Design and Force Analysis of Slider Crank Mechanism for Film Transport Used In VFFS Machine

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Abstract - *Vertical form (film) fill and seal machine was first built in middle of last century. During the development of the machine an attempt has been made to introduce plastic as packaging material which became more popular. Variety of mechanism can be used for transporting the film for packaging purpose. The packaging machines developed till date makes use of stepper motors and their supporting drive mechanism for transporting the plastic. In present work this mechanism is replaced with slider crank mechanism where intermittent motion is converted into continuous motion for packaging. Not only that this mechanism can be powered by an electric motor along with variable frequency drive (VFD).*

The length of the connecting rod of the slider crank mechanism is determined based on the requirement of lift for the table as well as on maximum bag length required for packaging.

Key Words: **VFFS machine, Belt transport mechanism, slider crank mechanism, synthesis of slider crank and connecting rod, force analysis with different transmission angle.**

1. INTRODUCTION

Vertical form (film) fill and seal (VFFS) machines are most commonly used in food packaging industries. Products like salts, sugar, snacks food, detergents are placed in formed vertical bag and then horizontal seal is applied. Continuous flat roll of plastic film of polyethylene material are used. Some of important factor which has to be considered are the product which has to be packed has to remain crispy for longer time, aroma of coffee has to be maintain. Different kind of product can be packed by using VFFS machine, they are mainly divided into four group. First group is bulk product such as nuts, cookies, bolts and screw. Second group is product which is present in powder state. Grain or granulate is of third group. And last one is liquid type product. The VFFS machine is highly suitable for this kind of product to be packed.

(VFFS) machine are automated assembly line product packaging systems. VFFS machine can be operated based on intermittent or continuous motion. Intermittent motion works on the principle of start and stop motion i.e. vertical seal are when film is continuous motion. Horizontal sealing bar which generates bottom seal at bottom edge of tube can be pre-determined at height in intermittent motion. This type of motion is more suitable where speed is not important. In continuous motion vertical and horizontal seal are applied without stopping film.

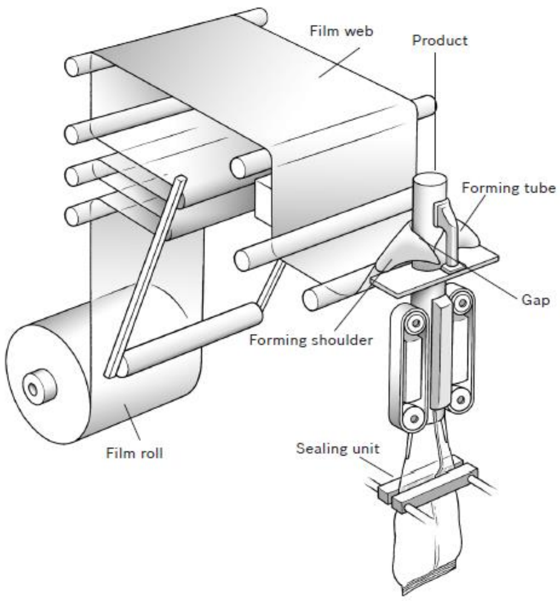

Fig -1.1: Layout of VFFS Machine

1.1 Sequence of operation of VFFS machine

1.1.1 Bag making

In bag making operation, the film which is enrolled is pulled out. The film remains flat but when it reaches to tube it takes the shape of the forming tube. The top opening is wide as compared to bottom. Gently the flat film takes the shape of bag.

1.1.2. Seaming operation

Three seams are longitudinal, bottom and top seam. Longitudinal seam which runs down to the length of the bag. Bottom seam and top seam are those which close the bottom and top of the bag.

1.1.3. Sealing operation

Seams which are created for bag making are sealed in sealing operation. In sealing operation, the film which is made of polyethylene is sealed by using sealer. Heater is present in sealer or sealing jaw which attains the temperature required for melting the polyethylene and also creates pressure by bringing both jaws together so that one side of film stick to other side of film. The sealing jaw is made of stainless steel. The temperature sensor is placed at the end of the sealing jaw for controlling the temperature.

