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An Improved Model for Jet Engine Fuel Control System Using Genetic Algorithm and Particle Swarm Optimization

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ABSTRACT

Today the most important issue in the jet airplanes flights is the security and optimal use of fuel. In this paper at the first simulate the fuel control system of a jet engine using an appropriate mathematical model. This model is a nonlinear model evaluate with a criteria that named the best compatibility and compared with another model which is linear. This criteria proves that nonlinear model have better accuracy. Then using intelligent algorithms like Genetic Algorithm and Particle swarm optimization (PSO) and with the aid of MATLAB design a PID controller for this model. Finally compare the designed controller with formers controller and the basic system with the help of data that results from Simulink. The compares prove that controller which used in this paper have better response in comparison with past controllers. We compared step unit response of the systems. Some parameters like rise time, setteling time, overshoot compared in this paper. The results prove an acceptable advantage of this controller than the formers.

Keywords: *jet engine, fuel control system, genetic algorithm, PSO*

1. INTRODUCTION

Gas turbine engines are constituted of a complex system. Their desired performance can guarantee the aircraft flight safety. This performance is impressed by some engine input controlling functions which are changing with the development of engines. Finding these functions can be a great success in jet engine control issue [1, 2]. Fuel control system is one of the most important units of a turbojet engine. This system must control the operation of engine and keep it on best condition and prevent to close to the dangerous work conditions. Jet engine fuel control constituted of fuel control unit (FCU) and electronic control unit (ECU). ECU is an electronic system which export servo command with collecting and processing rotational shaft speed and pilot command. FCU is an electrohydraulic system which determine the amount of entering fuel to the combustion chamber using servo amount and jet engine shaft speed. While the traditional control techniques for aero-engines are time-tested and reliable, modern control techniques promise to provide improved control and therefore improved aircraft propulsion system performance [3, 4]. The process of design and construct the fuel control system has been started from 5 decades ago and today is in the automation phase. For improve and optimize the designed controller we need an accurate model of jet engine components like fuel control unit. Considering lack of accurate information about some important input and output parameters of transient state in FCU modelling and also complicated terms in system it is so hard to find an accurate model for it even if we find a model it has not acceptable accuracy. To overcome this problem many methods are purposed. For example in [3] used system identification method for modeling fuel control unit. System identification is one of the most popular methods to model systems which have not enough information from their behavior. For the method used in this paper we gain the model by using sets of measured data from input and output and choose a suitable structure for modeling. First we must use simple and linear structures and if the model is not accurate then use more complicated and nonlinear models. One of the most important units in jet engine is fuel control unit. An accurate control of fuel control system can guarantees improved operation of engine. So it is necessary to study more in this field. In this paper we investigate and research about jet engine fuel control system. The model we used in this paper obtained from [3] which works on system identification of FCU. For improved control of system we used intelligent algorithms like GA and PSO. We define goal function of our problemas time and frequency parameters of unit response of fuel control system which used with weight coefficients in solution. The most important duty of these two algorithms we used is finding the best coefficients of the controller since the minimum goal function.

2. JET ENGINE FUEL CONTROL UNIT

A jet engine normally controlled with a control lever by pilot who observe and check special signs displays on pilot's monitor. The main duty of this lever that calls control lever is choosing flow rate of fuel consequently best rate of engine spin since a suitable thrust generated. There are many indicators on pilot's monitor but some of them are more important and usually common in all planes [4, 5]. Thrust meter: this indicator may show measured pressure of output gas from the engine or may show the respect between gas pressure in output nozzle and input air pressure in engine. Torque meter: this indicator normally shows the power of turboprops. Engine torque has a respect with engine power that makes airscrew to rotate. Engine rate indicator: for showing speed rate of engine it's common to use a small generator that rotate with engine. Due to this rotation, generator generates a specific current proportional with speed of engine. Output gas temperature indicator: it is necessary to know the temperature of output gas in every working motor. In jet engine normally used a thermocouple for this measurement. There are many different indicators on pilot's monitor. All of them measure and show a parameter that is so vital for a flight. All of these parameters can be a control parameter for improve jet engine operation. One of the most important units in jet engine is fuel control unit. FCU must control engine operation and keep it in best condition and prevent closing to dangerous work conditions. Jet engine fuel control constituted of fuel control unit (FCU) and electronic control unit (ECU). ECU is an electronic system which export servo command with collecting and processing rotational shaft speed and pilot command. FCU is an electrohydraulic system which determine the amount of entering fuel to the combustion chamber using servo amount and jet engine shaft speed.

