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Pressure Control of Steel-Ball Boring Bar Using Optimized PID Controller through Genetic Algorithm

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ABSTRACT:- *In order to overcome the self-excited vibrations in internal turning (chatter) a new design for boring bar, which depends on using steel-balls to support boring bar system* ***[1]****. The steel balls system increases the stiffness's of both boring bar and workpiece. The pressure of the pressurized oil used in this system has a noticed effect on the self-excited vibrations.*

In the present paper, a gear pump driven by a DC motor system is designed to control the pressure. The oil of this system is pumped to the boring bar with low pressure to decrease the tendency of the system to chatter. The pump-motor system model was created in MATLAB/ SIMULINK simulation and then PID controller parameters designed to control the pressurized oil for keeping it less or equal 4 bars to save these lf-excited vibrations within the desired limits. *The PID parameters were optimized by the Genetic Algorithm (GA). The algorithm gave the desired pressure in a noticed small time.*

Keywords: *Boring bar – Oil pressure – PID controller - GA*

I. INTRODUCTION

Machining self-exited vibration (chatter) **[2]** is one of the major constraints that limit productivity of the turning process. It is a self-excited vibration that is mainly depends on interaction between the machine-tool/workpiece structure and the cutting process dynamics. Chatter is resulted from dynamic instability of the cutting process **[3].**

Chatter reduction is achieved by some methodologies. Sliding mode control methodology was used to control the DC motor of drive system **[4]**. When the drive system is too fast to the response of the chatter mechanism then several controllers with feedback sensors could work effectively. These include PI (Proportional-Integral), PID (Proportional-integral-derivative), PDF (Pseudo Derivative Feedback), and LQR (linear Quadratic Regulator) controllers when the effects of an additional drive corrector are included, PDF and PI controllers are among the best systems **[5]**.

PID controller is one of the most adopted controllers in the industry due to its suitable cost and the good performance for industry. The speed control of DC motor is a common application of the PID controller **[6]**. In this research, the controller was designed and simulated using MATLAB to analyze their performance. The PID controller gives desired outputs, velocity, temperature, and position in a short time, with minimal overshoot, and with acceptable error.

PID controller has wide applications in hydraulic pump control such as regulating flow or pressure **[7]**. In this application, the PID controller has a set-point as the desired value of flow or pressure. The controller output signal regulates the desired value according to the deviation between the desired value and real value, which grasped via feedback system. This deviation is due to environment effects and/or modeling inaccuracies.

Genetic algorithm (GA) is mainly an optimization algorithm. This algorithm is based on simulation of learning, which behavior of the processes of evolution in nature **[8]**. It solves both constrained and unconstrained optimization problems based on a natural selection process that mimics biological evolution. The algorithm repeatedly modifies a population of individual solutions. At every step, the genetic algorithm randomly selects individuals from the current population and uses them as parents to produce the children for the next generation **[9].**

In the current research, a pressurized oil system is designed to be applied to steel-ball boring bar system. It contains a gear pump, which is driven by a DC motor. A PID controller is developed to maintain the pressure in the system within the desired limits. This is achieved by controlling the speed of the driving DC motor. GA is used for tuning the PID controller by generating parameters.

II. STEEL-BALLS BORING BAR SYSTEM

The steel-balls boring bar system is a novel designed boring bar system **[1].** It designed to decrease the chatter vibration by increasing the boring bar stiffness. Its theory is based on converting the boring bar fixation system from fixed-free to fixed-roller system.

It is done by using a wedge with circumferentially three spherical steel balls as shown in **Figure 1**. The balls are in contact with both the workpiece and the boring bar to transfer the reaction from the flexible boring bar to the more rigid workpiece.

When the pressurized oil is pumped to boring bar system through the oil inlet, the pressing wedge is derived. Accordingly the wedge forces the balls against the workpiece internal surface due to its tapered wedge shape. When the cutting process is finished, the pressure of the inlet oil is relieved and the wedge moves backwards by the action of the return spring.

