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FACULTY OF ELECTRICAL AND ELECTRONICS TECHNOLOGY

AND INFORMATION AND COMMUNICATION TECHNOLOGY

(DEPARTMENT OF ELECTRICAL AND ELECTRONICS

TECHNOLOGY)

DESIGN OF ACTIVE CONTROL SYSTEM USING ACO BASED PID

CONTROLLER FOR CIVIL STRUCTURE UNDER SEISMIC

EXCITATION.

MSc Thesis for the Partial Fulfillment of Master of Science in Electrical

Automation and Control Technology Management

BY

GETACHEW LEREBO

MTR/ 567/13

Supervisor

DR. ARUN RAMAVERAPHATHIRAN

Jan, 2023

Addis Ababa, Ethiopia

DECLARATION

Here by I declare that, this written thesis proposal on “Design of active controller using ACO based PID control system for civil structure under seismic excitation” is my original work. That is, it has not yet been submitted to any other university for the provision of an academic degree, diploma, or certificate. All sources of materials that are used for this thesis are fully acknowledged through citation.

Name: - GETACHEW LEREBO

Signature: _____

Place: Addis Ababa

Date of Submission: _____

This thesis proposal has been submitted for examination with my approval as a TVTI advisor.

Dr. ARUN RAMAVEERAPATHIRAN

Advisor Name

Signature

Date

APPROVAL SHEET
TECHNICAL AND VOCATIONAL TRAINING INSTITUTE (TVTI)
FACULTY OF ELECTRICAL AND ELECTRONICS TECHNOLOGY
AND
INFORMATION AND COMMUNICATION TECHNOLOGY
(DEPARTMENT OF ELECTRICAL AND ELECTRONICS
TECHNOLOGY)
THESIS ON
DESIGN OF ACTIVE CONTROL SYSTEM USING ACO BASED PID
CONTROLLER FOR CIVIL STRUCTURE UNDER SEISMIC
EXCITATION.

By

GETACHEW LEREBO

APPROVED BY THESIS ADVISORS COMMITTEE

Name of the Advisor	Signature	Date
Dr. ARUN RAMAVEERAPATHIRAN	_____	_____
Name of Examiner, Internal	Signature	Date
_____	_____	_____
Name of Examiner, Internal	Signature	Date
_____	_____	_____
Name of Examiner, External	Signature	Date
_____	_____	_____
Name of Chairperson	Signature	Date
_____	_____	_____

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ABSTRACT

The point of this research work is to develop structural control under seismic excitation. The background of this control mechanism is discussed in introduction part. In the second part, the reviews of literatures are discussed with their limitation and the third part includes the modeling of the civil building (2floor) structure to control, active control system with feedback mechanism has been developed. This feedback mechanism, PID controller with active mass damper is discussed with their designed specification and modeling. Active mass damper system and PID controller were designed for mitigating vibrations along the civil structure due to wind and earthquake. ACO and PSO algorithm are developed for tuning PID parameters. ACO based PID control mechanism has better performance and fast response. The sensor with dual properties has developed for vibration motion of the structure, this sensor is called piezoelectric sensor. Which can work with inverse operation and direct operation, in this thesis work direct operation or sensor operation was considered to sense vibration of the structure under earthquake. And 0.085ac voltage was produced. In spite of the ac output produced by piezoelectric element, rectifier is placed at the output side of the piezo element to convert ac to dc. And produced Dc voltage is low; boost converter is applied to step up this voltage and produces 11.18 Vdc. Dc motor as actuator was designed and produced mechanical force to apply in to active mass damper which is modelled in side of the civil structure. Actuator force produced is $1.9 * 10^{-3}N$ and disturbance force is $-2.7 * 10^{-5}N$.

Force produced by actuator has better performance to decrease vibration of the building. By applying active control mechanism in to the system, controlled structural responses (displacement, velocity) were measured. Displacement or position of the structure is 1.18m and as a force of the actuator increased, the position of the structure decreased and is at stable position.

Key words: PID, ACO, Active mass damper system, Tuning, PSO Piezo element

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List of Acronym

AMD	Active Mass Damper
AC	Alternate Current
DC	Direct Current
Cv	Damping vector
TMD	Tuned Mass Damper
ACO	Ant Colony Optimization
PSO	Particle Swarm Optimization
GA	Genetic Algorithm
SISO	Single Input and Single Output
MTMD	Multiple Tuned Mass Damper
ITAE	Integral Time Absolute Error
TSP	Traveling Sales Man Problem
GA	Genetic Algorithm
HS	Harmony Search
FPA	Flower Pollination Algorithm
LQR	Linear Quadratic Regulator
MIMO	Multi Input Multi Output
MR	Magneto Rheological
HSMC	Hierarchical Sliding Mode Control
NAF	Negative Acceleration Feedback
DOF	Degree of Freedom
MMNAF	Multi Modal Negative Acceleration Feedback
RLS	Recursive Least Square

List of Symbol

K_p	Proportional Constant
K_i	Integral constant
Γ	Location Matrix
K_d	Derivative Constant
ζ	Damping Factor or Coefficient
ω_n	Natural Frequency
\ddot{x}	Acceleration of Structure
\dot{x}	Velocity of Structure
$\dot{\theta}$	Shaft Velocity
X	Displacement of Structure
T_l	Load Torque of the Motor
η_m	Motor Efficiency

CHAPTER ONE

1. INTRODUCTION

1.1 Background

Earthquake and its effects on the building structure

Earthquakes are natural catastrophe under which a sudden accident is happen, Buildings and other man-made structures are primarily to blame for damage to or collapse. Experience has demonstrated that the most effective defense against earthquake-related damage for new projects is the establishment of earthquake resistant laws and their application. Prior to an earthquake, existing structures must be assessed and strengthened using the evaluation standards. Numerous factors can affect how much damage an earthquake does, including the strength, duration, and frequency of the ground motion, the geology and soil conditions, the caliber of the construction, etc. Buildings must be designed in such a way that they have sufficient strength, great ductility, and will remain intact even when subjected to extremely massive deformation [1].

In this paper active control system with PID controller is designed and by tuning PID controller parameters better performance of the objective function is obtained.

Earthquake Effects on the building structure

Damage brought on by earthquakes can be attributed to four main factors: ground tremors, ground failure, tsunamis, and fire. These earthquake sources result in structural vibration. As a result, buildings subject to vibrational motion are under two different types of load.

- ✓ unchanged loads
- ✓ variable loads

- Equation of Static Equilibrium: $F = KY$ (1.1)

F – External Force

K – Stiffness of Structure

Y – Resulting Displacement

The restoring Force (KY) resists the applied force.

- Equation of Dynamic Equilibrium: $Ma + Fd + Fk = F(t)$ (1.2)

$F(t)$ – External force

F_k – Stiffness force

F_d – Damping force

Along with the restoring Force, there are two more forces that oppose applied force (KY).

M is the inertia force.

Damping force F_d

Due to the structure's produced acceleration and velocity, these two forces are generated.

When dynamic load is applied, the structure shakes, that is [2],

(a) The structure develops significant level of inertia forces.

(b) Significant level of mechanical energy is stored as kinetic energy.

F is known as an inertial force,

- Created by building's tendency to remain at rest, in its original position, although the ground beneath it is moving.

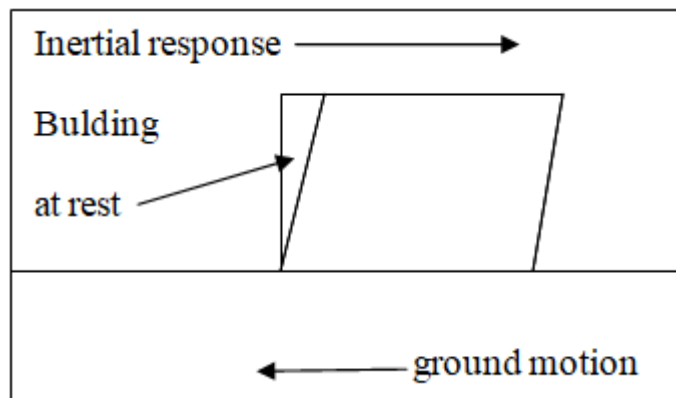


Figure 1.1 Representation of Inertial Force [2].

In figure 1.2 below, the building is thrown backwards and the roof suffers an inertial force when the earth rotates. The roofing moves differently from the ground because the walls or columns are flexible.

Higher inertia force comes from greater mass. Buildings that are lightweight can therefore resist earthquake shaking better.

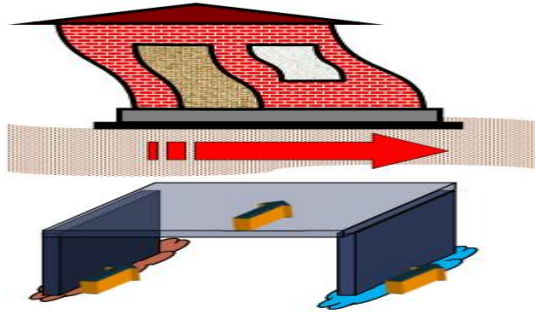


Figure 1.2 Seismic effects on structure[3]

- **Vibration motion**

Vibrational motion is defined as motion that repeatedly reverses in a single direction. Harmonic vibration is a type of vibration that occurs when a moving system continuously passes through a specific position at regular intervals. It is a non-harmonic vibration if it traverses the specified place at various time intervals. If the vibrational movements in a dynamic system slow down over time, the system is stable. If the vibratory motion increases over time, the system may become unstable or metastable [20].

Because of large external forces such as powerful winds and earthquakes, structure vibration control has improved quickly both in theory and practice recently. Earthquakes are stated as violent motion of the earth that is often unpredictable and occurs over a short period. Because of the loss of life and considerable property damage that often occurs of major earthquakes; the effect of earthquakes on structures has always received much interest. In earthquake-prone areas, the practice has been to employ light materials and impose zoning restrictions on structures to reduce loss of life and property damage. During this century, improvements in structural engineering analysis have allowed for more daring designs. As a result, big buildings have begun to appear [12].

Adding the resilience in to the structure, control the incoming signal from external sources. This incoming signal is may be due to large wind forces and earthquake. This strategy is called vibration isolation mechanism using rubber and steel plates. To reduce the vibrations produced by wind and earthquakes in tall buildings, an energetic composite tuned mass damper has been developed. Given that there are uncertainties in the buildings and that the system parameters are not constant, robust control techniques are used for the active control of the structure [4].

Structural control systems

Investigations into structural vibration control have received a lot of attention since it is important to improve the safety and controllability of structures activated by external dynamic loads. Many damping devices, like rubber bearings and buckling-restrained bracing, have been developed and used in civil structures as part of this control strategy, which also includes passive, active, semi-active, and hybrid control methods. Active/semi-active control outcomes have been shown to be influenced by input dynamic actions, control algorithms, the number and position of actuators/dampers, and other factors.

Active control system

In active control systems, the building is forced by the activator under the control of the external power source. The building's energy can be increased or decreased by using this force. Active feedback control systems send a signal to the control actuator that represents the function of the system response as determined by physical sensors. These systems are capable of regulating both internal and external impact responses [21].

A system with active controls is one that often needs a considerable amount of electricity to run the electromechanical or electrohydraulic actuators that actually apply control forces to the structure (notes). In this control approach, the control system is turned on by an external energy source by delivering an analog signal to it. The computer generates this signal by using a control algorithm that takes into account the structure's measured reactions. This work developed and implemented an active control technique using a PID controller. According to the findings, active control mechanisms are 90% more efficient than passive control mechanisms. And the use of external energy, such as actuation, was used in the design of this active mechanism.

The block diagram below shows how the active control system provides feedback solution for the structural responses [4].

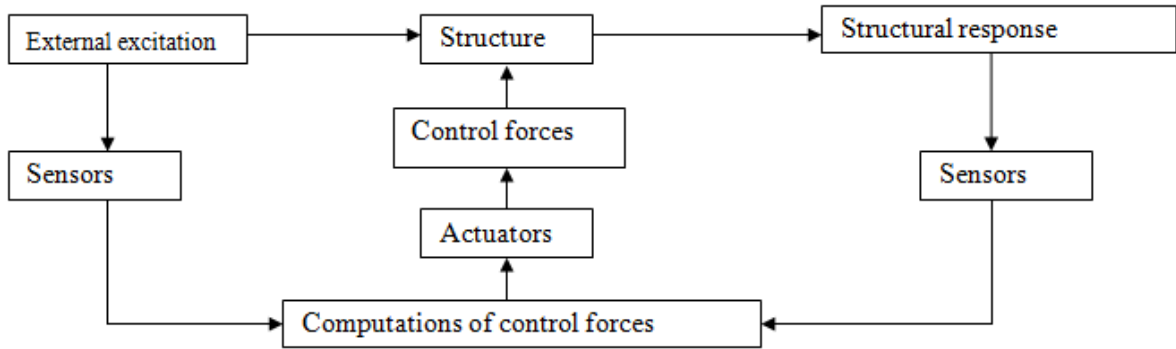


Figure 1.3 Schematic diagram of the active control system [4].

Types of AVC systems are:

- ✓ active mass damper system/tuned mass system
- ✓ active tendon system
- ✓ active brace system

Active mass damper system: it is involved from TMDS with the introduction of active control system strategy. This paper will introduce the design of active control system known as active mass damper system. It needs an external energy or forces from actuators and servomotors, therefore they are said to be energy dissipation devices. AMD is a device used to produce a force which opposes the force of high rising builds which are subjected to seismic excitation. They are also called anti- vibration devices. AMD is an active control, which includes algorithm such as classical controls, neural network control, fuzzy theory PID and mixed one [7].

In [4] stated that ACO based tuned PID controller was designed. ACO is an algorithm which is used to estimate parameters in tuning PID controller system design process. Active mass damper will be designed for structural control system. Tuned PID control with ACO mechanism is developed for controlling of AMD system in the structure. In chapter five the performance comparison of the ACO and PSO algorithm was explained with simulation graph.

ACO algorithm method has been selected for the optimization of PID controller, because it has the following advantages when compared with others such as GA, HA and search algorithms. Instead of using a PSO, an ACO tuned controller provides improved process characteristics such better time domain specifications, supply disturbance rejection, and error minimization. ACO is also far more efficient at adjusting PID control gains than PSO optimization. In this

study, a PID tuning mechanism was developed to minimize the rise time required for the system to respond quickly. The tuning graph's outcome shows that adjusting PID settings with ACO rather than PSO minimizes the goal function (ITAE).

PID Controller

In reference [6] author describes The most popular type of feedback is the PID controller. When process control first arose in the 1940s, it was a crucial component of the earliest governors and later evolved into the industry standard. More than 95% of the control loops in process control today. From mechanical and pneumatic devices to microprocessors via electronic tubes, transistors, and integrated circuits, PID controllers have weathered numerous technological advancements. The PID algorithm is described by:

$$u(t) = K_p e(t) + K_i \int_0^t e(t) dt + K_d (d_e(t))/dt. \quad (1.3)$$

Author in reference [7] illustrates about the optimized PID controller Where u is the control signal, e is the control error; K_p , K_i and K_d are the weights of the error, the integral of the error and the derivative of the error.

The controller has the ability to choose the control signal for the controlled item depending on different weights. If the controller design is fair, the error of the control signal will go down and it will satisfy the control requirements. Consequently, it's crucial to optimize the PID controller's settings. Individuals often configure the PID controller's parameters, which takes a lot of time and doesn't necessarily produce the best performance. PSO has been extensively used in the optimization of functional neural networks for pattern categorization and other uses. The ACO approach was used in this work to establish the PID controller parameter. The PID control system's block diagram is depicted in the figure below, where r, e, and y represent the reference, error, and controlled variables, respectively [19].

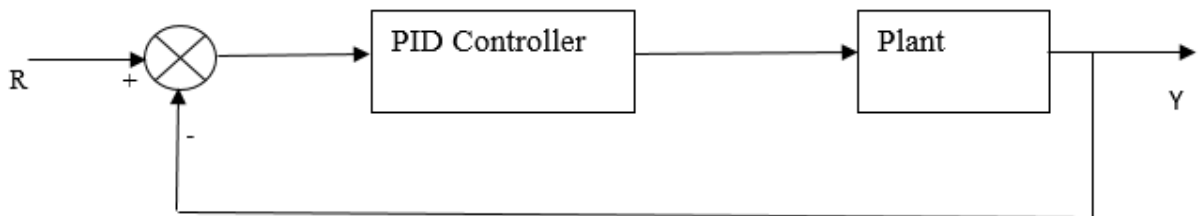


Figure 1.4 The PID control system block diagram [7].

Nonlinearity of Dynamic civil structures

Under actual operating conditions, a variety of engineering structures behave in a nonlinear manner. Unexpected nonlinear behavior of a system can occasionally lead to catastrophic failure. Grandstands for sporting events and concerts may be susceptible to nonlinear oscillations in civil engineering structures because of loose joints, friction, and crowd motion. And also earth quake and wind forces have nonlinear properties; their parameters change with time i.e. there is uncertainties in the system. Nonlinear system needs feedback control mechanism for linearization. In this research optimization technique, ACO algorithm is selected because of it has high performance in nonlinear system and it has shortest time response.

ACO and PSO algorithms

- **PSO algorithm**

PSO is a stochastic global optimization technique based on the intelligence and social behavior of swarms looking for the global optimal (think of flocks of birds or schools of fish). PSO and evolutionary computing methods like genetic algorithms have many similarities.

In reference [9] author states about, “the system is initialized with a population of random solutions and searches for optima by updating generations”. Each particle in the typical PSO has a position represented by a position-vector $x(i)$, (i is the particle's index) and a velocity-vector $v(i)$. Every particle retains both its own and the overall optimum positions (best solution of the entire group). Equation is used to update the velocity from the old velocity to the new velocity during the iteration period t . (2). Equation equ is then used to calculate the new position by adding the old position and the new velocity (1). Each particle that travels across the solution space keeps track of the best solution found. The best option is the new solution if it is less expensive than the existing global solution [10]. Then, this is repeated numerous times.

$$V(i + 1) = c.\{\omega v(i) + c1 r1 (xlbest(i) - x(i)) + c2 r2 (xgbest(i) - x(i))\} \quad (1.4)$$

$$x(i + 1) = x(i) + v(i) \quad (1.5)$$

Where $x(i)$, $xlbest(i)$, and $xgbest(i)$ represent the current particle, the local best solution, and the global best solution at the i th generation, respectively, and $v(i)$ is the particle velocity, $c1$ and $c2$ are learning factors, which are two positive constants defined empirically and in accordance with the relation $c1 + c2 \leq 4$, ω is the inertia weight, which regulates the influence of the previous velocity on the current one, and c is a positive constant known as the constriction

factor, which is used to control and constrict velocities. r_1 and r_2 are uniformly distributed between 0 and 1 [10].

The code for PSO and ACO algorithm is written in MATLAB software.

ACO algorithm

An ant colony's behavior served as the inspiration for the metaheuristic stochastic combinatorial computational technique known as ant colony optimization. While moving, ants leave pheromone on the ground to indicate a trail that other ants in the colony can follow. Shorter paths are more likely to be used by other ants, which further strengthens the pheromone on that path because they acquire pheromone faster than longer ones.

The traveling salesman problem (TSP), the vehicle routing problem, and other graph-related issues were among the first issues that ACO was employed to resolve. Ants pick the vertex to visit at random in order to solve these issues. The likelihood that ant k will go to vertex j is determined when it is in vertex i . Given by is the visibility value of an ant traveling from vertex i to vertex j [11].

$$\eta_{ij} = \frac{1}{d_{ij}} \tag{1.6}$$

d_{ij} is the gap between vertices i and j .

All of the m ants that have created a solution within the iteration itself update the pheromone values every iteration. The pheromone τ_{ij} , which is associated with the edge joining vertices i and j , is updated as follows:

$$\tau_{ij} = (1 - \rho)\tau_{ij} + \sum_{k=1}^m \Delta \tau_{ij}^k \tag{1.7}$$

Where ρ is the pheromone evaporation rate, m is the number of ants, and $\Delta \tau_{ij}^k$ is the quantity of pheromone laid on edge (i, j) by ant k .

ACO algorithm is used to solve a difficult combinatorial problem which is inspired by the pheromone trail lying behavior of real ant colonies what PSO can't solve which is listed above. Due to the fact that ants take shortest path to search the food away from the nest, this algorithm takes shortest iteration rather than PSO algorithm [10,12].

1.2 Statements of the Problem

Vibrations or motions from external sources such as earthquakes or large wind forces are commonly cause structural damage. This motion can happen for relatively a short period of time. Due to this case, civil engineering structures are exposed to vibration or series motion during their life time, so that there will be structural damage and failure.

Mitigation of structural responses against earth quakes and strong winds has always been a strong challenge for civil engineers.

The control mechanism of the structure with respect to incoming signal from external sources has been happen in many times. These control or mitigation strategies are mainly energy dissipation mechanism, non-energy dissipation mechanism or both mechanism. The concept of active structural control is clearly formulated that, during the design of the structure it is impossible to exactly to predict the dynamic disturbances such as ground or wind forces, the structure itself must react during to resist the environmental forces. AMD (tuned mass damper with tuned PID controller through active strategy) possess the necessary qualities to overcome the difficulties presented by a construction that is subjected to seismic stimulation.

1.3 Objectives

1.3.1 General Objective

To develop the optimum active control method for a tuned PID mode controller employing ant colony optimization.

1.3.2 Specific Objective

- ✓ To develop mathematical model of the active civil structure.
- ✓ To develop SISO System of active structural vibration control subjected to seismic excitation (for Active Mass Damper controlling System).
- ✓ To tune PID controller for improving the performance of active mass damper and to ameliorate the feedback of structure animated to seismic.
- ✓ To develop performance comparison of PSO and ACO.

1.4 Motivation of the Research

Earthquakes and large wind forces cause serious problems on the civil structures. Even though the structure is built safely and in the correct manner, external forces may occur to create disturbances. This problem causes the destruction of buildings and also there will be loss of life. To overcome this challenge of the civil structures, it is better to study about active vibration control systems. This is the main focus of this proposal.

1.5 Significance of the Research

Generating an active control structure is the most intentional in the world nowadays, since civil infrastructure has a major problem of damage when they are excited by incoming/disturbing signals. By applying externally opposing control forces, an energy dissipation or harvesting system lowers the structural reactions. The force produced by the active control is equal in magnitude and opposite in sign. So that the force produced by the external structure is cancelled out. These control strategies use sensors to detect the incoming signal and therefore the system will produce the cancellation signal to stop the vibration.

An active control system (AMD) is placed on the wall, if the structures face the problem due to external disturbances such as wind and earthquakes; it produces horizontal forces in order to make the civil structure stable. Structural vibration is reduced, and the system has a better quality diverse response, high adaptability and stability because AMD has a tuned PID feedback controller with a PSO algorithm.

1.6 Scope of the Research

This thesis work focuses on the mathematical model and MATLAB simulation design of an active control system for the application of civil structural control. A feedback ACO-based PID controller is applied to an active mass damper system and simulated in MATLAB/SIMULINK to improve the performances of the structural response. ACO and PSO algorithms are developed for tuning of the PID controller, so that the active mass damper has high energy to influence the disturbance of external forces.

1.7 Limitation of the Research

The thesis is limited to mathematical modeling and simulation of Active vibration controller. MATLAB/SIMULINK software is used to design controller and show the simulation results. Due to the shortage of time implementation of this system is recommended for the future work, because it needs additional time and cost to execute the prototype.

1.8 Methodology

1. Review of related literature.
2. Mathematical modeling of active civil structure and active mass damper system.
3. Design of controller.
4. Simulation using MATLAB 2015a.
5. Results and discussion.
6. Conclusion and recommendation.
7. Paper write up and submission.

