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The Modelling and Control of Hot Air Generator Process

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Abstract - *Our paper is to deal with the mathematical model for hot air generator, using the transfer function model. Best control schemes are going to be implemented and the outcome of performances are examined by comparing with the dynamic behavior of PID (Proportional Integral Derivative) controller with various optimisation technique. The hot air is used for food processing industries for the removal of moisture content and also drying of raw material used in the food processing industries. For example, for moisture removal of tea leaf in the tea manufacturing industries. The process variable in this process is affected by various disturbances such as environmental temperature, blower speed and non-linear behavior of converters and final control elements. The exact transfer function model will be obtained through open loop testing, and the model is fine-tuned, and the integer and non-integer models are obtained through model optimisation techniques and the standard PID controller with hybrid optimisation techniques such as Fmin Search-GA (Fmin-GA), Fmin Search-Pattern Search (Fmin-PS), and Model Predictive Control (MPC) also implemented, and performance is investigated using time domain specification. The algorithm will aid in the protection of the industrial environment against high temperatures.*

Key Words: *Hot air generator, Genetic algorithm, Internal model-based controller, PID controller, Transfer function.*

1.INTRODUCTION

The Modelling and Control Hot Air Generator Process aims to revolutionize the operation of hot air generator systems through an innovative software-driven solution. Leveraging contemporary software development practices, advanced process modelling, and cutting-edge control design techniques, this project is dedicated to enhancing the efficiency, safety, and reliability of industrial hot manufacturing process. Before crafting the proposed software solution, an exhaustive examination is conducted on the dynamics, thermodynamics, and energy transfer attributes of the hot air generator system. This comprehensive analysis serves as the foundation for constructing a dynamic mathematical model that intricately portrays the system's behaviour across various operational scenarios. The model's architecture adeptly encapsulates critical characteristics such as energy consumption, combustion air flow, temperature differentials, and heat transfer rates. Integrating this model with a software-based control system facilitates real-time monitoring and predictive analysis. The hot air generator is equipped with advanced sensors that continually collect data, empowering the software to make informed decisions based on system performance. The software interface offers users a user-friendly dashboard presenting vital information on process dynamics, operational status, and energy efficiency metrics. This dashboard equips users with the ability to swiftly detect anomalies, address issues, and implement proactive maintenance measures based on real-time data. The software's visualization tools assist in pinpointing potential bottlenecks and areas ripe for process enhancement, ultimately boosting productivity. The software system is equipped with safety protocols and emergency stop procedures to ensure secure operation and prevent catastrophic failures. Leveraging machine learning techniques, the software has the capacity to adapt to changing environmental conditions, augment its predictive capabilities, and enhance the overall reliability of the system. The project brings forth several benefits, including reduced energy costs, a diminished environmental footprint, enhanced process control, and heightened productivity. Utilizing a software-based approach enables seamless integration with existing industrial automation systems, fostering the adoption of Industry 4.0 principles within production operations. To sum up, the Hot Air Development Modelling and Control project introduces an advanced software-driven solution that empowers businesses to automate and optimize their hot air production processes. This research represents a significant contribution to an industrial landscape characterized by sustainability and efficiency, blending the principles of control technology, sophisticated process modelling, and state-of-the-art software.

1.1 Objectives

1. The initial step involves the collection of data pertaining to the operational parameters of the hot air generator. This dataset serves as the foundation for developing precise models that depict the behavior of the hot air generator accurately.

2. Following the data gathering process, the next task entails the creation of models that represent the hot air generator's behavior. These models are instrumental in simulating the generator's performance under varying conditions.

3. Subsequently, a real-time control system is implemented, based on the afore mentioned models, becomes imperative. This control system assumes the responsibility of managing and regulating the hot air generator's operations.

4. In the final stage, the control system is rigorously tested and validated. This rigorous approach assures the

control system's proper operation and verifies its capacity to deliver the desired results efficiently.

1.2 Scope of the Project

The prospects for the Modelling and Control of hot air generator process project are exceptionally bright. With the continuous advancement of software and computing capabilities, there exists substantial potential for pioneering applications within this technology. This potential translates into the substantial enhancement of hot air generators' efficiency, dependability, and safety, while concurrently mitigating their environmental footprint. Key points of progress include:

1. Advancements in the precision and dependability of models.
2. The formulation of innovative control strategies.
3. Seamless integration with diverse process systems.
4. The establishment of remote monitoring and control capabilities.

2. AIM

The hot air generator's temperature can be utilized for a variety of industrial operations, including the removal of moisture from food items in the food processing industry, the crystallization of sugar, the process of exchanging heat in thermal power plants, and the participation of extremely hot temperatures in furnaces. Not all processes' mathematical models are created using the same methods.

