

Modification of an Existing Batch-Type Industrial-Scale Filter Press into a Continuous Production System

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Abstract— The batch type filter press is a commonly used industrial filtration equipment in many industries for solid-liquid separation. Although this is simple to use and cost-effective, its underlying weakness is that it cannot be used continuously, resulting in major production bottlenecks, high labor costs and low efficiency. This research aims to study the main difficulties in the continuous operation of batch type industrial scale filter presses and suggests engineering solutions to tackle these. The four main challenges encountered were: problems with adhesion of filter cake to the filter frame and filter cloth, periodic replacement of filter cloth, time-consuming frame movement and cloth washing processes, and uniformity in slurry distribution in the filter frame. The study was conducted by systematical literature search and mechanical engineering analysis to present a new innovative automatic discharge mechanism for ability of handling two frame simultaneously with vibration-based cake discharge, hydraulic clamping mechanism and a centrifugal separation process to make slurry more uniform. The structural analysis validated the proposed design under operational loading conditions and cost-benefit analysis showed that the cost savings were about Rs. 1.4 annum. The ideas put forward are a big step towards the continuous or near-continuous filter press in industrial processes.

Keywords— Automation, Batch filter press, Cake adhesion, Centrifugal separation, Continuous operation, Filter cloth washing, Hydraulic clamping, Industrial filtration, Solid-liquid separation, Structural analysis, Vibration-assisted discharge.

I. INTRODUCTION

The filter press is a vital industrial apparatus in the filtration industry, such as water treatment, pharmaceutical production, chemical production, and food and beverage processing. It works on the principle of pumping a slurry mixture through a series of filter plates under high pressure, solid particles are filtered out as cake, and liquid is collected as filtrate. The fundamental filter press operation has remained fairly consistent since its first use in 1958, but the materials and the automation have evolved [1]. Batch type filter presses are especially common because they operate at low cost and can produce very fine particles, and are able to accommodate high feed concentrations. These machines, however, are unable to run on a continuous basis, which is a major limitation in industrial application. The most labor-intensive operations between filtration cycles like cake discharge, washing the filter cloth and frame repositioning, reduce the overall production capacity and increase the operating cost [2]

The major challenge is to investigate and solve mechanical and operational issues associated with the inability of currently available batch type filter presses to run continuously. These include cake adhesion to the filter frames, manual cleaning, wet cake centers due to incomplete filling of filter frames, slow frame movement and filter cloth degradation and necessitating a filter cloth change out periodically. These all contribute to cycle times of 2 - 10 hours depending on the frame amount and size of the machine [3]

The main aim of this research is to identify the current limitations in the operation of a batch type filter press machine and find appropriate engineering solutions to these limitations. In the study, each obstacle is analyzed systematically using

literature review and expert consultation in order to find the root cause of the obstacle, which will be categorized as mechanical or operational. In addition, the research includes the identification of effective solutions for the discharge of rapid filter cake and efficient mechanism for washing the filter cloth in the conventional industrial filter press systems. The proposed changes are intended to provide an economic advantage to industry in terms of less downtime, lower labor requirements and better filter press efficiencies with a move to continuous filter presses or near continuous filter presses.

By identifying and addressing obstacles to continuous operation, the filter press machine can run without interruption, allowing industry to produce more products in each period [4]. This can result in increased revenue and profits for the industry. By identifying the causes of downtime and addressing them, the filter press machine can run without interruptions. This can result in increased efficiency and reduced maintenance costs, as the machine will be running optimally for longer periods. In addition, increase in labor cost, increase in unnecessary operating time, increase in time taken for cake discharge can be indicated, it is reducing the efficiency and profitability of the industry [4].

II. LITERATURE REVIEW

Filtration is a process used to separate solid particles suspended in a liquid by passing the liquid through a filter. The filter retains the solid particles while allowing the liquid to pass through, and the resulting liquid is called the filtrate [5]. This process is commonly used in various industries, including water treatment, chemical and pharmaceutical production, and food and beverage processing, to remove impurities and separate substances. Accordingly, there are basically four factors

necessary for the filtration process to happen, that is, (i) Filter medium, (ii) Fluid with suspended solids, (iii) Driving force such as a pressure difference to cause fluid to flow, and (iv) device that holds the filter medium, contains the fluid [6].

There are several methods of filtration using pressure. This process involves passing a mixture of solid and liquid through a filter under high pressure, which results in the solid particles getting trapped in the filter media, while the liquid passes through. pressure filtration allows for the filtration of a large volume of slurry in a short amount of time, which makes it a highly efficient process [7]. Pressure filtration produces a high-quality filtrate with a low level of impurities. This is because the high pressure forces the liquid through the filter media, resulting in a more thorough separation of the solid and liquid components. Of these, filtration using a filter press is used in many batch type operations. Because of the ability to filter small size particles and feed concentration range that can be filtered is high. Because there are many factors that can be changed and because of the ease of use and low maintenance cost, many industries use filter press for filtration needs. The types of filter press produced by different requirements can be listed as follows [8]. (i) Plate and frame filter press, (ii) Vacuum filter press, (iii) Recessed or chamber plate filter press, (iv) vertical filter press, (v) membrane plate filter press and, (vi) Belt filter press. Also, Tower press, expression press, centrifugal press and tube press are some types of filter presses used in the industry [9].

A. Reasons for not being able to operate continuously

Filtration experts have long debated whether filter presses, one of the oldest mechanical dewatering devices, would be replaced by more modern equipment. However, despite this discussion, since 1950 filter presses have continued to be widely used in various industries and are expected to remain relevant for years to come. While they have undergone upgrades in materials and mechanics, the basics of the filter press remain the same. There are still inherent potential problems with its operation and since the basic principle of the press has not changed nor have its inherent limitations. Accordingly, batch type filter press has difficulty doing continuous operations [10]. There are several reasons for this, such as, (i) when the cake sticks to the cloth, it prevents the discharge of the solids from the filter press. This can result in reduced filtration efficiency and longer cycle times, as the press must be manually cleaned to remove the stuck cake. In severe cases, it may also damage the filter media or require costly repairs. The plates may warp as the plate pack closes, and if any of the cake does actually adhere to the cloth, notably around the edges, the following cycle may cause leaks. Therefore, those who need to clean manually, (ii) To begin with, the hydraulic or manual pump used to generate pressure in the filter press needs to be activated to release the pressure on the plates. Once the pressure has been released, the filter press needs to be manually or mechanically opened. This involves moving the plates away from each other to expose the filter media and the cake. The process of opening the filter press can take anywhere from a few minutes to several hours, depending on the size and complexity of the press, (iii) filtration cycle is too short, the cake may not have enough time to form properly, and this can

result in a cake with a wet center. Therefore, it is important to ensure that the cycle is long enough to allow the solids to form a dense and uniform cake, (iv) There is only a partial batch remaining in the reactor and the chambers cannot be fully filled, there may not be enough material to create a uniform and complete cake on the filter media. This can result in a partially filtered mess where some of the solids are retained on the filter media while others are not. This can make it difficult to wash or dry the solids, as the partially filtered material may not be able to retain its shape or form a cohesive mass and, (v) In some cases, the filter cloth may be damaged and, in such cases, it takes time to identify and replace them [10].

