"Multi Stage Synthesis and kinematic analysis of six link Four bar Mechanism for Fork Lift with only Revolute Pair"

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Abstract : In present study a fork lift mechanism is designed and analysed to make a best possible configuration on the basis of outcomes. Graphical method is used to find the dimensions of links. A set of link lengths and angles is made on the basis of variation in a fixed link length. By graphical data certain equations are finding for a MATLAB code. A MATLAB code is then generated. MATLAB code give best dimensions for fork lift mechanism. Velocity analysis is done on these sets of links. On basis of velocity analysis, it is find that for O2O4 = 1875mm are get maximum fork velocity of 0.495m/s with input link length 1080mm

Keyword: Four bar Mechanism, Revolute Pair, Mat lab

I. INTRODUCTION

Since the advent of mechanization, manual handling has been replaced by the use of mechanized lifting and transport equipment. The most effective workhorse for materials handling is the forklift truck. It was invented by Clark material handling about hundred years ago. Forklift truck is one of the most significant tools in logistics. Forklift trucks are usually used at railway stations, warehouses, ports and factories for loading, unloading and conveying. A general weight-balanced forklift truck consists of a chassis and a work device which can be tilted and lifted vertically. These Forklift trucks also commonly known as industrial trucks are frequently used in manufacturing industry on shop floors for material handling and storage and are individually operated by an operator. The need to operate and maneuver in narrow aisles on shop floors led to the introduction of standup narrow aisle trucks in to the material handling industry. Narrow aisle trucks are designed to use less floor space by stacking products vertically along aisles 5 to 10 feet wide. These Standup forklift trucks have been through lot of design changes over a period of time for ease of operation, superior visibility, to maximize the operator safety and for controllability to avoid accidents. However, the general mast system of a forklift truck not only restrains the driver's vision, but also increases the whole weight of a truck and decreases the fuel economy. Also the mechanism to operate the fork vertically from ground level to top most position, generally prismatic pair is used which also increase the friction between the parts and there is increased maintenance cost. So my focus in this project to be eliminates the same and design mechanism for fork lift without prismatic pair and mast [1]. In the beginning of this project, certain study on the background of a forklift was made to get the idea and concepts. From these inputs, the aims and scope of the project were determined. Besides, the findings from the research of theory and concept of forklift, as well as case studies of other models have been so helpful to project development process and all of the relevant information's were decided for the literature review. By reviewing the working system of a forklift, the structure and mechanism of the forklift have been fabricated. Forklift as shown in figure 1 is a powerful industrial truck that is to lift and transport material by steel forks that are inserted under the load.. It was developed in 1920 and has since become a valuable piece of equipment in many manufacturing and warehousing operations. The most type of forklift is the counter balance forklift. Forklifts are available in many types and different load capacities. In the average warehouse setting, most forklifts have load capacities of around one tons [2].

Figure 1.1: Typical industrial forklift overview.

II. RESEARCH METHODOLOGY

2.1Graphical Methodology

Fork lift truck mechanism can be considered as a slider mechanism to determine the three position of coupler. According to graphical method first determine three accuracy points by using Chebyshev's spacing.

$$x_i = a + h\cos\frac{(2i-1)\pi}{2k} \quad \text{(i=1, 2, 3, ……..k)}$$

Where $a = \frac{x^i + x^f}{2}$, $h = \frac{x^i - x^f}{2}$

Accuracy point B_1, B_2, B_3 determined with the help of Chebyshev's equation.

2.1.1For design and synthesis certain postulations are used-

- Design of link length so that rotating motion of crank converted into vertical motion of fork.
- Travel of fork is directly proportional to input rotation.
- Solve problem by multistage synthesis.

3.1.2 Required design specification-

60^0 rotation of output link converted into 2.5m of fork travel.

- Three Chebyshev's accuracy points are to be evaluated.

