A graphical approach for kinematic design and development of an automatic stamping machine using four bar chain

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In this paper, an attempt has been made to develop a stamping machine for making the labelling operation in any production line automatic. An inversion of the four bar chain with one link suitably shaped in the form of a stamp has been designed such that it labels each of the boxes present on the conveyor one by one. Though the stamping machine is not a new device and such devices have been made and are currently being used the world over, it is, the methodology of design used in this paper, which is rather unconventional. The mechanism has been designed graphically using the three position synthesis of four bar chain mechanism in which three positions of the coupler link of the mechanism have been fixed to carry out the synthesis. A prototype of the stamping machine has been fabricated and checked for smooth working.

Key words: Inversion, Three position synthesis, Coupler, Kinematic analysis, Freewheel.

A mechanism is an assemblage of links connected in such a manner that for a fixed input, there is some definite output\textsuperscript{1}. Different types of mechanisms form part of various machines for automation of many industrial functions such as forming, embossing and stamping. Each of these functions is important as they define a particular stage of product development and manufacture. Embossing/stamping defines a stage when the manufacturing of the product is complete and it is ready for despatch and hence enlists a very important industrial function\textsuperscript{2}. In the past when the production rates were low, the label stamping on the product/packages was done manually. With the industrial automation and ever growing production rates a strong need was felt to automate this function and many different techniques were employed to achieve it. In the process several kinds of stamping machines were devised and used in the past. However, most of these solutions provided a semi-automatic stamping process. Figure 1 shows a stamping machine used by the Chinese in 17\textsuperscript{th} century to press stacks of paper. Figure 2 (a, b) shows two variations of the stamping machines used in modern day industries.

All these stamping machines employ one or other type of mechanisms. The suitable mechanism is synthesised using either algebraic or graphical methods based on function or path generation\textsuperscript{3-5}. In the present paper, an attempt has been made to achieve the stamping operation by means of a mechanism which is an inversion of the well known four bar chain mechanism with one link shaped in the form of a stamp and with stamp pad and the conveyor belt as its limits of travel. The synthesis of the mechanism is done for two limiting conditions, i.e., the position of the ink pad and the position of the package/box on the conveyor. Another self imposed constraint is to use a single drive for operation of stamping machine as well as the conveyor carrying the packages/boxes. In order to achieve the limiting

\[\text{Fig.1— Stamping machine used by the Chinese}\]
conditions and self imposed constraint, different available approaches of mechanism design are applied. One such approach employs generating a function for the output link or input link but due to lack of the exact conditions, this approach failed in the present case. Next, attempts were made to use the method of two position synthesis for four bar mechanism but it required assuming the length of the input link as well as the angle to be moved by the input link. Finally, the method of three position synthesis for four bar mechanism is adopted for design.

Design Methodology

Various steps employed to synthesis the four bar mechanism for stamping machine are as follows:

Step 1— Fix two extreme positions for the mechanism. These are (refer Fig. 3): (i) the position when boxes/packages are being stamped and (ii) The position when the stamp hits against the ink pad.

Step 2—Since the above two positions came out to be anti-parallel, it implies that the link bearing the stamp became horizontal at some intermediate position. Hence, there is a need to define at least one intermediate position.

Step 3—The three positions for the design are fixed as: (i) The position in which the stamping operation is performed, (ii) The position in which the reinking is done and (iii) A position in between the above two, i.e., between the two vertical positions of the link bearing the stamp. This third position is assumed to be the horizontal position encountered while moving from (i) to (ii) (refer Fig. 4.).

Step 4—Choose a convenient length of one of the links which in this case is taken equal to 30 mm. Irrespective of this assumed value the other links will always bear a fixed proportion to this value.

