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APPLICATION OF FIREFLY ALGORITHM FOR TUNING OF PID CONTROLLER USING IN AN INDUSTRIAL FURNACE TEMPERATURE CONTROL SYSTEM

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Resumen: En este trabajo, la temperatura de un tanque de lotes pertenece a un horno de hornada industrial que se controla mediante el uso de un controlador PID que ha sido ajustado por algoritmo de luciérnaga. Los controladores PID son los controladores más populares que utilizan ampliamente en la gran mayoría de las industrias, especialmente en los procesos térmicos. Existen diferentes técnicas para ajustar el parámetro del controlador PID. Algunos de ellos son métodos convencionales tales como Ziegler-Nichols que es una técnica heurística para la afinación de parámetros PID. Sin embargo, en este trabajo se estudia la idea de utilizar algoritmos de luciérnagas para ajustar los parámetros de PID que controlan una temperatura industrial del horno discontinuo. Generalmente, en el horno discontinuo, la entrada de referencia tiene cambios de paso y la salida del control de bucle cerrado del horno discontinuo debe poder seguir la tendencia de entrada. El sistema de control propuesto se simula en MATLAB y los resultados muestran que el algoritmo de luciérnaga podría calcular la afinación de los parámetros del controlador PID correctamente.

Palabras claves: firefly, PID, temperatura, control, horno, MATLAB

Abstract: In this paper, the temperature of a batch tank belongs to an industrial batch furnace is controlled by using a PID controller which has been tuned by firefly algorithm. PID controllers are most popular controllers using widely in vast majority of industries, especially in thermal processes. There are different techniques to tune PID controller parameter. Some of them are conventional methods such as Ziegler-Nichols which is a heuristic technique for PID parameters tuning. But, in this paper the idea of using firefly algorithms for tuning the PID parameters controlling an industrial batch furnace temperature is investigated. Generally, in the batch furnace, the reference input has step changes and the output of close loop control of the batch furnace should be able to follow the input trend. The proposed control system is simulated in MATLAB and the results depict that firefly algorithm could figure out tuning of the PID controller parameters properly.

Keywords: firefly, PID, temperature, control, furnace, MATLAB

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1. INTRODUCTION

The batch type furnace is a special type of chamber furnace which is used in many industrial application. The batch furnace provides the best trade-off between equipment cost, flexibility and production rate. By definition a batch furnace handles on work load at a time and can use different sources to get required energy for generating heat such as electricity, fossil fuels, and natural gas to suit your application and preferred source of energy (Mclellan, Errol 1984). In this paper, the studied batch furnace is used in glass factory which melts batch loaded in the furnace tank over roughly 36 hours.

Typically, PID controller is used in glass melting process because it is easy to use and simple to understand (Johnson, Moradi 2017). In addition, has been proved practically that PID controller performance is good in most industrial mechanisms such as thermal plants. From this point of view, using PID controllers is applicable and more interesting than other advanced control methods unless PID controllers show weak performance or defeat in control action (Freire, Oliveria 2017). On the other hand, sometimes set the parameters of PID controllers seems no to be easy and takes a lot of time. Also, as the operation and environmental conditions tend to change over time, re-tuning of PID controllers is emerged necessarily after a certain time. Since the reference input of the batch melting furnace has step changes during melting time period, the output of the closed loop control has overshoots and undershoots solidly. In this paper, the tuning of the PID controller parameters is done by firefly algorithm.

Optimization methods get involved in many scientific areas because in many cases, figuring out a solution with minimum cost, time, or a quality is desired. So many methods has been developed for optimization, but some of them has been inspired from nature and called metaheuristic such as genetic algorithm, bee algorithm, particle swarm optimization (Freire, Oliveria 2017).

The firefly algorithm was developed by Xin-She Yang at Cambridge University in 2008 and inspired by flashing behavior of fireflies. The firefly algorithm has a distinctive feature of high speed of execution compared with other inspired-nature methods (Gupta, Padhy, 2015). Firefly algorithm can be used as an optimization method in order to set the PID controller parameters. In this case, the coefficients of PID controller are tuned by firefly algorithm to obtain minimum discrepancy between the actual output of the plant and set-point. In the other words, the ISE performance criterion is considered as the cost function and the firefly algorithm tries to minimize the cost function. This method of tuning of PID parameters has been used in many electrical engineering applications (Liang, Wang, Chen, Tseng 2015), (Sundari, Rajaram, Balaraman 2016), (Zaman, Sikder 2015).