3.1.3Procedure- First draw a proposed sketch for reference. Two pivoted points O_2 and O_4 are to be taken on the body of truck at convenient position. Two points B and D defined the fork completely, 60^0 rotation of crank cause 2.5m travel along the line. Assume O_2 point on the body of truck at suitable position and vertical line PQ which is at a linear distance of 2120mm in front of truck where BD has to travel.

Let B_i and B_f represents the initial and final point of B on vertical line PQ. The distance between B_i to B_f is 2.5m and corresponding rotation of input link is 60^0. First step is to determine the three Chebyshev's accuracy point on vertical line PQ of B which is in between B_i to B_f. Three accuracy points which have to be determined are B_1, B2 and B_3 and these precision points in interval B_i to B_f are to be determined by the following equations

Given $\Delta S = 2.5$ m

Chevshev's accuracy points $n = 3$

$$a = \frac{\Delta X}{2}, \quad h = \frac{\Delta X}{2}$$

$$X_i = \frac{\Delta X}{2}\left(1 - \cos\frac{\pi}{2n}\right)$$

According to postulation, travel of fork is proportional to the input link which is the crank rotation of OA. We calculate the corresponding moment of link OA which is called Θ_2^{12} and Θ_2^{23}.

Also calculate $X_{12} = X_2 - X_1$

$X_{23} = X_3 - X_2$

As rotation of crank is proportional to vertical motion of fork, according to function

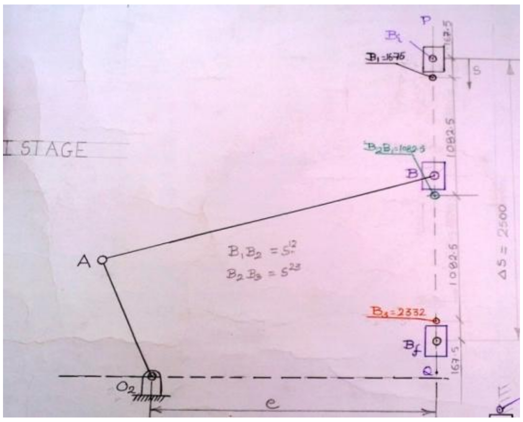

Fig 3.1

$$\frac{\theta_2^{12}}{X_{12}} = \frac{\Delta\theta}{\Delta X} = \frac{60}{2.5}$$

$$\theta_2^{12} = 26^0 (ccw)$$

$$\theta_2^{23} = 26^0 (ccw)$$

In first stage of synthesis the problem is worked down to design sliders crank B_2AB such that of B shows sliding movements at its position. So that B coordinate with the rotation of crank as mentioned above.

In first stage of synthesis it is considered as crank slider problem. So first design slider crank mechanism and for it graphical method of "function generation" is used. Three points are to be taken as B_1, B_2 and B_3 corresponding to the sliding movement at B.

Choose O_2 arbitrary and the whole problem is now "function generation" problem of slider crank. Such that downward movement of B from B_1 to B_2=1082mm and for B_2 to B_3=1082mm for each 26° CCW rotation of crank. To locate the crank pin A_1, such that slider crank O_2 AB access a function generation. By applying the method of inversion, the crank is to be holding fixed at its first position and then the position of crank pin at A_1 is located.

If crank is hold fixed then O_2B_2 rotate 26° but in CW direction. Then by using compass, find the inverted position of B_2 as B_2^1. Also by rotating O_2B_3 52^0 in CW direction, the new inverted position of B_3 is located as B_3^1. So new inverted position of B_1, B2 and B_3 are B_1^1,B_2^1 and B_3^1 respectively since after inversion position of B_1 remains same.

Now as A_1 is on the center of the circle passing through B_1^1, B_2^1 and $B_3^1$and to find it use simple geometry procedure. We draw bisector of B_2^1 B_1^1& $B_3^1B_2^1$. This bisector intersectsat A_1 which is the required pointSo in the first stage we find length of crank O_2A_1& coupler A_1B_1, for the 26°CCW rotation of crank, and the slider move from B_2 to B_3.

