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APPLICATION OF THE BEES ALGORTIHM UPON HYDRAULIC CYLINDER DESIGN AND OPTIMIZATION

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ABSTRACT: In this study, mass minimization of **a** simple double-acting hydraulic cylinder has been studied using The Bees Algorithm (BA) for a specific force and known material, considering the buckling and pressure constraints. A Hydraulic cylinder is a hydraulic actuator that creates linear movement by converting hydraulic energy back to a mechanical movement. Hydraulic-driven working machines are widespread in the industry today. Hydraulic cylinders are used in mobile applications such as container lifting devices, excavators, dump trucks, loaders, graders and dozers. Weight reduction in these cylinders plays a fundamental role in the performance of the machine in terms of lifting capacity, speed, costing, etc. The Bees Algorithm is a metaheuristic algorithm that mimics the natural foraging behavior of honey bees to find the optimum solutions. The advantages over other algorithms are its ability to search both locally and globally and being applicable for several optimization problems with the chance to be integrated with other algorithms. In this study, it is also aimed to determine the optimal parameters of the bees algorithm for minimum computation cost.

Keywords: The Bees Algorithm, Hydraulic Cylinder, Mass Minimization, Optimization

Hidrolik Silindir Tasarımı Ve Optimizasyonunda Arı Algoritmasının Uygulanması

ÖZ: Bu çalışmada, belirli bir kuvvet ve bilinen bir malzeme için, basit bir çift etkili hidrolik silindirin kütle minimizasyonu, burkulma ve basınç kısıtlmaları da dikkate alınarak, Arı Algoritması kullanılarak incelenmiştir. Hidrolik silindir, hidrolik enerjiyi tekrar mekanik harekete dönüştürerek doğrusal hareket oluşturan bir hidrolik aktüatördür. Hidrolik tahrikli iş makineleri günümüzde endüstride oldukça yaygındır. Hidrolik silindirler; konteyner kaldırma cihazları, ekskavatörler, damperli kamyonlar, yükleyiciler, greyderler ve dozerler gibi mobil uygulamalarda kullanılmaktadır. Bu silindirlerdeki ağırlık azaltımı, kaldırma kapasitesi, hız, maliyet vb. açılardan makinenin performansında önemli bir rol oynar. Arı Algoritması, optimum çözümleri bulmak için bal arılarının doğal yiyecek arama davranışını taklit eden metasezgisel bir algoritmadır. Hem lokal hem de global arama yapabilmesi ve diğer algoritmalar ile entegre olabilme şansı, diğer algoritmalara göre avantajlarını oluşturur ve bu sayede birçok optimizasyon problemine uygulanabilir. Ayrıca bu çalışmada, minimum hesaplama maliyeti için Arı Algoritmasının optimum parametrelerinin belirlenmesi de amaçlanmıştır.

Anahtar Kelimeler: Arı Algoritması, Hidrolik Silindir, Kütle Minimizasyonu, Optimizasyon

1. INTRODUCTION

The aim of optimization is **to find** the minimum or maximum value of **a** function consisted one or more dependent variable**s**. This function is named **an** objective function. According to being **a** single or multiple objective function, problem is called **a** single function and multi-objective optimization problem respectively (Pham and Ghanbarzadeh, 2007).

The Bees Algorithm (BA) is a population-based search algorithm that was devised by Pham et al in 2005. BA involves a swarm intelligence approach and focuses on problem-solving behavior of the swarm to improve effective metaheuristic methods. This algorithm is inspired by the food foraging behavior of honeybees and it is a multivariable global search algorithm (Pham et al., 2005). The basic form of the BA algorithm performs a kind of neighborhood search combined with a global search (Pham et al., 2006).

The efficiency and specific abilities of BA have been proven in several studies:

Pham et al. have solved the constrained optimization problem about welded beams designed using the BA. In terms of the accuracy of the result, BA has outperformed other optimization techniques. They have notified that **a** number of parameters must be chosen as a challenge of **the** algorithm. After a few trials, setting these parameters' value**s** is possible, fortunately (Pham et al., 2008). Pham et al. **have** utilized BA to optimize parameters of fuzzy logic parameters for vibration analysis and thanks to **the** algorithm efficiency and robustness of the system have been improved (Pham and Kalyoncu, 2009).

Fahmy and Kalyoncu have used BA to solve **a** problem that **has** complicated parameters for robot manipulator control. Their study consists of two cases one of them is modeling of inverse kinematic**s** of **a** robot arm and **the** second one is **the** minimization of connection weight between nodes to minimize positional inaccuracies and vibrations. As a result of **the** number of trials, PID controllers designed using BA have predominated **over** robot controller**s** designed using manual approaches (Fahmy et al., 2012). Bilgic et al. have used BA for **the** optimal setting of **a** linear quadratic regulator (LQR) for a linear inverted pendulum. They optimized the weight matrix of LQR to move the cart's desired location with **a** minimum pendulum angle. As a result of **the** study, **the** performance of **the** LQR controller has been improved (Bilgic et al., 2016). Sen et al. **have** studied earthquake excitation based on BA. They optimized the gain coefficient of **the** PID controller and compared experimental results with **a** genetic algorithm(GA) (Arif Şen et al., 2018). Dat et al. **have** studied nanocomposite multilayer solar cells that are exposed to axial compressive load and carried out BA to maximize the value of buckling load ((Dat et al., 2020).

