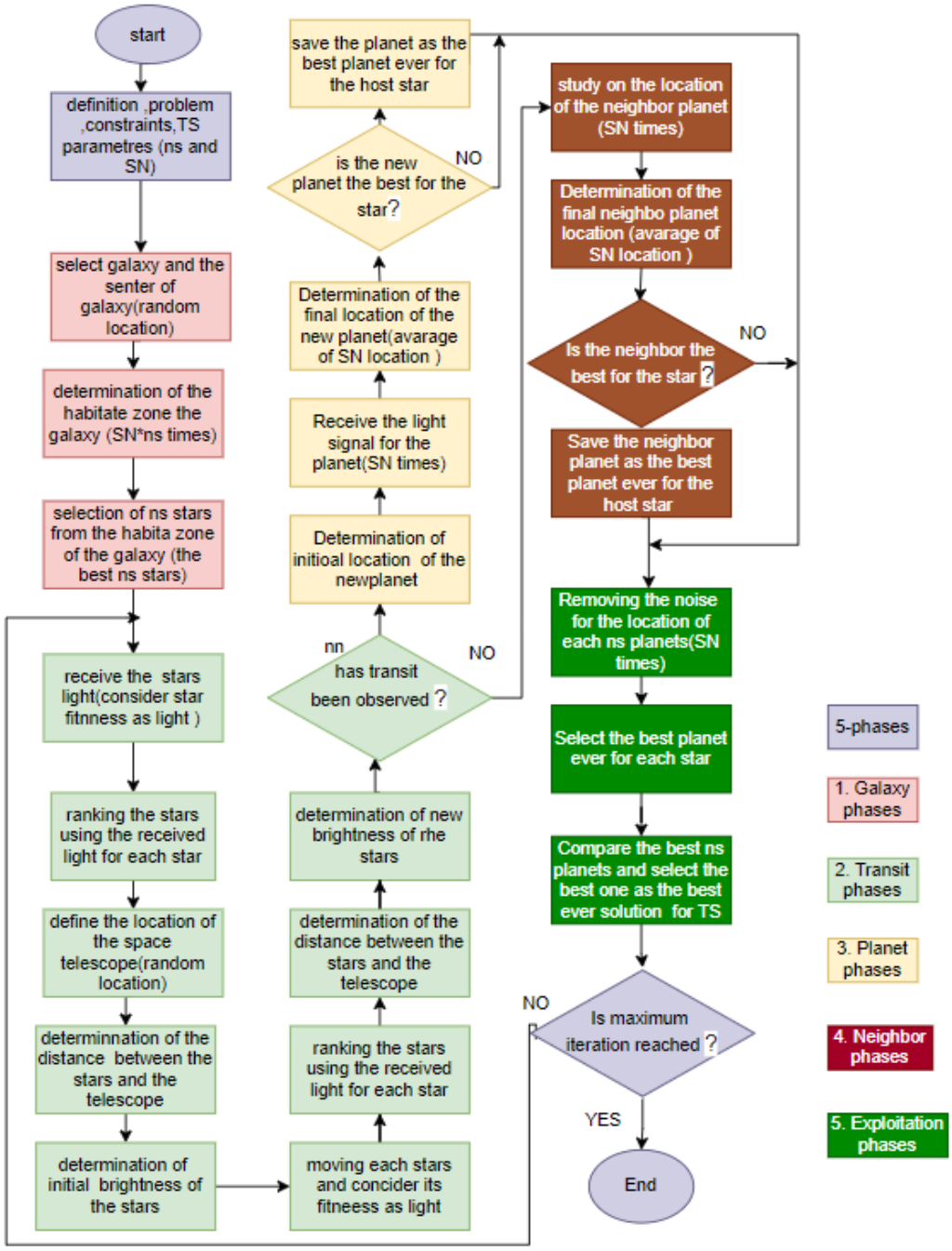


Fig 4.4 Flow chart of TS Algorism

4.4.2.1 Five Phases of TSOA

There are five phases to implementation TSOA : galaxy (star), transit, planet, neighbor, and exploitation.

Galaxy phase : The galaxy center is selected as the appropriate place in the search space at random. Once this position is known, it will be necessary to establish the galaxy's habitable zones (life belt). To do this, the potential for the best star systems in ns*SN random regions LR is evaluated by Eqs. (1) to (3).the probability of existence of maximum host of life). Then, this host star with the best fitness are chosen.

$$L_{R,}l = L_{Galaxy,}D - Noise \qquad l = 1,2,3,\ldots\ldots,(n_{s,} * NS) \tag{1}$$

$$\text{In which D} = \begin{cases} c_{1,}L_{Galaxy} - L_{r,} & if\ z = 1\ (negative\ region) \\ c_{1,}L_{Galaxy} + L_{r,} & if\ z = 2\ (posative\ region) \end{cases} \tag{2}$$

$$\text{Noise} = (c_1)^3\ L_r \qquad \text{Noise} = (c_2)^3\ L_r \tag{3}$$

The galaxy's center is represented by L (Galaxy,) in the equations described above. In the search space, L (r) is a random position as well. To illustrate how the situation of the research area differs from that of the galaxy's center, parameter D is used as a comparison. This region can be found either in the galaxy's front or behind part of the main state zone. In order to improve positioning accuracy, noise associated with the data gathered from the signals that were received must also be eliminated. In order to lower its computational value, a coefficient c2 with a power of 3 has been applied. The following phase involves selecting a star that corresponds to a stellar system using equations (4), one from each of the designated regions (6). As a result, the algorithm can search ns stars at the conclusion of this stage. Ls in Eq4. indicates the location of the stars. In these equations, the coefficients c_3 and c_4 arbitrary values with range of zero and one.

$$L_{s,}i = L_{R,}i + D - Noise \qquad i = 1,\ldots\ldots,n_{s,} \tag{4}$$

$$\text{In which D} = \begin{cases} c_4\ L_{R,}i - c_3\ L_{r,} & if\ z = 1\ (negative\ region) \\ c_{4,}L_{R,}i + c_3\ L_{r,} & if\ z = 2\ (posative\ region) \end{cases} \tag{5}$$

$$\text{Noise} = (c_5)^3\ L_r \tag{6}$$

The galaxy phase of the suggested algorithm is run only once before the iterations begin. This stage's goal is to determine the proper circumstances in which to carry out the algorithm's key steps (phases 2 to 5).