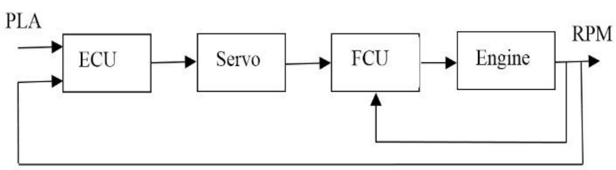

Fig1. A simple schematic of jet engine system

As we said before, fuel control unit one of the most complicated units in every jet engine and usually called the brain of engine. Since high reliability it is common to use hydro mechanical fuel control systems. But because of very high cost of them due to large amount of elements of processor unit, in applications like remotely pilot vehicle which don't need very high reliability than airliners or fighter ones use electrohydraulic fuel control units that much cheaper in cost. The most important reason of low cost of this type of controller is eliminating the mechanical computing part and replace it with electronic circuits [6, 7]. For a fuel control unit it is so desirable to keep pressure between two ends of fuel control valve equal and minimize the variety of this difference. In [8] fuel control electrohydraulic design optimization presents. To aim this goal three goal functions considered. 1. Minimize the pressure difference between two terminals of fuel control valve. 2. Minimize the sensitivity of fuel flow adjustment system output due to possible changes in system parameters. 3. Increase the speed of dynamic response of system. Schematic of system used in this paper shows in fig2. In this system fuel pumps in a filter through a fuel pump which rotate by main shaft of engine. The filter prevent to enter any fuel or air pollution into combustion chamber. Next, fuel enter to fuel flow control valve which rotate by stepper motor. To keep constant the pressure difference between two terminals of fuel control valve use a spool control valve. The valve provide necessary fuel flow in low rate fuel with make the minimum pressure. At the end there is fuel nozzle [9].

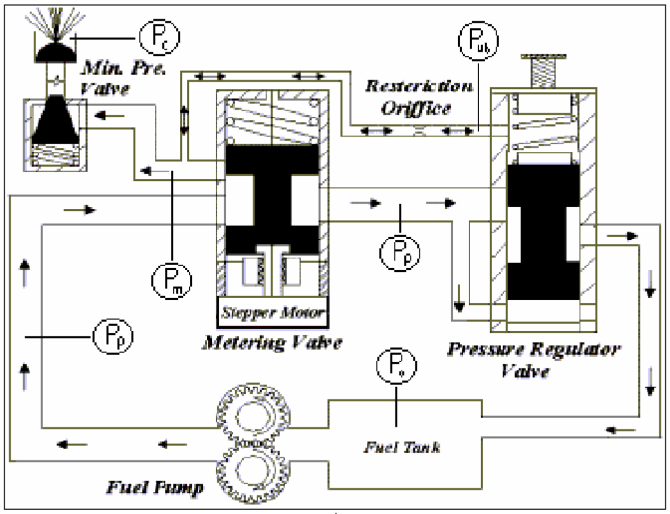

Fig2.Schematic of fuel control unit used in this paper

3. CONTROLLER DESIGN USING INTELLIGENT ALGORITHMS

For optimize the model we used in this paper, we use two intelligent algorithms. Genetic algorithm and particle swarm optimization (PSO) are these two methods. First we describe these two algorithms briefly, then explain application of these two in our controller design. Genetic algorithm: genetic algorithms are a family of computational models inspired by evolution. These algorithms encode a potential solution to a specific problem on a simple chromosome-like data structure and apply recombination operators to these structures so as to preserve critical information. Genetic algorithms are often viewed as function optimizers, although the range of problems to which genetic algorithms have been applied is quiet broad. An implementation of a genetic algorithm begins with a population of (typically random) chromosomes. One then evaluates these structures and allocate reproductive opportunities in such a way that those chromosomes which represent a better solution to the target problem are given more chances reproduce that those chromosomes which are poorer solutions. The goodness of a solution is typically defined with respect to the current population. In a broader usage of the term, a genetic algorithm is any population based model that use selection and