1.1.4. Cutting operation

Series of bag is separated by cutting operation. For this operation separate cutter is placed inside the sealing jaw with spring attached to it. Normally perforated cutter is placed inside, it comes out during cutting operation and moves back with the help of spring.

1.2 Existing Mechanism

Various mechanisms can be used for transporting film. In below diagram the film is pulled through belt were friction is created for pulling action. It is intermittent motion, for operating intermittent motion high precision motor is required which is controlled by PLC controller.

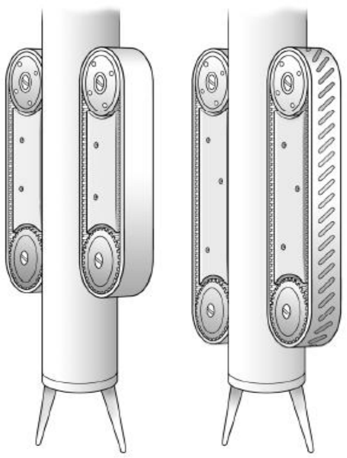

Fig -1.2: Belt Transport Mechanism

Belt transport mechanism consists of timer belt with pulley and gears. This mechanism is powered by servo motor. Servo mechanism is a closed loop mechanism which uses position feedback given by visual sensor to plc controller to control the motion. Belt is used to pull the film or plastic in bag making process. Friction is created between the film and belt, so that film is pushed forward.

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Limitation of belt transport mechanism

1. It is driven with help of servo motor which increases the cost.

2 Sensor are used to detect the film registration mark.

3. PLC controller is required to control to the motion.

4. Belt transport mechanism yields low downward force.

5. Extra resistance due to bottom block section, the film material get bunched up in forming tube.

1.3 Slider Crank Mechanism

Whole mechanism i.e. (belt puller) is replaced by slider crank mechanism. It is continuous motion. Volume of bag is also increased. Optimization is done by replacing the belt transport mechanism through slider crank motion mechanism.

Advantage of slider crank mechanism

1. By using the slider crank mechanism we can set the particular limits without using the sensor.

2. Servo motor is replaced by A.C. motor in which cost of servo motor is two times higher than the ac motor. By selecting the ac motor cost is minimized to 50% in this mechanism.

3. Force which is used to transport the film is more as compared to belt transport mechanism

4. Gear train is also eradicated.

5. Volume of bag is increased.

2. DESIGN OF SLIDER CRANK MECHANISM OF VFFS MACHINE

Slider crank mechanism is used to move the table up and down. Horizontal sealing bar is placed in table which holds the film and pull it downward. Horizontal sealing bar is also operated with the help of Slider crank mechanism. Length of the crank and connecting rod is selected according to the vertical bag length i.e. space between the top and bottom seal. And also depends upon the force which is required to lift the table. The above table is connected to plain linear slider which keeps the table to move only in one direction. Vertical bag length is depends on movement of the table i.e. slider length. For different bag length table movement can be adjusted. Adjustment is done by restricting the table up to particular length, it does not move beyond the required length. This can be achieved by keeping the restrictor between the movements of the table. The slider is free to move beyond the restriction of table, this is done by connecting it to another plain linear slider which also acts like a guider in one direction.

