Technical report submitted to UGC Minor Research Project

Design of Optimum PID controller for Aircraft attitude control system using TAGUCHI combined Genetic Algorithm

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<u>CERTIFICATE</u>

This is to certify that the present work titled "**DESIGN OF OPTIMUM PID CONTROLLER FOR AIRCRAFT ATTITUDE CONTROL SYSTEM USING TAGUCHI COMBINED GENETIC ALGORITHM**" is carried out by me and was not submitted for partial / full financial assistance to any other funding agency.

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(V.E. [illegible] AD)
Principal Investigator

Contents

CHAPTER-1

PID Control Theory

Introduction:

Feedback control is a control mechanism that uses information from measurements. In a feedback control system, the output is sensed. There are two main types of feedback control systems:

1) positive feedback
2) negative feedback.

The positive feedback is used to increase the size of the input but in a negative feedback, the feedback is used to decrease the size of the input. The negative systems are usually stable. A PID is widely used in feedback control of industrial processes on the market in 1939 and has remained the most widely used controller in process control until today. Thus, the PID controller can be understood as a controller that takes the present, the past, and the future of the error into consideration. After digital implementation was introduced, a certain change of the structure of the control system was proposed and has been adopted in many applications. But that change does not influence the essential part of the analysis and design of PID controllers. A proportional– integral–derivative controller (PID controller) is a method of the control loop feedback. This method is composing of three controllers:

1. Proportional controller (PC)
2. Integral controller (IC)
3. Derivative controller (DC)

1.1 Role of a Proportional Controller (PC)

The role of a proportional depends on the present error, I on the accumulation of past error and D on prediction of future error. The weighted sum of these three actions is used to adjust Proportional control is a simple and widely used method of control for many kinds of systems. In a proportional controller, steady state error tends to depend inversely upon the proportional gain (ie: if the gain is made larger the error goes down). The proportional response can be adjusted by multiplying the error by a constant Kp, called the proportional gain. The proportional term is given by:

$$P = K_P.error(t) - - - (1.1)$$

A high proportional gain results in a large change in the output for a given change in the error. If the proportional gain is very high, the system can become unstable. In contrast, a small gain results in a small output response to a large input error. If the proportional gain is very low, the control action may be too small when responding to system disturbances. Consequently, a proportional controller (Kp) will have the effect of reducing the rise time and will reduce, but never eliminate, the steady-state error. In practice the proportional band (PB) is expressed as a percentage so:

$$PB\% = \frac{100}{K_P} - - - - - - - - (1.2)$$

Thus a PB of 10% ⇔ Kp=10

1.2 Role of an Integral Controller (IC)

An Integral controller (IC) is proportional to both the magnitude of the error and the duration of the error. The integral in a PID controller is the sum of the instantaneous error over time and gives the accumulated offset that should have been corrected previously. Consequently, an integral control (Ki) will have the effect of eliminating the steady-state error, but it may make the transient response worse. The integral term is given by:

$$I = K_I \int_0^t error(t)dt - - - - - - -(1.3)$$

1.3 Role of a Derivative Controller (DC)

The derivative of the process error is calculated by determining the slope of the error over time and multiplying this rate of change by the derivative gain Kd. The derivative term slows the rate of change of the controller output. A derivative control (Kd) will have the effect of increasing the stability of the system, reducing the overshoot, and improving the transient response. The derivative term is given by:

$$D = K_D \frac{d.error(t)}{dt} - - - - - - -(1.4)$$

Effects of each of controllers Kp, Kd, and Ki on a closed-loop system are summarized in the
table shown below in tableau 1.

1.4 PID controller (PID)

A typical structure of a PID control system is shown in Fig.1. Fig.2 shows a structure of a PID control system. The error signal e(t) is used to generate the proportional, integral, and

Parameter	Rise time	Overshoot	Settling time	Steady-state error
K_p	Decrease	Increase	Small change	Decrease
K_i	Decrease	Increase	Increase	Decrease significantly
K_d	Minor decrease	Minor decrease	Minor decrease	No effect in theory

Table 1. A PID controller in a closed-loop system

derivative actions, with the resulting signals weighted and summed to form the control signal u(t) applied to the plant model.

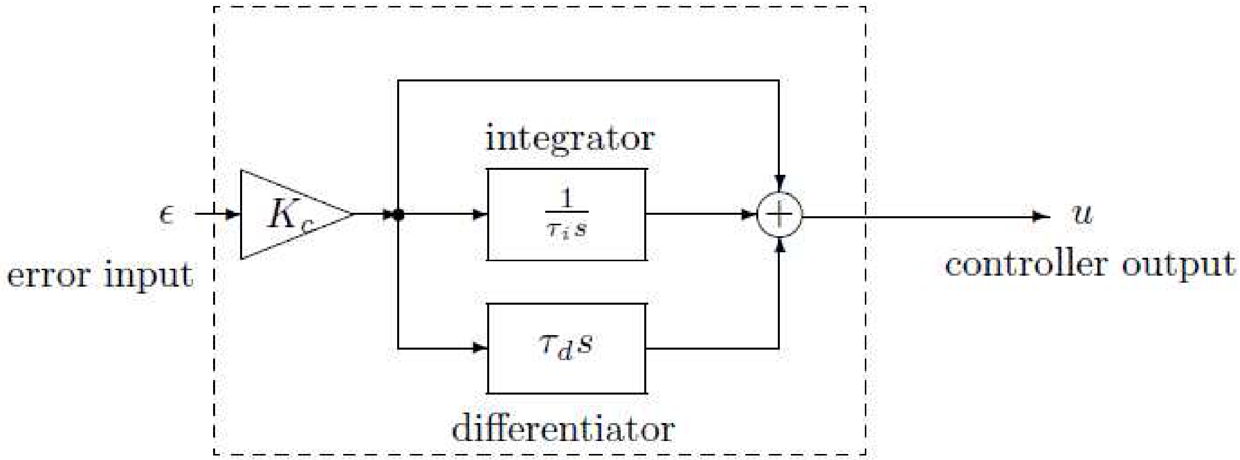


Fig.1.1: A PID control system

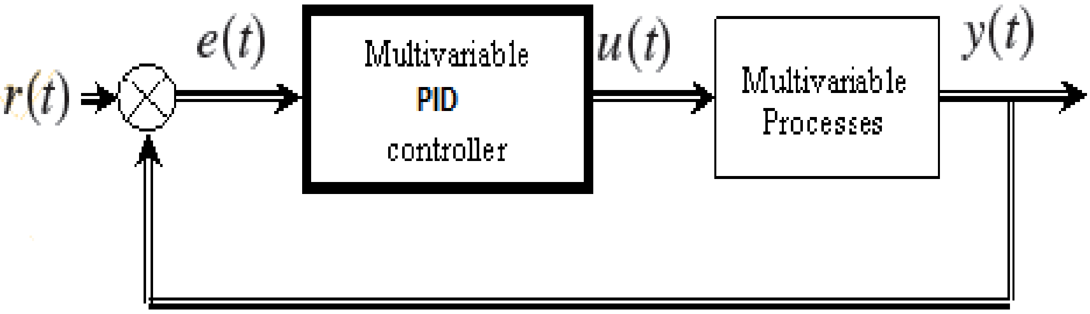


Fig.1.2: A structure of a PID control system

where u(t) is the input signal to the multivariable processes, the error signal e(t) is defined as e(t) =r(t) − y(t), and r(t) is the reference input signal.

A standard PID controller structure is also known as the "three-term" controller. This principle mode of action of the PID controller can be explained by the parallel connection of the P, I and D elements shown in Figure1.3.