Step 5—(a) Draw three positions as A1 B1, A2 B2, A3 B3, (refer Fig. 5a); (b) Join points A1 A2 and A2 A3 by dotted lines. (refer Fig. 5b); (c) Similarly, join
points B₁B₂ and B₂B₃ by dotted lines. (refer Fig. 5c); (d) Draw perpendicular bisectors of lines A₁A₂ and A₂A₃ to intersect at point O₁. (refer Fig. 5d); (e) Draw perpendicular bisectors of lines B₁B₂ and B₂B₃ to intersect at point O₂ and point O₁ respectively. (refer Fig. 5e); (f) Join points O₁A₁ and B₁O₂ to obtain the required four bar mechanism. (refer Fig. 5f)

The final link lengths obtained from actual measurement are as: O₁A₁ = 55 mm (A); O₂B₁ = 60 mm (L); A₁B₁ = 30 mm (B); O₁O₂ = 17 mm (S); where L, S, A and B represents lengths of longest link, shortest link, and other two links respectively. The outcome of the geometric synthesis leading to a four bar mechanism is shown in Fig. 5f. The correctness of the design needs to be checked using appropriate criterion and this is done in the next sub-section.

**Grashof’s Criterion**

In order to ascertain the correctness of design for providing the required movement/rotation of links in between inking and stamping operations, the Grashof’s criterion\textsuperscript{10,11} is applied to the link lengths obtained from geometric synthesis and it is found that: L+S (77 mm) < A+B (85 mm) (for rotation) where L, S, A and B represents lengths of longest link, shortest link, and other two links respectively. Therefore, in the present case Grashof’s equation is satisfied and the mechanism shall rotate and perform the desired movement. Once the link lengths/proportions are determined and validated, next step is to model and simulate the motion of actual mechanism for stamping, inking and intermediate positions using appropriate software.

![Fig. 5—Graphical determination of link lengths](image-url)
Modelling and Simulation of the Mechanism

The modelling and simulation of the mechanism for the three critical positions namely stamping, intermediate and re-inking is done using the Working Model 2D software and is shown in Figs 6-8. The results of the simulation indicate that the designed mechanism shall work well within the designed space (working envelop) without any entanglement. The simulation of mechanism gives its configuration in each position and thus the relative position/displacement of its links. In order to access the velocity and acceleration of various links of the mechanism during operation, the kinematic analysis of the stamping machine mechanism needs to be carried out.

Kinematic analysis

The objective of kinematic analysis is to determine the kinematic quantities such as displacements, velocities and accelerations of the links of a mechanism when the input motion is given. Conversely, the objective may be to determine the input motion required to produce a specified motion of another element. Both graphical and analytical methods can be used for kinematic analysis. However, the graphical methods, providing better insight and visualisation, still occupy a prominent place in planar kinematics though at the cost of slight compromise in accuracy of results\(^\text{12}\). In the present work, the velocity and acceleration of each of the links of the mechanism have been calculated using graphical methods.

Velocity analysis

The velocity and acceleration analysis of most of the simple mechanisms can be carried out graphically. The general principle for carrying out the kinematic analysis of most problems is to construct the velocity and acceleration diagrams starting from the input link. In these diagrams, the fixed link is represented by a point known as the pole of velocity diagram or the acceleration diagram. For the purpose of velocity and acceleration analysis, it is assumed that a low speed and high torque electric motor is employed to run the crank or input link O\(_2\)B\(_1\) at 9 rpm thus giving the angular velocity of this link as 0.942 rad/s. The step-wise procedure to construct the velocity diagram and hence to determine the velocities of other links is given below.

Step 1 — Draw the configuration diagram (O\(_1\)A\(_1\)B\(_1\)O\(_2\)) of the mechanism to some suitable scale (1: 1 in this case). (refer Fig. 9)

Step 2 — Calculate the velocity of link O\(_2\)B\(_1\) = \(\omega_{O_2B_1} \times \text{Length of Link } O_2B_1\) which is 56.5 mm/s.

Step 3 — Draw a line O\(_2\)O\(_1\)b\(_1\) = velocity of link O\(_2\)B\(_1\) and perpendicular to it. (refer Fig. 10)

Step 4 — Draw a line from b\(_1\) perpendicular to A\(_1\)B\(_1\) which contains the point a\(_1\). (refer Fig. 10)

Step 5 — Draw a line O\(_1\)a\(_1\) perpendicular to O\(_1\)A\(_1\). It contains a\(_1\) (refer Fig. 10). The point at which the above two lines meet gives the point a\(_1\) and thus the velocity triangle is completed.