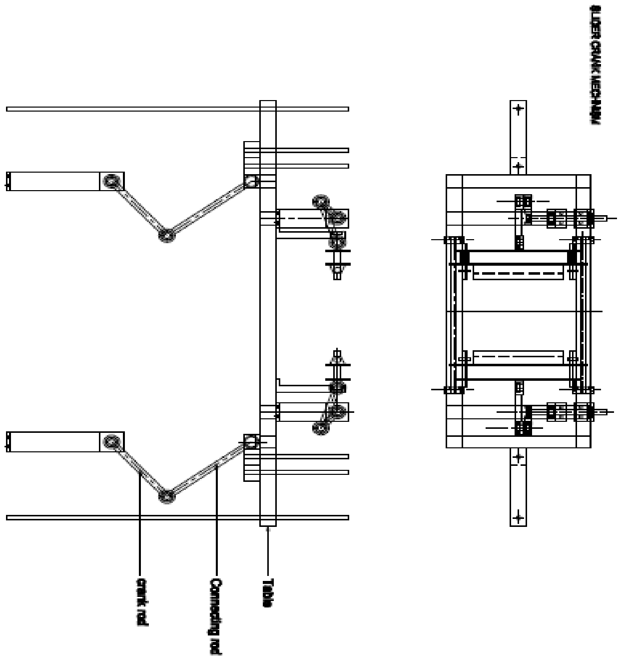

Fig -2.1: Layout of Slider Crank Mechanism

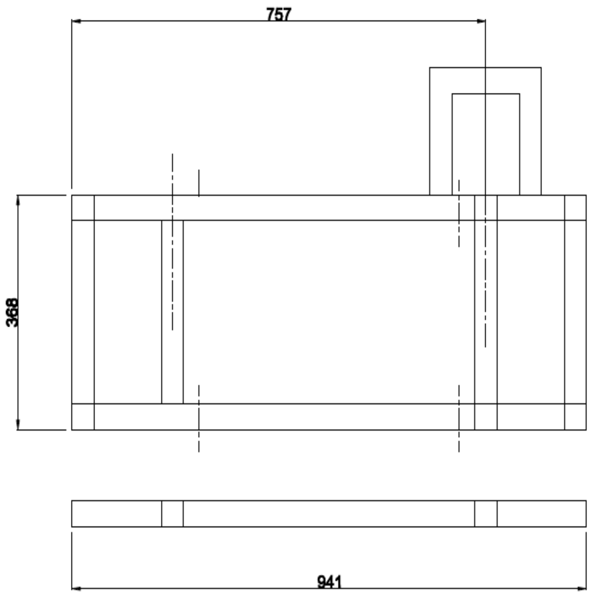

Fig -2.2: Film Pulling Table

Table which moves upward and downward with the help of slider crank motion.

Total Weight of the table: 245 N

Distribution of weight in left and right side: 98 N on left side and 147 N on right side

Additional weight: 58.84 N of motor weight.

Machine Motor: 0.5 hp.

2.1. Synthesis of Slider-Crank Mechanism Using Freudenstein Equation (By 3-Point Accuracy)

The synthesis of mechanism is done by general approach. In this approach the displacement equation is taken as first step by considering all parameter of linkages.

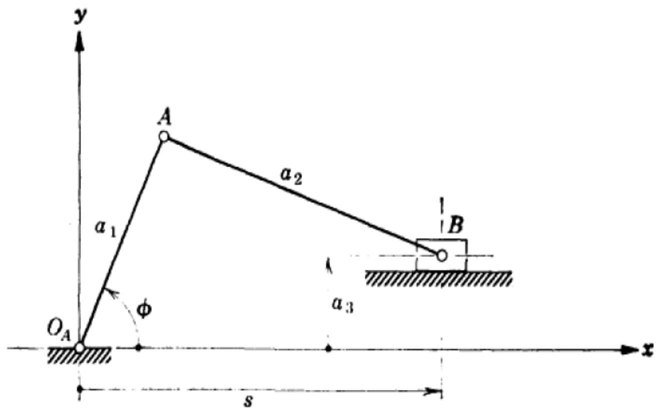

Fig -2.3: Synthesis of slider crank mechanism with three accuracy point

Co-ordinates of points A and B with respect to axes O_aXY are

$$x_A = a_1 cos\emptyset$$

$$y_A = a_1 sin\emptyset$$

$$x_B = s$$

$$y_B = a_3$$

Distance $AB = a_2$,as

$$(AB)^2 = (x_B - x_A)^2 + (y_B - y_A)^2$$

Or

$$a_2^2 = (s - a_1 \cos\varphi)^2 + (a_3 - a_1 \sin\varphi)^2$$

By using trigonometric identities, the equation get reduced to

$$2a_1 s\cos\phi + 2a_1 a_3 \sin\phi - (a_1^2 - a_2^2 + a_3^2) = s^2 \quad \text{...............} \text{..... (1)}$$

Three co-efficient K_1, K_2, K_3 is defined in terms of three parameter a_1, a_2, a_3 of linkages to carry out the three point synthesis.