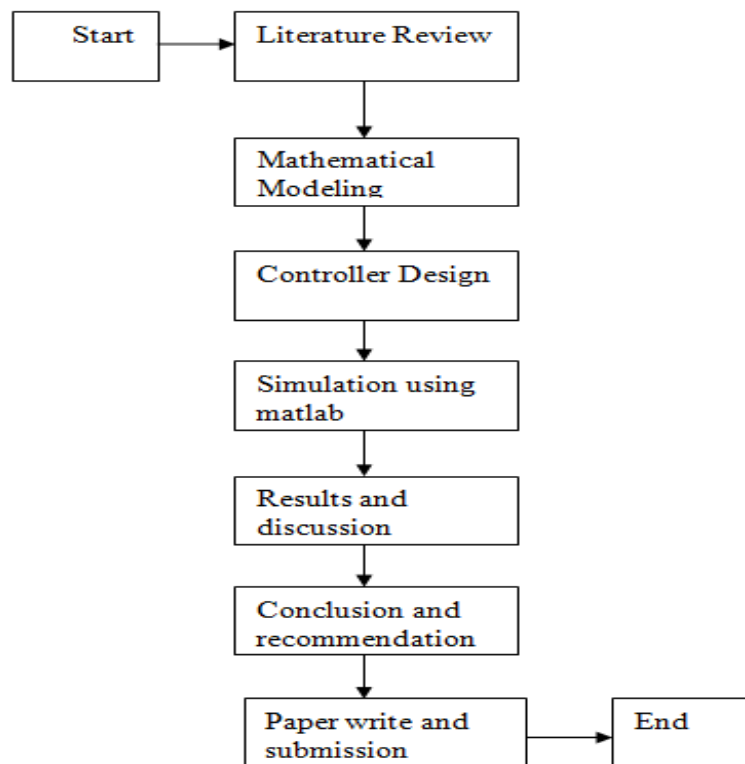


Figure 1.5 Methodology used in this thesis work.

1.9 Thesis Organization

Six chapters make up this thesis document. The introduction, presentation of the problems, objectives, relevance, scope, and constraints of the thesis work that follows the second chapter are all illustrated in the first chapter. The second chapter provides a brief overview of the system components and literature study on the active control mechanism of the ACO-based PID controller used in civil structures. The third chapter of this thesis work addresses the modeling of civil structures, which includes the modeling of two-story civil structures with provided specifications.

Fourth chapter presents the controller design for the civil structure modeled in the chapter the two tuning algorithms are developed in MATLAB. And fifth chapter is about simulation results and discussion. At the end, the overall system is concluded and recommendations are made and references which are cited and available in this research work is also putted finally.

CHAPTER TWO

2. REVIEW OF LITERATURE

Applications of closed loop control system in to the structure with active control strategies Mitigate vibrations along the structure. This vibration is may be due to the large wind forces and earth quake, the simplistic weighted combinations is implanted in real time in order to reduce control algorithm. PSO algorithm method was applied for developing weights of algorithm (PSO_H) [13].

Variations of structural parameters like stiffness, and damping are commonly called parameter uncertainties, this causes structural vibrations, hence increases the amplitude of the structure. To mitigate the disturbance of the structure due to incoming signal, robust based data sampling mechanism had been introduced [5]. The structural parameters cannot be determined effectively by this method; by using ACO based tuned PID controller will overcome this limitation.

The passive energies have better performance for vibration control in civil structure, subjected to dynamic excitation. One of the best example of passive energies device is TMD. To challenge the problems of external forces on the civil structures by using this method it is better to determine the parameter in terms of stiffness and damping and positioning of TMD is also recommended.

And also positions of multiple tuned mass damper (MTMDs) and simultaneous optimization parameters methodology in buildings subjected to earth quakes is proposed. These optimization methodologies proposed to considers uncertainties present in the large structural parameters, in the dynamic load [14]. MTMD is not sufficient method to overcome the overcome the problem associated with dynamic behavior of structural systems, i.e. if there is a parameter variation in the system. Passive control system is a system which has no sensors to sense external forces acting on the structure, active control system has a sensor in which, when an earth quake hits the building, the sensors of active vibration control system detects forces of incoming signal and then the system produces a force opposite to structural force. So that the incoming signal along the structures becomes cancel out.

The active control method is used for reducing structural forces through counteracting external forces. This scheme consists of sensing devices which are used for measurement of external disturbances and also structural responses. The output information of the sensing devices is fed

into the controller, then controller produce the control signal. The actuator takes this signal as the input to produce desired control action if they are driven by adequate power source. The active control action provides an important response reduction under severe dynamic loads. Under this control action complexities and uncertainties are much greater than passive control action. An important issue of this control action is that the magnitude of the control forces required meaningful levels [1]. Here active control system without additional feedback controlling mechanism cannot produces enough controlling that opposes structural disturbances, here I will use tuned PID controller for this limitation.

Large civil structures which are subjected to random seismic excitation are controlled by optimum active control systems by using genetic algorithm. A novel genetic algorithm can optimize the control algorithm, in addition to indication of number and location of actuators, while the structure is randomly subjected to seismic excitation [15].The limitation of this research is, the system may have much iteration to produce a control force which enforces the force of structure, and this is due to using of genetic algorithm. Here it is better to replace ACO algorithm instead of GA, because ACO algorithm will not need more iteration to improve the structural response.

Investigations of the different combinations of feedbacks of the active control were deployed to evaluate the performance of various feedback strategies. The feedback control strategies in the active control systems have better performances in that the structural properties and the motion along the ground play a great role in the performances of the feedback control strategies. HS and FPA are an important algorithm used to determine PID control parameters. Which are useful in providing realized control approach [16]. Problem of this method is, there may be a control force limitations. In this paper tuned PID using particle swarm optimization algorithm will be discussed, so that designed system will have enough controlling force to mitigate the structural vibration.

AMD was constructed to control the vibration along lively foot bridge, in positioning of this device in several deck, reduces the influences of external loads like walking or skipping, exciting the structure in resonance conditions [17].The control strategy is restricted to design of AMD control system. This has no feedback control system like PID, LQR, Neural Network, So that the response of the structure under seismic condition takes some delay to mitigate the vibration of the structure.

- Application of feedback control structure for active control system:

There are many feedback control system to control active mass damper in civil controlling mechanism, such as LQR, Neural network, PID and so on. In this proposed system neural network is applied. A neural oscillator in the neural system synchronizes to the structure's acceleration response, and its outputs can be used to provide the desired value for the auxiliary mass. Using a PID controller, an auxiliary mass is calculated to the desired value, and this auxiliary mass generates the inertial force needed to disperse the energy of structural vibration motion [16],17]. Adding damping system in to the structures needs tuned controller mechanism, in order avoid time delay that affects the system stability. This is the drawback of this research paper. The improved process characteristics that an ACO tuned controller offers include supply disturbance rejection, better time domain specifications, and error minimization. According to this strategy, a PID tuning mechanism will be created to shorten the rise time so that the system responds quickly.

In [19] The AMD was designed and built to lessen the vertical vibration of the simpler bridge model using a linear motor and coil spring. The AMD was managed via a linear quadratic Gaussian method, which combines a linear quadratic regulator and Kalman filter. The AMD's moving mass was found to be 50 kg (3.8%), and tension coil springs were used to modify the moving mass's position in order to increase the motor's output.

An active vibration absorber has been modeled as an electromechanical device using a 1-DOF model for the absorber and an analogous electrical circuit for the electromagnetic actuator. It was applied to an actual structure using the cantilever beam continuous model, which is the most accurate one that can be used. An active vibration absorber works to reduce the primary system's vibration amplitude when a cantilever beam is triggered at its resonance frequencies. The continuous cantilever beam model absorbs the vibration amplitude throughout, not just at the location of the active vibration absorber. The cantilever beam's active absorber's location has a big impact on how much vibration is reduced, especially if it's close to a principal system vibration node where the active absorber is ineffective. It was discovered that the ideal location for the active vibration absorber correlates to the location of the primary system's greatest vibration amplitude [20].

In reference [21] author states that, Application of MIMO Control Algorithm for Active Suspension System was investigated. Focuses on simulating the oscillation of the vehicle with

the LQR control algorithm for the MIMO system. In this paper a quarter dynamic model with hydraulic actuator was considered.

In [22] AMD was developed with rotating actuator in order to overcome the limited mass stroke. AMD with movable actuator has nonlinearities and uncertainties; sliding mode control algorithm is adopted to design controller because of its robustness to suppress the uncertainty of disturbance. In this work there are more independent state variables, which make the system in under actuation system. To solve this problem, Hierarchical sliding mode control (HSMC) method is adopted to design the controller.

Magneto-rheological (MR) actuator is installed by using particle swarm optimization. In this instance, the MR damper is situated between the first and second floors. A magneto-rheological fluid-filled chamber is the inside of an MR damper, which is a mechanical device. A non-magnetic carrier fluid is suspended over small magnetizable particles in this fluid. Three-story non-located building's vibration is managed by the brain's emotional controller [23].

An essential field for determining an experimentally vibrating body's properties is vibration measuring. In order to collect the necessary data for analysis, a combination of an accelerometer and an Arduino is used to record small and quick vibrations, primarily in high speed machines. The accelerometer is attached to a structure with one degree of freedom. The accelerometer counts the number of vibrations over time. This data is subsequently gathered and processed by Arduino to produce the desired output graphs for analysis. The structure is subjected to the experiment twice: initially without any dampening and again with a tuned mass damper (TMD)[24].

In this paper, effect of different mass ratio on performance of tuned mass damper is not present and stable data acquisition system for vibration measurement is also not available.

In [26] Instead of using the traditional approach of tuning the parameters, evolutionary algorithms are employed as optimization methods for the purpose of parameter estimation of a PID controller. By reducing the cost function, search techniques such as GA, PSO, and BBO are utilized to identify the parameter values that are best. The performance of BBO is superior to that of GA and PSO when Type 0 system is used. Due to decreased percentage overshoot and phase margin, the performance of GA improves faster than that of PSO and BBO as the type of the system is raised.

With the increase of system transfer function, the system stability is decreased.

In reference [10] author describes that, a current survey of articles published recently, particularly since 2013, on active, passive, semi-active, and hybrid vibration control methods for structures under dynamic loadings. This is applicable for bridges and buildings.

Two floor (2DOF) vibration structures were controlled by using active control system, i.e. active mass damper used like a cart. In this research project, to prevent earthquake and wind disturbance of the actual structural model, which incorporates MDOF with an active mass damper system, a second-order LQR controller was created. By monitoring the cart, the PID controller makes sure that the floors' deflection control stays within predetermined deflection limits. The PID controller is tuned using a swarm intelligence-based metaheuristic algorithm (bees and genetic algorithms). When compared to genetic algorithms, the performance of the bees algorithm is superior [30].

To achieve good performances and optimize the PID settings, a proficient and effective tuning strategy based on ant ACO is developed. The outcomes of the simulations show how adaptive and effective the suggested technique was in terms of dynamic performance, such as a decrease in maximum overshoot, rise time, and settling time. The ACO had the tools necessary to conduct close-by research at a rapid rate of convergence. The findings produced for the real plant data received from the experimentation measures show good overall system performance and thus show the prudent selection of the ACO criterion for optimizing the PID parameters provided in this work [31].

Here there is no performance comparison; performance comparison is used for evaluating the performance of the ACO algorithm with the other, in that we can develop the selection criteria of this algorithm over the other.

In [32] The MMNAF control algorithm was recommended for use with the AMD system, which comprises of an AC servo motor and an accelerometer. The intended multi modal negative acceleration feedback control establishes the active mass's proper location using the acceleration signal. The AC servo motor is controlled by the acceleration integrator command mode, thus an extra control is necessary for it to obey the position instruction. The MMNAF control has the advantage that it can compute velocity or displacement using acceleration data without utilizing a different method. Theoretically, it has been shown that a single negative acceleration feedback controller for the Single DOF system is stable and that, unlike PPF control, the low frequency area is not made unstable by the NAF. Additionally, it was

demonstrated theoretically and empirically that the MMNAF control is applicable in an MDOF system with a single AMD if the gain matrix satisfies the stability criterion. The test bed was constructed to evaluate how well the study's proposed controller functioned. AMD is developed with feedback controller using PID controller as a driving force. In this study there is no optimization technique, to tune PID parameters.

Reference [33] author implies that PID controller is designed and tuned by ACO algorithm and Zeigler Nicholas method for the human heart control system. In that PID controller with ACO algorithm is better stabilizing effort of cardiovascular system than PID with ziggeler Nichols method, because it has margin of amplitude error.

An efficient approach for determining the AMD-1 EOM, a more accurate representation of the AMD-1 system, and the creation of a feedback control that successfully lowers the AMD-1 structure's oscillation upon excitation are all presented.

Due to their straightforward architecture, generally acceptable control performance, and simplicity of usage, PID controllers are a frequently used control system. Through modeling of the DC motor speed control system, the PID controller has been fine-tuned using the Ziegler-Nichols approach and Particle Swarm Optimization (PSO). In terms of system overshoot, settling time, and rise time, the PSO algorithm approach of tuning a PID controller has been shown to perform better than the conventional Ziegler-Nichols method [34]. The oldness of PSO algorithm is not performed that its response time is somehow slow than the new algorithm such as, ACO. In this paper ACO algorithm is developed to tune PID controller in that the system has better performance time

A magneto-rheological fluid-filled chamber is the inside of an MR damper, which is a mechanical device. A non-magnetic carrier fluid is suspended over small magnetizable particles in this fluid. When exposed to an external magnetic field, the MR fluid has the capacity to modify its rheological characteristics. This process is reversible since the yield stress lowers when the magnetic field is turned off. An evolutionary algorithm-tuned brain-emotional controller was used to present the vibration of a non-collocated, three-story building [23].

The controller here used is semi active system. When compared to the active control system, it has no better performance to mitigate the structural vibration because it has no enough external energy as that of active control system.

By managing the cart, the PID controller makes sure that the floors' deflection control stays within predetermined deflection limits. In order to offer the least amount of floor deflection under Northridge, the gain of PID controller parameters are optimized with the use of the bees' algorithm and genetic algorithm. This study proposes a swarm intelligence-based metaheuristic method for modifying a PID controller for a two-floor structure, in contrast to earlier publications in the field. To reduce floor deflection, PID controller gains are essential, but they are often set using conventional techniques like auto-tuning and the approach of trial and error. PID controller gains are altered using the bees' algorithm and put into practice in the experimental setting in order to contribute to the research and create a novel methodology from other studies. The bees' algorithm combines an exploratory global search with an exploitative local or neighborhood search. A uniform random search is used in both categories of search modes. The bees' algorithm, which has several advantages over other algorithms, is suggested as a versatile method in this study. It is simple to use, capable of both local and global search, implemented with a variety of optimization problems, and available for hybridization with other algorithms. The outcomes of the bees' algorithm are contrasted with those of the genetic algorithm, an established optimization technique, to show the usefulness of the suggested approach [4].

In reference [28] author states that, occurrence history of 1995 earthquake in Mexico City was discussed. In this paper nonlinear sliding mode controller with feedback control loop and boundary layer thickness proved the robustness and the stability of the civil structure excited under earthquake was stated.

An external power source or hydraulic or electromechanical actuator force that delivers a predefined force to the structure makes up an active control system. These forces can be exploited to waste energy or attract it. Based on measurements from sensitive receptors that have been implanted in flooring, this system works [24].

An optimal self-tuning PID controller for tremor defeat of flexible manipulator structures was developed. For optimization techniques PSO algorithm was used. In contrast to the traditional recursive least square (RLS) method, the global search technique of PSO is utilized to estimate the model transfer function by parametric identification. Hub angle and end point displacement system responses are recorded and discussed [29].

A structural test plan can be thought of as a typical actuator and sensor positioning issue for structural testing. The plan is based on information that is currently known about the structure, disturbances that may affect the structure, and predicted structural performance. The finite element model typically provides the initial data on structural characteristics. The location of the disturbance and its spectral contents are included in the disturbance information. The displacements or accelerations of specific structural areas are frequently used to assess the structural performance. Similar definitions apply to the control design problem of a structure. In particular, sensors are located at the sensor permitted sites, which are typically outside of the places where performance is evaluated; actuators are put at the allowable locations, which are not always adjacent to the places where disturbances are applied [30].

Placing sensors and actuators in appropriate position in structural control system is the critical issue to control structure motion during the seismic problem.

Piezoelectric materials enable an efficient conversion from mechanical energy into electrical energy and vice versa. I.e. piezoelectric materials senses physical environments and generating electrical energy and it also converts electrical potential into force or pressure when it is excited to get electric voltage. At both cases crystal between the two electrodes deforms, when it gets either mechanical or electrical energy. The former one is direct form of the piezoelectric materials and the later one is inverse form of the piezoelectric materials. It can works as actuator when voltage applied on it and it can works as transducer or sensor when pressure, forces, vibration is applied [31].

The regulator is a device that is based on the output signal of the actuator to modify the quantity of energy or material, whereas the actuator is a device that refers to the regulator control signal to generate thrust or displacement. One of the parts of automation systems that is being used more and more in many spheres of life is the electric actuator. When it gets a control signal, the operating parameters change [32].

In [40] Active control schemes for vibration suppression of flexible aluminium cantilever beam with bonded piezoelectric actuators was designed. The PZT patches were surface bonded near the fixed end of flexible cantilever beam. The state space model of the flexible cantilever beam with collocated sensor and actuator was derived. To suppress vibration, Positive position feedback control (PPF) and Strain rate feedback control (SRF) were investigated and implemented using CRIO real-time system [33].

Proportional integral (PI), fuzzy logic controller (FLC) and sliding mode controller (SMC) are design to minimize the vibration of the system that represent as building structure towards earthquake. In FLC, the relative rules are the most important part to obtain the desired output. Sliding mode controller is applicable to non-linear system, having high performance and robustness. Among the three types of the controller, SMC have superior performance [34].

In [35] Vibrations being induced on a main structure due to fluctuating force disturbances are suppressed by delayed parameters. A type of Rekasius transformation with frequency sweeping approach is adopted for the stability analysis of the LTI vibration control problem.

2.1 Summary of the Literature Review

The disturbance signal which comes from external sources in to the civil structures has been mitigated by robust based data sampling mechanism. Due to the passive control mechanism, this is insufficient to reduce parameter variations or dynamics of the structure, because passive system has no sensor device to send vibration signal to the controller in order to produce control signal to cancel out the force which produced by the structure. Passive control mechanism (MTMD) was proposed to overcome the problem of earthquake in to the civil structures. This multiple tuned damper is work in the principle of adding mass in the structure. This Passive control mechanism has also no sensors or external energy, so it has time delay to cancel the external signal comes from earthquake or wind forces. An active control structure with improvement mechanism of GA was proposed for controlling of civil structure which is subjected under seismic excitation for better performance of the PID parameters proposed ACO algorithm has a very good efficient. A neural network was proposed for developing active control system to control civil structure. In this paper, active control system was designed. To avoid time delay, ACO algorithm is selected and optimizes PID controller. Piezoelectric sensor with actively working system has been investigated.

AMD was constructed to control the vibration along lively foot bridge, in this case author has developed stated several placement for AMD. He install two AMD in the structure. This is not economical. Placing AMD in physical center with good design specification, can control the entire motion. Hydraulic actuator was developed to overcome 3 floor structural motion. This mechanism needs additional external force. Auto tuned PID controller was developed for active control of flexible manipulator structure. In this case, if the external force increases the vibration

of structure also increases, so that PID parameters tuned by this method are not effective enough to control this arbitrarily changing force. Algorithm based tuning mechanism has good efficient for this, as external force increases the PID parameters are optimized automatically and produces a control force. Some of the specific problems are:

- PSO–PID active control mechanism is not sufficient for mitigating uncertainties of structural parameters. So that ACO based PID controller was developed in this thesis work.
- Due to the sudden disturbance of the earthquake. MTMD cannot produce enough control force, because of its passivity. Active mass damper by the help of the actuator, produces large force to control vibration.
- Bees' algorithm cannot gives fast response when compared to ACO algorithm, it needs more iteration to minimize the objective function. Proposed ACO algorithm with PID controller has fast response and needs low iteration.
- Installing and placing of multiple AMD in to the structure is not economical. Instead by designing active strategy with proportional mass of structure (5% to 10%), in physical center of the structure or installing it, at the top surface of the building can resist vibration.

CHAPTER THREE

3. MODELING OF CIVIL STRUCTURE

3.1 Introduction

The primary topic of this chapter is the modeling civil structure which is 2 DOF (2floor story) the materials, analysis techniques, mathematical modeling of active civil structure and active mass damper has developed. ACO and PSO algorithms are developed for tuning of PID controller for this selected structure and the algorithm was selected with minimum objective function (ITAE). Design of PID controller with active mass damper for civil structure was presented.

3.2 Materials

Software like MATLAB/2015a, Microsoft Office 2013, and Math Type 6.0 Equations are used in this study project. The computer program known as MATLAB includes Simulink and technical toolboxes. Writing of the thesis documentation is done using Microsoft Office. For composing mathematical equations and formulas in Microsoft Office word processing and PowerPoint presentation software, utilize Math Type 6.0.

3.3 Building/ Structure Selected For This Research

Civil structure with two floors is shown as following figure. There are many ways to limit structural vibration brought on by an earthquake or wind, including changing rigidity, masses, damping, or shape, and applying active and passive counterforces. Some structural control techniques have already been employed successfully, and newly proposed approaches may be used to expand applications and boost effectiveness. Civil engineering structural control research has just recently been undertaken. It is already well-established that structural control can play a significant role in both the design of new structures and the seismic and wind adaptation of existing structures [2].

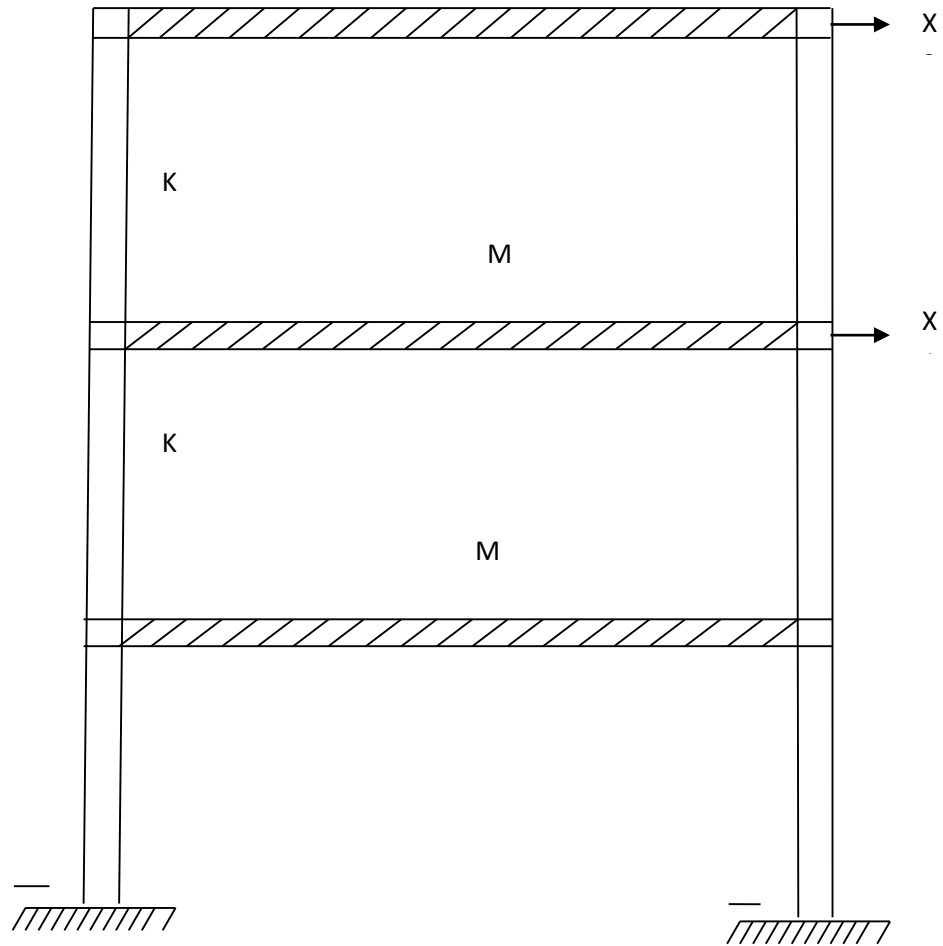


Figure 3.1 Schematic diagram of 2DOF or 2 Floor of civil structure [53].

Description of the structure

Many factors are considered when building is designed. These factors are importance categories of the factors, seismic zone, soil type categories and etc. In this paper ordinary or residential building was considered to control earthquake or seismic force act up on it.