Energy manipulations are used to carry out the heat exchange process in the bath control system, which uses a PID controller. By separating their individual connections, which are individually constrained by controllers based on the predictive control of the full developed model, the device is upgraded to a variety of single input output frameworks. On the presented magazine, the PI and PID controller is studied. This issue is solved using fuzzy logic, which also makes the system less complex. The low-cost controller didactic card is seen here. The correctness of the workplace temperature as it relates to the profile and impact of the alarming force is an important part of this project. The air and room temperatures are both adjusted and explained. The most recent structure of the rules also includes factors related to distributed processing capacity and the viability of using organized correspondence among individual controllers to consider the rules. The dynamic change in a non-linear process is not handled by a PID controller. On the PID's controlling strategy, tuning is used.

2.1 Materials and Methods

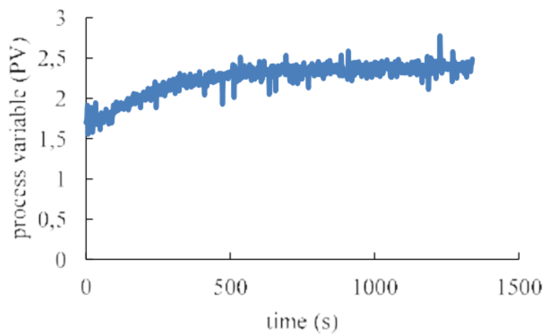
In this work, the MATLAB program's library function is utilized as a controller component, with a PC-based control environment considered. The setup of the closed-loop hot air generator process is detailed.

In this configuration, a blower operating at 200 rpm is employed to draw in ambient air through a pipeline with a 15 cm diameter. Within the pipeline, a heating coil is positioned concentrically. The heating coil is powered by an alternating current power supply, facilitated by an SCR-based firing circuit. Various sensors are strategically placed along the pipeline to capture the temperature of the hot air as it flows through.

The open-loop test for this hot air generator system involves setting the set point in terms of input voltage within the range of (0-5) V. This set point is directly applied to the final control element through MATLAB, which interfaces with the data acquisition card (DAQ). This direct supply to the SCR-based firing circuit does not incorporate any feedback. The final control element's output modifies the heating coil's temperature. To facilitate this, a voltage-to-current converter is used in the interfacing process since the final control element accepts current as input. The heater receives 230 V as input and can attain a maximum temperature of 200 degrees Celsius. The Silicon Controlled Rectifier (SCR), serving as a power controller, is the ultimate control component in the air flow temperature station.

The open-loop system, sometimes known as a "non-feedback system," does not provide any feedback. It is a continuous mechanism in which the input signal remains unaffected by the output signal. The figure yields a simple model by taking into account parameters such as gain (k), time constant (t), and transportation delay (l). The time constant represents the system's ability to respond to changes quickly, achieving 63.2% of its final value. Gain is defined as the ratio of the steady-state output to the magnitude of the input.

Due to the SCR firing circuit's continuous switching action, the open-loop response does not follow the anticipated smooth curve. To construct a mathematical transfer function model, specific values are selected. Disturbances occur due to variations in the system's frequency. To counteract this effect, PID and MPC controllers are developed and tuned for the air flow temperature system.

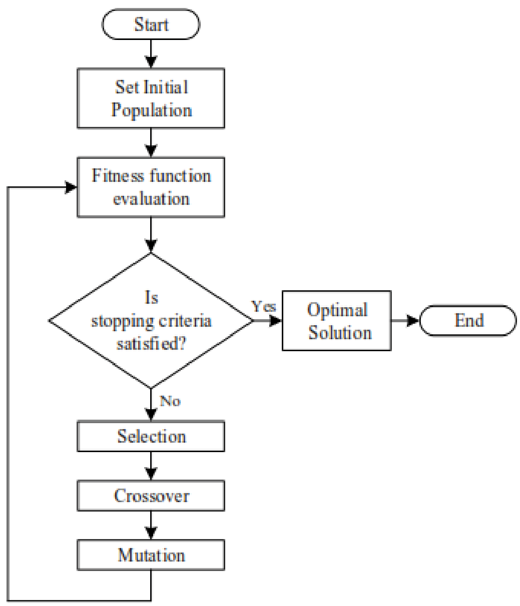


Graph-1: Response of Open loop test

2.2 Optimisation of Controller & Fine-tuning

Initially, the PID controller's tuning parameters are determined through an auto-tuning process using MATLAB. The resulting reference values serve as the starting point for the Fmin search unconstrained optimization method, which calculates the optimal tuning parameters. These values also establish the lower and upper ranges for the Genetic Algorithm (GA).

GA follows strict guidelines throughout its operations. Selection rules identify individuals, known as parents, who contribute to the population of the next generation. Crossover rules join two parents to produce offspring for the next generation, whereas mutation rules introduce random alterations to individual parents to produce children.



In the context of optimizing the PID controller using GA, the process starts with the establishment of an initial population. This population is randomly chosen within predefined limits. The fitness function evaluation is based on metrics like Integral Square Error (ISE) and Integral Absolute Error (IAE). If the specified criteria are met within the sample values, the fitness function evaluation concludes. Otherwise, values may be adjusted through crossover or mutation processes.