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recombination operators to generates new sample points in a search space. Many genetic algorithm models have been introduced by researchers largely working from an experimental perspective. Many of these researchers are application oriented and are typically interested in genetic algorithms as optimization tools [10]. Particle Swarm Optimization: Particle swarm optimization (PSO) is a population based stochastic optimization technique developed by Dr. Eberhart and Dr. Kennedy in 1995, inspired by social behavior of bird flocking or fish schooling.PSO shares many similarities with evolutionary computation techniques such as Genetic Algorithms (GA). The system is initialized with a population of random solutions and searches for optima by updating generations. However, unlike GA, PSO has no evolution operators such as crossover and mutation. In PSO, the potential solutions, called particles, fly through the problem space by following the current optimum particles. The detailed information will be given in following sections. Compared to GA, the advantages of PSO are that PSO is easy to implement and there are few parameters to adjust. PSO has been successfully applied in many areas: function optimization, artificial neural network training, fuzzy system control, and other areas where GA can be applied.As stated before, PSO simulates the behaviors of bird flocking. Suppose the following scenario: a group of birds are randomly searching food in an area. There is only one piece of food in the area being searched. All the birds do not know where the food is. But they know how far the food is in each iteration. So what's the best strategy to find the food? The effective one is to follow the bird which is nearest to the food. PSO learned from the scenario and used it to solve the optimization problems. In PSO, each single solution is a "bird" in the search space. We call it "particle". All of particles have fitness values which are evaluated by the fitness function to be optimized, and have velocities which direct the flying of the particles. The particles fly through the problem space by following the current optimum particles. PSO is initialized with a group of random particles (solutions) and then searches for optima by updating generations. In every iteration, each particle is updated by following two "best" values. The first one is the best solution (fitness) it has achieved so far. (The fitness value is also stored.) This value is called pbest. Another "best" value that is tracked by the particle swarm optimizer is the best value, obtained so far by any particle in the population. This best value is a global best and called gbest. When a particle takes part of the population as its topological neighbors, the best value is a local best and is called lbest.Comparisons between Genetic Algorithm and PSO: Most of evolutionary techniques have the following procedure:1. Random generation of an initial population2. Reckoning of a fitness value for each subject. It will directly depend on the distance to the optimum. 3. Reproduction of the population based on fitness values. 4. If requirements are met, then stop. Otherwise go back to 2 [11].As we said before, these two algorithms have many things in common and both of them can apply in many problems. Problems which need to improve and optimize one generation of a solution are one of them. In this paper we want to design a PID controller, so the coefficients of controller are our solution. And optimize them is our final destination. So we can use these two algorithms to find the best answer. We can use many goal functions to solve this problem. Like linearity index, sensitivity index and integral of time weighted absolute error (ITAE).If we want study on effect of design parameters on these three indices, we see the changes of linearity index and sensitivity index under the changes of design parameters (spool stiffness and spool constant in here) are vice versa. It means with increasing the spring stiffness, linearity decrease and sensitivity increases. And also with increasing spring stiffness and spring constant simultaneously cause improve (decrease) of ITAE. In this case usually say goal functions are compete with each other, so simultaneous optimizing are very complicated. These changes of indices shows in fig3.

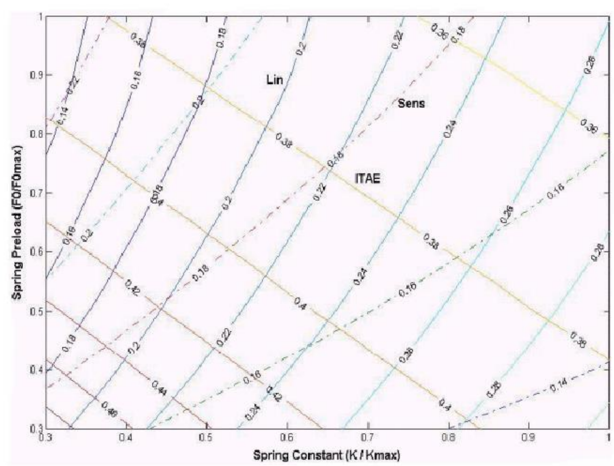

Fig3.Effect of design parameters on ITAE, Sens, Lin indices

We can express our problem in this form:

Minimize F(x) = [LIN(x), SENS(x), and ITAE (x)]

$15.5<F0<50$, $150<K<50000$

This problem has three goal functions and two conditions which shows operation limitations. To solve this problem we use two methods. Global criteria method and Goal attainment method are these two. Results of Goal Attainment method shows in table1. As we see, with changing the weight of functions we have different answers which all of them are optimal solutions. Choose the best answer is depend on designer’s opinion and knowledge about the problem.