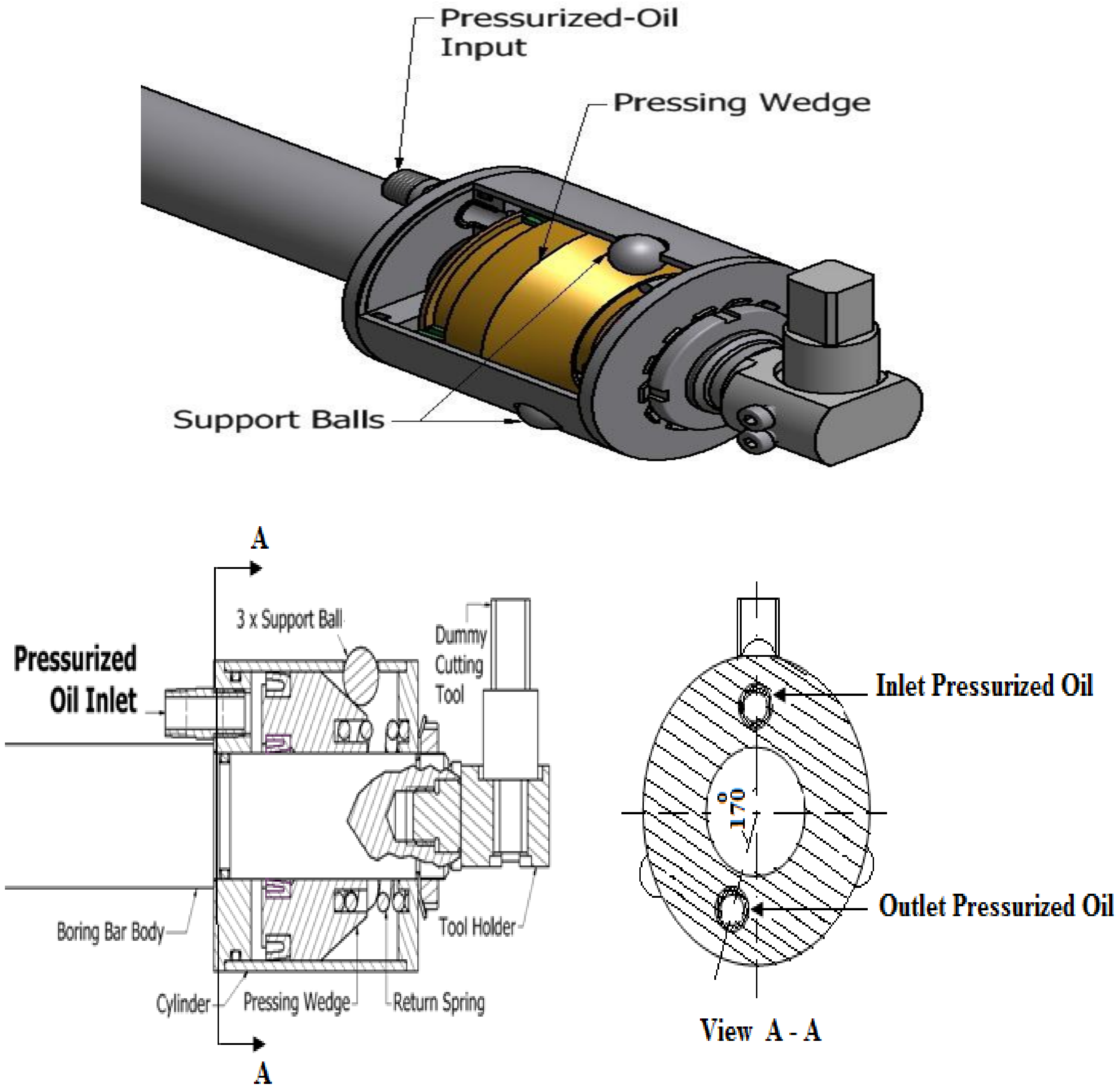

Figure 1: Steel-Balls Boring Bar System

III. SIMULATION MODEL

The simulation model for the pressurized oil system is shown in **Figure 2**. It consists of a DC motor coupled with a gear pump. The gear pump is connected with the boring bar through two openings, inlet and outlet, to move the steel balls during cutting process. The motor and pump parameters **[10, 11]** used in the cycle are shown in **Table 1.**