In the glass industry, furnaces which are being used for glass melting have a considerable impact on quality of glasses producing. Therefore, research and development efforts on temperature control system of the furnace is considered as an eminent step to have a good production (Yang 2010). In this paper, mathematical model derived from real data of an actual furnace which belongs to L. E. Smith Glass Company in Mount Pleasant in United States is used as the plant. Then firefly algorithm is used and applied to set the PID controller coefficients. The closed loop control system is simulated in MATLAB and the results depict that proposed control unit is able to control temperature of the furnace well and show a satisfactory performance.

2. FIREFLY ALGORITHM

The firefly algorithm was developed by Xin-She Yang at Cambridge University in 2008 and inspired by flashing behavior of lighting bugs (Rhodes 2001). The firefly's flash attracts other fireflies. The algorithm is established on three basic rules (Rhodes 2001):

1. All fireflies are unisexual, so one firefly will be attracted by other fireflies.
2. There's a direct relation between attractiveness and lighting intensity. For any two fireflies, the less bright one will be attracted by the brighter one and thus move toward it, and the brightness decreases as the distance between the fireflies increase.
3. A given firefly move randomly if there is no brighter one than the given firefly.

Firefly algorithm has been using in control system mostly to determine PID controller parameters. In this method every lighting bug represents a solution to the problem. Each firefly has a position and light intensity individually. In d dimensional vector space, the current position of i^{th} firefly is given by $X_i = (X_{i1}, X_{i2}, X_{i3} \ldots X_{in} \ldots X_{id})$. The fireflies are located randomly in the d dimensional space as the initial condition. Position updating equation for the firefly I which is attracted by a brighter firefly j is given by

$$x_i(t+1) = x_i(t) + \beta_0 \exp(-\gamma r_{ij}^2)(x_j - x_i) + \alpha(\text{rand} - 0.5) \quad (1)$$

And the position updating equation for the brightest firefly is given by

$$xbest_i(t+1) = xbest_i(t) + \alpha(\text{rand} - 0.5) \quad (2)$$

Where the first term $x_i(t)$ and $xbest_i$ of equations (1) and (2) are the current positions of less bright firefly and the brightest firefly respectively. The second term in equation (1) is used for considering a firefly's attractiveness to light intensity. β_0 is the initial attractiveness at r = 0, γ is the absorption parameter in the range [0, 1] and r_{ij} is the distance between any two fireflies i and j, at position x_i and x_j, respectively, and can be defined as a Cartesian and Euclidean distance as follow:

$$r_{ij} = (\sum (x_{i,n} - x_{j,n})^2)^{0.5} \qquad (3)$$

where x_i and x_j are the position vectors for firefly i and j, respectively with $x_i(n)$ representing the position value for the nth dimension and the third term in equations (1) , (2) are used for reducing the randomness i.e. the motion of the fireflies gradually reduced via $\alpha=\alpha_0\delta^t$ where α_0 is in the range [0 , 1]. δ is the randomness reduction parameter where $(0<\delta<1)$ and t is the iteration number. The flowchart of firefly algorithm is shown in Figure 1.
Every new position must be evaluated by fitness function which is assumed as Integral Square Error (ISE).

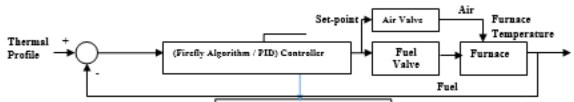

Fig. 2. Batch Furnace Control System

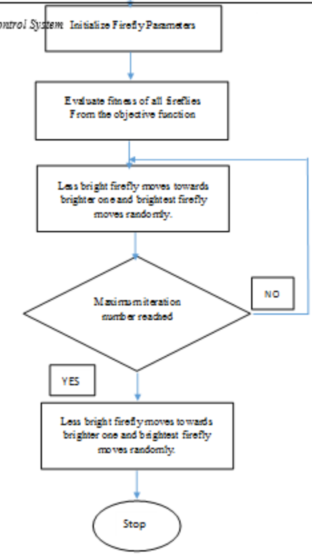

Figure. 1. Flowchart of firefly diagram [4]