$$k_1 = 2a_1$$

$$k_2 = 2a_1 a_3$$

$$k_3 = a_1^2 - a_2^2 + a_3^2$$

By using these terms, the equation became

$k_1 s\, cos\phi + k_2 sin\phi - k_3 = s^2$……………….(2)

It satisfies the last section .The notation for last section is

$G_1 = s\cos\phi$

$G_2 = \sin\phi$

$G_3 = -1$

$F = s^2$

This notation are identified as function of input and output variable Ø and s, this function is independent of parameter a. For three pair of values for ($Ø_1$,s_1),($Ø_2$,s_2),($Ø_3$,s_3) the above equation (2) can be converted into

$$k_1 s_1 \cos\varphi_1 + k_2 \sin\varphi_1 - k_3 = s_1^2$$

$$k_1 s_2 \cos\varphi_2 + k_2 \sin\varphi_2 - k_3 = s_2^2$$

$$k_1 s_3 \cos\varphi_3 + k_2 \sin\varphi_3 - k_3 = s_3^2$$

2.2. Buckling of Connecting Rod (Rankine's Formula)

Connecting rod is subjected to alternate tension and compression load, where compressive load is much higher than tensile load. Hence strut is considered while designing the cross section of connecting rod and rankine's formula is used.

$$W_{cr} = \frac{\sigma_c \times A}{1 + a\left(\frac{l}{k}\right)^2}$$

$W_{cr} = F_C$.

σ_c = Crushing stress

A = Area of connecting rod.

l = Length of connecting rod.

K = Radius of gyration.

F_C= Force on connecting rod.

W_{cr} = Factor of safety × Force on Connecting rod.

Total weight of table = 245 N

Weight on left side of slider crank = 98 N

Since it has low RPM, force is considered with factor of safety = 5

Total load on left side with factor of safety = 98 × 5

= 492 N

σ_c = 320 MPa

C = 1 (Since it hinged at both end)