B. Filtration time cycle and specific filter volume

Having a proper cycle time for each discharge is very important for continuous operation of the filter press. Otherwise, uniform cake will not be formed on the filter media and the period of applying pressure before cake drop may be prolonged. Then the bottleneck of the whole process can increase. Accordingly, the life cycle for batch type filter press can be shown in TABLE I.

TABLE I. Filtration time cycle [11]

| Stage | Operation | Approximate time |
|-------|--|------------------|
| 1 | Fill vessel with precoat slurry | 1 min |
| 2 | Establish precoat on filtration surface(s) | 2-5 min |
| 3 | Recirculating precoat filtrate | As required |
| 4 | Drain precoat heel | 1 min |
| 5 | Fill with filter feed liquor | 1 min |
| 6 | Recirculate filtrate | As required |
| 7 | Filtration (cake formation) | Up to 10h |
| 8 | Drain any unfiltered heel | 1 min |
| 9 | Fill with wash liquor | 1 min |
| 10 | Wash filter cake | Up to 1h |
| 11 | Drain wash liquor | 1 min |
| 12 | DE liquor filter cake | 5-30min |
| 13 | Discharge filter cake | 2-10min |
| 14 | Rinse filter surface(s) and drain vessel | min |

C. Filter media

Filter cloths are used to separate the solid and liquid portions of the slurry once it is pumped into the void spaces between the filter plates [12]. Due to the reasons described above, the thickened slurry bonded in the filter cloth. These deposits are inevitable. So, the cloth must be cleaned from time to time. Then the filter cloth gets scratched, and this is a big obstacle for the continuous operation of the batch type filter press [12].

Filter cloth wear occurs when the filtering process of the machine is running for a long time. Also, after dehydrating and finally discharging from the cake within filter cloth, the surface of the clot wears. These depends on the abrasive characteristic and wear resistance of the cloth. Also, with each filtration cycle, some slurry particles are likely to become trapped within the filter cloth mesh. Over time, these particles accumulate and impede the slurry's filtration rate, leading to longer cycle times. These are affecting the periodic replacement of filter cloth and another reason for the large time required to check the cloth one by one in a batch type filter press machine [13]. Most of the above problems have been reduced based on today's technology, but still a batch type filter press machine has not been able to operate continuously

However, there are some continuous filter press machines that are expensive to operate. But the cost of batch type filter press is relatively less so the demand for this machine has not decreased yet. But the following improvements have been made to the batch type filter press machine. As indicated in filter clothes undergo a finishing process (calendaring treatment) before they can be used. The finishing process serves three main purposes: to ensure the fabric's stability, modify its surface characteristics, and correct its permeability.

Calendaring treatment is applied to fabric for two reasons: to improve surface smoothness and prevent clogging of the filter media, and to make cake release easier. Additionally, the treatment helps to rectify the permeability of the fabric, stabilizing the filtration efficiency. Accordingly, calendaring treatment can increase the strength of the filter cloth and make the cake easier to remove. But this does not provide a complete solution to that problem [13] Fig.1.shows variation of filter cloth before and after applying calendaring treatments.

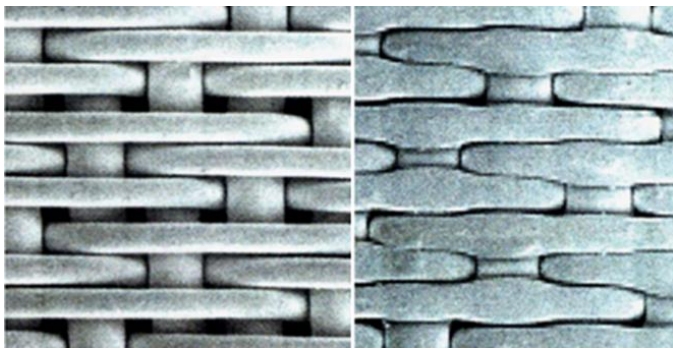


Fig.1. cloth before and after applying calendaring treatment [13]

Also, some machines contain automatic filter cloth washing and cake removing mechanisms. But it takes a relatively long time, which is an existing difficulty.

Even if there have been remedies for some issues, if the above main problems can be avoided, a faster filtering mechanism can be made, and the cost can be reduced.

III. FILTER PRESS DESIGN

When designing filter press should be consider factors as follows;

- Friction between the filter frame and filter hole: When the slurry passes through the hole in the frame. If the roughness of the hole is high, it will prevent the slurry from being evenly distributed un the filter frame [14].
- On-uniform plate spacing: Slurry will flow more easily through areas with wider plate spacing. This can lead to uneven distribution of slurry across the frame, with areas with wider plate spacing having thinner filter cakes and areas with narrower plate spacing having thicker filter cakes [14].
- Incomplete plate closure: If the filter plates are not completely closed during the filtration cycle, slurry can flow through the gaps between the plates, leading to uneven distribution of slurry across the frame [14].
- Operating conditions: The operating conditions of the filter press, such as the feeding pressure and the temperature of

the slurry, can also affect the flow of the slurry through the filter press frame. For example, increasing the feeding pressure will increase the flow rate of the slurry through the filter press frame [14].

D. Slurry properties

If the slurry has more viscosity, then it's more difficult to distribute evenly throughout the filter press frame. This is because the slurry will not flow as easily. High viscosity slurry can also lead to longer filter cycle times, due to the increased resistance to flow. Fig.2. graph shows how the viscosity of the slurry and filtrate volume affects the filtration process. Accordingly, it says when viscosity and density of the slurry is increased then filtrate volume is reduced, and the time is reduced [15].