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Table1. Goal Attainment Results with using Different Weights

weight	Optimum [f0,k]	Minimum objective vector [lin, sens, ITAE]
[0.2,0.2,0.6]	[24.2,14065]	[0.1632,0.1958,0.4076]
[0.2,0.4,04]	[30.1, 12500]	[0.1401,0.2122,0.3972]
[0.2,0.6,02]	[32.9, 11750]	[0.1295,0.2196,0.4098]
[0.2,0.8,0.0]	[36.1,11725]	[0.1235,0.2245,0.3870]
[0.4,0.2,0.4]	[17.7,15525]	[0.1883,0.1771,0.3950]
[0.4,0.4,0.2]	[24.1,14030]	[0.1632,0.1958,0.4077]
[0.4,0.6,0.0]	[28.1,13260]	[0.1492,0.2061,0.3965]

We can see the pump and fuel control valve pressure differences with optimal and non-optimal parameters in fig4.

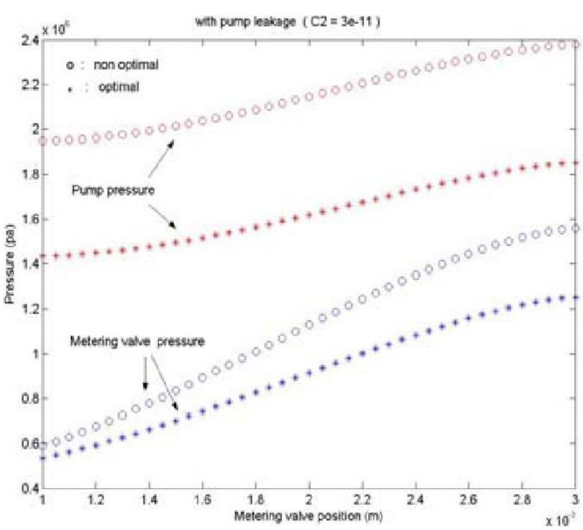

Fig4.Pump and fuel control valve pressure with optimal and non-optimal values.

Improve of pressure difference between two end of fuel control valve with optimal and non-optimal values shows in fig5.

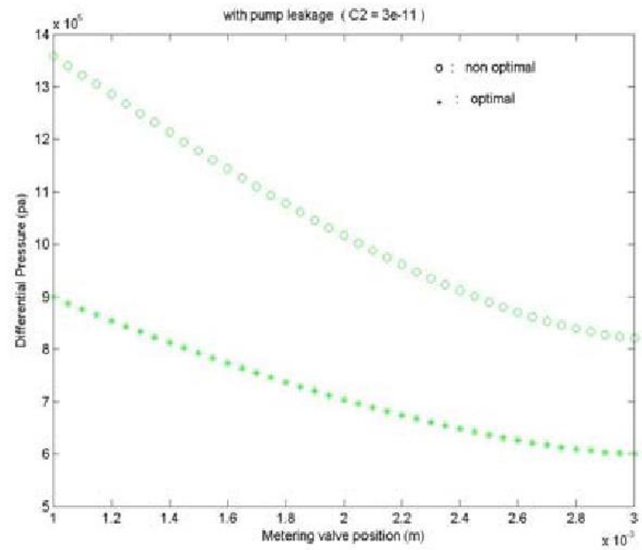

Fig5.pressure difference between two end of fuel control valve with optimal and non-optimal values.

Improve of rate of fuel passed from pump, fuel control valve, pressure control valve foroptimized parameters shows in fig6.

