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MODELING OF ELECTRO-HYDRAULIC SERVO SYSTEM USING THE BEES ALGORITHM

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ABSTRACT: In this study, a method is proposed to find the unknown simulation parameters of an industrial electro-hydraulic proportional valve. Electro-hydraulic servo systems are one of the most widely used actuator systems, and proportional valves are commonly found in hydraulic systems. Hydraulic systems are complicated to linearize, because nearly whole elements are nonlinear, with the inclusion of the valve actuators. The system model must be linearized to make it feasible for analysis of the system linearly or the characteristics must be identified by comparison the output responses suitable for the inputs. However, it is not easy to obtain a perfect system model for use in simulation studies without prior knowledge of the system. Obtaining a perfect model of a system that is not easy to model can be done in two different ways; applying one of the system identification methods after collecting experimental data or using manufacturers' datasheets. In this paper, simulation parameters of MOOG brand D675 series proportional servo valve system were obtained using The Bees Algorithm, an optimization algorithm, to match the dynamic specifications in the datasheet provided by the manufacturer. The obtained system model and the answers are shown graphically and the effectiveness of the proposed method is discussed.

Keywords: *The Bees Algorithm, Electro-hydraulic, Servo Valve, System Identification, Matlab*

Elektro-Hidrolik Servo Valf Sisteminin Arı Algoritması (AA) Kullanılarak Modellenmesi

ÖZ: Bu çalışmada, endüstriyel bir elektro hidrolik oransal valfin bilinmeyen benzetim parametrelerini bulmak için bir yöntem önerilmektedir. Elektro hidrolik servo sistemler en yaygın olarak kullanılan eyleyici sistemlerinden biridir ve hidrolik sistemlerde yaygın olarak oransal valfler bulunur. Hidrolik sistemlerin doğrusallaştırılması karmaşıktır, çünkü valf eyleyicileri dahil neredeyse tüm elemanlar lineer değildir. Sistemin doğrusal olarak analiz edilmesini mümkün kılmak için sistem modeli doğrusallaştırılmalı veya sistem özellikleri girdilere uygun çıktı yanıtlarının karşılaştırılmasıyla tanımlanmalıdır. Sistem hakkında önceden bilgi sahibi olmadan, benzetim çalışmalarında kullanmak için sistemin kusursuz bir modelini elde etmek oldukça zordur. Modellenmesi kolay olmayan bir sistemin kusursuz bir modelinin elde edilmesi iki farklı şekilde yapılabilir; deneysel verileri topladıktan sonra sistem tanımlama yöntemlerinden birini uygulamak veya üreticilerin veri sayfalarını kullanmak. Bu çalışmada, bir optimizasyon algoritması olan Arı Algoritması kullanılarak MOOG marka D675 serisi oransal servo valf sisteminin benzetim parametreleri, üretici tarafından sağlanan veri sayfasındaki dinamik özelliklere uyacak şekilde elde edilmiştir. Elde edilen sistem modeli ve cevaplar grafiksel olarak gösterilmiş ve önerilen yöntemin etkinliği tartışılmıştır.

Anahtar Kelimeler: *Arı Algoritması, Elektro-hidrolik, Servo Valf, Sistem Tanımlama, Matlab*

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1. INTRODUCTION

Electro-hydraulic servo systems are widely used in industrial process and engineering applications (Qing-hua *et al.*, 2008; Kalyoncu and Haydim, 2009). To design a precise controller for electro-hydraulic servo systems, a perfect model of the system should be obtained to simulate and test the controller behavior (Feng *et al.*, 2019). In addition, this model can be used in controller design and optimization of control parameters when necessary. However, it is not easy to obtain a perfect system model for use in simulation studies without prior knowledge of the system. Problems in obtaining a precise nonlinear and time-varying dynamics model also complicate controller design processes. Therefore, modeling is the first and most important process in scientific studies. Obtaining a perfect model of a system that is not easy to model can be done in two different ways; applying one of the system identification methods after collecting experimental data or using manufacturers' datasheets (Tchkalov and Miller, 2014). System identification is constructing linear and nonlinear dynamic system models from experimental input and output data. Experimental data can be obtained in the time domain as well as in the frequency domain. The use of ancillary information in describing nonlinear systems can be handled in different ways and at different levels. The goal is to find models that perform well in both transient and steady-state regimes.