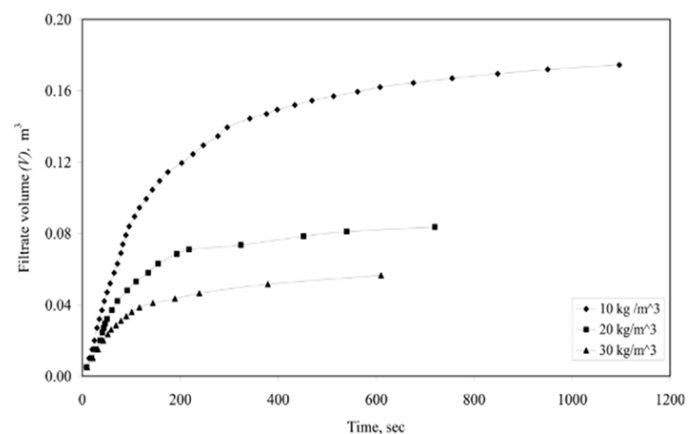


Fig.2. Filtrate volume Vs. Time variation [15]

Also, the slurry with high solids content and large particles also be affected to distribute evenly throughout the filter press frame. This is because the solids can settle out, causing uneven distribution. High solids content slurry can also lead to longer filter cycle times, due to the increased resistance to flow and the need to remove more water from the filter cake [15].It can be seen from Fig.3. that only 1/4 of the entire cycle is spent on this cake formation and it takes place under constant pressure.

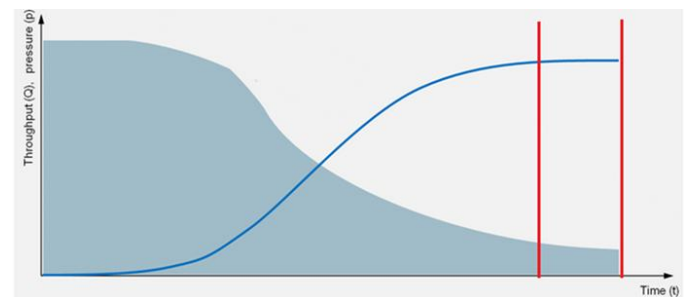


Fig 3. Filter press pressure variation Vs Time for entire cycle

There are a few reasons why a filter press needs to run sometime after removing the feed pump; To ensure that all the slurry has been filtered: The feed pump helps to ensure that the slurry is evenly distributed throughout the filter press frame and that all the chambers are filled. However, even after the feed pump is removed, there may still be some slurry in the chambers

that have not yet been filtered. Running the filter press for a short time after removing the feed pump helps to ensure that all the slurry has been filtered and that the filter cakes are as dry as possible [16]. To remove any air pockets: Air pockets can form in the filter press chambers during the filtration process. If these air pockets are not removed, they can reduce the quality of the filter cakes and can make it difficult to remove the filter cakes from the chambers. Running the filter press for a short time after removing the feed pump helps to remove any air pockets and ensures that the filter cakes are of high quality and easy to remove. To clean the filter cloths: The filter cloths in a filter press can become clogged with solids over time. This can reduce the flow of slurry through the filter cloths and can make it difficult to filter the slurry effectively. Running the filter press for a short time after removing the feed pump helps to clean the filter cloths and ensures that they are in good condition for the next filtration cycle [17].

IV. METHODOLOGY

The main purpose of this research is to identify the possible changes and obstacles for the continuous operation of the filter press machine that couldn't be repaired for a long period of time. As mentioned in the above literature review [18] [19], there are several factors affecting the inability to operate a filter press machine continuously. Accordingly, in data collection of this purpose, findings solution for those drawbacks one by one has been done here. In finding solutions for this, what was basically done was to study the literature review of previous research related to this and ask expert opinions.

Accordingly, the studies were conducted mainly according to the factors that affect this and then, solutions were searched for each of those factors separately. Finally, several factors can conclude affecting the inability to operate the filter press machine continuously were found by studying the facts mentioned in above literature review section.

- Adhesion of filter cake with filter frame and filter cloth. Having to apply and additional external force to discharge them.
- Over time, the filter cloth gets torn and worn must be replaced from time to time.
- Takes more time to move the frame and wash the filter cloth in a filter press machine with more filter frames.

Accordingly, the above factors mainly affect the inability to operate filter press machine continuously, therefore, applying a solution for these can reduce the time spent for one cycle of a filter press machine.

A. Cake sticks with filter frame and cloth

Often, sticking to the cake frame or filter cloth is due to defects in the existing frame or due to asymmetric liquid removal during the cake DE liquor process. Accordingly, it is hoped to find solutions according to the following methods.

- Designing a new filter press frame or finding solutions to the weaknesses of the existing frame.
- Information retrieval, designing, calculating and error analysis based on filter frame that can be made to be non-sticky in cake filter frame.
- Evaluating and investigating air DE liquoring systems.

- Study of the change in the amount of moisture percent in the cake with the pressure deference.

B. Strong filter cloth

Often the filtering cloth of the filter press must be changed from time to time. Studying more detail about existing solutions and new solutions for this.

Accordingly, study about Calendaring methods, Heat setting methods, Resin impregnation, Coating, Lamination

- Studying for information on strong filter cloth that can be sued for a longer period so that the cake parts don't stick to the filter cloth.

Under this, checking the various filter cloths available and checking which types of filter cloth have a stronger and more suitable particle structure.

C. Fast frame moving and cake discharge mechanisms

Cake discharge can be introduced as a process that takes more time than the entire filter press process. Studying methods to make this continuous and faster. Studying the existing cake discharge methods and finding their deficiencies.

1. Automatic cake discharge mechanism.
2. Cake washing mechanism.
3. Air blow cake discharging mechanism.

D. Solution for ensuring filter frame fully filled with slurry

Studying detail about the existing methods and find and solve errors of those methods/ parameters.

1. Stirring or agitation method
2. Optimizing the filter cake thickness
3. Slow and steady feeding
4. Adding more process to existing process

Most of the concepts presented here are related to existing methods and some mechanisms are an extension of an existing method. These extensions are related to previous research, and some concepts are presented by me based on mechanical knowledge.

V. RESULTS AND DISCUSSION

The one of the main reasons for the inability to operate the filter press machine continuously and the increase in the time taken for a cycle is that it takes more time to move the frame and time to remove the cake. Usually, it takes more than 4-8 (Depending on the frame amounts) hours to manually remove the filter cake and wash the filter cloth. For this, the entire machine has to be stopped and it causes a significant delay for the entire production process.

As mentioned in [20], every filter press machine that is said to be automatic has a mechanism that moves the filter frame away sequentially. it is clearly state that this plate mover is essential for larger machines (2m). the reason for that is the weight of the existing filter frame, which is about 1 ton. However, for smaller machines (below 1.5m) it is assumed that this can be done manually. Also. [20], goes on to say that impressions gained from plant visits and operators' reports are that many plate shifting devices fitted to large presses do not work particularly well. With side bar presses it appears that the most common mode of plate transfer failure is that one of the pair of side lugs on a plate fails to be engaged by the shifting

device. This leads to one side only of the plate being pulled away from the compressed stack, a dangerous situation since this 'crabbing' can in extreme cases lead to the filter plate falling out of the press altogether.