A hydraulic cylinder or actuator uses liquid pressure to obtain linear movement. Hydraulic-driven working machines are widespread in the industry today. Hydraulic cylinders are used in mobile applications such as container lifting devices, excavators, dump trucks, loaders, graders, and dozers (Shah and Upadhyay). Weight reduction in these cylinders plays a fundamental role in the performance of the machine in terms of lifting capacity, speed, cost, energy saving, etc. Mass optimization of cylinders has been investigated with different algorithms and theoretical or experimental approaches by many researchers. For instance, Solazzi et al. have focused on the weight optimization problem of hydraulic actuator that has many parameters with the help of a classical mechanic and finite element analysis (Solazzi et al., 2020). Ghasemi et al. studied on minimum mass **cost** and maximum buckling pressure of cylinders using **a** non-dominated sorting genetic algorithm (NSGA) Ghasemi et al., 2017).

Xu et al. have studied on disassembly that is key step of remanufacturing to improve resource utilization rate and reduce manufacturing cost. For disassembly process, they used BA to find optimal disassembly sequence. Thus, efficiency of disassembly has been increased (Xu et al., 2020).

Shouran et al. have focused tuning parameters of various controllers to stabilize and balance the frequency in the Great Britain (GB) power system and they applied BA algorithm for the problem. As a result of the studies, it has been observed that BA can significantly reduce the deviation in the frequency (Shouran et al., 2021).

Baronti et al. have searched mathematical analysis of BA's search capabilities and treated it as a mathematical description beyond the qualitive biological metaphor. They found that local search is mainly influenced by neighbourhood size rather than the number of sent foragers (Baronti et al., 2020).

Unal et al. have investigated on the cost-effective optimal dimensions of a solar chimney with BA and they determined sizes of collector diameter and chimney height that can be useful in the optimal design of solar chimney systems (Unal et al., 2022).

In the literature studies, various problems are defined and generally different optimization process has been applied depending on these problems. However, the number of studies examining the effect of algorithm parameters on optimization problem is insufficient. To fill this gap, firstly this study deals with the application of the BA for the optimum design of hydraulic cylinders and then effect of BA parameters on the optimization problem in terms of inside diameter, thickness, mass and elapsed time for solving the problem is compared via response surface design that is used for parameter optimization of algorithm. According to inferences, it is focused on the determination of the best parameter set for minimum computation time by using the response surface method and analysis of variance.

2. MATERIALS AND METHODS

2.1. Cylinder Components

Generally, structural steel is used in the pipe part of hydraulic cylinders, and tempered steel is used in other components. In this study, it is assumed that the specified materials are used. Cylinder components that are involved in the weight optimization problem are the barrel and piston rod. A schematic representation of cylinder components is given in Figure 1.

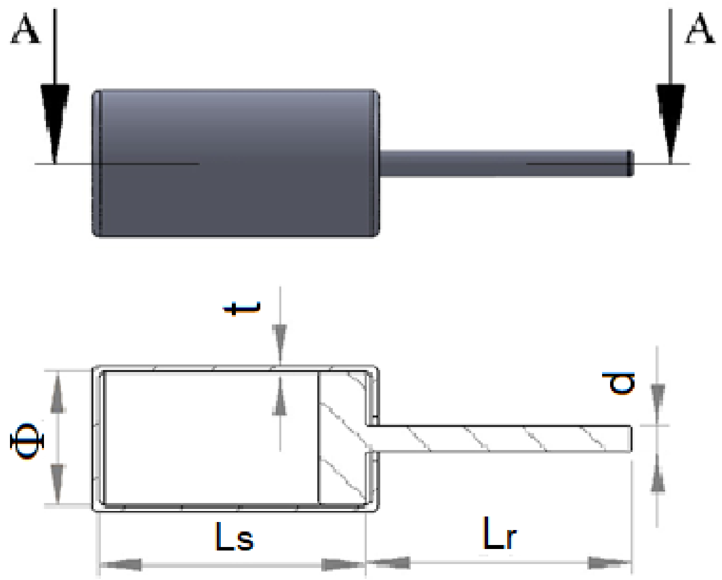

Figure 1. Schematic representation of cylinder

2.2. Obtaining Objective Function and Constraints

In this paper, weight optimization of **the** hydraulic cylinder has been carried out depending on the cylinder's inner diameter and wall thickness. The material of the cylinder is St37 steel. Constants and variables of **the** optimization problem **are** given in Tables 1-2.

Table 1. Given values of the optimization problem (Dengiz et al.,2018)

Constant	Symbol	Value
Density of material (kg/m³)	ϱ	7800
Elasticity modulus (GPa)	E	210
Yield strength (MPa)	σ_y	235
Force (kN)	F	500
Length of stroke (m)	L_s	0,5
Length of **the** rod (m)	L_r	0,5
Safety factor (plastic deformation)	m	2,5
Safety factor (buckling)	n	4

Table 2. Variables of the optimization problem

Variable	Symbol
Inside diameter of **the** cylinder (m)	Φ
Wall thickness of cylinder (m)	t
Pressure of liquid (Pa)	P
Rod diameter (m)	d

There are some physical equations in optimization problems to obtain objective functions and constraints. Force-pressure equality is given as in Equation 1.

$$\mathrm{F} = \frac{\mathrm{P}\pi\emptyset^2}{4} \quad 1$$

Tangential stress in **a** pressurized cylinder (given in Figure 2) can be found in Equations 2 – 4 (Beer et al., (2017).

$$\sum Fz = 0 = \sigma_1 dA - pdA \quad 2$$

$$\sum Fz = 0 = \sigma_1 2t\,\Delta x - p\emptyset\Delta x \quad 3$$

$$\sigma_1 = \frac{p\emptyset}{2t} \quad 4$$

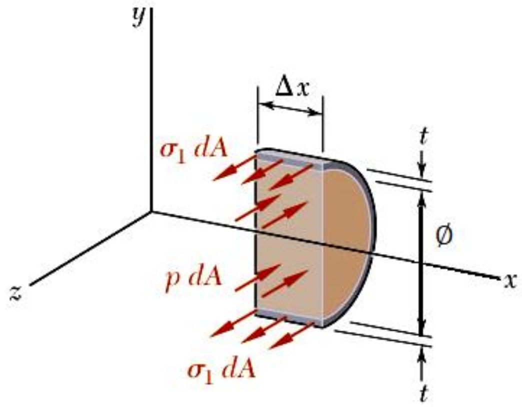

Figure 2. Tangential stress at the pressurized cylinder (Beer et al., (2017).

