Design, Fabrication and Analysis of Four Bar Walking Machine Based on Chebyshev's Parallel Motion Mechanism

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Abstract

A mechanism is the heart of a machine. Machines are mechanical devices used to accomplish work. Since ancient time, mechanisms and machines have been used to reduce human effort. They have entered and impacted almost all aspects of human society since the industrial revolution. It is the mechanical portion of machine that has the function of transferring motion and forces from a power source to an output. This research paper involves the design, synthesis and fabrication of a four bar link kinematic walking machine. These kinematic walking machines have four-legged that can walk on any surface. It is an arrangement of six linkages that are powered together by a single motor. The rotation is transferred by chain drive to the links. This device is analogous to a four-legged such as an animal. The motor can either be powered by mains or a battery. The kinematic walking machine comprises four legs that move simultaneously to provide motion. Each of these four linkages are made of a four bar mechanism. This mechanism is based on the Chebyshev's parallel motion. The Chebyshev linkage is a mechanical linkage that converts rotational motion to approximate motion. His equation defines the dimensions and relations of the links. Four driving links have 90° angular difference. Because of this, the legs are moving front and back in such a way to move the body. Out of four links, one link is driving, second one is used to move the leg, third one is guiding the second link and the fourth one is the body. To avoid friction between rotating parts, the brass bushing are used. The moving of the leg is traced and compared with the theoretical values.

Keywords: analysis, mechanism, linkage, four-bar linkage, Chebyshev's straight line legged motion

1. Introduction

A four-bar linkage, also called a four-bar, is the simplest movable closed chain linkage. They perform a wide variety of motions with a few simple parts. This paper involves the design, synthesis and fabrication of one such mechanism (four bar mechanism). In this paper four Leg Kinematic movement works on Chebyshev's parallel motion which deals the relation between the links. This mechanism satisfying his condition and fall into slider crank mechanism. A frame, connecting rod, crank & a lever constitute to obtain the required motion.

1.1 Linkage

A *linkage* is an assembly of bodies connected to manage forces and movement. The movement of a body, or link, is studied using geometry so the link is considered to be rigid. The connections between links are modeled as providing ideal movement, pure rotation or sliding for example, and are called joints. A linkage modeled as a network of rigid links and ideal joints is called a kinematic chain.

Linkages may be constructed from open chains, closed chains, or a combination of open and closed chains. Each link in a chain is connected by a joint to one or more other links. Thus, a kinematic chain can be modeled as a graph in which the links are paths and the joints are vertices, which is called a linkage graph.

The movement of an ideal joint is generally associated with a subgroup of the group of Euclidean displacements. The number of parameters in the subgroup is called the degrees of freedom (DOF) of the joint.

Mechanical linkages are usually designed to transform a given input force and movement into a desired output force and movement. The ratio of the output force to the input force is known as the mechanical advantage of the linkage, while the ratio of the input speed to the output speed is known as the speed ratio. The speed ratio and mechanical advantage are defined so they yield the same number in an ideal linkage.

A kinematic chain, in which one link is fixed or stationary, is called a mechanism, and a linkage designed to be stationary is called a structure.

1.2 Mobility

The configuration of a system of rigid links connected by ideal joints is defined by a set of configuration parameters, such as the angles around a revolute joint and the slides along prismatic joints measured between adjacent links. The geometric constraints of the linkage allow calculation of all of the configuration parameters in terms of a minimum set, which are the *input parameters*. The number of input parameters is called the *mobility*, or degree of freedom, of the linkage system.

1.3 Four Bar Mechanism

When one of the links of a kinematic chain is fixed, the chain is known as mechanism. It may be used for transmitting or transforming motion e.g. engine indicators, typewriter etc. A mechanism with four links is known as simple mechanism, and the mechanism with more than four links is known as compound mechanism. When a mechanism is required to transmit power or to do some particular type of work, it then becomes a machine. The mechanism, as shown in figure1.1 has four links and four binary joints, i.e.

$l = 4$ and $j = 4$. (l=No. of links, J=No. of Joints)

$n=3(l-1)-2*J$

$\therefore n = 3(4 - 1) - 2 \times 4 = 1$- One Degree of Freedom

In this paper, researchers used 4 set of four bar mechanism.

