Application of Genetic Algorithm to Determine the Optimal Technical Data Domain of a Percussion Hammer with Acceleration ability of Dust Settling, Satisfying the Durability of Collecting Plate

Nguyen Tien Sy
Hanoi University of Industry, No. 298, Cau Dien Street, Bac Tu Liem District, Hanoi, Vietnam
tiensyhaui.edu@gmail.com

Hoang Van Got
National Research Institute of Mechanical Engineering, No. 4, Pham Van Dong Street, Bac Tu Liem District, Hanoi, Vietnam

Duong Van Long
National Research Institute of Mechanical Engineering, No. 4, Pham Van Dong Street, Bac Tu Liem District, Hanoi, Vietnam
longdv.mt@narime.gov.vn

Hoang Trung Kien
National Research Institute of Mechanical Engineering, No. 4, Pham Van Dong Street, Bac Tu Liem District, Hanoi, Vietnam
kienvairo@gmail.com

***Abstract*—This article studies the influence of some technological parameters of the hammer type on the ability of dust settling of the deposition electrodes in electrostatic precipitators.The methods of regression analysis and genetic algorithm are tools to determine the mathematical relationship between the technological parameters, impact force of a hammer and propagation acceleration of tension waves (quantity impacts to the ability of dust settlingThe results obtained in the study will be used as reference material when designing the percussion of electrostatic precipitators with different dust filtration capacities**

Keywords—Electrostatic precipitator, hammer rapping, collecting flate, percussion force and acceleration

I. INTRODUCTION

In a electrostatic precipitator, in order to separate the dust from the surface of deposition electrodes, the principle of impact impulse transmission is applied, the hammer's impact on the end of cross-bas(anvil) of deposition electrodes is carried out on the principle of periodic free fall. At the location of impact, the impulse is occurred and creates stress waves that propagate in the deposition electrode.The wave energy will generate acceleration at every point on the plate [6]. In order to separate the dust particles (positively charged) attached to the surface of the plate (negative charged), the acceleration value of the wave must reach a certain value, creating a force that can overcome the electrostatic attraction between the deposition electrodes and dust particles [3].This study aims to find out the influence relationship between the technological parameters of the hammer on the acceleration with the value within the range that satisfies the durability condition of deposition electrodes

II. THEORETICAL BASIS OF DUST SETTLING

The ability of dust settling is the level of separating clean dust on the surface of deposition electrodes after the hammer force has applied to the anvil of deposition electrodes. The dust cleanliness on the surface of filters affects the ability of electrostatic attraction among dust particles. For the purpose of evaluating the ability of dust settling, they use the acceleration quantity (a) of stress wave [4] which is related to percussion force (F) and described by a general mathematical relation function (1) [1]:

$$a = f_1(F) \qquad (1)$$

While the percussion force (F) depends on the mass parameters of the hammer block (m_1) and the drop height of hammer (H). The impact process is described as Figure 1 [2].

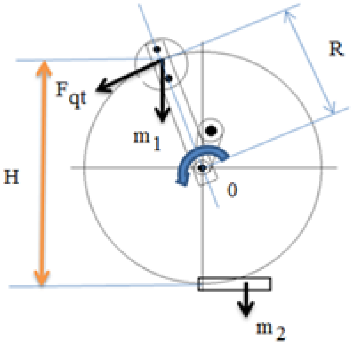


Figure 1. Diagram of the impact principle by percussion hammers

The relationship between the technological parameters of a hammer and the percussion force is described by a general mathematical function (2):

$$F= f_2(\varphi, m_1, H) \qquad (2)$$

Of which: φ - angle of hammer falling; m_1 - weight of the percussion hammer; H - dropping height of hammer

III. EXPERIMENTAL STUDY

A. Matrix design

When the hammer moves to the maximum potential energy and is aligned with the vertical direction to be an angle (φ), it performs a free-fall motion in a circular orbit around a fixed axis with a radius (R) and impacts to an anvil, the height of hammer falling (Hi) is calculated by the formula (3) [3].

$$H_i = R(1 - \cos\varphi) \qquad (3)$$

According to the practical experience form the manufacturers of electrostatic precipitators, the rotatory radius of the hammer is taken from (0,25 to 0,29m), the height of hammer falling is calculated according to formula (3) and recorded in Table 1.