The system identification process can be considered as an optimization problem and this approach can provide system models with better dynamic and static performance than other techniques. Genetic Algorithm and Particle Swarm Algorithm are widely used algorithms in system identification studies (Zhang and Xia, 2017; Ding et al., 2019). Optimization algorithms are also used to define the unknown system parameters of the obtained mathematical models (Yu et al., 2017). In studies on the definition of electro-hydraulic systems and obtaining system parameters, it is seen that different optimization algorithms and system identification methods are used (Bakırcıoğlu et al., 2017; Khadim et al., 2021). In this article, the simulation parameters of the MOOG brand D675 series electro-hydraulic servo valve system were obtained using The Bees Algorithm (BA) to match the dynamic specifications in the datasheet provided by the manufacturer (Moog, 2010). The considered system was modeled with the help of Matlab Simscape Fluids and the Matlab platform was used to implement The Bees Algorithm (BA). Simulation studies were carried out with the help of Matlab Simulink (MathWorks, 2021).

2. MATERIAL AND METHOD

2.1. Structure of electro-hydraulic servo valve

The MOOG brand D675 series 4-way electro-hydraulic servo valve modeled in this article is shown in Figure 1. This valve series; is used in applications that require position, speed, pressure or force control and high dynamic requirements (Moog, 2016).

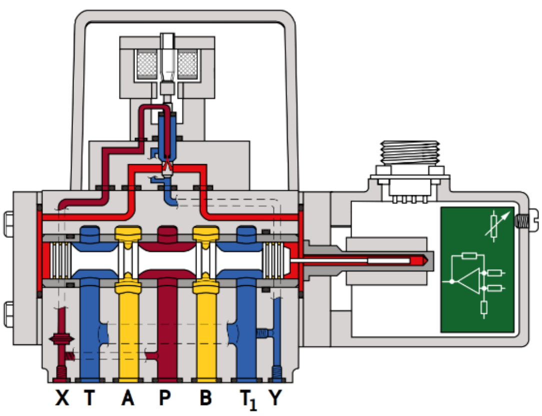

Figure 1. Schematics of MOOG D675 Series valve.

The model structure for the 4-way directional valve is determined as in Eq. 1 to Eq. 3. Here, q and C_d are the flow through the orifice and the flow relief coefficient, respectively. h_{max}, h, A_{max} and A are maximum orifice opening, orifice opening, maximum orifice area and orifice area, respectively. Finally, p, x_0 and x are the pressure difference across the orifice, initial opening and slider distance, respectively.

$$q = C_d \cdot A\sqrt{\frac{2}{\rho}|p|} \cdot sign(p) \quad (1)$$

$$A = \frac{A_{max}}{h_{max}} \quad (2)$$

$$h = x_0 +/- x \quad (3)$$

In the literature , the embedded electronic dynamics is represented by a theoretically equivalent second-order transfer function. Therefore, a quadratic delay is used to model the onboard electronics as in Eq. 4 to Eq. 6. Unknown parameters must be determined after the 4-Way valve and onboard electronics models have been created.

$$G(\omega) = \frac{1}{\frac{1}{\omega_n^2}s^2 + \frac{2\xi}{\omega_n}s + 1} \quad (4)$$

$$\omega_n = \sqrt{\frac{K}{\tau}} \quad (5)$$

$$\xi = \frac{1}{2}\sqrt{\frac{1}{K\tau}} \quad (6)$$

Here, ω_n and ξ are the natural frequency and damping ratio, respectively. K and τ are gain and time constants, respectively.

The model created will be used to represent the valve system behaviors. Therefore, it is necessary to determine the unknown parameters of the model. This can be done using system identification techniques. In this study, unknown parameters are obtained with the help of The Bees Algorithm (BA) until the simulation results match the graphics in the manufacturer's datasheet. The system model structure consists of two different parts and these structures were created using Matlab/Simulink. The Simulink environment can model physical components using the Simscape plugin. Simscape allows the creation of physical system models in the Simulink environment quickly. In addition, Simscape allows the creation of physical models that integrate directly with block diagrams and other modeling methods.