Tangential stress should be lower than the yield stress of the material. It is given in Equation 5:

$$\frac{P\emptyset}{2t} \leq \frac{\sigma_y}{m} \quad 5$$

The mass equation and volume calculation of the cylinder tube are given in Equations 6-8 respectively (Beer et al., (2017).

$$m = \rho V \quad 6$$

$$V = \left(\frac{\pi(\emptyset + 2t)^2}{4} - \frac{\pi\emptyset^2}{4}\right)L \quad 7$$

$$V = \pi t L\,(\emptyset + t) \quad 8$$

The objective function of the optimization problem is obtained as in Equation 9.

$$m = \rho\pi t L(\emptyset + t) \quad 9$$

If it is written $P\emptyset = \frac{4F}{\emptyset\,\pi}$ in Equation 1 and substituted in Equation 5, then Equation 10 is obtained:

$$\frac{4F}{2\pi\emptyset t} \leq \frac{\sigma_y}{m} \quad 10$$

The critical buckling load of the cylinder rod according to Euler's approach can be found in Equation 11 (Beer et al., (2017).

$$P_{cr} = \frac{\pi^2 EI}{{L_B}^2} \quad 11$$

L_B is taken $L_R + L_s$= 1m. I is the moment of inertia of the rod and found as in Equation 12 (Beer et al., (2017). The diameter of the rod can be found in the relation between critical buckling load and force.

$$I = \frac{\pi d^4}{64} \quad 12$$

Force acting on the cylinder should be lower than **the** critical buckling load as in Equation 13.

$$F \leq \frac{P_{cr}}{n} \quad 13$$

The constraints of the optimization problem are the following:

$$C1 => \frac{4F}{2\pi\emptyset t} \leq \frac{\sigma_y}{m} \quad 14$$

$$C2 => 20000000 - P \leq 0 \quad 15$$

$$C3 => \frac{P\emptyset}{2t} \leq \frac{\sigma_y}{m} \quad 16$$

$$C4 => F \leq \frac{P_{cr}}{n} \quad 17$$

2.3. The Bees Algorithm (BA)

Solution strategies of classical optimization algorithms generally depend on the objective function, types of constraints (linear, nonlinear, etc.), and types of variables. So classical optimization algorithms don't offer general solution strategies for optimization problems that have different types of variables, objective functions and constraints (Baykasoglu, 2006). Researchers have endeavored to adapt different optimization problems to classical optimization problems and it hasn't been easy. To overcome these shortcomings of classical optimization techniques, nature-inspired, heuristic optimizing algorithms are recommended. These techniques are both effective and more flexible and can be customized according to specific problems (Muhammed Arif, 2014).

BA algorithm which is a global search algorithm mimics honey bees' foraging method to obtain the best solution. It is one of the metaheuristic optimization types for learning, remembering, sharing information, searching for resources and obtaining optimum results by moving away from the penalty area (Pham et al., 2006).

The basic BA requires a number of parameters to be set and these are as follows: the number of explorer or scout bees (n), number of the most suitable sites among the n points visited (m), number of top rated (elite) sites among the m selected sites (e), number of bees recruited for the best e sites (nep), the number of bees sent to the remaining (m-e) area (nsp), the region size (ngh) and stopping criterion (itr) (Ilgen et. al., 2022). The flowchart of the BA is given in Figure 3. Boundary conditions for $\emptyset$ and t variables are determined as follows:

$\emptyset$ = [0.1   0.6] m
t = [0.001 0.03] m

The searching area of the bees is shown in Figure 4.

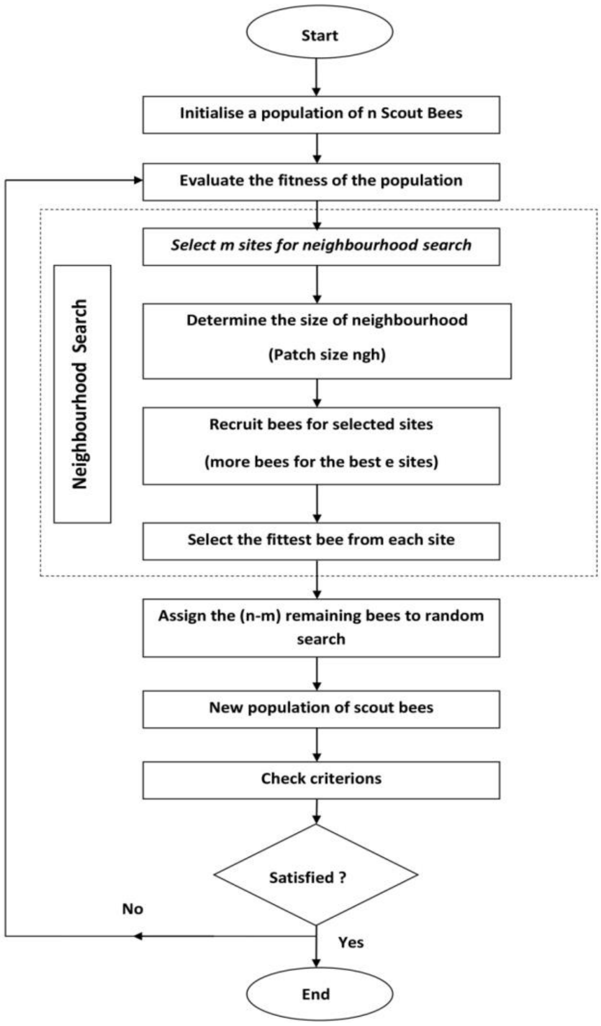

Figure 3. Flowchart of BA (Sen et al., 2015).