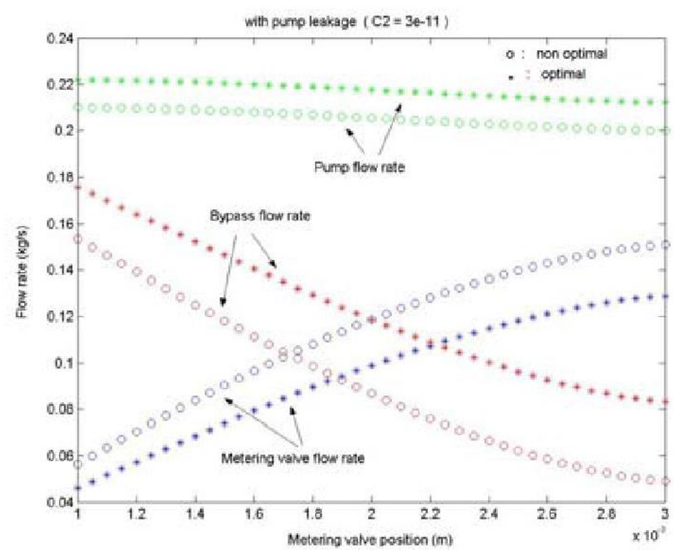

Fig 6. rate of fuel passed from pump, fuel control valve, pressure control valve with optimal and non-optimal

Improve transient pressure after fuel pump with optimal values shows in fig7.

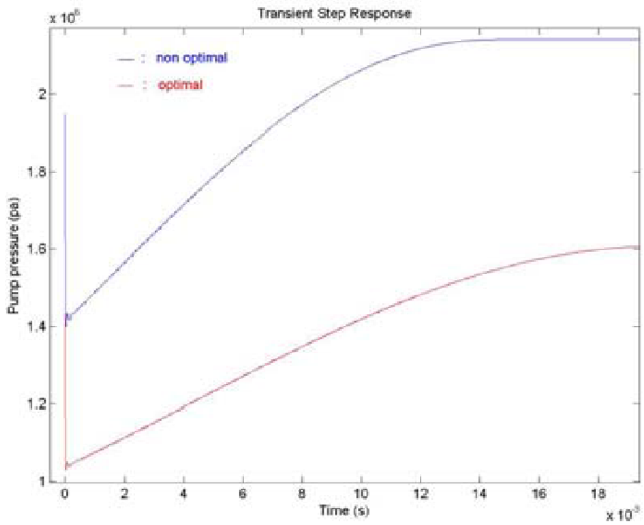

Fig7. Transient pressure after pump with optimal and non-optimal values

Comparison of transient pressure after flow rate control valve with optimal and non-optimal values shows in fig8. Then comparison between Flow rate passed from flow rate control valve with optimal and non-optimal values shows in fig9.

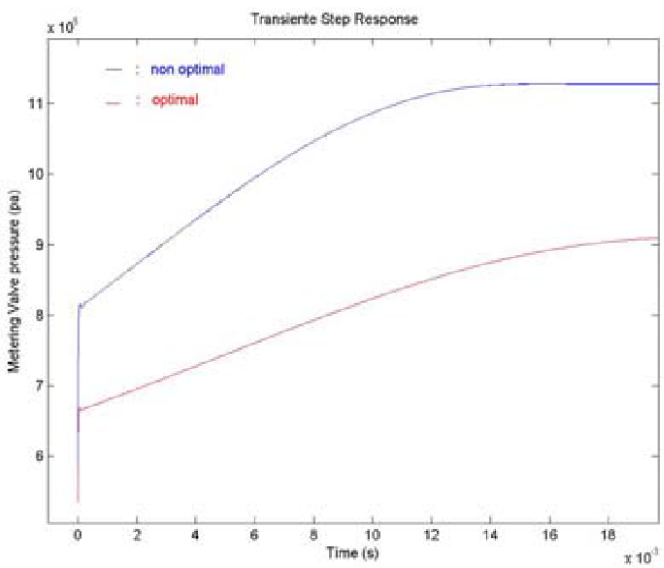

Fig8. Transient pressure after flow rate control valve with optimal and non-optimal values.

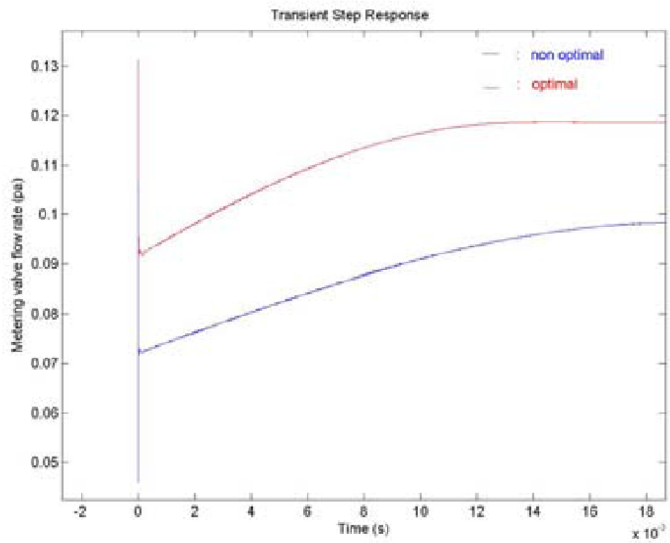

Fig9. Flow rate passed from flow rate control valve with optimal and non-optimal values