In next stage, our task is to remove the slider and make B as coupler point till it passes through B_1, B_2, B_3 by making it 4 bar linkage O_2AO_4C.

In second stage, we choose O_4 conveniently on the truck body and try to locate C_1 on coupler link AB. In this procedure we say $O_2A_1B_1$; $O_2A_2B_2$& $O_2A_3B_3$ are already known to us. To determine point C_1 on the coupler link AB, we use the kinematic inversion by fixing the coupler and obtained the different inverted position of O_4.

As C belongs to the coupler & O_4C does not changed. If we hold the couple fixed at its Ist position, then O_4 point moves on a circle. To obtain the inverted position of O_4 used graphical method of motion generation.

First mark A_2, B_2& O_4 on trace paper which are related position of A, B & O_4 on second configuration. As kinematic inversion means the relative position of AB doesn’t change while the mechanism moves. So move the tracing paper and place it on the worksheet such that A_2 and B_2 coincide with A_1 and B_1 & mark point O_4 by piercing on tracing paper as $O^I_{4,2}$ on drawing sheet. This is second inverted position of O_4. Then repeat the same procedure by marking A_3, B_3& O_4 which are relative positions of A, B& O_4 for third configuration. Inverting on first position A_3& B_3 coincide A_1& B_1 respectively and wherever point O_4 goes it is called $O^I_{4,3}$marked on drawing sheet. So three inverted position of O_4 are $O^I_{4,1}$, $O^I_{4,2}$ & $O^I_{4,3}$. If we draw a circle passing through these three points, then center of the circle, C_1 is obtained by using simple geometry. Draw the perpendicular bisector of line $O^I_{4,1}$ $O^I_{4,2}$ and draw bisector of line $O^I_{4,2}$, $O^I_{4,3}$. These two bisector meet at point C_1 as shown in fig. and this determine the revolute pair O_4C & AC and coupler point C on link AB.

So 4R mechanism O_2ACO_4 is available with coupler point B, which must pass through B_1, B_2& B_3 and maintain coordination with input link. Here coupler is in triangular shape and it is a heavy member. Up to second stage of synthesis, A_1 and C_1 have been determined and O_2, O_4& vertical line which passes through point B_1, B2& B_3 have been chosen.

But if the fork is hinged at only one point B, then this fork swing like a pendulum. So chose point D arbitrary on fork to guide it vertically. For 1st configuration B is B_1& D is D_1, and for second & third it is B_2& B_3. Distance between point B & D is fixed, so D_2& D_3 is easily located on same vertical line.

Now, D_1 which is a revolute pair has to be connected with link O_4C, such that D passes on through D_1, D_2 & D_3. To determine the E_1 on O_4C, we used method of kinematic inversion by keeping the follower link O_4C of 4R mechanism O_2AO_4C link fixed at its 1st configuration by using graphical method of motion generation.

Mark point C_2,O_4& D_2 on tracing paper which are the related position of C, D & $O_4$of second configuration.As O_4C fixed at its position, move the tracing paper and place it on the worksheet such that C_2 and O_4coincide with C_1& O_4&where ever point D_2 goes, marked as D^I_2. This is second inverted position of D_2. Then repeat the same procedure by marking C_3,O_4& D_3 which are relative positions of C, D & O_4 for third configuration. Inverting on first position C_3 & B_3 coincide C_1& O_4respectively and wherever point D_3 goes it is called D^I_3 marked on drawing sheet. This is second inverted position of D_3. Since link 4 is fixed at first position the link E_1 can be located at the center of circle which is pass through D^I_1, D^I_2, D^I_3. By simple geometry locate the revolute pair on link 4 say E_1. Now connect link D_1 & E_1 by rigid link.

So at this stage design of a six link mechanism has been finished which give a fork lifter, where the fork goes almost vertically, at least passing through B_1,B_2& B_3 the point D passes through D_1,D_2& D_3 laying on vertical line as shown in the Fig. Thesis little vertical deviation but it is not much more which affect the function of fork lift.