Table 3.1 Important Categories and importance factors for buildings.

Importance categories	Buildings	Importance factor I
I	Hospitals, fire stations, power plant and etc.	1.4
II	School, assembly halls cultural, institution and etc.	1.2

III	Ordinary buildings not belong to other buildings, residential commercial and small building category.	1
IV	Building of minor importance (for agricultural building).	0.8

This paper deals about residential building or belongs to category two.

The above figure – indicates the schematic of residential or ordinary building. The characteristics of this building are shown in the following table.

Analysis of the structure under the lateral force

Lateral forces: Lateral forces are those that operate parallel to the ground and perpendicular to the direction of the earth's gravitational pull. This force is parallel to the plane of reference of the structure and perpendicular to its axis of rotation. Wind, earthquake, and other lateral forces are examples of lateral forces [36].

Base shear of the structure is calculated by the:

Coefficient of the frame resistance c_1

$c_1 = 0.085$, for steel moment of resisting frame.

$c_1 = 0.075$, for RC moment frame

$c_1 = 0.050$ for other buildings

The residential building selected in this research is categorized under RC moment frame ($c_1 = 0.075$).

According to EBCS8 regarding to ground acceleration Ethiopian boundary divided in to 4 zones. This is referred to as α_0 . α_0 Is measured as ground acceleration.

Table 3.2 Zone of Ethiopian boundary according to ground acceleration.

Zone	1	2	3	4
α_0	0.03	0.05	0.07	0.10

Table 3.3 Characteristics of civil building modeled.

Property of the building	Classification
Type	Residential/ Ordinary
C1 selection	moment frame ($c_1 = 0.075$)
α_0 Selection	Zone1
Height of the building	10m

3.4 Mathematical Modeling

In this chapter mathematical modeling of active civil structure and designing of AMD and PID is considered. Active mass damper consists parameters such as mass, damping coefficient and stiffness, these parameters are calculated mathematically. Then AMD with this parameter is attached to secondary structure which is going to be controlled. PID controller is designed and tuned by ACO and PSO algorithm. And then performance comparison of algorithms was presented.

Simulation was done by using MTALAB/SIMULINK Software.

This structural system encounters nonlinearity, due to the earthquake and wind forces parameters of the structure has uncertainties.

3.4.1 Mathematical modeling of civil building / Model of a Two-story system

The study of vibrations present in structures is a component of structural mechanics. It's critical to understand a structure's dynamics in order to control it properly. Control of structures has an impact on how well buildings are protected from unidirectional or bidirectional seismic forces. Modeling dynamic loadings and creating novel methods to reduce vibration are two structural design objectives [37].

Recent earthquakes show that the main source of structural damage is the bidirectional effect. There is the unidirectional force which is acting on the building structure, Represents in the following equations.

$$Fx = -M\ddot{x}g \quad (3.1)$$

But the longitudinal force when compared to the lateral force is negligible, in this paper unidirectional force which is lateral force is considered.

In [38] The standard method of structural design accounts for the seismic response coming from two orthogonal axes of ground motion acting independently. An earthquake typically has random ground movement that is represented as moving in both directions, and it may only affect the torsional and lateral stiffness of the structure with little to no participation from the traverse frames. The motion's equation is presented as [37]:

$$M\ddot{x} + C\dot{x} + SX = f_e, f_e = -mg_a(t) \quad (3.2)$$

M, C, and S are the mass, damping coefficient, and stiffness, respectively, f_e is an external factor that disturbs the process, and x , \dot{x} and \ddot{x} are the displacement, velocity, and acceleration, respectively.

The equation of the motion:

$$M\ddot{x} + C\dot{x} + F_s = f_e, M\ddot{x} + C\dot{x} + F_s = d, d = f_e = -mg_a(t). \quad (3.3)$$

Where, $-mg_a(t)$ is external force due to ground acceleration. Ground acceleration is arbitrarily changing with time. Therefore the force acting on the structure during earthquake is variable with time we cannot measure it by using numerical method.

So, f_e can be represented as:

$$f_e = -f\sin\omega t, \quad (3.4)$$

Where, g_a is ground/external acceleration of the external force.

Negative sign indicates that, external force acting on the structure during ground acceleration is inversely proportional to the lateral force of the structural base. In general equation (3.4) introduces about the behavior of vibration. That is sinusoidal in nature.

All the parameters are expressed in matrix form as

$$\begin{bmatrix} m_{11} & m_{12} \\ m_{21} & m_{22} \end{bmatrix} \ddot{x} + \begin{bmatrix} c_{11} & c_{12} \\ c_{21} & c_{22} \end{bmatrix} \dot{x} + \begin{bmatrix} k_{11} & k_{12} \\ k_{21} & k_{22} \end{bmatrix} x = d, \text{ (external disturbance to the structure).}$$

Where $x \in \mathfrak{R}^m$, $M \in \mathfrak{R}^{m \times m}$, $C \in \mathfrak{R}^{m \times m}$, $f_k = (f_k, 1 \dots f_k, n) \in \mathfrak{R}^m$ is the building stiffness vector and $f_e = \bar{d} \in \mathfrak{R}^m$ is the outside disturbance put in to the process (seismic force). Also $M = \text{diag}(M_1, M_2) \in \mathfrak{R}^{(n) \times (n)}$, $M = \text{diag}(M_1 \dots M_i)$ M_i is the i th floor's mass.

$$f_e = [F_1 F_2]^T, \text{ have 2 components } x = [x_1 x_2]^T. \quad (3.5)$$

$$F_s = Sx, x = [x_1 \dots x_n]^T \in \mathbb{R}^{2n}.$$

$$S = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} = K = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \quad (3.6)$$

The C-matrix damping is corresponding to the mass matrix M and the total stiffness matrix, which is represented by the matrix S. Using the Rayleigh approach, the equation is $C = aM + bS$. As a result, the stiffness matrix S and the damping matrix C have the same shape.

$$C = \begin{bmatrix} c_{11} & c_{12} \\ c_{21} & c_{22} \end{bmatrix} \quad (3.7)$$

In reference [39] if there is a bidirectional external force, torsion coupling occurs in addition to the X- and Y-axis vibrations. The asymmetry of the building, where the mass center is different from the physical center (c f), is what causes the torsional oscillation (cm). However, this research report only takes into account one direction while ignoring the vertical direction in relation to the x direction. The following ODE is obtained by adding the term $d = k\bar{d}$ and multiplying equation (3.3) by m.

$$\ddot{x} + 2\zeta\omega_n\dot{x} + x = \omega_n^2 \bar{d} \quad (3.8)$$

$$\text{Hence, } \left| \frac{[k]}{[m]} \right| = \omega_n^2 \text{ and } \left| \frac{[c]}{[m]} \right| = 2\zeta\omega_n \quad (3.9)$$

And also K, M and C are matrix representation of mass, stiffness coefficient and damping coefficient of the structure.

In order to represent the system in state-space form, state variables are introduced as follows.

$$x_1 = x$$

$$x_2 = \dot{x} = \dot{x}_1 \quad (3.10)$$

Using equ. (3.7) and (3.8) can be rewritten as follows.

$$\dot{x}_2 + 2\zeta\omega_n x_2 + \omega_n^2 x_1 = \omega_n^2 \bar{d} \quad (3.11)$$

By rearranging equ. (3.9) and (3.10), the following system of simultaneous ODE can be obtained.

$$\begin{cases} \dot{x}_1 = x_2 \\ \dot{x}_2 = \omega_n^2 \bar{d} - 2\zeta\omega_n x_2 - \omega_n^2 x_1 \end{cases} \quad (3.12)$$

Equation (3.11) can be stated as follows in a matrix.

$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ -\omega_n^2 & -2\zeta\omega_n \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} 0 \\ \omega_n^2 \end{bmatrix} \bar{d} \quad (3.13)$$

The sensor equation is an additional necessary component in the motion equation. Assume that the sensor is unaffected by the external force and that displacement or x can be measured. The sensor equation can be stated as follows when x_1 of the state vector can be measured in this situation.

$$Y = x = x_1 = [1 \quad 0] \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + [0] \bar{d} \quad (3.14)$$

Equations (3.12) and (3.13) can be expressed as follows by adding a matrix and a vector equation.

$$\dot{x} = AX + B\bar{d} \quad (3.15)$$

$$y = Cx + D\bar{d} \quad (3.16)$$

Where $x = [x_1 \quad x_2]^T$ and $y = x = x_1$

$$A = \begin{bmatrix} 0 & 1 \\ -\omega_n^2 & -2\zeta\omega_n \end{bmatrix}, \quad B = \begin{bmatrix} 0 \\ \omega_n^2 \end{bmatrix}$$

$$C = [1 \quad 0] \text{ And } D = [0]$$

Displacement and velocity measured, and then y , C s, D s will be:

The output equation is: $y = \begin{bmatrix} x \\ \dot{x} \end{bmatrix}$ and then

$$C = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \text{ And } D = \begin{bmatrix} 0 \\ 0 \end{bmatrix}$$

- By using equation 3.8, transfer function of the two floor structural system is therefore:

$$\frac{x(s)}{\bar{d}(s)} = \frac{\omega_n^2}{s^2 + 2\zeta\omega_n s + \omega_n^2}, \text{ but } \bar{d}(s) = -f \sin \omega t \quad (3.17)$$

Therefore equation (3.17) becomes:

$$\frac{x(s)}{\bar{d}(s)} = - \frac{\omega_n^2}{s^2 + 2\zeta\omega_n s + \omega_n^2} \quad (3.18)$$

As mentioned above, negative sign indicates the force acting on the base of the structure is inversely proportional to the lateral force of the structure. This external force due to the

earthquake excitation has form of sinusoidal wave in nature with magnitude of F. this magnitude is changed as value of ωt is changed with time.

Where ω_n and $2\zeta\omega_n$ are calculated by using equation (3.9).

$$\omega_n = \sqrt{\frac{k}{m}}, k = \left\| \begin{bmatrix} k_1 + k_2 & -k_2 \\ -k_2 & k_2 \end{bmatrix} \right\| \text{ and } m = \left\| \begin{bmatrix} m_1 & 0 \\ 0 & m_2 \end{bmatrix} \right\|$$

$$\text{And } 2\zeta\omega_n = \frac{|[c]|}{|[m]|}, c = \left\| \begin{bmatrix} c_1 + c_2 & -c_2 \\ -c_2 & c_2 \end{bmatrix} \right\|$$

The two floors column have the same stiffness, damping coefficient and mass. Then, $m_1 = m_2 = 200kg$, $c_1 = c_2 = 90Ns/m$ and $k_1 = k_2 = 140N/M$.

$$\omega_n = \sqrt{\frac{\left\| \begin{bmatrix} k_1 + k_2 & -k_2 \\ -k_2 & k_2 \end{bmatrix} \right\|}{\left\| \begin{bmatrix} m_1 & 0 \\ 0 & m_2 \end{bmatrix} \right\|}}, \omega_n \text{ is natural frequency.}$$

$$\left\| \begin{bmatrix} k_1 + k_2 & -k_2 \\ -k_2 & k_2 \end{bmatrix} \right\| = \left\| \begin{bmatrix} 140 + 140 & -140 \\ -140 & 140 \end{bmatrix} \right\| = 39200 - 19600 = 19600N/m$$

$$m = \left\| \begin{bmatrix} m_1 & 0 \\ 0 & m_2 \end{bmatrix} \right\| = \left\| \begin{bmatrix} 200 & 0 \\ 0 & 200 \end{bmatrix} \right\| = 40000kg$$

$$\text{Therefore, } \omega_n = \sqrt{\frac{k}{m}} = \sqrt{\frac{19600/M}{40000kg}} = 0.7rad/s$$

$$2\zeta\omega_n = \frac{|[c]|}{|[m]|} = \frac{\left\| \begin{bmatrix} 90 + 90 & -90 \\ -90 & 90 \end{bmatrix} \right\|}{\left\| \begin{bmatrix} 200 & 0 \\ 0 & 200 \end{bmatrix} \right\|} = \frac{8100Ns/m}{40000kg} = \frac{0.2025Ns}{m}/kg$$

$$\zeta = \frac{\frac{0.2025Ns}{mkg}}{2 * \omega_n} = \frac{0.2025Ns/mkg}{2 * 0.7} = 0.145$$

Then transfer function of the system $\frac{x(s)}{d(s)}$ is therefore;

$$\frac{x(s)}{d(s)} = -\frac{(0.7)^2}{s^2 + (2*0.145*0.7)s + (0.7)^2} = -\frac{0.49}{s^2 + 0.203s + 0.49} \quad (3.19)$$

3.4.2 Active Control of Structural Vibration (active mass damper placement)

In [12] The system, a single variable system (SISO) system, has two degrees of freedom. The system is known as a second order differential equation since the motion equation is a matrix equation. This equation can be divided into a first order differential equation. State space equation system is what this is. Now that the state space equation has been reduced to a single transfer function, we refer to this as the MIMO system (SISO system). So that, the SISO system of the civil structure is modeled in this research. Reducing the vibrations brought on by outside forces (f_x), an AMD is installed in the structure. AMD is positioned close to the building's mass center. The control force is u .

Considering the building model equation (), the closed loop system is:

$$M\ddot{x} + C\dot{x} + f_s - f_e = \Gamma(u - d_u). \quad (3.20)$$

The control equation, which represents closed-loop methodology in the aforementioned equation, is used for monitor and stability interpretation. In the above equation $u \in \mathbb{R}^{3n}$ is the control signal that the damper receives, where damper is AMD. d_u is the damping and rubbing force vector of the damper, and Γ is the position matrix of the damper [40]. This is defined as:

$$\Gamma_{i,j} = \begin{cases} 1 & \text{if } i = j = f_l \\ 0 & \text{otherwise} \end{cases} \quad (3.21)$$

Where, $\forall i, j \in \{1 \dots n\}$, $f_l \subseteq \{1 \dots n\}$, the floors that the dampers are mounted on are f_l . For a two-story structure.

$$\Gamma = \begin{bmatrix} \Gamma_{1,1} & \Gamma_{1,2} \\ \Gamma_{2,1} & \Gamma_{2,2} \end{bmatrix}, \text{ location matrix} \quad (3.22)$$

Putting the damper on the second floor

$$\Gamma = \begin{bmatrix} 0 & 0 \\ 0 & 1 \end{bmatrix}. \text{ If both the first and second floors are, where the damper is located, } f_l = \{1, 2\},$$

$$\Gamma = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$$

In this paper AMD is designed and put down in the 2nd story.

$$\text{Therefore } \Gamma = \begin{bmatrix} 0 & 0 \\ 0 & 1 \end{bmatrix}$$

If we use the aforementioned closed-loop system as an example by equ (3.1), then we have:

$$M\ddot{x} + C\dot{x} + f_s - f = \Gamma(u - d_u) \quad (3.23)$$

The AMD force in i^{th} floor is defined as f_i

$$f_i = m_{di}(\ddot{d}_i + \ddot{Y}_i) \quad (3.24)$$

Where, m_{di} is the mass of the AMD, \ddot{d}_i is the acceleration of the AMD and \ddot{Y}_i acceleration of the structure along the AMD

3.5 Structural dynamic analysis (two story building structure)

Considering MOE of the structure: inertial, damping and stiffness force respectively create a dynamic force.

$$M\ddot{x}(t) + C\dot{x}(t) + Kx(t) = f_e; M\ddot{x} + C\dot{x} + F_s = -mg_a \quad (3.25)$$

Which is equation of motion, if structure displaced with infinitesimal displacement with applied force. When there is external force, ground surface will vibrate and then structural vibration occurs. Due to this case structure will have inertial force, damping force and stiffness force. When this occurs, external force is equal to the sum of the structural force, the system is at rest and stable. And if applied force is greater than the sum of the system force, the system will be deformed and loose original shape.

- $f_e > M\ddot{x} + C\dot{x} + kx$, the system will be deformed, there is motion or vibration.
- $f_e = M\ddot{x} + C\dot{x} + kx$, the system is at rest and no deformation, there is no motion vibration
- For this case, $\ddot{x} = 0$, $\dot{x} = 0$ and $x = 0$, the system is at equilibrium position.

Damping factor calculated is 0.145, this is less than one. Therefore the system is underdamped. Vibration of the structure or building is nonlinear, because when disturbance occurs, its parameters or its force changes with time. For this nonlinear system, the active control system was designed in this paper. Which makes the system to be stable and linear as discussed in chapter five.

CAPTER FOUR

CONTROLLER DESIGN

4.1 Introduction

Often the dynamics of the system cannot be changed by the designer to improve system performance. The controller's primary objective is to create a control law u that will allow the system to behave as desired [41].

This paper mainly deals about designing of active control strategies the system of civil structure which is SISO system i.e. has a transfer function of single input single output (SISO). The equation of motion for 2 DOF systems is shown as a matrix equation of motion in the time domain. In chapter three we have seen that, equation of motion represents 2nd ODE, we can separate it into the 1st ODE which is in the form of state space analysis finally it has changed in to the transfer function. So designing in this form of the system is SISO system.

4.2 Control strategies of AVC

A sensor that measures vibration, a control algorithm that uses the sensor value to determine the proper control force, and an actuator that applies the control force are all required to provide active vibration control. In order to prevent external disruptions and structural behavior, control force must be generated [42]. Depending on the technique used to generate the control force, active vibration control can be classified as either feed-forward or feedback. The development of AVCs via feedback control loops is covered in this chapter. Because the control force is determined only by the structure's observable vibration, the control performance varies depending on the sort of external disturbance [12].

4.3 Design of PID controller

In [12,13] PID controllers are tools that can control any process variable in industrial control applications. The most precise and reliable controller is PID (proportional integral derivative) controller, which use a control loop feedback mechanism to control process variables. Time-delayed process compensation techniques can be roughly divided into structurally optimized controllers and parameter optimized controllers, such as proportional-integral (PI) and proportional-integral-derivative (PID) controllers, where the controller structure and

parameters are optimally adapted to the structure and parameters of the process model. The control engineer actually only employs more advanced techniques when the process environment calls for a more sophisticated controller or a more complicated controller solution to govern a complex process. There are three reasons that make PID controller to be an important control tool [43].

- It is very simple in use.
- It found in everywhere.
- It has a successful history.

It is represented by three components:

- Proportional gain, K_p represents the controller gain, depending on the error determines the actual response.
- Integral gain K_i performs the sum of past deviation.
- Derivative gain, K_d works with the rate of change of error.

In this research work PID with single loop is designed.

Table 4.1 Characteristics of PID coefficients

Parameters	Overshoot	Settling time	Steady state error
K_p	Increase	Minor change	Decrease
K_i	Increase	Increase	Eliminate
K_d	Decrease	Decrease	Minor change

PID controller with single loop is indicated as follows.

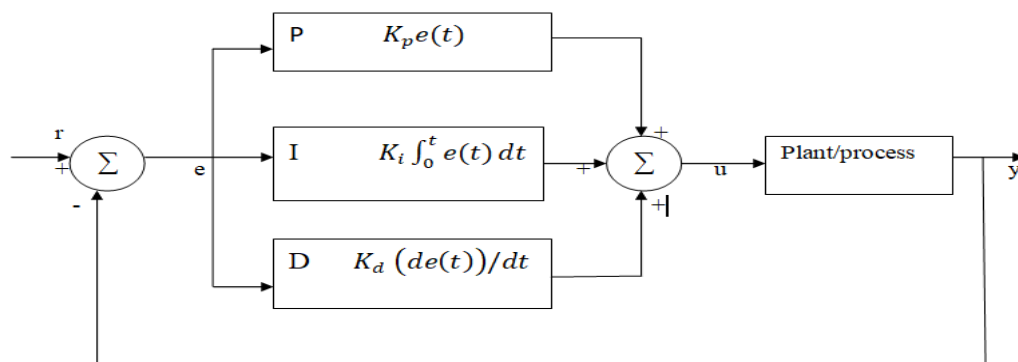


Figure 4.1 Schematic diagram of PID controller with single loop [44].

The PID block diagram is expressed in the following equation.

$$u(t) = K_p e(t) + K_i \int_0^t e(t) dt + K_d \frac{d e(t)}{dt} \quad (4.1)$$

A desired set point = $r(t)$.

Measured process variable $PV = y(t)$.

Here, r is reference variable, u is the control signal and e is the control error

($e = Y(t) - r(t)$). The reference variable is often called the set point.

Let take Laplace transform on both sides.

$$u(s) = K_p e(s) + K_i \frac{1}{s} e(s) + K_d s e(s) \quad (4.2)$$

$$\frac{u(s)}{e(s)} = K_p + \frac{K_i}{s} + K_d s = \frac{1}{s} (K_p s + K_i + K_d s^2) \quad (4.3)$$

In this chapter discrete PID controller is designed, because we need dc supply for dc motor actuator. By changing above expression in to the discrete form, we get the discrete PID parameters. Z transform is used for deriving transfer function of the PID parameters. The discrete Z transform formula is express as [45].

$$X(z) = Z(x(k)) = \sum_{k=0}^n x(k) Z^{-k} \quad (4.4)$$

Transfer function for derivative term

$$Y(k) = \frac{f(k) - f(k-1)}{T_s} = Y(z) = f(z) - Z^{-1} f(z)$$

$$\frac{Y(z)}{f(z)} = \frac{Z-1}{Z T_s} \quad (4.5)$$

Transfer function for integral term

$$Y(k) = y(k-1) + \frac{f(k) + f(k-1)}{2} T_s$$

$$Y(z)(1 - z^{-1}) = \frac{T_s}{2} (f(z)(1 + z^{-1}))$$

$$\frac{Y(z)}{f(z)} = \frac{T_s z + 1}{2(z-1)} \quad (4.6)$$

Transfer function for proportional term

$$Y(z) = k_p \quad (4.7)$$

TF of discrete PID is therefore:

$$\frac{u(z)}{E(z)} = k_p + \frac{T_s z + 1}{2 z - 1} + \frac{Z - 1}{Z T_s} \quad (4.8)$$

The following block diagram shows the overall block diagram active structural control system. Structural control system is refers to the modern technique in any environmental conditions, this system is designed to prevent or divert the external energy of the system. External energies are wind energy and seismic energy which are suspected to the civil structure. In this paper active control system was designed to overcome the structural motion. Active control system is a type of structural control system which generates the cancellation signal by using additional energy from servomotor and actuator. The major topic of this thesis work is an active damping system, which is a type of active control system that has no resonance and doesn't enhance vibrations at any frequency.

In [20] stated that, The following benefits of active control systems over passive ones include:

1. More effectively can be used to control motion.
2. It is comparatively insensitive to ground motion.
3. It can be used in situations where there are multiple hazards.
4. The choice of control objectives is flexible.

In this thesis work active control strategy known as active damping system will be designed. Active mass damper is a type of active damping system which is used to control the civil structure subjected to seismic excitation. The controller will be designed with feedback controller strategy known as PID control system. For the fast response of structural behavior, PID controller is tuned by using ACO algorithm.