4. PID DESIGN USING GA AND PSO

To design a proper controller we need to find an accurate model so first we find an accurate model for our system. In this paper we use and investigate on models in [18]. Considering lack of existing of system parameters, we used system identification method. System is single input – single output. Input is the frequency applied on stator and output is the frequency of rotor rotate. The model gained for the system is:

$$G(s) = \frac{0.73}{\left(1 + 0.24s + .04s^2\right)\left(1 + 0.32s\right)}$$

Now we are ready to design an appropriate controller for it. For the best operation of controller we consider four criteria. Overshoot, rise time, settling time and gain margin. Now we can define our goal function as:

$$OF = w_1 OV + w_2 RT + w_3 ST + w_4 GM$$

Which w_i is goal functions weights. System response to unit step is shown in fig10.

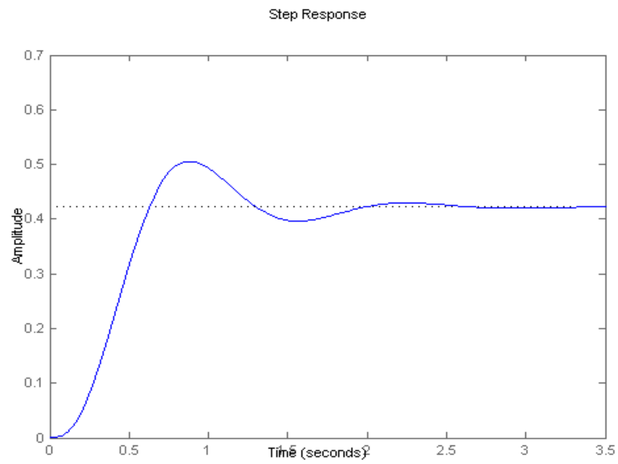

Fig10. Unit step response of system with no controller

Now we want to design the controller using GA. First we set population to 20 and maximum iteration to 30, then we repeat the algorithm with 50 and 150 maximum iterations. The convergence process for genetic algorithm with 150 iteration showed in fig11. Unit step response of the system with this controller shown in fig12.

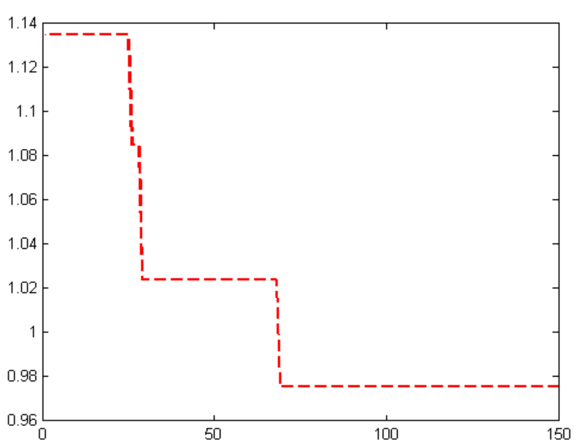

Fig11. Convergent process of GA for 150 iterations

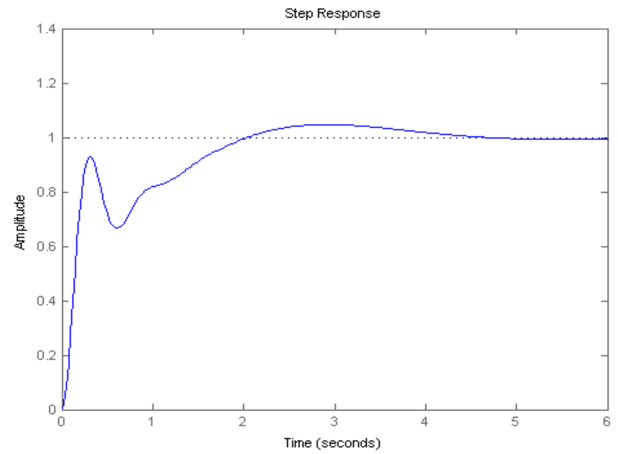

Fig12. Unit step response of system with GA designed controller with 30 iterations

Unit step response of system with GA designed controller with 50 iterations shows in fig13. Unit step response with 150 iterations and same other circumstances shows in fig14.