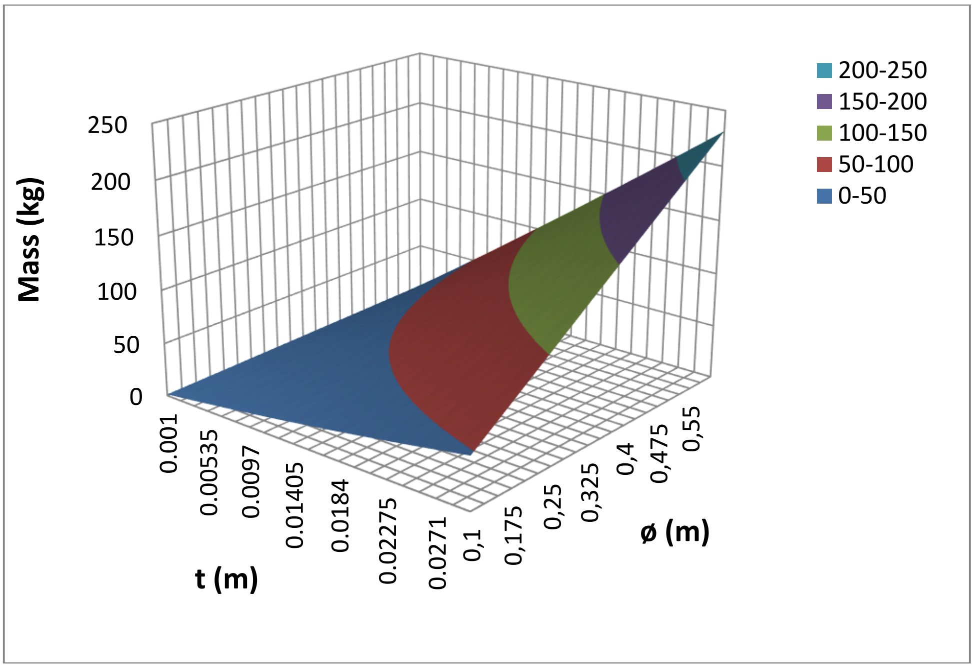

Figure 4. Searching area of the bees

BA parameters that **are** used in optimization problem solutions are given in Table 3.

Table 3. Parameters of BA that **are** used in optimization problem solution

n	m	e	nep	nsp	ngh	itr
20	8	5	20	10	.01	20

Each parameter is applied for five different values as given in Table 4 and the effect of BA parameters on the optimization problem in terms of inside diameter, thickness, mass and elapsed time for solving the problem is compared via response surface design that is used for parameter optimization. Eighty-eight experimental designs were performed for a combination of seven BA parameters.

Table 4. Parameters of BA

n	**m**	**e**	**nep**	**nsp**	**ngh**	**itr**
20	8	3	20	5	.01	10
40	10	4	30	10	.02	20
60	12	5	40	15	.03	30
80	14	6	50	20	.04	40
100	16	7	60	25	.05	50

3. RESULT AND DISCUSSION

The mass optimization problem of the cylindrical tube is created and solved using Matlab R2020b. Intel Core i7-2670QM CPU 2.20 GHz processor is used for analysis. The optimum mass that depends on the inside diameter (∅) and wall thickness (t) value of the cylinder is obtained. Data obtained from each of the 20 bees at the end of the 20th iteration according to the Matlab solution is shown in Figure 5.

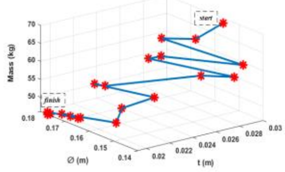

Figure 5. Obtained data from the bees

When the integer value of the wall thickness is preferred for the accessibility of cylindrical metallic pipes, optimum ∅ and t parameter values that provide mass minimization are given in Table 5.

Table 5. Optimum parameter values for mass minimization

∅ (mm)	t (mm)	Mass (kg)
171,2	20	46,8

Cylinder components that are involved in mass minimization are cylinder tubes and piston rods. Tube's mass optimization is provided with basic BA. The rod diameter of the cylinder is calculated considering buckling load as in Equation 13 and found that it should be larger than 66,3 mm. If it is chosen simply 67 mm, the mass of the rod is found 27,5 kg according to Equation 18.

$$m_{rod} = \rho \frac{\pi d^2}{4} L_r \quad (18)$$

The required fluid pressure that is needed for opening the cylinder for ∅ = 0,177 m is found at 202,7 Bar according to Equation 19.

$$P_o = \frac{4F}{\pi \emptyset^2} \quad (19)$$

Required fluid pressure that needed for closing cylinder for ∅ = 0,177 m and d= 0,067 m is found 236,6 Bar according to equation 20.

$$P_c = \frac{4F}{\pi(\emptyset^2 - d^2)} \quad (20)$$

With the choice of 250 bar pump, the active opening (F_{AO}) and closing force (F_{AC}) of the cylinder can be determined. F_{AO} and F_{AC} should be greater than the opening and closing force values and can be calculated as equations 21-22.

$$F_{AO} = \frac{P_{pump}\, \pi \emptyset^2}{4} \quad (21)$$

$$F_{AC} = \frac{P_{pump}\, \pi(\emptyset^2 - d^2)}{4} \quad (22)$$

F_{AO} and F_{AC} are obtained at 616,5 and 528,4 kN respectively. These values are greater than the opening and closing force values that are given and calculated as 500 and 428,4 kN.