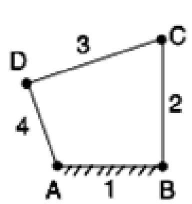

Figure 1.1 Four bar Mechanism

2. Literature Review

A large number of research papers have been studied on four bar link mechanism. A review of related literature has been described as under:

Hamid M. and Saeed A. (2008) concluded that Watt's six-bar mechanism generates straight and parallel motion. This mechanism can be utilized for legged machines. In this mechanism, the leg remains straight during its contact period due to its parallel motion. The legs can be as wide as desired to increase contact area and decrease the number of legs required to keep body's stability statically and dynamically [1].Burak B. et al, (2011) designed a parallel hinged luggage door mechanism and its kinematics analysis by an analogy to a four bar mechanism [2]. Retheesh Kumar and Prof .Akash Mohanty (2013) investigated the design, synthesis and simulation of four bar mechanism to eliminate the plowing depth fluctuation in tractors. The projected four bar linkage mechanism can eliminate the plowing depth fluctuations. The output link generates exponential path suggests that initial stage link can provide low sensitivity and later output link motion can generate high sensitivity [3]. Mulla Abdulkadar and Bhagyesh Deshmukh (2013) suggested that in the analysis of a four bar mechanism of various combinations, it is observed that the path traced by the link of mechanism of input link-crank and the output link-rocker mechanism are equal replicates the path. It is essentially required in case of micro mechanisms [4].An US army investigation reports stated that about half of the earth's surface is inaccessible to wheeled or tracked vehicles, whereas this terrain is mostly exploited by legged animals [5].M.G. Bekker concluded that legged locomotion should be mechanically superior to wheeled or tracked locomotion over a variety of soil conditions and certainly superior for crossing obstacles [6].

It would be difficult to compete with the efficiency of a wheel on smooth hard surfaces but as condition increases rolling friction, this linkage walking machines become more viable and wheels of similar size cannot handle obstacles. Based on literature review, researcher has designed and fabricated four bar walking machine. This linkage mechanism is capable and enough to carry a battery and a small motor.

In toy industries for making robotic toys it has got many applications. It can also be used for military purpose. By placing bomb detectors in the machines we can easily detect the bomb without harmful to humans. It can be used as heavy tanker machines for carrying bombs as well as carrying other military goods. It can be used for space research where the wheeled machines have difficulties to move.

It is also applicable in the goods industries for the small transportation of goods inside the industry. The mountain roads or other difficulties where ordinary vehicles cannot be moved easily can be replaced by our four leg mechanical spider. Heavy loads can be easily transported if we made this as a giant one. It has got further application for the study of linkage mechanism and kinematic motions. The geometry and conditions can be changed according to application needs. This walking machine can travel in rough surfaces very easily, so this machine can be used in rough surfaces were ordinary moving machine cannot travel.

3. Design Concept of parallel motion mechanism

Chebyshev Parallel Motion -a linkage, proposed by P. L. Chebyshev in 1868, such that some point on it describes a nearly straight line.A straight-line mechanism, the Chebyshev parallel motion is a four-bar linkage *ABCD* (figure 3. 1) in which the lengths of the links satisfy the relation $3d - a = 2b$.

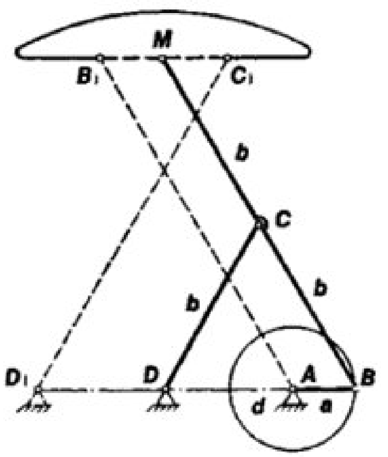

Figure 3.1 Chebyshev parallel motion

An increase in *AB* results in an increase in the length of the approximately rectilinear segment of the path traced by point M; at the same time, however, the deviation from a true straight line also increases. When in middle position, the Chebyshev parallel motion shown by solid lines in figure 3.1 is reminiscent of the Greek letter lambda (λ); for this reason, it is referred to as lambda shaped. Chebyshev also proposed the variant$AB_1C_1D_1$ which is shown in figure 3.1 by broken lines. In this crossed-bar mechanism, the path of M coincides with the path of the same point in the lambda-shaped mechanism, and the lengths of the links satisfy the following relations: $AB_1 = C_1D_1 = 2b$, $B_1C_1 - 2a$, $B_1M - a$. and $AD_1 = 2d$. In another variant of Chebyshev parallel motion, the angle between the lines CB and CM is not 180°. The Chebyshev parallel motion is employed in devices for obtaining rectilinear motion of a point without the use of guides [7].