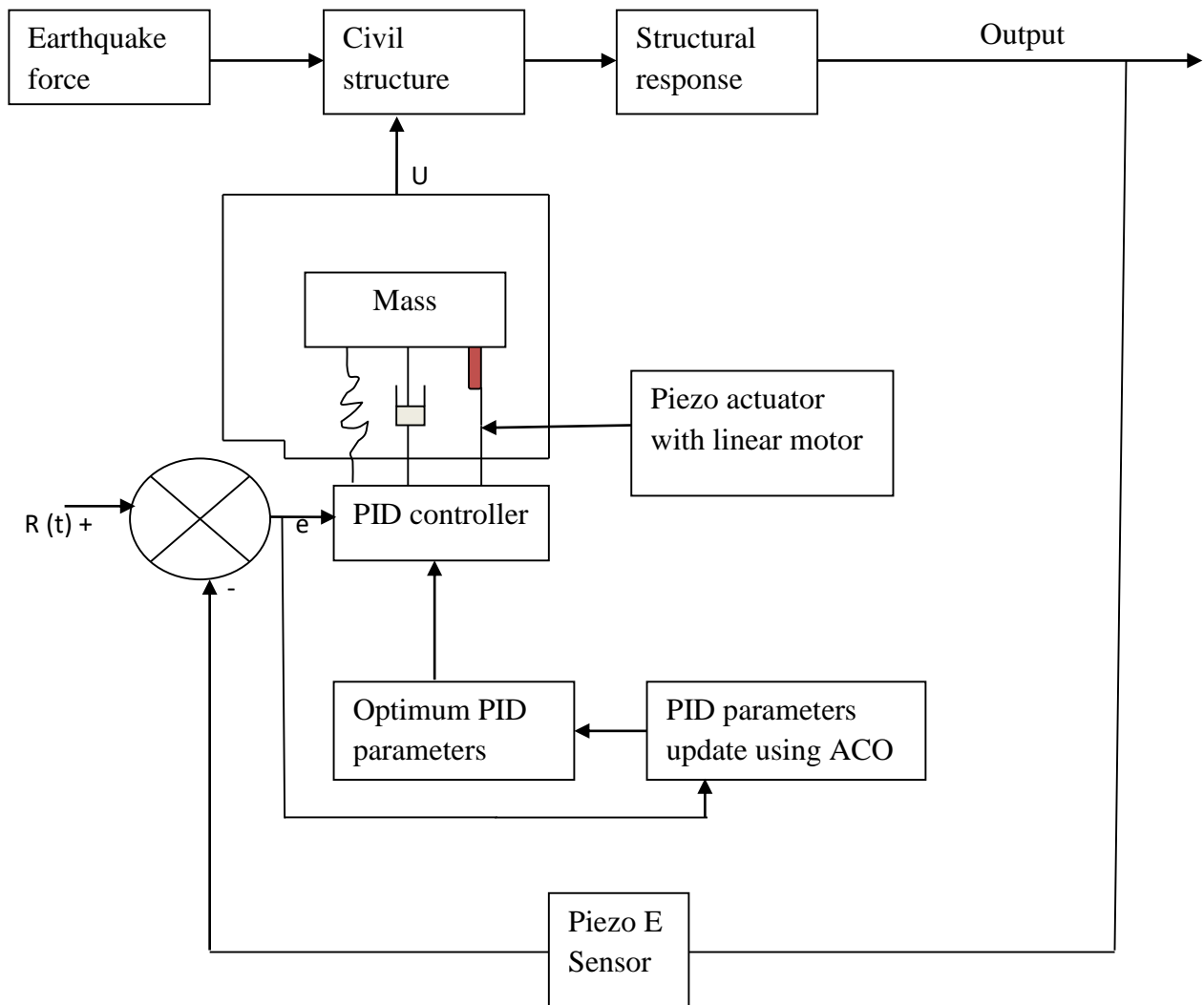


Figure 4.2 Block diagram of the active control system

Where, u is the output of the AMD controller

Accelerometer detects changes in gravitational acceleration, making it possible to measure tilt, vibration and of course vibration. Accelerometers sensors are used in a wide range of industries. Output of the actuator is either voltage or current.

4.4 Description of the system

Earthquake is the disturbance signal applied its force in the structure and there by building will face vibration and produce vibration responses. To control this vibration response of the system, active mechanism is designed in this chapter. Active control system includes active

mass damper with tuned PID controller and piezo sensor. PSO and ACO are algorithms used to tune PID controller. Piezo sensor is a transducer used to sense the vibration of the system and generate useful electrical energy.

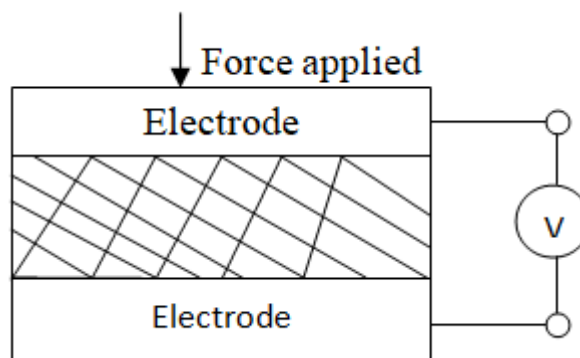
4.5 Design of Piezoelectric transducer/sensor

Feedback element for the controller is sensor. Here piezoelectric sensor is designed in order to sense vibration of building motion. And then by converting this mechanical stress applied on it in to the electrical signal can give feedback to the controller.

- Is active sensor or self-generating device that does not require external power to produce electrical voltage [46].

4.5.1 Working principle of piezoelectric element

In [47] author explains that , When quartz crystal is subjected to mechanical force on one pair of parallel faces, then electric charges are produced on another pair of parallel faces. Due to this case, electric voltage is produced which directly proportional to applied force and opposite direction. In contrast to the inverse piezoelectric effect, which changes electrical energy into mechanical energy, the piezoelectric effect changes mechanical energy into electrical energy. The piezoelectric actuator and mechanical mass spring damper system have similar properties. While the piezoelectric actuator extends as a result of voltage acting on the system, the mass spring damper extends as a result of mass acting on the system. As a result, it is also known as a voltage spring system



(a)

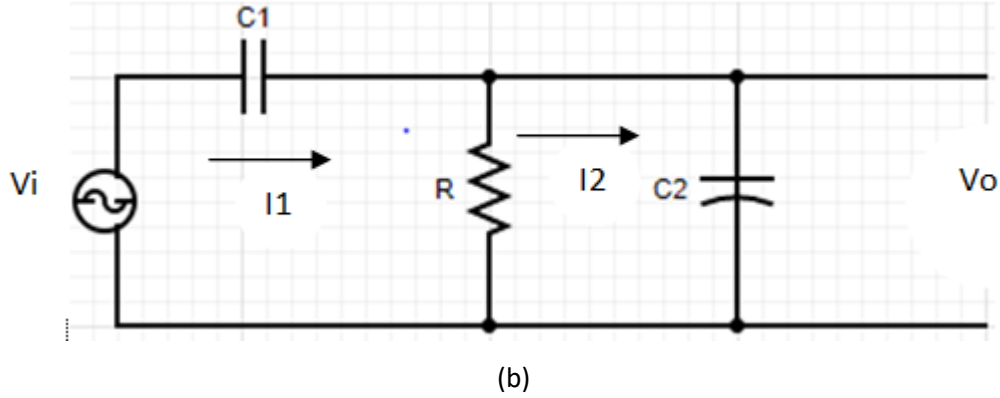


Figure 4.3 (a) piezoelectric crystal/ sensor (b)equivalent electrical circuit [47].

By applying Kirchoff's law to drive voltage equation from

$$v_i(s) = \frac{1}{c_1 s} I_1(s) + R(I_1(s) - I_2(s))$$

$$v_i(s) = I_1(s) \left(\frac{1}{c_1 s} + R \right) - R I_2(s) \quad (4.9)$$

$$\frac{1}{c_2 s} I_2(s) + R(I_2(s) - I_1(s)) = 0$$

$$I_2(s) \left(\frac{1}{c_2 s} + R \right) = R I_1(s)$$

$$I_1(s) = I_2(s) \left(\frac{1}{c_2 s R} + 1 \right) \quad (4.5)$$

Substitute equation two in to equation one, we get:

$$v_i(s) = I_2(s) \left(\frac{1}{c_2 s R} + 1 \right) \left(\frac{1}{c_1 s} + R \right) - R I_2(s)$$

$$\frac{I_2(s)}{v_i(s)} = \frac{s^2 R c_1 c_2}{1 + c_1 s R + c_2 s R + c_1 c_2 s^2 R^2} = \frac{s^2 R c_1 c_2}{1 + (R c_1 + R c_2) s + s^2 c_1 c_2 R^2} \quad (4.10)$$

Table 4.2 Parameters of piezoelectric crystal material

Parameters	Values
R	0.2Ω
c ₁	0.3 F
c ₂	0.4 F

By substituting the values of parameters in (4.6) the final transfer function is therefore;

$$\frac{I_2(s)}{v_i(s)} = \frac{s^2(0.2 * 0.3 * 0.4)}{s^2(0.3 * 0.4 * 0.2) + s(0.2 * 0.3 + 0.2 * 0.4) + 1} = \frac{0.024s^2}{0.048s^2 + 0.14s + 1} \quad (4.11)$$

The above equation is the transfer function of the sensor equation. This gives feedback to the PID controller. The generated ac voltage by piezoelectric circuit is low, rectifier is developed at the output side of the piezo element to convert low ac voltage to low dc and another circuit known as dc to dc converter, named as boost converter [48] is developed at the output side of the rectifier to step up the dc voltage generated by rectifier. Boost con

4.6 Active Mass Damper (AMD) System

Similar to TMDs, Active Mass Dampers (AMDs) stabilize the system by using a driving mechanism as opposed to energy dissipaters. The system is often driven by hydraulic actuators, which are based on the structure's motion sensor and have a high durability and cost performance rating. Input Sensor is used to senses the external disturbances or motion in to the structure, and the system takes measurements and compute the control forces, which is opposite to the external force produced on the structure. Actually this force is produced through AMD by absorbing energy from the actuator and servomotors. Figure 4 indicates that the feedback loop has iteration until the force produced by AMD and the structure will be counterbalance.

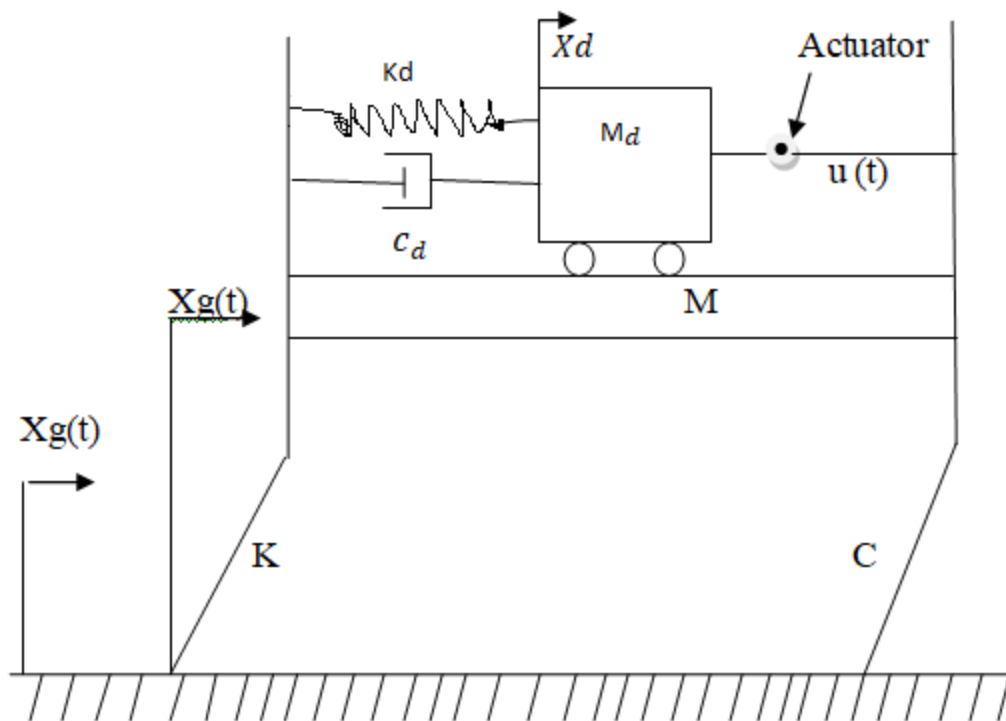


Figure 4.4 Schematic diagram of AMD [19].

In reference [49] According to the author, an active mass damper works by causing a small mass to move out of phase in order to dampen an object's vibration. The mass's inertia forces stop the vibrations. Active mass damping systems' main impact is to change a structure's damping level while just slightly altering its stiffness. The main components of active mass damper system includes:

- ✓ A mass that is connected to the structure is said to have an active mass. Typically, this active component's mass is between 1% and 10% of the vibrating structure's mass.
- ✓ Actuator: This electromechanical gadget obtains its active mass from a vibration that is out of phase with it. The actuator will probably be either a piezoelectric or voice coil electromagnetic device.
- ✓ Transducer: This will detect the structure's vibrations. Most likely, the accelerometer will be MEMS-based.
- ✓ Signal processor: The transducer's vibration measurements will be processed to create an actuator or inertia mass control signal.
- ✓ Power amplifier and supply: in order to power the amplifier and determine the inertia mass, the control signal for the signal processor will be amplified.

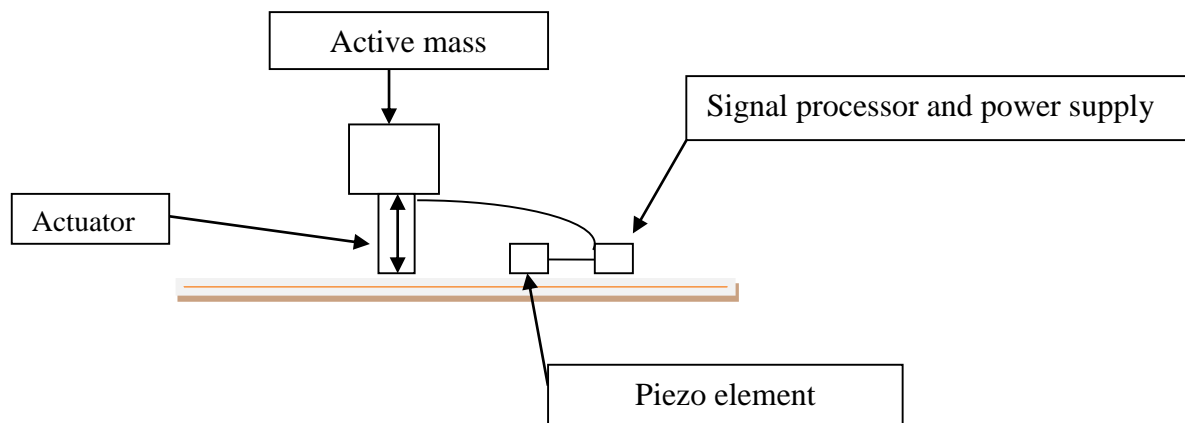


Figure 4.5 Components of active mass damper system

A very idealistic representation of damping in real structure. Damping is the process through which the amplitude of free vibration gradually decreases. For many uses, a linear viscous damper or dashpot may idealize the actual damping in an SDF structure satisfactorily. The damping coefficient is chosen such that the energy lost during vibration equals the energy lost throughout all of the damping mechanisms present in the real structure [2].

In this paper civil structure with SISO system is modeled, and then PID is designed as with single loop produces output u which is used to apply on the AMD which is attached on the structure. And applied in to the SISO system.

Piezoelectric actuator works as inversely to that of piezoelectric sensor (i.e. if voltage source is applied on it, it will changes the electrical voltage in to mechanical forces.

First let design active mass damper system.

The above diagram shows simple mass damper system with spring attached with structure in floor two, with additional of actuator. The equation of this system is shown below.

$$f = m\ddot{x} + c\dot{x} + kx \quad (4.12)$$

Where, f is applied force.

Take Laplace transform on both sides:

$$\begin{aligned} f(s) &= ms^2x(s) + csx(s) + kx(s) \\ f(s) &= x(s)(ms^2 + cs + k) \end{aligned} \quad (4.13)$$

Therefore, transfer function of the active mass damper system is:

$$\frac{x(s)}{f(s)} = \frac{1}{ms^2 + cs + k} \quad (4.14)$$

The value for each parameter is given below

$$m = 100kg$$

$$c = 32Ns/m$$

$$k = 50N/m$$

By substituting the values in equation (4.9) we get the transfer function of AMD.

$$\frac{x(s)}{f(s)} = \frac{1}{100s^2 + 32s + 50} = \frac{0.5}{50s^2 + 16s + 25} \quad (4.15)$$

Application of Actuator

In [6] author implies, a DC motor operating as a power actuator is taken into account. It converts electrical energy into mechanical energy that rotates. The table below is a list of the motors' specifications. The voltage applied to the armature, expressed in volts, serves as the input.

Table 4.3 Parameters of DC motor of the actuator.

Parameters	Symbol
Armature resistance	R_m
Armature inductance	L_m

moment of inertia of the motor system	J_{eq}
damping friction of the mechanical system	B_{eq}

Kirchhoff's law is applied to drive the voltage equation.

$$V_m - R_m I_m - L_m \left(\frac{dI_m}{dt} \right) - E_{emf} = 0 \quad (4.16)$$

$L_m \ll R_m$, the armature inductance is neglected, therefore ;

$$I_m = \frac{V_m - E_{emf}}{R_m} \quad (4.17)$$

The drive shaft velocity $m\dot{\theta}$ yields is inversely related to the drive emf;

$$I_m = \frac{V_m - k_m \dot{\theta}_m}{R_m} \quad (4.18)$$

The torque relation is given by applying Newton's Second Law of Motion to the mechanical component of the system:

$$J_m \ddot{\theta}_m = T_m - \frac{T_l}{\eta_g k_g} \quad (4.19)$$

Where, $\frac{T_l}{\eta_g k_g}$ is the load torque found through the gears, and η_g is the efficiency of the gear box[6].

Using the second law of motion to the motor's load results in:

$$J_l \ddot{\theta}_l = T_l - B_{eq} \dot{\theta}_l \quad (4.20)$$

Substituting in equation 4.14 for T_l we get,

$$J_l \ddot{\theta}_l = \eta_g k_g T_m - J_m \ddot{\theta}_m \eta_g k_g - B_{eq} \dot{\theta}_l \quad (4.21)$$

Given that $\dot{\theta}_m = k_g \dot{\theta}_l$ and $T_m = \eta_m k_l I_m$ where, η_m the motor efficiency and equ. (4.16) become:

$$J_l \ddot{\theta}_l + J_m \ddot{\theta}_l \eta_g k_g^2 + B_{eq} \dot{\theta}_l = k_g k_l \eta_m \eta_g I_m \quad (4.22)$$

Transfer function of the motor actuator is:

$$\frac{\Theta_l(s)}{V_m(s)} = \frac{K_g K_l \eta_m \eta_g}{J_{eq} R_m S^2 + (B_{eq} R_m + \eta_m \eta_g k_m k_g^2) S} \quad (4.23)$$

Where, J_{eq} reflects the motor system's corresponding moment of inertia as seen at the equation's output.

$$J_{eq} = J_l + \eta_m \eta_g k^2_g \quad (4.24)$$

4.7 Developing ACO algorithm

Algorithm for pseudo code given below is developed in MATLAB software.

Optimized gain K_p , K_i and K_D of PID controller are obtained by using ACO. Discrete optimization issues can be solved using this search strategy for optimization, which is employed in computers. ACO is swarm intelligence that takes its cues from the way ants give each other indirect directives. Finding the shortest route between the ants' colony and food sources is the most striking feature of the cooperative behavior of ant species. By pursuing pheromones left out by other ants, they determine the quickest route between their colony and a food source. The likelihood that an ant will follow a trail and add its own pheromone to it increases with its intensity. The longest pathways' pheromone trails vanish [50].

ACO key terms

Ants K : any potential remedies

N : population of all ants

All potential solutions to the issue can be found in the $[lb, ub]$ search space.

Step size h divides the search space.

ρ , ζ and τ : Evaporate rate, scaling parameter, and pheromone trail respectively.

Procedure

- Initialization: Initialize all discrete design variable values with the same pheromone r concentrations.
- Build tours: the likelihood of choosing discrete design variable values is

$$p_j^k = \frac{\tau_j}{\sum_{j=1}^m \tau_j} \quad (4.25)$$

- Based on its probabilities, determine the cumulative probability range related to various discrete values.
- Generate N random number r in the range $(0, 1)$ one of each ant.
- Use an ant K to compute the discrete value for the variable whose cumulative probability distribution contains the random number r .

Procedure

- ✓ Update pheromone
 - Find the objective functions of each ant.
 - Perform the best F_{best} and the worst F_{worst} objective functions of the discrete value among the ants.
 - Best ants: reinforcement the pheromone of the best path by:
 - $\tau_j^{new} \leftarrow \tau_j^{old} + \sum_k \text{delta} \tau_j^k$. (4.26)

$$\text{delta} \tau_j^k = \frac{\zeta F_{best}}{F_{worst}}$$

Other ants evaporate the pheromone of other paths by:

$$\tau_j^{new} \leftarrow (1 - \rho) \tau_j^{old}$$

Termination: algorithm repeated until the maximum number of iteration is reached.

Parameters required from the user

- ✓ Population size N
- ✓ Initial pheromone τ
- ✓ Step size h divides the search space.
- ✓ ρ , ζ and τ : Evaporate rate, scaling parameter, and pheromone trail respectively.
- ✓ r with uniform distribution, in the range $(0, 1)$.

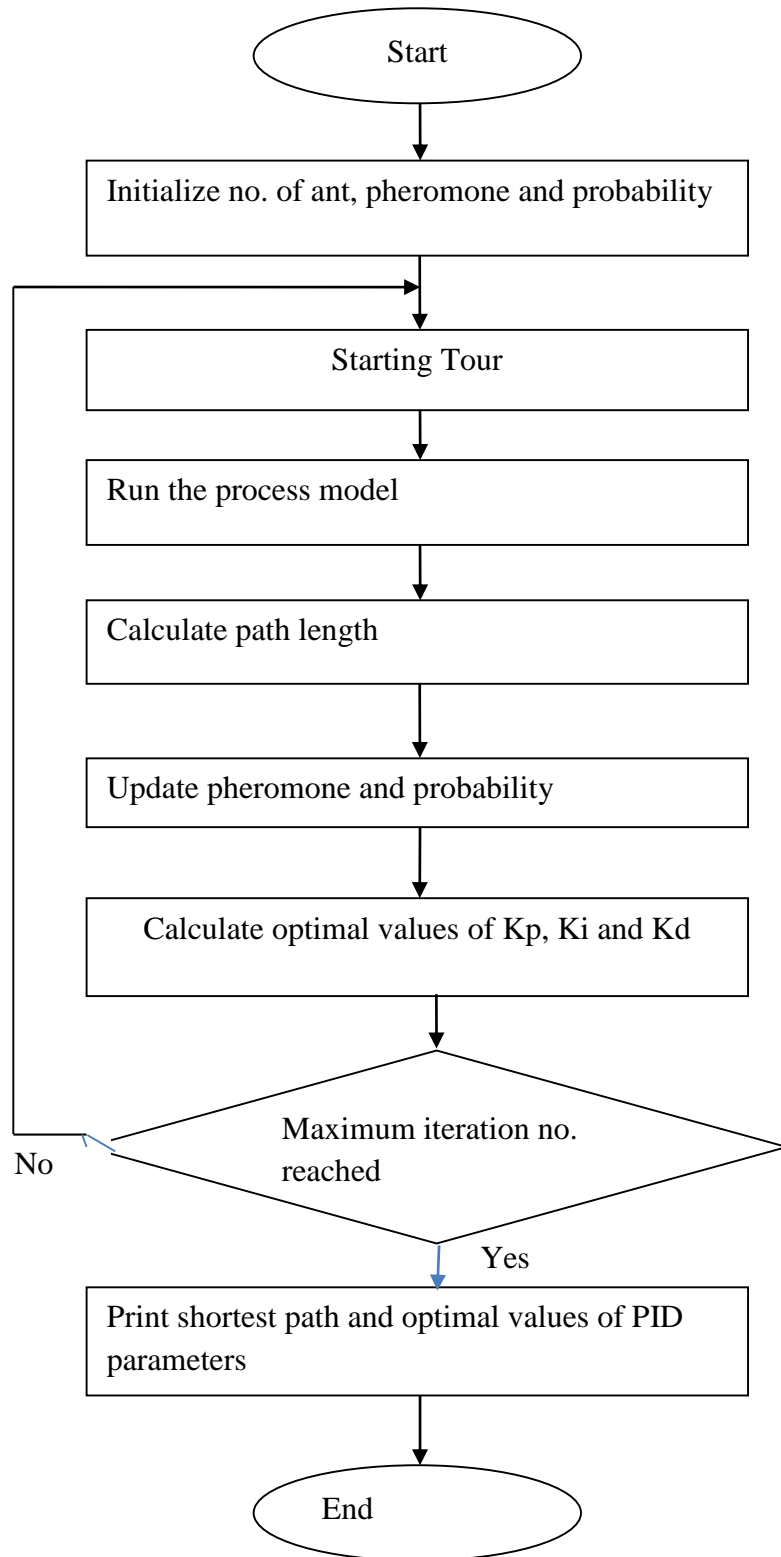


Figure 4.6 Flow chart of the ACO algorithm [50]

4.8 Tuning of PID controller with ACO and PSO algorithms for the system

4.8.1 Tuning of PID controller with ACO algorithm

Optimization process

- The design key the controllers is to find the right value adjusted parameters with in each controller.
- Often the selection of this parematers is based on the tri and error.
- To overcome the dtaw back of using tri and error in the selection procces, the tunng proces in this study is formulated as an optimization problem.
- Then, an optimization techniques is utilized to solve problems.