However, because of the high cost of large machines nowadays, there is a tendency to use smaller machines with more filter frames. But, even now, such automation mechanism exists only for machines with large frames (frame size more than 2m). However, such automation is required for small filter presses as well, if operators are to be removed from day-to-day operations. It is said that the gantry robot developed in the [20], can provide a solution for the fast frame moving process of these small filter press machine

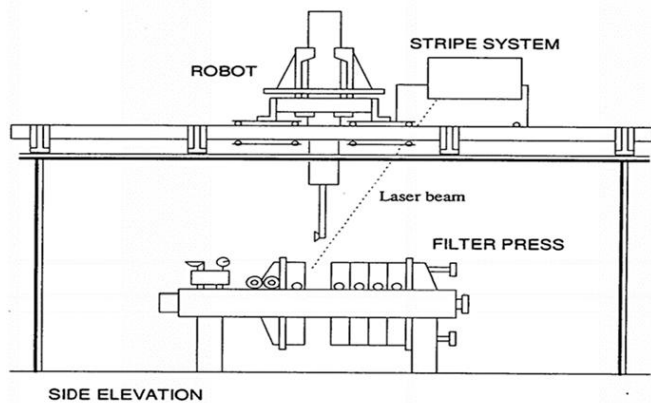


Fig.4. Side view of [20]'s gantry robot

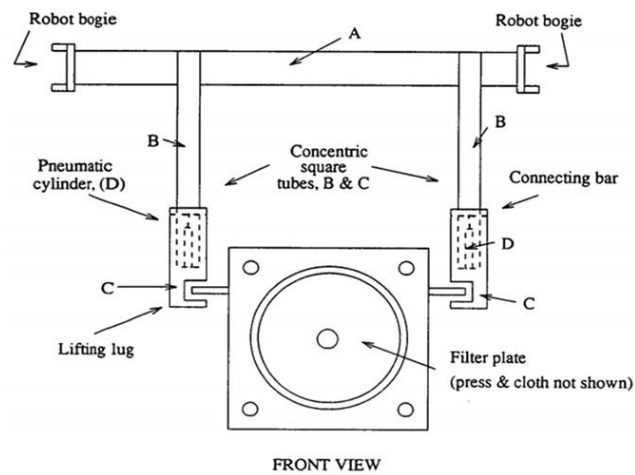


Fig.5. Front view of the gantry robot [22]

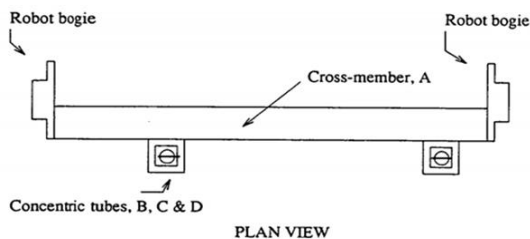


Fig.6. Top view of the gantry robot [22]

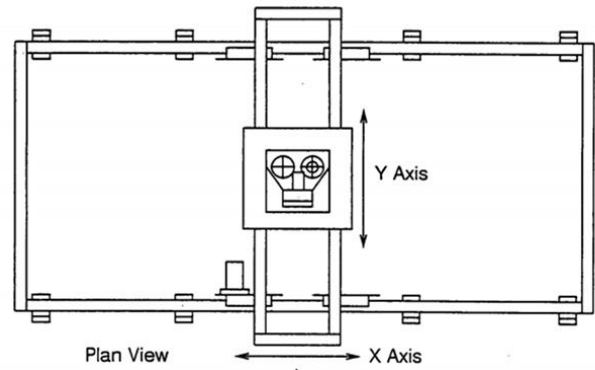


Fig.7. Side and plane view of the gantry robot [22]

As illustrated in Fig.4., Fig.5, Fig.6.and Fig.7. , a hollow, square-section cross-member (A) is fitted between two of the robot's bogies and two square-section tube vertical members (B) extend downwards almost to press side bar level from it. Each of the vertical members, B, has another shorter but larger square tube telescoped outside it (C). The larger tubes, C, extend below the ends of the smaller ones, B, such that their lower ends reach below the level of the filter plate support lugs resting on the side bars of the press. The bottom of each larger tube is fashioned into a lifting hook which, in its default low, or down, position, clears the lugs during longitudinal motion of the robot. Two pneumatic cylinders (D), one per leg, act on the larger tubes, C, to lift these when air is supplied; when the air is removed, the tubes drop due to their own mass.

Accordingly, the gantry robot developed here makes the filter cake fall to the ground by the shock generated when the filter frame is lifted. But in practice, the filter cake falls to the ground only in filter cakes that have been completely drained of water, otherwise the filter cake may stick to the filter cloth. Therefore, in such a case they may have to be discharge by manually. In such a case, each filter frame should be checked and checking one by one is a very easy task. Therefore, it may be more advantageous if this can be done through a forced vibration system. Also, it is obviously more advantageous if one or more filter frames can be moved around rapidly or if the washing can be done at the same time only using one machine. Also, in modern, although there are filter press machines with automatic filter frame moving mechanism and filter cloth moving mechanism, it also takes 4-5 hours. This is less time compared to the above values and if this can be reduced further, it can be indicated as a close approach for the continuous production process.

Accordingly, the following machine proposed as one solution to this problem, which can be considered as an extension of the machine developed in[20].

The below solution is shown in Fig .8, Fig.9, Fig.10 and Fig.11 can carry two filter frames at a time. Also, the cake parts present in both the filter frames can be dropped into the drip tray at the same time by acting a vibration force on the frame. A method available in all automatic discharging machine is to move the plate one by one to remove the cake parts adhesion to it. The time taken here is relatively high, causing significant disruption to the entire process. Also, washing the filter clothes

one by one and having installed a separate mechanism for that is another error.

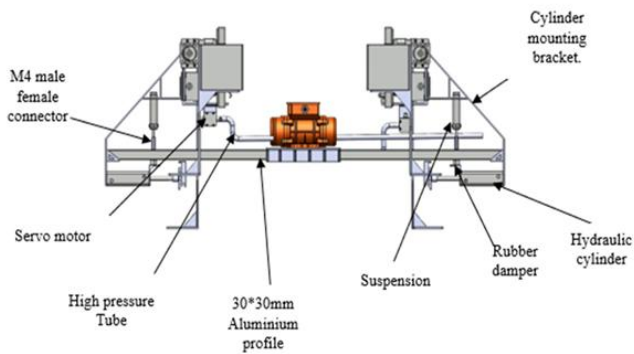


Fig.8. Front view of the proposed design.

