Indian Institute of Technology Gandhinagar

ME 322 : Synthesis and Analysis of Mechanism

Mini Project 3

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Introduction:

We have developed a printing machine that moves a roll of paper intermittently, allowing for the stamping of two IITGN logos on the paper before rolling it further to prepare for the next set of logos, as shown in Figure 1. The machine is powered by a single constant-speed motor, which ensures consistent operation. To achieve the best possible results, we have designed the machine to stop the paper's movement during the logo-stamping process, enabling precise and accurate placement of the logos. Furthermore, we have ensured that the stamping blocks remain pressed against the roll of paper for at least 5% of the entire cycle to ensure that the logos are correctly stamped with the appropriate pressure.

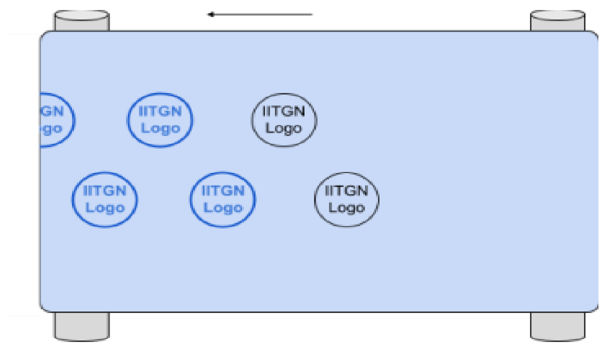


Fig. 1 - Desired mechanism

Mechanism: Our Thought Process

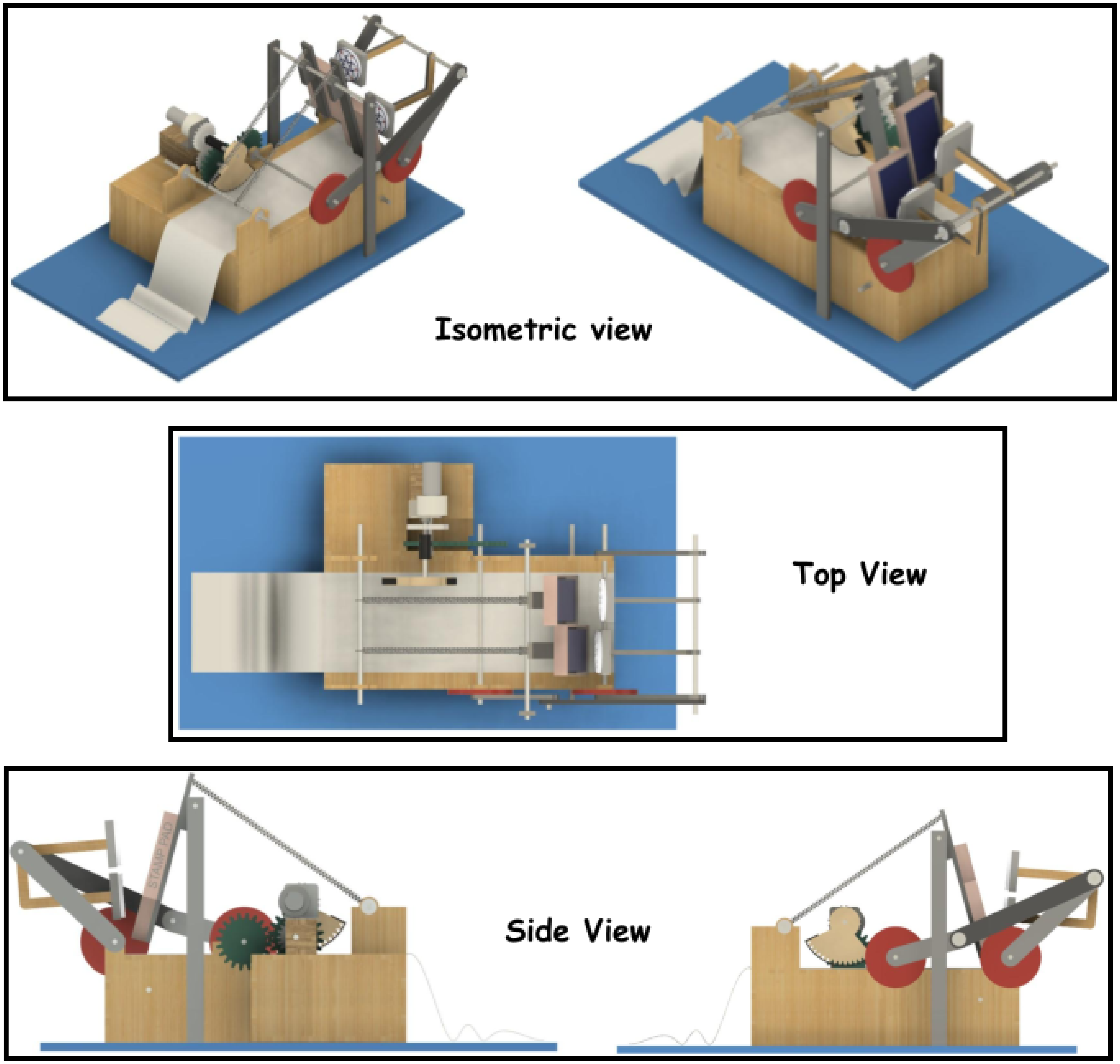


Fig. 2 - CAD model for the designed mechanism

The stamp should go through a periodic motion with different velocities at different points, its velocity should be low when it is in contact with the paper, which approximately acts as a dwell time and go back and return for the next cycle. A rocker motion would be a good motion that can support the stamping mechanism, which can be provided by a simple four-bar mechanism. The fewest parts that can do the job will usually give the simplest and most reliable solution. Thus, the four-bar linkage should be among the first solutions to motion control problems that come to our mind.