Table 1. Value at levels for parameters

No.	Factors	Levels		
		Up (1)	Base (0)	Low (-1)
1	Weight of a percussion hammer m_1(N)	90	70	50
2	Dropping height of hammer H_i (m)	0.57	0.53	0.49

The percussion force before the impact of the hammer and deposition electrode is determined by formula (4):

$$F = m_1\frac{\Delta V}{\Delta t} = m_1\sqrt{2gR(1-\cos\varphi)} \qquad (4)$$

Replacing the values (m1, R, φ = 165^0) into formula (4) will get the corresponding value of percussion force (F) and recording them in Table 2. The number of affecting factors is 2, each factor changes 2 levels, therefore, the number of tests to be carried out is N = 2^2 = 4, combined with 1 central test, thus N = 5 test [5].

Assigning variables: (X_1 - weight of a percussion hammer; X_2 - dropping height of hammer)

Table 2. Table of experimental results

No	X1	X2	m1 (N)	H (m)	F (N/m)
1	-1	-1	50	0.49	217.26
2	1	-1	90	0.49	391.07
3	**1**	**1**	**90**	**0.57**	**421.79**
4	-1	1	50	0.57	234.33
5	0	0	70	0.53	316.34

B. Data processing

1) Pareto analysis

From the testing data in Table 2, using Minitab statistical analysis software and Pareto diagram is obtained as shown in Figure 2 [13]

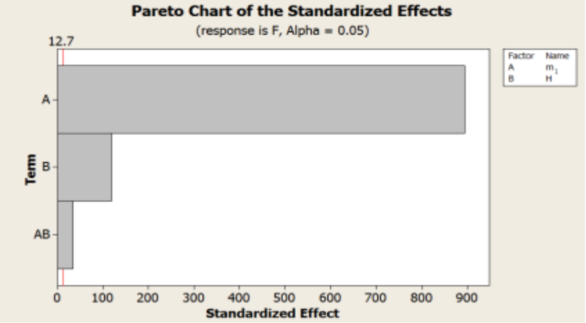


Figure 2. Diagram of the influence of variables on the percussion force

Pareto diagram shows that the factors A and B all have influence on the percussion force, of which the biggest influence A is equal to the hammer weight m1, in addition the interaction between A and B also has a small influence.This is the basis for designing the input parameters of the acceleration measurementtest on the deposition electrode of electrostatic precipitators [8].

2) Regression function to experiment percussion force with hammer parameters

Based on the correlation of the dust settling percussion, select the regression function in the form of reduced first order (5), then check the model's compatibility, if the model is compatible, then stop, but if it is not compatible, we will raise the order and check until the model is compatible and then stop [5] [13].

$$y = a_0 + a_1x_1 + a_2x_2 + a_{12}x_1 x_2 \qquad (5)$$

Of which:y - the value of percussion force (F)

x_1- value of the hammer weight (m_1)

x_2 - value of hammer falling height (H);

a_i - regression coefficient

At that time, the equation (5) becomes (6):

$$F = a_0 + a_1m_1 + a_2H+ a_{12}m_1H \qquad (6)$$

Using the statistical analysis method in Excel, we obtain the coefficients of the regression function (6) as shown in Table 3:

Table 3. Analyzing the influence of technological factors with percussion force

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.999999387
R Square	0.999998775
Observations	5

ANOVA

	df	SS	MS	F	Significance F
Regression	3	33246.0589	11082.0196	272099.61	0.001409241