Block diagram of the PID controller

$$G(S) = K_P\left(1 + \frac{1 + T_I T_D S^2}{T_I . S}\right) = K_P\left(1 + \frac{1}{T_i S} + T_D S\right) ------(1.5)$$

where K_P is the proportional gain, T_I is the integral time constant, T_D is the derivative time constant, $K_I = K_P / T_I$ is the integral gain and $K_D = K_P T_D$ is the derivative gain. The "three - term" functionalities are highlighted below. The terms K_P , T_I and T_D definitions are:

1 The proportional term: providing an overall control action proportional to the error signal through the all pass gain factor.

2. The integral term: reducing steady state errors through low frequency compensation by an integrator.

3. The derivative term: improving transient response through high frequency compensation by a differentiator.

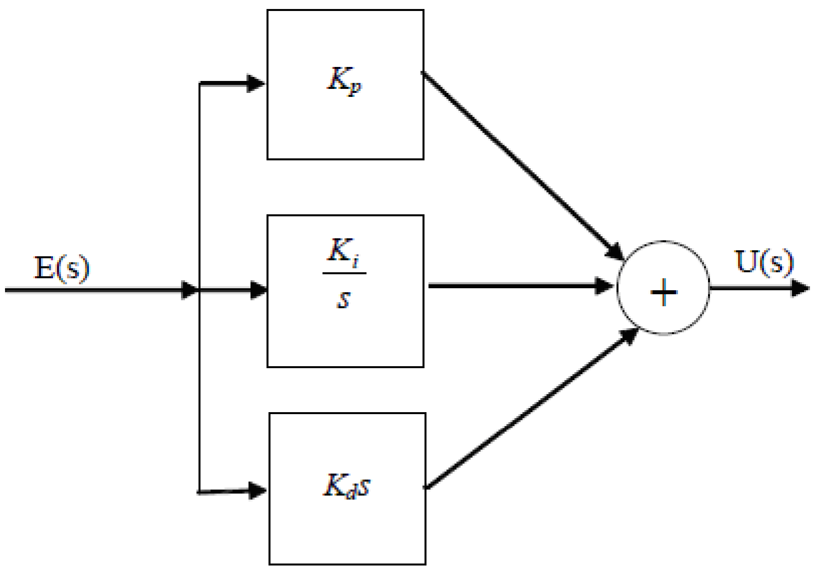


Fig. 1.3. Parallel Form of the PID Compensator

These three variables *KP* , *TI* and *TD* are usually tuned within given ranges. Therefore, they are often called the *tuning parameters* of the controller. By proper choice of these tuning parameters a controller can be adapted for a specific plant to obtain a good behaviour of the controlled system.

The time response of the controller output is

$$u(t) = K_P\left(e(t) + \frac{\int_0^t e(t)dt}{T_i} + T_d\frac{de(t)}{dt}\right) - - - - - - (1.6)$$

Using this relationship for a step input of $e(t)$, i.e. $e(t) = \delta(t)$, the step response r(t) of the PID controller can be easily determined. The result is shown in below. One has to observe that the length of the arrow $K_P T_D$ the D action is only a measure of the weight of the δ impulse.

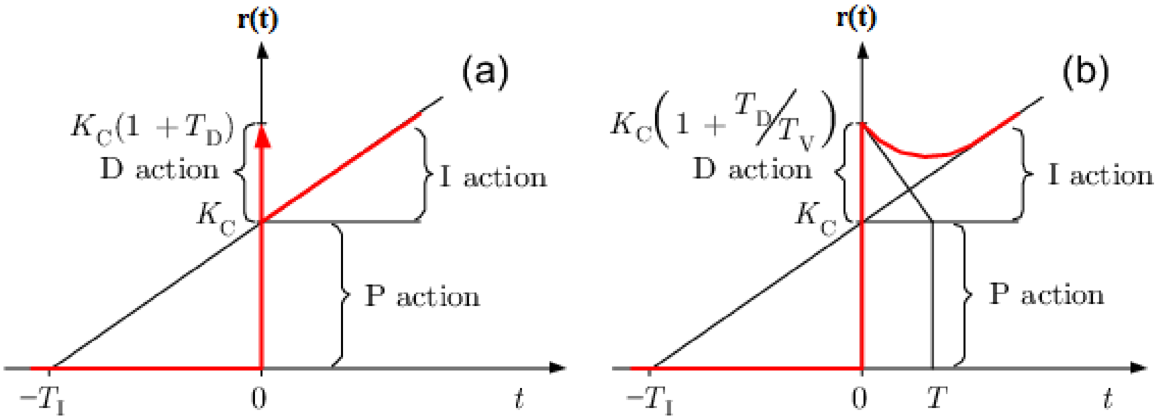


Fig:1. 4. a) Step response of PID ideal form b) Step response of PID real form

1.5 The transfer function of the PID controller

The transfer function of the PID controller is

$$G(S) = \frac{u(S)}{E(S)} - - - - - - (1.7)$$

$$G(S) = K_P + \frac{K_I}{S} + K_D S = \frac{K_D S^2 + K_P S + K_I}{S} - - - - - - (1.8)$$

1.6 PID pole zero cancellation

The PID equation can be written in this form:

$$G(S) = \frac{K_d\left(S^2 + \frac{K_P}{K_d}S + \frac{K_i}{K_d}\right)}{S} - - - - - (1.9)$$

When this form is used it is easy to determine the closed loop transfer function.

$$H(S) = \frac{1}{S^2 + 2\xi\omega_0 S + \omega^2{}_0} - - - - - - (1.10)$$

If

$$\frac{K_i}{K_d} = \omega^2{}_0 - - - - - - - - - - (1.11)$$

$$\frac{K_P}{K_d} = 2\xi\omega_0 - - - - - - - - -(1.12)$$

Then

$$G(S)H(S) = \frac{K_d}{S} - - - - - - - - -(1.13)$$

This can be very useful to remove unstable poles.

There are several prescriptive rules used in PID tuning. The most effective methods generally involve the development of some form of process model, and then choosing P, I, and D based on the dynamic model parameters.

1.7 Tuning methods

We present here four tuning methods for a PID controller.

Method	**Advantages**	**Disadvantages**
Manuals	Online method No math expression	Requires experienced personnel
Ziegler-Nichols	Online method Proven method	Some trial and error, process upset and very aggressive tuning
Cohen-Coon	Good process models	Offline method Some math Good only for first order Processes
Software tools	Online or offline method,	Some cost and training Involved

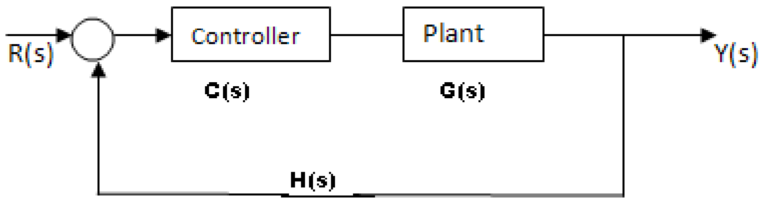
	consistent tuning, Support Non-Steady State tuning	
Algorithmic	Online or offline method, Consistent tuning, Support Non-Steady State tuning, Very precise	Very slow

Tuning of a PID controller refers to the tuning of its various parameters (P, I and D) to achieve an optimized value of the desired response. The basic requirements of the output will be the stability, desired rise time, peak time and overshoot. Different processes have different requirements of these parameters which can be achieved by meaningful tuning of the PID parameters. If the system can be taken offline, the tuning method involves analysis of the step input response of the system to obtain different PID parameters. But in most of the industrial applications, the system must be online and tuning is achieved manually which requires very experienced personnel and there is always uncertainty due to human error. Another method of tuning can be Ziegler-Nichols method. While this method is good for online calculations, it involves some trial-and-error which is not very desirable.

