EMPIRICAL STUDY ON THE RELATIONSHIP BETWEEN CYCLIC RAPPING FORCE AND THE LIFESPAN OF DISCHARGE ELECTRODE FRAMES IN DUST FILTER CHAMBERS

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Abstract

This study aims to investigate the relationship between the cyclic rapping force of a hammer (F) and the lifespan of a discharge electrode frame, which is an important component of dust filter chambers. The phenomenon of vibration propagation due to cyclic impacts is beneficial for dust removal, but it can also cause fatigue damage to key components such as the discharge electrode frame, collecting electrode plates, and hammers. In order to address this issue, the theory of radial collisions of two rigid bodies has been applied, and experiments have been conducted on a dust filter chamber model to establish the experimental curve according to the authors' theory. The relationship between the impulse (F) of the rapping hammer and the durability (N) of the discharge electrode frame has been explored and analyzed. The findings of this study can be used to inform the design and optimization of dust filter chambers, ultimately contributing to improved efficiency and effectiveness in industrial dust removal processes.

Keywords: Dust Filter Chambers, Cyclic Rapping Force, Discharge Electrode Frame, Fatigue Damage, Industrial Dust Removal Processes.

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1. Introduction

In Vietnam, the use of thermal power generator units and electrostatic precipitators (ESPs) in manufacturing plants is prevalent, with over a hundred thermal power generator units and several hundred ESPs currently in operation [1]. The filter chamber is a crucial component of the ESP, with plate-type collecting electrodes serving as the cathode and spike-type discharge electrodes being used to ionize and positively charge dust particles in the flue gas stream [2]. The flue gas from coal-fired boilers entering the filter chamber typically contains hundreds of mg/Nm3 of dust, with the output exhaust gas requiring a reduction to 50-100 mg/Nm3, depending on the environmental air quality requirements.

To meet the increasing demand for new, repaired, and replaced electrostatic precipitators for thermal power plants, cement factories, and metallurgical industries in Vietnam, local engineering industries need to master the design of the filter chamber in the electrostatic precipitator [3]. Ensuring the durability of the discharge electrode sets is essential for meeting the country's demand for air pollution control, which is equivalent to imported equipment currently being used nationwide [4-10]. This study aims to investigate the relationship between the cyclic rapping force of the hammer and the lifespan of the discharge electrode frame, which is a crucial component of the dust filter chamber. By conducting experiments and applying the theory of radial collisions of two rigid bodies, the experimental curve on the relationship between the impulse of the rapping hammer and the durability of the discharge electrode frame has been established. The findings of this study can be used to inform the design and optimization of dust filter chambers, contributing to improved efficiency and effectiveness in industrial dust removal processes in Vietnam.

2. Urgency of the research

The importance of electrostatic precipitators (ESP) in reducing air pollution from thermal power plants cannot be overstated. The filter chamber, with the discharge electrode frame as its main component, is crucial for the functioning of ESPs. The discharge electrode frame ionizes dust particles in the flue gas stream, enabling them to be attracted to the collecting electrode plates. However, due to the high dust concentration in the flue gas, the discharge electrode frame is subjected to cyclic impact forces from the rapping hammer. This leads to fatigue damage, reducing the lifespan of the discharge electrode frame and ultimately affecting the efficiency of the ESP.

Despite the success of localizing and supplying ESP equipment for some projects in Vietnam, the durability of the discharge electrode frame is still an existing problem. The urgent need to address this issue has become apparent as local engineering industries need to be able to take control and master the designing of the filter chamber in the ESP to ensure that the discharge electrode sets' durability is equivalent to the imported equipment used countrywide.

To determine the durability of the discharge electrode frame in terms of its ability to withstand the cyclic impact forces of the rapping hammer, an experimental curve needs to be established. This curve will illustrate the relationship between the rapping force (F) of the hammer and the durability of the discharge frame in accordance with the authors' theories in [6,7]. Therefore, the research for the durability ensuring of the discharge electrode frame is currently an urgent issue in Vietnam, as it is necessary to improve the efficiency and effectiveness of ESPs in reducing air pollution from thermal power plants.

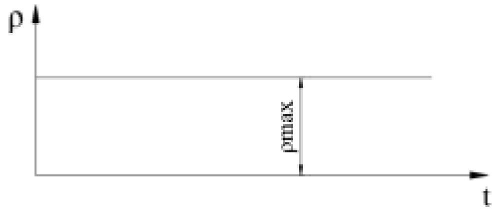
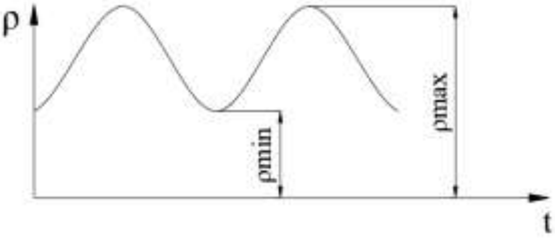
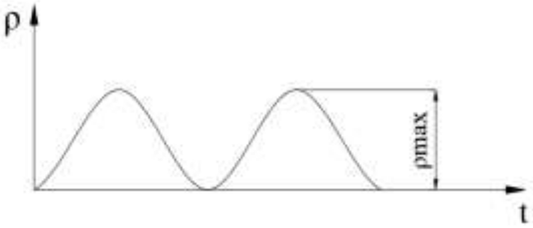
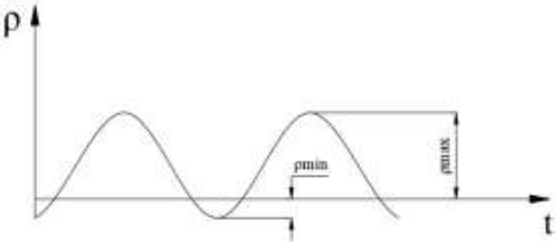
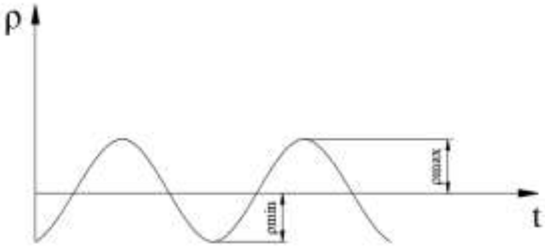
3. Research content