	Coefficients	Standard Error	t Stat	P-value	Lower 95%
Intercept	-2.60781	0.09025276	3502.99241	0.0001817	315.0079638
m	2.33472	0.100905653	895.064129	0.0007113	89.03490282
H	0.09375	0.100905653	118.384837	0.0053774	10.66357144
m*H	4.26563	0.100905653	33.8242392	0.0188159	2.130929062

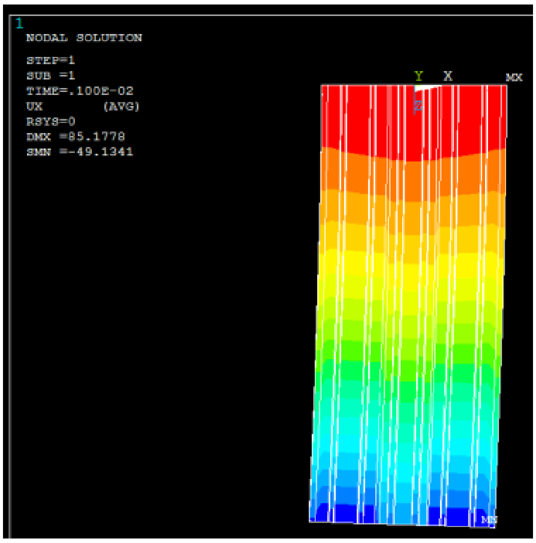
Replacing the value of regression coefficients in column (df) corresponding to the variables in table 4, we obtain the equation (7)

$$F = -2{,}60781+2{,}33472*m+0{,}09375*H+4{,}26563*m*H \qquad (7)$$

The testing material is CT3 steel (standard of Supreme Soviet) with the yield strength σ = 25 (kN/cm²). In order to ensure the service life of the equipment within the yield strength of the material, choose a safety factor (k = 0.8) less than the permissible yield strength [σ_{ch}] as [9]:

$$[\sigma] = k*\sigma = 25*0.8 = 20 \ (kN/cm^2) \qquad (8)$$

Using the Ansys workbench tool to analyze the stress and deformation on deposition electrodes. When there is external force, the computer screen will display the stress distribution domain of the plate in color as shown in Figure 3, observing if the yield strength of the material is more than the permissible yield strength [σ_{ch}], then stop the analysis and record the corresponding maximum stress result in Table 4.



```
1
NODAL SOLUTION

STEP=1
SUB =1
TIME=.100E-02
UX         (AVG)
RSYS=0
DMX =85.1778
SMN =-49.1341
```

Figure3. The change in stress on the plate surface

Table 4. Maximum stress with corresponding stimulating force

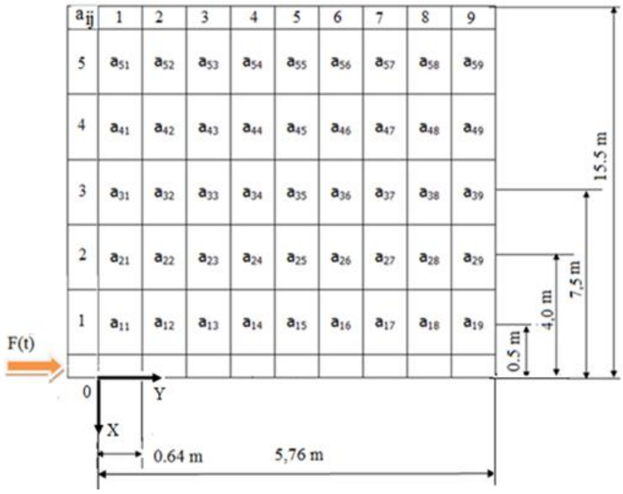
Name	Value of parameters				
Hammer weight m_1 (N)	50	60	70	80	90
Force F(N)	217.26	260.71	316.34	374.92	421.79
Stress (kN/cm^2)	15.062	**16.377**	**17.251**	**18.076**	21.088

According to the durability condition (8), choose the value domain of hammer weight parameter (m_1 = 60N to 80N) to perform experiments of measuring acceleration (a) that propagates in the deposition electrodes.