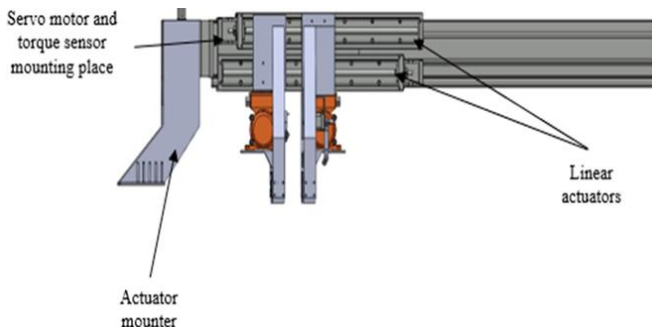


Fig.9. Side view of the proposed design

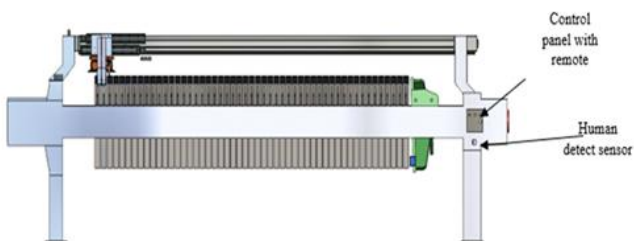


Fig.10. Full design after place filter frames

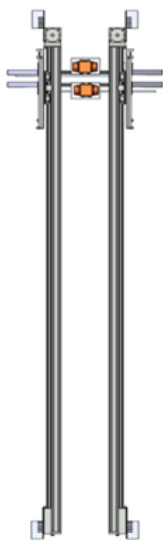


Fig.11. Side view of proposed design

However, the above method has the advantage of being able to perform both these processes at the same time. Also, the linear actuators mount here allow for faster and more stable frame movement and the wheels attached to the frame make it more stable. As shown in Fig.12., for this process, the following parts should be installed for the existing frame.

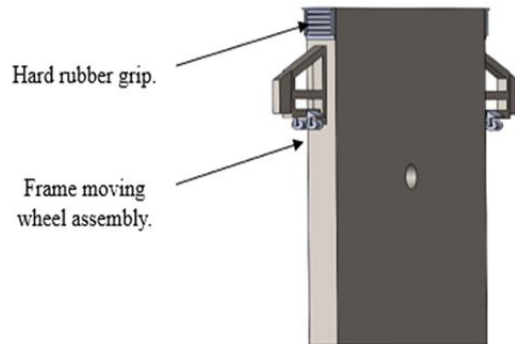


Fig.12. Proposed filter frame with required attachment

A. Details of the working process

Using this proposed mechanism, and opportunity of fast frame moving, and cloth washing can be obtained than the existing frame moving mechanism. And this machine can use 500mm to 1500mm frame sizes available machines.

Accordingly, the first thing that happens after the cake formation process is to remove the cake parts that stick to the frame and cloth. There, instead of lifting and dropping the filter frame several times by the handle of the frame as in the system used currently, while the frame is held tightly by the hydraulic cylinder, the main purpose of this is to make the cake parts that stick to the cloth fall to the ground using a vibration force transmitted through it. Also, when the sensor attached with the linear actuator indicates a traveling torque greater than the normal travelling torque, it is further vibrated and thereby ensures that the cake falls completely to the ground.

1. Humans detect sensors.

The human detect sensor installed at the end of the filter press body helps to stop the process of the machine, where the person is given the opportunity to check the filter cloth and if there are any more cake particles, it gives time to remove them.

2. Hydraulic cylinder (CHKDB20-100)

The main purpose of this is to transmit vibration power to the filter frame. This working as a holding method for that. This applies a force of 2198N on the filter frame under a pressure of 7 bar and thus prevents the filter frame from moving around. Also, the rubber grip part that is installed to cylinder reduces the relative movement between the parts that are connected to the filter frame and gives safer movement to the filter frame.

3. Vibration motor (MVE 60/3)

This provides the necessary vibration force to loosen the cake parts stuck to the filter frame. A 30mm*30mm aluminum profile is used to mount this, and it provides a medium for transmitting the vibration force to the filter frame. The working moment of the vibration motor is 1.31kgcm and it is transmitted through the hydraulic cylinder connected to the filter frame.

4. Suspension (MC600EU)

This prevents unnecessary transmission of vibrating force to the linear actuator and belt linear actuator

5. Small Linear actuator with torque sensor

As shown in the Fig.13. The small linear actuator is used to provide small and separate linear movement to frame. This one linear actuator can provide a linear force of about 1900N. Also, by the torque sensor attached to it, it is used to check whether the cake particle is still adhesion with filter cloth after first vibrating (for this, the change in torque to be given to move in the filter frame is considered) and if it is, it will issue a signal to activate the vibration motor. This design has 4 small linear actuators mounted with a main belt actuator. The advantage of using small linear actuator is it provide filter frame to very fast movement rather than moving large belt actuator.

6. Washing mechanism

This servo motor driven high pressure washing process enables 2 filter frames to be washed at the same time, which is twice as fast as normal filter cloth washing mechanism.

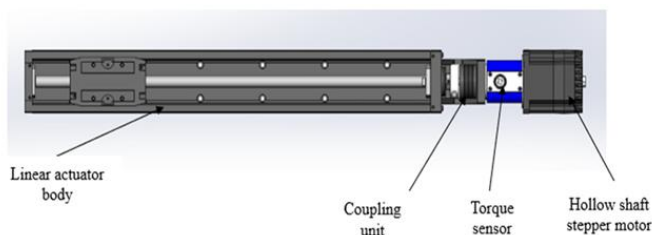


Fig.13. small linear actuator with torque sensor

7. Belt linear actuator.

Main belt linear actuator used to provide large movement to small actuators. And this provides movement of washing mechanism to the desired position in the filter press.

These are the main parts of the proposed machine and main purpose of each part.

B. Calculating the main forces acting on the machine

The following calculations can further confirm the machine's ability to do this and its validity. Fig.14. and Fig.15 will illustrate forces acting on the machine.