After the mass optimization process is completed, the effects of BA parameters on mass, inside diameter, thickness and solution time are achieved by Response Surface Method. For this, eighty-eight experimental designs are performed using different combinations of parameters as in Table 6. As can be seen from Table 6, although the parameters of the algorithm are changed, the minimum mass value remains the same with a small standard deviation. However, the time required for a solution varies widely.

Table 6. Experimental designs data depend on all BA parameters

n	itr	m	e	nsp	nep	ngh	Ø (m)	t (m)	mass (kg)	time (s)
80	40	14	6	10	50	0.02	0,1779	0,019	45,946	384,9
60	30	16	5	15	40	0,03	0,1769	0,0192	46,0248	169,3
40	20	10	6	10	30	0,02	0,1775	0,0191	46,0277	67,3
80	40	10	4	10	30	0,04	0,1778	0,0191	45,9728	391,1
40	20	14	6	10	30	0,04	0,1764	0,0192	46,0205	70,5
80	40	10	6	20	30	0,04	0,1773	0,0191	46,0089	401,7
80	40	14	4	10	50	0,04	0,1775	0,0191	45,9692	394,5
80	40	10	4	20	50	0,04	0,1778	0,0191	45,9936	422,2
40	40	10	4	20	50	0,02	0,1774	0,0191	45,9667	159,9
60	30	12	5	15	40	0,01	0,1777	0,0191	46,0178	170,1
40	40	14	4	10	50	0,02	0,1779	0,019	45,9533	160,7
40	20	10	4	20	30	0,02	0,1776	0,0191	46,0615	65,3
80	20	14	6	10	50	0,04	0,1768	0,0192	46,0726	140,2
40	40	14	6	20	50	0,02	0,1770	0,0191	45,9971	169
60	30	12	5	15	20	0,03	0,1772	0,0191	45,9799	172,4
60	30	12	5	15	40	0,03	0,1770	0,0191	45,9899	174
40	40	10	4	20	30	0,04	0,1774	0,0191	46,0084	156,8
80	20	14	4	20	50	0,04	0,1783	0,019	46,0068	142,7
60	30	12	3	15	40	0,03	0,1746	0,0194	46,135	179,2
40	40	10	6	10	50	0,02	0,1778	0,0191	45,9563	163,8
80	20	14	6	10	30	0,02	0,1780	0,019	45,9414	133,7
80	40	10	6	10	30	0,02	0,1766	0,0192	46,0583	396,7
60	30	12	5	15	40	0,03	0,1780	0,0191	46,0294	169,4
60	30	12	5	15	40	0,03	0,1779	0,0191	45,9685	174,9
80	40	14	6	20	30	0,02	0,1782	0,019	45,9752	399
60	30	12	5	15	40	0,03	0,1781	0,019	45,9282	172,9
60	30	12	5	25	40	0,03	0,1783	0,019	45,9148	167,7
40	40	10	4	10	30	0,02	0,1764	0,0192	46,0546	164
60	30	12	5	15	40	0,03	0,1777	0,0191	45,9532	170,2
80	20	10	4	10	30	0,02	0,1753	0,0193	46,1121	132,6
40	40	14	4	10	30	0,04	0,1769	0,0192	46,0053	156
80	20	10	4	20	30	0,04	0,1781	0,0191	46,0515	130,8
60	30	12	5	15	40	0,03	0,1782	0,0191	46,0376	172
80	20	14	4	10	30	0,04	0,1760	0,0192	46,0465	131,9
20	30	12	5	15	40	0,03	0,1754	0,0193	46,0648	61,5
80	40	14	6	10	30	0,04	0,1755	0,0193	46,0697	406,4
40	40	10	6	20	50	0,04	0,1776	0,0191	45,9661	158,3
60	30	12	5	15	40	0,03	0,1776	0,0192	46,0172	170,9
60	30	12	5	15	40	0,03	0,1751	0,0194	46,1244	175,5
80	40	14	4	20	50	0,02	0,1769	0,0191	45,9816	394,9
80	40	10	6	20	50	0,02	0,1777	0,0191	46,0277	387,5
80	20	14	6	20	50	0,02	0,1778	0,019	45,9454	134,9
80	40	10	6	10	50	0,04	0,1783	0,019	46,0415	380,2
80	20	14	4	10	50	0,02	0,1765	0,0192	45,9992	135,2
60	30	8	5	15	40	0,03	0,1763	0,0192	46,0257	166,9
60	30	12	7	15	40	0,03	0,1784	0,0191	46,1091	165,1
40	40	10	6	10	30	0,04	0,1774	0,0191	46,0021	158,7