C. Experimenting to determine the relationship between the percussion force and the acceleration

Carrying out 3 tests of measuring acceleration (a) on deposition electrodes with an area of (L*B = 15,5*5,76 m^2) with the corresponding hammer weight of (60N, 70N, 80N).The location diagram of measurement points on 9 plates is shown as Table 5 [10].

Table 5. Grid for measuring acceleration on the Colecting flate



a_{ij}	1	2	3	4	5	6	7	8	9
5	a_{51}	a_{52}	a_{53}	a_{54}	a_{55}	a_{56}	a_{57}	a_{58}	a_{59}
4	a_{41}	a_{42}	a_{43}	a_{44}	a_{45}	a_{46}	a_{47}	a_{48}	a_{49}
3	a_{31}	a_{32}	a_{33}	a_{34}	a_{35}	a_{36}	a_{37}	a_{38}	a_{39}
2	a_{21}	a_{22}	a_{23}	a_{24}	a_{25}	a_{26}	a_{27}	a_{28}	a_{29}
1	a_{11}	a_{12}	a_{13}	a_{14}	a_{15}	a_{16}	a_{17}	a_{18}	a_{19}

The experimental results of the test are shown in Table 6.

Table 6. Acceleration measurement results with the hammer weight of 60N, 70N, 80N

No	Measurement point (a_{ij})	Test 1		Test 2		Test 3	
		Hammer weight (N)	Acceleration a(m/s^2)	Hammer weight (N)	Acceleration a(m/s^2)	Hammer weight (N)	Acceleration a(m/s^2)
1	a11	60	2307	70	2213	80	2333
2	a12		1945		2109		2213
3	a13		1935		2003		2207
4	a14		1745		1956		2128
5	a15		1794		1889		2004
6	a16		1596		1790		1978
7	a17		1539		1677		1730
8	a18		1239		1588		1712
9	a19		1134		1389		1632
10	a21		2019		2100		1301
11	a22		1901		2008		2102
12	a23		1802		1978		1983
13	a24		1688		1656		2011
14	a25		1745		1726		1902
15	a26		1478		1487		1930
16	a27		1476		1477		1743
17	a28		1145		1243		1674
18	a29		1020		1954		1324
19	a31		1933		1879		2100
20	a32		1867		1869		1912
21	a33		1830		1865		1901
22	a34		1704		1700		1933
23	a35		1693		1345		1832
24	a36		1389		1343		1865
25	a37		1390		1132		1670
26	a38		1034		1980		1589
27	a39		957		1802		1458
28	a41		1890		1980		2008
29	a42		1783		1802		1980
30	a43		1759		1862		1857
31	a44		1809		1655		1854
32	a45		1576		1789		1893
33	a46		1460		1577		1789
34	a47		1345		1232		1567
35	a48		987		1085		1403
36	a49		833		940		1330
37	a51		1703		1900		1998
38	a52		1720		1798		1867
39	a53		1600		1689		1720
40	a54		1789		1567		1789
41	a55		1409		1580		1730
42	a56		1399		1432		1682
43	a57		1203		1089		1420
44	a58		1094		998		1329
45	a59		760		858		1206
Average			**1543**		**1644**		**1790**

From the acceleration results (a) in Table 6, calculating the average acceleration value corresponding to the percussion force value (F) and recording them in Table 7.[12]

Table 7. The relationship of percussion force with average acceleration

No	Force F (N)	Average acceleration a (m/s^2)
1	260.71	1543
2	316.34	1644
3	374.92	1790

The regression equation describing the relationship between the percussion force (F) and the acceleration (a) has the form: $\hat{y}_x = b_0 + b_1x$ (9)

Of which: x – percussion force (F)
y – acceleration (a)

Using the statistical analysis method and it is expressed on the graph of the regression function in Figure 4.

