United States Patent [19]

Ogawa et al.

[11] **3,783,706**

[45] **Jan. 8, 1974**

[54] **SIX-BAR LINKAGE HAVING SYMMETRICAL DISPLACEMENT CURVE**

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[73] Assignee: **Kabushiki Kaisha Ricoh,** Tokyo, Japan

[22] Filed: **Mar. 10, 1972**

[21] Appl. No.: **233,455**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 23,073, March 26, 1970, abandoned.

[52] **U.S. Cl.** **74/469,** 74/47

[51] **Int. Cl.** **G05g 1/04**

[58] **Field of Search** 74/469, 103, 47

[56] **References Cited**

UNITED STATES PATENTS

2,900,830	8/1959	Eisenburger et al.	74/103
3,501,120	3/1970	Daniel, Jr.	74/103 X

Primary Examiner—Allan D. Herrmann

Attorney—Milton J. Wayne et al.

[57] **ABSTRACT**

A six-bar linkage which has an angular displacement curve between θ and ϕ where θ is the angle of rotation of a driving link and ϕ is the angle of rotation of a driven link for producing a rectilinear motion of one point of the six-bar linkage without guide means when the driving link rotates.

5 Claims, 5 Drawing Figures

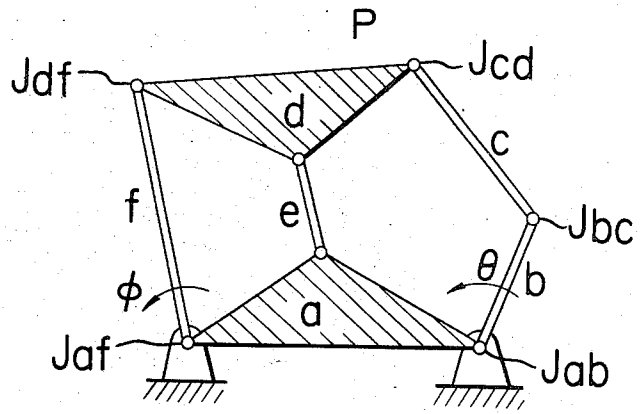


FIG. 1

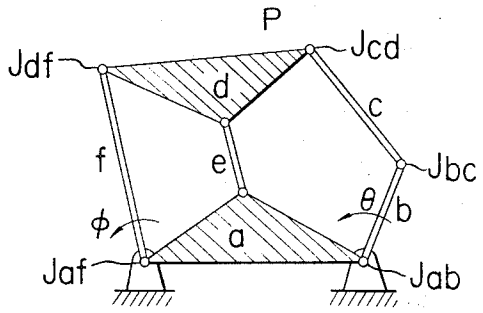


FIG. 2

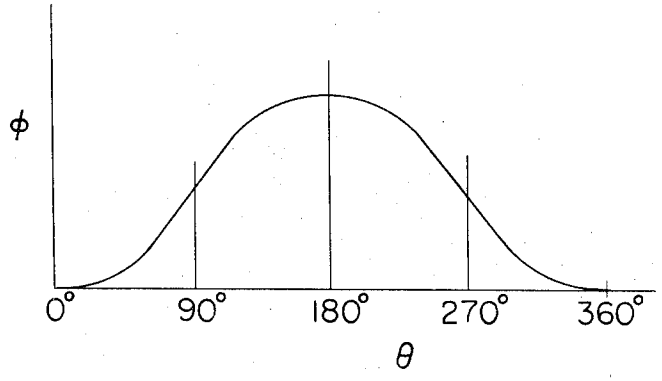


FIG. 3

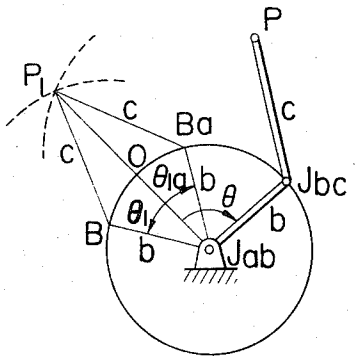


FIG. 4

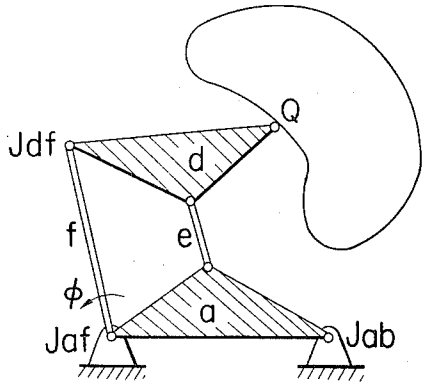
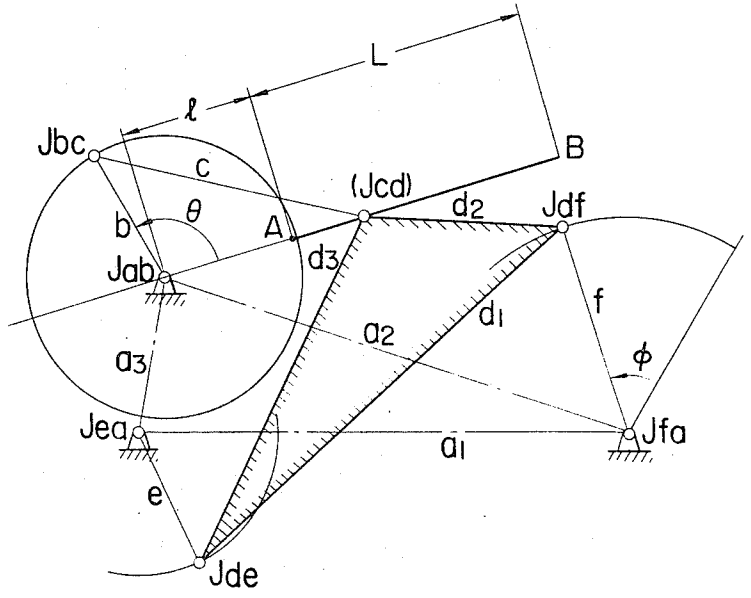

Q
Jdf
d
f
e
φ
a
Jaf
Jab

FIG. 5


L
ℓ
Jbc
B
c
(Jcd)
d2
Jdf
b
θ
A
d3
Jab
d1
f
a2
φ
a3
Jea
Jfa
a1
e
Jde

SIX-BAR LINKAGE HAVING SYMMETRICAL DISPLACEMENT CURVE

BACKGROUND OF THE INVENTION