Transit phase : It is required to reassess the light received from the star in order to identify any potential drop in received light signals that could herald the transit. The two meanings of LS and its corresponding fitness f_s in the TS algorithm are M1 is employed when it is desired to determine and update a planet's location using the location of the star. M2 is employed when it is desired to ascertain and update the star's brightness received. Accordingly, a change in LS in the case of M2 denotes a novel characteristic of the brightness data whereas a change of L_s due to M1 denotes a variation of star's location.[30]. A star's intrinsic brightness, also known as luminosity or absolute brightness, refers to how much energy a star emits per second. In addition, how bright a star seems to observers is known as apparent brightness. A crucial factor used for to determine the habitable region of stars is luminosity. Therefore, scientists take into account classes to discover planets where life is likely to exist near the star. The new L_s and the location of the telescope can be used to determine the parameter $d_{i\,new}$ .It is possible to determine whether a transit is possible by comparing L_i with $L_{i\,new}$

This probability, P_T is based on Eqn(7) and is represented by the numbers one indicate presence while zero stands for nonexistence.[26]

If $L_{i\,new} < L_i$ P_T =1(Transit) , $L_{i\,new} \geq L_i$ P_T = 0 (No Transit) (7)

Planet phase : when the planet passes separating of the star and the telescope, less light is seen (a transit happens). This information can be used to determine the planet original position L_Z . The amount of signals received is analyzed to pinpoint the planet's location in its star system by estimating the planet's approximate situation. The Aphelion and Perihelion are the terms used in astronomy to describe the separations between a planet. If the discovered planet in the under-researched star system performs better than the previously identified planet (has better conditions for life), its position is kept in each iteration of the algorithm.

Neighbor phase : This is carried out in the Exploitation step of the TS algorithm. A new definition for the L_P is expressed in this phase. In other words, L_E in the current phase of

L_P corresponds to the planet's properties (such as its density, materials, atmosphere, etc.). The best L_E in this phase can be determined as the best planet for each star. The best planet ever among all n_s detected planets is the algorithm's global solution.

4.4.3 Formulation of Objective Functions

A set of standards is provided to judge the appropriateness of the objective functions, which are framed as indicators of the quality of fit between the equations and experimental data. We evaluate the convergence properties of two existing objective functions.. The objective functions must be capable to “direct” effectively the optimization procedure to get the desired value to experimental data. The objective function provided must adhere to the same distinctive qualities A set of standards is provided to judge the appropriateness of the objective functions, which are framed as indicators of the quality of fit between the equations and experimental data. Two existing objective functions' convergence characteristics are examined[31].

The Objective Function (OF), which keeps track of the optimization search, determines how well the TSO method performs overall. The objective function is chosen as a minimization issue in this thesis. Physical Function The ITAE performance criterion is, as was already established, the fitness function that needs to be minimized. The ITAE performance index has an advantage over the IAE (integral of the absolute error) and ISE (integral square error) performance index in that it produces smaller overshoots and oscillations. Additionally, it has the finest selectivity and is the most sensitive of the three. The ITSE (integral time-square error) produces system with settling time much more quickly. The method of ITAE can be used as one of the best robust FOPID control system design. The ITAE performance criterion for a step input has been determined for the general closed loop transfer function as computationally uncomfortable and some what less sensitive [36], Since integrating up to infinity is not practical, it is customary to select a value for T that is sufficiently large for e(t) to be negligible for t > T. T was set to 10 seconds F = (0.5* ITAE) + (0.25* Tr) + (0.25* Os) The objective functions are not limited to the above equations. Engineers can provide customized objective functions depending on the target design and control system.

CHAPTER 5

SIMULATION RESALT AND DISCUSION

This chapter, the fractional-order PID controller is constructed and investigated for the electrohydraulic actuation system. The performance of the fractional-order PID controller is analyzed using graphical and numerical results obtained from the simulation studies. This work employs the PSO and TSCO optimization algorithms to tune the parameters of the fractional-order PID controller. In this study the electrohydraulic actuator system performance of FOPID controllers are analyzed.

5.1 Open loop response of EHSA system

The open-loop response of a control system is the combined response of the plant and the controller, excluding the effect of the feedback loop.

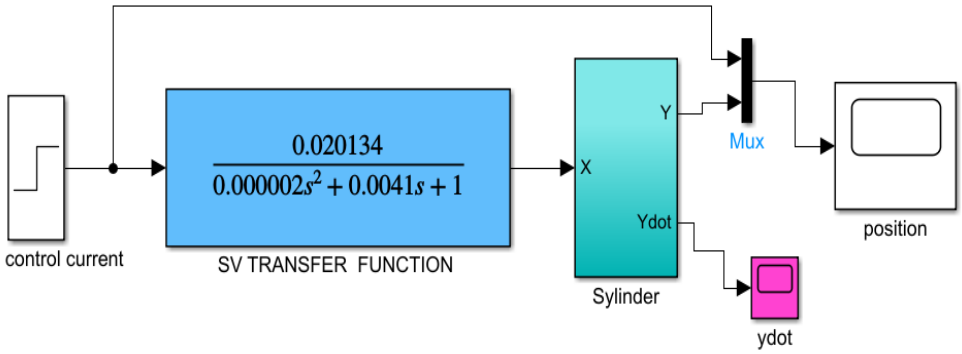


Fig5. 1Simulink model for Open loop response of EHSA system

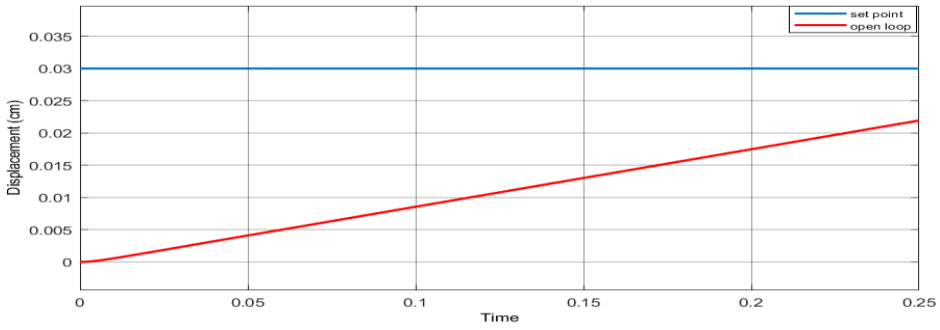


Fig5. 2 Step input for Open loop response of EHSA system graph

Descusion : As we have seen from the graph it does not converge to the set point so the open loop response of the electrohydraulic actuator system is unstable system.