3. CLOSED LOOP CONTROL SYSTEM

In this section, a brief description about the batch furnace controlled under PID controller is presented. The glass furnace has many functions that have to work to achieve the melted glass. The glass furnace consists of a couple of elements; pipe train, actuated natural gas valve, actuated air valve, burner, tank, and controller. In this process, the thermal energy obtained by burning of the mixture of air and fuel in the burner is flown into the furnace and makes glass melted. Having a control on fuel flow and air flow which are introduced to the burner, the temperature control of the furnace will be obtained (Rhodes 2001). Figure. 3 shows the block diagram of batch furnace control system which is investigated in this paper. In the other words, the temperature control of the furnace is obtained by applying control on air and fuel control valves and adjust the mixture of fuel and air introduced to the burner.
. In the following section the results of the simulation are presented.

4. SIMULATION

The proposed method of firefly algorithm is applied to the batch furnace with 20 firefly, 20 step, α = 0.1, β_0 = 2, and γ = 0.01. The simulation results are shown in Figure 3. In Figure 3. a the diagram of reference input is shown. As it can be seen from T = 0 to T = 400 min, batch is preheated at 1850^{0F}. Then temperature of the batch furnace rises to 2550 to get batch melted untill T = 1400 min and decreases to 2150^{0F} to cool the melted batch from T = 1400 min to T = 1800 min. In Figure 3.b the temperature of the

According to [9], the transfer function is shown in equation (4) can be used as a model for glass furnace.

$$G_T(s)=(9.2*10^{-3}s+8.2*10^{-3})/(3.4*10^{-14}s^4+3.9*10^{-10}s^3+1.6*10^{-6}s^2+2.3*10^{-3}s+2.7*10^{-4}) \qquad (4)$$

The controller used in the plant is a PID controller. In this kind of controller tuning of the PID parameters including integral, derivative and proportional coefficients is very important to achieve best control action. Although conventional methods such as Ziegler-Nichols method proved their efficient performance in PID parameters tuning, the inspired-nature methods have been introduced to the industrial control systems. In this paper, the ISE criterion is used as the cost function. Then, the firefly algorithm is employed to set the PID parameters to obtain minimum cost function

furnace under PID controller is shown. According to Figure 3.b the batch furnace temperature follows the reference input exactly. In Figure 3.c, the reference input and the diagram of the furnace temperature are shown simoultanasely. As shown in Figure 3.c the reference input is followed by the temperature of the furnace closely. Figure 3.d, Figure 3.e, and Figure 3.f are depicted proportional, derivative, and integral coefficients respectively. According to the diagrams, proportional coefficient is changed at the beginning of run time while the other coefficients have not considerable changes. The error signal which is the difference between the reference input and the actual temperature of the furnace is steady and fixed. Figure 3.g is shown the cost function. According to the diagram, after iteration number 3 there is no considerable change for the trend which depicts a meaningful correlation between proportional coefficient and cost function.

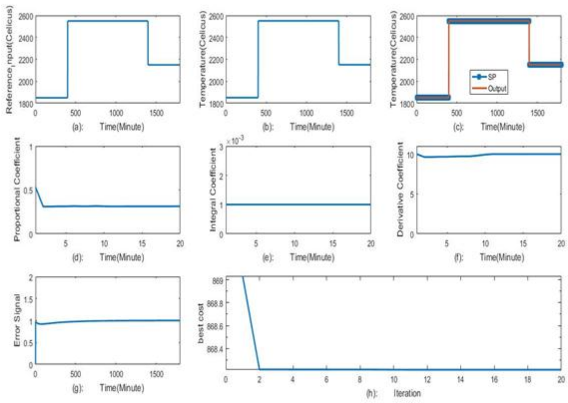

Figure. 2. Simulation results: (a): Reference Input (b): Batch Furnace Temperature under Control (c): Batch Furnace Temperature and Reference Input diagrams (d)Proportional Coefficient of PID Controller (e): Integral Coefficient of PID Controller (f): Derivative Coefficient of PID Controller (g): Error signal (h): Trend of Best Costfunction

5. CONCLUSION

The using of firefly algorithm to set the PID controller used in batch furnace temperature control is proposed in this paper. As discussed, applying modern mathematical method in industrial control has been studied in different references and by consequence firefly algorithm will be a strong option to use in different cases. In this paper using firefly algorithm has been proposed and applied to the batch furnace system. The simulation results depict that the proposed method has a good performance in controlling the batch furnace temperature.

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