We get diameter (d) = 3.447mm

Similarly for Total load on right side with factor of safety = 147× 5 = 736

For total load 882 N we get d= 3.8546 mm

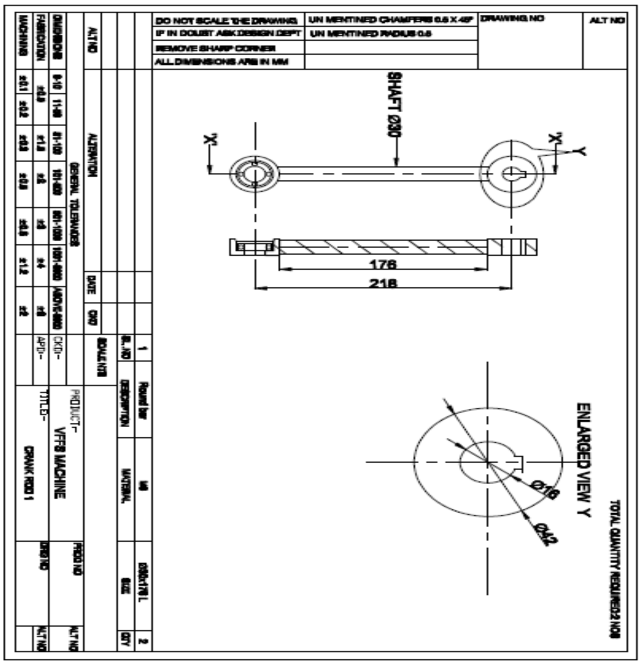

Fig -2.4: Dimension of Crank Rod

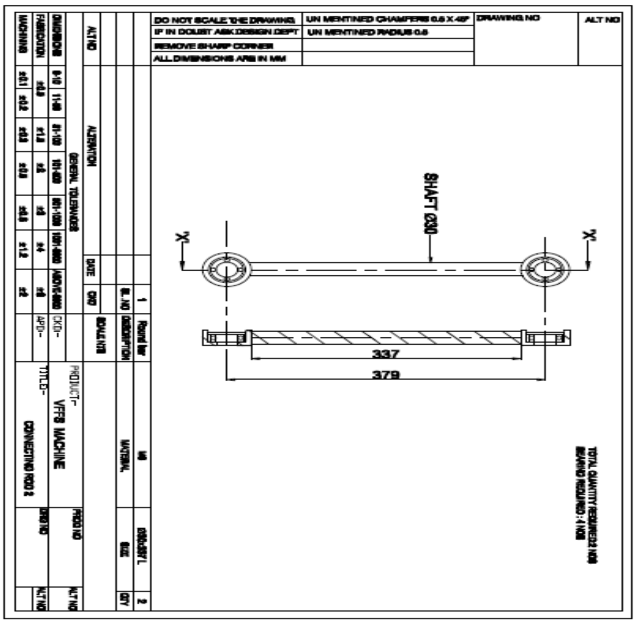

Fig -2.5: Dimension of Connecting Rod

Anysis R15.0 solution

Considering both ends as hinged and factor of safety as 5 ,force will be 492 N. This force is applied at both end by considering as compression load. Fine meshing is done.