Step 6 — From this velocity triangle, i.e., Fig. 10, by measurement, a\(_1\)b\(_1\) gives the velocity of link A\(_1\)B\(_1\), i.e., \(V_{A1B1} = 38.0 \text{ mm/s}\) and o\(_1\)a\(_1\) gives the velocity of link O\(_1\)A\(_1\), i.e., \(V_{O1A1} = 39.0 \text{ mm/s}\).

![Fig. 6— Stamping in action](image1)

![Fig. 7— Intermediate position](image2)

![Fig. 8— Re-inking in action](image3)
Acceleration analysis

Using the configuration diagram, i.e., Fig. 9 and the values of the velocities obtained in the previous sub-section, the acceleration diagram is constructed and the acceleration of various links of the mechanism is determined using the steps given below.

Step 1 — Calculate radial acceleration of link O₂B₁, i.e., \( F_{O2B1}^r = (V_{O2B1})^2 / (O₂B₁) \) which is equal to 53.3 mm/s². Further, assuming that the link O₂B₁ undergoes pure rotation, the tangential component is taken as zero, and therefore, the net acceleration of link O₂B₁ is equal to its radial acceleration.

Step 2 — Draw a line \( O₁O₂ \) and parallel to the line O₂B₁ (refer Fig. 11).

Step 3 — Calculate the radial component of the acceleration of the link A₁B₁, i.e., \( F_{A1B1}^r = (V_{A1B1})^2 / (A₁B₁) \) which is equal to 48.1 mm/s².

Step 4 — Draw a line \( b₁x = F_{A1B1}^r \) (refer Fig. 11).

Step 5 — From point x (Fig. 11), draw a line perpendicular to the link A₁B₁ representing the tangential component of the acceleration of the link A₁B₁. It contains the point a₁.

Step 6 — Calculate the radial component of the acceleration of the link O₁A₁, i.e., \( F_{O1A1}^r = (V_{O1A1})^2 / (O₁A₁) \) which is equal to 27.6 mm/s².

Step 7 — From point o₁ (Fig. 11), draw a line \( o₁y \) equal to \( F_{O1A1}^r \).

Step 8 — From point y draw a line perpendicular to the link O₁A₁ representing the tangential component of the acceleration of the link O₁A₁. It contains the point a₁. The point where the line of Step 6 meets this line gives the point a₁ (refer Fig. 11).

Step 9 — Draw a line \( b₁a₁ \) representing the acceleration of the link A₁B₁, i.e., \( F_{A1B1} \). By measurement, \( F_{A1B1} \) is 48.9 mm/s² (refer Fig. 11).

Step 10 — Draw a line \( a₁o₁ \) representing the acceleration of the link A₁O₁, i.e., \( F_{A1O1} \). By measurement, \( F_{A1O1} \) is 29.4 mm/s² (refer Fig. 11).

By selecting the appropriate material for links, the forces and hence stresses in various links can be determined and hence the section of different links may be decided, i.e., dynamic analysis may be carried out. However, the present work is limited to only kinematic analysis. The results of synthesis of link lengths and kinematic analysis are shown in Table 1. For a larger set-up the link lengths may be proportionately increased.
Prototype fabrication

The link lengths determined in earlier section are used to fabricate a prototype of the stamping machine which is then tested for successful operation. Various components used to fabricate the prototype are described below.

Base — A block board (600 mm × 600 mm) is chosen as the base and two stands are provided at its bottom so that the whole set-up gets a strong and stable foundation and there are a minimum of vibrations.

Links — Thin wooden flat strip is used for making the links owing to its light weight. Holes are drilled at each end of the links to screw them together using nuts and bolts.

Conveyor belt — A flat cotton belt of 50 mm width is used for carrying the sample packages.