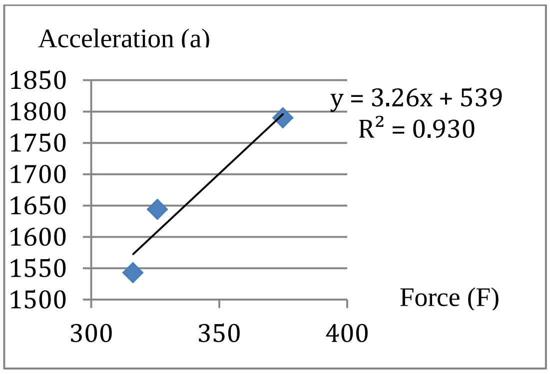


Figure 4. Correlation regression graph of the force and acceleration

Replaceingthe variable of percussion force (F) and acceleration (a) into the regression equation (y = 3.26x + 539), we have:

$$a = 539 + 3.26 F \quad (10)$$

IV. OPTIMMINING THE OPTIMAL VALUE DOMAN OF FERCUSSION HAMER PARAMETERS WITH ACCELERATION

From the equations (6) and (10), using the GA (Genetic Algorithm) source [6] to optimize multiple targets in order to find the optimal parameter domain of the percussion hammer to create the acceleration value which is capable of dust settling and satisfies the durability of the deposition electrodes. The optimization diagram is shown in Figure 5.

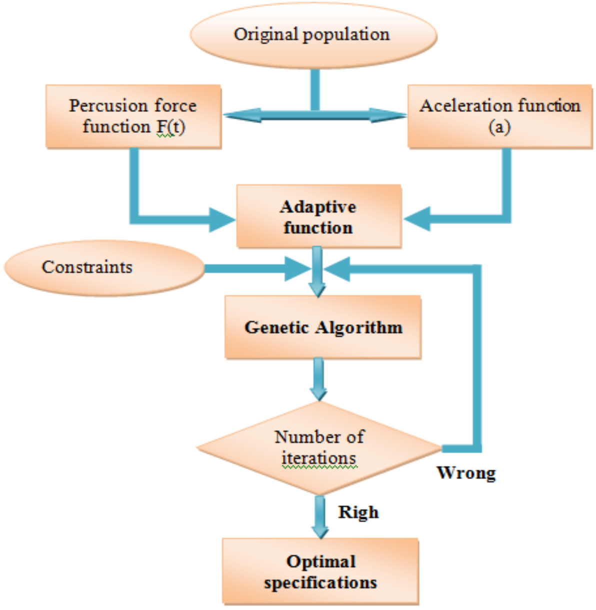


Figure 5. Block diagram of solving the optimal problem to target the process of dust settling percussion

In which:

- The original population is the input parameters of the process, in this problem including: percussion hammer weight (m1) and drop height (H).
- Hammer percussion force function (F) and acceleration function (a) are single target functions.
- The adaptive function is a multi-objective function and is a function of single target functions.
- Constraints include function and variable constraints, function constraints in terms of typing force and acceleration, and binding variables are percussion technology parameters (m_1, H).
- The selection, hybridization and mutation steps are the steps of genetic algorithm.
- The number of iterations to create the best of the selected individuals and the purpose is to give optimal parameters.

A. *Multi-objective function*

Dust settling percussion needs to create a force (F) large enough to have an acceleration (a) and be capable of separating dust from the deposition electrodes surface. However, that force must satisfy the permissible strength limit of the plates. Thus the multi-objective function needs to satisfy the condition:

- The smallest in terms of acceleration value: a ⟶ Min
- The smallest in terms of deformation characterized by yield stress: σ ⟶ Min

B. Constraints

1) Function constraint

Are regression functions relating to the force of the hammer percussion with the technological parameters of the hammer percussion and the force of the percussion force with the acceleration of the deposition electrodes, showing the system of equations (11).

$$\begin{cases} F = -2{,}60781 + 2{,}33472m + 0{,}09375H + 4{,}26563mH \leq F^* \\ a = 539 + 3{,}26\,F \leq a* \end{cases} \quad (11)$$

(F*) and (a*) are is the boundary limit of percussion force and acceleration. It is determined by analytical method and reference to production practices:

F*= 374,92 (N) ; a* = 200g (m/s^2) [7].