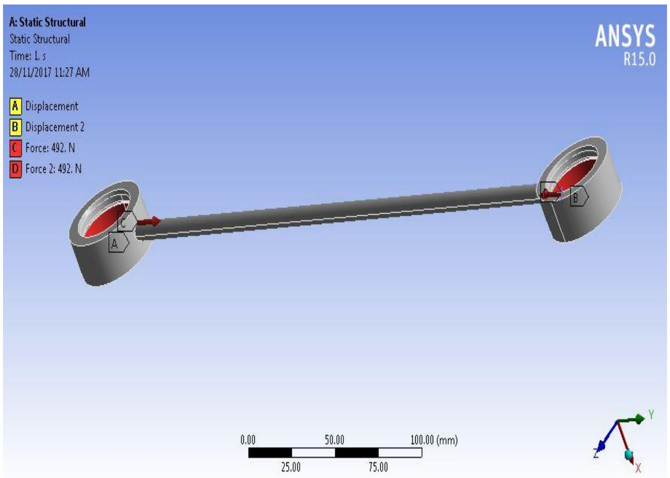

Fig -2.6: Load Condition of Connecting Rod for 492 N

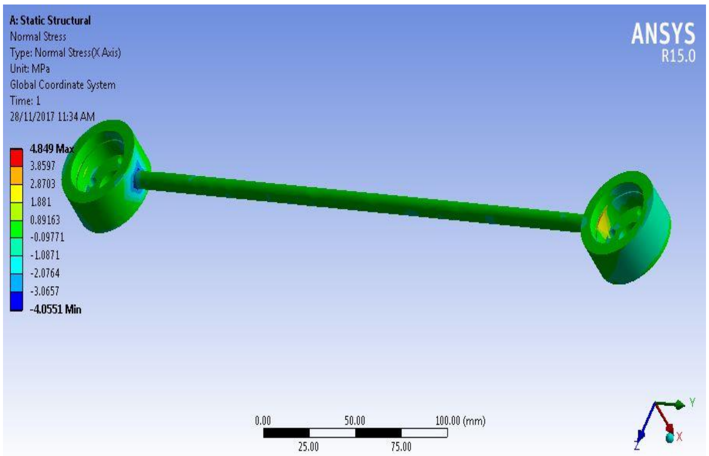

Fig -2.7: Stress Analysis of Connecting Rod for 492 N

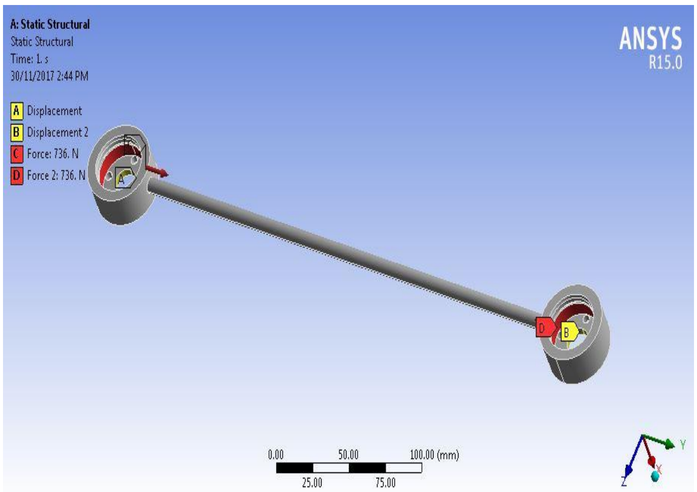

Fig -2.8: Load Condition for 736 N

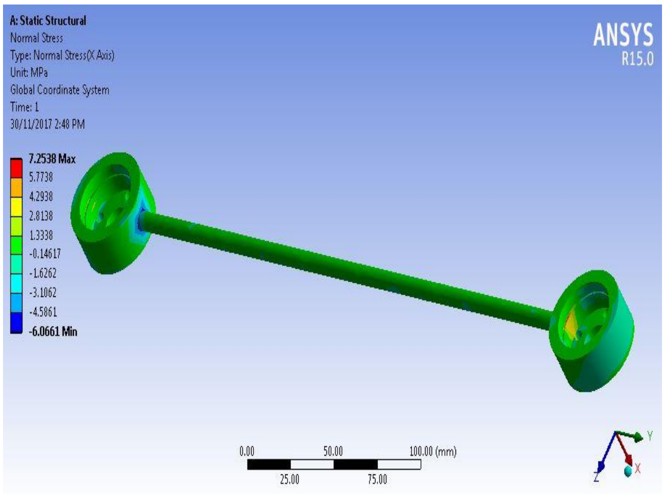

Fig -2.9: Stress Analysis for 736 N

3. ANALYSIS OF SLIDER CRANK MECHANISM FOR FILM TRANSPORT USED IN VFFS MACHINE

To set the stroke of 280mm, the initial position is obtained by assuming the initial value of crank length is 150mm and twice length of crank length for connecting rod. By assuming this value, putting the value in equation

$$x = r.cosA + \sqrt{l^2 - r^2 sin^2 A}$$

Initial position is

S=181 mm.

For finding the suitable length for crank and connecting rod, we have to try for initial position for S1=181 mm. S2=200 mm and check their transmission angle and velocity and acceleration and force required to lift the table.

3.1. Force Analysis of Slider Crank Mechanism

Selection of motor

Total weight of table= 245 N

Torque required to lift the table

(T)= $\frac{d}{2} \times weight\ of\ table = \frac{218}{2} \times 245$

T=26705 N-mm

T=26.705 N-mm

H.P= $\frac{16.034 \times 2 \times \pi \times 12}{4500}$

H.P=0.4474

H.P=0.5

Transmission Angle

a. The application of transmission angle γ is to determine the force transmission through linkages and it affect on mechanical efficiency.

b. In slider-crank mechanism, the mechanical is driven by crank. Mechanical advantage is constantly changing. Hence extreme transmission is taken or considered.

c. In slider-crank, the angle between the coupler and line normal to sliding direction is taken as transmission angle.

d. The value of min transmission angle is calculated by analytically or by graphical method.

$$\gamma = \cos^{-1}\frac{(L_1+L_2)}{L_3} \quad \text{(Min transmission angle)}$$

$$\gamma = \cos^{-1}\frac{(L_1-L_2)}{L_3} \quad \text{(Max transmission angle)}$$

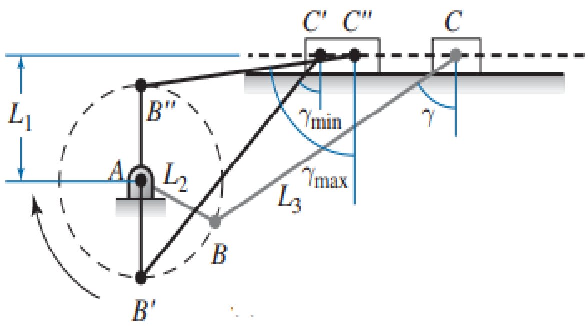

Fig -3.1: Minimum Transmission Angle

After getting minimum transmission angle, force with respect minimum transmission angle is determined. Force diagram is determined graphically in figure 3.2.

Force along sliding for min transmission

The force the connecting rod is resolved into two forces .