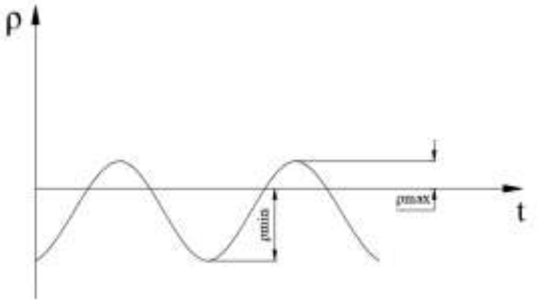
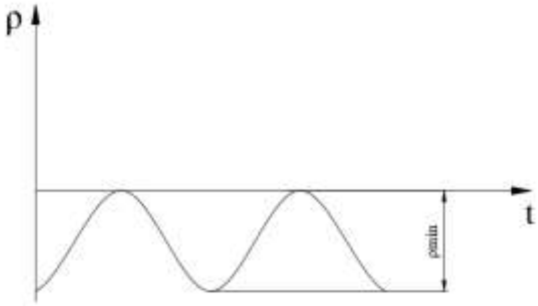
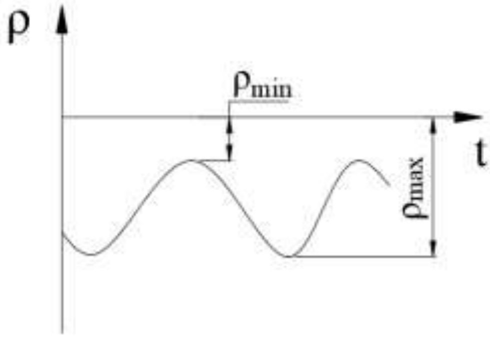
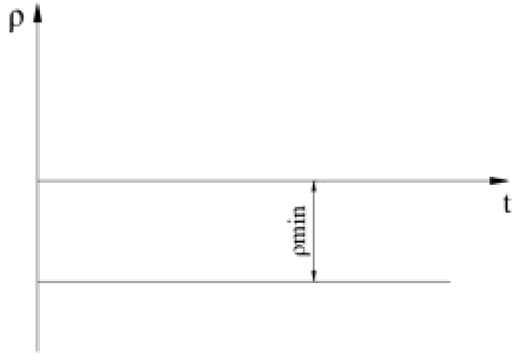
3.1 Experimental determination of the durability of the discharge electrode frame

3.1.1 Selecting the case of the rapping force and the formula for the durability of the discharge electrode frame

After analyzing the impact of the rapping hammer on the discharge electrode frame, nine force distribution cases were observed, and it was determined that case 3 (as shown in Table 1) was the most appropriate diagram and calculation formula to use [6,7]. The cyclic forces were simulated, and the results are shown in Figure 1. The specific model of the discharge electrode frame only experiences one collision per cycle. This means that the collision cycle between the hammer and the discharge electrode frame is an asymmetric cycle, where Pmax is greater than zero and Pmin is equal to zero, while r equals zero. The parameters of the collision cycle are summarized in Table 2. The determination of these parameters is essential for understanding the behavior of the discharge electrode frame under the cyclic impact forces of the rapping hammer and for establishing an experimental curve that will illustrate the relationship between the rapping force of the hammer and the durability of the discharge frame. This research is crucial in addressing the issue of the discharge electrode frame's durability and improving the overall efficiency of electrostatic precipitators in reducing air pollution.

Table 1. The force distribution cases for the impact of the rapping hammer on the discharge electrode frame.