40	20	14	6	10	50	0,02	0,1776	0,0191	46,0542	70,6
80	20	10	6	10	30	0,04	0,1776	0,0192	46,1976	134,2
80	40	10	4	10	50	0,02	0,1772	0,0191	46,0178	376,1
80	20	10	6	10	50	0,02	0,1773	0,0191	45,9814	133
60	30	12	5	15	40	0,03	0,1760	0,0193	46,0644	164,8
40	40	10	6	20	30	0,02	0,1779	0,019	45,9535	159
40	20	10	4	10	50	0,02	0,1759	0,0193	46,0748	64,9
40	20	14	4	20	50	0,02	0,1772	0,0191	46,0248	70
80	40	10	4	20	30	0,02	0,1778	0,019	45,9341	370,3
40	40	14	4	20	50	0,04	0,1782	0,0191	46,0745	164,4
80	20	10	4	10	50	0,04	0,1764	0,0192	46,0366	160,8
40	40	14	6	10	30	0,02	0,1781	0,019	45,9695	160,3
80	20	10	6	20	30	0,02	0,1783	0,019	45,9222	140,2
40	20	14	4	20	30	0,04	0,1789	0,0192	46,3856	64,1
80	20	14	4	20	30	0,02	0,1759	0,0193	46,0627	136,4
40	20	10	6	20	50	0,02	0,1780	0,019	45,9342	68,8
60	30	12	5	5	40	0,03	0,1773	0,0191	45,9864	169,2
40	40	10	4	10	50	0,04	0,1769	0,0191	45,9823	154,5
40	20	10	6	10	50	0,04	0,1780	0,019	45,9443	66,3
80	20	10	6	20	50	0,04	0,1781	0,019	45,957	134,2
80	40	14	6	20	50	0,04	0,1784	0,019	46,0551	382,9
60	50	12	5	15	40	0,03	0,1771	0,0191	46,0127	362,2
40	20	14	4	10	50	0,04	0,1779	0,0191	46,0371	69,9
40	20	14	6	20	30	0,02	0,1752	0,0193	46,0784	66,4
40	20	14	4	10	30	0,02	0,1774	0,0191	45,9797	65,8
40	40	14	6	20	30	0,04	0,1773	0,0192	46,1751	162,5
40	40	14	4	20	30	0,02	0,1772	0,0191	45,9785	163,4
40	20	10	4	10	30	0,04	0,1761	0,0192	46,0529	65,2
80	20	14	6	20	30	0,04	0,1777	0,0191	46,0106	135
40	40	14	6	10	50	0,04	0,1776	0,0191	45,9472	157,7
100	30	12	5	15	40	0,03	0,1759	0,0193	46,1607	328,5
80	20	10	4	20	50	0,02	0,1768	0,0192	45,9843	130,6
60	10	12	5	15	40	0,03	0,1781	0,019	45,9429	43,1
40	20	14	6	20	50	0,04	0,1748	0,0194	46,2542	67,1
60	30	12	5	15	60	0,03	0,1759	0,0192	46,0314	166,5
40	20	10	4	20	50	0,04	0,1755	0,0193	46,1437	66,4
60	30	12	5	15	40	0,03	0,1777	0,0191	45,9506	166,6
40	20	10	6	20	30	0,04	0,1757	0,0193	46,0755	67,3
80	40	14	4	10	30	0,02	0,1780	0,019	45,9463	408,5
80	40	14	4	20	30	0,04	0,1775	0,0191	45,9736	407,9
60	30	12	5	15	40	0,05	0,1761	0,0192	46,0477	176,1
40	20	14	6	20	50	0,04	0,1748	0,0194	46,2542	67,1
60	30	12	5	15	60	0,03	0,1759	0,0192	46,0314	166,5
40	20	10	4	20	50	0,04	0,1755	0,0193	46,1437	66,4
60	30	12	5	15	40	0,03	0,1777	0,0191	45,9506	166,6
40	20	10	6	20	30	0,04	0,1757	0,0193	46,0755	67,3
80	40	14	4	10	30	0,02	0,1780	0,019	45,9463	408,5
80	40	14	4	20	30	0,04	0,1775	0,0191	45,9736	407,9
60	30	12	5	15	40	0,05	0,1761	0,0192	46,0477	176,1

A ccording to the results, it is observed that the number of bees (n) and the number of iterations (itr) have a remarkable effect over the solution time. The main effects and interaction plots of all algorithm parameters over time are given in Figures 6-7. As seen in the figures, n and itr have a clear effect on the solution time. However, it is seen that other parameters don't have a clear effect on the solution time.