Table 1: DC Motor and Oil Gear Pump Parameters

Parameter	Value
Armature resistance = R_a	7.31 Ω
Armature inductance = L_a	0.831 mH
Back EMF constant = K_e	0.0195 Vs/rad
Torque constant = K_b	0.044 Nm/A
Rotor inertia = J	9.87e-6 kg.m^2
Friction coefficient = B	1.42e-6 Nm s/rad
Motor volt = V_a	*24 volt*
Motor current = i_a	*4 A*
Motor power = P_m	*52 watt*
Motor Torque = T_m	*0.1834 Nm*
Motor speed = N_m	*3200 r.p.m*
Pump oil pressure = P_p	*4 bar*
Pump oil head = H_p	*0.4m*
Pump oil flow rate = q_p	*4 cm^3 /s*
Pump Efficiency = η	87%
Pump torque = T_p	*0.0984 Nm*
Density of oil = ρ	*900 kg/m^3*
Steady state time = t	*15 min*

The oil cycle starts with the start of the cutting process where the pump suctions the oil from the oil-tank to inject it into the boring bar through small diameter flexible hoses. After the cutting process finished, the oil gets out from the boring bar back to the oil-tank. Therefore, the oil pressure through the pump should be coupled with the motor to be controlled by changing the applied voltage to the motor.

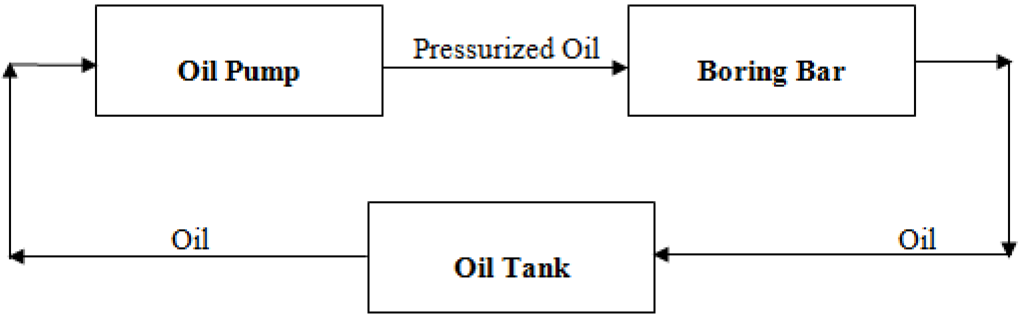

Figure 2: Pressurized Oil Cycle

IV. IMPLEMENTED CONTRL STRATEGY

In order to keep the pressure of the oil within the required range of pressure, a proportional-integral-derivative (PID) controller is proposed. It continuously calculates the error value as the difference between the pressure value and the desired set point **[12, 13]**.

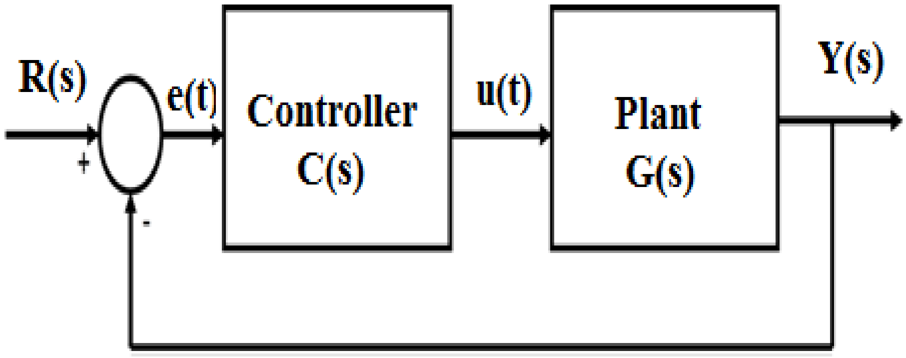

Figure 3: Block Diagram for Feedback Control System

As show in **Figure 3**, the variable e(t) denotes the tracking error, which is sent to the (PID) controller. The control signal u(t) from the controller to the plant is equal to the proportional gain (K_p) times the magnitude of the error plus the integral gain (K_i) times the integral of the error plus the derivative gain (K_d) times the derivative of the error.