2) Variable constraint

Is a condition that limits the working parameters of the dust settling percussion, determined by analytical method, numerical simulation analysis method on Ansys and practical testimonials from manufacturers of electrostatic precipitators [7], which is expressed as (12).

$$\begin{cases} 50g \leq a \leq 200g\ \left(\frac{m}{s^2}\right) \\ [\sigma] \leq 19{,}23\ \left(\frac{kN}{cm^2}\right) \\ 60 \leq m_1 \leq 80\ (N) \\ 0{,}49 \leq H \leq 0{,}57(m) \end{cases} \quad (12)$$

Optimization of the target function by Turkkan's written Excel evolution program with the basic parameters of the algorithm (number of population, hybrid probability, mutation probability) selected according to [6] with the value written in Table 8 [14].

Table 8. *Parameter value when being optimized*

Number of population	150
Hybrid probability	0,25
Mutation probability	0,05

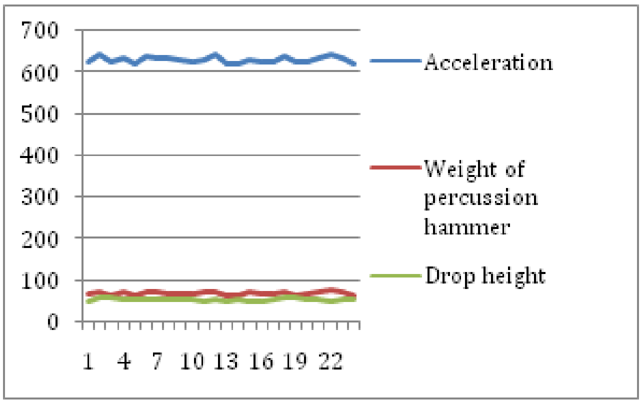
Enter the data in Table 8 and the variable constraints into Turkkan's Excel table, click run the program and obtain the resulting table with 150 values after hybridization. Based on the target functions, the results will be filtered to determine the effective range of percussion hammer parameters (m_1,H) corresponding to the minimum acceleration value (a) that can be dust settling as shown in Table 9.

Table 9. Value of useful parameters after being *optimized*

Pop No	Fitness (m/s^2)	m_1 (N)	H (cm)
1	623.8239	64.37085	49.44192
2	641.0369	71.13093	56.93739
3	624.1526	60.64707	56.19351
4	**634.877**	**69.08675**	**53.83419**
5	**621.9132**	**61.91083**	**51.34854**
6	**636.9974**	**70.77531**	**53.40421**
7	**632.3942**	**67.74241**	**53.35102**
8	**631.6884**	**66.65373**	**54.34874**
9	**629.7602**	**65.81053**	**53.63942**
10	**626.8407**	**63.1918**	**54.79695**
11	**630.5484**	**68.50424**	**50.22347**
12	639.8402	71.66486	54.91224
13	621.7791	61.91213	51.19111
14	621.2794	60.37636	53.27853
15	629.0113	67.44812	50.22517
16	624.1916	64.66653	49.37551
17	624.9887	63.86332	51.5728
18	635.4743	67.84324	56.44543
19	624.1837	60.70629	56.12254
20	625.9619	63.01987	54.09496
21	632.5038	67.76514	53.43087
22	639.1299	74.07801	50.66989
23	632.707	68.15334	53.03153
24	623.1217	62.23279	52.1941

From the effective value domain after optimization in table 9, construct a graph of the values variation: Weight of percussion hammer (m1), drop height (H) with (a) as shown in Figure 6 .