5.2 Position control of EHSA system using PID controller Simulink diagram.

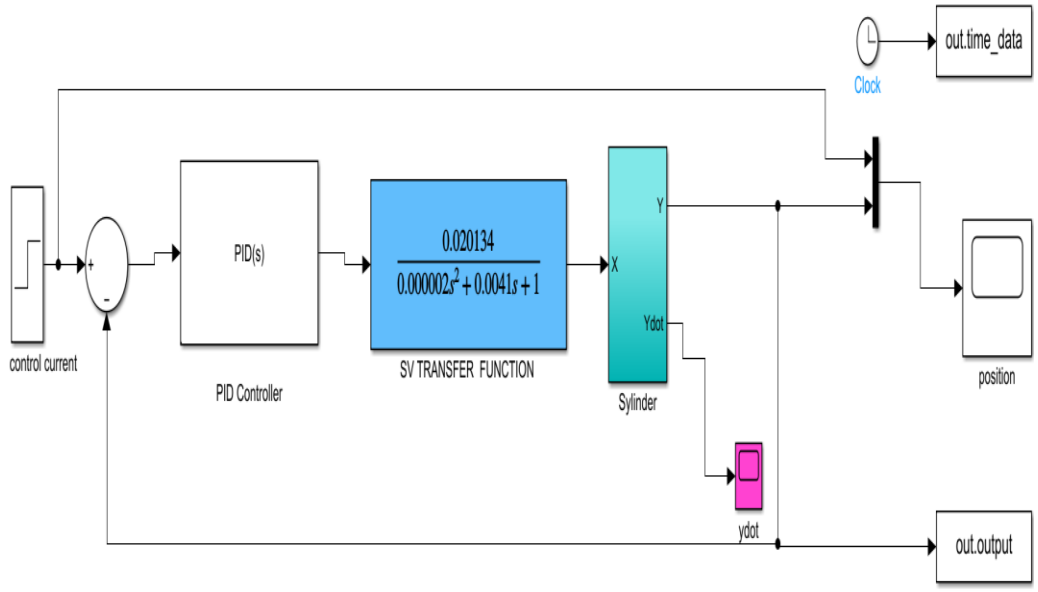


Fig5. 3 Simulink model (PID) controller loop response of EHSA system.

TABLE 5. 1 parameters of conventional the PID controller

controller	Kp	Ki	Kd	Tr	Ts	Mp
CONV.PID	24	2369.4	0.060774	0.0099	0.1270	53.8061

OUTPUT RESPONSE OF CONTROLLED BY THE PID CONTR

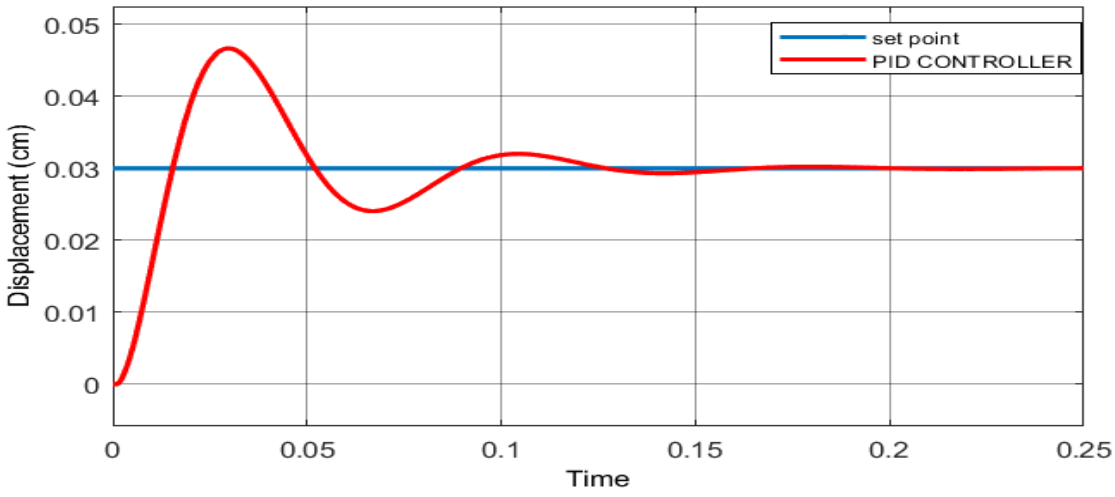


FIG5. 4 LOSED-LOOP OUTPUT RESPONSE PID CONTROLLER FOR THE S.P 0.03CM

From the graph we can get the following parameters

Rise Time: 0.0099

Settling Time: 0.1270

Settling Min: 2.6826e-04

Settling Max: 5.0498e-04

Overshoot: 53.8061

Peak: 5.0498e-04

Peak Time: 0.0294

Discussion

Closed-loop (feedback) output response of electrohydraulic actuator system controlled by the conventional PID controller for the set point 0.0033 cm is more stable than open loop response of the electrohydraulic actuator system because which has small settling time, rise time than open loop system.

5.3 Position control of EHSA system using Conventional FOPID controller

Closed-loop output response of electrohydraulic actuator system controlled by the conventional FOPID controller for the set point 0.03 cm.