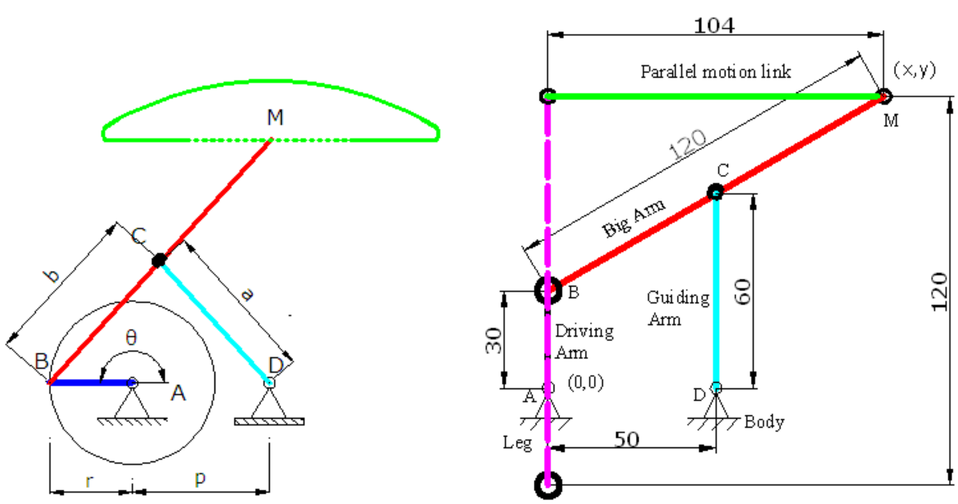

Figure3.2. Basic concept

The basic concept of the four leg parallel motion walking machine was derived from Chebyshev parallel motion concept.

r= radius of driving arm (AB) = 30mm

a= length of guiding arm (CD) =2*r=60mm

d=length of big arm=2*a=2*60=120 mm

b=0.5*distance of big arm (Centre of big arm) = a
p= distance between driving arm and the guiding arm in the body (AD)

3*p-r =2*b
3*p-30=2*60
P=50 mm

At the point of M, one link is attached to get the parallel motion. The other end of the link is connected to the driving crank which is 180° phase difference with the driving crank which is inside the body.
Researchers have been used empirical formula to find the coordinate position(x, y) of four bar link mechanism for formulation of coupler curve which is given below:

$$x = p + \frac{rsin\theta}{\sqrt{(p^2 + r^2 - 2prcos\theta)}}\sqrt{(4a^2 - (p^2 + r^2 - 2prcos\theta)} \qquad --- \quad (i)$$

$$y = \frac{(p - rcos\theta)\sqrt{(4a^2 - (p^2 + r^2 - 2prcos\theta)}}{\sqrt{(p^2 + r^2 - 2prcos\theta)}} \qquad --- \quad (ii)$$

4. Process Involvement

For Fabrication of four leg kinematic walking machine involved the following process.

- Selection of sizes of all components like arm, base, centre rod, Legs etc
- Cutting the materials
- Selection of Motor
- Threading of centre rod
- Fixing motor
- Final finishing work, etc

5. Parts of the Walking Machine

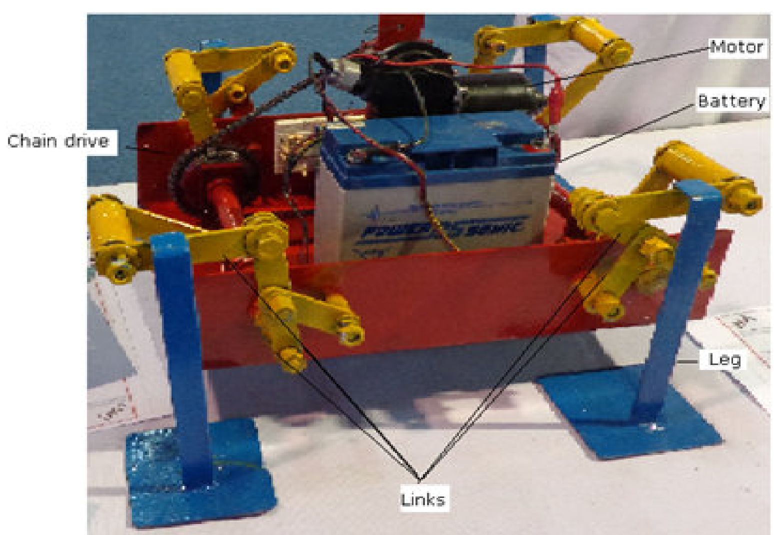

Figure 5.1 Parts of the Walking Machine

A complete walking machine is as shown in figure 5.1 and their components details are given below:

(i) **Complete link set:** Four sets of links were used for this machine. Mild steel plate 25 mmX4 mm thicknesses is used. Cutting, drilling and grinding processes have been involved.