1.8 FRACTIONAL ORDER PID CONTROLLER

1.8.1 Basic concept of Fractional order PID controller:

Consider the negative feedback control system as shown in fig



The continuous transfer function of the PI $^{\lambda}$D $^{\mu}$ controller is obtained through Laplace transform as

$$C(s) = K_p + \frac{T_i}{s^{\lambda}} + T_d s^{\mu}$$

The PID controller expands the integer order PID controller from point to plane, there by adding flexibility to controller design and allowing us to control our real world processes more accurately but only at the cost of increased design complexity.

1.8.2 Tuning method for the fraction order PID controller:

To obtain the K_p (proportional gain), a constant of integral term (K_i), the constant of derivative term K_d, the fractional order of differentiator μ and the fractional order of integrator λ . The method uses classical Zeigler – Nichols tuning rule to obtain K_p and K_i . To obtain initial value of K_d , then some fine tuning has been done by using Astrom-Hagglund method described earlier. The fractional order λ and μ are obtained to achieve specified phase margin. Let φ_{pm} be the required phase margin and ω_{cp} be the frequency of the critical point on the Nyquist curve of G(s) at which $\arg(G(j\omega_{cp}))= -180$, then the gain margin defined as

$$g_m = \frac{1}{|G(j\omega_{cp})|} = K_c$$

In order to make the phase margin of the system equal to φ_{pm} and $|C(j\omega_{cp})G(j\omega_{cp})=1|$ the following equation must be satisfied.

$$C(j\omega_{cp}) = \frac{1}{|G(j\omega_{cp})|} e^{j\phi_{pm}} = K_c \cos\phi_{pm} + jK_c \sin\phi_{pm}$$

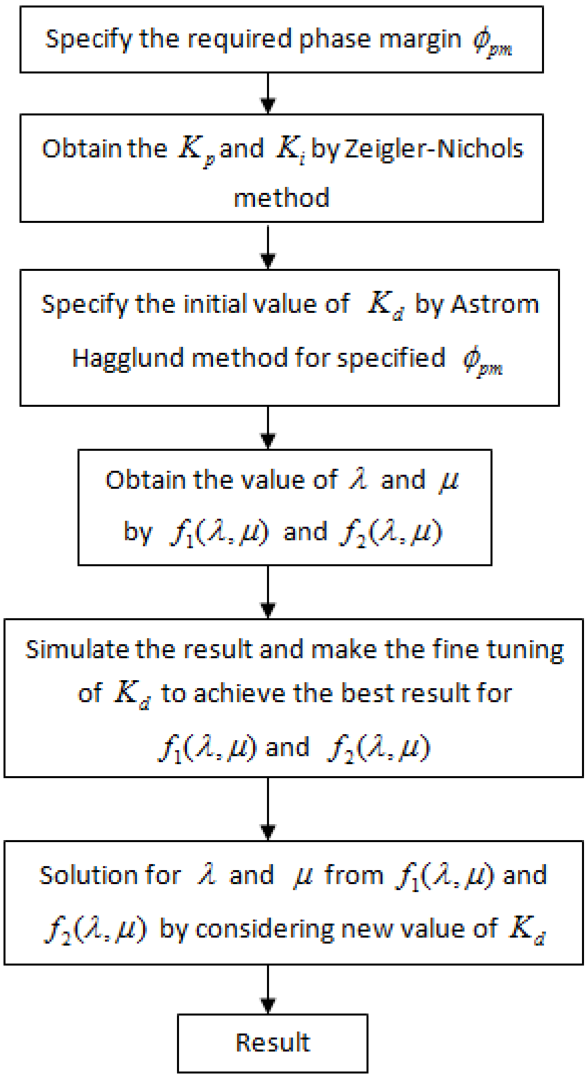
Then we write C ($j\omega_{cp}$) using equation

$$C(j\omega_{cp}) = K_p + K_i\omega_{cp}^{-\lambda}\cos(\frac{\pi}{2}\lambda) + K_d\omega_{cp}^{\mu}\cos(\frac{\pi}{2}\mu)$$
$$+\left[-K_i\omega_{cp}^{-\lambda}\sin(\frac{\pi}{2}\lambda) + K_d\omega_{cp}^{\mu}\sin(\frac{\pi}{2}\mu)\right]$$

Considering the above equations we can write

$$f_1(\lambda,\mu) = K_p + K_i\omega_{cp}^{-\lambda}\cos(\frac{\pi}{2}\lambda) + K_d\omega_{cp}^{\mu}\cos(\frac{\pi}{2}\mu) - K_c(\cos\phi_{pm}) = 0$$
$$f_2(\lambda,\mu) = -K_i\omega_{cp}^{-\lambda}\sin(\frac{\pi}{2}\lambda) + K_d\omega_{cp}^{\mu}\sin(\frac{\pi}{2}\mu) - K_c(\sin\phi_{pm}) = 0$$

1.8.3 Algorithm for tuning of PI $^{\lambda}$ D $^{\mu}$ controller:



Specify the required phase margin ϕ_{pm}
Obtain the K_p and K_i by Zeigler-Nichols method
Specify the initial value of K_d by Astrom Hagglund method for specified ϕ_{pm}
Obtain the value of λ and μ by $f_1(\lambda, \mu)$ and $f_2(\lambda, \mu)$
Simulate the result and make the fine tuning of K_d to achieve the best result for $f_1(\lambda, \mu)$ and $f_2(\lambda, \mu)$
Solution for λ and μ from $f_1(\lambda, \mu)$ and $f_2(\lambda, \mu)$ by considering new value of K_d
Result

CHAPTER-2

2.PID TUNING ALGORITHMS

2.1.Ziegler–Nichols Tuning Formula

A very useful empirical Tuning formula was proposed by Ziegler and Nichols in early 1942.the tuning formula was obtained by conducting experiment on plant or process under open loop. i.e. without connecting controller at feed back path and step response is observed. from the step response the parameters K,L, and T(or a where a=KL/T). with L and a the Ziegler-Nichols formula shown in Table 2.1

Table 2.1: PID Tuning parameters by Ziegler-Nichols method

S.NO	CONTROLLER TYPE	CONTROLLER GAINS OR VALUES		
		K_p	T_i	T_d
1	P	1/a	----	---
2	PI	0.9/a	3L	---
3	PID	1.2/a	2L	L/2

2.2.The Wang-Juang-Chan Tuning Formula:

Based on the optimum ITAE criterion, the tuning algorithm proposed by Wang, Juang, and Chan is a simple and efficient method for selecting the PID parameters. If the *k,L, T* parameters of the plant model are known, the controller parameters are given by

$$K_p = \frac{(0.7303+0.5307\,T/L)(T+0.5L)}{K(T+L)}$$

$$T_i = T+0.5L \qquad T_d = \frac{0.5LT}{T+0.5L}$$

2.3 Optimum PID Controller design

Optimum setting algorithms for a PID controller were proposed by Zhuang andAtherton
for various criteria. Consider the general form of the optimum criterion

$$J_n(\theta) = \int_0^{\infty} [t^n e(\theta, t)]^2 dt$$

where *e(θ, t)* is the error signal which enters the PID controller, with θ the PID controller
parameters. For the system structure shown in Fig. 6.1, two setting strategies are proposed:
one for the set-point input and the other for the disturbance signal *d(t)*. In particular, three
values of n are discussed, i.e., for n = 0, 1, 2. These three cases correspond, respectively, to
three different optimum criteria: the integral squared error (ISE) criterion, integral squared
time weighted error (ISTE) criterion, and the integral squared time-squared weighted error

(ISTE) criterion. The expressions given were obtained by fitting curves to the optimum
theoretical results.