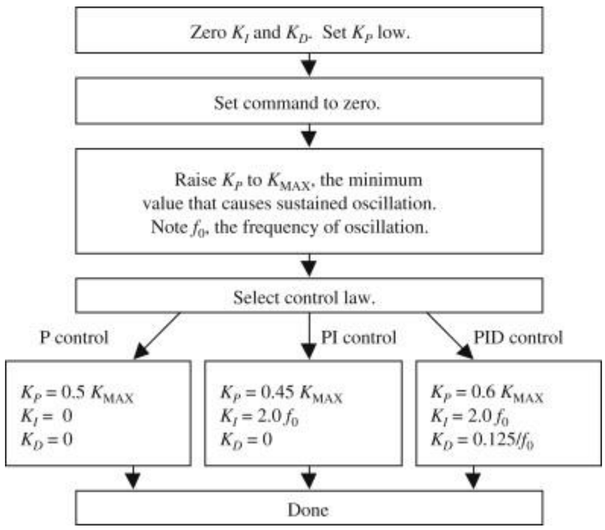
$$\Phi = \sum_{i=1}^{P} |r_{k+i} - \hat{y}_{k+i}| + w \sum_{i=0}^{M-1} |\Delta u_{k+i}|.$$

Optimization aims to maximize or minimize a particular performance criterion, often referred to as an objective function, to attain the most favourable outcome. Optimization becomes achievable by modifying the control signal and the modelling equations. In predictive control models, least square formulations are predominantly employed. These formulations offer theoretical solutions for unconstrained problems while mitigating significant errors in comparison to minor ones.

Table 1. MPC setting for air flow temperature process

Sampling time (T_s)	0.5
Prediction horizon (P)	3000
Control horizon (M)	3
Objective function	quadratic

One of the most well-known tuning approaches is the Ziegler-Nichols Method, which is based on an open loop step-response function of time. A first order transfer function with dead time approaches the produced response function. This approach begins by zeroing the integral and differential gains before increasing the proportional gain until the system becomes unstable. KMAX is the maximum value of KP at the time of instability; f0 is the frequency of oscillation. The approach then subtracts a predefined amount from the proportional gain and sets the integral and differential gains as a function of f0.



Ziegler-Nichols Method

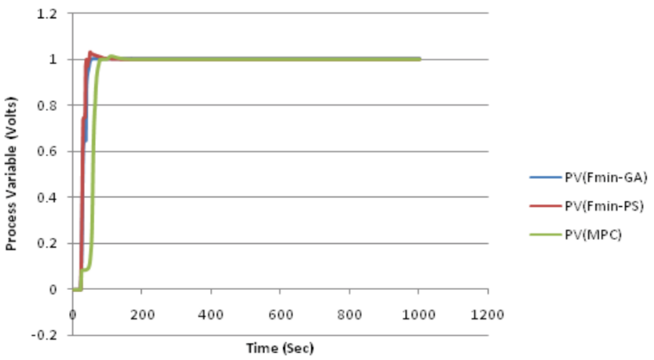
3. RESULT

The hot air generator's mathematical model is derived from the transfer function model. This model is established through open-loop testing, and both integer and non-integer order models are generated by fine-tuning of the system's parameters. The optimization process of the model involves refining the existing system parameters. Subsequently, the resulting transfer functions are documented and tabulated for reference.

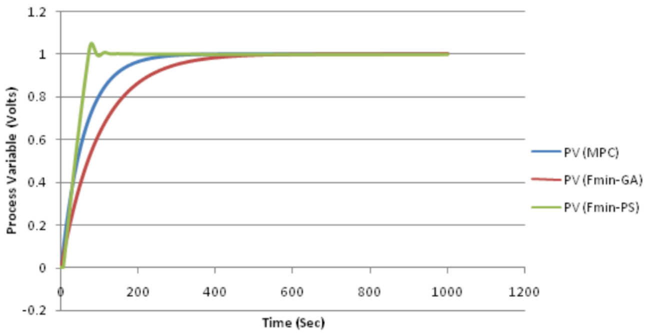
Table 2. Transfer function of Integer order (IO) and Fractional order (FO) processes

Nature of the model	Transfer function	Integrated synthesis environments
Model	$G_0(s) = 0.56e^{-ts}/(180s + 1)$	17.838
Model using Genetic Algorithm	$G(s) = 0.534e^{-6178s}/(185.377s^{0.9} + 1)$	14.326

The following graphs represented the outcome of an Overall Integer order (IO) and Fractional order (FO) temperature process responses,



. Overall IO-temperature process responses



Overall FO – temperature process response

4. CONCLUSION

Controlling temperature is vital in food processing, especially during drying. Effective control can optimize energy usage in hot air generator systems. The optimization of classic integer order and non-integer order PID controllers, applied to both order models, is achieved through hybrid optimization techniques like Fmin-pattern search (Fmin-PS), Fmin-genetic algorithm (Fmin-GA), and Model Predictive Controller (MPC). This approach consistently outperforms other existing methods.

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