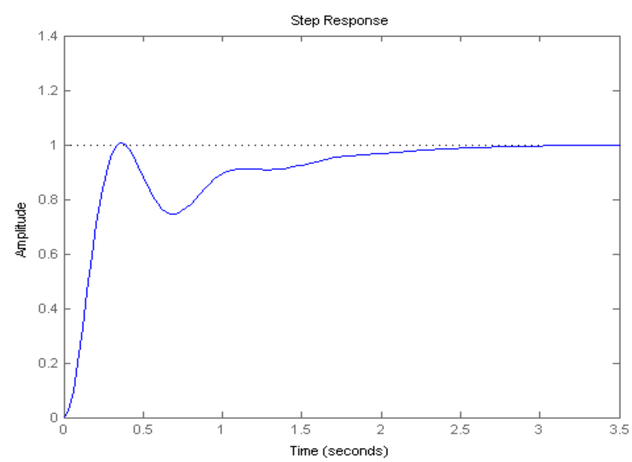

Fig13. Unit step response of system with GA designed controller with 50iterations

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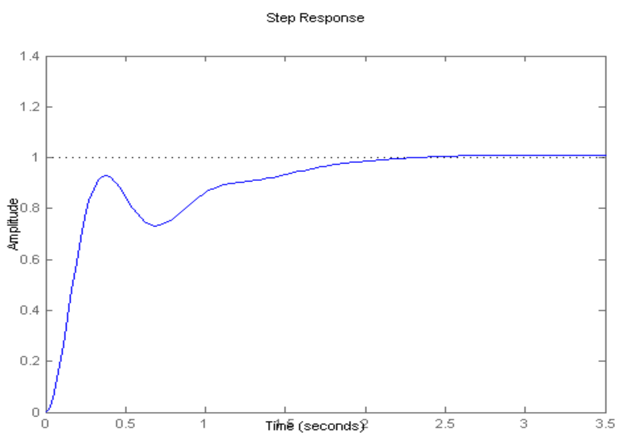

Fig14. Unit step response of system with GA designed controller with 150 iterations

And when we try to design controller with PSO, the results are different. Results for PSO shows in fig15.

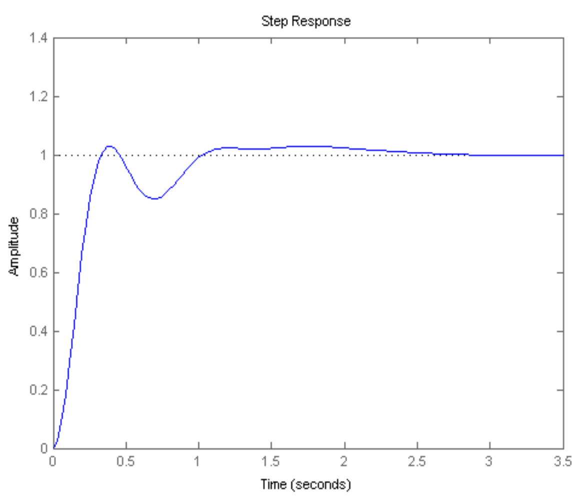

Fig15. Closed loop unit step response of system with controller designed by PSO

Coefficient values of these designs are shown in table2.

Table2. Coefficients of PID controller using GA with different iterations and PSO.

coefficient	GA/30 it	GA/50 it	GA/150 it	PSO
K_p	3.3753	1.7526	2.4971	3.0847
K_i	3.9496	3.9779	3.8573	1.0897
K_d	1.1436	1.4884	1.0532	7.4785

As we said before, we used the model of system which gained in [3] that is NARX model. For improve its more accuracy than ARMAX model we can use the best compatibility criteria which define as:

$$\text{Best compatibility} = \left(1 - \frac{\sum_{i=1}^{N}|y_i - \hat{y}_i|}{\sum_{i=1}^{N}|y_i - \bar{y}|}\right) \times 100\%$$

That this criteria for ARMAX model is 80.87 and for NARX is 89.14, so NARX is more accurate than ARMAX, however is more complicated and nonlinear. fig16 and fig17 are show these two model's compatibility with system output.