Table 2.2: PID Tuning parameters by Optimum method

S.NO	RANGE OF L/T	0.1 – 1			1.1 - 2		
	CRITERION	ISE	ISTE	IST^{2}E	ISE	ISTE	IST^{2}E
1	A_1	1.048	1.042	0.968	1.154	1.142	1.061
2	A_2	-0.897	-0.897	-0.904	-	-	-0.583

					0.567	0.579	
3	B_1	1.195	0.987	0.977	1.047	0.919	0.892
4	B_2	-0.368	-0.238	-0.253	-0.220	-0.172	-0.165
5	A_3	0.489	0.385	0.316	0.490	0.384	0.315
6	B_3	0.888	0.906	0.892	0.708	0.839	0.832

For the PID controller, the gains are set as follows

$$K_p = \frac{A_1}{K}\left(\frac{L}{T}\right)^{B_1}$$

$$T_i = \frac{T}{A_2 + B_2\left({}^{L}/_{T}\right)}$$

$$T_d = A_3 T\left(\frac{L}{T}\right)^{B_3}$$

2.4.Chien-Hrones-Reswick algorithm

According to Chien-Hrones-Reswick, the tuning parameters are

$$K_p = \frac{0.95}{a} \quad ; \quad K_i = \frac{1}{2.4L} \quad ; \quad K_d = 0.42L$$

2.5 Cohen-Coon algorithm

According to Cohen-Coon algorithm tuning parameters are

$$K_p = \frac{1.35}{a}\left(1 + \frac{0.18\mu}{1-\mu}\right)$$

$$K_i = \frac{1}{Ti} = \frac{2.5 - 2\mu}{1 - 0.39\mu T}L$$

$$K_d = \frac{0.37 - 0.37\mu}{1 - 0.81\mu}L$$

CHAPTER-3

GENETIC ALGORITHM

3.1 Introduction

Genetic Algorithms (GA�s) are a stochastic global search method that mimics the process of natural evolution. It is one of the methods used for optimization. John Holland formally introduced this method in the United States in the 1970 at the University of Michigan. The continuing performance improvements of computational systems has made them attractive for some types of optimization. The genetic algorithm starts with no knowledge of the correct solution and depends entirely on responses from its environment and evolution operators such as reproduction, crossover and mutation to arrive at the best solution. By starting at several independent points and searching in parallel, the algorithm avoids local minima and converging to sub optimal solutions.

3.2 Characteristics of Genetic Algorithm

Genetic Algorithms are search and optimization techniques inspired by two biological principles namely the process of .natural selection. and the mechanics of .natural genetics.. GAs manipulate not just one potential solution to a problem but a collection of potential solutions. This is known as population. The potential solution in the population is called .chromosomes.. These chromosomes are the encoded representations of all the parameters of the solution. Each chromosomes is compared to other chromosomes in the population and awarded fitness rating that indicates how successful this chromosomes to the latter. To encode better solutions, the GA will use �genetic operators� or �evolution operators� such as crossover and mutation for the creation of new chromosomes from the existing ones in the population. This is achieved by either merging the existing ones in the population or by modifying an existing chromosomes The selection mechanism for parent chromosomes takes the fitness of the

parent into account. This will ensure that the better solution will have a higher chance to procreate and donate their beneficial characteristic to their offspring. genetic algorithm is typically initialized with a random population consisting of between 20-100 individuals. This population or also known as mating pool is usually represented by a real-valued number or a binary string called a chromosome. For illustrative purposes, the rest of this section represents each chromosome as a binary string. How well an individual performs a task is measured and assessed by the objective function. The objective function assigns
each individual a corresponding number called its fitness. The fitness of each chromosome is assessed and a survival of the fittest strategy is applied. In this project, the magnitude of the error will be used to assess the fitness of each chromosome. There are three main stages of a genetic algorithm, these are known as *reproduction, crossover* and *mutation*. This will be explained in details in the following section

3.3 Population Size

Determining the number of population is the one of the important step in GA.There are many research papers that dwell in the subject. Many theories have been documented and experiments recorded However the matter of the fact is that more and more theories and experiments are conducted and tested and there is no fast and thumb rule with regards to which is the best method to adopt. For a long time the decision on the population size is
based on trial and error. In this project the approach in determining the population is rather unsciencetific. From my reading of various papers, it suggested that the safe population size is from 30 to 100. In this project an initial population of 20 were used and the result observed. The result was not promising. Hence an initiative of 40, 60, 80 and 90 size of population were experimented. It was observed that the population of 80 seems to be a good guess. Population of 90 and above does not results in any further optimization.

3.4 Reproduction

During the reproduction phase the fitness value of each chromosome is assessed. This value is used in the selection process to provide bias towards fitter individuals. Just like in natural evolution, a fit chromosome has a higher probability of being selected for reproduction. An example of a common selection technique is the .*Roulette Wheel* selection method . Each individual in the population is allocated a section of a roulette wheel. The size of the section is proportional to the fitness of the individual. A pointer is spun and the individual to whom it points is selected. This continues until the selection criterion has been met. The probability of an individual being selected is thus related to its fitness, ensuring that fitter individuals are more likely to leave offspring. Multiple copies of the same string may be selected for reproduction and the fitter strings should begin to dominate. However, for the situation illustrated in Figure 8, it is not implausible for the weakest string (01001) to dominate the selection process. There are a number of other selection methods available and it is up to the user to select the appropriate one for each process. All selection methods are based on the same principal that is giving fitter chromosomes a larger probability of selection.

Four common methods for selection are:

1. Roulette Wheel selection
2. Stochastic Universal sampling
3. Normalized geometric selection
4. Tournament selection

Due to the complexities of the other methods, the Roulette Wheel methods is preferred in this project.

3.5 Crossover

Once the selection process is completed, the crossover algorithm is initiated. The crossover operations swaps certain parts of the two selected strings in a bid to capture the good parts of old chromosomes and create better new ones. Genetic operators manipulate the characters of a chromosome

directly, using the assumption that certain individual.s gene codes, on average, produce fitter individuals. The crossover probability indicates how often crossover is performed. A probability of 0% means that the .offspring. will be exact replicas of their
.parents. and a probability of 100% means that each generation will be composed of entirely new offspring. The simplest crossover technique is the Single Point Crossover.

There are two stages involved in single point crossover:
1. Members of the newly reproduced strings in the mating pool are .mated. (paired) at random.
2. Each pair of strings undergoes a crossover as follows: An integer *k* is randomly selected between one and the length of the string less one, [*1,L-1*]. Swapping all the characters between positions k+1 and L inclusively creates two new strings.
Example: If the strings *10000* and *01110* are selected for crossover and the value
of *k* is randomly set to 3 then the newly created strings will be *10010* and *01100*

More complex crossover techniques exist in the form of Multi-point and Uniform Crossover Algorithms. In Multi-point crossover, it is an extension of the single point crossover algorithm and operates on the principle that the parts of a chromosome that contribute most to its fitness might not be adjacent. There are three main stages involved in a Multi-point crossover.
1. Members of the newly reproduced strings in the mating pool are .mated. (paired) at random.
2. Multiple positions are selected randomly with no duplicates and sorted into ascending order.
3. The bits between successive crossover points are exchanged to produce new offspring.