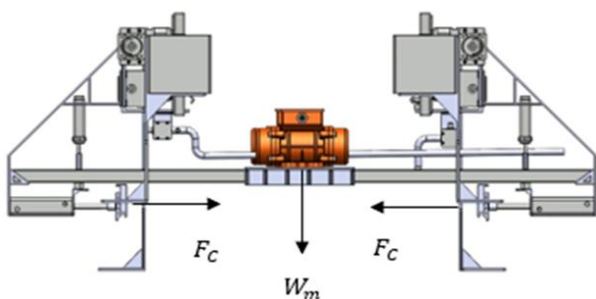


Fig.14. Front view diagram of forces acting on the machine

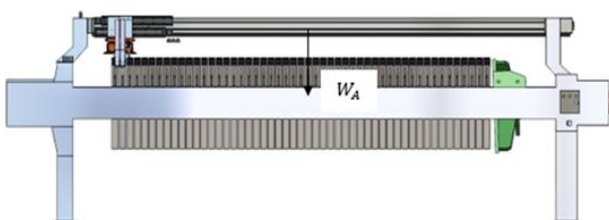


Fig.15. Side view diagram of the force acting on the machine

W_A = weight of linear actuator

W_m = motor weight

F_c = Hydraulic cylinder force

TABLE II. Table of mass

| | |
|--|---------|
| Mass of the motor | 4kg |
| 800*800mm filter frame mass | 27-35kg |
| Thickness of the cake | 30mm |
| The weight of the unit length in belt driven linear actuator | 3kg/m |
| Approximate weight of the other components | 25Kg |

TABLE.II. gives masses of components needed for the calculations to obtain required results.

Calculating the weight of the 2 linear actuators

Here liner actuator length is 4.5m. By Eq. (1) we can find the weight.

$$Force = mg \quad (1)$$

$$2 * 3 * 4.5 * 9.81 = 264.87N$$

Calculating the effective area of the filter frame by using Eq.2

$$Effective\ area = Total\ area - Unused\ area \quad (2)$$

$$800 * 800 = 640000mm^2$$

Unused area typically around 10% of total area,

Accordingly calculating the unused area,

$$640000 * 0.1 = 64000$$

Calculating the effective area

$$640000mm^2 - 64000mm^2 = 576000mm^2$$

Assuming the density of the slurry is 1800kg/m³ Calculating the weight of the filter frame with slurry,

The Eq.3 for calculating the weight of slurry inside the filter frame is:

$$W = A \times \rho \times t \times g \quad (3)$$

Where:

- W = Weight of slurry (N)
 - A = Effective filtration area (m^2)
 - ρ = Density of slurry (kg/m^3)
 - t = Thickness of filter cake (m)
 - g = Gravitational acceleration ($9.81\ m/s^2$)
- $$576000mm^2 * 10^{-6} * 1800 * 30 * 10^{-3} * 9.81 = 301.104N$$

Calculating the total weight of the proposed design, By Eq.4 we can calculate the total force.

$$Total\ force = Actuator\ force + (M + m) * 9.81 \quad (4)$$

M = estimated structural/mechanical load

m = additional load/component weight

$$264.87 + (50 + 8) * 9.81 = 833.85N$$

Calculating the cylinder force by Eq.5 ,

Assume the cylinder pressure is 3.5Mpa and piston area 314mm² ,

Outward force

$$P = \frac{F}{A} \quad (5)$$

$$F = 314 * 3.5 * 10 = 1099N$$

effective inward (retraction) area of the cylinder is 210 mm².

Inward force

$$F = 201 * 3.5 * 10 = 704N$$

This hydraulic cylinder force depends on the amount of pressure developed by the hydraulic pump. The following stress and deflection analysis shows the changes that occur in the

system when vibration force is applied and the effect it has on the system.

C. Displacement analysis

This analysis was done by giving a known force (150N) along the X axis to the machine. That force is considered equal to the force given to the system by vibration motor. Also, direction Y is no need to be considered because machine is not moving along Y direction. Fig.16. gives displacement analysis for X direction and Fig.17. gives displacement analysis for Z direction.

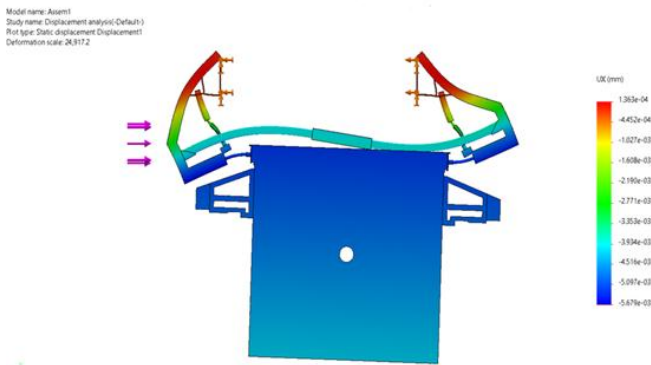


Fig.16. Displacement analysis for X direction

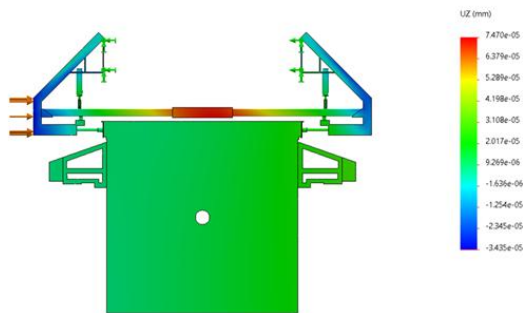


Fig.17. Displacement analysis for Z direction

Fig.18. shows the Von misses analysis for X direction.

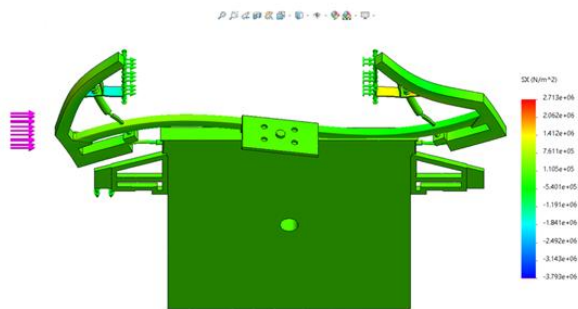


Fig.18. Stress analysis along X direction

Maximum stress value is $2.71 \times 10^6 Pa$. For making the proposed design 1020 steel cold rolled is used. The yield strength of 1020 steel is 350 MPa also the actuators yield

strength is greater than 2.71 Mpa there for machine does not undergo fail under this frequency force range.

Graphs in Fig.19. shows how displacement varies in motor mount bar along Z-Axis.