Figure 6. Graph of variations of values after searching optimal



*Comment:*The graph in Figure 6 shows that the results in the range of numbers (4 to 11) almost reach stable values (adjacent to the horizontal line), this is the basis for choosing a reasonable set of parameters for the percussion hammer when designing a dust settling percussion. The example in row 7 (table 9) gives the result set as table 10.

Table 10. Reasonable percussion parameter set values

m_1 (N)	70,77531
H (cm)	53,4042
a (m/s^2)	636,9974

V. CONCLUSION

1) From the experimental results to determine the percussion force (F) of hammer and acceleration (a)respectively, a regression equation (7) has been developed that affects the technological parameters of the hammer to the percussion force and the regression equation (10), the relation of the percussion force (F) with the acceleration (a) of the propagation wave in the deposition electrodes.

2) Applying genetic algorithm to search the reasonable parameter value domain of the percussion hammer (F) corresponding to the value range of m_1 weight of the hammer in accordance with the minimum acceleration (a) which has the ability to settle dust and maximum value, satisfying the durable conditions of the deposition electrodes.

3) The research results are used with a reference for designing percussion in electrostatic precipitator and can also be used as a teaching material in the environmental emission treatment industry.

REFERENCES

1. Nguyen Tien Sy, Hoang Van Got (2014) “Research on overview and selection of dust settling percussion of electrostatic precipitators in exhaust treatment of industrial plants” - Journal of Science and Technology - Hanoi University of Industry, No. 23, pages 28-31.
2. Nguyen Tien Sy, Hoang Van Got and Duong Van Long (2017) ″Evaluate the effect of circulating excitation force on vibration and deformation of the deposition electrodes in filter chamber, electrostatic precipitator equipment". Journal of Science and Technology - Hanoi University of Industry, No. 42, pages 21-28.
3. Nguyen Tien Sy, Hoang Van Got and Duong Van Long (2018) ″Study on the influence of technology of percussion on dust settling performance in the experimental model of electrostatic dust filter". 5th National Conference on Science and Technology on Mechanics, page 57.
4. Nguyen Van Vuong, (2008) Propagation of stress waves in an object. Bach Khoa Publishing House - Hanoi.
5. Prof. Dr. of Science Nguyen Minh Tuyen (2005) Experimental planning, Science and Technology Publishing House.
6. Nguyen Dinh Thuc (2008). Artificial intelligence of evolutionary programming. Education Publishing House
7. Sproull (1965), Fundamentals of electrode rapping in industrial electrical precipitators, Journal of the Air Pollution Control Association, No 2, p. 50-55.
8. Ali Akbar Lotfi Neyestanak, (2014). “Fatigue Durability Analysis of Collecting Rapping System in Electrostatic Precipitators under Impact Loading”. Cyrus Advances in Materials Science and Engineering.
9. S.H. Kim, K.W. Lee (1999) “Experimental study of electrostatic precipitator performance and comparison with existing theoretical prediction models”. Kwangju Institute of Science and Technology, Department of Environmental Science and Engineering.South Korea.
10. Heinz L. Engelbrecht ”rapping systems for colecting surfaces in an electrostatic precipitator”
11. [27] “Fatigue Durability Analysis of Collecting Rapping System in Electrostatic Precipitators under Impact Loading”.Department of Mechanical and Aerospace Engineering, Science and Research Branch, Islamic Azad University,Tehran 14778 93855, Iran.
12. Adamiec-Wójcik,J. Awrejcewicz,A. Nowak,and S. Wojciech (2014)“Vibration Analysis of Collecting Electrodes by means ofthe Hybrid Finite Element Method” University of Bielsko-Biała, Willowa 2, 43-309 Bielsko-Biała, Poland.
13. F. Miloua, A. Tilmatine. (2007) “Optimization of the rapping process of an intermittent electrostatic precipitator”, Univ. of Poitiers, France
14. Turkkan N. (2001), Floating Point Genetic Algorithm Genetik V2.02, http://www.umoncton.ca, dated June 8, 2019.