3.6 Mutation

Using *selection* and *crossover* on their own will generate a large amount of different strings. However there are two main problems with this:

1. Depending on the initial population chosen, there may not be enough diversity in the initial strings to ensure the Genetic Algorithm searches the entire problem space.
2. The Genetic Algorithm may converge on sub-optimum strings due to a bad choice of initial population.

3.7 Elitism

In the process of the crossover and mutation-taking place, there is high chance that the optimum solution could be lost. There is no guarantee that these operators will preserve the fittest string. To avoid this, the elitist models are often used. In this model, the best individual from a population is saved before any of these operations take place. When a new population is formed and evaluated, this model will examine to see if this best structure has been preserved. If not the saved copy is reinserted into the population. The GA will then continues on as normal.

3.8 Objective Function Or Fitness Function

The objective function is used to provide a measure of how individuals have performed in the problem domain. In the case of a minimization problem, the most fit individuals will have the lowest numerical value of the associated objective function. This raw measure of fitness is usually only used as an intermediate stage in determining the relative performance of individuals in a GA.

Another function that is the *fitness function*, is normally used to transform the objective function value into a measure of relative fitness, thus where f is the objective function, g transforms the value of the objective function to a nonnegative number and F is the resulting relative fitness. This mapping is always necessary when the objective function is to be minimized as the lower objective function values correspond to fitter individuals. In many

cases, the fitness function value corresponds to the number of offspring that an individual can
expect to produce in the next generation. A commonly used transformation is that of proportional fitness assignment.

CHAPTER-4

TAGUCHI METHOD

4.1 Introduction

The Taguchi method is an optimization method. This method has been applied to solve many optimization problems in electrical machines design and electric power systems . It does not need to use sophisticated algorithms and extra programming besides the software tool used for system modeling . For the same number of design variables and levels, the Taguchi method gives a lower number of design experiments than that of the response surface methodology. Therefore, time saving and lower cost can be achieved by using this method. However, the Taguchi method is sufficient to deal with multiobjective optimization problems requiring more than two factors, but the Taguchi method can be combined with another technique to obtain accurate results.

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4.2 Optimisation by the TAGUCHI method

The Taguchi method was constructed based on the principle of an orthogonal array that can effectively minimize the number of design experiments required in any design process. The Taguchi method can provide an efficient way to obtain the optimal parameters in an optimization problem. In the Taguchi method, an orthogonal array that depends on the number of factors and their levels is used to study the parameters' variation effect. This method has a low number of experiments. For example, if there are four factors each at three levels, the full factorial design method requires $3^4 = 81$ experiments while the Taguchi method needs only nine experiments to obtain the approximate optimal values.

4.2.1 Orthogonal Array

In establishing an orthogonal array, four factors A, B, C, and D are considered. A is the proportional gain, B is the integral gain, C is the derivative gain, and D is the saturation limit of an integral action. The saturation limit fixes 100 for the AVR system stability. Table II illustrates the design variables

or factors and their levels. The standard Taguchi's orthogonal array L-9 is used for this numerical experiments study.

4.2.2 perform the experiment

Nine experiments should be carried out in order to know the dynamic response of the AVR system with the PID controller at combination levels of these factors. The maximum percentage overshoot (MPOS), the rise time ($T\ r$), the settling time ($T\ s$), and the steady-state error (Ess) of the terminal voltage of a synchronous generator are the most important variables. To obtain the values of MPOS, $T\ r$, $T\ s$, and Ess for each experiment, the MATLAB-Simulink model of the AVR system with the PID controller is used. After performing the nine experiments and obtaining all experimental data, ANOM and ANOVA are carried out to estimate the effects of the three design parameters and to determine the relative importance of each design parameter, respectively.

4.2.3 ANOM

1) *Overall Mean:* The mean or average value of all results can be calculated as follows:

$$m = \frac{1}{9}\sum_{i=1}^{9} MPOS_i$$

2) *Average Effect of a Design Variable at One Setting:* The MPOS of factor A at level three is calculated by

$$m_{A3}(MPOS) = \frac{1}{3}(MPOS(7) + MPOS(8) + MPOS(9))$$

where the factor A is set to level three only in experiments . The MPOS for all levels for all factors can be determined by a similar way In a similar way, $T\,r$, $T\,s$, and Ess can be obtained for all levels of all factorsIt can be realized that the factor-level combination (A3, B1, C1) contributes to minimization of $T\,r$, $T\,s$, and Ess.

4.2.4 ANOVA

ANOVA is used to determine the relative importance of the various design variables. To perform ANOVA, the sum of squares should be calculated. The sum of squares of factor A (SSFA) can be computed as follows:

$$SSFA = 3\sum_{i=1}^{3}(m_{Ai} - m)^2$$

SSFB and SSFC can be obtained by using the same way.

CHAPTER-5

SIMULATION & RESULTS

5.1 Optimal Design

The design optimization process is presented in this paper for optimizing the PID controller parameters using the TCGA method. This method refers to the accurate optimum design
that improves the dynamic response of the Aircraft attitude system. However, the procedure for the optimal design consists of two main steps. In the first step, the optimization is carried out by the Taguchi method in order to obtain the approximate optimal values of the PID controller parameters using ANOM. Then, ANOVA is used to choose the design variables influencing the objective function. In the second step, a multiobjective GA is carried out to find the accurate optimum values of these influential design variables. The proposed optimization method has many merits. In the Taguchi method, the number of design experiments is reduced in comparison with the full factorial design. Moreover, by using ANOVA to select the influential design variables, the design area for optimization using GA is greatly reduced

5.2 Optimisation by the TAGUCHI method

The Taguchi method was constructed based on the principle of an orthogonal array that can effectively minimize the number of design experiments required in any design process. The Taguchi method can provide an efficient way to obtain the optimal parameters in an optimization problem. In the Taguchi method, an orthogonal array that depends on the number of factors and their levels is used to study the parameters' variation effect This method has a low number of experiments. For example, if there are four factors each at three levels, the full factorial design method requires

34 = 81 experiments while the Taguchi method needs only nine experiments to obtain the approximate optimal values.

5.3 Orthogonal array

In establishing an orthogonal array, four factors X, Y, Z are considered. X is the proportional gain, Y is the integral gain, and Z is the derivative gain. Table 5.1 illustrates the design variables or factors and their levels. The standard Taguchi's orthogonal array L-9 is used for this numerical experiments study, as shown in Table 5.2

Table 5.1: Design Variables and Levels

Design variable	**Level 1**	**Level 2**	**Level 3**
X	6	7	8
Y	0.5	0.6	0.7
Z	0.2	0.25	0.3

Table 5.2: Actual Values of Three Settings of Three Design Variables

EXP.NO	X	Y	Z
1	6	0.5	0.2
2	6	0.6	0.25

3	6	0.7	0.3
4	7	0.5	0.25
5	7	0.6	0.3
6	7	0.7	0.2
7	8	0.5	0.3
8	8	0.6	0.2
9	8	0.7	0.25

5.4 perform the experiment

Nine experiments, as shown in Table III, should be carried out in order to know the dynamic response of the Aircraft attitude control system with the PID controller at combination levels of these factors. The maximum percentage overshoot (MPOS), the rise time ($T\ r$), and the settling time ($T\ s$) of the terminal voltage of a synchronous generator are the most important variables. To obtain the values of MPOS, $T\ r$ *and* $T\ s$ for each experiment, the MATLAB-Simulink model of the Aircraft system with the PID controller is used. Table 5.3 shows the simulation results on each experiment.

After performing the nine experiments and obtaining all experimental data, ANOM is carried out to estimate the effects of the three design parameters and to determine the relative importance of each design parameter.