In the synthesis of the fork lift, as $O_2$is fixed, the assumption is taken as that is B is at the distance of 2500 m from the ground and BD translate along a vertical trajectory, which is at the distance of 2120m from O_2. By doing the synthesis of the mechanism, BD goes beneath the ground level, which is not feasible.

In the second synthesis initial position of B is kept same as B, since the vertical distance between B and ground level is same as above. The distance between $O_2$and the vertical trajectory on which BD is translating is now 200m. There is slide change in the angle between fixed link O_2O_4again, BD goes beneath the ground level as shown in the fig. So that data is again not sufficient as per our requirement.

In this third synthesis the horizontal distance between $O_2$and vertical line on which BD is translating is kept same as 2000m. The change is done in the vertical distance between B, and ground level, as 300m. By considering the data and rotating the crank by 60^0 the value of input angle is 144^0, which is less than 180^0 and also the translator is translating above the ground level.

Now in the next level, change the position of link O_4 with respect to link $O_2$and sees the repercussion.

Computational Methodology: Here first generate a equation to find out the relation between the different link length and angles to synthesis the mechanism with analytical method and then a programme for same.

3.1.4Kinematic Analysis for Transmission angle

The objective of kinematic analysis is to determine the kinematic quantities such as displacements, velocities, and accelerations of the elements in a mechanism when the input motion is given. In short, kinematic analysis establishes the relationship between the motion of the various componentsandlinks of a mechanism. Besides satisfying kinematic requirements, a mechanism should move freely. In earlier stages of kinematic design, assuming all binary link as two force members (i.e., neglecting gravity, inertia, and frictional effects), we can express the free running quantity of simple mechanisms (like 4R or slider crank mechanism) through an index known as the transmission angle .

For Case I:

First find maximum and minimum transmission angle, when fixed link O_2O_4=2280,Therefore, μ = Cos^{-1} (0.2498)μ = 157^0

∴ Maximum transmission angle = 157^0, Minimum transmission angle is when ϴ = 0^0 as shown in fig. i.e.

Thus, $(d - a)^2 = b^2 + c^2 - 2abc\cos\mu$

$$\mu = Cos^{-1}(0.948034)$$

∴ μ = 18.5^0

Here μ is vary from 18.5^0 to 157^0

As minimum transmission angle is less than 30^0, so we have to redesign or check for IInd case.

CASE II:

Here,O_2O_4 = 1875mm

For ϴ = 84^0

$$\mu = Cos^{-1}(0.11853)$$

$$\mu = 83.19°$$

For ϴ = 144^0

$$\mu = Cos^{-1}(0.88539)$$

$$\mu = 152.3°$$

$$\mu = 180° - 152.3°$$

$$\mu = 38°$$

As μ is vary between 38^0 to 83^0, so this mechanism can work properly.

Case III-

O_2O_4 =1350 mm ,For ϴ = 84^0

$$\mu = Cos^{-1}(0.29937), \mu = 72.58°$$

For ϴ = 144^0, $\mu = Cos^{-1}(0.88089)$

$\mu = 151.75°$,So, μ = 38^0

So, μ is vary between 38^0 to 83^0, so this mechanism can work properly, but required more torque around maximum position of crank.

Velocity Analysis:

There are various method to find out the velocity of link relative Velocity method is used to find the velocity of link of the mechanism.

Step 1: Draw the configuration diagram as per the dimensions of a given mechanism on suitable scale as shown in fig.

Step 2: Calculate velocity of input link. As there is 2500 mm translation of fork for 60^0 input rotation of crank. The required velocity of output link BD is 0.4 to 0.5 m/sec.

Step 3: Draw the velocity diagram of mechanism by a relative velocity method, when O_2O_4=2250

1)Vo_2a = 226 mm/sec will be in the direction perpendicular to link O_2A and it will be represented by vector $\mathbf{o_2a}$. In velocity diagram, draw a vector o_2a=226mm/sec on chosen scale, 1mm = 5 mm/sec, as shown in fig.