	Applied force for each particular case	p_{max} ; p_{min}	$p_c = \frac{p_{max} + p_{min}}{2}$ $p_c = \frac{p_{max} - p_{min}}{2}$	$r = \frac{p_{min}}{p_{max}}$
1		$p_{max} = p_{min} > 0$	$p_c = p_{max} = p_{min} > 0$ $p_a = 0$	$r = +1$
2		$p_{max} > 0$ $p_{min} > 0$	$p_c > 0$ $p_a \neq 0$	$0 < r < +1$
3		$p_{max} > 0$ $p_{min} = 0$	$p_c = \frac{1}{2} p_{max}$ $p_a = \frac{1}{2} p_{max}$	$r = 0$
4		$p_{max} > 0$ $p_{min} < 0$	$p_c > 0$ $p_a \neq 0$	$-1 < r < 0$
5		$p_{max} = -p_{min}$ $p_{min} < 0$	$p_c = 0$ $p_a = p_{max}$	$r = -1$

6		$p_{max} > 0$ $p_{min} < 0$ $p_{max} < \|p_{min}\|$	$p_c < 0$ $p_a \neq 0$	$-\infty < r < -1$
7		$p_{max} = 0$ $p_{min} < 0$	$p_c = \frac{1}{2}p_{min}$ $p_a = \frac{1}{2}\|p_{min}\|$	$r = -\infty$
8		$p_{max} < 0$ $p_{min} < 0$	$p_c < 0$ $p_a \neq 0$	$+1 < r < +\infty$
9		$p_{max} = p_{min} < 0$	$p_{max} = p_{min} < 0$ $p_a = 0$	$r = +1$

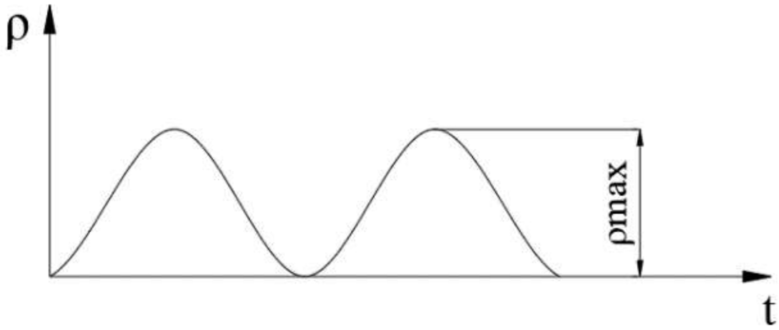


Figure 1. Graph describes the applied force cycle on the frame type of the discharge electrode frame [6,7]

Table 2. Parameters of the impact force cycle

Applied force	Average value of the cycle	Characteristic factor of the cycle
$p_{max} > 0$ $p_{min} = 0$	$p_c = \frac{1}{2}p_{max}$ $p_a = \frac{1}{2}p_{max}$	$r = 0$

3.1.2 Calculation of fatigue strength of discharge electrode frame beam

In this section, we will discuss the modeling and calculation process involved in determining the durability of the discharge electrode frame. Firstly, in order to analyze the structural principles and force characteristics of the frame, it is important to model the force acting on the discharge electrode beam. As per the author's theory about fatigue strength, the external force (F) of the rapping hammer acting on the anvil end of the discharge electrode frame is a concentrated force. The model for this force is shown in Figure 2.

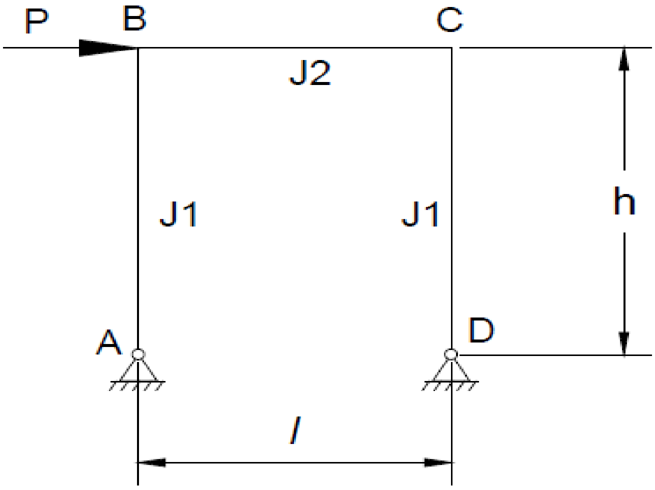


Figure 2. Modeling the external force acting on the anvil end of the discharge electrode frame [6,7]

Once the force model is established, the next step is to determine the stress graph and calculation formula for fatigue stress (σmax) at the dangerous cross-section (B, C) of the discharge electrode frame. This is an important basis for the objective of experimentally studying the durability of the discharge electrode frame. Based on this analysis, the appropriate cases of the stress graph and calculation formula for fatigue stress can be established.

Moving on to the calculation for the durability of the discharge electrode frame, it is important to note that there are a total of 9 frames installed together with the same structure, geometric parameters and load characteristics. Therefore, for durability calculation, it is necessary to survey only one discharge electrode frame to understand the durability of the entire 9-frame system in the filter chamber.

In summary, modeling the force acting on the discharge electrode frame beam and calculating the fatigue stress at the dangerous cross-section are essential steps in determining the durability of the discharge electrode frame. By conducting these analyses, we can gain important insights into the load-bearing capacity of the frame and make informed decisions about its design and maintenance.

Based on the model shown in Figure 2, the cases of the stress graph and calculation formula for fatigue stress (σ_{max}) at the dangerous cross-section (B, C) of the discharge electrode frame can be established. This is an important basis for the objective - experimentally studying the durability of the discharge electrode frame.