e(t) = error = Set point - Process variable (1)

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

Where;

e(t); t is instantaneous time.

e(τ); τ is the variable of integration, it takes on values from time 0 to the present *t*.

K_p ; is the Proportional gain

K_i ; is the Integral gain and

K_d ; is the Derivative gain

The transfer function of the most basic form of PID controller,

$$C(s) = K_p + \frac{K_i}{S} + K_d\, S = \frac{K_d\, S^2 + K_p\, S + K_i}{S} \quad (3)$$

PID tuning **[14]** is adjustment of control parameters (K_p, K_i, and K_d) to the optimum values for the desired control response. There are a number of methods for loop tuning, like manual tuning method, Ziegler–Nichols tuning method, and artificial intelligence methods. For the dynamic plants, which its parameters are constantly changing like the pump–motor system, it is required to do retuning in real time. The artificial intelligence tuning methods such as genetic algorithm tuning (GA) is suitable in this case.

For optimization of the PID controller parameters, the genetic algorithm starts without reference for the correct solution and depends entirely on the responses from its environment and evolution operators such as reproduction, crossover and mutation to arrive at the best solution **[15]**.

GA algorithm starts with a randomly generated population of chromosomes (values of K_p, K_d, and K_i) **[16]**. Then, the population size (number of roots closer to the required root those are K_p, K_d, and K_i) is created. The roots (K_p, K_d, and K_i) are selected as the initial values of the roots required. The selection method, which is called normalized geometric selection, is applied so that any random value can be selected. Selection is based on the fitness value of the root. Reproduction of the selected roots (K_p, K_d, and K_i) is done to get optimized solution. A crossover called arithmetic crossover and uniform mutation are performed to alter the roots to get an optimized root (K_p, K_d, and K_i). After that the fitness f(x) are calculated. The fitness is done using fitness function/ performance index of each root (K_p, K_d, and K_i) in the population. And then, these steps repeat the offspring, which have been created. The fitness function are used to finds the value of the error in the generation, and choose the roots, which having the highest fitness value. Finally they obtained roots are the final values of K_p, K_d, and K_i. Based on these sequences the flowchart for GA is as shown in **Figure 4**.