2) Now, point 'C' is to be located on velocity diagram. Velocity, V_{CA} = **ac** is only known in direction. It is perpendicular to AC. Therefore from point A draw a line perpendicular to AC in velocity diagram. Similarly, V_{CO4} = **oc**is only known in direction, it is perpendicular to O_4C in velocity diagram which cuts the direction of vector ac at C.

3) Now point 'B' located on velocity diagram. Velocity, V_{BA} = **ab** is only known in direction. It is perpendicular to AB. Therefore from point A draw a line perpendicular to AB in velocity diagram. Similarly, V_{CB} = **bc** is only known in direction, it is perpendicular to BC in velocity diagram which cuts the direction of vector ac at B. Join the B with O_2 to find the absolute velocity of B with respect to O_2.

Step 4: Find out the velocity of various links by measurement of respective vectors from the velocity diagram.

IV. RESULT AND DISCUSSION

Motion of mechanism is explored graphically for different O_2O_4. Length of links and angles between links of mechanism find graphically for different O_2O_4shown in fig 4.1 to 4.5 and table 1 to 5. Summary of different links length and angles are summarized in table 6.

First Case when Link length O_2O_4=2280mm

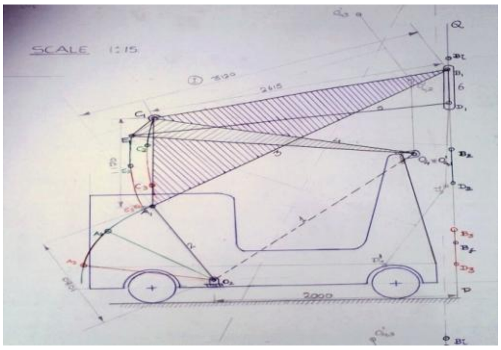

Fig 4.1

Second case when Link length O_2O_4=1875mm

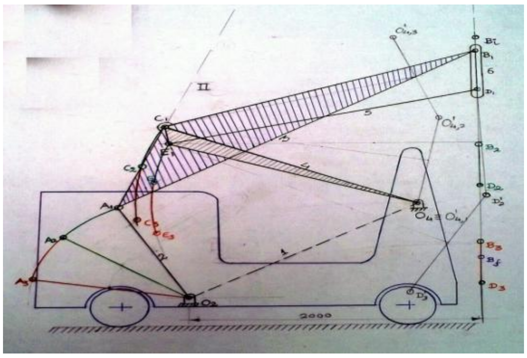

Fig 4.2

Third case when Link length O_2O_4=1350mm

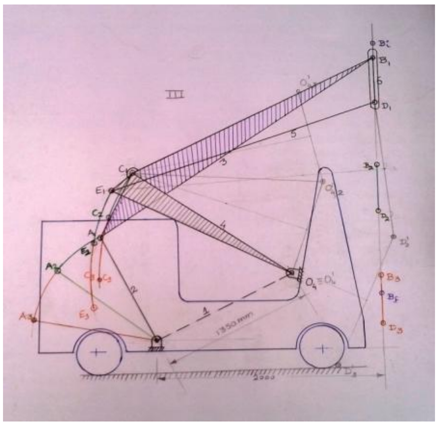

Fig 4.3

Different link length and angles for all synthesis

Link length and angles	O_2O_4 = 2280	O_2O_4 = 1875	O_2O_4 = 1350	O_2O_4 = 1620	O_2O_4 = 2055
O_2A_1	1080	1080	1080	1080	1080
A_1B_1	3120	3120	3120	3120	3120
A_1C_1	1170	930	660	825	1125
B_1C_1	2615	2400	2550	2430	2240
O_4C_1	2250	1950	1710	1935	1838
C_1E_1	300	195	255	360	210
E_1D_1	2745	2280	2610	2685	2340
$<O_4O_2A_1$	74^0	84^0	90^0	90^0	78^0
$<A_1C_1O_4$	78^0	84^0	80^0	78^0	88^0
$<O_2A_1C_1$	151^0	134^0	128^0	133^0	132^0
$<O_2O_4C_1$	57^0	58^0	61^0	59^0	62^0
O_4E_1	2400	1860	1800	2085	1980
B_1D_1	450	450	450	450	450

Table 1(All dimensions in mm)

Using table 6 to plot a graph in between Link lengthO_2O_4 and all other link length and obseved the result.