3.1.3 Developing the experimental steps and determine the fatigue strength limit of the discharge electrode frame

Fatigue strength is an important factor that needs to be considered when designing a discharge electrode frame. According to the authors [2,6,7], determining the fatigue strength of a specific type of part and material can only be done by experimental methods. In this regard, the authors have established an experimental curve to determine the strength of the frame corresponding to the maximum impact force and fatigue stress of the discharge electrode frame.

As the life span of the discharge frame cannot be directly determined on the experimental model at the National Research Institute of Mechanical Engineering workshop, it is necessary to conduct the experiment under certain conditions. The discharge electrode frame has specific technical specifications that must be considered during the experiment. These include beams AB and CD that are subjected to pure bending force due to the rapping force of the hammer. The most dangerous cross-section position is at A and B, and the dimensions at A and B are pipes with an outer diameter of D=25mm and a wall thickness of 3mm (i.e., an inner diameter of d=19mm). The material used is CT3 Steel, and the allowable yield stress is 21 kN/cm2 = 21MPa. The hammer mass should be between 60N ≤ m ≤ 80N, and the drop height of the hammer should be between 0.49 m ≤ H ≤ 0.57 m. Therefore, the test sample should be a CT3 steel pipe beam with a height of 7.5m, from point (B) applying force (P) to point A, and a frame weight of 200kg.

Table 3. Test conditions for hammer mass (m_1) and drop height (h_i)

No	Factor	Test level		
		Upper level (1)	Base level (0)	Lower level (-1)
1	Hammer mass m_1 (kg)	9	7	5
2	Drop height h_i (m)	0,57	0,53	0,49

The experimental conditions should be simulated using CAE (Computer-Aided Engineering) in the range of (+1) to (-1). Table 3 shows the test conditions for hammer mass (m1) and drop height (hi). The process of determining the fatigue limit for the discharge electrode frame by the CAE simulation method includes the following main contents:

Step 1: Establishing a force distribution model for the discharge electrode frame based on the author's theory [6]. The impact force is the concentrated force applied by the hammer on the anvil beam end, and the model of force distribution is depicted in figure 2.

Step 2: Conducting experiments on 9 samples, including 6 samples corresponding to 6 hammer weight cases from 5kg to 10kg and 3 samples corresponding to 3 cases of drop heights from 0.49m, 0.53m, and to 0.57m. The process involves increasing the impact pulse force by the hammer mass and gradually increasing the impulse force on the basis of increasing the drop height of the hammer until the test piece is destroyed.

Step 3: Determining the stability stress of the experimental curve using the method of decreasing mass. This involves reducing the hammer mass from the high level to the low level and maintaining the hammer mass by carrying out 3 times of rapping mode with constant values. By this procedure, it is possible to achieve a line that is roughly parallel to the time axis (N) shown in Figure 3.

Step 4: Evaluating the obtained results, which is the experimental durability curve of the discharge electrode frame with the boundary value of N = 1.15x107 cycles, and obtaining the stable mass (mod), stability rapping force (F) - (F_{od}) and stress (σ_{-1}) of the discharge electrode frame girder.

The experiment results determine the value of fatigue stress for the discharge electrode frame for 3 options of hammer mass 6, 7, and 8 kg and minimum drop height (h=0.49m) in Table 4 [4].

Table 4. Experiment result determining the fatigue stress values for discharge electrode frame

No	Parameter	Value of parameter				
1	Hammer mass m_1 (kg)	5	6	7	8	9
2	Drop height H (m)	0.49	0.49	0.49	0.49	0.49
3	Impulse force F(Ns)	154.95	185.94	216.93	247.92	278.91
4	Stress value (kN/cm^2)	15.062	**16.377**	**17.251**	**18.076**	21.088

4. Results and analysis:

The experiment results, as shown in Table 4, indicate that the hammer mass of 5 kg has a lower fatigue stress compared to the allowable stress of the CT3 steel material of the frame, while the hammer mass of 9 kg with a minimum drop height of 0.49m shows a stress σ_m = 21.088 kg/cm^2 = 21.088 Mpa, which is only slightly higher than the allowable value of $[\sigma_m]$ = 21.00 MPa [6]. Hence, the article only considers experiment results with hammer weights in the range of 6kg ≤ m ≤ 8kg. The parameter values of the hammer were determined by conducting experiments with a hammer mass of 8kg and a lower level drop height of 0.49m, and the results are presented in Table 5

Table 5. Values of experimental parameters

No	Hammer mass m_1 (kg)	Drop height H (m)	Impact force F (kN)	Impact cycle n (impact/cycle)	Fatigue stress of frame σ (MPa)
		0.49	167.12	2.133	16.377
		0.53	172.20	2.133	16.600
1	6	0.57	178.30	2.133	16.800
		0.49	172.00	3.133	17.251
		0.53	276.00	3.133	17.400
2	7	0.57	280.20	3.133	17.700
		0.49	247.00	4.133	18.076
		0.53	250.15	4.133	18.300
3	8	0.57	253.00	4.133	18.520
4	9	0.49			21.088

The analysis of the results in Table 5 shows that when the hammer mass is m_1= 9 kg and the drop height is h=0.49m, the tensile stress of the CT3 material of the discharge electrode frame is 21,088 MPa, which is smaller than the allowable yield strength CT3 $[\sigma_{ch}]$ = 23 MPa [6]. On the other hand, a hammer mass of 5kg generates a relatively small rapping force (F) that can affect the dust removal ability of the collecting plate. Therefore, to ensure the durability of the discharge electrode sets, as well as the dust removal ability and durability of the collecting electrode plates, the experimental design should consider hammer mass within the range of $m_{1(min)}$ = 6 kg and $m_{1(max)}$ = 8 kg. The specifications of hammer mass and drop height are presented in Table 6.