This is a continuation-in-part of our earlier filed copending U.S. Pat. application Ser. No. 23,073 filed Mar. 26, 1970, now abandoned. This invention relates to a six-bar linkage having a symmetrical displacement curve.

The six-bar linkage herein referred to is a locked chain linkage with six links which are connected to each other in a selected manner to have a predetermined degree of freedom.

To satisfy the condition of the degree of freedom with respect to the six-bar linkage comprising pivoting connections for all links, as disclosed in the present invention, two links out of the six bar linkage should be ternary links or three-sided links, and the remaining four should be binary links. Thus it is seen that the number of connections must amount to seven and number of sides must amount to ten, in total.

It is also known that when calssifying all the possible six-bar links which will satisfy the requirements as described above, the following two fundamental types can be enumerated. That is;

i. The one wherein two ternary links have one common connection to each other

ii. The one wherein two ternary links do not have one common connection

Further classification of these links enables them to be classified into five types from A through E as shown in FIG. 1 in Bulletion of JSME Vol.5, No. 19 (1962) by K. Ogawa, in accordance with how to select the fixed pivot in the coordinated linkage, namely, as to which link should be selected as a driving link and which should be selected as a driven link.

By maintaining the characteristics of each type of linkages which belong to each classification, numerous combinations can be produced in accordance with the variation of lengths of each side.