Table 5.3: Results of Dynamic Response Analysis

EXP.NO	MPOS(%)	Tr(sec)	Ts (sec)
1	50.8	4.11	62.2
2	53.6	3.81	58.7
3	55.9	3.59	63.6
4	48.2	3.82	48.8
5	51	3.56	53.7
6	54.2	3.25	50.3
7	45.9	3.6	45.3
8	49.5	3.25	41.7

9	51.7	3.07	46.7

5.5 ANOM

i) *Overall Mean:* The mean or average value of all results can be calculated as follows:

$$m = \frac{1}{9}\sum_{i=1}^{p} MPOS_i$$

Table 5.4 shows the mean of MPOS, Tr, and Ts.

Table 5.4: Mean of Results

	MPOS(%)	Tr(sec)	Tssec)
m (overall mean)	51.2	3.56	52.33

ii) *Average Effect of a Design Variable at One Setting:*

The MPOS of factor A at level three is calculated by

mx_3 (MPOS) =1/3 (MPOS(7)+MPOS(8)+MPOS(9))

where the factor X is set to level three only in experiments 7–9. The MPOS for all levels for all factors can be determined by a similar way. The results are given in Table:5.5. Fig.5.1 shows main factor effects on the MPOS. It can be noticed that the factor-level combination (X1, Y1,Z3) contributes to minimization of the MPOS.

Table 5.5: MPOS for All Levels of All Factors

settings of factor	MPOS of X	MPOS of Y	MPOS of Z
1	53.33	48.3	51.5

2	51.13	51.36	51.16
3	49.03	53.93	50.93

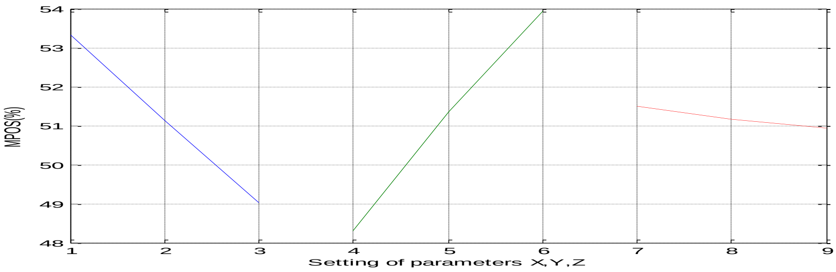

Fig 5.1: Main factors effects on the MPOS

In a similar way, Tr, Ts, and Ess can be obtained for all levels of all factors. Tables 5.6&5.7 illustrate these results. Also, Figs.5.2 &5.3 show main factor effects on Tr and Ts. It can be realized that the factor-level combination (X3, Y1, Z1) contributes to minimization of Tr and Ts,

Table:5.6 Tr for All Levels of All Factors

settings of factor	Tr of X	Tr of Y	Tr of Z
1	3.83	3.84	3.53
2	3.54	3.54	3.56
3	3.3	3.3	3.58

Table:5.7 Ts for All Levels of All Factors

settings of factor	Ts of X	Ts of Y	Ts of Z
1	61.5	52.1	51.4
2	50.93	51.3	51.4
3	44.56	53.53	54.2

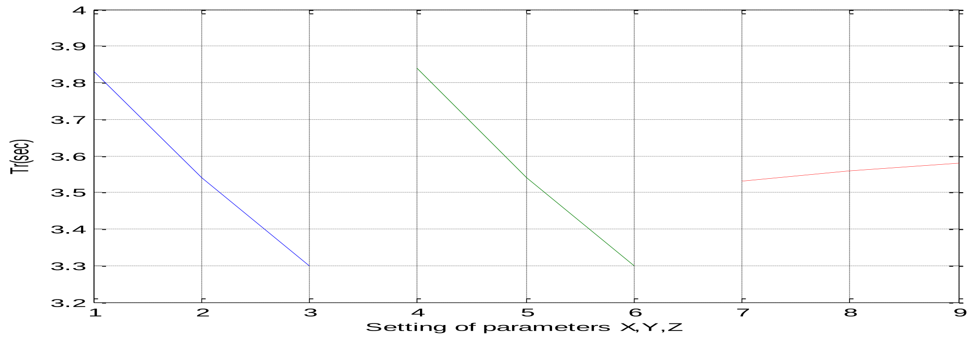

Fig:5.2 Main factors effects on the T_r

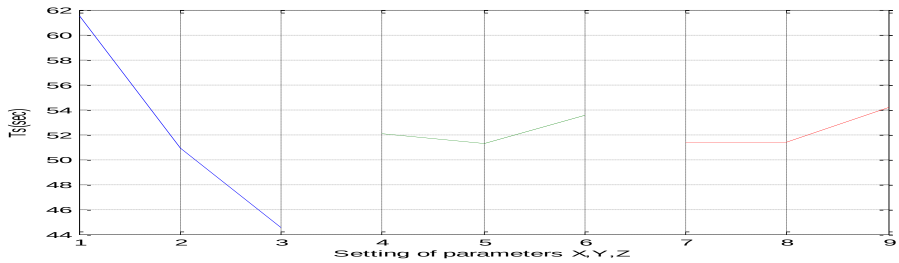

Fig:5.3 Main factors effects on the T_s

5.6 Discussion

It is noted from Tables VI–IX and Figs. 2–5 that factor Y, the integral gain, contributes to minimization of the MPOS, Tr and Ts. Therefore, Y1 is the optimal value of this factor. Also, factors X and Z are used to regulate the values of the MPOS, Tr and Ts. It can be seen that the effect of factor X, the proportional gain, on Tr, MPOS, and Ts is not comparatively large. Also, factor Z, the derivative gain, has not a great effect notably on Tr. MPOS, and Ts. Therefore, factors X and Z are the most effective and important for the dynamic response. These factors are selected for the next optimization process using GA in order to obtain their accurate optimal values. The optimal value of factor Y is fixed at obtaining by the Taguchi method. In the proposed TCGA method, the design area is decreased, and the simulation time and memory capability of GA are also reduced.

5.7 Optimisation by GA

The GA is a powerful search technique used in many engineering studies to find the solution of optimization problems. GA has widely been applied for solving optimization problems of electrical power systems. The heuristic search of GA is based on the principle of survival of the fittest Generally, GA starts the optimization process with random generation of a population, which consists of a set of chromosomes. Once the random population is achieved, the solution represented by each string should be evaluated. The fitness or objective function is the function responsible for evaluation of the solution at each step. The objective of this analysis is to minimize the MPOS of the voltage ($Y1$), $T\ r$ ($Y2$), $T\ s$ ($Y3$). The optimized model here is a multiobjective design problem. Therefore, a multiobjective GA is used in this paper. The rank fitness scaling is applied to avoid premature convergence. Moreover, GA uses techniques inspired by evolutionary biology, such as natural selection, mutation, and crossover. There are several selection techniques in GA.

Selection of Variables

In this project , the proportional gain and derivative gain of the PID controller are selected to be the design variables. $X1$ is the proportional gain and $X2$ is the derivative gain.

5.8 Simulation Results:

The proposed TCGA methodology is introduced to fine tune the PID controller parameters with an AVR system The MATLAB-Simulink model of the aircraft attitude control ystem with the PID controller is used in this paper. A step reference voltage signal of amplitude 1 pu is applied to the system. Table:5.8 Fig:5.4 shows the step response of change in the terminal voltage of the aircraft attitude control system using the PID controller. Note that the response has several fluctuations with high overshoots and larger settling time. The MPOS reduced by12.3%, the Tr reduces by 0.6 s, the Ts reduces by 17.3 s.