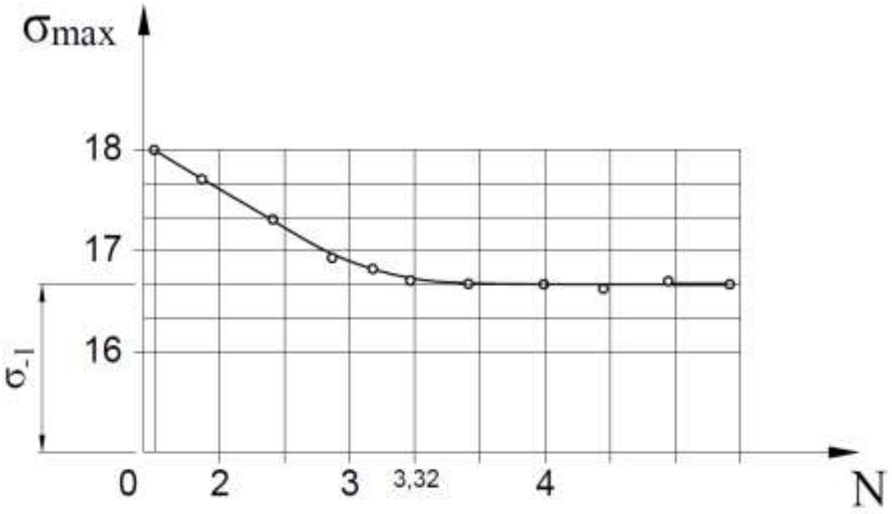


Figure 3. Experimental fatigue curve of the discharge electrode frame

From the experimental curve (Figure 3), it is observed that the fatigue stress limit of the discharge electrode frame is σ_{-1}= 16.80 MPa corresponding to an impact force of F = 178.30 kN with an impact cycle of the hammer n = 3.32. However, in practice, the impact cycle of the hammer is ntt = 3.133 times/rev. Therefore, the value n = 3.133 is taken into account to calculate for practical purposes. The stress value σ_{-1} greater than 16.68 MPa is the load that can destroy the fatigue test specimen. Hence, it is recommended to use a set of hammer parameters within the limit impact force of the hammer F= 178.30 kN and the fatigue stress of the discharge electrode frame σ_{-1}= 16.68 MPa. These parameters include hammer weight in the range of $6kg \leq m \leq 8kg$, drop height of hammer H in the range of $0.49m \leq H \leq 0.57m$, and impact cycle n of 3.133 impact/cycle ≤ n, with a corresponding force of F= 178.30 kN and σ_{-1}= 16.68 MPa.

In conclusion, the experimental results indicate that the hammer mass, drop height, and impact cycle significantly affect the fatigue stress of the discharge electrode frame and the dust removal ability of the collecting electrode plates. The recommended set of hammer parameters ensures the durability of the discharge electrode sets, as well as the dust removal ability and durability of the collecting electrode plates, for practical operation.

3.2 Measures to ensure the durability of the discharge electrode frame while maintaining the dust removal ability and the durability of the collecting electrode plates

This section focuses on measures that need to be taken in order to ensure the durability of the discharge electrode frame while also maintaining the dust removal ability and durability of the collecting electrode plates. Achieving these objectives requires an understanding of the relationship between the rapping force (F) of the hammer on the discharge electrode frame and its ability to generate the dust removal acceleration (a) necessary for removing dust layers off the surface. Consequently, this is a multi-objective problem that requires careful consideration.

The internal force diagram of the discharge electrode frame is shown in Figure 4 and the formula for calculating the bending moment Mu is given by formula (1). The diagram shows that the bending moment is greatest at the cross-section at 2 points B and C. Therefore, it is essential to optimize the set of parameters of the hammer's rapping mode, including the hammer mass (mi), hammer drop height (hi), and rapping frequency (ni) within 5 minutes of operation in practice. These parameters must satisfy the strength of the discharge electrode frame (σm) and also provide the necessary dust removal acceleration (a) for dust removal ability and durability of the collecting plate.

To achieve these objectives, it is crucial to strike a balance between the durability of the discharge electrode frame and the dust removal acceleration required for effective dust removal. Failure to strike this balance can lead to a decrease in the dust removal efficiency or a reduction in the durability of the electrode frame. Therefore, careful consideration must be given to the design and implementation of measures to ensure the durability of the discharge electrode frame while still maintaining the necessary dust removal ability and durability of the collecting electrode plates.