However, it is generally not known as to what kind of functions will be obtained from what kind of combinations that are constructed with respect to the different lengths.

Accordingly, when a linkage having a specified function is required, even if the skilled in the art could surmise that the requirement would be satisfied by use of the six-bar linkage, no means for realizing it theorectically have been disclosed heretofore.

It had been impossible to provide a link mechanism which makes a rectilinear motion unless it includes more than seven links. In a most simplified link mechanism or four-bar linkage, there has not been established a method of computation for moving a point on a coupler link along a straight line, and the same is true for a six-bar linkage. That is, in the conventional method for designing a four-bar or six-bar linkage capable of rectilinear motion, various hypotheses must be established as to the lengths of the links and the distances between the fixed pivots, and the tremendous amount of computations, which seems almost impossible, must be carried out in a trial-and-error manner.

However, without the necessity to take into consideration the motion of a point on a coupler link, there has been proposed a computation method for designing a four-bar or six-bar linkage which satisfies any arbitrary angular relation between the driving and driven links

(which will be referred to as "displacement curve" hereinafter). Therefore, a relationship between the rectilinear motion of the point on the coupler link, hitherto impossible by the conventional six-bar linkage, and more particularly a planar six-bar linkage, has established one point which may make a rectilinear motion when one link rotates about a fixed pivot.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a schematic diagram illustrating a general form of a type of a six bar linkage;

FIG. 2 is a graph illustrating one example of a symmetrical displacement curve;

FIG. 3 is a diagram illustrating the relation between the rectilinear motion and an angular displacement of one link of the mechanism shown in FIG. 1;

FIG. 4 is a diagram illustrating that some of the links of the mechanism shown in FIG. 1 constitute a four-bar linkage; and

FIG. 5 is a diagram of one example of a six-bar linkage which satisfies the symmetrical displacement curve shown in FIG. 2.

DETAILED DESCRIPTION OF THE INVENTION

The primary object of the present invention is to provide a novel six bar linkage or six link mechanism capable of rectilinear motion which has a clarified displacement curve whereby, the rectilinear motion of the one point may be analyzed or synthesized by in an established method through the displacement curve.

The present invention is characterized in that the relation between the linear motion and the displacement curve is clarified in the six bar linkage, whose general form is illustrated in FIG. 1.

The linkage shown in FIG. 1, which belongs to type A in the classification mentioned above, comprises six links *a*, *b*, *c*, *d*, *e*, and *f*. The link *a* is a fixed link having three connections, which is fixed in a coordinate system at rest; the link *b* rotates about a fixed pivot J_{ab}; and the link *f* rocks about a fixed pivot J_{af}. The links *c* and *d* are called coupler links and connected to each other at a pivot J_{cd}, and the first coupler link *c* is connected to the link *b* at a pivot J_{bc} while the second coupler link *d* is connected to the link *f* at a pivot J_{df}. The second coupler link *d* having three connections is connected to the fixed link *a* through a link *e*. Thus the six bar linkage is a locked chain.

For simplifying the explanation of the six bar linkage described above, it is divided into two sections, one section consisting of the links *b* and *c* and the other links *a*, *b*, *e*, and *f*.

Referring to FIG. 3, one end of the driving link *b* which rotates about the pivot J_{ab} is connected to one end of the link *c* at the pivot J_{bc}. The other end of the link *c* is designated by P. The reference lne $J_{ab}O$ is a line arbitrarily drawn to pass through the pivot J_{ab}, and an angle θ is defined an angle between the reference line $J_{ab}O$ and the link *b*. When the link *b* coincides with the reference line $J_{ab}O$, the angle θ is 0° and when the link *b* concides with an opposite extension of the reference line $J_{ab}O$, the angle $\theta = 180°$.