Grashof crank rocker mechanism:

The shortest link and the link which drives the mechanism is the crank, and since the crank should be continuously rotating, it should satisfy the grashof condition:

$$S+L <= P+Q$$

In this case, we have used S+L < P+Q. Grounding the link adjacent to the shortest link will give the crank rocker mechanism where the shortest link will rotate completely and the other link pivoted to the ground will oscillate. Here, the crank will transmit the power.

When the stamp is in contact with the paper, we require that the stamp should be perpendicular to the paper surface so it gives a good image of the logo when it lands on the paper. When the stamp is in the air and contacting the inkpad's surface, we require that it be perpendicular to the inkpad so it will absorb the ink properly and completely as shown in the image below.

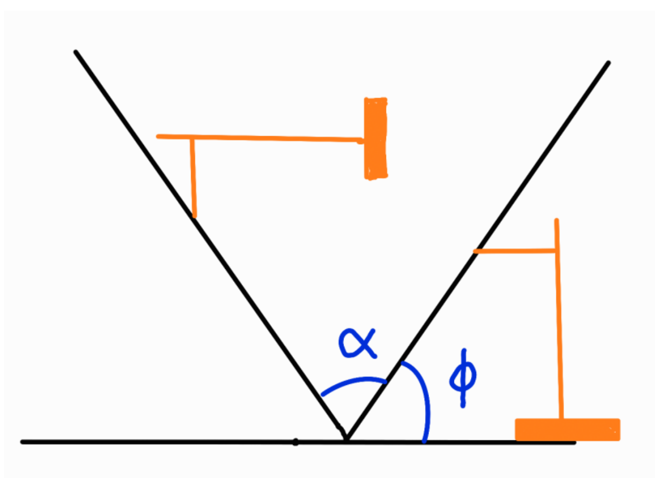


Fig. 3

We assumed a symmetric motion to make calculations simpler , this will mean φ = 45 degree and α = 90 degrees.

We started with an arbitrary size of 15 cm for the rocker (around 3 times the size of our stamp) and 15 cm for the ground link and calculated the length of the other links[1] . The link lengths were round to the nearest integer and chosen as :

Crank = 8 cm

Coupler = 20 cm

Rocker = 15 cm

Ground = 15 cm

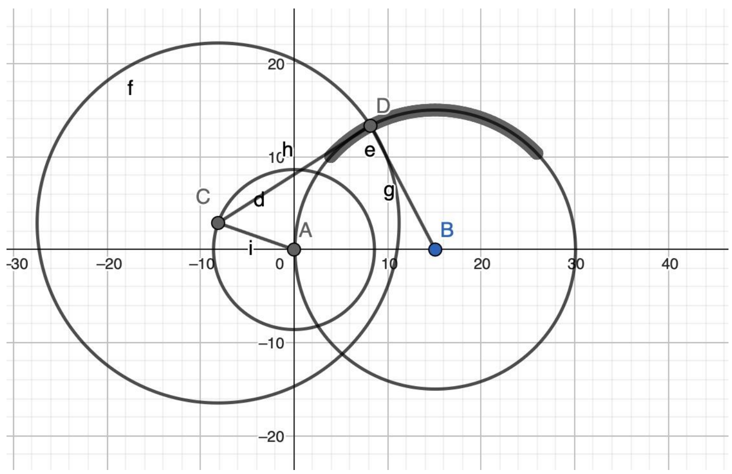


Fig. 4 - Geogebra simulation

Quick Return Mechanism:

A quick return mechanism converts rotary motion into reciprocating motion with varying speeds in the forward and backward directions. Theoretically the above mechanism will give a time ratio[1] of 1.3 . The four bars are arranged in a specific way to achieve the desired motion. The input crank rotates at a constant speed, whereas the output rocker oscillates back and forth. This mechanism is designed so that the lengths of the crank and rocker are not equal. This causes the rocker to travel a shorter time in the one direction and a longer time in the other direction, allowing the stamps to return slowly but land quickly on the paper. The stamping returning quickly and halting to a stop will also mean a greater change in momentum translating to greater force applied on the paper.

[1] https://www.ias.ac.in/article/fulltext/sadh/046/0004, the length of the links and time ratio were calculated using formulas from here.

For rolling of paper:

For moving the roll of paper intermittently and stopping while two IITGN logos are stamped on the paper, we used a customized wheel for dwelling, as shown in the figure below. The wheel is directly connected to the motor. When the wheel surface is in contact with the paper's surface, it rolls the paper, and when it is in the air, the paper stops rolling to stamp the logo. Angle of the wheel was chosen such that the paper moves sufficiently and no overlap happens between the stamps. For this to happen the paper should move at least = 11.2 cm (length of one stamp = 5.6) . The radius of the wheel is 6.2 cm (distance between motor shaft and paper)

$$\frac{\theta}{360} * 2\pi r = 11.2\ cm$$

θ ~ 103.7 degrees

We took θ = 105 degrees .

Fig. 5 - Mechanism for rolling the paper

Ink retention mechanism:

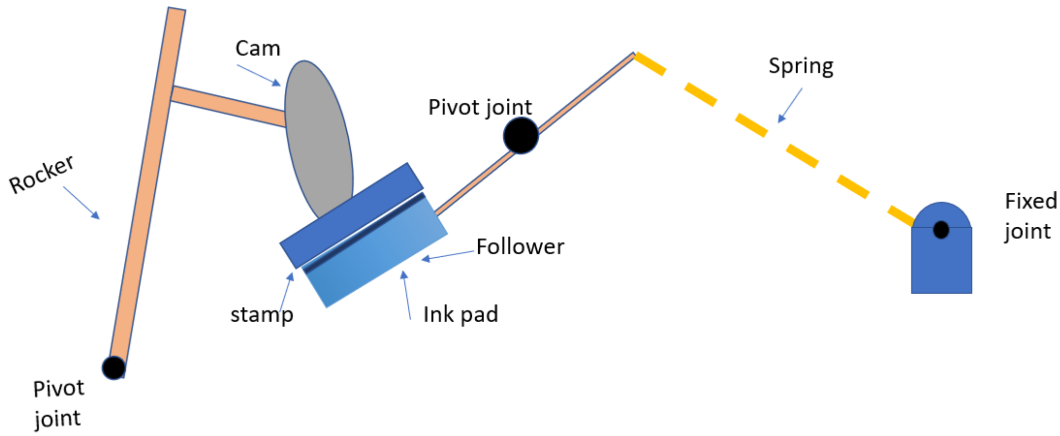


Fig. 6 - When the ink pad and stamp surfaces are parallel

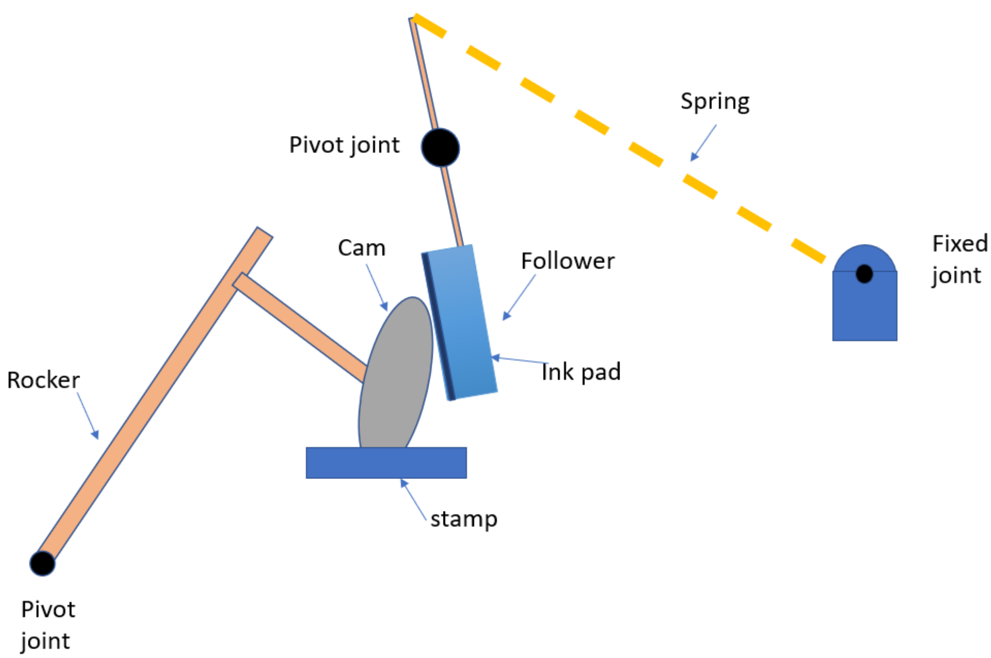


Fig. 7 - when the stamp surface moves away from the ink pad surface

To keep the stamps layered with ink as it continuously keeps stamping, we have designed a mechanism inspired from the cam-follower mechanism. As the stamp moves forward, it pushes the ink pad which moves along with the stamp for a very small distance and then the stamp moves past the inkpad to press on the paper, the stamp acts as a cam and when the stamp is moving backward the profile on the back of the cam allows it to move freely past the inkpad. The spring attached to the other end of the inkpad allows it to keep exerting force against the stamp, follow its motion and also come back to its original position at the end of the cycle. The dimensions of the cam are chosen based on experimentation.The dimensions of the cam were derived experimentally after the crank rocker mechanism was built.

Final setup for stamping mechanism:

Fig 8: Final Setup

Analysis:

Mobility:

As our mechanism is a four bar mechanism, the number of links in our mechanism are four. Number of joints in the mechanism are four.

We know that,

Mobility (M) = 3(L-1) - 2J_1 - J_2

Links, L = 4,

Binary joint, J_1 = 4,

Half joint, J_2 = 0, (No half joints)

Thus,

M = 3 (4-1) - 2×4 -0

M = 9 - 8

M = 1

The mobility of our four bar crank rocker mechanism is one. The entire mechanism is controlled by a single motor, so we can say that the mobility is one.

Position Analysis:

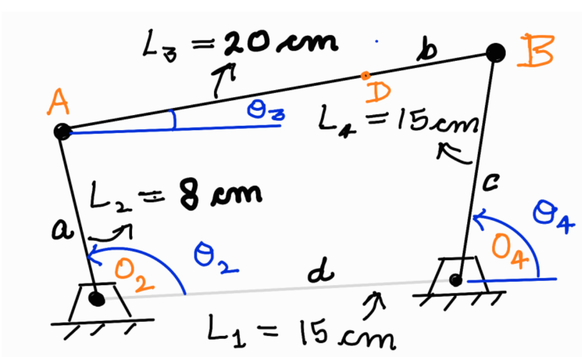


Fig 9 : Four Bar

Here,

Crank (a) = 8 cm = 0.08 m

Coupler (b) = 20 cm = 0.2 m

Rocker (c) = 15 cm = 0.15 m

Ground (d) = 15 cm = 0.15 m

From the vector loop equation, we get:

$$acos\theta_2 + bcos\theta_3 - ccos\theta_4 - d = 0$$

$$asin\theta_2 + bsin\theta_3 - csin\theta_4 = 0$$

$$A = cos\theta_2 + k_1 - k_2 cos\theta_2 + k_3$$

$$B = -2sin\theta_2$$

$$C = K_1 + (k_2 + 1) cos\theta_2 + k_3$$

K_1 = d/a = 1.744,

K_2 = d/c = 1,

$$K_3 = \frac{a^2 - b^2 + c^2 + d^2}{2ac} = 0.579$$

K_4 = d/b = 0.775

$$K_5 = \frac{c^2 - d^2 - a^2 - b^2}{2ab} = -1.347$$

$$D = cos\theta_2 - k_1 + k_4 cos\theta_2 + k_5$$

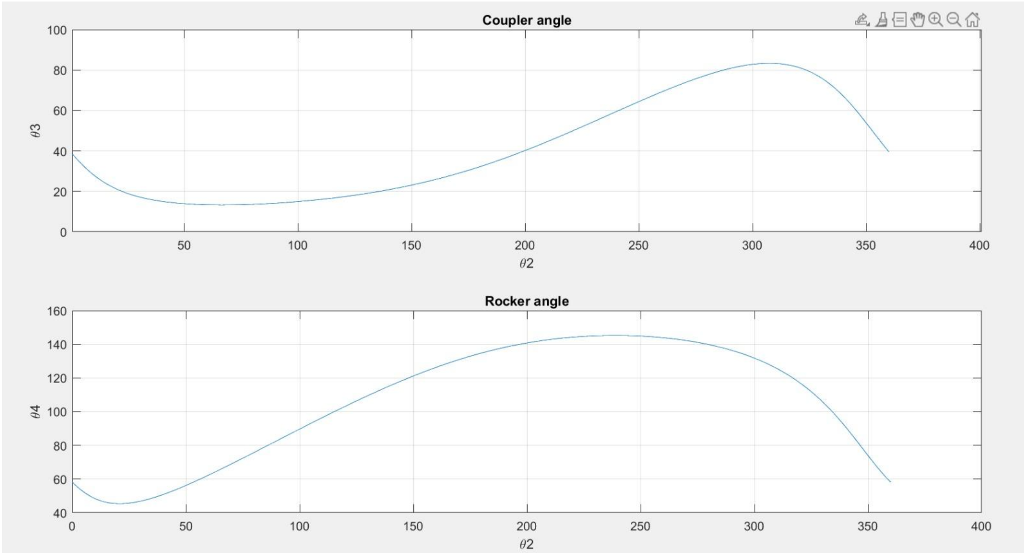
$$E = -2sin\theta_2$$

$$F = K_1 + (k_4 - 1) cos\theta_2 + k_5$$

$$\theta_3 = 2tan^{-}\left(\frac{-E - \sqrt{E^2 - 4DF}}{2D}\right)$$

$$\theta_4 = 2tan^{-}\left(\frac{-B - \sqrt{B^2 - 4AC}}{2A}\right)$$

Using these relations, and plotting the rocker angle with respect to crank angle in matlab gives us the following plot.



Graph 1: Crank angle Vs Rocker & Coupler angles

Velocity Analysis:

From the vector loop equation, we get

$$ae^{j\theta_2} + be^{j\theta_3} - ce^{j\theta_4} - de^{j\theta_1} = 0$$

By differentiating the above equation, we get

$$ja\omega_2 e^{j\theta_2} + jb\omega_3 e^{j\theta_3} - jc\omega_4 e^{j\theta_4} = 0$$

By equating real part and imaginary part to zero, we get:

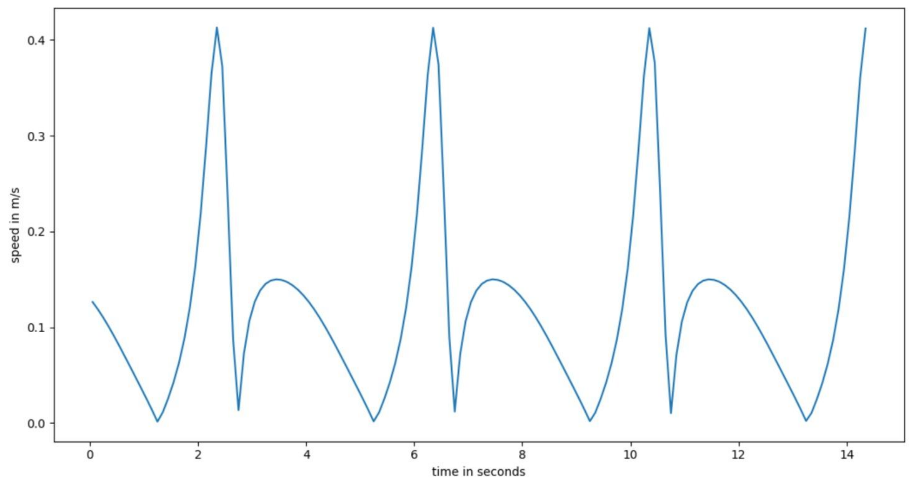
$$\omega_3 = \frac{a\omega_2}{b}\frac{\sin(\theta_4 - \theta_2)}{\sin(\theta_3 - \theta_4)}$$

Similarly,

$$\omega_4 = \frac{a\omega_2}{c}\frac{\sin(\theta_2 - \theta_3)}{\sin(\theta_4 - \theta_3)}$$

For the motor used , ω_2 = 1.57 rad/s

with the previous position relations and these angular velocity relations can be used to calculate the linear velocity of any point on the links. Since our motor's rpm was 15, we have obtained the magnitude of the velocity of our stamp with respect to time, this also helps us estimate our approximate dwell time by checking the time range at which there is a very little speed when the stamp touches the base. We also observe that when the stamp is moving towards the paper, it moves with a higher momentum than that when it goes back.