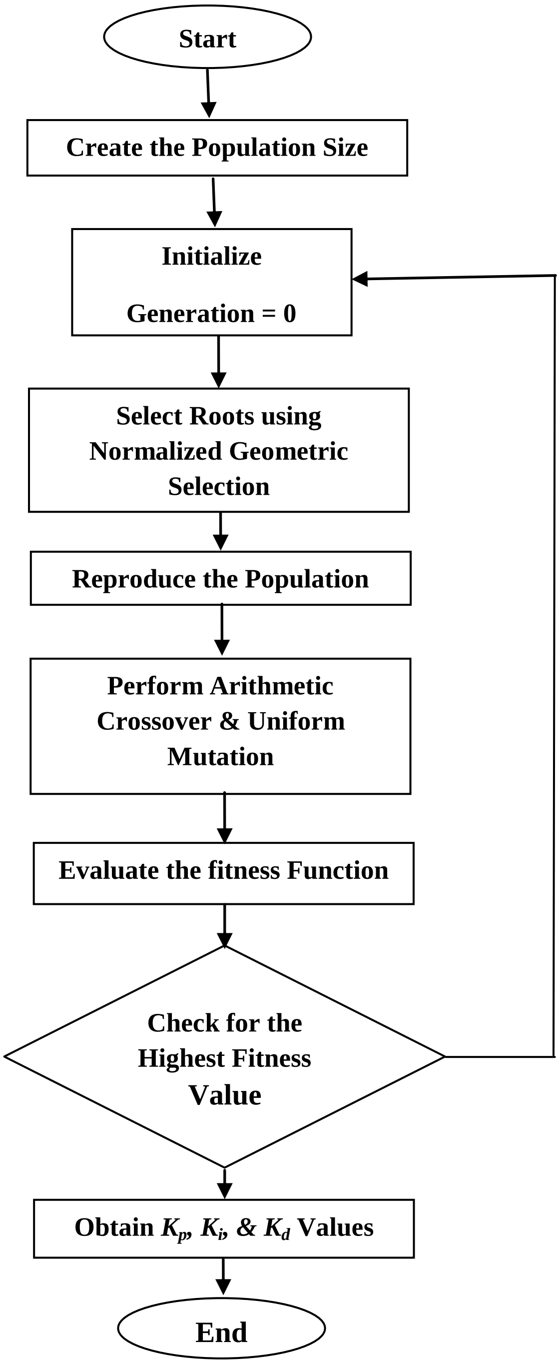

Figure 4: Flow Chart for GA

In the present research, the Genetic Algorithm Toolbox of MATLAB is used **[17]**. The first and the most crucial step is the encoding of the problem into suitable GA chromosomes and then constructing the population. Each chromosome comprises of three parameters, K_p, K_i, and K_d, with value bounds varying depending on the delay and objective functions used.

The fitness function is a particular type of objective function that is used to summarize, as a single figure of merit, how close a given design solution is to achieving the set aims **[18]**. In this work the Integral Time Absolute Error (ITAE) is used as fitness function.

IV.I. DC Motor

The dynamic behavior of a DC motor **[19]** can be split into electrical (4) and mechanical (5) parts. Both parts can be modelled by differential equations (4, 5) which are interconnected by torque (6) and back EMF constant (7).

$$V_a = i_a R_a + L_a \frac{di_a}{dt} + e_b \qquad (4)$$

$$T_m = B\,\omega + J\,\frac{d\omega}{dt} + T_p \qquad (5)$$

$$T_m = K_b\ i \qquad (6)$$

$$e_{b=} k_e\ \omega \qquad (7)$$

IV.II. Oil Pump

The dynamic behavior of the oil gear pump **[20]** can be modelled by differential equations explaining its power, and torque (8, 9).

$$P_m = \frac{P_p q_p}{\eta_p} \qquad (8)$$

$$T_p = \frac{P_m}{2\pi N_m} \qquad (9)$$

IV.III. Implementation of GA Based PID Controller

The block diagram simulating the oil gear pump and DC system is shown in **Figure 5**. The GA parameters are given in **Table 2.**They is used to adjust the PID controller K_p, K_i, and K_d values. ,The error criteria is the ITAE fitness function