2.2. Physical model of electro-hydraulic servo valve

The physical model of the electro-hydraulic servo valve was created with Simscape. Simscape is a potent tool for fully modeling hydraulic components. The physical model of the discussed servo valve has been created to simulate dynamic behavior by using *Proportional and Servo-Valve Actuator* and *4-Way Directional Valve* blocks in Simulink Simscape environment. The created servo valve Simscape model is shown in Figure 2.

Each block in Figure 2. has some characteristic parameters. These parameters determine the model behavior. The *4-Way Directional Valve* block represents a conventional four-way hydraulic valve. The block consists of six orifice blocks connected, as shown in Figure 3. The fluid is pumped to the valve via the inlet line *P* and distributed between the two external hydraulic lines *A* and *B* (usually connected to a double-acting actuator) and the return line *T*. The block has four hydraulic connections corresponding to the inlet port (*P*), actuator ports (*A* and *B*) and return port (*T*) and a physical signal port link (*S*) that controls the slider position. To model the *4-way directional valve* block to match the graphics in the manufacturer's datasheet, aperture area vector parameters must be determined.

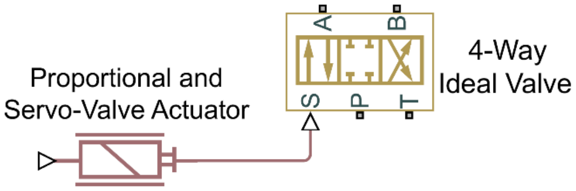

Figure 2. Simscape model of electro-hydraulic servo valve system.

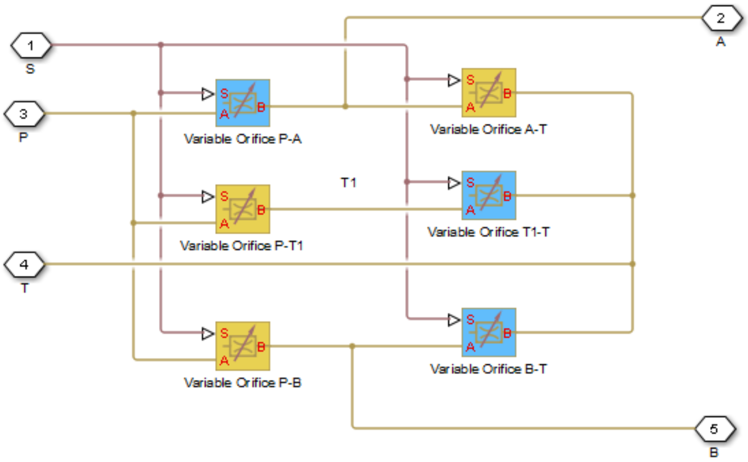

Figure 3. Construction of 4-way directional valve.

The actuator block represents the electromagnetic actuator found in proportional and servo valves. This electromagnetic actuator is used to drive the slide element. The block has been designed to work with one of *the* directional valve models to create the desired configuration of the proportional or servo valve. The block diagram of the model is shown in Figure 4. The *proportional and servo-valve actuator* block consists of gain, time constant and saturation. These values must be determined to match the graphics in the manufacturer's datasheet.

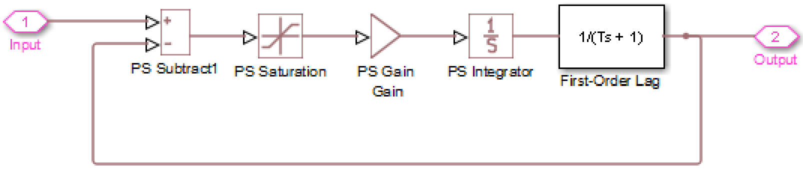

Figure 4. Construction of proportional and servo-valve actuator.

Servo Actuator and 4-Way Valve model parameters, flow rate and frequency responses were determined *using* the graphs in the manufacturer's datasheets. Parameter values is determined using The Bees Algorithm (BA) to decrease the difference between actual data and measured data from simulations.