- **(ii)** **Central Shaft:** It is made up of mild steel rod of 30 mm diameter in two numbers. Turning, facing and threading processes have been involved.
- **(iii)** **Body:** It is made up of MS plate of 5 mm thickness having dimension 450X300X100 mm. Cutting, bending, drilling and threading processes have been involved.
- **(iv)** **Bushing:** It is made up of brass in eight numbers. Cutting, facing, turning, drilling reaming and chamfering processes have been involved.
- **(v)** **Chain sprocket:** It is made up of MS plate of 6 mm thickness in three numbers. Two driving chain sprocket contained 36 teeth and one driven chain sprocket contained 15 teeth. Cutting, drilling and gear cutting processes have been involved.
- **(vi)** **Shaft mounting:** It is made up of MS plate of 8 mm thickness of dimension 40X80X8 mm in 4 numbers. Cutting, drilling and grinding processes have been involved.
- **(vii)** **Motor:** A DC Motor of 12 Volt with a current rating of 14 Amps is to produce the movement of the machine. The motor is internal geared one. So it is strong enough to give the required torque. It can give two different speeds in one direction and two different speeds in the opposite direction.
- **(viii)** **Final Finishing:** After connecting the links, lot of adjustments was did to make the perfect alignment and reduce the friction. After that the remote control unit and sensor unit is fixed. Finally the cover was made and painted.

6. Results and Discussion

When the linkages are connected as per the drawing, it produces the motion same like Chebyshev‘s parallel motion. The path of the legs was analyzed by using the AutoCAD software and MATLAB software. For every 30° rotation of the driving arm, the path of the end point (M) was identified and joined. The path trace by leg is as shown in figure 6.1.

The first point is at the position where the driving link is at horizontal. At 0° the leg (point M) is at the maximum height. The analysis starts when the driving link rotates counter clockwise. It is noted that after the third point (60°) the leg remains straight line position approximately till the 11th point (300°). At the 11th point the leg is raised till the first point or 13th point. After the first point the leg moves downward towards the ground till the third point (60°). Out of 360°, the leg remains parallel (straight) for 240° rotation. The remaining120° angle is used for the next step movement of the leg. During the angles 270°, 300°, 330° the leg goes left side of the driving arm. In the remaining angles the leg is at the right side of the crank only. The coordinate point(x,y) of four bar link mechanism using empirical equation (i) and (ii) are given in the table 6.1 by placing the value $p = 50$, $r = 30$, $a = 60$ and $\theta =$ 0°,30°,60°,90°,120°,150°,180°,210°,240°,270°,300°,330° and360° from the figure 3.2.