Sprocket — A standard chrome plated (44 teeth) sprocket of a bicycle is used for driving the input link of the mechanism.

Free-wheel — A standard bicycle freewheel (bore 35 mm and having 18 teeth) is used to connect the axle/roller on which conveyor belt runs.

Axles — Two bicycle axles (dia 20 mm) are used and on one of these, the free wheel is mounted. The conveyor belt is made to move between these two axles. A Velcro strip is fixed to each axle to prevent the slipping of the smooth cotton belt while transmitting motion.

Chain — A cycle chain is used to connect the sprocket at one end and the free-wheel on the other.

Stepper motor — A stepper motor (18 V) which accepts the input in the form of pulses and delivers the output in steps of a definite angle is used so as to give sufficient time for stamping during movement of packages on the conveyor belt.

Batteries — Two 9 V batteries are used to power the motor which in turn controlled the whole set-up.

Sprocket is fitted on an M.S. shaft using interference fit. One end of this shaft is fitted on the motor shaft, which is half round using screws and the other end is connected (pinned) to the input link of stamping mechanism.

Though the mechanism can rotate completely and thus the free-wheel may be eliminated, however, in case full rotation is allowed, the end of the stamp would hit against the conveyor and would hinder smooth and neat marking (refer Fig. 12). It would also obstruct the motion of the conveyor and the chain may become loose and thus come out of the teeth on the sprocket and free-wheel.

The motor is clamped on the board base with help of M.S. clamps. It is necessary to make the motor stable and ensure that the alignment between the sprocket and the free wheel is maintained at all times during operation. The prototype thus fabricated is shown in Fig. 13.

The suggested mechanism has immense applications in production lines in its present configuration as well as after making some modifications. Apart from its present application as stamping machine, it can be used for punching operation by mounting a punch on the output link/free end of the mechanism and also by adjusting the stroke so that a hole of the desired depth and size is punched in each of the work pieces placed on the conveyor belt. It can be also used as press whereby different shapes and patterns can be embossed on work pieces coming on the conveyor by mounting a suitable die in place of the stamp on the mechanism. However, for the above applications, the dynamic synthesis of the mechanism needs to be done and a motor with a higher torque rating shall have to be employed so that greater force can be exerted on the work pieces. Further, in conjunction with a manipulator, this mechanism can be used in a robot controlled cell. The suggested mechanism/set-up can even be employed

Table 1— Results of mechanism synthesis and analysis

<table>
<thead>
<tr>
<th>Link &amp; nomenclature</th>
<th>Length (mm)</th>
<th>Velocity (mm/s)</th>
<th>Acceleration (mm/s^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>O1A1 (follower)</td>
<td>55</td>
<td>39.0</td>
<td>29.4</td>
</tr>
<tr>
<td>O2B1 (crank)</td>
<td>60</td>
<td>56.5</td>
<td>53.3</td>
</tr>
<tr>
<td>A1B1 (coupler)</td>
<td>30</td>
<td>38.0</td>
<td>48.9</td>
</tr>
<tr>
<td>O2O1 (fixed link)</td>
<td>17</td>
<td>0.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>

Fig. 12— Interference occurs if full rotation is allowed
Conclusions

A stamping machine set-up has been designed and fabricated. The suggested methodology of synthesis is based entirely on what function/motion is desired from the mechanism. Thus, since the basis for design is this intended function, the mechanism synthesised in this manner would definitely carry out the intended function with ease.

The approach used highlights the flexibility one can get while designing mechanisms for specific applications by employing the methodology used in this paper. The other aspect that this paper highlights is how a whole set-up for marking, punching or stamping can be made to operate with a single drive without the need to use a separate drive for the conveyor belt. This is achieved by employing a free-wheel arrangement. The suggested arrangement can be very useful especially in case the layout is by process.

The kinematic analysis of the mechanism has also been carried out in order to determine the acceleration and velocity of each of the links in a particular configuration of the mechanism. The whole set-up has been successfully fabricated and tested thereby validating the design and the design procedure employed.

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References