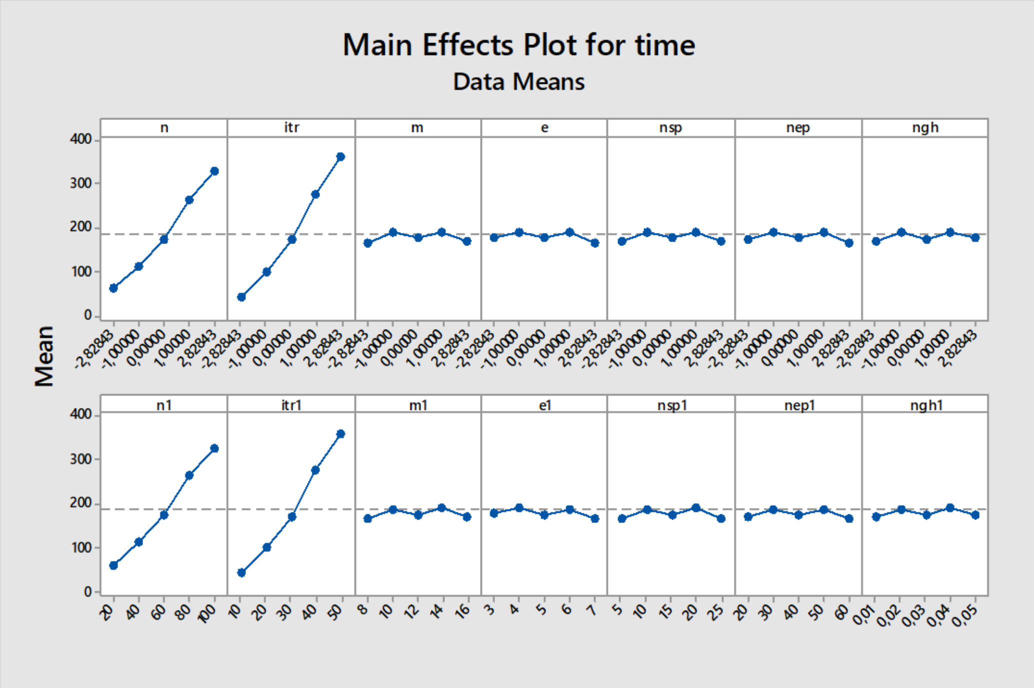

Figure 6. Main effects of BA parameters over time

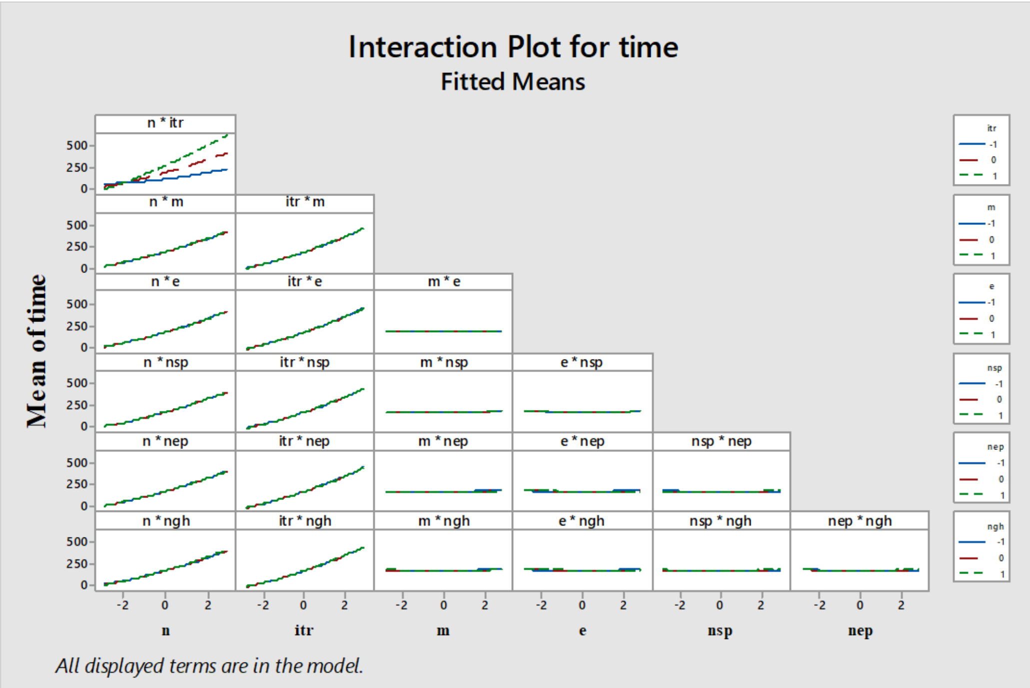

Figure 7. Interaction effects of BA parameters over time

After determining the most effective parameters over time (n, itr or their interaction), the pure effect of n and itr parameters on solution time is analyzed, keeping the other five BA parameters (m, e, nsp, nep, ngh) constant. For this, thirteen experimental designs are performed using different combinations of n and itr parameters as can be seen in Table 7.

Table 7. Experimental design data depend on n and itr parameters

n	**itr**	**Ø** (m)	**t** (m)	**mass** (kg)	**time** (s)
60	30	0,1769	0,0192	46,0231	197,09
60	10	0,1735	0,0195	46,2288	44,18
80	40	0,1779	0,019	45,955	389,52
60	30	0,1767	0,0192	46,0215	164,29
40	40	0,1779	0,019	45,946	162,77
40	20	0,1782	0,019	45,9315	64,5
100	30	0,178	0,0191	46,0508	341,56
60	50	0,1783	0,019	45,9864	341,39
60	30	0,1784	0,019	45,9784	156,2
20	30	0,1757	0,0193	46,1319	60,24
60	30	0,1781	0,019	46,0142	159,28
80	20	0,1779	0,0191	46,0028	126,51
60	30	0,178	0,019	45,9784	165,38
60	30	0,1769	0,0192	46,0231	197,09
60	10	0,1735	0,0195	46,2288	44,18
80	40	0,1779	0,019	45,955	389,52

The main effects and interaction plots of n and itr algorithm parameters over time are given in Figures 8-9.