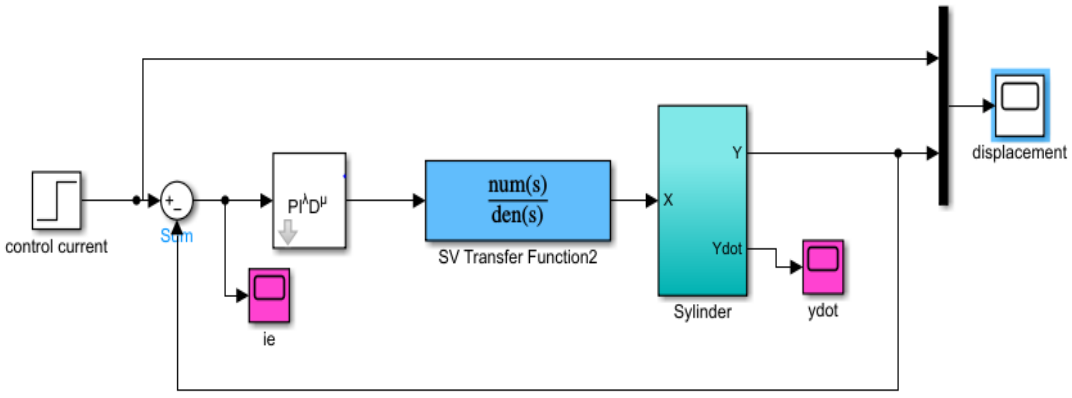


Fig5. 5closed-loop output response PID controller for the set point 0.03 cm

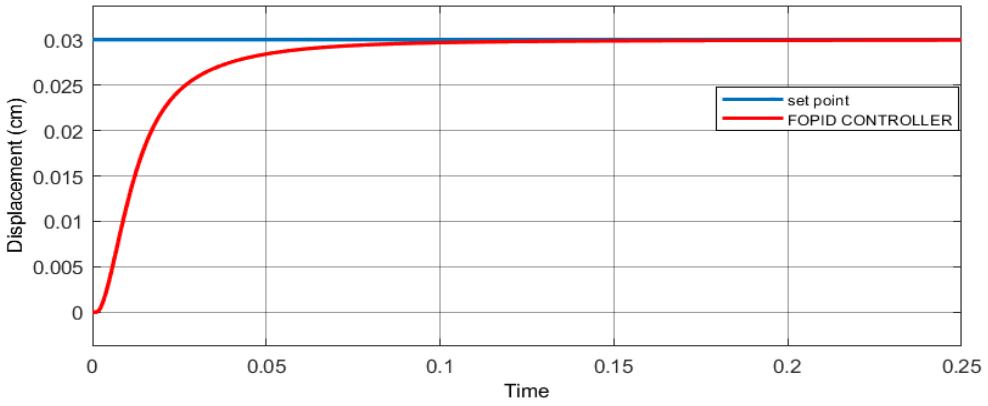


FIG5. 6OUT PUT RESPONSE OF EHAS BY FOPID CONTROLLER FOR THE SET POINT 0.03 CM.

TABLE 5. 2 PARAMETERS OF CONVENTIONAL FOPID CONTROLLER

controller	Kp	Ki	Kd	Lamda	mu	Tr	Ts	Mp(O.S)
FOPID	4.35	14	0.5	0.0009	0.582	0.0327	0.0867	0.0370

Rise Time: 0.0327

Settling Time: 0.0867

Settling Min: 2.9596e-04

Settling Max: 3.2818e-04

Overshoot: 0.0370

Undershoot: 4.0637e-57

Peak: 3.2818e-04

Peak Time: 0.248

Discussion

As we have seen from the graph the fractional order proportional integral derivative controller converge more quickly than conventional PID controller because it has two more additional parameters lamda and mu to adjust the system ,by searching the value of these parameters by try and error because there is no any general formula for conventional fractional order PID controller so its settling time, rising time and over shoot is small so fractional order proportional integral derivative controller is more advanced to control position control of EHS actuators.

5.4. Tuning of FOPID by PSO Algorisms for EHAS at Set point 0.03cm

TABLE5.3 CONTROL GAIN AND TIME RESPONSE SPECIFICATIONS OF PSO ALGORISMS FOR VARIOUS OBJECTIVE FUNCTION

Runs	K_{p1}	K_i	K_d	λ	μ	Tr In sec	Ts in sec	Os	O.F(F	Conv. Itrr. no.
Run 1	6.4597	18.5424	2.1690	0.0349	0.1573	0.0183	0.0310	0	0.0046	97
Run 2	18.7888	1.5352	2.3862	0.7585	0.2336	0.0236	0.0660	0.0233	0.0118	97
Run 3	18.7992	16.9286	2.1822	0.9897	0.1514	0.02154	0.0581	0.0225	0.0120	45
Run 4	19.8534	18.2452	2.6384	0.9947	0.1706	0.0224	0.0548	0.0253	0.0120	99
Run 5	20	3.9872	1.5848	0.5870	0.2231	0.0236	0.0537	0.0209	0.0112	26
Run 6	19.8116	2.9556	3.0380	0.7859	0.0604	0.0229	0.0445	0.0221	0.0113	48
Run 7	19.9999	5.0479	1.6193	0.9118	0.2172	0.0241	0.0578	0.0203	0.0112	98
Run 8	19.0018	0.9289	2.8976	0.7973	0.1820	0.0225	0.0583	0.0237	0.0116	63
Run 9	13.579	0	3.9421	0.2938	0.1730	0.0296	0.0837	0.0182	0.0121	49
Ru10	19.987	6.2939	2.4698	0.0305	0.0676	0.0194	0.0321	0	0.0048	86

After 100 runs of the PSO algorithm, the position vector of the best particle gives the optimized parameters of the fractional order PID controller as shown below

Table 5. 4 Best values of time response from ten iteration of PSOA

Kp	Ki	Kd	lamda	mue	Rise time	Settling time	O.S	F	C.I no.
6.4597	18.54	2.1690	0.0349	0.1573	0.0183	0.0310	0	0.0046	97

Rise Time: 0.0183 Settling Time: 0.0310 Settling Min: 2.9874e-04

Under .shoot: 0 Peak: 3.3003e-04 Peak Time: 0.2500

FRACTIONAL ORDER PID CONTROLLER TUNED BY PSO ALGORISM FOR PLANT EHA

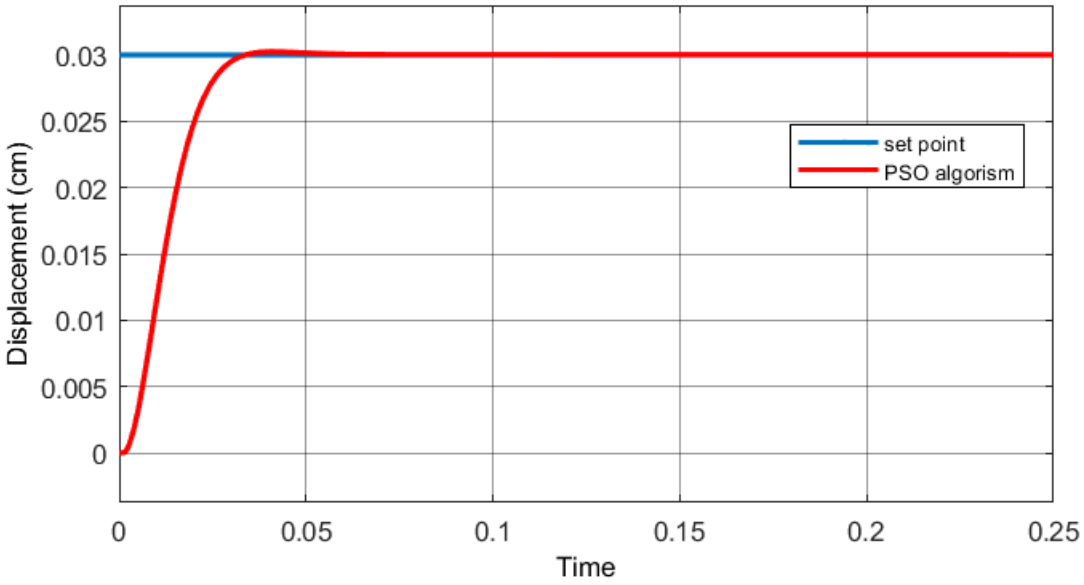


FIG5. 7OUTPUT RESPONSE OF EHAS BY PSO ALGORISM FOR THE SET POINT 0.03 CM.