Graph 2: Velocity vs time

Acceleration Analysis:

The velocity expression obtained after differentiating the equation we got from vector loop equation is

$$ja\omega_2 e^{j\theta_2} + jb\omega_3 e^{j\theta_3} - jc\omega_4 e^{j\theta_4} = 0$$

Differentiating and simplifying the above equation, we get

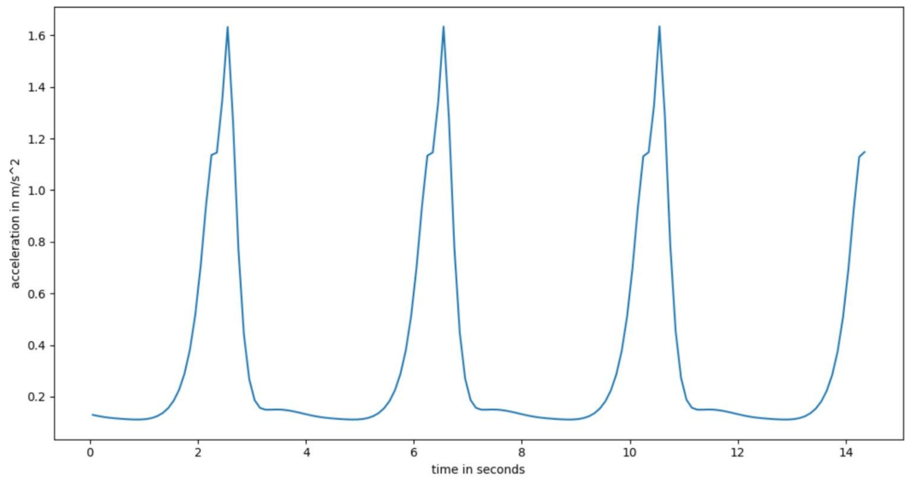
$$\left(a\alpha_2 je^{j\theta_2} - a\omega_2^2 e^{j\theta_2}\right) + \left(b\alpha_3 je^{j\theta_3} - b\omega_3^2 e^{j\theta_3}\right) - \left(c\alpha_4 je^{j\theta_4} - c\omega_4^2 e^{j\theta_4}\right) = 0$$

$$\alpha_3 = \frac{CD - AF}{AE - BD}$$
$$\alpha_4 = \frac{CE - BF}{AE - BD}$$

Where,

$$A = c\sin\theta_4$$
$$B = b\sin H_3$$
$$C = a\alpha_2\sin\theta_2 + a\omega_2^2\cos\theta_4 + b\omega_3^2\cos\theta_3 - c\omega_4^2\cos\theta_4$$
$$D = c\cos\theta_4$$
$$E = b\cos\theta_3$$
$$F = aY_2\cos\theta_2 - a\omega_2^2\sin\theta_2 - b\omega_4^2\sin\theta_3 + c\omega_4^2\sin\theta_4$$

Using these relations, we plotted the acceleration vs time for our stamp.



Graph 3: Acceleration vs time

Force Analysis:

Below figure represent the four bar mechanism used in our setup

Crank (a) = AO_2 = 8 cm

Coupler (b) = AB = 20 cm

Rocker (c) = BO_4 = 15 cm

Ground (d) = O_2O_4 = 15 cm

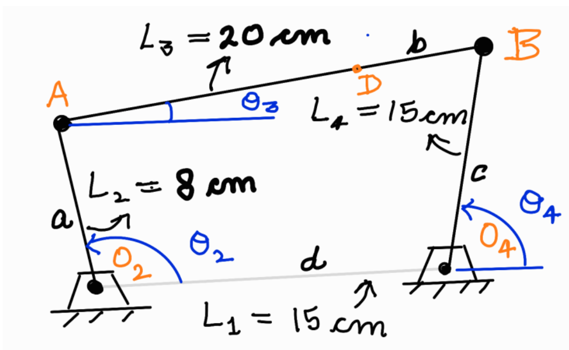


Fig. 10 - Four bar links

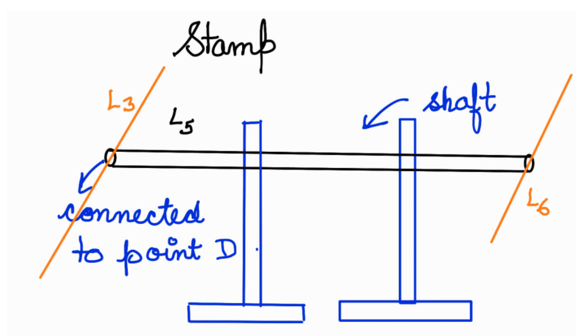


Fig. 11 - For stamp

For force analysis, first we drew the FBD of all links.