Next we consider the conditions under which the other end P of the link *c* occupies position P_1 which is reached when the link *b* rotates symmetrically from the reference line $J_{ab}O$, through an angle θ_1 in the counterclockwise direction or through an angle of θ_{1a} in the clockwise direction. The positions of the pivot J_{bc} are

designated by B and B_a respectively, and $|\theta_{1a}| = |\theta_1|$. By drawing circles with the positions B and B_a as the centers and with radius equal to the length of the link c, the intersection of these two circles is the position P_1.

Since the corresponding three sides of the triangles $\Delta J_{ab}BP_1$ and $\Delta J_{ab}B_aP_1$ are equal respectively, these two triangles are congruent. Hence

$$< BJ_{ab}P_1 = \ < B_aJ_{ab}P_1$$

Therefore, the straight line $J_{ab}P_1$ coincides with the reference line $J_{ab}O$. In other words, the point P_1 is located on the extension of the reference line $J_{ab}O$. Since θ_1 may be an arbitrary angle, it may be generally stated that whatever the value of angle θ may be, the point or position P is always found on the extension of the reference line $J_{ab}O$ as far as the angle θ_1 is equal to the angle θ_{1a}. Accordingly, BJ_{ab} is symmetrical to B_aJ_{ab} with respect to the reference line OJ_{ab}. In other words, the point P will move along one straight line as the angle θ varies from 0° to 360°. However, the condition $c>b$ must be satisfied so that the link b may rotate about the pivot J_{ab} through 360°.

As is clear from FIG. 3, the length of $J_{ab}P$ becomes maximum when θ is equal to 0° and is equal to $(c+b)$, and minimum when θ is equal to 180° and is equal to $(c-b)$. Therefore the stroke or displacement L of the point P is given by

$$L = (b+c) - (c-b) = 2b.$$

The mechanism shown in FIG. 4 constitutes a locked chain and this is a four bar linkage. This mechanism is considered as an independent four-bar linkage in the following discussion. The link f is a driving link which rotates through 360°, and the displacement angle of the link f from a reference line is ϕ. When the link f rotates, a point Q on the coupler link d moves generally along a closed curve. There is only one-to-one correspondence between a point on the closed curve and the displacement ϕ of the link f. In other words, with respect to a point on the closed curve, only one displacement angle ϕ exists.

However, when the driving link f does not rotate through 360°, but rocks through an angle, the point Q on the coupler link reciprocates along a part of the closed curve.

If in FIG. 4 a link c were provided connecting pivot J_{ab} with the unconnected end of link d, this connection would then become J_{cd} and locate point P as in FIG. 1, and if the point Q on the coupler link of the four-bar linkage is connected to the other end P of the link c at the pivot J_{cd}, then the six-bar linkage as shown in FIG. 1 is obtained. In this case, when the lengths of the four-bar linkage shown in FIG. 4 are predetermined the point Q on the coupler link d will not always make a rectilinear motion. Therefore, the driving and driven links are first determined, and then the lengths of the links are left as unknown values to be computed.

When the point P makes the rectilinear motion explained for FIGS. 1 and 3, two symmetrical angles of θ with respect to the reference line $J_{ab}O$ are determined while only one angle ϕ is determined in correspondence with each position of the point P. Therefore, the displacement curve is symmetrical with respect to $\theta = 0°$. Since the link b coincides with the extension of the reference line $J_{ab}O$ when θ is equal to 180°, the displacement curve is also symmetrical with respect to θ whice is equal to 180° when $0° \leqq \theta \leqq 360°$. Therefore, the displacement curve is drawn as symmetrical with respect to 180° of θ as shown in FIG. 2 which represents the angular relation between the angles ϕ and θ. Some values of the displacement curve shown in FIG. 2 are shown below:

θ	0°	90°	180°	270°	360°
ϕ	0°	42°	71°31′	42°	0°

Each pair of the angles θ and ϕ having a predetermined relation or predetermined values is called "precision point." An equation satisfying these values may be obtained by use of Newton's interpolation as is fully discussed in the papers distributed in the 46th meeting of The Japan Society of Mechanical Engineers in Tokyo. The equation is

$$\phi = 0.4666666\theta - 0.044150760\ (\theta - \pi/2) - 0.034937040\ (\theta - \pi/2)\ (\theta - \pi) + 0.011120810\ (\theta - \pi/2)(\theta - \pi)\ (\theta - 3\ \pi/2).$$

All angles shown above are represented to radians for computation. Further reference is made to "Researches on the Synthesis of the Six-Bar Linkage" by K. Ogawa, The Japan Society of Mechanical Engineers, Vol. 39, No. 205, pp. 2,084–2,089, published in June 1963. As to the selection of the "precision points" which minimize the deviation from the continuous displacement curve, reference is made as "Chebyshev Spacing" in "Kinematic Synthesis of Linkages," by R.S. Hartenberg, McGraw-Hill, 1964.

Employing these computation methods, the six-bar linkage which satisfies the above displacement curve may be obtained. Only one point P corresponds to one angle ϕ, and two symmetrical angles θ correspond to this point P with respect to the reference line θ which is equal to 180°.

Therefore, it is seen that when the link b, rotates about the pivot J_{ab}, the point P reciprocates along the extension of a reference line with the stroke which is equal to $2b$. It is to be understood that the stroke L as herein employed is the stroke length, in other words, the length of the path of rectilinear displacement through which the point P passes during a full cycle of rotary movement of the driving link.

From the foregoing description it is clarified that when a six-bar linkage is desired, in which a point P on one coupler link thereof reciprocates along a straight line with a specific stroke, it may be obtained by providing a desired symmetrical displacement curve and determining the length of the driving link as b which is equal to one-half of the stroke.

Example

The example is illustrated in FIG. 5, in which the point P reciprocates along the straight line AB with a stroke L which is equal to 25 mm. The length of the driving link is b which is equal to L/2 or 12.5 mm; and the distance from the point A to the fixed pivot J_{ab} is l which is equal to 12.3 mm, so that, the length of the first coupler link c is equal to $b+l$ or 24.8 mm. It is assumed that the linkage shown here satisfies the displacement curve shown in FIG. 2. However, any other displacement curve may be employed as far it is symmetrical, but the design factors will be different from those explained with reference to FIG. 5. It was confirmed by simulation of an analog computer and by a fabricated model of the linkage that the point P of the six-bar linkage illustrated in FIG. 5 reciprocates along the straight line AB.

When the links b and c are removed from the six-bar linkage shown in FIG. 5, the links a, d, e and f constitute a four-bar linkage as has been explained previously with reference to FIG. 4. It is readily seen that even with this four-bar linkage the point P reciprocates along the straight line when the link f is rocked or swung within a range of ϕ which is equal to (0°~71°31'). That is, it is very difficult to design directly a four-bar linkage which makes a rectilinear motion, but if a six-bar linkage of the type described hereinabove is designed, the desired four-bar linkage may be easily designed by removing the driving link and the first coupler link of the six-bar linkage. The links of other links can be calculated by the calculation method as described above.

In the six-bar linkage in FIG. 5, lengths of the links are approximately as follows:

$a_1 = 44.3$ mm
$a_2 = 43.9$ mm
$a_3 = 13.8$ mm
$b = 12.5$ mm
$c = 24.8$ mm
$d_1 = 44.3$ mm
$d_2 = 17.9$ mm
$d_3 = 34.1$ mm
$e = 12.7$ mm
$f = 19.0$ mm

A linkage consisting of more than seven links has been known in which a point on its mechanism moves along a straight line when one link is rotated, but so far it had been impossible to design a six-bar linkage which makes a rectilinear motion in a predetermined arrangement. However, according to the present invention, from a symmetrical displacement curve a rectilinear motion mechanism is obtained which eliminates any need for a guide for rectilinear mition. Thus the advantages of the present invention is the reduction in number of machine elements, the simplification and compactness of a hitherto complex machine.