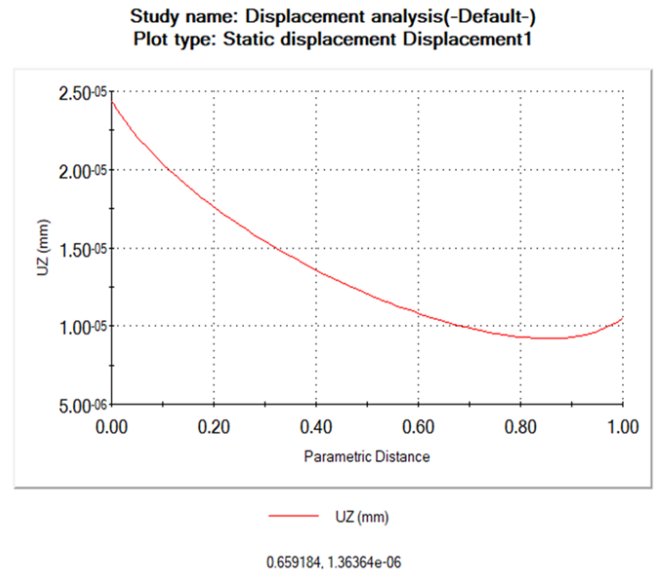


Fig.19. Displacement vs distance graph along motor mount bar for Z Direction

D. Frequency Analysis

As state by [21] & [22] when the $\tau_{\text{Cake}}/\sigma_{\text{Cake}}$ ratio is greater than 17.4, gravity cake discharge does not occur. Therefore, it indicates that it needs to be sheared and collapsed in another way. Like vibration, shaking or manual scraping. Here, the adhesion shear between the filter cloth and filter cake indicates that it is an obstacle to remove from the filter cloth. That shear stress is dependent on according to the filter press pressure and filter cloth types [21].

As stated by [23] when vibrating the clay at given sinusoidal frequency then it forms oscillatory shear stress. Also, [24] state observed results were independent of the shear cell geometry. Also, it states particles remain in close contact for all strain amplitudes, there is a strong dependence on the angular pair distribution function which results in the observed changes in shear stress with applied strain amplitude (γ_0).

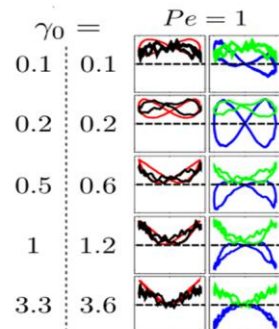


Fig.20. Strain amplitude Vs Peclet number for small particles

Pe = Peclet number is approximately 1 for filter press

Accordingly, Fig.20. shows when γ_0 increase the ring braking probability is increased. According to the [23] the

minimum amplitude of vibration required to discharge the filter cake from a filter cloth was 0.2 mm. The authors also found that the amplitude of vibration required to discharge filter cake increased with the thickness of the filter cake and the viscosity of the filtrate. Also, when increasing γ_0 it states the bond between filter cake and filter cloth can bend shown in figure 24.

The following frequency analysis results show the first 4 possible vibrating mode shapes that machine can get. (motor frequency range 0-50Hz)

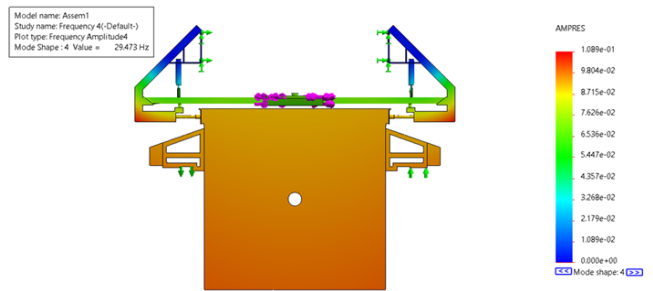


Fig.24. Mode shape 1

When calculating the natural frequency of the machine only need to consider displacement along the X direction because the Z direction displacement is negligible compared to the X direction value.

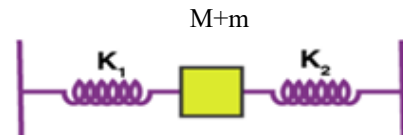


Fig.25. Equivalent system

The above system in Fig.25. is equal to the proposed machine. $M =$ mass with filter frame and cake $m =$ mass of the machine

Calculating the stiffness of the system by Eq.6.

$$2k = \frac{F}{\delta} \quad (6)$$

$F =$ applied force

$\delta = 0.004m =$ deflection

$2k =$ stiffness of two actuators together

$$k = \frac{150}{2 * (0.004 * 10^{-3})}$$

$$k = 18750 * 10^3 Nm^{-1}$$

Calculating the natural frequency of the system by Eq.7.

$$N_f = \sqrt{\frac{2k}{(M + m)}} \quad (7)$$

$$= \sqrt{\frac{2 * 18750 * 10^3}{317.6kg}}$$

$$= 343.6Hz$$

The motor frequency is less than 343.6 Hz there because machine structure failure does not occur.

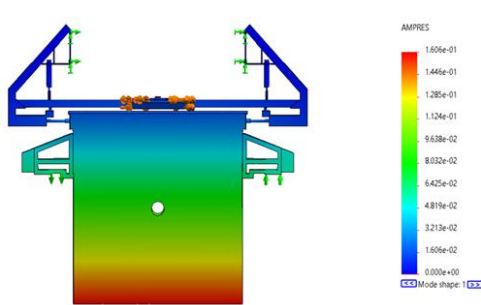


Fig.21. Mode shape 1

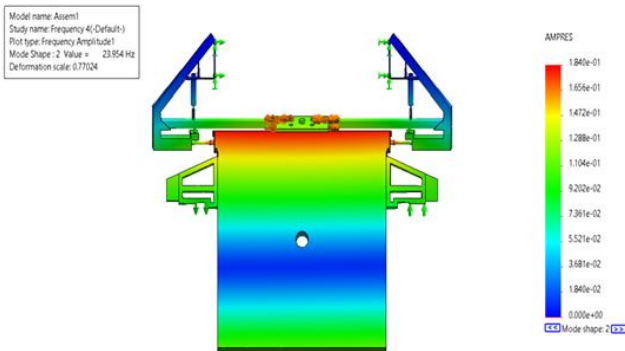


Fig.22. Mode shape 1

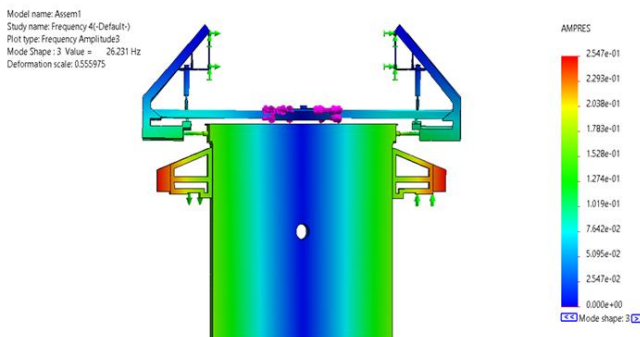


Fig.23. Mode shape 1

Above shown Fig.21, Fig.22, Fig.23 and Fig.24 are the first 4 mode shapes that can be generated by this vibration motor. Amplitude of all the above cases is close to 0.2mm and above. Accordingly, it is possible to discharge tailing parts stuck in the filter cloth using the proposed design.