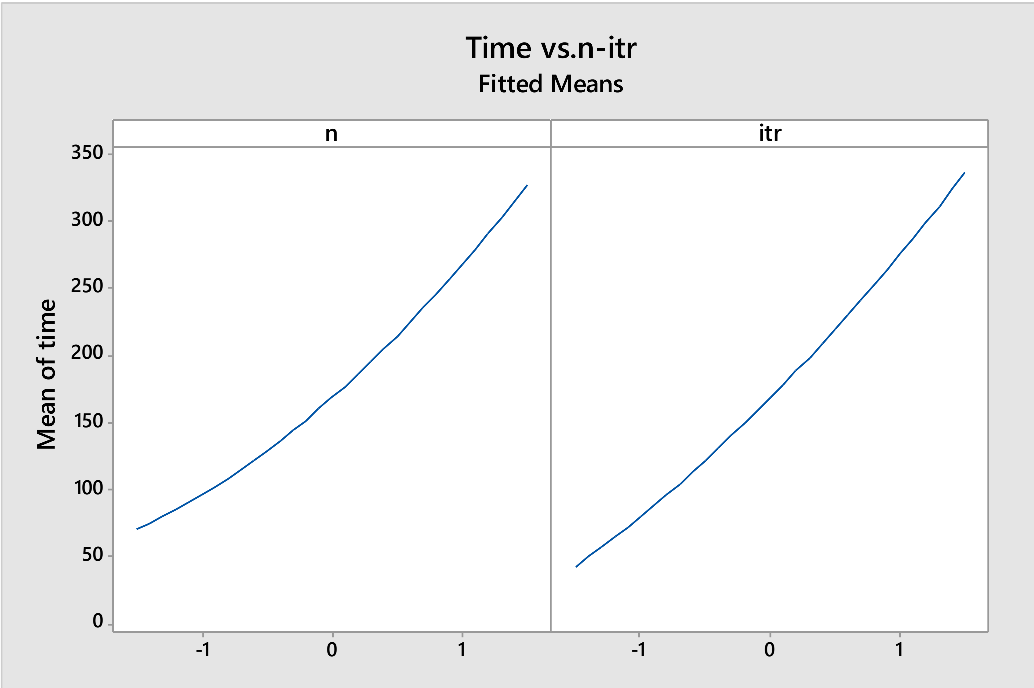

Figure 8. Main effects of n and itr parameters' over time

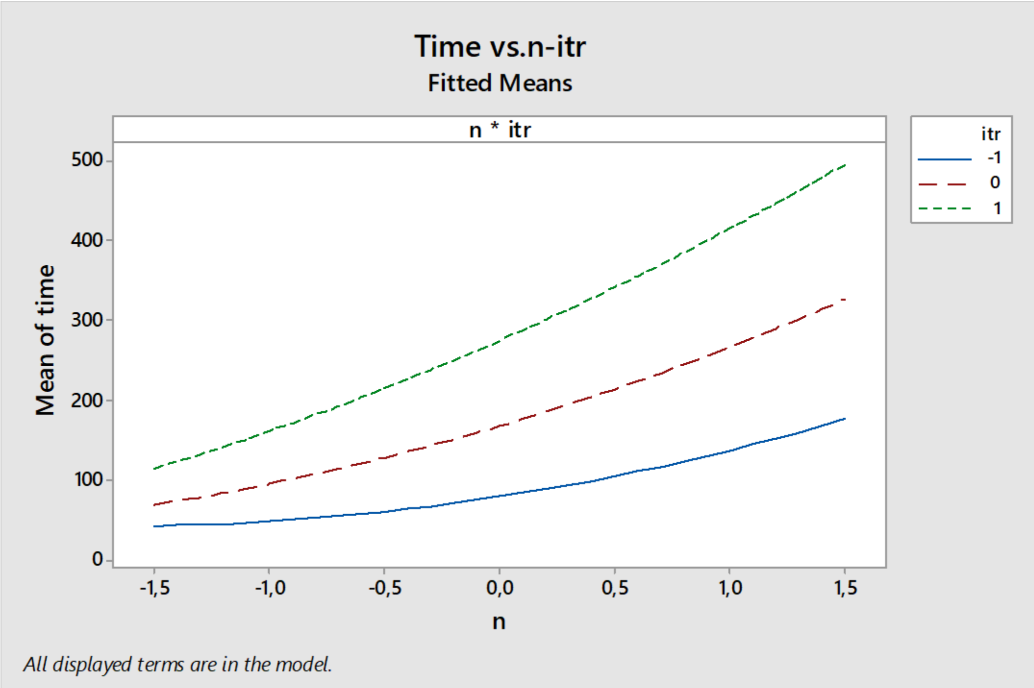

Figure 9. Interaction effects of n and itr parameters' over time

The variance analysis table obtained as a result of the statistical calculations mentioned above is presented in Table 8. As can be seen in the table, the number of bees(n) and the number of iterations (itr) have a significant effect on the solution time. It is evaluated that this significant effect is linear and cross interactions and/or quadratic terms also, but remains outside the level of significance. In the light of the obtained data, it is evaluated that the time required for the solution can be expressed with equation 23, the relative effects of the number of iterations and the number of bees on total time are 52% and 40% respectively, and that the other parameters contribute around 8% in total.

Time = 168,45 + 85,83 n + 97,7 itr + 13,47 n*n + 9,41 itr*itr + 41,2 n**itr* 23

Table 8. Results of variance analysis

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	5	143753	28750,6	61,98	0
Linear	2	135291	67645,3	145,83	0
n	1	58929	58928,6	127,04	0
itr	1	76362	76362	164,62	0
Square	2	1677	838,7	1,81	0,233
n*n	1	1263	1262,5	2,72	0,143
İtr*itr	1	617	616,5	1,33	0,287
2-way interaction	1	6785	6784,8	14,63	0,007
n*itr	1	6785	6784,8	14,63	0,007
Error	7	3247	463,9		
Lack-of-Fit	3	2166	722	2,67	0,183
Pure Error	4	1081	270,3		
Total	12	147000			

4. CONCLUSIONS

In this study, the availability of the Bees Algorithm is investigated **to** optimize the geometry of hydraulic cylinders. Required objective functions and constraints are presented for the hydraulic cylinder to have a minimum weight without buckling under a certain opening and closing load. Since BA has many parameters, the issue of which parameters should be selected is also examined. For this purpose, experimental design is carried out with the response surface method and the problem is solved by using a total of 88 parameter sets. Obtained optimum geometric parameters and the required time to achieve this result is evaluated. In light of the findings, it has been shown that BA can be used in the solution of the problem in question. In addition, it is observed that the results for the specified 88 different sets are the same with a very small standard deviation, but the time required to reach the result is directly related to the parameters of the selected algorithm. It has been shown that the solution time is directly related to the number of bees and the number of iterations, but the other parameters of the algorithm don't have a significant effect on the solution time.

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