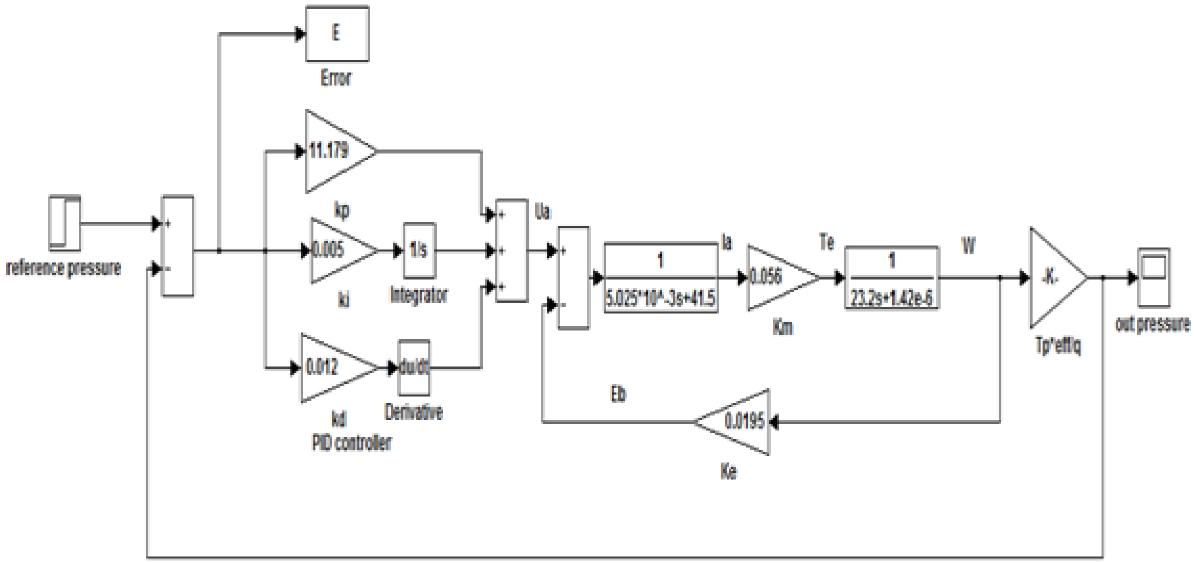

Figure 5: Block Diagram of Oil Pump DC Motor to Adjust PID Controller Parameters via GA

Table 2: Parameters of GA

GA Parameters	Values and Methods
Population Size	100
Variable bounds [K_p, K_i, K_d]	Open range
Maximum number of generations	30
Perform Index/Fitness function	Integral Time Absolute Error
Selection method	Default of MATLAB
Crossover method	Default of MATLAB
Mutation method	Default of MATLAB

V. RESULTS

The step response of the system with GA tuned PID controller is shown in **Figure 6**. The desired pressure of oil pumping to the boring bar is got around 0.5 s.

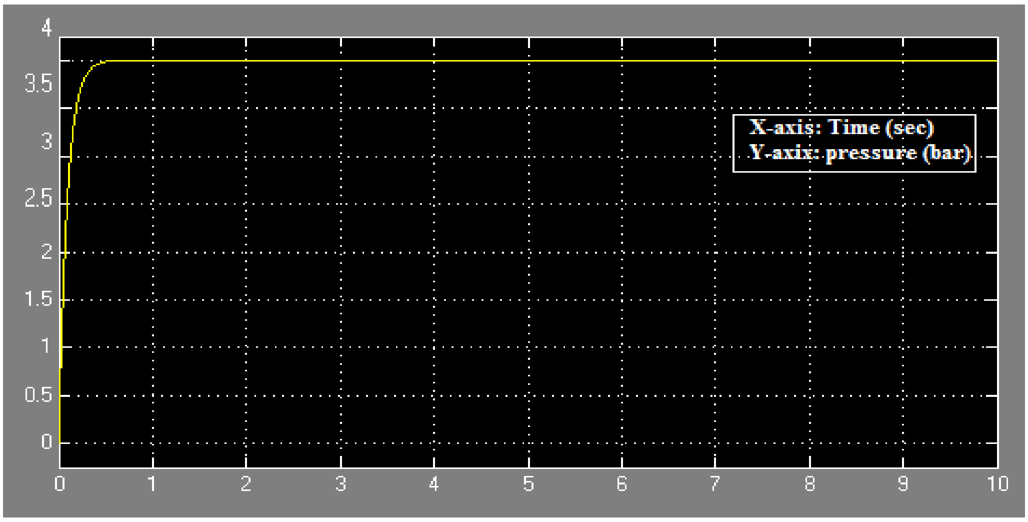

Figure 6: The Optimized Oil Pressure

As shown in **Figure 7,** the used objective function (fitness function) with GA is the integral Time Absolute Error (ITAE), which its values appear in Y-axis and number of generations shown in X-axis. It is used to optimize the rise time, and the PID controller parameters.