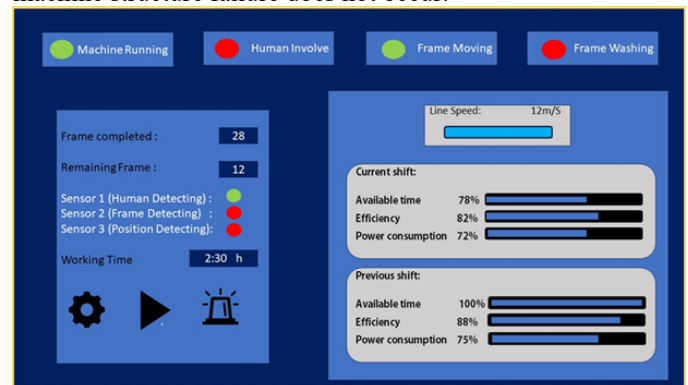


Fig.26. Machine interface of purposed design

The above interface (Fig. 26) shows the efficiency of the machine and allows its operation. Here, the machine vibrates the filter frame and the cake stuck with the filter cloth was removed. Here, also an operator waits to check the process of the machine and if any particle of cake remains with the filter cloth (after vibration is done), activating human detecting mode on machine given chance to remove it.

Also, machines provide manual operating mechanisms to operators, from using this method operator can move frames one by one and inspect whether filter cloth needs to change or not.

E. Cost estimation for proposed design

Normal automatic filter press machine price Rs 2,250,000-5,000,000 generalizing TABLE.III. gives cost calculation of the proposed system.

TABLE III. Cost calculation

| Part | Quantity | 1 piece price Rs. | Total Rs. |
|-----------------------------------|----------|-------------------|-----------|
| Belt linear actuator | 2 | 75000 | 150000 |
| Small linear actuator | 4 | 9500 | 38000 |
| Dampers | 4 | 2500 | 10000 |
| Vibration motor | 2 | 18000 | 36000 |
| Hydraulic cylinder | 4 | 11000 | 44000 |
| Other material and machining cost | | 15000 | 20000 |
| Total | | | 298000 |

Compared to normal automatic filter press machine, the price of the proposed machine is about 1/8 of total value. There are several filter press machines in large factories, where using this machine can save extra wasting time. Also, when needed, it can be removed and attached to another machine, which brings an additional advantage. Also, two filter frames can be moved and discharged at a time using this, so it takes less time than the cycle usually takes.

F. Calculating power consumption of proposed machine,

Machine working time approximately 3-4.5 hours per day (depending on size of the filter press machine). TABLE.IV. gives power requirement for the system.

TABLE IV. Power requirement

| Power requirement of machine part | Total requirement | For 4.5 hours |
|------------------------------------|-------------------|----------------------------------|
| Belt linear actuator motor (1kW) | 1000*2=2000W | $\frac{2000 * 4.5}{1000} = 9kWh$ |
| Small linear actuator motor (400w) | 400*4=1600W | 7.2kWh |
| Vibration motor (250W) | 250*2=500W | 2.25kWh |
| Hydraulic pump (1.2kW) | 1200W | 5.4kWh |
| Total consumption | | 23.85kWh/day |

The 1kWh price = Rs. 32.00

$$23.85 * 32 = Rs. 763.20$$

Saving =6153-762.20=Rs. 5390.80

Yearly saving= Rs. 1.4millions (Without maintenance cost)

Accordingly, using this machine can save about 1.4 million annually. If a worker is employed to Checking the functionality of the machine can save around Rs 0.62 million per year. This is more advantage for industry to minimize their annual cost.

Also, for this proposed machine no need external hydraulic pump, the machine can operate using filter press hydraulic lines. This provides additional benefit to the industry.

G. Comparison between the available automatic filter frame moving mechanism and advantage of this machine.

The current modern filter press automation processes use separate removal of cake particles in each filter frame one by one or removal cake at ones using a rotating beam. But in this rotating beam mechanism gives damaged to the filter frame and this mechanism is not widely used because of this didn't provide an opportunity to closely monitor the filter cloth and frame. Also, all the existing machines doesn't have the ability to wash two filter frames at the same time and above desired machine provides that ability and it reduces the cyclic time spent for that process. Accordingly, these can be stated as the main difference between the machine mentioned above and the existing machines. In TABLE.V. discussed the comparison.

TABLE V. Comparison between available machine and proposed machine

| Currently using machines | Proposed machine |
|--|---|
| Most of the machines can only carry one filter frame at once | Can carry two filter frames at once. |
| Only one filter frame can wash at one time. | Two filter frames can wash at one time |
| Cyclic time is higher | Cyclic times are reduced than currently used machines. |
| Some mechanism damaged the filter frame | Filter frames can securely move |
| | Ability to control manually and automatically. |
| | Provide safe work environment for the person. |
| | Can be upgradable. (A sensor can be installed to detect the damaged areas of the filter cloth.) |
| | Moving capability |

VI. CONCLUSION

According to the facts studied above, the conclusion stated as follows. Accordingly, as per the methodology, there are mainly 4 reasons can be identified which make it impossible to operate the filter press continuously. When considering the adhesion of filtrate (cake), filter cloth and filter frame it is mainly affected by the forces between the cake and cloth, and it can be recognized that the magnitude of those forces often depends on the moisture percentage of the cake. Accordingly, it can be concluded that this can be reduced to some extent by controlling the filtrate condition, changing the type of filter cloth, controlling the properties of the slurry and precoating the frame and filter cloth. But it is physically impossible to control this 100%. Therefore, cake discharging methods can be used for this. The proposed design discussed above fulfills this requirement and it is quite different from the existing automatic discharging, frame moving mechanism. The reason for that is its speed and the ability to move and wash two filter frames at the same time. Accordingly, by improving this mechanism, it is hoped to quickly remove the cake parts stuck to the filter cloth and improve the efficiency of the machine.

Also, new filter clothes should be washed at least once after a few complete cycles. It can be insisted that it is better if it can

be resolved to minimize it. It should also be mentioned that by using this method, an average filter press operator can save almost half of the amount paid annually. Also, compared to the filter press machine, the cost of production is low and therefore it is not disadvantageous to manufacture and use it. Also, it can be indicated that this will reduce the additional time and human labor spent in the entire process and bring an opportunity to move the filter frames more effectively and faster. Accordingly, this solution can also be called an approximation for continuous operation of the filter press machine, which is the goal of the entire project.

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