2.3. Determination of servo valve parameters using The Bees Algorithm

The Bees Algorithm (BA) was first proposed by D. T. Pham et al. in 2006, and an intuitive point of view was captured by comparing the bees' searching behavior for resources such as water and nectar to learning, remembering and sharing information using swarm intelligence (Pham *et al.*, 2006). Pham and

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Kalyoncu, who optimized the control parameters with The Bees Algorithm, laid the foundations of the studies in this area (Pham *et al.*, 2008). Under the leadership of Kalyoncu, optimization studies of many control types such as PID and SMC is made and published in the literature (İlgen *et al.*; Karakoyun *et al.*). Besides the controller optimization studies, determining model parameters is also made such as this paper (Eser *et al.*). In this study, it has been shown that The Bees Algorithm can be used as a system identification method by determining the parameters of the electro-hydraulic servo valve system with The Bees Algorithm.

The Bees Algorithm contains many parameters explained in Pham et al. in 2006, these parameters must be select carefully to obtain optimum results. Figure 5. shows The Bees Algorithm flowchart. As seen in the figure, this cycle continues until the optimization's stopping criterion (*itr*) is met. The Bees Algorithm parameters used in this study are given in Table 1.

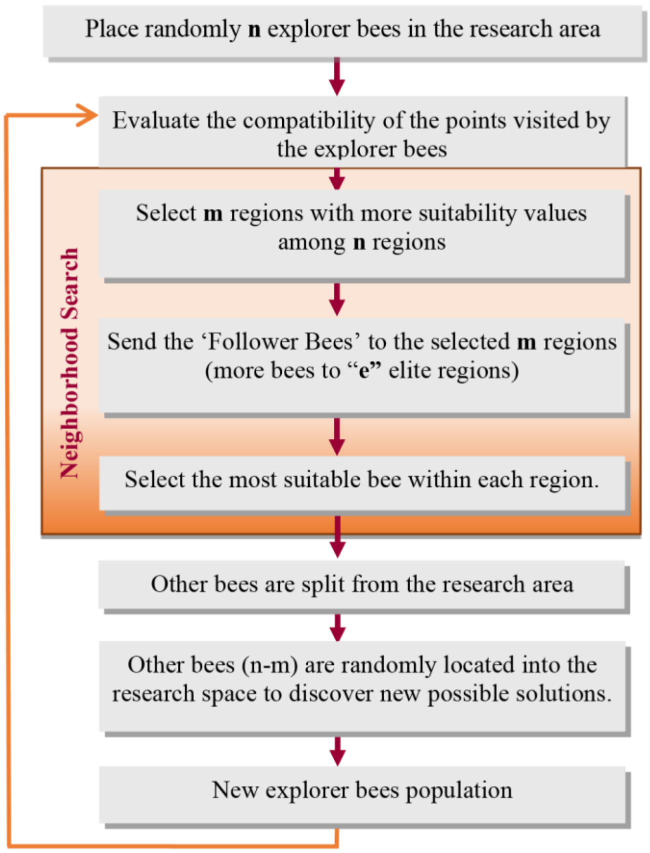

Figure 5. Flowchart of The Bees Algorithm.

Table 1. The Bees Algorithm parameters.

Itr	*n*	*m*	*e*	*nep*	*nsp*	*ngh*
20	15	8	5	20	10	0.01

In this study, first, 4-Way Valve parameters were determined. A test model was created to determine the parameters. The test model created is given in Figure 6.

The flow chart from the manufacturer's data sheets is used as a reference in this model, the reference flow chart is shown in the Figure 7. The objective function used to determine the parameters is given in Eq. 7. Here, Q_a and Q_r are the measured and reference flow values, respectively, and k_i is the weight multiplier.