Discussion : As shown above we have seen from the graph the fractional order proportional integral derivative controller tuned by PSO Algorithm gives better performance and stability parameters and converge more quickly than conventional FOPID controller because PSO Algorithm searches for (10 run) 100 iteration to get the best desired parameter values so its settling time, rising time and over shoot is small so PSO Algorithm makes EHAS stable than conventional FOPID controller.

5.5 (TSCO-based FOPID controller tuning) at Set point = 0.03cm

TABLE 5. 5 SEARCHING OF OPTIMIZATION PROCESS VALUES OF OBJECTIVE FUNCTION AND FOPID PARAMETERS.

Runs	K_{p1}	K_i	K_d	λ	μ	Ris.tisec	Set.tiin sec	overshoot	F	C .I No.
Run 1	3.4446	21.8264	0.8701	0.0074	0.1147	0.0185	0.0312	0	0.0047	41
Run 2	0.0710	21.9972	1.2535	0.0228	0.1398	0.0224	0.0295	0	0.0056	61
Run 3	12.5460	5.6314	2.6394	0.0000	0.1557	0.0242	0.0583	0.0228	0.0118	54
Run 4	1.9160	23.9314	0.0002	0.0000	0.0098	0.0185	0.0312	0	0.0047	4
Run 5	19.09148	9.1658	0.1579	0.0003	0.0715	0.0175	0.0290	0	0.0044	1
Run 6	7.6792	17.8451	0.0906	0.0104	0.1180	0.0198	0.0337	0	0.0050	89
Run 7	15.5112	12.0444	0.3057	0.0000	0.0238	0.0177	0.0294	0	0.0045	57
Run 8	17.0572	6.4195	3.9118	0.0538	0.0381	0.0188	0.0316	0	0.0047	39
Run 9	14.5956	6.8031	1.2726	0.0000	0.2726	0.02190	0.0544	0	0.0118	75
Run 10	8.3466	16.4157	0.4399	0.0367	0.3608	0.0213	0.0383	0.0123	0.0084	98

Table 5. 6 The Best tuned parameters values from above ten TSCO iteration

Kp	Ki	Kd	lamd	mue	R.T	S.T	OS	F	C.I.no
19.092	9.168	0.1579	0.0003	0.0715	0.0175	0.0295	0	0.0044	1

By using the best parameters values of TSCO algorism we can draw the Simulink response

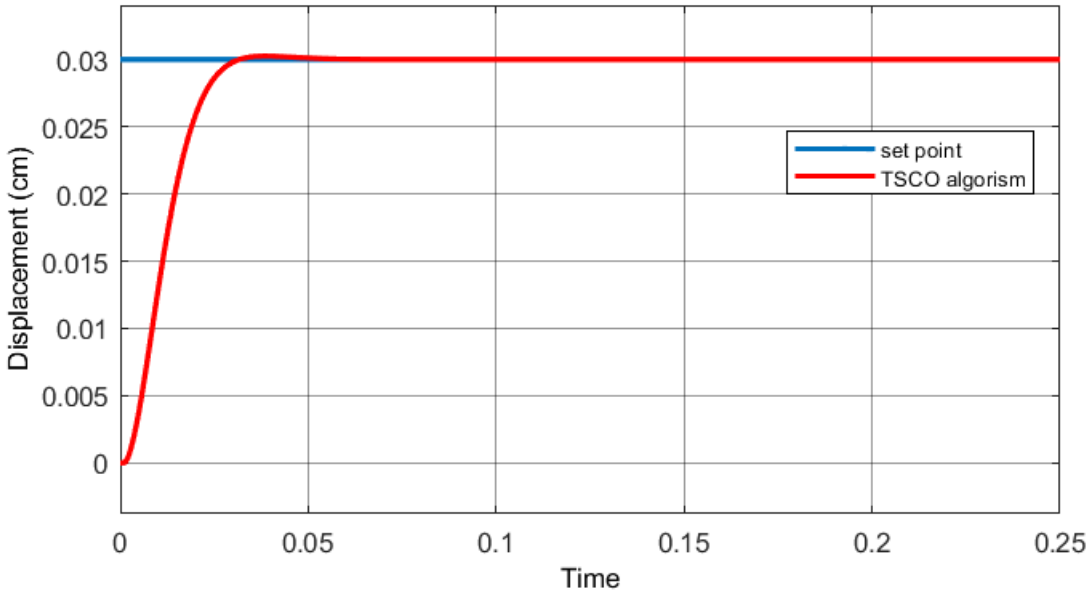


Fig5. 8 Out put response of EHAS by TSCO Algorism for the set point 0.03 cm

Discussion： As shown above we have seen from the graph the fractional order proportional integral derivative controller tuned by TSCO Algorithm gives better performance and stability parameters and converge more quickly than conventional FOPID controller and PSO Algorithm which searches for 100 iteration to get the best desired parameter values so its settling time, rising time and over shoot is small so TSCO algorism makes EHAS stable than conventional FOPID controller and PSO algorism.

5.6 Performance comparison of all used controller at set point 0.03cm

TABLE 5. 7 TUNED PARAMETRE FOPID, PSO AND TSO TUNED FOPID CONTROLLER

controller	Kp	Ki	Kd	Lamda	Mu	Tr	Ts	Mp	F	CI No
Conv-PID	24	2369.4	0.0608	0.0099	0.1270	53.8061	24	2369.4		
Conv-FOPID	4.35	14	0.5	0.0009	0.5820	0.0327	0.087	0.0370		
PSO-FOPID	6.4597	18.5424	2.1690	0.0349	0.1573	0.0183	0.0310	0	0.0046	97
TSCO-FOPID	19.092	9.1658	0.1579	0.0003	0.0715	0.0175	0.0290	0	0.0044	1