Optimization problems

- ✓ Finding the best solluton among set of all feaseble sollution.
- ✓ Optimization terminologies:
 - Objective function: the function that is desired to maximize or minimize.
 - Decision variable: quantify that the desiciion maker controls.
 - search space.

Optimization process

decision variables:

PID parameters (K_p , K_i and K_d).

Objective function: Performance indicies are used to evaluate system response.

Time Integral absolute error (ITAE).

$$ITAE = \int_0^t t|e|dt. \quad (4.27)$$

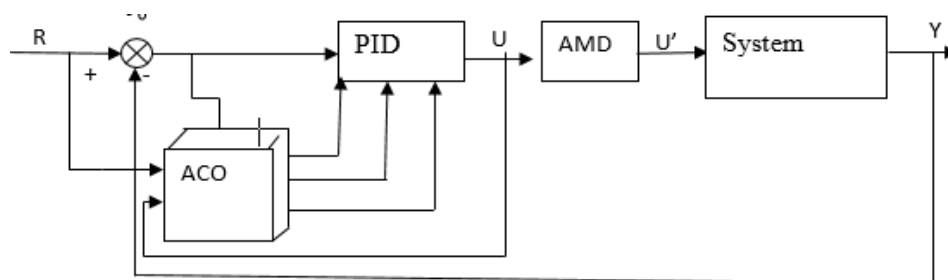


Figure 4.7 Optimization of PID controller with ACO

4.8.2 Tuning of PID controller with PSO algorithm

Pid controller for this process is tuned by using ACO and PSO algorithm to increase the performance of the controller on the system and then performance comparison have been done.

- A search method used in computers to locate solutions to optimization issues that are close to ideal.
- PSO is a swarm intelligence that draws its social behavior and dynamic motions from those of fish, insects, and birds in nature.
- • Employs a swarm of particles that moves through the search space in pursuit of the best answer.
- Each particle in the search space modifies its "flying" in accordance with both its own and other particles' prior flying experience [51].

Key terms

- ✓ Particle I any possible solution.
- ✓ Population N group of all particles.
- ✓ Search space [a, b] all possible solutions to the problem.
- ✓ Each particle is assumed to have two characteristics.
 - A position x_i
 - A velocity v_i
- ✓ Each particle keep track:
 - Personal best p_{best}
 - Global best, g_{best}

○ Procedure

- Initial population (number of particles N)
 - Initial position (x) and initial velocity (v)
 - Assign p_{best} and g_{best} (based on the objective function)
- **Update**

Velocity and position of each particle are updated as [51].

$$v_i(t) = \Theta v_i(t - 1) + c_1 r_1 (p_{best,i} - x_i(t - 1)) + c_2 r_2 (g_{best} - x_i(t - 1)) \quad (4.28)$$

$$x_i(t) = x_i(t - 1) + v_i(t)$$

- The steps of PSO algorithm are iteratively repeated until the maximum number of generations is reached or a termination criterion is met.
- Parameters required from the user:
 - ✓ Population size N
 - ✓ Initial population (x) and initial velocity (v)
 - ✓ Inertial weight (θ)

The objective functions of the optimization problem:

Performance indices are used to evaluate system responses.

- ❖ Time integral of Absolute error (TIAE)

$$\text{TIAE} = \int_0^t t|e|dt \quad (4.29)$$

Objective function indicates (Performance indices of the tuning process) which is the same for both cases, that is time integral absolute error.

This is the evaluation criteria for both algorithms, and then the algorithm with the least error is selected for the process.

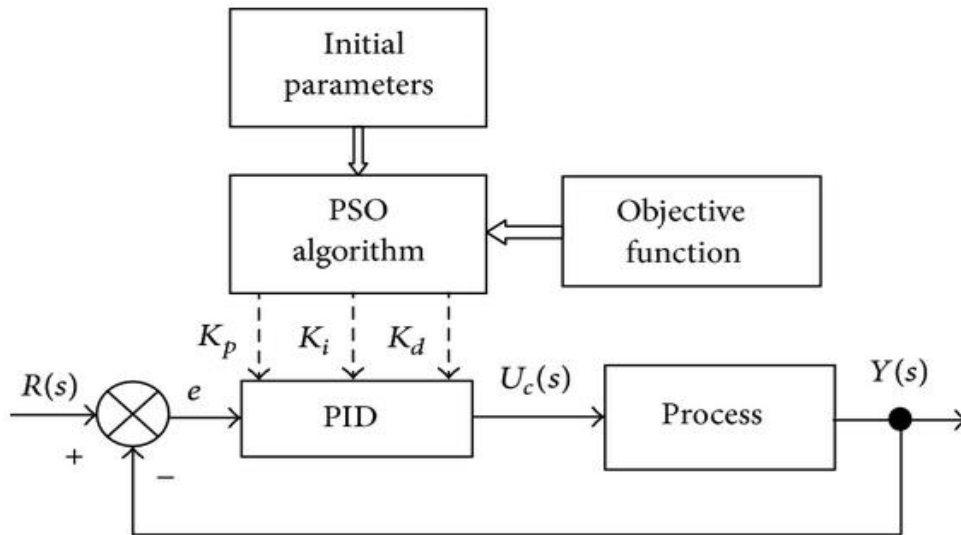


Figure 4.8 Block diagram of PID controller with PSO algorithm for tuning parameters [52].

Initially PID parameters are adjusted, to calculate Pbest and Gbest of the controller then performances are compared. This algorithm is used for tuning PID parameters and optimized parameters are used apply in the system or process.

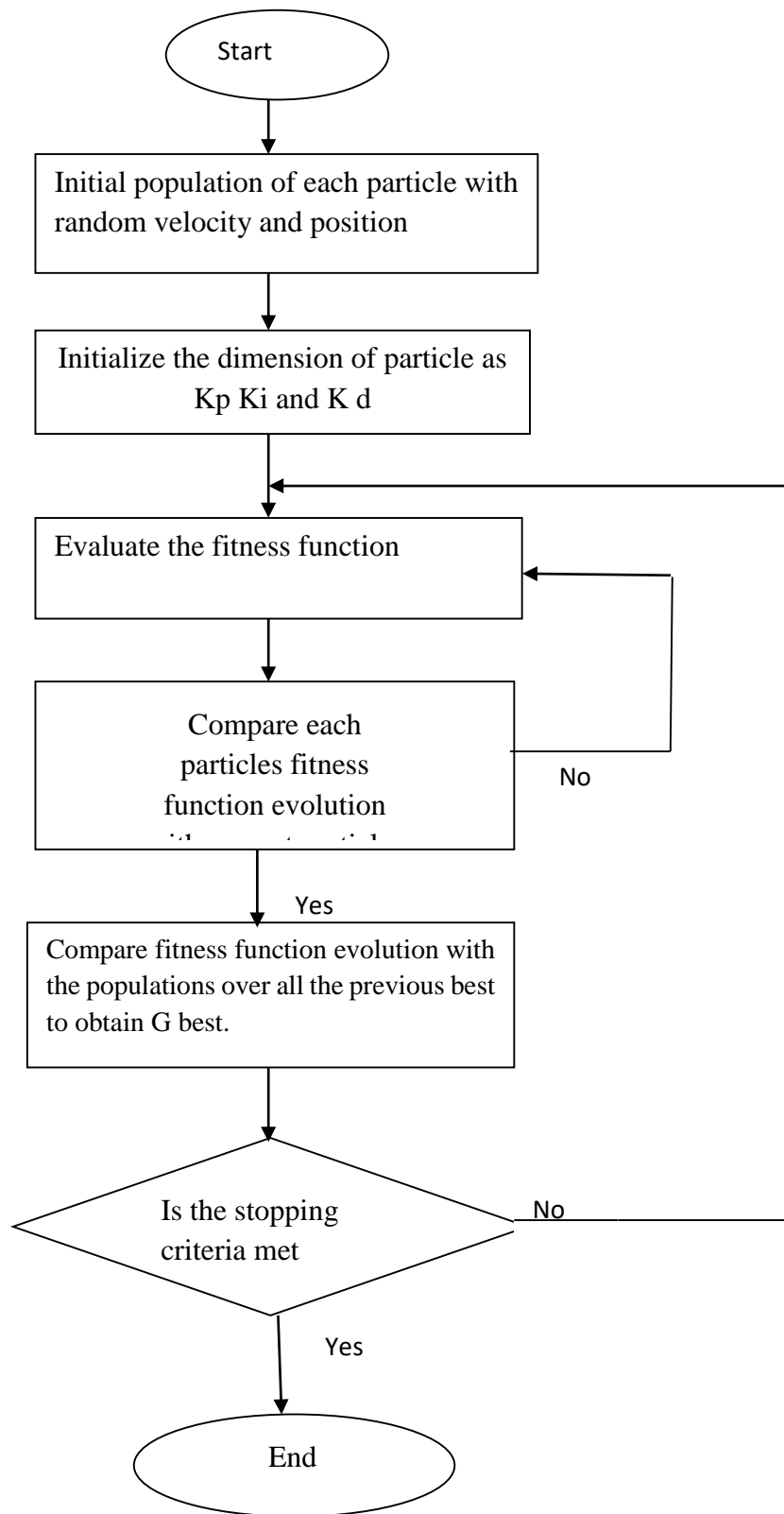


Figure 4.9 Flow chart of PSO algorithm for PID controller tuning [52].

CHAPTER FIVE

5. RESULTS AND DISCUSSION

The simulation of the active control system has performed in MATLAB/SIMULINK software. AMD which is used for applying force on vibrating structure is simulated in this software. PID was tuned and simulated using MATLAB software. ACO and PSO algorithm is developed in MATLAB and then applied to tune PID controller.

5.1 Effects of open loop and closed loop control on the system

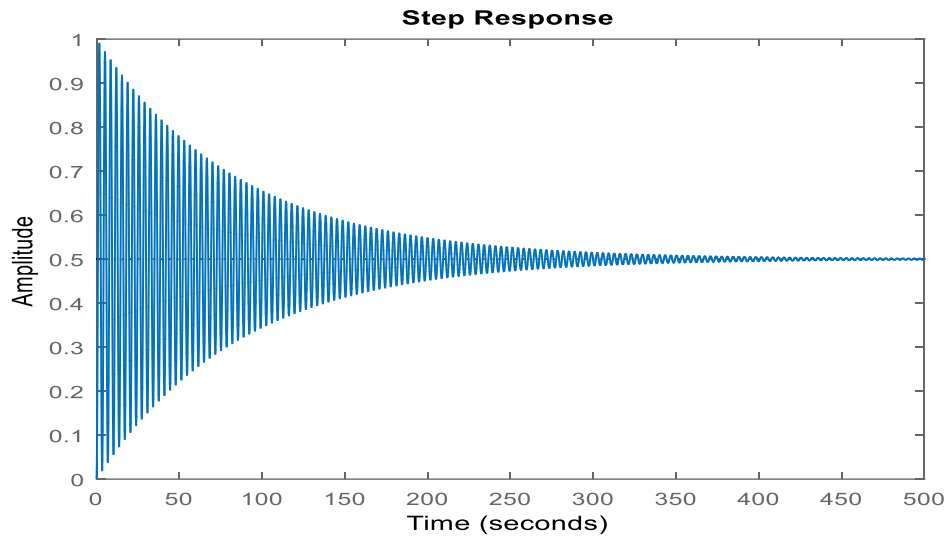


Figure 5.1 Open Loop Control System (No Control)

The graph above indicates, the behavior of the output of the system without applying feedback controller. Which is open loop control system. So that the output takes more time to become settle down. The system becomes settled after 250 seconds. This indicates the system has no fast response to become steady state. And the following graph is closed loop control mechanism for vibrational control.

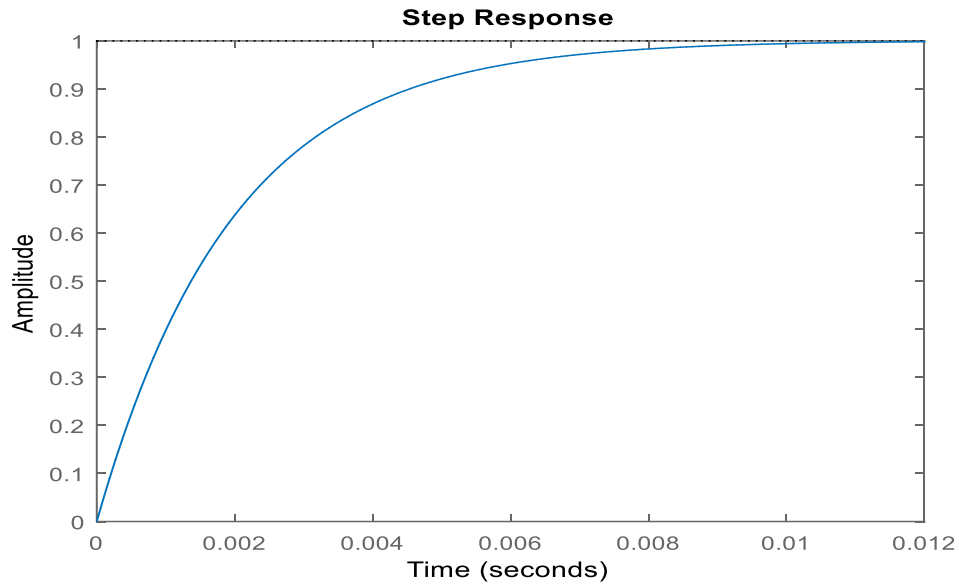


Figure 5.2 Closed Loop Control System (With Control)

And after applying feedback PID controller in to the system, it has fast response and the rise time is also small. And the graph has good transient response behavior rather than the former one.

5.2 Tuning responses of PID Controller with ACO and PSO

Algorithm for system.

5.2.1 Simulation results of PID Controller tuning using PSO algorithm.

The following figure has information about the step response of the system when PID controller is optimized by PSO algorithm.

PID controller is tuned to control vibration of the 2 floor structure by using PSO and ACO. As a result indicates that, PID controller tuned with ACO has better performance than tuned by PSO algorithm.

Responses of the system with PSO- PID and without PSO-PID

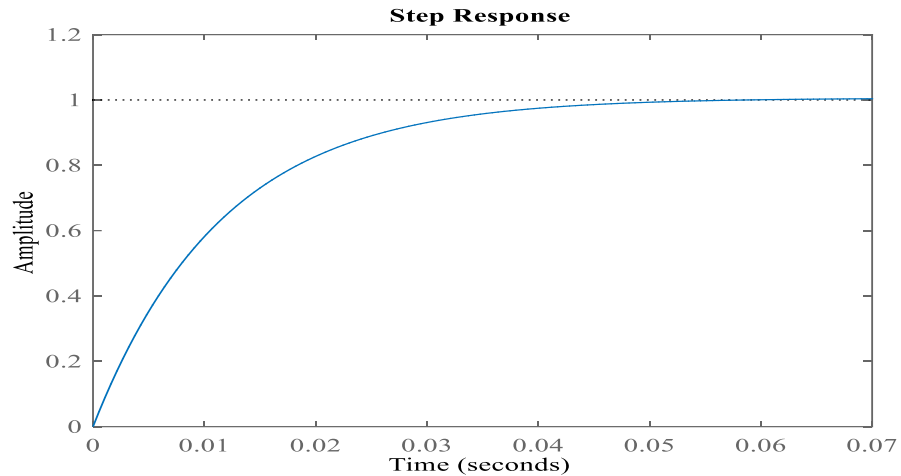


Figure 5.3 Step response of the system without optimized PID

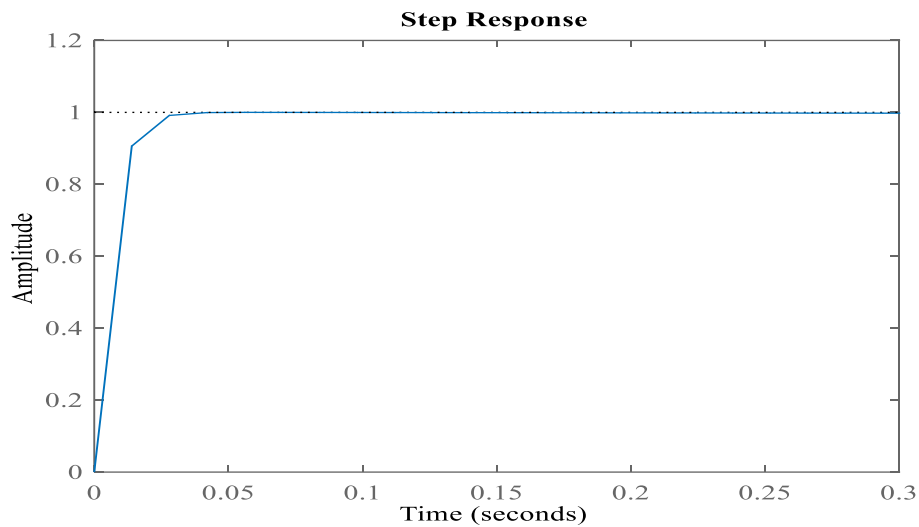


Figure 5.4 Step response of the system using PID controller with PSO algorithm

Tuning of PID controller by using PSO algorithm is shown above. As per the graph, step response of the system without PID is not good. Because it's settling time is very high than the one with PID controller. The 2nd graph (figure 5.4) has settling time of 0.04seconds, which is smaller than the former one.

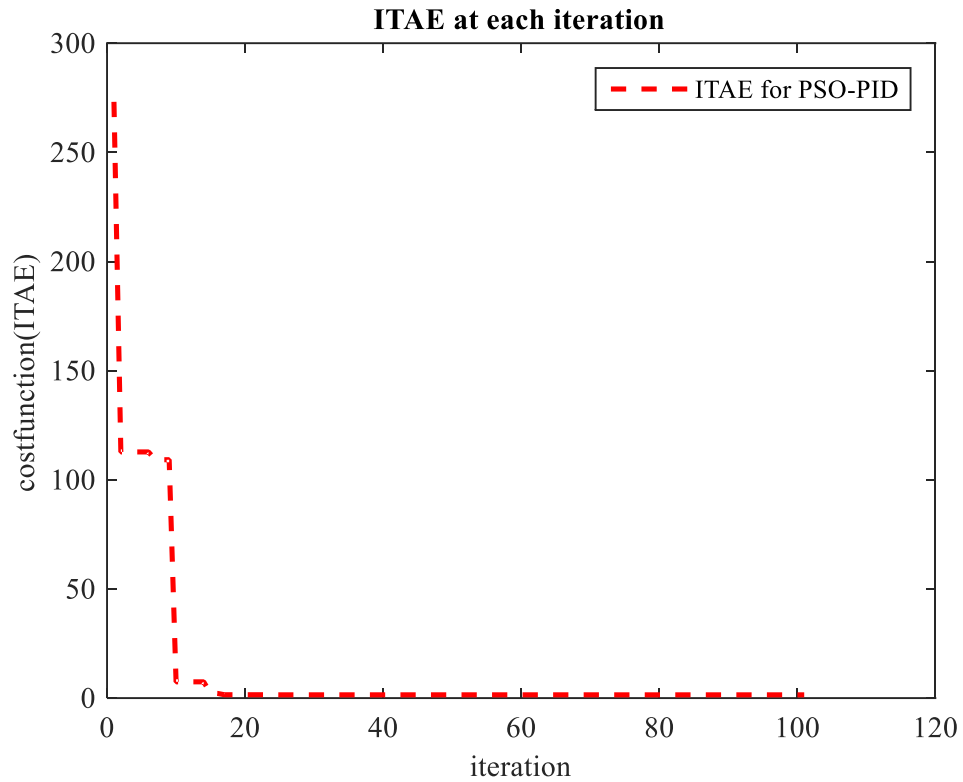


Figure 5.5 Objective function plot of PID controller tuning using PSO algorithm

Plotting of error function, here by it is found that using PSO_PID method objective function is obtained as shown in the above graph. Which is approximately equal to 1.5. This is min_ITAE value.

5.2.2 Simulation results of PID tuning with ACO algorithm

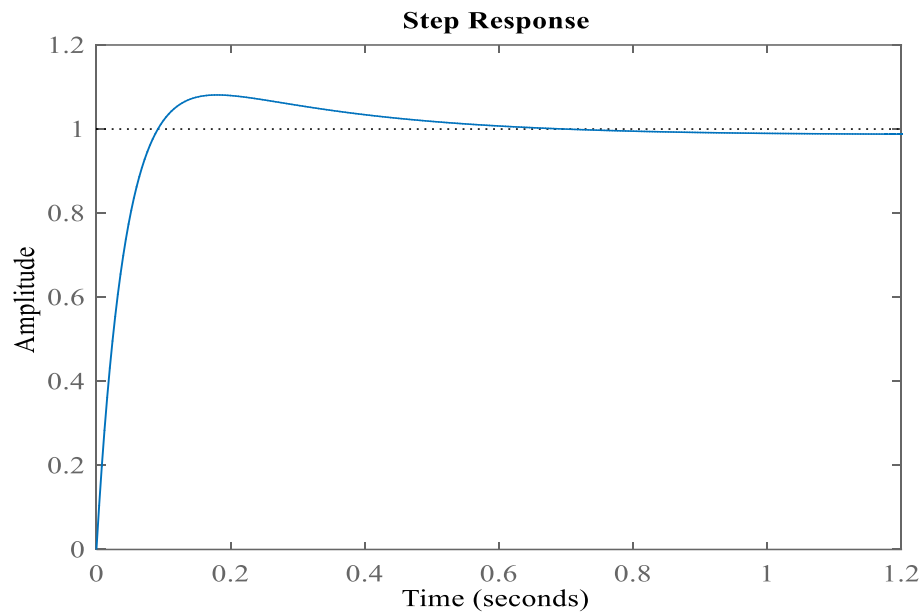


Figure 5.6 System response of the system without PID tuning

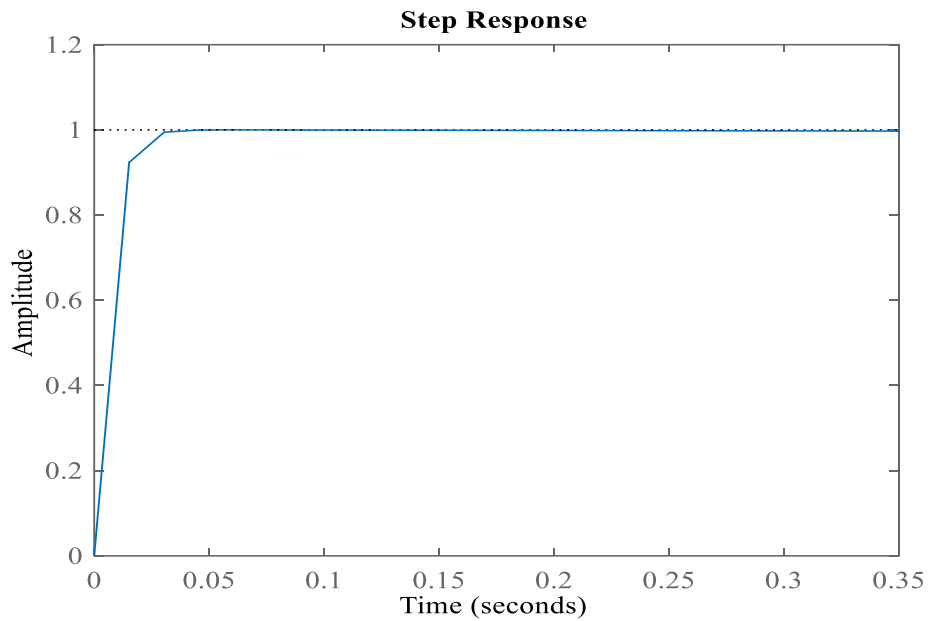


Figure 5.7 Step response of the system with optimized PID controller

The settling time for the first graph is 0.5 seconds and for the 2nd response is 0.03 seconds. The latter one has better response performance.