1. Tangential force of crank rod. (F_{TC})

2. Connecting rod force (F_Q)

3. Force along sliding (F_s)

$$T = \frac{4500 \times HP}{2 \times \pi \times N} kg - m$$

$$T = F \times r \; N - mm$$

$$F_{TC} = \frac{T \times 2}{d} N$$

$$F_Q = F_{TC} \times Cos\theta \; N$$

$$F_S = F_Q \times Cos\theta \; N$$

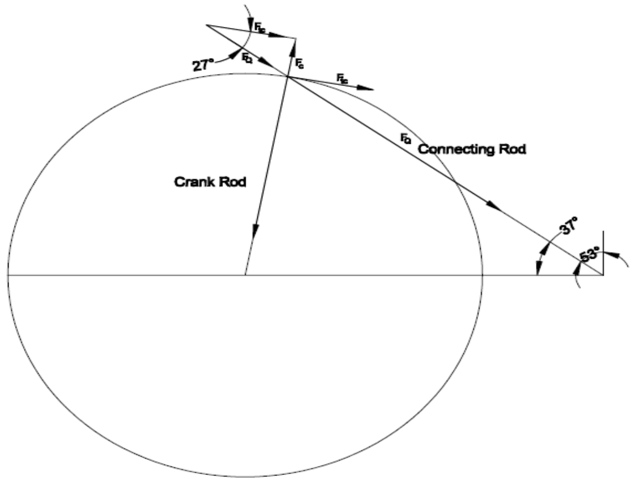

Fig -3.2: Minimum transmission force along connecting rod

Minimum force along connecting rod:

It is force required at starting point were lifting of table began. Force diagram is determined graphically in figure 3.3

The force the connecting rod is resolved into two forces.

1. Tangential force of crank rod. (F_{TC})

2. Connecting rod force (F_Q)

3. Force along sliding (F_s)

$$F_{TC} = \frac{T \times 2}{d} N$$

$$F_Q = F_{TC} \times Cos\theta \; N$$

$$F_S = F_Q \times Cos\theta \; N$$

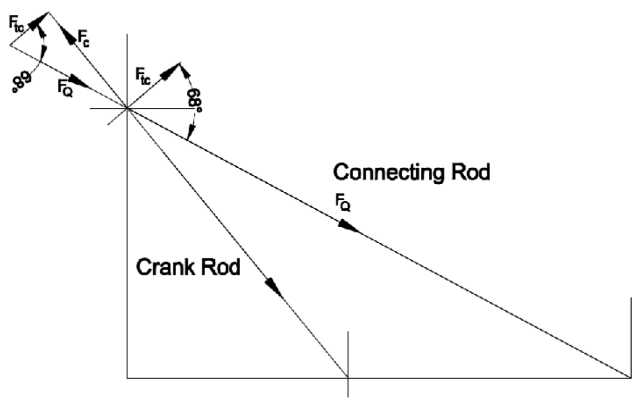

Fig -3.3: Minimum force along connecting rod

Force Calculated Table

Table -1: Force Analysis of Different Crank and Connecting rod with Various Transmission Angle

Initial Position	180	200
Crack Length	218	218
Connecting Length	360	379
Minimum Force	448	490
Mechanical Efficiency	33%	36.5%
Force Transmission	480.5	516.4
Mechanical Efficiency	72%	77%

With existing VFFS machine motor minimum transmission angle of crank length 218mm and connecting length 379 has max force transmission through connecting rod.

4. CONCLUSION

As it is compared with belt film transport mechanism, slider crank mechanism is continuous motion. Hence it does not require high precise motor. It can be powered by simple existing machine electric motor with VFD (variable frequency drive) attached to it. Volume of bag is also increased as compared to sealing jaw draw principle.

Slider crank mechanism does not required sensor which is used to specify the bag length. The bag length is decided by sliding length (movement of table). Flexibility of length adjustment (variation of length) can be achieved by placing restrictor in between the movement of table. By comparing the obtain crank and connecting length from synthesis of mechanism, the crank length 218mm and connecting rod length of 379mm is optimum for the following reason:

1. The force which is obtained from crank and connecting rod is high as compared to other length. And also force during minimum transmission angle is more.

2. Velocity and acceleration curve have defined relation with each other. They also satisfy the required condition.

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