Draw the comparison on the mat lab soft ware

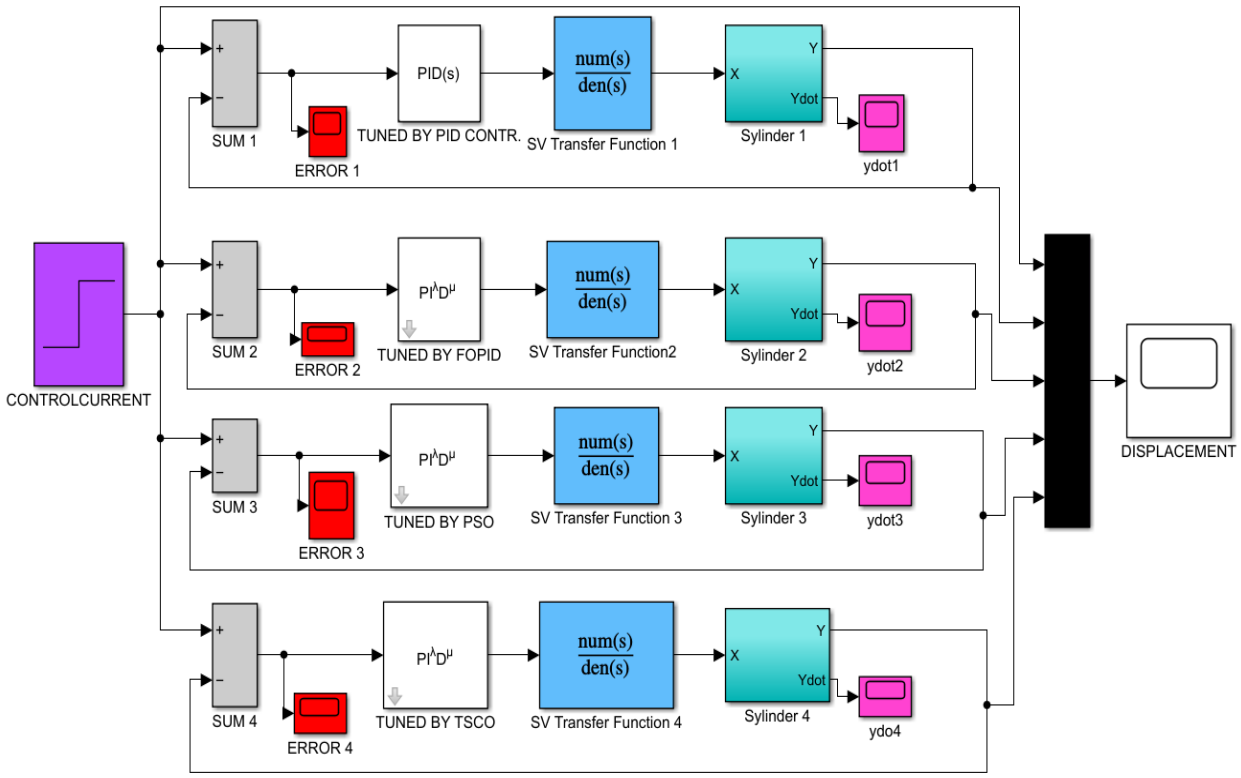


FIG5. 9 SIMULINK GRAPH OF COMPARISON OF ALL TUNING METHODS SET POINT 0.03CM

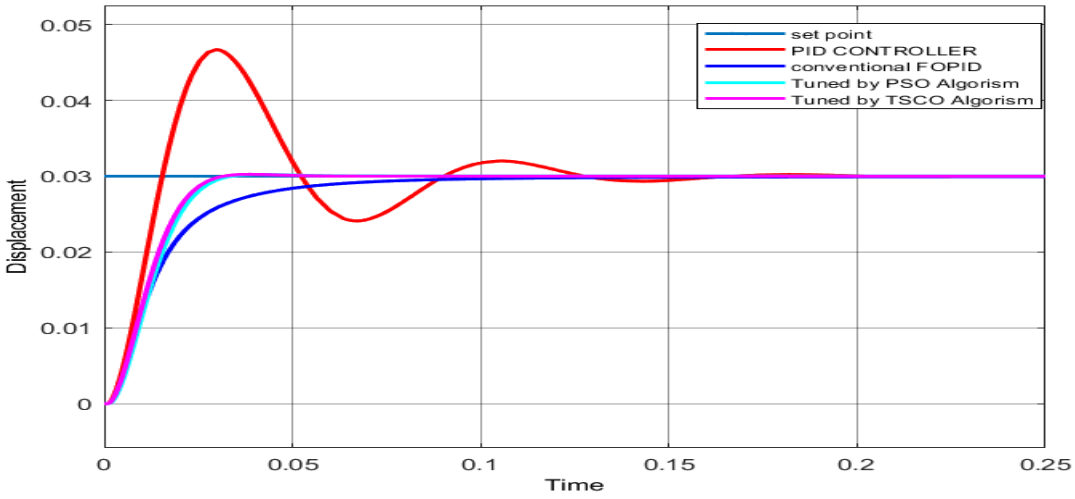


Fig5. 10 output response of comparison of all tuning methods set point at 0.03cm

In this simulation study, the parameters of the FOPID controller is optimized using PSO and TSCO algorithm by considering ITAE as an objective function. The optimized FOPID controller parameters and time domain specifications are tabulated in Table 5.6 and Figure 5.9 shows the closed-loop output response comparison of Electrohydraulic actuator system controlled by the conventional FOPID controller, PSO and TSO tuned FOPID controller for the set points 0.03. From table 5.6 and figure 5.9,it has been observed that the TSO and PSO algorithm-based FOPID controller's performance with ITAE objective function produces better response with less % overshoot, rise time, and settling time than the conventional FOPID controller. Also convergence characteristics of these two iterative algorithm is said to converged when as the iterations proceed the output gets closer and closer to a specific value (set point). In some circumstances, an algorithm will diverge; its output will undergo larger and larger oscillations, never approaching a useful result. But TSCO in its first iteration converge and it finds the desire parameters of FOPID controller parameters, in the case of PSO algorithm it convergence after **97** iteration to get its desire FOPID controller parameters the TSO tuned FOPID controller performs well in convergence with in small iteration number in this system convergence iteration fast settling time and rise time and minimum percentage overshoot for the set point 0.03cm.