Table:5.8 Comparision between PID and GA-PID

parameters	PID	GA-PID
MPOS(%)	54	41.7
Tr (sec)	2.89	2.29
Ts (sec)	44.4	27.1

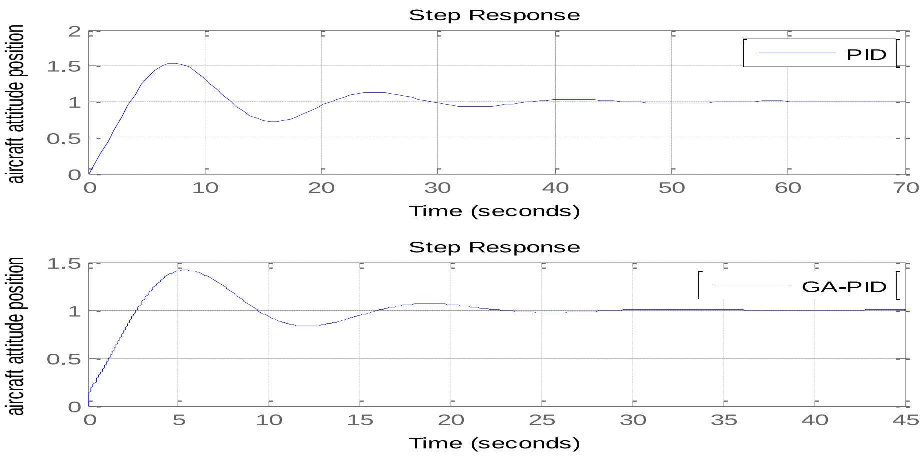

Fig:5.4 Comparison of step responses of PID with proposed method.

5.9 Conclusion

In this project, a novel Taguchi combined genetic algorithm method was presented to optimally design a PID controller in the aircraft attitude control system for improving the step response of attitude voltage. The proportional gain, the integral gain and the derivative gain were chosen to define the search space for the optimization problem. The near optimum values of the design variables were determined by the Taguchi method using analysis of means. Analysis of variance was used to select the two most influential design variables. As a result of the proposed approach, fast design and an accurate performance prediction was achieved. Therefore, when this proposed approach is applied, it is more efficient in raising the precision of optimization.

5.10 Acknowledgement

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TUNING OF PID CONTROLLER FOR AIRCRAFT ATTITUDE CONTROL SYSTEM BY TCGA METHOD

By

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ABSTRACT

The optimum design of the proportional-integral derivative (PID) controller plays an important role in achieving a satisfactory response in the aircraft attitude control system. This paper presents the optimal design of the PID controller in the aircraft attitude control system by using the Taguchi Combined Genetic Algorithm (TCGA) method. A multi objective design optimization is introduced to minimize the maximum percentage overshoot, the rise time and settling time. The proportional gain, the integral gain, the derivative gain defines the search space for the optimization problem. The approximate optimum values of the design variables are determined by the Taguchi method using analysis of means. Analysis of variance is used to select the two most influential design variables. MATLAB toolboxes are used in this paper. With this proposed TCGA method, the step response of the aircraft attitude control system can be improved.

Keywords: Aircraft Attitude Control System Optimization, Genetic Algorithm (GA), Proportional-Integral-Derivative (PID) Controller, Taguchi Method.

INTRODUCTION

In aircraft attitude control, for tuning of the controller, a brute force linearization approach was suggested along with a method based on the desired Lyapunov stability of the closed loop system [1]. A visually based horizon detection system to monitor and control the attitude of an aircraft not only to stabilize flight using UAV vision based algorithm [2]. Active centre gravity (C.G) control is a key technology of vehicle management system, which has been extensively used in various types of aircraft. With active C.G control system, aircraft may deviate flight control system [3]. The design of the Aircraft attitude control system can be carried out in either the time domain and frequency domain. Graphical tools such as bode plot, Nyquest plot, and Nicholos chart are carried out in the frequency domain. Design in time domain using performance specifications as rise time, delay time, setting time and maximum overshoot, and so on, is feasible analytically systems which are approximated for a second order system. In the Aircraft attitude control system the attitude of the aircraft is a control parameter and maintains the desired limits which can be accomplished by a PID controller in a control system [4] Many tuning algorithms are available for selection of PID parameters to achieve the time domain specifications of the control system. In this paper the author, presented one of the tuning algorithm for PID controller using genetic algorithm.

The overall transfer function of third order aircraft attitude control systems is

$$G(s) = \frac{2.718 \times 10^9}{s(s+400.26)(s+3008)} \quad (1)$$

1. Integer Order PID Controller

It is generally believed that PID controllers are the most popular controllers used in process control [5]. Because of their remarkable effectiveness and simplicity of implementation, these controllers are overwhelmingly used in industrial applications [6], and more than 90% of existing control loops involve PID controllers [7]. Since the 1940s, many methods have been proposed for tuning these controllers, but every method has brought about some disadvantages or limitations [8]. As a result, the design of PID controllers still remains a challenge before researchers and engineers.

A PID controller has the following transfer function,

$$G(c) = K_p\left(1 + \frac{K_I}{s} + K_d s\right) \quad (2)$$

2. Optimisation Tuning Algorithm

The Taguchi method was constructed based on the principle of an orthogonal array that can effectively minimize the number of design experiments required in any design process. The Taguchi method can provide an efficient way to obtain the optimal parameters in an optimization problem. In the Taguchi method, an orthogonal array that depends on the number of factors and their levels is used to study the parameters' variation effect This method has a low number of experiments. For example, if there are four factors, each at three levels, the full factorial design method requires $3^4 = 81$ experiments while the Taguchi method needs only nine experiments to obtain the approximate optimal values.

2.1 Orthogonal Array

In establishing an orthogonal array, four factors X, Y, Z are considered. X is the proportional gain, Y is the integral gain, and Z is the derivative gain. Table 1 illustrates the design variables or factors and their levels. The standard Taguchi's orthogonal array L-9 is used for this numerical experiments study, as shown in Table 2.

3. Perform the Experiment

Nine experiments, as shown in Table 2, should be carried out in order to know the dynamic response of the Aircraft attitude control system with the PID controller at combination levels of these factors. The maximum percentage overshoot (MPOS), the rise time (Tr), and the settling time (Ts) of the terminal voltage of a synchronous generator are the most important variables. To obtain the values of MPOS, Tr and Ts for each experiment, the MATLAB-Simulink model of the Aircraft system with the PID controller is used. Table 3 shows the simulation results on each experiment.

After performing the nine experiments and obtaining all experimental data, ANOM is carried out to estimate the effects of the three design parameters and to determine the relative importance of each design parameter.

3.1 ANOM

Overall Mean: The mean or average value of all results can be calculated as follows,

$$m = \frac{1}{9}\sum_{i=1}^{p} MPOS_i$$

Table 4 shows the mean of MPOS, Tr, and Ts.