$$F(x) = \sum_i^n k_i(Q_r - Q_a)^2 \qquad (7)$$

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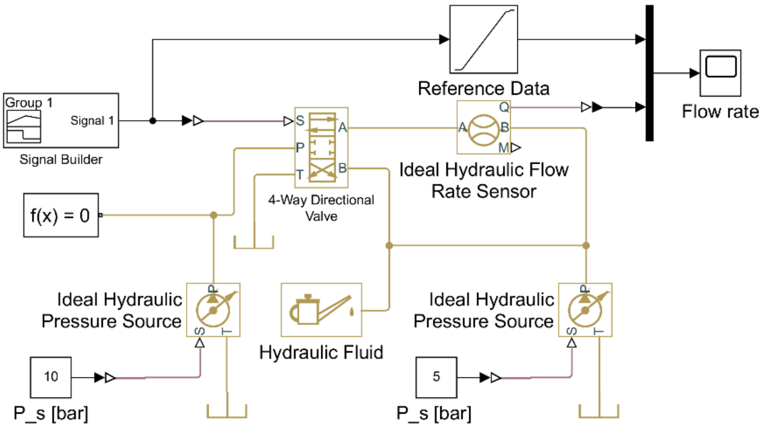

Figure 6. Test model of 4-way directional valve.

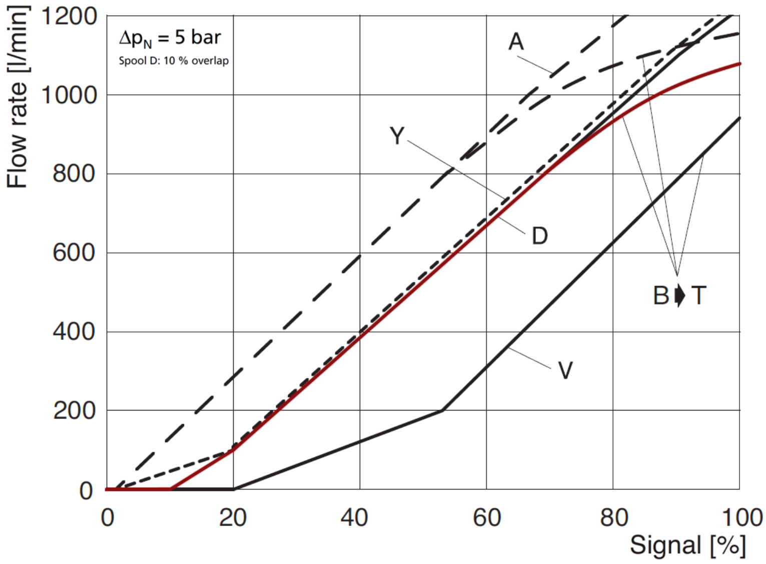

Figure 7. Flow-signal characteristic.

The variable parameter vector in Eq. 7 consists of 21 parameters. 20 orifice area values were determined as the model parameters of the *4-Way Valve* block, which provides results as near as possible to the flow rate graph given in the data sheet with The Bees Algorithm (BA), and which is seen to be used in Figure 8. These are 0, 0, 0, 0.6983, 1.1992, 1.6193, 2.1000, 2.6000, 3.0724, 3.6808, 4.2893, 4.7984, 5.2496, 5.7222, 6.0858, 6.5140, 6.8634, 7.1390, 7.4000, 7.5980 from a_1 to a_{20}.

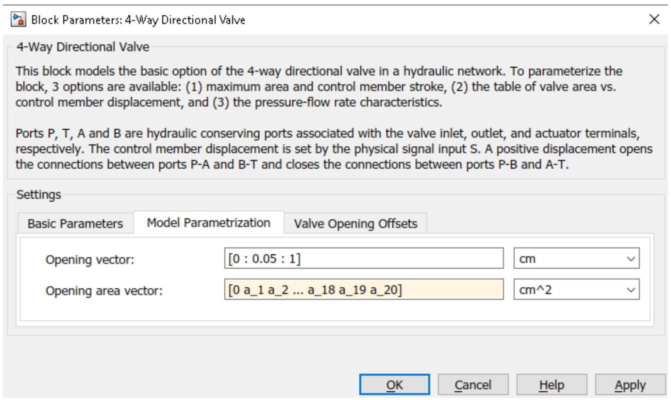

Figure 8. Block parameters of 4-way directional valve block.

Because electro-hydraulic systems are nonlinear, their frequency characteristics depend on controller performance, fluid properties, and other factors. Therefore, to determine the parameters of the Servo-Valve Actuator model, parameters should be reflected in the model and all features should be aforethought at the same time. Hydraulic systems are complicated to linearize, because nearly whole elements are nonlinear, with the inclusion of the valve actuators. However, the system model must be linearized to make it feasible for analysis of the system linearly or the characteristics must be identified by comparison the output responses suitable for number of frequencies sinusoidal inputs. The second method was used in this study. The test model used to determine the parameters is given in the figure 9.