5.7. Performance comparison of all used controller for multiple set point

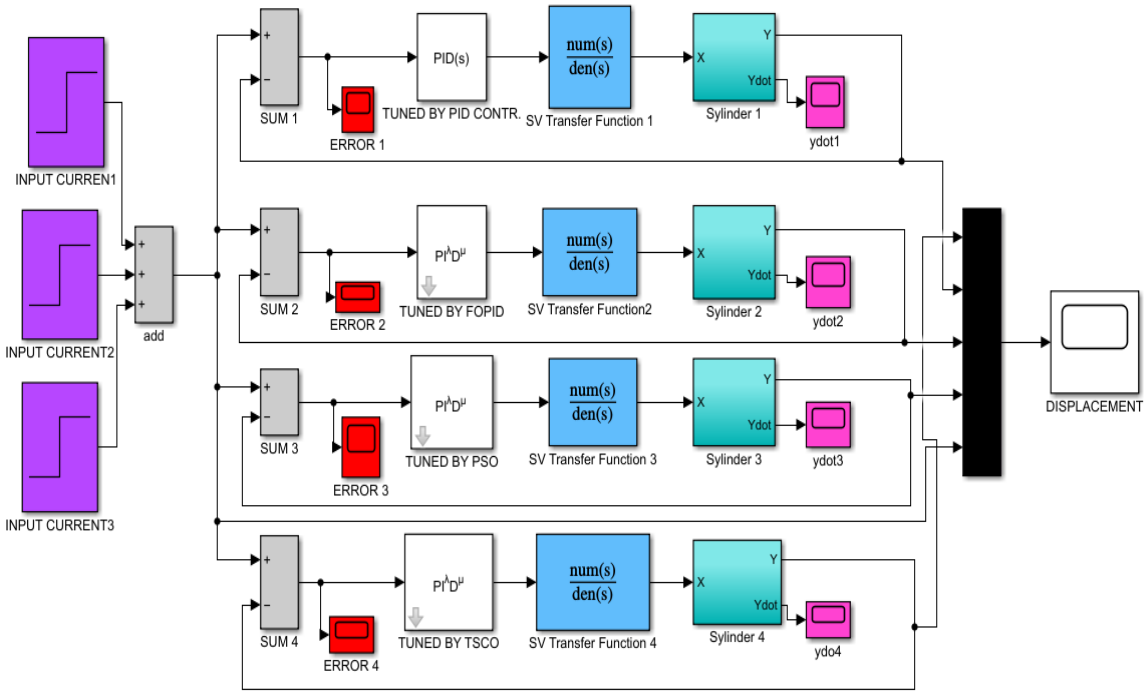


FIG5. 11SIMULINK DIAGRAM OF ALL TUNING METHODS FOR MULTIPLE INPUT SET POINT 0.03CM

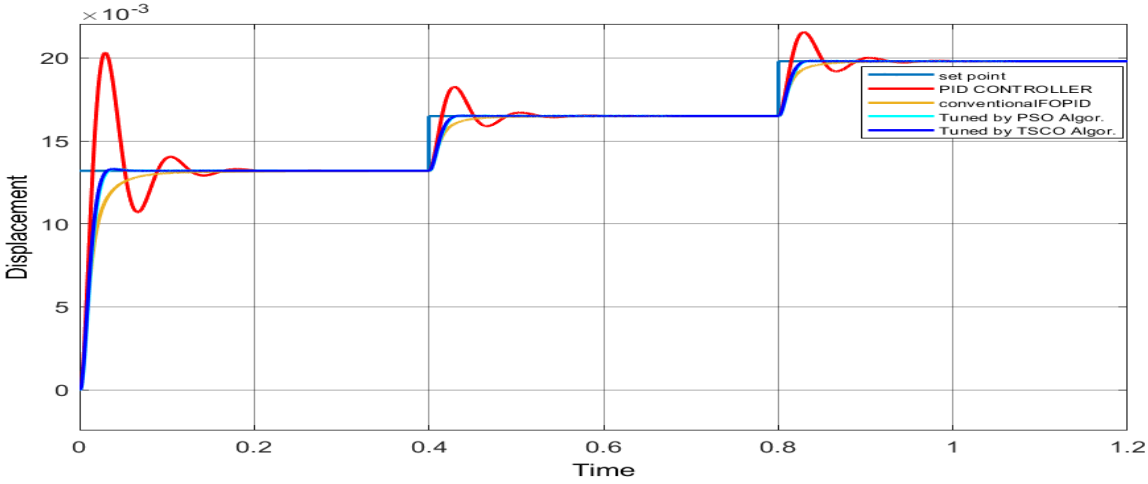


FIG5. 12 OUT PUT RESPONSE OF ALL TUNING METHODS FOR MULTIPLE INPUT SET POINT 0.03CM

In this simulation study, the PSO and TSCO tuned FOPID controller performance is validated for the multiple set points 0.03cm, 0.06 cm, and 0.09 cm. In this case, the FOPID controller parameters tabulated in Table 5.6 are used for the conventional FOPID, PSO and TSCO tuned FOPID controller. The Simulink model for position control of electrohydraulic servo actuator system using FOPID controller for the multiple set points

is shown in figure 5.11. Figure 5.11 shows the closed-loop output response of the position control of electrohydraulic servo actuator system controlled by the conventional FOPID controller, PSO and TSCO tuned FOPID controller for the multiple set points. From Figure 5.9, it is observed that the TSCO and PSO algorithm tuned FOPI controller effectively tracks the set point and produces better response with less % overshoot, rise time, and settling time than the conventional FOPID controller. Significantly, the TSCO tuned FOPID controller performs slightly better with fast settling time, rise time, and minimum percentage overshoot than PSO tuned FOPI controller.