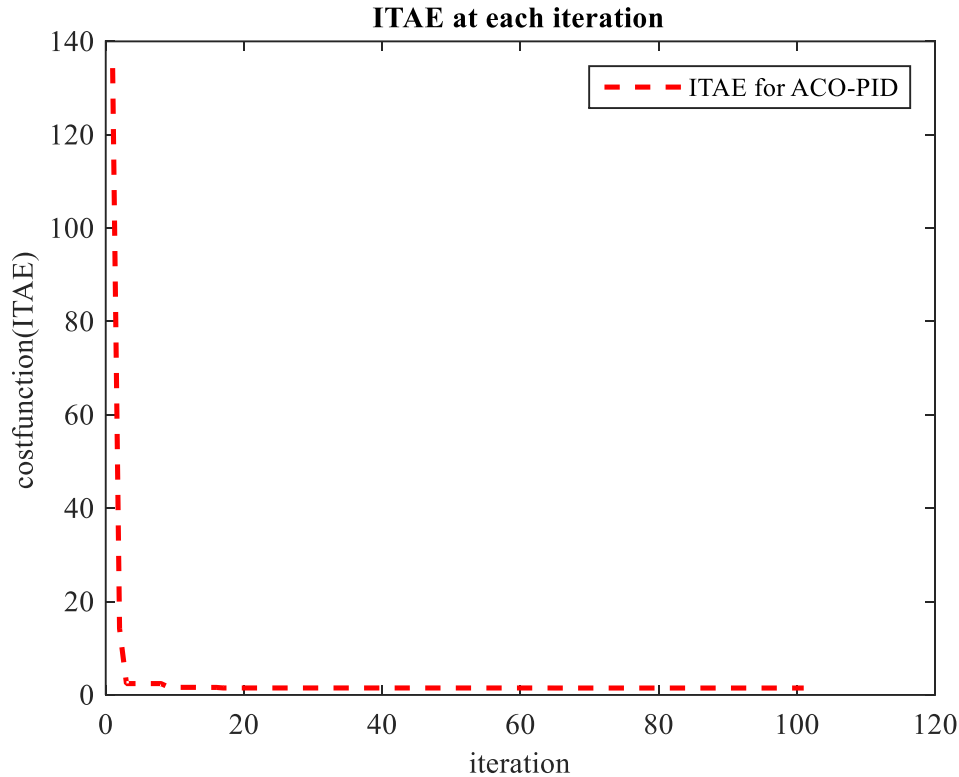


Figure 5.8 ITAE plot of the system by using optimized PID controller with ACO. The first two graphs are related with each other, but the later one has better performance, in that it has small rise time so that, fast response indicated.

Figure above give an idea about the Cost function values for each iteration, which indicates that (ITAE value is smaller than previously obtained value (i.e. PSO-PID)). The objective of this plot is to minimize of ITAE value through process. The MIN_ITAE value obtained by using this method is 1.45, which is smaller than the value obtained by using PSO algorithm.

5.3 Performance comparison of ACO algorithm and PSO algorithm

ACO and PSO have a good performance for optimization of the PID controller. In that both of them minimize the objective function of tuning system. The main objective of this tuning system is to get better values of the PID parameters which are suitable for controlling of civil structure excited to earthquake excitation and minimizing objective function. In this paper ACO and PSO algorithms are under taken to optimize and minimize integral time absolute error (ITAE).

But ACO has better performance than PSO algorithm in that, it gives minimum value of (ITAE) and at the same iteration tuning has good parametric estimation than PSO algorithm.

In general, the following point of view is taken for the difference between ACO and PSO algorithms.

- ACO takes minimum number of iteration time than PSO algorithm.
- PSO optimization is a little bit time taking algorithm than ACO.
- Tuned parameters are good in ACO than PSO algorithm.
- The lower value of objective function (ITAE) value is obtained when PID is tuned by ACO.
- Step response of the system is a good in ACO optimization than PSO algorithm.

By considering figures above ITAE value converged to small value fast in ACO algorithm but, in PSO algorithm ITAE value converged to small after some iteration has past.

Table 5.1 Performance comparison of ACO and PSO parameters

Parameters	ACO	PSO
Proportional gain k_p	11.9	12
Integrator gain k_i	0.17	0.18
Derivative gain k_d	100	100
Objective function (ITAE)	1.45	1.5

5.4 Simulation of PID control and AMD

PID is a feedback controller which is used to design and simulated for error minimization. Takes the difference of desired output and feedback (actual output). AMD is active device used to produce control force for vibration of structure. It takes a force from actuator and moves its mass in the structure to cancel of vibration.

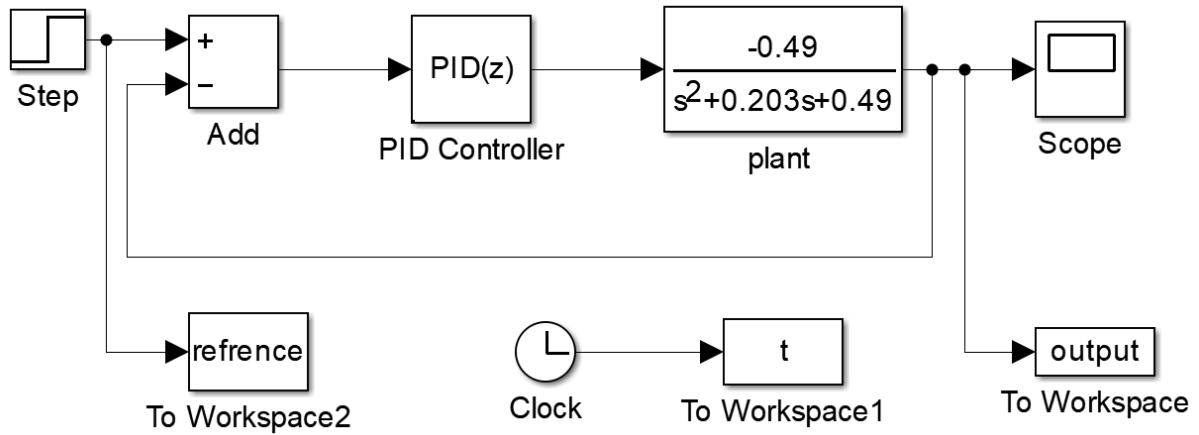


Figure 5.9 Simulink model of optimized PID controller for the system

Structure controlled with PID controller by using of ACO optimization algorithm. PID parameters are tuned with ACO algorithm and PID is designed and attached in to the AMD to control the vibration. It produces a control signal and gives to actuator and actuator produces a control force and applied it in to the AMD system.

5.5 Responses of the structure during external disturbance.

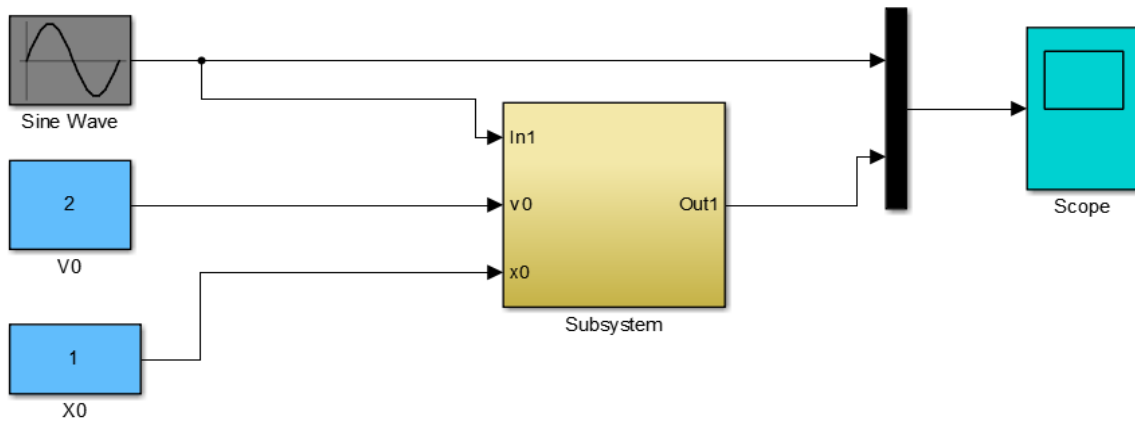


Figure 5.10 Simulink model of AMD

Active mass damper is modeled with actuator in the second floor which is mathematically expressed in chapter three. The above Simulink diagram indicates that, if there is vibration along with structure, active mass damper will focus on the position of the building, and then its force dampen the motion of the structure. This is done by adding the force of AMD to the

vibration motion of the structure. According to this, vibration of the structure is reduced. But, it is not effective when external force vary with time, And it has time delay to control this motion variation. To overcome this problem, AMD with feedback controller has designed. The movement of mass, in the mass damper is due to actuator. Force produced from the actuator motor has been attached to the mass damper to move the mass of the damper in linear fashion, i.e. mass of the AMD moves in horizontal direction. The results of the structural motion by applying AMD without feedback controlling mechanism is shown in the following diagram. In this case velocity and displacement were measured.

Building or civil structure subjected under external force may encounter motion, then will be deformed. Their original shape is changed to the deformed one. From figure (5.10), displacement and velocity are measured. Which is indicated in the following graph.

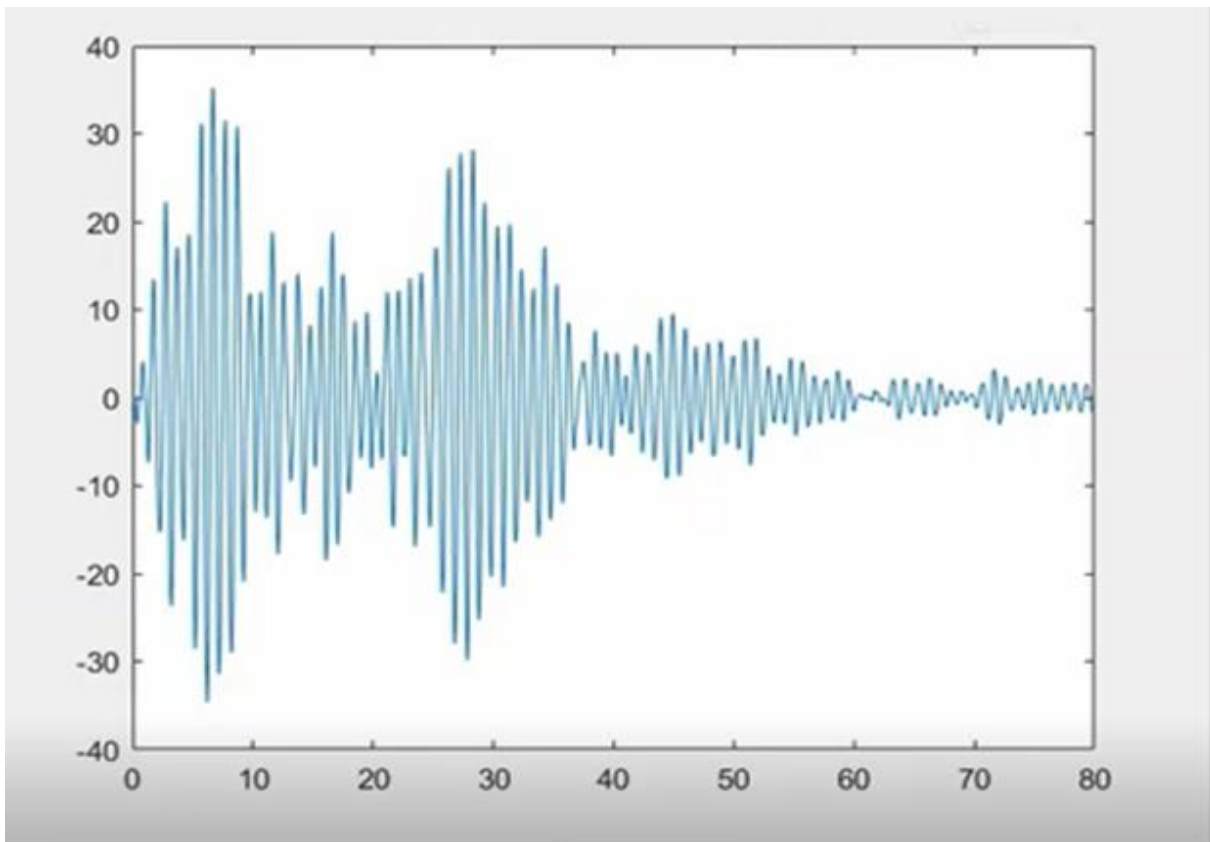


Figure 5.11 Displacement response of the structure during external force before control
Simulation results of the above graph indicates, the displacement response of the structure under earthquake excitation. Which has maximum amplitude of the 35m. This value is the result of

the structural motion before controlling mechanism has been applied. And also it has minimum amplitude of the excitation, -35m. This result is the controlling of the system by using AMD controller without applying feedback PID. The graph above and below indicates the plot of displacement and velocity respectively. Which has many oscillation, Therefore controlling structural vibration with AMD controller without applying PID is not effective. Therefore to overcome this problem, active control mechanism with piezoelectric transducer was developed.

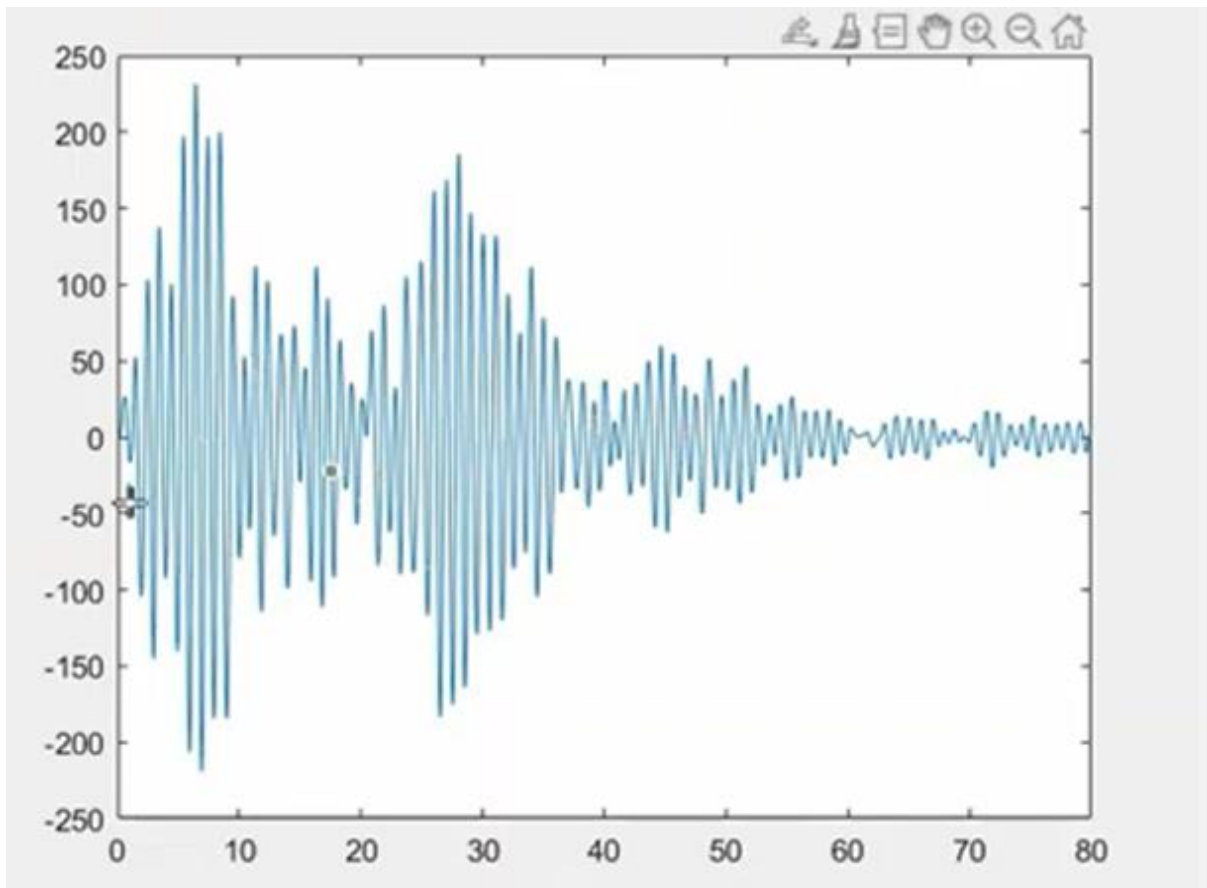


Figure 5.12 Velocity response of the structure during external force before control

Velocity of the controlled structure with AMD only has been measured as the above graph indicates. This is the main application of the thesis it has been done in this mechanism. As the graph shown above the velocity of the structural motion before the complete active control mechanism has been applied in to the system. The maximum measured values of the velocity is the 240m/s. both graph have oscillations.

5.6 Simulation results of piezoelectric sensor

The figure below is piezoelectric sensor diagram which is used to produce an electric voltage as discussed in chapter four, it takes mechanical force and produce ac output. Here it takes vibration source force from the structure and generates AC sinusoidal voltage. Which consists of spring mass damper which is constructed with ideal force source then mass of this system moves and produce a motion.

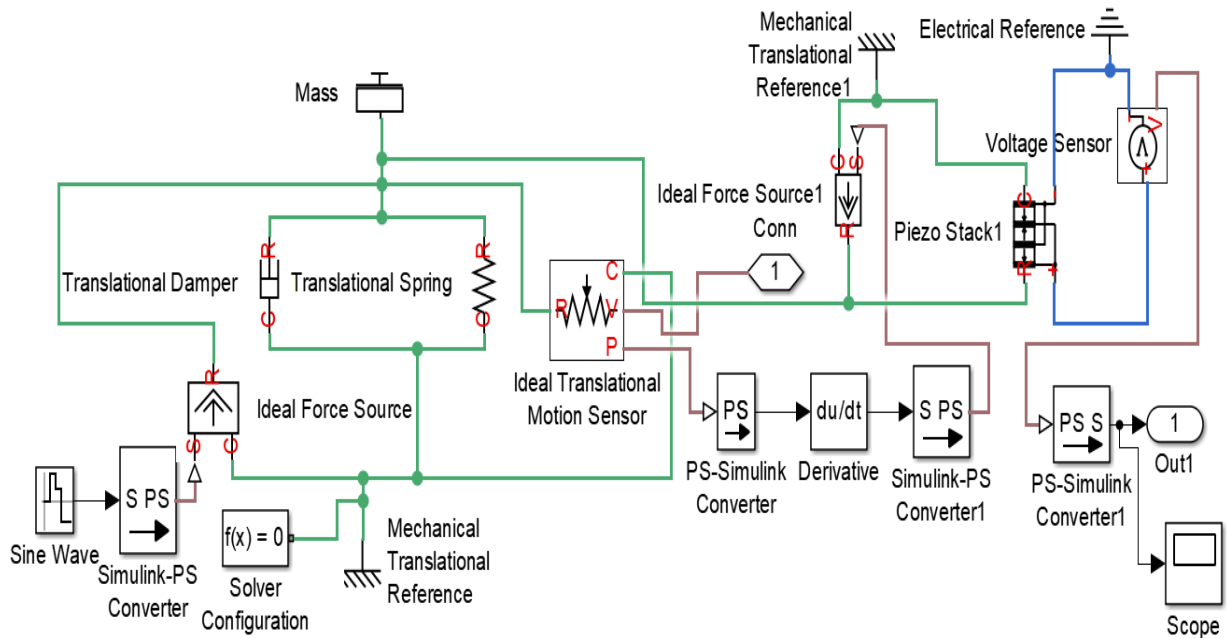


Figure 5.13 Simulation model of piezoelectric voltage generator

As mentioned earlier, piezoelectric sensor is a sensor which is used to produce electrical signal, when mechanical force is applied in to the piezo materials, the materials shrinks and electrode at the opposite sides produces charges.

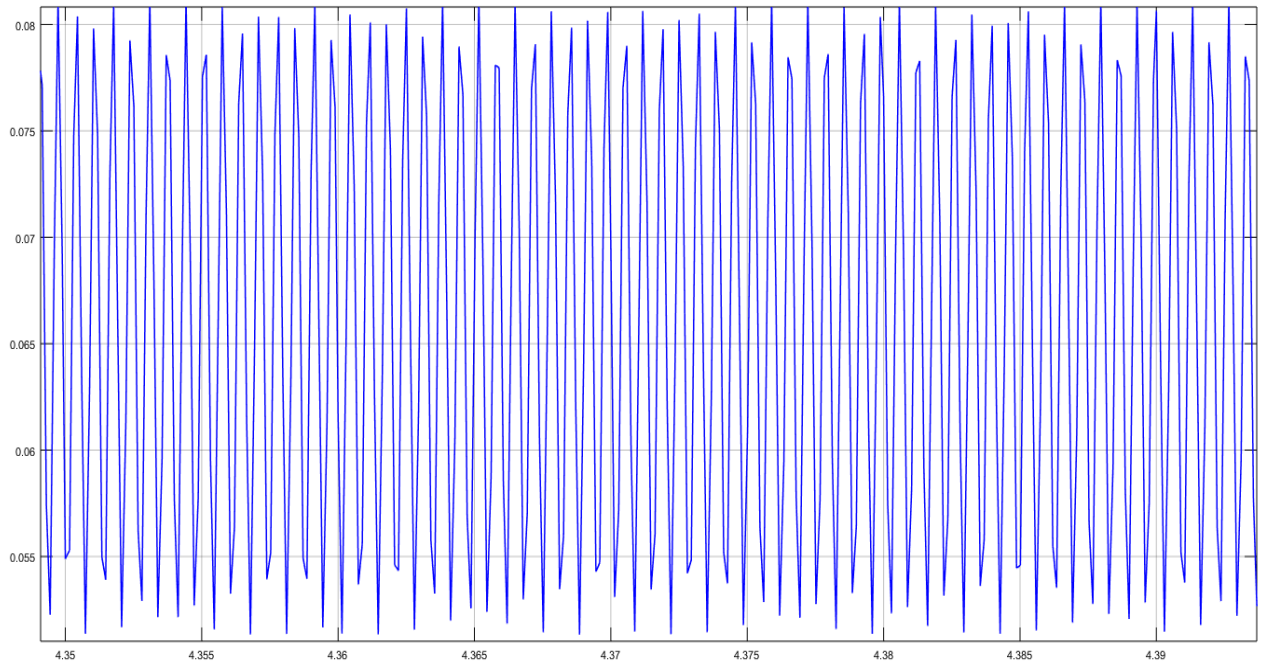


Figure 5.14 AC voltage generated in piezo subsystem

Due to the displaced of the metallic materials and produced charges, an electric charge has been produced. The voltage signal produced from piezoelectric sensor is sinusoidal, which is direct relation between applied force signals. This voltage signal is low in magnitude which is about 0.085VAC and it is not enough to apply in the PID controller in order to produce output the output to control vibration motion. So step up it, first we have to convert it in to the dc voltage by using PWM rectifier and then by using DC-DC converter, it is step up to dc high voltage. This produced voltage signal is fed in to the PID controller the PID controller process signal and produce a control electrical signal for the motor actuator at the output side.