The internal force diagram has the form as in Figure 4 and the formula for calculating the bending moment M_u is as formula (1)

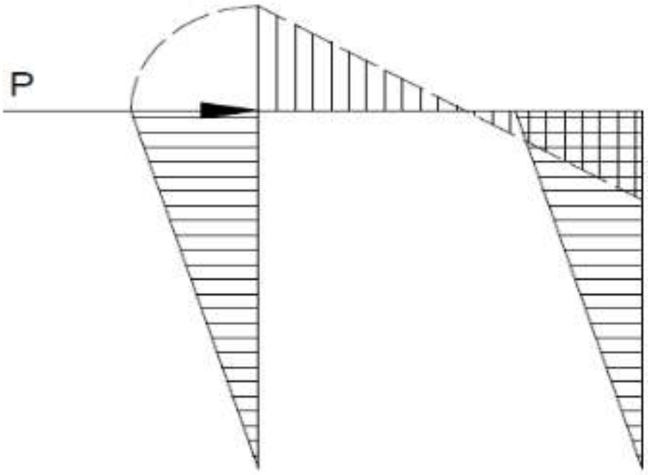


Figure 4. Internal force diagram of bending moment at the section at 2 points B and C

Bending moment: $M_B = M_C = \frac{1}{2}hP$ (1)

3.3 Testing the strength of the discharge electrode frame with hammer mass m=8kg, h=0.57m

In testing the strength of the discharge electrode frame, an experiment was conducted with a hammer mass of 8kg and a drop height of 0.57m. The results showed that the allowable yield stress of the discharge electrode frame steel (CT3) (σ_{ch}) was 21 kN/cm2 (21 MPa) compared to the force (F) of 247.92 kN according to the author's document. The limit range of hammer mass was determined to be 6kg ≤ m_i ≤ 8kg for a maximum falling height (h_{max}) of 0.57m. To determine the strength limit (σ_m) of the discharge electrode frame as required by the objectives of the article, the hammer mass limit (m_i) was used to find the impulse force (F) applied on the anvil beam of the discharge electrode frame. Three cases were considered with hammer masses of 6kg, 7kg, and 8kg, and the maximum falling height was 0.57m. The results are presented in Table 6.

Table 6. value of force Fmax when mi=6,7,8 kg and hi=0,57m

No	m_i (kg)	h_i (m)	n_i (cycle/5min)	F_{max} (kN)
1	6	0.57	3.133	185.94
2	7	0.57	3.133	216.93
3	8	0.57	3.133	247.00

The moment acting on the discharge electrode frame affects the acceleration and stability of the collecting plate. The bending moment (M_u) acts on the discharge electrode frame for the cases where m_i= 6,7,8 kg, and produces a stress (σ) as shown in Table 7. Based on the determination of the dust removal acceleration (a_i), the yield stress (σ_{ch}), and the drop height (h_i) by the authors [6,7], it was found that 500m/s2 ≤ $[a_i]$ ≤ 2000 m/s2, 500 ≤ a_{itn} = 1543.1644:1790 m/s^2 ≤ 2000 m/s^2, $[\sigma_{ch}]$=18 kN/cm^2 ≥ σ_{chtn}= 17,876 kN/cm^2=17,876MPa, and $[h_i]$ ≤ h_{itn} = 0.57m = 57mm.

The experiment results show that the appropriate selection of hammer mass (m_i) and hammer drop height (h_i) is 6kg ≤ m_i ≤ 8kg and falling height h_i ≤0.57m. However, the rapping frequency of the hammer (n_i) does not affect the impact force of the hammer but does affect the fatigue strength of the discharge electrode frame. In conclusion, it is crucial to optimize the rapping mode's parameters to ensure the discharge electrode frame's durability, the dust removal ability, and the collecting plate's longevity.

Table 7. Values of M_u and σ for cases of m_i= 6,7,8 kg

No	m_i (kg)	M_u (kNm)	σ (kN/cm^2) (MPa)	Average a_{itn} (m/s^2) in collecting electrode [4]
1	6	50,82	16,377	1543
2	7	52,75	17,251	1644
3	8	65,607	17,876	1790

3.4 Determine the fatigue strength of the discharge electrode frame

3.4.1 Graph to describe the impact cycle

The impact cycle of a horizontal electrostatic precipitator (ESP) can be described using a graph, as outlined in this section. Results from an experiment, shown in table (6), indicate that the hammer's continuous working mechanism operates for 5 minutes with an average of 3,133 cycles. This means that each discharge electrode frame experiences the same rapping cycle. As a result, it is only necessary to assess the fatigue strength of one frame instead of all 9 sets of discharge electrode frames in the filter chamber.