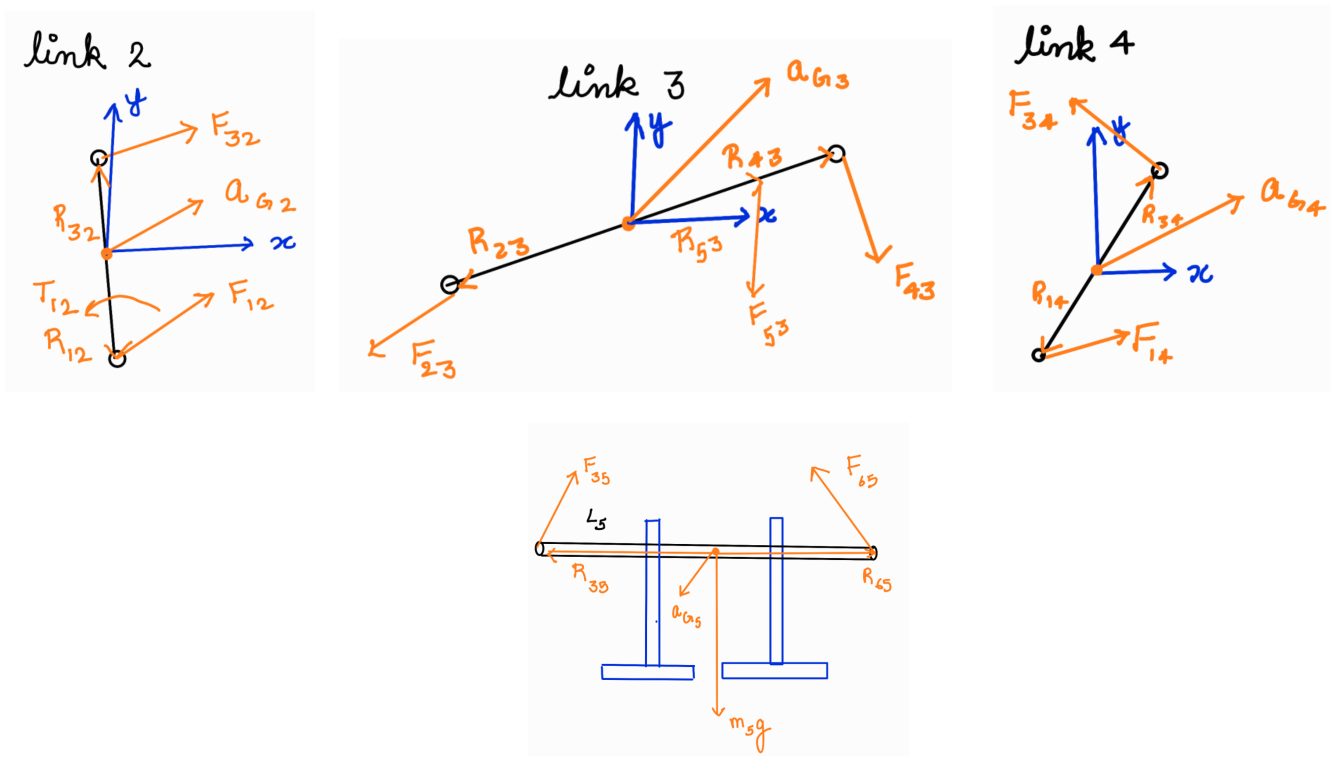


Fig. 12 - FBD of Four Bar

After drawing FBD, we calculated the desired dynamics equation as:

For link 2

$$F_{12x} + F_{32x} = m_2 a_{G2x}$$

$$F_{12y} + F_{32y} = m_2 a_{G2y}$$

$$T_{12} + (R_{12x}F_{12y} - R_{12y}F_{12x}) + (R_{32x}F_{32y} - R_{32y}F_{32x}) = I_{G2}\alpha_2$$

For link 3

$$F_{43x} - F_{32x} + F_{53x} = m_3 a_{G3x}$$

$$F_{43y} - F_{32y} + F_{53y} = m_3 a_{G3y}$$

$$(R_{43x} F_{43y} - R_{43y} F_{43x}) - (R_{32x} F_{32y} - F_{32y} F_{32x}) + (R_{53x} F_{53y} - R_{53y} F_{53x}) = I_{G_3} \alpha_3$$

For link 4

$$F_{14x} - F_{43x} = m_4 a_{G4x}$$

$$F_{14y} - F_{43y} = m_4 a_{G4y}$$

$$(R_{14x} F_{14y} - R_{14y} F_{14x}) - (R_{34x} F_{34y} - R_{34y} F_{34x}) = I_{G_4} \alpha_4$$

For link 5

$$-F_{53x} + F_{65x} = 0$$

$$-F_{53y} - F_{65y} - m_5 g = m_5 a_{G5y}$$

$$(R_{35y} F_{35x} - R_{35x} F_{35y}) - (R_{65y} F_{65x} - R_{65x} F_{65y}) = I_{G_3} \alpha_3$$

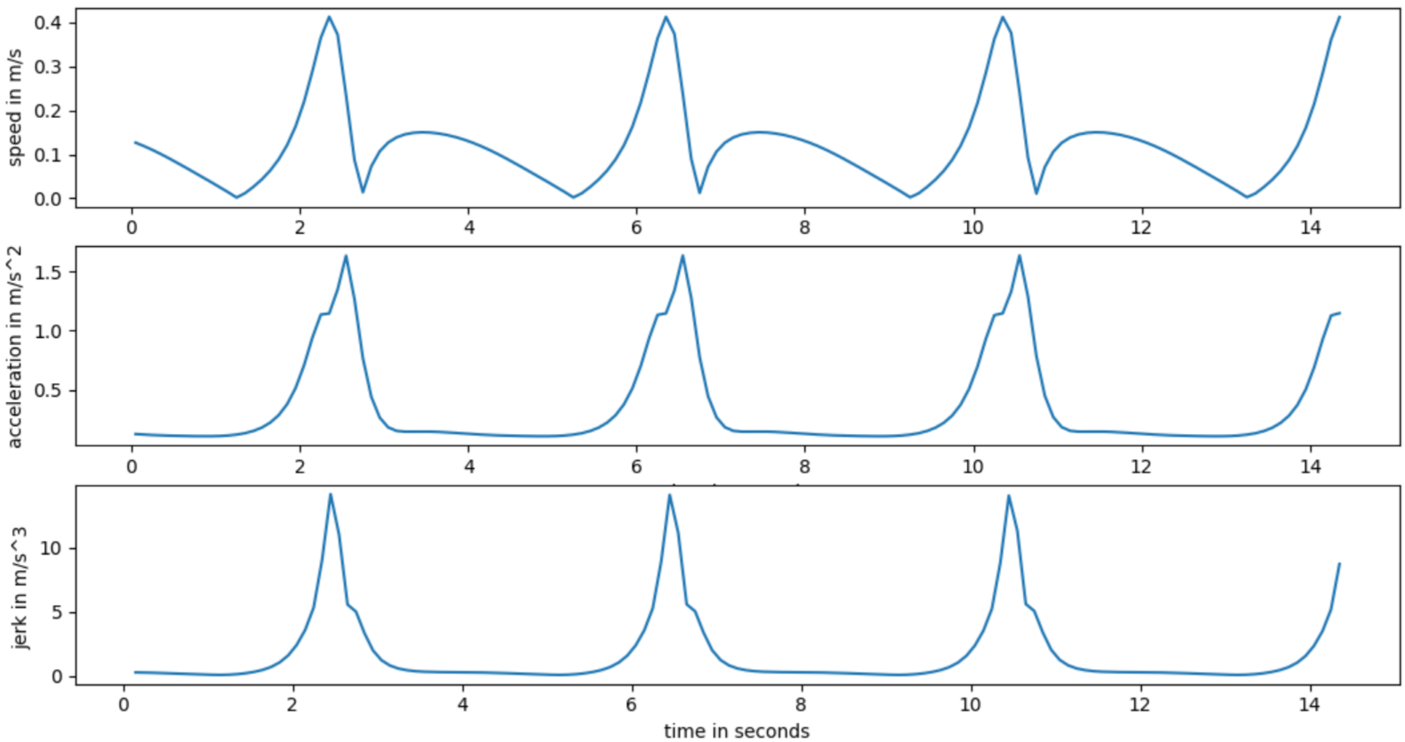
Matrix form(12 X 12) including all the above dynamic equation can be written as:

$$\begin{bmatrix}
-1 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & -1 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
R_{12y} & -R_{12x} & -R_{32y} & R_{32x} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & -1 & 0 & 1 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\
0 & 0 & 0 & -1 & 0 & 1 & 0 & 0 & 0 & 1 & 0 & 0 \\
0 & 0 & R_{32y} & -R_{32x} & -R_{43y} & R_{43x} & 0 & 0 & -R_{53y} & R_{53x} & 0 & 0 \\
0 & 0 & 0 & 0 & -1 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & -1 & 0 & 1 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & -R_{34y} & R_{34x} & -R_{14y} & R_{14x} & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -1 & 0 & 1 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -1 & 0 & -1 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -R_{35y} & R_{35x} & -R_{65y} & R_{65x}
\end{bmatrix}
\begin{bmatrix}
F_{21x} \\ F_{21y} \\ F_{32x} \\ F_{32y} \\ F_{43x} \\ F_{43y} \\ F_{14x} \\ F_{14y} \\ F_{53x} \\ F_{53y} \\ F_{63x} \\ F_{65y}
\end{bmatrix}
=
\begin{bmatrix}
m_2 a_{G_2x} \\ m_2 a_{G_2y} \\ I_{G_2}\alpha_2 - T_{12} \\ m_3 a_{G_3x} \\ m_3 a_{G_3y} \\ I_{G_3}\alpha_3 \\ m_4 a_{G_4}x \\ m_4 a_{G_4y} \\ I_{G_4}\alpha_4 \\ 0 \\ m_5 a_{5y} \\ I_{G_3}\alpha_3
\end{bmatrix}$$

Number of unknowns are 12, which includes, F_{12x}, F_{12y}, F_{32x}, F_{32y}, F_{53x}, F_{53y}, F_{43x}, F_{43y}, F_{14x}, F_{14y}, F_{65x} and F_{65y}.

Results:

The region around where the velocity is approximately zero is used as a dwell period using an extra joint attaching the rocker to the stamp.



Graph 4

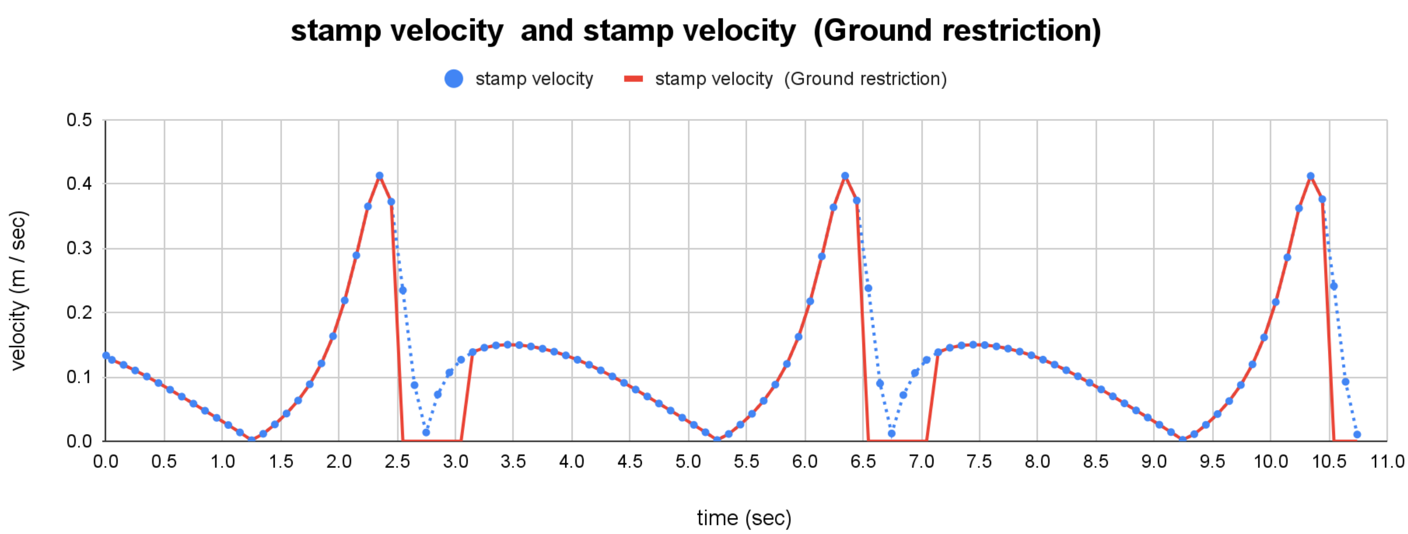
Graph 4(a) - X axis: time in sec and Y axis: magnitude of velocity in m/s

Graph 4(b) - X axis: time in sec and Y axis:magnitude of acceleration in m/s^2

Graph 4(c) - X axis: time in sec and Y axis:magnitude of jerk in m/s^3

As we can see in graph 4(a) that between 6 to 8 sec, the velocity of the point where the stamp is attached(on the four-bar links) is approximately zero. From the graph, it appears that the speed of stamps is never actually zero. However, in our mechanism, the stamp touches the paper for approximately 2 sec (between 6 and 8) and when it touches the paper, a frictional force acts between the paper and the stamp. In this time period, we can see in Graph 4 (b) acceleration of the stamp is 0 (approximately). So, the force exerted on the stamp by the motor is reduced to 0 by frictional force and it remains in contact with the paper in this time period. Since our stopping time was just provided by the simple four-bar mechanism and frictional force, we didn't have to use Geneva or any other intermittent motion mechanism, which would have unnecessarily increased the load on the motor.