5.6.1 Simulation result of piezoelectric output conversion

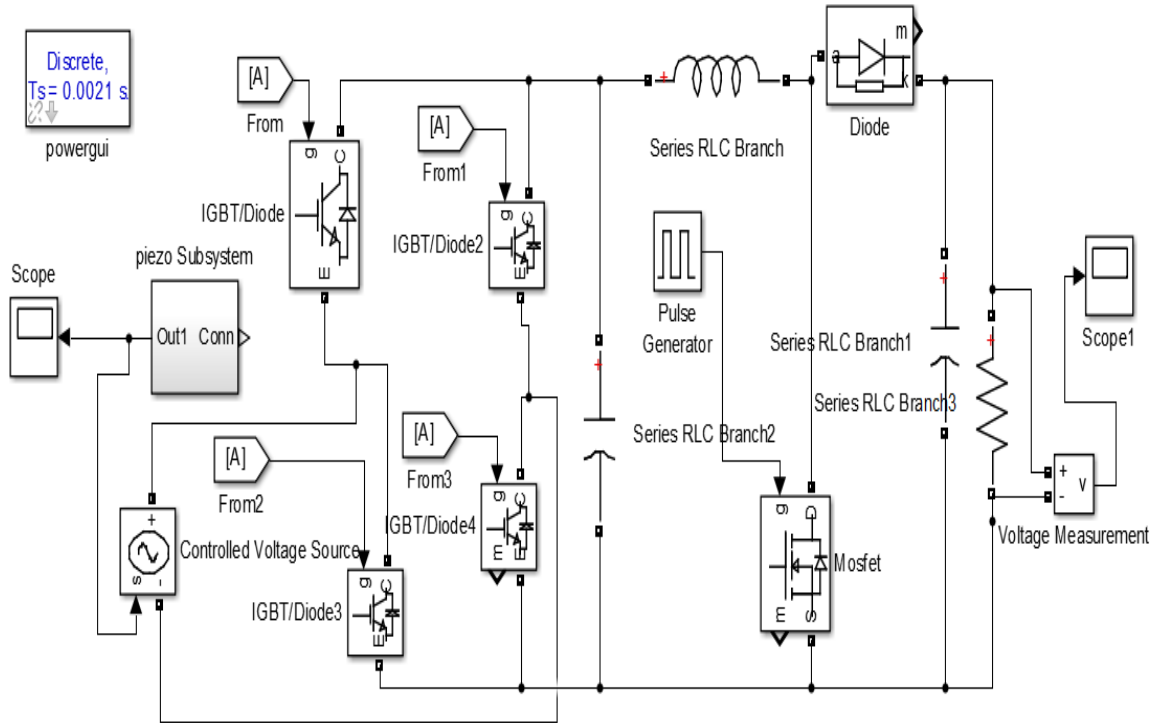


Figure 5.15 Simulink model for AC voltage conversion of piezoelectric system to DC voltage.

The above diagram shows the rectification and dc to dc conversion mechanism. This mechanism is designed because the generated AC voltage in piezoelectric system is a little bit not enough to apply in to the PID controller. Generated AC voltage as indicated in the figure 5.14 is 0.088v. This voltage is not enough to apply in the Controller to produce a controller signal for the process. These diagram contain two parts, the first part is rectifier circuit that converts ac to dc. But converted dc is not enough for the next process, so that it has been step up in to the high voltage value. Which is done by using dc to dc converter. We call it boost converter. Boost converter is a type of the converter which converts low dc voltage to high dc voltage.

5.7 Output of controlled structure with tuned PID and AMD controller.

The figure below is the result of structural control with PID controller. The PID control mechanism without application of piezoelectric transducer system is attached to structure. Due to this control mechanism, the following results (displacement and velocity are measured). The measured displacement with magnitude is 1.8m. Which is less than that of uncontrolled structural displacement. But still structure is not stable and the motion is not removed, because the obtained graph is sinusoidal. And the measured velocity indicated in the first graph is with maximum amplitude of 2m/s.

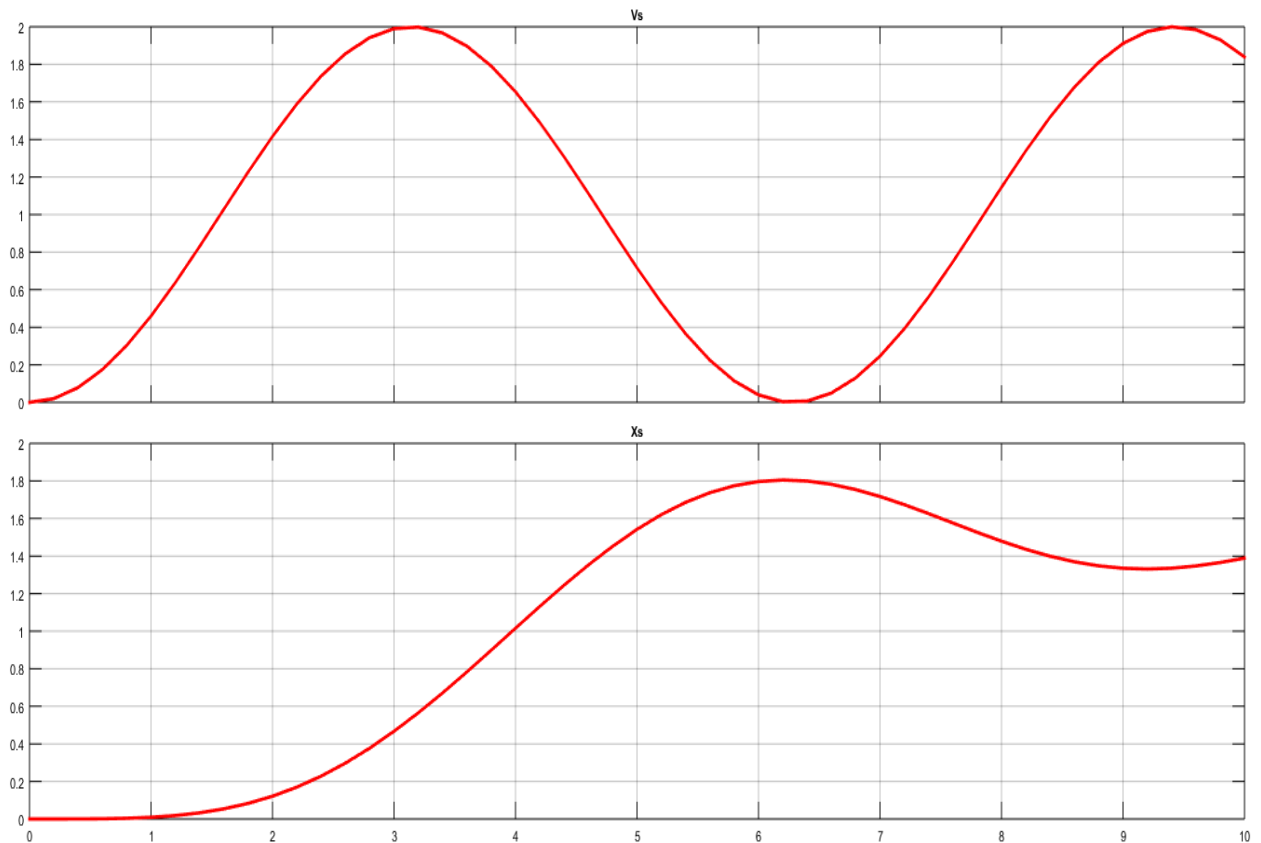


Figure 5.16 Magnitude plot of the displacement of the structure under external excitation

5.8 Simulation results of controlling 2story of building with active control mechanism.

The following diagram is the overall active controlling mechanism of the two floor building. This consists the sensor block diagram and PID controlling block diagram. Sensor block diagram has a full wave rectifier that converts ac output of the piezo sensor to the dc voltage and boost converter is used to convert low V_{dc} output of the rectifier in to the high dc value. Then this high V_{dc} value generated by the boost converter is fed to the PID controller and PID controller takes the error signal which is the deviation of actual output to the desired output. And the n produce output dc voltage signal. Actuator takes the output of the PID as input and generate controlling force for the structure.

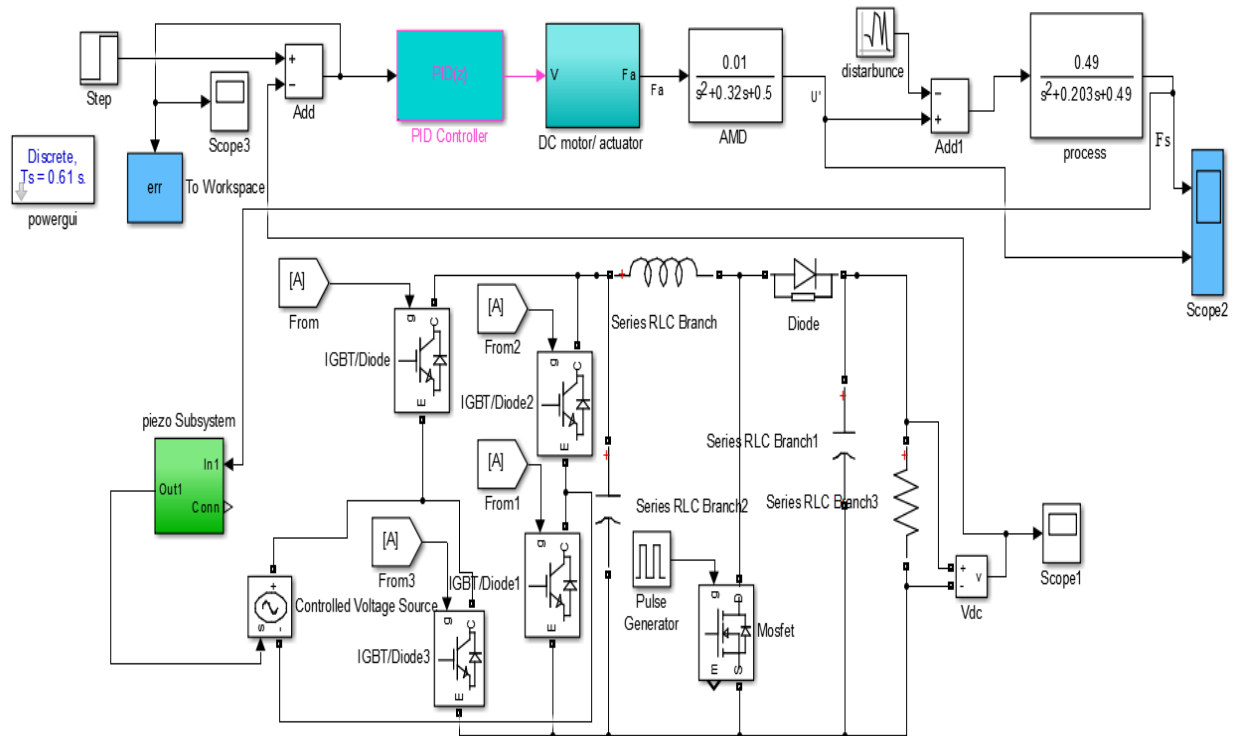


Figure 5.17 Simulink block model of the overall active controller system

Table 5.2 Obtained Tuned PID parameters using ACO algorithm for the system

Parameters	Value
k_p	11.98
k_i	0.176
k_d	100

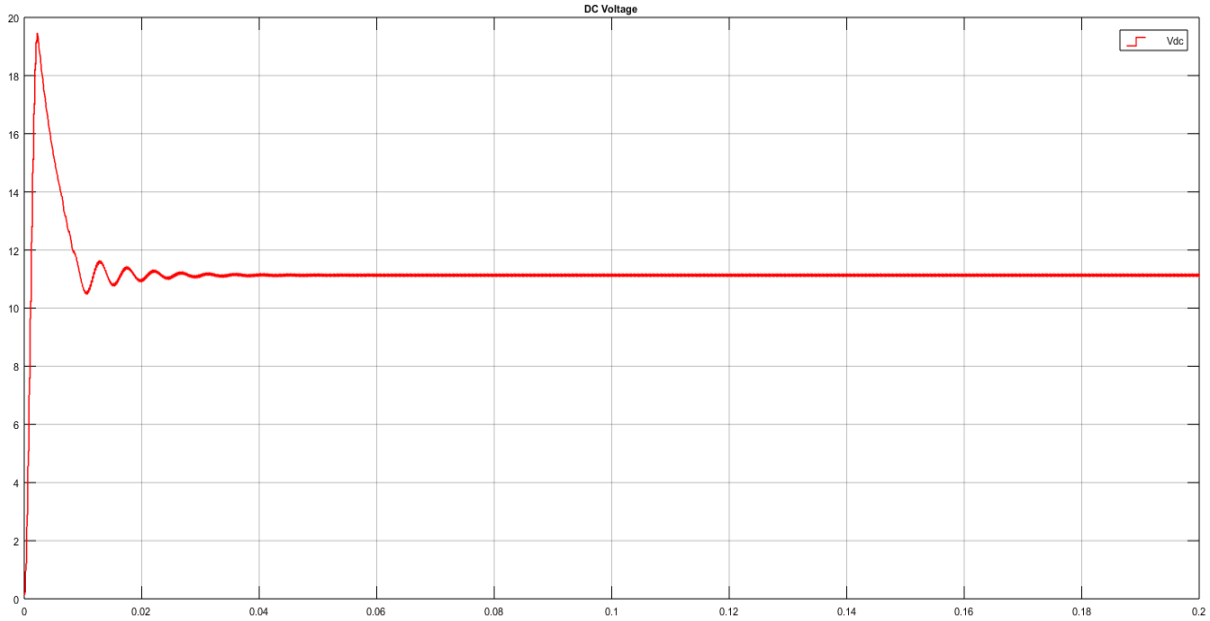


Figure 5.18 Dc voltage generated from DC to DC (boost) converter.

The voltage generated is DC, Which is 11.18v this voltage is used as input for the PID controller. The error is measured by deviating this signal from set point. Then PID process error signal and produces control force for the actuator.

Boost converter is a type of dc to dc converter, is used to convert low level dc voltage to high level dc voltage. In this paper piezo sensor is developed to change vibration energy in to the electrical energy. In the sinusoidal wave form, we have seen that generated ac voltage from structural motion is 0.08v. It has been converted to dc voltage by using half wave PWM rectifier circuit. And this circuit has been used to convert AC to low voltage DC, it is not enough to feed in to the PID controller, so that it is changed in to the DC high voltage.

5.8.1 Simulation results of actuator control force and structural force.

The following block diagram indicates that the force applied in to the system is equal in magnitude and opposite in direction. The actuator or active control output force is greater than the structural force. Maximum force of the structure is -2.7×10^{-5} and the maximum amplitude force of the AMD is 1.89×10^{-3} . If they interact with each other, the external force is canceled out.

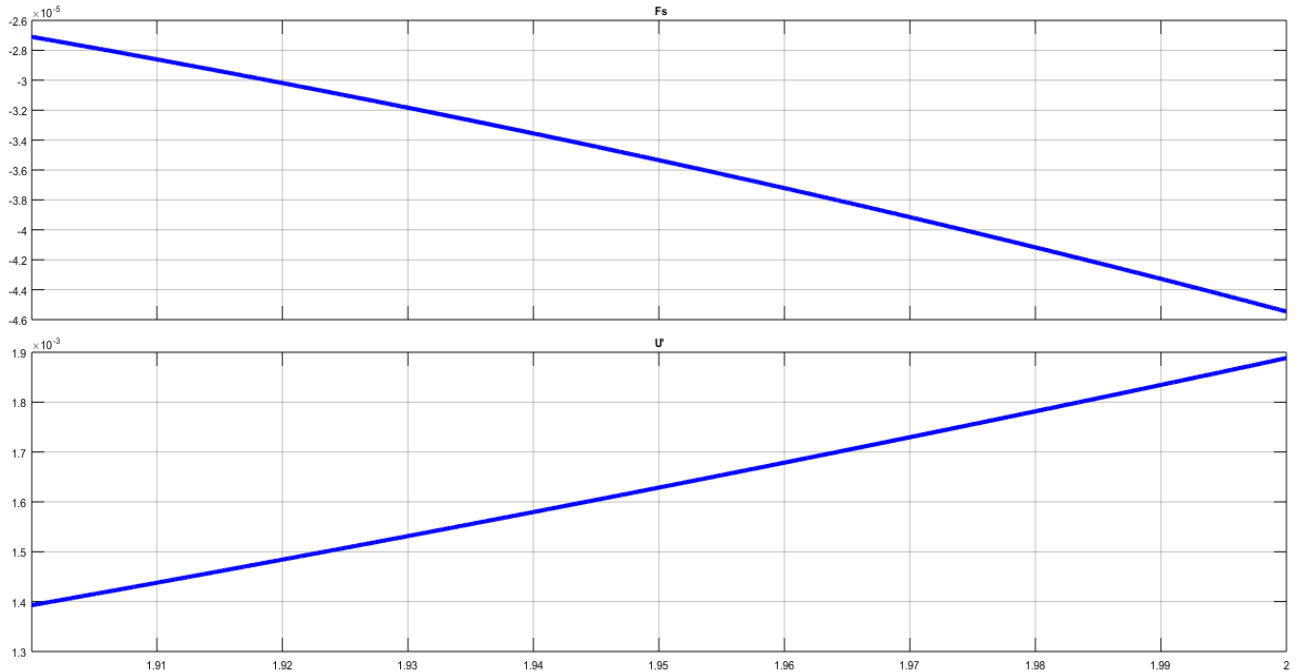


Figure 5.19 Actuator control force and structural force

The force produced by the active control is more effective than passive control. It produces force which is equal and opposite in direction. The force of the actuator is large in magnitude and opposite in sign. Therefore, if it has interaction the produced force cancel out the external force.

5.9 Vibration Reduction of the Two Floor Structure

By considering figure 5.16 and 5.21, vibration of the structural motion has been reduced. According to figure 5.16, measured velocity and displacement of the structure by using AMD and PID controller is 2m/s and 1.8m respectively. Now the structure is controlled but it is not still stable. Because the graph is sinusoidal. In contrast figure 5.21 indicates that, by increasing the control force in to the structure, the structural force was reduced and position of the building is controlled and reduced by this manner. Initially building has the displacement of 1.18m at time $t= 1$ second and then reduced to 0.29m at time $t= 1$ second to 1.02 seconds. And also by considering figure 5.19 above, the force produce by the actuator is greater and opposite in direction. Therefore by using this force, the vibration of the structure is decreased by 98.9%.

5. 10 Transient Responses of the System

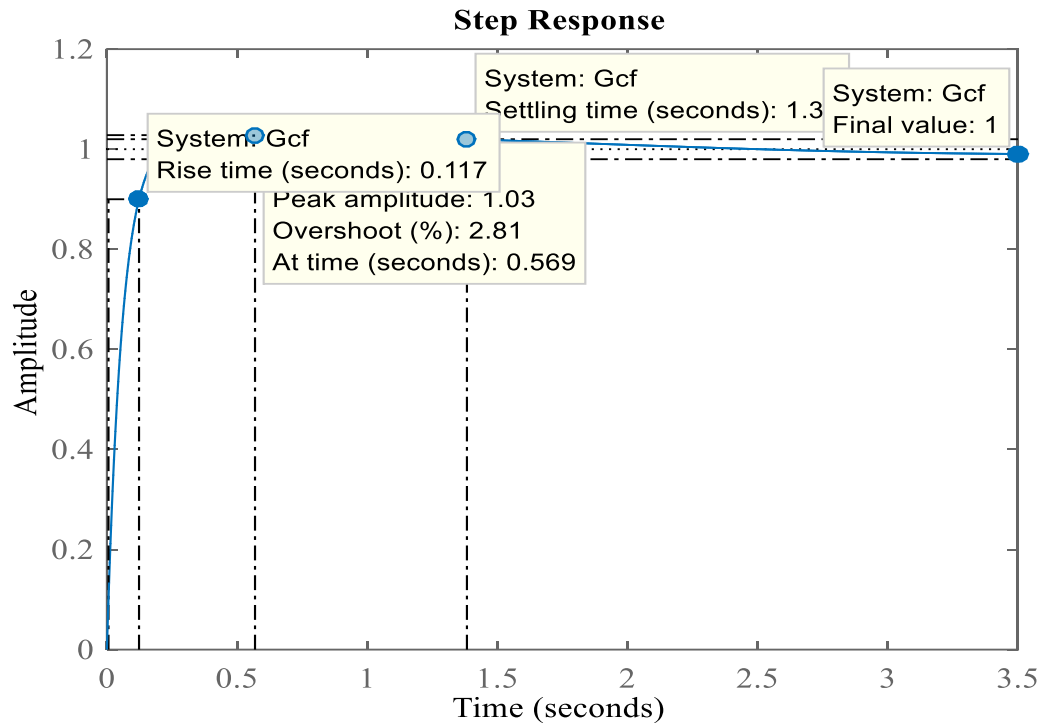


Figure 5.20 Transient responses of the system

Transient response characteristics includes: rise time, peak overshoot, settling time and steady state values. The rise time required to rise the system signal from initial value to final value is 0.117 seconds, peak amplitude is 1.03 maximum overshoot (%) is 2.81, settling time is 1.38seconds and the final value is 1. i.e. there is no steady state error in the process when control mechanism of active control system with tuned PID controller is applied. This response result is shown in the following table.

Reference for result:

Finally the graph in (5.19) above is obtained, this indicates the obtained force due to actuator is opposite sign to the disturbance force. This result obtained by the settling time of 1.38seconds and rise time of 0.117seconds. In this point, the system is stable and no oscillation. If rise time is greater than this point, the controlled actuator force is less than the disturbance force. In that point the system get instability.

Table 5.3 Transient responses of the system

Characteristics	Obtained value
Rise time	0.117seconds
Settling time	1.38 seconds
% overshoot	2.81
Peak amplitude	1.03
Final value	1

5.11 Simulation results of controlled structure

From the controlled structure, displacement is measured. The figure below is the simulation graph of the active control system. The measured signal is displacement. Structural initial position is stated. The one at the top with magnitude one is step input given to the controller. And the red graph is the position of structure under application of PID controller without active control. And the last with blue color having lowest amplitude is the controlled structural displacement.

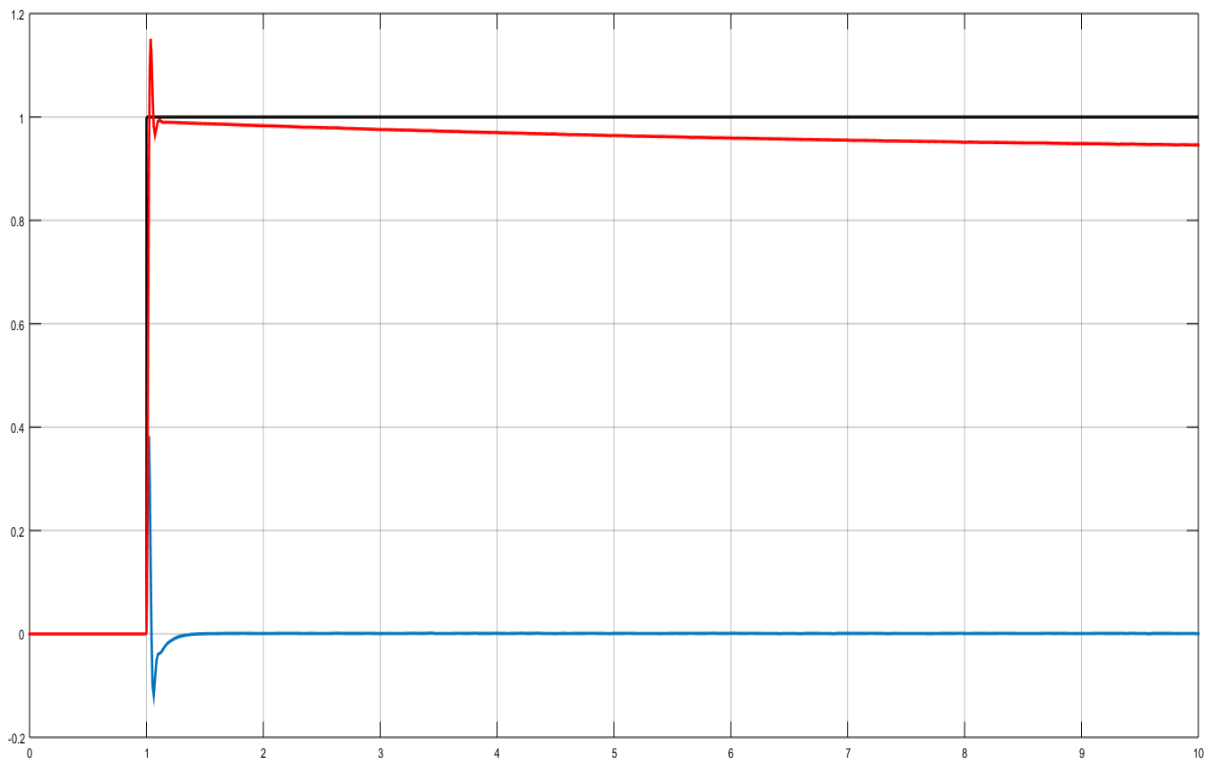


Figure 5.21 Simulation results of building structure under control

This graph illustrates that Controlled acceleration, velocity and displacement of the structure by using tuned PID and active mass damper system. According to the graph above, active control system has an ability to remove the disturbance signal more efficiently.