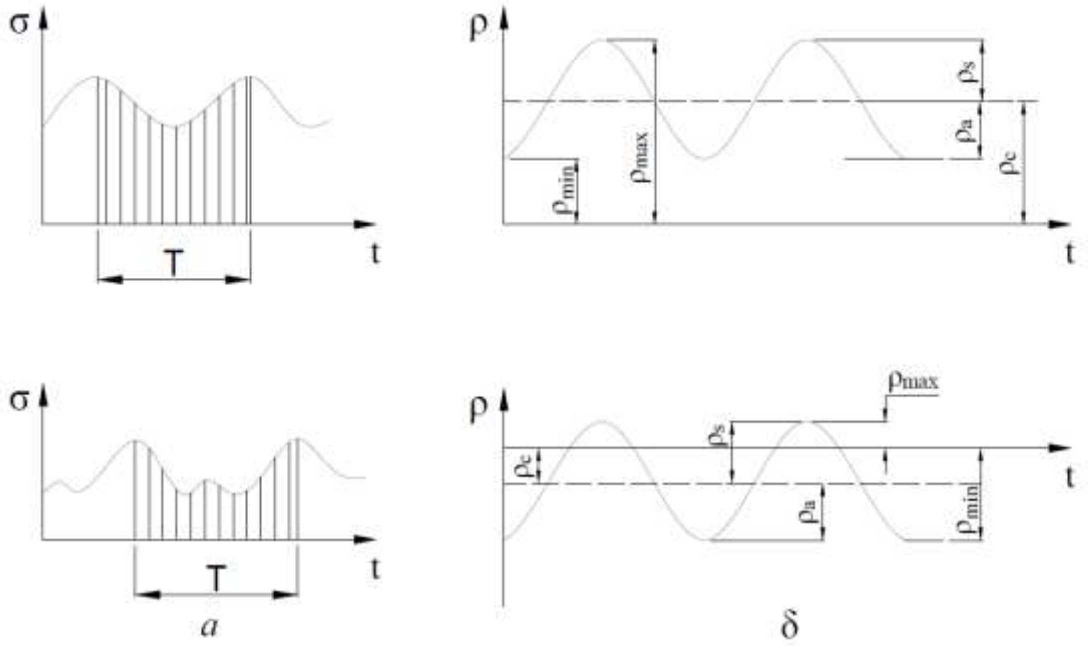


Figure 5. Graph depiction of fatigue stress cycle of periodically force (P) acting on bearing beam

The author's research on strength of materials [6] suggests that a cycle occurs only on the horizontal axis, meaning that the force acting on the positive portion (+) is the only factor to consider mathematically. Figure 5 depicts the fatigue stress cycle of a periodically acting force (P) on a bearing beam. The graph demonstrates one cycle (T) caused by fatigue from force (P), and illustrates the impact forces, including the average force (P_c), amplitude (P_a) in the cycle (T), and the maximum force (P_{max}) and minimum force (P_{min}).

In the case of the discharge electrode frame of a horizontal ESP, the impact force of the cycle is asymmetric, resulting in Pmin being equal to 0. The graph in Figure 5 simulates an asymmetrical force cycle to the horizontal axis. By utilizing this graph, it is possible to determine the impact of the force cycle on the fatigue strength of the discharge electrode frame, which is essential for the proper functioning of the horizontal ESP.

3.4.2 Calculation of fatigue strength

3.4.2.1 Definition of forces

In this section, we describe the definition of forces as they relate to the fatigue strength of parts. According to their research in the field of strength of materials, when a force varies with time (t), the stress function (σ) is described by equation: σ = f(t). The cyclic coefficient (r) is then determined by equation $r = \frac{p_{\min}}{p_{\max}}$, which uses the maximum and minimum stresses (P_{max} and P_{min}) as inputs. The mean stress (p_c) and period amplitude (p_a) are calculated using equations (2) and (3), respectively. The authors also provide formulas for calculating the absolute values of P_{max} and P_{min}.

$$P_c = \frac{P_{\max} + P_{\min}}{2} \qquad (2)$$

$$P_a = \frac{P_{\max} - P_{\min}}{2} \qquad (3)$$

The absolute values of P_{max} and P_{min} are calculated as follows:

$P_{max} = P_c + p_a$

$P_{min} = P_c - p_a$

From formulas (4 and 5) : $P_{max} = - P_{min}$ and $P_c = 0$. This is a dangerous situation when cycling load.

$$r = \frac{p_{\min}}{p_{\max}} = -1$$

$$r = \frac{0}{p_m} = 0$$

Fatigue limit at constant load $P_{max} = P_{min} = P$

Then the coefficient (r):

$$r = \frac{p_{\min}}{p_{\max}} = 1$$

In the case of beams subjected to fatigue strength of the discharge electrode frames in an ESP due to cyclic bending forces, the symbols used for mean stress, period amplitude, and maximum and minimum stresses are replaced by symbols for mean bending stress ($б_c$) and period bending amplitude ($б_a$), $б_{max}$ and $б_{min}$.

We note that in the specific case of the discharge electrode frame, which is subjected to fatigue due to a bending moment M_u with a period of 1 impact per cycle, the asymmetric impact period has the following characteristics: $б_{max} > 0$ and $б_{min} > 0$, with $0 < r < +1$. It is important to determine the relationship between the impact impulse force (F) with the impact cycle of the hammer on the discharge electrode frame causing fatigue, in order to determine the fatigue limit of the discharge electrode frame. When the yield strength of the material of the discharge electrode frame is exceeded due to fatigue, the beam will be destroyed at a certain time limit. We provide detailed formulas and descriptions for understanding the impact of cyclic forces on the fatigue strength of parts, specifically as they relate to the discharge electrode frame in an ESP. These findings can be valuable in determining the durability and safety of such systems in practice.