What is claimed is:

1. A six-bar linkage for converting rotary motion of a driving link to rectilinear motion of the pivot connecting a first intermediate link with a second intermediate link having a stroke length equal to a predetermined segment of a line comprising

a driving link having a length equal to one-half of said stroke length;

said driving link being connected to a fixed pivot point, said fixed pivot point lying on an extension line of said predetermined segment of line including said stroke;

said first intermediate being a first coupler line connected to said driving link and having a length equal to the sum of the driving link and the distance between the fixed pivot point and the adjacent end of said segment of a line, and

said extension line provided as a reference for an angular measure θ of said driving link whereby a symmetrical displacement curve is provided.

2. A six-bar linkage according to claim **1** wherein said linkage comprises

first link means having a three-sided form with the sides terminating in points and two of said points being fixed to be stationarily positioned;

said driving link provided as a second link means attached to the said one of said fixed points;

third link means attached to the other of said fixed points, said third link means being a driven link rotatable through an angle ϕ;

fourth link means having a three-sided form with the sides terminating in points;

said coupler link provided as a fifth link means extending between a point of said fourth link means to provide the rectilinear motion and a rotatable end of said driving link;

sixth link means formed as a link extending between an unfixed point of said first link means and a second point of said fourth link means; and

a rotatble end of said third link means being attached to a third point of said fourth link means whereby rotation of said driving link through the angle θ provides the symmetrical displacement curve desired from back and forth angular rotation of said third link means through said angle ϕ and the rectilinear movement of said point on said fourth link means.

3. A six-bar linkage according to claim **2** wherein rotation of said driving link and said link means provides the following angular relationships:

θ	0°	90°	180°	270°	360°
ϕ	0°	42°	71°31'	42°	0°

4. A six-bar linkage for converting rotary motion of a driven link to rectilinear motion of a given point on the linkage and having a given stroke length, comprising first and second ternary links, driving and driven links pivoted to separate points of said first ternary link, and intermediate link pivoted to the other end of said driving link, theother ends of said driven link and intermediate link being pivoted to separate points of said second ternary link whereby the pivot points between said intermediate link and said second ternary link define said given point, and further link pivoted between further points of said first and second ternary links, said driving link having a length equal to half of the stroke length, said intermediate link having a length equal to the sum of said stroke length and the length of said driving link, the angular displacement of said driven link being symmetrical with respect to the angular displacement of said driving link from a given angular position of the driving link, said rectilinear motion of said given point extending along a straight line passing through the pivotal connection between said driving link and said first ternary link, which straight line corresponds to said given angular position of said driving link.

5. The six-bar linkage of claim **4**, wherein the angular displacement ϕ of the driven link is defined by the angular displacement θ of said driven link by the relationship:

$$\phi = 0.4666666\theta - 0.0441507\theta(0 - \pi/2) - 0.0349370\theta\,(0 - \pi/2)\,(\theta - \pi) + 0.0111208\theta\,(\theta - \pi/2)\,(\theta - 3\pi/2).$$

* * * * *

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,783,706 Dated January 8, 1974

Inventor(s) Kiyoshi Ogawa, Yoshiaki Yokoyama and Yoshio Fukushima

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 1, line 22: "calssifying" should be --classifying--

line 32: "Bulletion" should be --Bulletin--

line 49: "theorectically" should be --theoretically--

Column 2, line 55: "lne" should be --line--

line 61: "concides" should be --coincides--

Column 3, line 67: "whice" should be --which--

line 36: "mition" should be --motion--

line 52: "line" should be --link--

Column 6, line 17: "rotatble" should be --rotatable--

line 25: after "said" (2nd occurrence) insert --third--

line 37: "theother" should be --the other--

line 41: after "and" insert --a--.

Signed and sealed this 3rd day of December 1974.

(SEAL)
Attest:

McCOY M. GIBSON JR.
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents

FORM PO-1050 (10-69)

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