Stamp is attached to the rocker link so it will also perform a quick return motion. While the stamp is going towards paper, it's change in velocity will be in less time due to quick return because of which stamp will apply force while stamping. Stamp velocity will tend to zero at extreme points of motion but due to ground restriction we will get some dwell time where the stamp will rest on paper for little time but the rocker will continue moving. So we can assume that restriction as shown in fig. below.

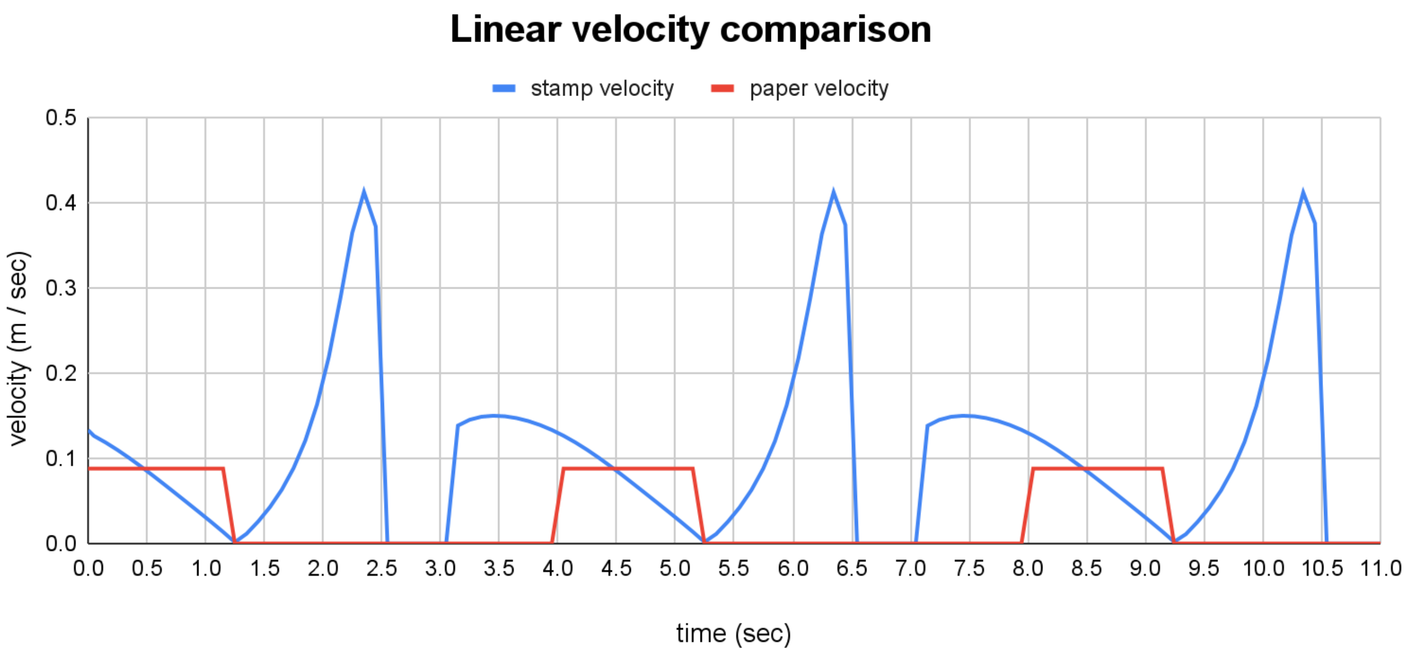


Graph 5

From above graph, One full cycle time = 4 sec (rpm of motor = 15)

Dwell time for stamping = 0.5 sec

So we compared paper rolling velocity with stamp velocity as shown in fig. below,



Graph 6

From above graph, paper rolling time = 1.2 sec

The final stamps we printed using our stamping mechanism are as shown below:

Fig. 13 - The Final output

Challenges:

The major challenges we faced while doing this project are:

- Having a suitable transmission angle was a challenge.
- We had to change our motor, as the load that the previous motor had was not enough to drive our mechanism.
- Initially, the mechanism was not sturdy due to the misalignment of the gears and the motor was vibrating. Later, we fixed the motor with the base box so that the motor was not vibrating and there was a proper alignment of gears.

Scope of Improvement:

- If we could use spring instead of a rubber band for the stamp holder then it would be better. As it looks more aesthetic and it will hold the stamp properly.
- After stamping on the paper, there needs to be a paper roll which collects the paper. It helps for frequent reloading, reducing downtime and increasing productivity. It can be easily replaced when it runs out, making it convenient and user-friendly.

Key Learnings:

- To ensure accurate and consistent printing results, the machine must be precisely engineered. This requires a meticulous approach to design and manufacturing, including the selection of high-quality materials, precise machining, and careful assembly.
- We identified potential issues, such as misalignment or improper pressure, and developed effective solutions to ensure that the machine operates correctly.
- To achieve the best possible results, we paid close attention to even the smallest details. This includes carefully calibrating the machine's movements, ensuring precise alignment of stamping blocks, and maintaining the correct pressure during stamping.
- Building a mechanism such as a printing machine is rarely a one-shot process. We iterated various designs based on testing and feedback and finally came up with the above model.

Acknowledgement:

In the accomplishment of completion of our project on **'Stamp Mechanism'** we would like to convey our special gratitude to Prof. Harish Palanthadalam Madapusi. Your valuable guidance and suggestions helped us with project completion. We will always be thankful to you in this regard. We would also like to thank our TAs for their continuous motivation and support. We would also like to thank the Tinkerer's Lab and Machine Shop team for letting us build our project in it and providing us with the tools necessary for the project's successful completion.