Average Effect of a Design Variable at One Setting:

The MPOS of factor X at level three is calculated by

mx3(MPOS) = 1/3 (POS(7)+MPOS(8)+MPOS(9))

where the factor X is set to level three only in experiments 7-9. The MPOS for all levels for all factors can be determined by a similar way. The results are given in Table 5 and Figure 1 shows main factor effects on the MPOS. It can be noticed

Design variable	Level 1	Level 2	Level 3
X	6	7	8
Y	0.5	0.6	0.7
Z	0.2	0.25	0.3

Table 1. Design Variables and Levels

Exp. No	X	Y	Z
1	6	0.5	0.2
2	6	0.6	0.25
3	6	0.7	0.3
4	7	0.5	0.25
5	7	0.6	0.3
6	7	0.7	0.2
7	8	0.5	0.3
8	8	0.6	0.2
9	8	0.7	0.25

Table 2. Actual Values of Three Settings of Three Design Variables

Exp. No	MPOS (%)	Tr (sec)	Ts (sec)
1	50.8	4.11	62.2
2	53.6	3.81	58.7
3	55.9	3.59	63.6
4	48.2	3.82	48.8
5	51	3.56	53.7
6	54.2	3.25	50.3
7	45.9	3.6	45.3
8	49.5	3.25	41.7
9	51.7	3.07	46.7

Table 3. Results of Dynamic Response Analysis

	MPOS (%)	Tr (sec)	Ts (sec)
m (overall mean)	51.2	3.56	52.33

Table 4. Mean of Results

that the factor-level combination (X1, Y1, Z3) contributes to minimization of the MPOS.

3.2 MPOS

In a similar way, Tr , Ts, and Ess can be obtained for all levels of all factors. Tables 6 and 7 illustrate these results. Also, Figures 2 and 3 show main factor effects on Tr and Ts. It can be realized that the factor-level combination (X3, Y1, Z1) contributes to minimization of Tr and Ts.

4. Discussion

It is noted from Tables 5-7 and Figures1-3 that factor Y, the integral gain, contributes to minimization of the MPOS, Tr and Ts. Therefore, Y1 is the optimal value of this factor. Also, factors X and Z are used to regulate the values of the MPOS, Tr and Ts. It can be seen that the effect of factor X, the proportional gain, on Tr , MPOS, and T s is not comparatively large. Also, factor Z, the derivative gain, has not a great effect notably on Tr. MPOS, and T s. Therefore, factors X and Z are the most effective and important for the dynamic response. These factors are selected for the next optimization process using GA in order to obtain their accurate optimal values. The optimal value of factor Y is fixed at obtaining by the Taguchi method. In the proposed TCGA method, the design area is decreased, and the simulation time and memory capability of GA are also reduced.

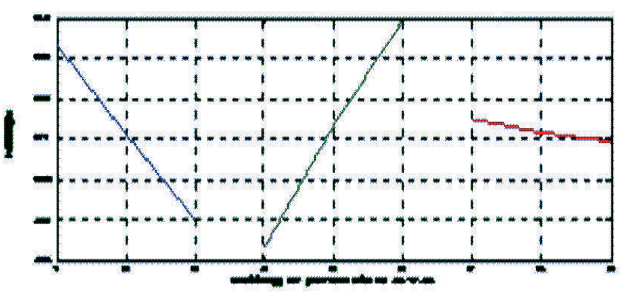

Figure 1. Main Factors Effects on the

Settings of Factor	MPOS of X	MPOS of Y	MPOS of Z
1	53.33	48.3	51.5
2	51.13	51.36	51.16
3	49.03	53.93	50.93

Table 5. MPOS for all Levels of all Factors

Settings of Factor	Tr of X	Tr of Y	Tr of Z
1	3.83	3.84	3.53
2	3.54	3.54	3.56
3	3.3	3.3	3.58

Table 6. Tr for all Levels of all Factors

Settings of Factor	Ts of X	Ts of Y	Ts of Z
1	61.5	52.1	51.4
2	50.93	51.3	51.4
3	44.56	53.53	54.2

Table 7. Ts for all Levels of all Factors

5. Optimisation by GA

The GA is a powerful search technique used in many engineering studies to find the solution of optimization problems. GA has widely been applied for solving optimization problems of electrical power systems. The heuristic search of GA is based on the principle of survival of the fittest Generally, GA starts the optimization process with random generation of a population, which consists of a set of chromosomes. Once the random population is achieved, the solution represented by each string should be evaluated. The fitness or objective function is the function responsible for evaluation of the solution at each step. The objective of this analysis is to minimize the MPOS of the voltage (Y1), Tr (Y2), Ts (Y3). The optimized model here is a multiobjective design problem. Therefore, a multiobjective GA is used in this paper. The rank fitness scaling is applied to avoid premature convergence. Moreover, GA uses techniques inspired by evolutionary biology, such as natural selection, mutation, and crossover. There are several selection techniques in GA.

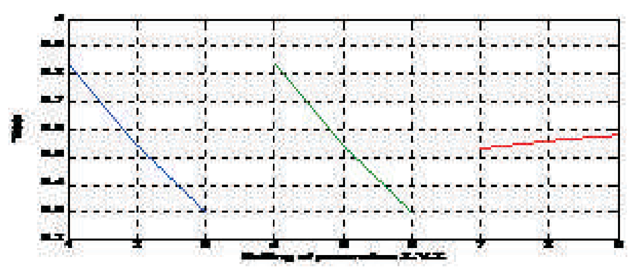

Figure 2. Main Factors Effects on the T_r

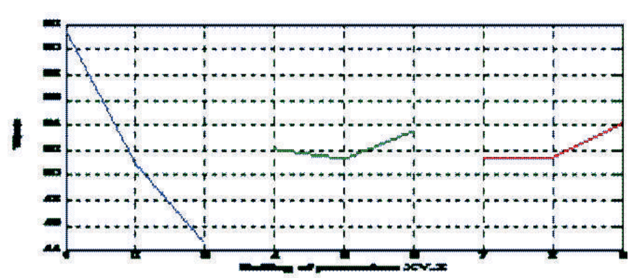

Figure 3. Main Factors Effects on the T_s

5.1 Selection of Variables

In this project, the proportional gain and derivative gain of the PID controller are selected to be the design variables. X1 is the proportional gain and X2 is the derivative gain.

6. Simulation Results

The proposed TCGA methodology is introduced to fine tune the PID controller parameters with an AVR system The MATLAB-Simulink model of the aircraft attitude control system with the PID controller is used in this paper. A step reference voltage signal of amplitude 1 pu is applied to the system. Table 8 Figure 4 shows the step response of change in the terminal voltage of the aircraft attitude control system using the PID controller. Note that the response has several fluctuations with high overshoots and larger settling time. The MPOS reduced by 12.3%, the Tr reduces by 0.6 s, the Ts reduces by 17.3 s.

Conclusion

In this project, a novel Taguchi combined genetic algorithm method was presented to optimally design a PID controller in the aircraft attitude control system for improving the step response of attitude voltage. The proportional gain, the integral gain and the derivative gain were chosen to define the search space for the optimization problem. The near optimum values of the design variables were determined by the Taguchi method using analysis of means. Analysis of variance was used to select the two most influential design variables. As a result of the proposed approach, fast design and an accurate performance prediction were achieved. Therefore, when this proposed approach is applied, it is more efficient in raising the precision of optimization.

Parameters	PID	GA-PID
MPOS (%)	54	41.7
Tr (sec)	2.89	2.29
Ts (sec)	44.4	27.1

Table 8. Comparision between PID and GA-PID

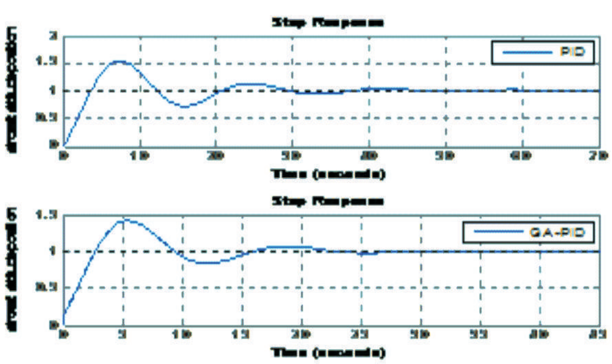

Figure 4. Comparison of step responses of PID with Proposed Method.

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