5.8 Simulink model for EHAS using FOPI controller for the disturbance rejection

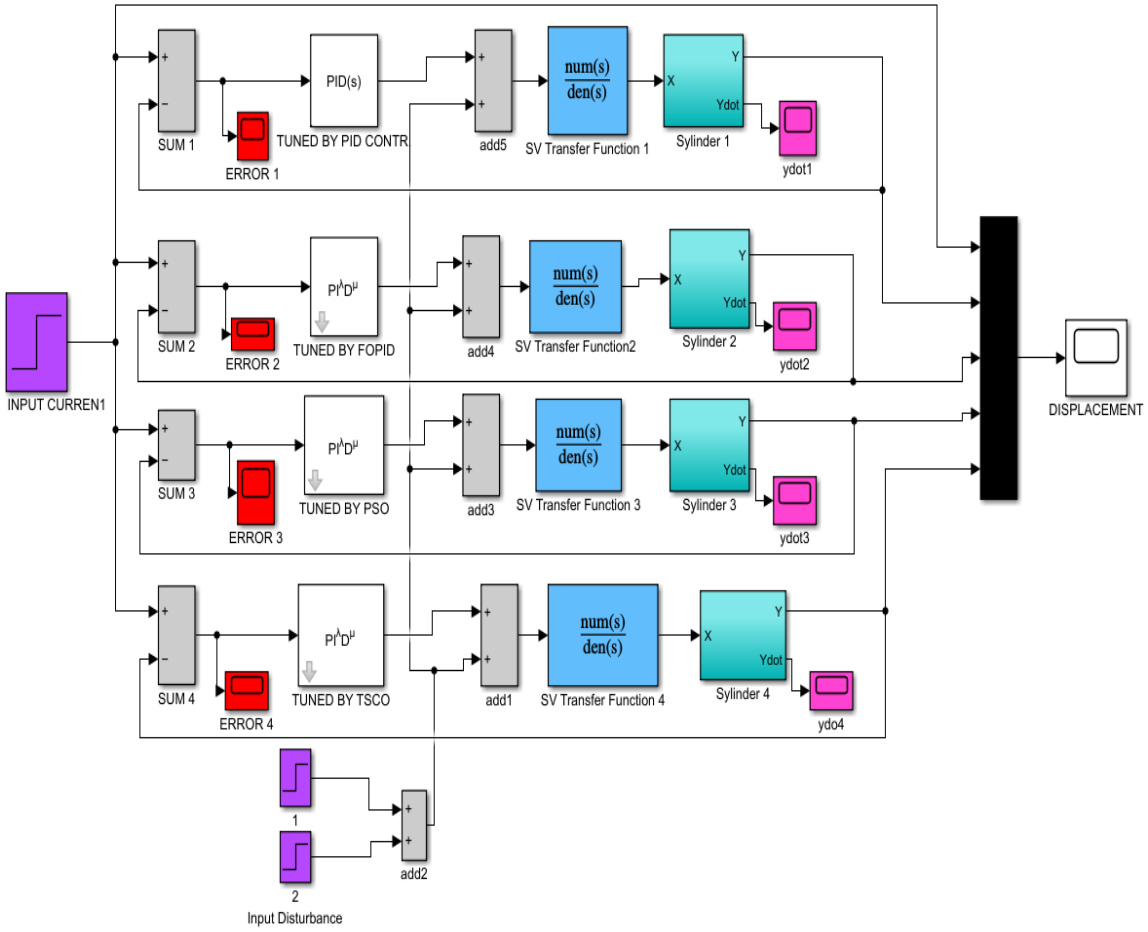


FIG5. 13 SIMULINK MODEL FOR EHAS USING FOPI CONTROLLER FOR THE DISTURBANCE REJECTION

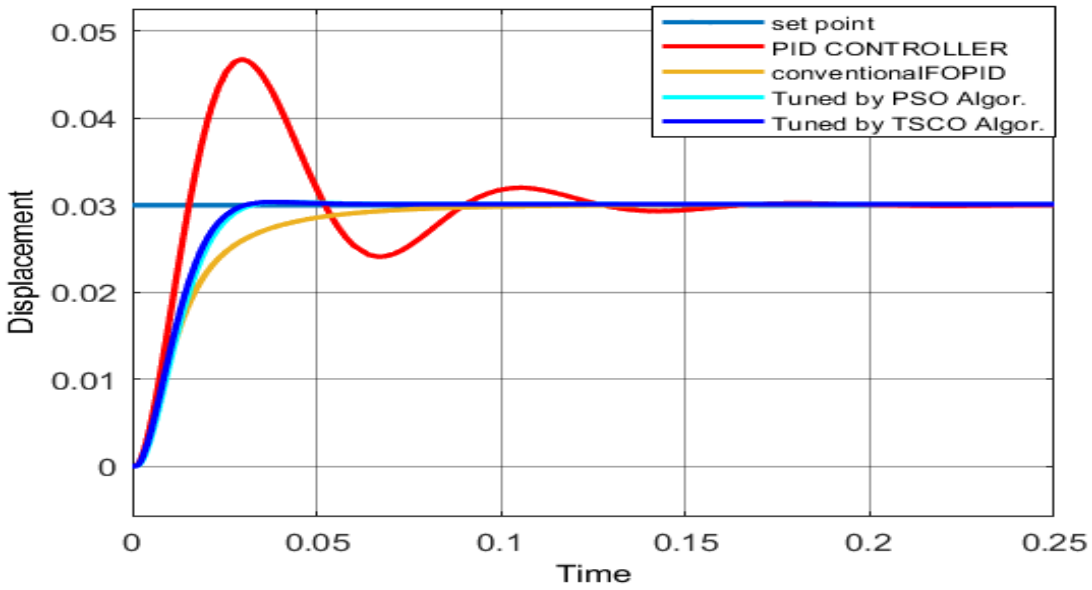


FIG5. 14 MODEL FOR EHAS USING FOPI CONTROLLER FOR THE DISTURBANCE REJECTION

The Simulink model for electro hydraulic servo actuator system using FOPID controller with disturbance input is shown in figure 5.12 and Figure 5.13 shows the closed-loop output response of the electro hydraulic servo actuator system controlled by the conventional FOPID controller , PSO and TSCO tuned FOPID controller for the disturbance rejection. In this simulation, the input flow disturbance of 0.0066 is applied but it is not affected by input disturbance in the interval of 0 up to 0.40 sec, as shown in figure 5.13. From Figure 5.13, it is observed that the TSCO and PSO algorithm tuned FOPID controller effectively rejects the disturbance and regulates the set point level in a short interval of time. Significantly, the TSCO tuned FOPID controller performs slightly better than PSO tuned FOPID controller.

CHAPTER 6

CONCLUSION AND RECOMMENDATION

In this thesis, a FOPID controller is considered to control the position of the electrohydraulic actuator. The plant process is dynamic due to the nonlinear behavior of the tank EHSA system. The parameter of the FOPID controller is initially adjusted by the conventional tuning method, then these parameters are optimized using Particle swarm optimization (PSO), Transit Searches optimization (TSCO) algorithms. And comparing these tuning methods is validated in MATLAB-Simulink software. The TSO algorithm tuned FOPID controller has satisfied all the design necessaries in all of the operating positions than the conventional FOPID and PSO algorithm tuned FOPID controller. The PSO and TSCO tuned FOPID controller provides more well results in terms of better step response such as reduced overshoot, fast response, and rapid settling time in the position control of the electrohydraulic actuator in the production plant. Finally, It is difficult to specify unique approach to get desired solution for all optimization tricky due to existence of variety optimization problems, the computing complexity required, scientific advancements, and the creation of more challenging optimization problems. In order to give various optimization strategies, academics have extensively investigated meta-heuristic methods. The algorithm proposed in this thesis the performance of the proposed algorithm is greater than PSO algorithm . Also, its results were compared with PSO algorithms, the results of which indicate the satisfactory performance of the TS, so that the average has the highest rank between the two algorithms. The most important thing that should be considered for an applicable exploration is definition of random nature to find the solutions at the first stages of each iteration of the algorithm, which makes exploration more efficient. The second case, namely exploitation, is used to improve the solution found by the algorithm. TS algorithm performance in addressing more challenging engineering issues when compared to PSO algorithms. It has been concluded that TSO based optimal tuning method is the best tuning approach chosen rather than PSO and conventional tuning methods.

6.2 RECOMMENDATION FOR THE FUTURE WORK

- The Evolutionary algorithm-based tuning can be improved further by adding more constraints and increasing population size to reduce overshoot during the change in load conditions.
- Depending on load change the derivative control mode is also incorporated to speed-up response and eliminated if the process attains efficiency. The controller can be implemented to other control schemes like flow, temperature, pH, pressure, etc.
- The EA-based tuning method can be used for other multi-input and multi-output systems. The periodic output feedback controller can be designed and implemented for nonlinear processes.
- To improve the performance of the electrohydraulic servo actuator control system, some advanced control techniques such as Harris hawks optimization (HHO) algorithm, Artificial intelligent Neural, Network controller and some advanced controller may be used instead of an evolutionary algorithm-based FO-PID controller.

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