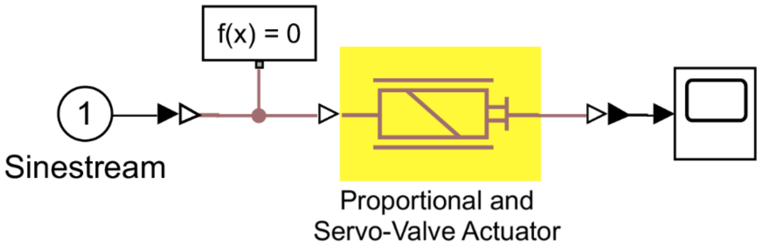

Figure 9. Test model of servo valve actuator.

In this study, the Proportional and Servo-Valve Actuator is modeled according to the frequency response characteristics at 90% of the input signal. The frequency graph from the manufacturer data sheets is used as a reference in this model and the frequency curve used is shown in Figure 10. In addition, the objective function used to determine the parameters is given in Eq. 8.

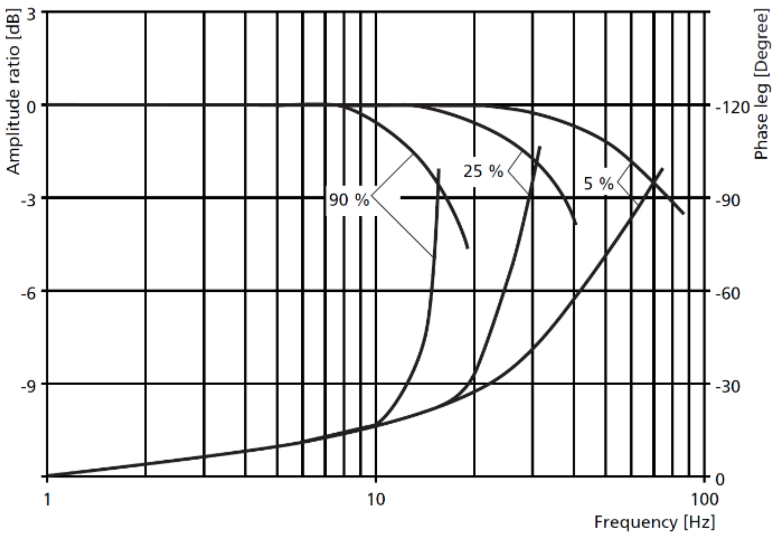

Figure 10. Frequency response.

$$F(x) = \sum_{i}^{n} k_i (f_r - f_a)^2 \quad (8)$$

Here, f_a and f_r are the measured and reference frequency values, respectively, and k_i is the weight multiplier. The variable parameter vector in Eq. 8 consists of 3 parameters: Gain, Time Constant and Saturation. The Bees Algorithm (BA) determined the values of these parameters to obtain results of the simulations as near as possible to the frequency response graph given in the datasheet. The determined Gain, Time Constant and Saturation values are 253.7128, 0.0211 and 12.4498, respectively.

Test models and objective functions defined in this section is created using Matlab, Simulink and Simscape platforms and simulation studies is carried out. First, however, The Bees Algorithm (BA) was run until the unknown parameters of the test models matched the desired results with the actual data.

3. RESULT AND DISCUSSION

In the proposed method in this study, the Simscape model of the electro-hydraulic servo valve system was created. Then, The Bees Algorithm (BA) was used to determine the parameters used on the model and match the graphics in the manufacturer's data sheets of the servo valve considered.

The flow characteristics of the valve model created by using the initial parameters and the parameters obtained with The Bees Algorithm (BA) are given in Figure 11. The command signal increasing from 0% to 100% in 10 seconds was obtained with the Signal Configuration block in the pattern shown in Figure 6.