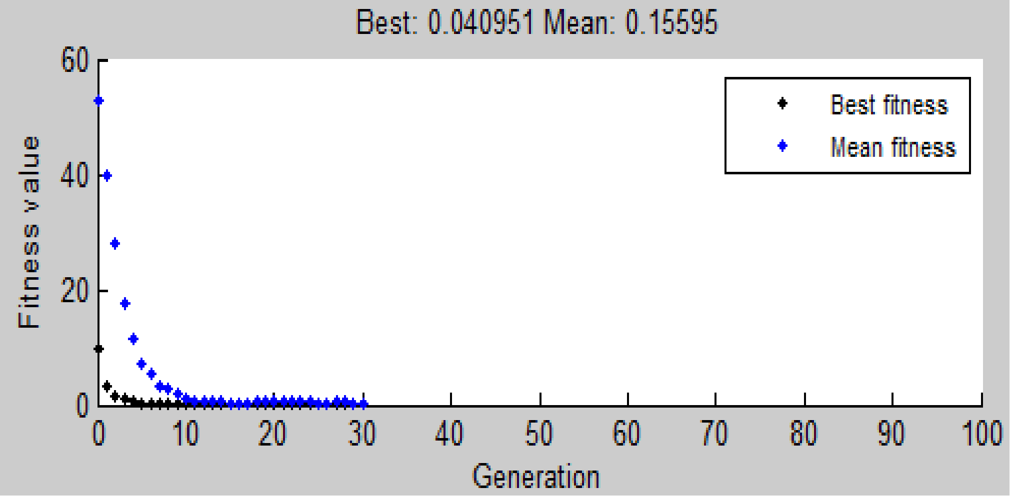

Figure 7: ITAE Value against Tuning Method

X-axis in **Figure 8,** represented the PID controller parameters (K_p, K_i, and K_d)**.** Maximum number of generations (current best individual) appeared at Y-axis.

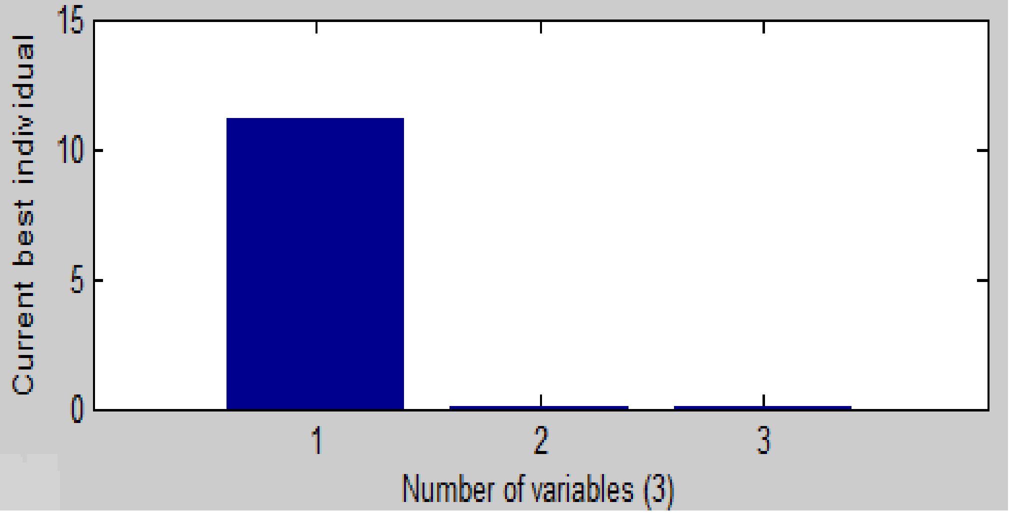

Figure 8: PID Controllers Parameters [K_p, K_i, K_d]

VI. CONCLUSIONS

Gear pump-DC motor system is designed to pump oil with desired pressure. In order to achieve this oil pressure in short time, a PID controller is designed with the GA tuning method. As a result of the using of the PID controller, the pressure arrived to 4 bar in approximately 0.5 sec. Short arrival time is due to the using of GA in tuning with ITAE fitness function. The GA helps in the determination of PID controller gains and its absolute values after small generations.

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