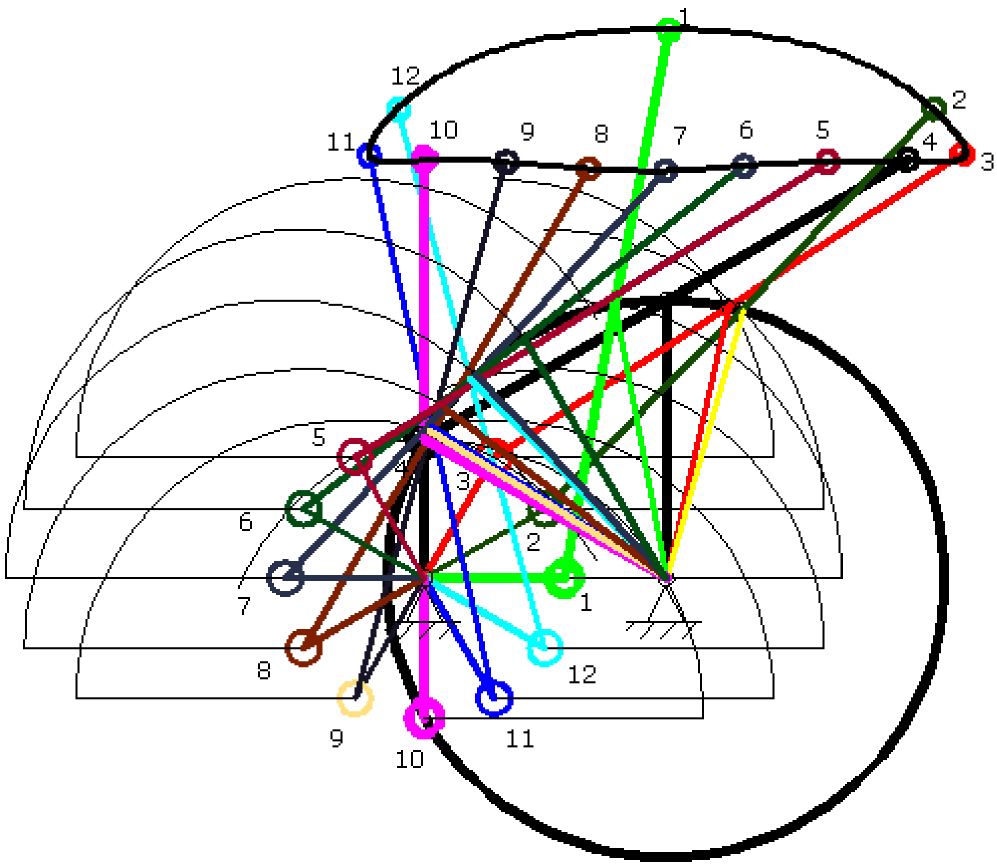

Figure 6.1 Path tracing of the leg

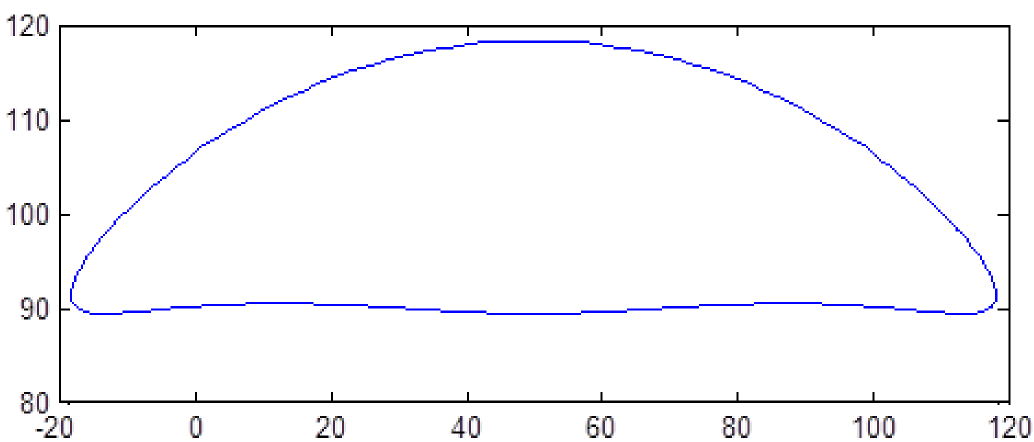

Figure 6.2 Path Tracing of the leg by MATLAB

Table 6.1 Path Tracing Points

Position No.	θ	x	y
1	0	50.0000	118.3216
2	30	117.7680	98.9080
3	60	116.6392	89.7731
4	90	103.9608	89.9346
5	120	86.1756	90.5059
6	150	67.7531	89.9264
7	180	50.0000	89.4427
8	210	32.2469	89.9264
9	240	13.8244	90.5059
10	270	-3.9608	89.9346
11	300	-16.6392	89.7731
12	330	-11.7680	98.9080
13	360	50.0000	118.3216

It has been compared and noted that the path tracing of the leg by using MATLAB as shown in figure 6.2 and using AutoCAD software as shown in figure 6.1 is same.

Since this is a moving mechanism, lot of problems were encountered during fabrication and assembling. Initially it was started with little big dimensions. Because of that, it was more weight and lengthy legs. When the assembly moved, the legs tends to bend and so that the motor could not drive it. Then the dimensions of the links are reduced and it was repeated.

The main problem faced in this machine fabrication is the alignment of the rotating and moving parts. Anyhow researcher has tried our level best and completed. This walking machine can be upgraded with camera and remote control. The solar energy system can also be incorporated for self charging of battery.

Acknowledgement

We are thankful Dr. Said Omar Al-Mashikhi Head, Department of Engineering, and Dr. Maryam Al-Awadi, Dean, Salalah College of Technology for their valuable inspiration, encouragement and providing necessary facilities for the study and completing fabrication work. Grateful thanks are expressed to Er. ArmadoLojoHiplito for supporting us and helping us in completing fabrication work.

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