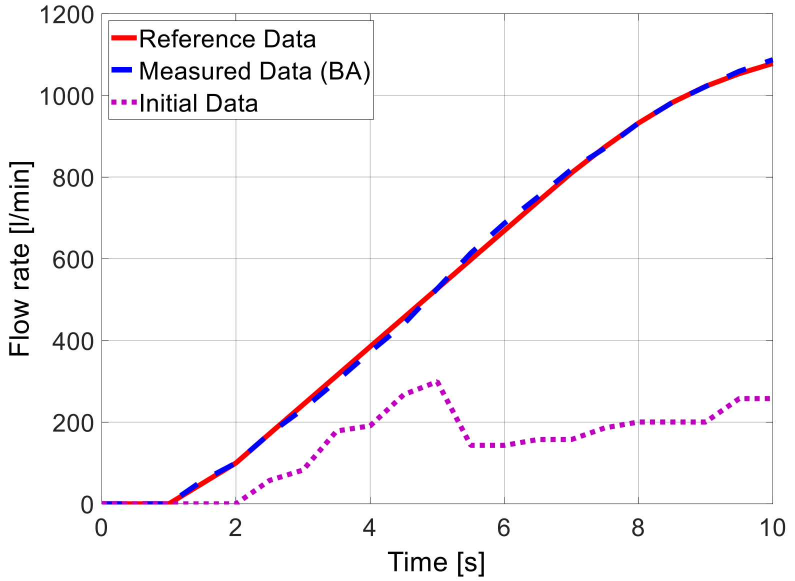

Figure 11. Comparison of optimized and reference flow characteristics response.

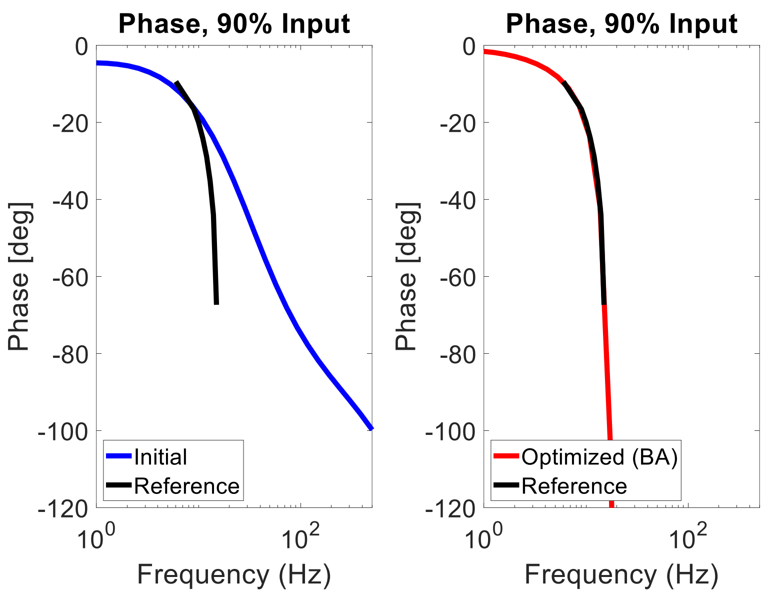

Figure 12. Comparison of optimized and reference frequency response.

The Bees Algorithm (BA) was also used to determine the parameters of the Servo Valve Actuator model. The phase-frequency response characteristic of the Servo Valve Actuator model obtained by using the initial parameters and optimized parameters is given in Figure 12. The excitation signal used to collect the phase-frequency response of the model was obtained with a Matlab command called *frest.Sinestream*, which is a series of sine wave signals.

As can be seen in Figure 11. and Figure 12., there is a great deal of similarity between the graphs created with the parameter values obtained by The Bees Algorithm (BA) and the graphs taken as reference from the datasheet.

4. CONCLUSION

It is not easy to obtain a perfect system model for use in simulation studies without prior knowledge of the system. Obtaining a perfect model of a system that is not easy to model can be done in two different ways; applying one of the system identification methods or using manufacturers' data sheets after collecting experimental data. In this paper, simulation parameters of the MOOG brand D675 series proportional servo valve system was obtained using The Bees Algorithm, an optimization algorithm, to match the dynamic specifications in the datasheet provided by the manufacturer. As a result, it has been concluded that The Bees Algorithm (BA) can be used as a fast and reliable way to determine unknown parameters for modeling systems studies.

5. ACKNOWLEDGE

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