1)When point O_4 is close to O_2, the distance between A and C is close and the resulting linkage will have poor transmission qulity. But if O_4 is far away from O_2, then point C far away from the link AB, then the thickness of Link AB increased which is not acceptable.

2) There is no change in the link length O_2A and AB with variation in link length O_2O_4.

3) Link lengthC_1E_1,E_1D_1 and O_4E_1 also change with the change in the linklength O_2O_4, but its not showing a similar pattern.

After different observation it found that link length AC is suitable for mechanism when O_2O_4=

1875mm as it is not far away from link AB and also point C not close to A.

From Velocity analysis, tangential velocity and at different fixed length O_2O_4 is found and summarized in table. And draw a graph between fixed length O_2O_4 and tangentialandangular velocity of different link length.

Link	O_2O_4 = 1350		O_2O_4 = 1620		O_2O_4 = 1875		O_2O_4 = 2055		O_2O_4 = 2280	
	ώ (rad/s)	V (m/s)	ώ (rad/s)	V (m/s)	ώ (rad/s)	V (m/s)	ώ (rad/s)	V (m/s)	ώ (rad/s)	V (m/s)
O_2A	0.209	226	0.209	226	0.209	226	0.209	226	0.209	226
AC	0.16	105	0.14	115	0.15	142	0.138	135	0.154	180
AB	0.17	365	0.17	365	0.15	460	0.17	365	0.165	515
O_4C	0.11	185	0.088	170	0.09	170	0.10	180	0.06	135
BC	0.11	280	0.107	275	0.15	355	0.116	260	0.15	387
O_2B	-	405	-	395	-	495	-	405	-	495

Table 2: Velocity and angular velocity of different link for different link length O_2O_4

V= relative Velocity of different link length,$O_2O_{4=}$ fixed lengthFrom graphit is observed that velocity of link AB attains maximum value at large value of $O_2O_4$and also attain a higher value at O_2O_4=1875 mm as comparison to different value of O_2O_4.Velocity of other links are also varies with respect to different length of O_2O_4. It observed from the graph that velocity of different link is maximum for O_2O_4=2280mm and 1875mm. So from velocity graph, the mechanism with fixed length O_2O_4=2280mm and 1875mm is best. Vo_2b= Absolute velocity of coupler point B ,$O_2O_{4=}$ fixed length

From table one, another graph between absolute velocity Vo_2b and fixed link length $O_2O_4$is drawn and find that for angular velocity of input crank there is maximum absolute velocity of point B for fixed length O_2O_4= 1875mm.So minimum input is required for mechanism with fixed link length O_2O_4= 1875mm. Graph between angular velocity and O_2O_4 is plotted. The angular velocity is varying with different link length of O_2O_4, but it is not proportional to O_2O_4. With observation it is found that angular velocity of link is more for link with maximum length as here in case of link AB. Find out the transmission angle for a complete rotation of 60^0 of the input link at different position and plot a graph in between transmission angle 'μ' v/s angular rotation 'Ө'It is observed from thegraph that transmission angle for O_2O_4=1875 is vary from 79^0 to 139 (i.e. 34^0) while for link length O_2O_4=2280 it is vary from 54^0 to 101^0(i.e. 79^0). So with this graph, either choose mechanism with link length O_2O_4=1875, O_2O_4=2280 and O_2O_4=1620mm.

V. CONCLUSION AND FUTURE SCOPE

With observations of different set of mechanism, on the basis of different factors discussed above it founds that mechanism with fixed link length O_2O_4=1875 is best from all the set and synthesis of four bar mechanism for fork lift without Sliding pair is completed.

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