3.4.2.2 Determination of the fatigue limit of discharge electrode frame

In this section, we investigate the determination of the fatigue limit of the discharge electrode frame, an important component of the horizontal type electrostatic precipitator (ESP) commonly used in plants and factories in Vietnam. We base the calculations on the average service life of the filter chamber, which estimate to be between 5-10 years, with a chosen life span of 7 years for the study. We then calculate the total operating time of the ESP to be 50,400 hours based on the equipment's annual working hours of 300 days and 24 hours per day. The dust removal system is programmed to activate at a cycle of 5 minutes, corresponding to the number of rappings (n), with the motor that drives the hammer bearing shaft rotating at a speed of 0.63 rpm.

We further determine that the discharge electrode frame's durability is essential to maintaining the durability of the other components, such as the collecting electrode plates and the hammers. In this regard, we calculate the ideal number of cycles for the rapping system, C, to be $1.44\text{x}10^7$ cycles, based on the yield strength of CT3 steel used in the discharge electrode frame. However, considering the equipment's actual durability, we apply a safety factor of 0.8, resulting in an allowable actual life span of $1.15\text{x}10^7$ cycles.

We also note that the impact period of the rapping force is asymmetrical, with no rapping force at ½ cycle, and only the maximum rapping force Pmax is available when the number of impacts (n) in 1 cycle is n=3.133. We determine that the maximum rapping force F occurs when P_{max}=253,00 kN, and h_i=0.57m. Based on this, we calculate the allowable yield stress [б] for the CT3 steel discharge electrode frame to be 21 kN/mm^2 when P_{max}=253.00kN, with a measured stress of $б_{-1}$=16.68 kN/mm^2, indicating that it is safe.

We also consider the effect of bending moment on the discharge electrode frame and determine that the allowable fatigue stress causing beam failure is within safe limits. They note that the discharge electrode frame is made from CT3 steel, with a yield strength of 21 kN/cm^2 > $б_{-1}$ = 16.68 kN/cm^2, and the collecting plate's dust removal acceleration (a_i) is a_i=1790m/s^2 < [a]= 2000 m/s^2, and the yield strength of the collecting plate is [σ_{ch}]= 18 kN/mm^2 ≥ $б_{tn}$ = 17.876 kN/mm^2. Finally, we conclude that the hammer mass m = 8kg and drop height [h_i] ≤ h_{itn} = 0.57m =57mm, which meets the required standards.

3.4.3 Discussion on the achieved results

In this section, we will discuss the results that were achieved through the implementation of appropriate parameters for the rapping hammer in the dust removal system of the Electrostatic Precipitator (ESP). The main aim of selecting the appropriate parameters is to ensure that the discharge electrode frame in the dust removal system of the ESP has a longer lifespan. This is achieved by selecting the corresponding parameters such as the hammer weight (m_1), the hammer drop height (h), and the dust removal acceleration (a), which are sufficient enough to remove the dust from the collecting plate. The set of parameters that were selected for this purpose are m_i = 8 kg, number of impacts in 1 cycle n = 3.133, drop height of hammer h_i = 0.57 m, maximum impact force F_{tn} = 253 kN to create a cyclic bending moment M_u = 72 kNm, and fatigue stress σ_{-1} = 16.68 kN/cm^2 ≤ 18 kN/cm^2.

The selected parameters were chosen to ensure that the highest life span of the discharge frame (C) is achieved, and this is given by the inequality C ≤ [C] = 1.15 x 10^7 (cycle). This means that the actual lifespan of the discharge frame must not exceed the value of 1.15 x 10^7 cycles to ensure that the system functions optimally. It is important to note that the selection of appropriate parameters is critical in achieving the desired results, and any deviation from the selected parameters may lead to a reduction in the lifespan of the discharge electrode frame, which can negatively impact the efficiency of the dust removal system. Therefore, it is essential to carefully consider the parameters and ensure that they are within the recommended range to guarantee the optimal functioning of the system.

5. CONCLUSION

The results of the experiments conducted indicate that the appropriate set of experimental parameters of a rapping hammer can be selected based on actual operating parameters and stress and strain CAE analysis on Ansys. This set of parameters generates a hammer rapping force (F) with a dust removal acceleration (a) that satisfies the fatigue limit of the discharge electrode frames as well as the durability of the collecting electrode plates.

Furthermore, for the first time in Vietnam, the theory of fatigue strength was applied through the authors' experiments [6,7]. An experimental curve was established on the experiment model at the National Research Institute of Mechanical Engineering workshop, and an appropriate impact force $F = F_{tn} = 253$ kN was successfully determined. This impact force satisfies the given fatigue life of the discharge electrode frame: $C \leq [C] = 1.15 \times 10^7$ (cycle) while maintaining the dust removal acceleration on the collecting plates.

The research results obtained can be applied to optimize the parameters of the rapping hammer (m^1, h, a) to design the rapping system and the main parameters of the collecting plate (B, L, m^2) in the filter chamber model of the horizontal ESP equipment with a capacity of 1,000,000 m^3/hour and the filter chamber of other horizontal ESP equipment with different capacities.

In summary, this study provides valuable information on optimizing the design parameters of the rapping system and collecting plates in horizontal ESP equipment, which can enhance the dust removal efficiency and durability of the equipment. This study also paves the way for further research on the application of fatigue strength theory to other industrial equipment to improve their performance and lifespan.

6. References

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