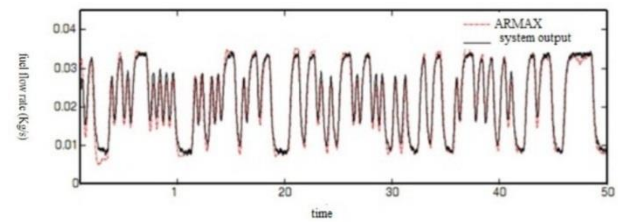

Fig16. ARMAX model coincidence with system output

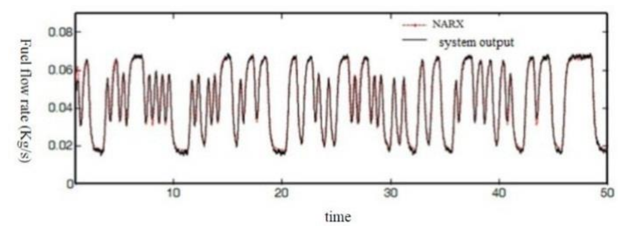

Fig17. NARX model coincidence with system output

Now all of the results from tests are shown in table2.

5. CONCLUSION

Today, Jet engines play very important role in transportation industry. An appropriate control of them is main duty of engineers in this field. Fuel system control can effect on all parts of engine and provide better operation for them. GA and PSO are most used algorithms in control. For best operation of fuel control system, first we provide an accurate and appropriate model for it. Then using GA and PSO design different controllers for this model and test them. Results show an acceptable improvement in system operation with presence of designed controller. Results also show in this specific case GA did better than PSO, and NARX model is so better and more accurate than ARMAX, concluding better results. We gathered all information about step responses of system in table3.

Table3. Results for applying GA and PSO to model of fuel control system. A) System model without any controller B) NARX model of system with controller designed by GA C) ARMAX model of system with controller designed by GA D) NARX model of system with controller designed by PSO.

parameter	A	B	C	D
t_r (sec)	0.6	0.24	0.35	0.31
t_s (sec)	3	2.5	2.8	2.8
Overshoot	1.5	0	1.23	1.05
GM (dB)	10	18	15	15
PM (degree)	21	32	26	28

REFERENCES

[1]. M. Bazazzade, H. Badihi, and A. Shahriari, "Improved turbineengine hierarchical modeling and simulation based on enginefuel control system," Journal of Aerospace Science&Technology,vol. 6, pp. 45–53, 2009.

[2]. H. Badihi, A. Shahriari, and A. Naghsh, "Artificial neuralnetwork application to fuel flow function for demanded jetengine performance," in Proceedings of the IEEE AerospaceConference, IEEE, Big Sky, Mont, USA, March 2009.

[3]. A. Salehi, M. Montazeri, M. Nasiri, "Fuel Control unit modelling using NARX structure" Journal of modarres mechanic engineering, vol. 13, no. 7, pp. 1-9.

[4]. Cook, Alan F. (July 2003). "JOHN BARBER – The Inventor of the Gas Turbine: A Potted History".

[5]. Jaw, Link C., Garg, Sanjay, "Propulsion Control Technology Development in the United States: A Historical Perspective."

[6]. Ruano A. E., Fleming P. J., Teixeira C., RodrıEguezVázquez K., Fonseca C. M., "Nonlinear Identification of Aircraft Gas-Turbine Dynamics", Neuro computing, Volume 55, Issues 3-4, October2113, pp. 551-579.

[7]. A. Salehi, M. Montazeri, M. Nasiri, "Jet engine Fuel Control unit modelling using ARMAX structure" first conference of gas turbines in Tehran 2012.

[8]. Mohtasebi & H. Hong "Low Cost Electronically Controlled Fuel Metering System for Small Gas TurbineEngines" SAE, 11-1545, 19996. H. E. Merritt "Hydraulic Control Systems" J. Wiley, NY, 1967.

[9]. T. Krepec & I. Georgantas "New Family of Low Cost Electronic Fuel Control Units for Small Gas TurbineEngines" SAE, 911139, 1991.

[10]. Whitley, Darrell. "A genetic algorithm tutorial." Statistics and computing 4.2 (1994): 65-85.

[11]. Hu, Xiaohui. "PSO tutorial." URL: http://www. Swarmintelligence. Org-/tutorials. php (2006).