5.12 Physical modeling of AMD in to the structure.

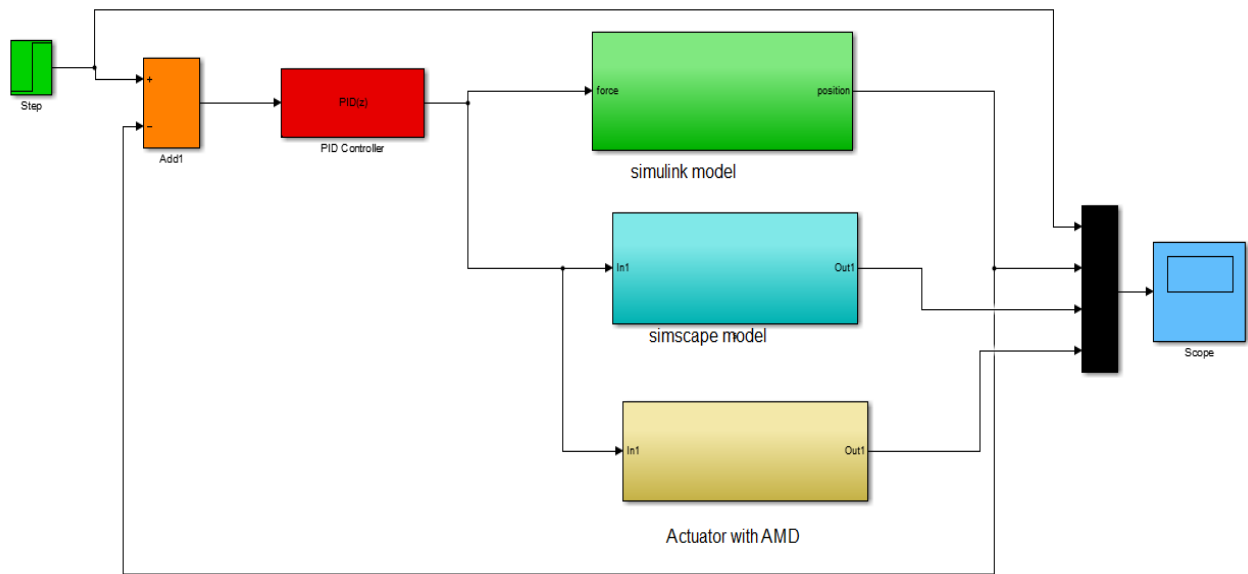


Figure 5.22 physical Modeling of the active mass damper in to the civil structure

- ✓ The first subsystem indicated the structure with PID controller and along which building is controlled without AMD application.
- ✓ And the second subsystem indicates that piezoelectric sensor attached with PID controller and has a feedback with actuator.
- ✓ In the actuator block or in the third subsystem actuator with AMD is actuated with linear piezo motor and then produce force to apply on the structure.

The result of the above Simulink model is shown below which indicates how the actuation of the active mass damper will result the vibration reduction of the building which is coupled in the second floor of the structure. The movements of AMD indicates on the wall suspended by the spring and actuated by the piezoelectric actuator indicates that cancellation of incoming signal on the wall or the structure. This done by simply clicking running button on the bottom left corner of the diagram. By doing this AMD moves its mass along opposite direction of the vibration of the structure.

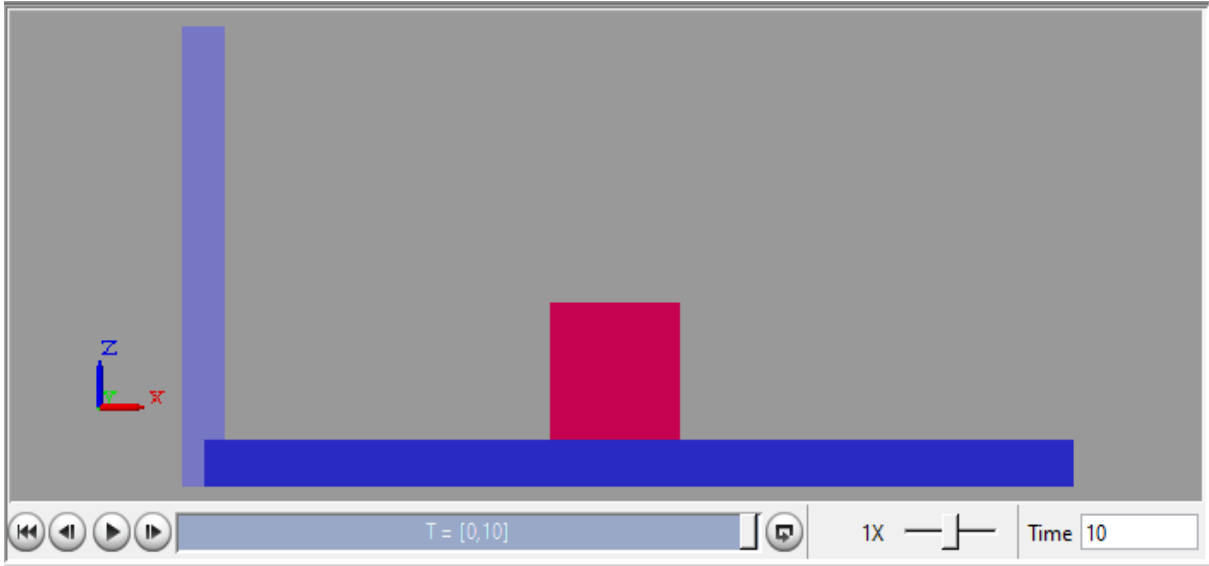


Figure 5.23 Simulation results for active mass damper modeling in the structure.

Above simulation figure illustrate that how the actuator make the movement of the active mass damper in side of the structure. Here it is simulation result of the physical modeling of the active mass damper in to the structure. So that, if structure excited in to the external disturbance, the mass of AMD moves to produce force which influences incoming force.

5.13 Disturbance Rejection Before and After Active Control applied

By increasing the control force along the structural motion will make the system stable. The quantitative measurement of the displacement and velocity has done in this paper. By applying AMD in to the building disturbance, displacement and velocity measured is 35m and 240m/s respectively, which is shown in velocity graph of figure 5.12 and displacement graph of 5.11. After applying tuned PID for the AMD, displacement decreased to 1.8m and magnitude of velocity is decreased to 2m. But still structure is not stable because there is no piezo sensor applied. Finally applying piezo sensor in to the structure, actuator produces enough force for the disturbance force. And it has mitigated external force in that position of the system was measured which is 1.18m. So that the system has get stability i.e. there is no sinusoidal wave form obtained as shown in figure 5.21.

CHAPTER SIX

6. CONCLUSION AND RECOMMENDATION

6.1 CONCLUSION

In this work, civil structure with two degree of freedom (with two floor) is modelled. The transfer function derived indicates that, the system is SISO system. Active mass damper is modelled in accordance of the system to produce force on the structure which is act as opposite to the applied force on the structure.

Feedback PID controller is developed and optimized for the application of the active control mechanism of civil structure. PID has tuned with two algorithms. These are, PSO and ACO algorithm. The result indicates that, tuned PID parameters with ACO algorithm have better performance than parameters tuned by the PSO algorithm. ACO algorithm gives fast response of the system, which minimizes the objective function (ITAE) value with small iteration. The ITAE obtained by ACO algorithm is smaller than the value obtained by PSO algorithm. Therefore to control structural motion, ACO based PID controller has better performance than PSO based PID controller. The control force produced from the active control system is equal and opposite to that of external force. The result of actuator force is $1.9 * 10^{-3}$ N and disturbance force is $-2.7 * 10^{-5}$ N. The displacement measured before active control mechanism applied has many oscillation, with magnitude of 35m and after active control applied is 2m and velocity measured after and before controlling mechanism is 2m/s and 240m/s respectively. And after the enough interaction force produced, the position of the structure is decreased to 0.39m and the system has no oscillation. Therefore it is at stable state.

6.2 RECOMMENDATION

The controller design in the event of the external excitation in building structure for both lateral and torsional force will be the main topic of the upcoming study. It is advised that the hardware implementation portion of the study's future lab experiments.

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APPENDIXES

Appendix A

ACO and PSO Algorithm for tuning PID controller for active control of civil structure

```
clc; clear; close all
ns =[1.69];
ds = [1 0.0234 1.69];
G = tf (ns,ds);
Gf=feedback (G,1);
step (Gf)
% constant parameters for PSO
c=2;z=0.7;particles=20;iteration=50;var=3
% search space
a=0; %bottom bound
b= 30; % top bound
% steps for optimization
c_cf=0;
% initialization
for s=1: particles
    for t=1:var
        r(s,t)=0;          %velocity particles
        xl(s,t)=a+rand*(b-a); % position particles
        xl(s,t)=x(s,t);
    end
    % model variables
    kp=x(s,1);
    ki=x(s,2);
    kd=x(s,3);
    % model for simulation
    G=pid (kp,ki,kd);
```

```

Gf=feedback (G*G, 1);
y=step (Gf);
%TIAE (cost function)
ff1=0;
sim1=size(y);
for s1=1:sim1;
ff1=ff1+ ((abs(y(s1)-1))*s1);
end
ITAE (s) =ff1;
end

%find the best value
[Best_Performance, position]=min (ITAE);
fg=Best_Performance
xk(1)=x(position,1);
xk(2)=x(position,2);
xk(3)=x(position,3);
G=pid (kp, ki, kd);
Gf=feedback (G*G, 1);
step (Gf);
For i=1: repetition %No of repetition
For s=1: spots %No of spots
For t=1: var %No. of variables
v(s,t)=(w*v(s,t)+(c*rand*(xp(s,t)-x(s,t)))+(c*rand*xg(t)-x(s,t))); % upgrade velocity
X(s, t) =x(s, t) +v(s, t); % update position
end
% Verify Bound
for t=1:var
if x(s,t)<a
x(s,t)=a;
end

if x(s,t)>b
x(s,t)=b;

```

```

    end
end

% model variables
kp=x(s,1);
ki=x(s,2);
kd=x(s,3);
% model for simulation
G=pid (kp, ki,kd);
Gf=feedback (G*G, 1);
y=step (Gf);
%TIAE (Cost function)
ff1=0;
sim1=size(y);
for s1=1:sim1;
ff1=ff1+ ((abs(y (s1)-1))*s1);
end
ITAEp(s) =ff1;
% contrast local
if ITAEp(s)<ITAE(s);
ITAE(s)=ITAEp(s);
xr(s,1)= x(s,1);
xr(s,2)= x(s,2);
xr(s,3)= x(s,3);
end
end
[B_fg, position]=min (ITAE);
% contrast best
if B_fg<fg
fg=B_fg;    % New best value
xk(1)=xr(location,1); % location of first variable
xk(2)=xr(location,2); %location of second variable

```

```

xk(3)=xr(location,3); %location of third variable
end
c_cf=c_cf+1;
best_cf_ac (c_cf)=fg; %#ok<SAGROW>
end
min_ITAE=fg
kp=xk(1)
ki=xk(2)
kd=xk(3)
G= pid(kp,ki,kd);
Gf=feedback (G*G, 1);
Step (Gf);
t_cf=1:c_cf;
Figure
Plot (t_cf, best_cf_ac,'r','Linewidth', 2), xlabel ('iteration'), ylabel ('costfunction (ITAE)')
Legend ('ITAE for PSO-PID')
Title ('ITAE at each repetition')

```

ACO algorithm for tuning PID controller for active control of civil structure.

```

clc;clear; close all
ns =[0.49];
ds = [1 0.203 0.49];
G = tf (ns, ds);
Gf=feedback (G,1);
Step (Gf)
% ACO constant parameters
c=2; %scaling factor
z=0.7; %pheromone factor decay
Particles=50; %No. of Ants
Iteration=100;
Var=3; %No. of tuning variables

```

```

%search space
a=0; %bottom bound
b= 100; % top bound
% steps for optimization
c_cf=0;
%initialization
For s=1: particles
    for t=1:var
        V(s,t)=0;          % particles' velocity
        x(s,t)=a+rand*(b-a); % particles' position
        xp(s,t)=x(s,t);
    end
    %model variables
    kp=x(s,1);
    ki=x(s,2);
    kd=x(s,3);
    % model for simulation
    G=pid(kp,ki,kd);
    Gf=feedback(G*G, 1);
    y=step(Gf);
    %TIAE (Cost function)
    ff1=0;
    sim1=size(y);
    For s1=1:sim1;
        ff1=ff1+((abs(y(s1)-1))*s1);
    end
    ITAE(s) =ff1;
end
%find the best value
[Best_Performance, position]=min (ITAE);
fg=Best_Performance

```

```

xk(1)=x(position,1);
xk(2)=x(position,2);
xk(3)=x(position,3);
G=pid (kp,ki,kd);
Gf=feedback (G*G, 1);
Step (Gf);
For i=1: repetition %No of repetition

For s=1: spots %No of spots

For t=1: var %No. of variables
    v(s,t)=(w*v(s,t)+(c*rand*(xp(s,t)-x(s,t)))+(c*rand*xg(t)-x(s,t))); % upgrade velocity
    x(s,t)=x(s,t)+v(s,t); % update position
end
% Check Bound
for t=1:var
    if x(s,t)<a
        x(s,t)=a;
    end
    if x(s,t)>b
        x(s,t)=b;
    end
end
end
% model variables
kp=x(s,1);
ki=x(s,2);
kd=x(s,3);
% model for simulation
G=pid (kp, ki,kd);
Gf=feedback (G*G, 1);
y=step (Gf);
%TIAE (Cost function)
ff1=0;
sim1=size(y);

```

```

For s1=1:sim1;
ff1=ff1+((abs(y(s1)-1))*s1);
end
ITAEp(s)=ff1;
% contrast local
if ITAEp(s)<ITAE(s);
ITAE(s)=ITAEp(s);
xr(s,1)= x(s,1);
xr(s,2)= x(s,2);
xr(s,3)= x(s,3);
end
end
[B_fg, position]=min (ITAE);
% contrast best
if B_fg<fg
fg=B_fg; % New best value
x(k1)=xr(position,1); % position of variable 1
xk(2)=xr(position,2); %position of variable 2
xk(3)=xr(position,3); %position of variable 3
end
c_cf=c_cf+1;
best_cf_ac (c_cf) =fg; %#ok<SAGROW>
end
min_ITAE=fg
kp=xk(1)
ki=xk(2)
kd=xk(3)
G= pid (kp, ki, kd);
Gf=feedback (G*G,1);
Step (Gf);
t_cf=1:c_cf;

```

Figure

Plot (t_cf, best_cf_ac,'r--','Linewidth', 2), xlabel ('repetition'), ylabel ('costfunction (ITAE)')

Legend ('ITAE for ACO-PID')

Title ('ITAE at every repetition')

Appendix B

Simulink Block diagrams modeled in active control system

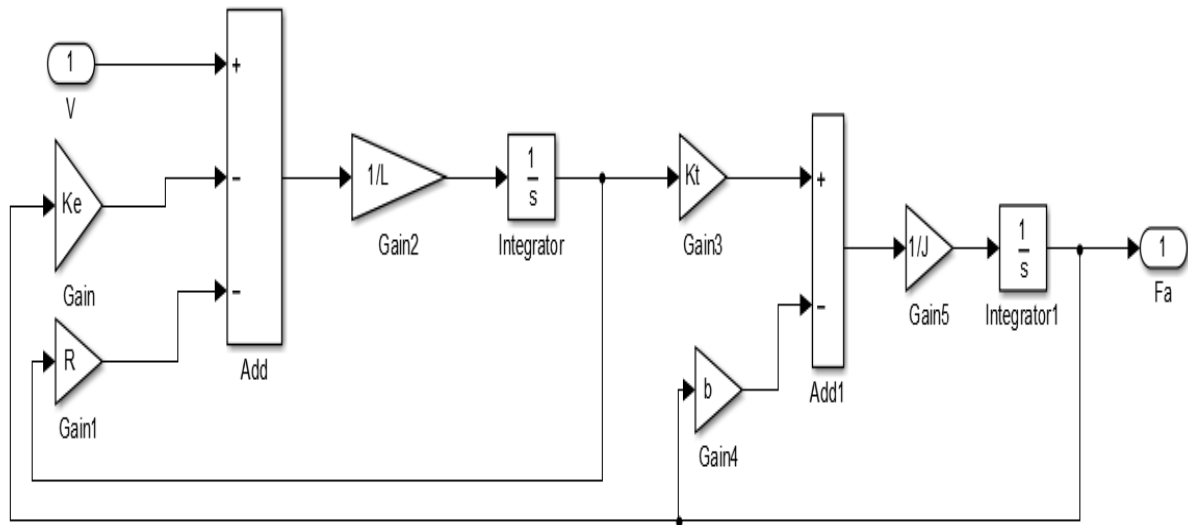


Figure B1 DC motor actuator design for active control system

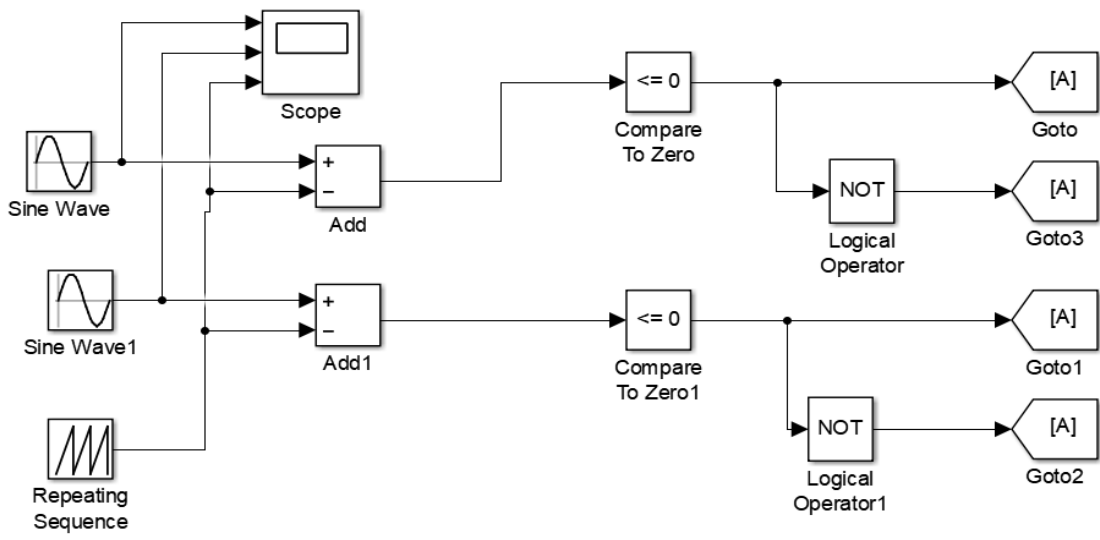


Figure B2 PWM rectifier circuit

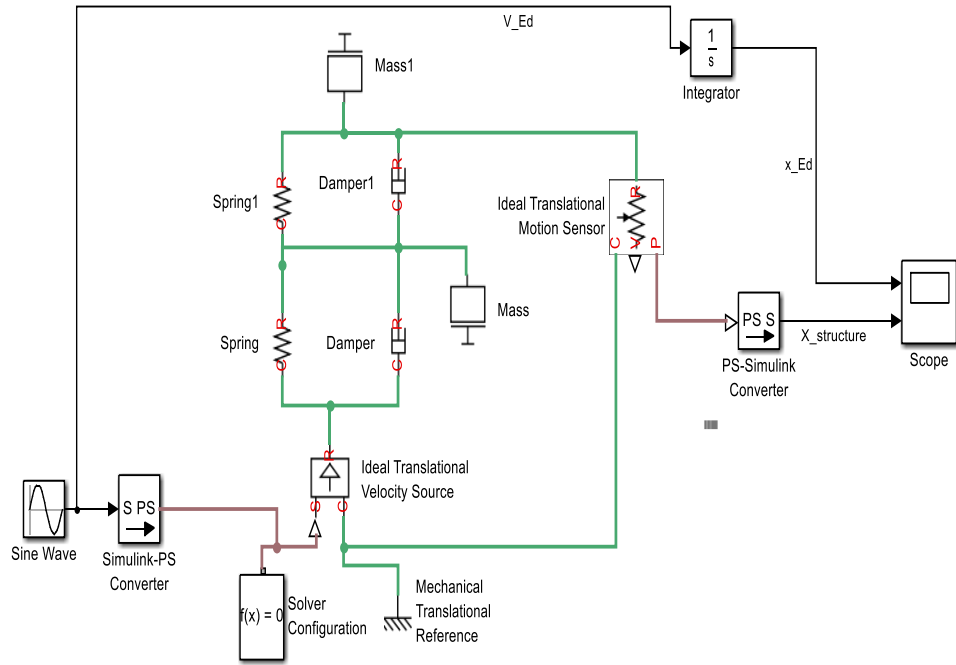


Figure B4 Sims cape modeling of AMD with structure

Table B1 Dc motor actuator parameter value

Parameters	Symbol	Values
Back EMF Constant	k_m	0.00767
Motor Torque Constant	k_t	3.87×10^{-7}
Motor Moment of Inertia	J_m	2×10^{-3}
Equivalent Moment of Inertia at the Load	J_{eq}	4×10^{-3}
Equivalent Viscous Damping Coefficient	B_{eq}	0.9
Gearbox Efficiency	η_j	0.69
Motor Efficiency	η_m	$14 \times 5 = 70$
System Gear Ratio (For High Gear)	K_g	2.6
Armature Resistance	R_m	3

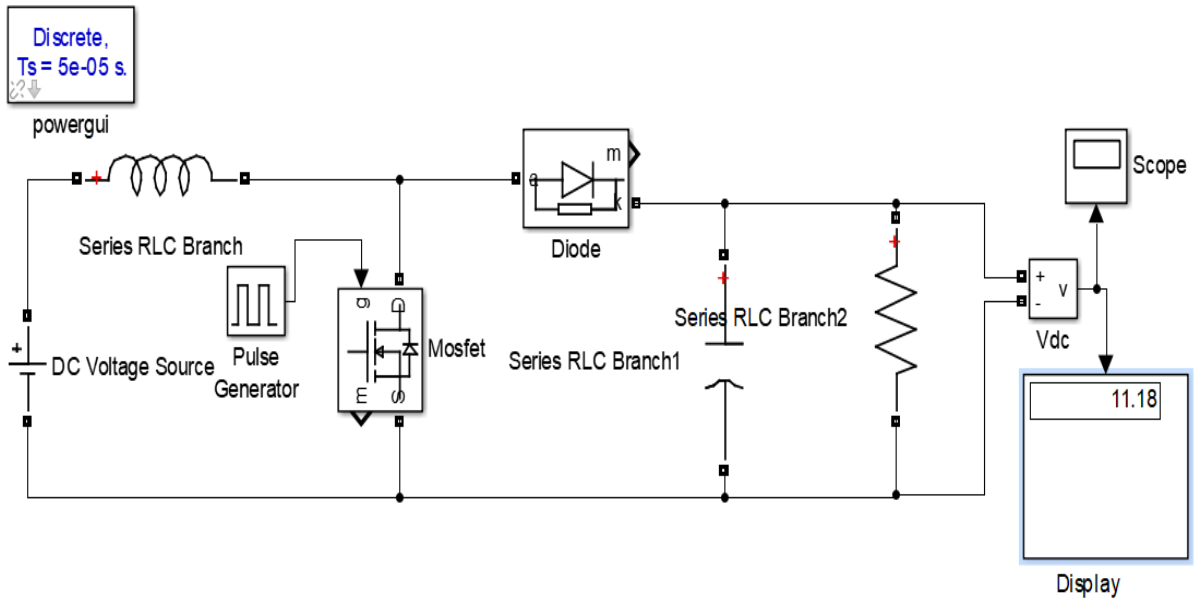


Figure B5 Dc voltage produced from dc to dc (boost converter)