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How to compose mechanisms with parallel moving bars
(with application on a level-luffing jib-crane consisting of a four-bar linkage and exploiting a coupler-point curve)

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Abstract: Application of the principle of stretch rotation gives an easy way of finding the 3 four-bar cognates and also the 6 six-bar linkages of Watt's type with translating bars. With the same principle an adjoined linkage is built to hold a platform, attached to the end point of a jib-lever of a level-luffing jib-crane, in a horizontal position during luffing. A measuring apparatus attached to this platform enables the crane-driver to weigh the load while it is suspended from the crane.

1. Introduction

Six-bar linkages of Watt's type having turning-pairs only, and having one parallel moving (or translating) bar, have been designed by K. Hain [1]. His design, with which he found six different solutions, was based on the theorem of Roberts-Chebyshev [2].

In the present paper the same result will be obtained using the principle of stretch rotation as introduced by H. Pflieger-Haerel [3] in his derivation of the mentioned four-bar cognates.

An example is worked out as an application for a level-luffing crane, enabling the crane-driver to weigh the load while the latter is hanging from the crane.

2. Application of the principle of stretch rotation in the derivation of four-bar cognates

A four-bar coupler-curve may be generated by an arbitrarily chosen coupler-point (K) in the coupler-plane (ABK) which is attached to the coupler (AB) of some four-bar (AoABBo).

In Fig. 1 a source mechanism of this kind is drawn, generating a curve of order 6 and genus 1. The moving links in this mechanism are numbered from 1 to 3. The frame-link AoBo is indicated by the number 0.

1) This theorem states that three different planar four-bar linkages will trace identical coupler curves.

The so-termed 2/3-cognate of the source mechanism may now be obtained following the design instructions given next (see Fig. 2):

a. Form the linkage-parallelograms ABBoB' and BoBKB'.

b. Frame the rigid 2-bar triangle B'B'B which is identically equal to the coupler-triangle ABK.

c. Turn the four-bar AoAB'B'o about B'o over \( \beta = \) angle ABK and multiply the four-bar geometrically by the factor \( f_\beta = B'B'o / B'B'o \). (One is thus using the principle of stretch rotation, with which one obtains the four-bar BoBC'C'o which is similar to the four-bar BoB'A'o.)

d. Form the similar and rigid triangles KB'C'o and AoBoC'o. (Both triangles are similar to the coupler-triangle ABK.)

The initial four-bar mechanism is now supplemented by another one, BoB'C'C'o, of which the coupler-point K also traces the same four-bar coupler-curve.

The obtained alternative mechanism is called a cognate of the source mechanism. And, since the angular velocities of the links 2 and 3 are interchanged, one may speak of the 2/3-cognate for short. It is clear that the 1/2-cognate as shown in Fig. 3 may be obtained in a similar way.

And, finally, it may be shown that the 1/3-cognate of the 1/2-cognate of the source mechanism, turns out to be identical.

2) Throughout the paper, triangles are made rigid as long as two sides of such a triangle may move at the same angular velocity at any point of time.
Fig. 1. Initial four-bar linkage generating a unicursal coupler-curve.

Fig. 2. The 2/3-cognate of the initial four-bar linkage.

Fig. 3. The 1/2-cognate of the initial four-bar linkage.

Fig. 4. The 1/3-cognate of the 1/2-cognate (of the initial four-bar) identical to the 2/3-cognate of the initial four-bar.

Fig. 5. Roberts' Law demonstrated.

Link lengths are, in addition to Cayley's plan, found by the similarity of the frame-triangle and the coupler-triangle of the source mechanism.

3. Composition of six-bar translating mechanisms through stretch rotation

The first six-bar with translating rod is to be designed through the following instructions (see Fig. 7):

a. Start the design with an arbitrarily chosen four-bar \( A_0 A B B_0 \) and coupler-triangle \( A B K \).

b. Form the linkage-parallelogram \( A_0 B B_0 B_0 \).

c. Turn the four-bar \( A_0 A B B_0 \) about \( A \) over the angle \( \alpha = \angle BAK \) and multiply the four-bar geometrically by the factor \( f_4 = K A / B A \).

(One thus obtains the four-bar \( \square E A K F \) which is similar to \( \square A_0 A B B_0 \).)

d. Frame the rigid triangle \( A_0 A E \) which is similar to the coupler-triangle \( BAK \).

Since \( FK \) and \( B_0 B \) enclose the fixed angle \( \alpha \), rod \( FK \) will move...
Fig. 6. Cayley's plan for determining the lengths of cognate links.

Fig. 7. First Watt's six-bar with translating bar.

Fig. 8. Second Watt's six-bar with translating bar.

Fig. 9. Third Watt's six-bar with translating bar.

parallel to the frame. The obtained mechanism has one degree of freedom of movement and since \( A_0B_0 \) and \( B_1B \) may be considered as redundant bars, the linkage resembles a six-bar mechanism.

A second solution, as shown in Fig. 8, is obtained by interchanging the functions of the turning-joints \( A \) and \( B \).

A third solution to the problem of finding six-bar mechanisms with translating rods is demonstrated in Fig. 9. The design of this mechanism follows the next pattern of instructions:

a. Start the design with the same initial four-bar \( A_0ABB_b \) as chosen with the first two solutions. (Here, too, the coupler-point \( K \) is similarly situated in the coupler-plane attached to \( AB \).)

b. Form the linkage-parallelograms \( A_0AKA' \) and \( A_0ABA'' \).

c. Make the four-bar \( \Box KA'E'F' \) identically equal to the four-bar \( \Box A_0ABB_b \).

d. Frame the rigid triangle \( \triangle A_0A'E' \) which is similar to the initial coupler-triangle \( \triangle KA'B \).

e. Turn the four-bar \( \Box A_0A'B'B_0 \) about \( A_0 \) over the angle \( \alpha = \angle A_0A'A' = \angle BAK \) and multiply the four-bar geometrically by the factor \( f_\alpha = \frac{A_0A'A'}{A_0A''} = \frac{KA}{BA} \). (One obtains the four-bar \( \Box A_0A'C'C_0 \) which is similar to the four-bar \( \Box A_0A'B'B_0 \).)

f. Frame the rigid and similar triangles \( KA'C' \) and \( B_0A_0C_0 \). Since \( F'K \) remains parallel to \( A_0B_0 \), the rod \( F'K \) is a translating bar. Thus the six-bar mechanism, as shown in the figure in solid lines, resembles a mechanism with a parallel moving rod.

A similar translating rod will be obtained if the functions of the turning-joints \( A \) and \( B \) are interchanged. The resulting mechanism is shown in Fig. 10 as a fourth solution.

The fifth solution to the problem, as illustrated in Fig. 11, may be found by following the next pattern of design instructions:

a. Start the design with the same source mechanism as before (i.e. four-bar \( A_0ABB_b \) and coupler-triangle \( ABK \)).

b. Form the linkage-parallelograms \( A_0AKA' \) and \( A_0AAA' \).

c. Turn the four-bar \( A_0AB'B_0 \) about \( B_0 \) over the angle \( \beta = \angle B'B_0A_0 \) and multiply the four-bar by the factor \( f_\beta = \frac{B'B_0}{B'B_b} = \frac{B_0K}{BA} \).

(One thus obtains the four-bar \( \Box B_0B'C'C_0 \) which is similar to the four-bar \( \Box B_0B'B'B_b \).)

d. Frame the rigid and similar triangles \( A_0B_0C_0 \) and \( KB'C' \).

e. Make the four-bar \( KC'=A'D' \) similar to the four-bar \( B_0B'A'A_0 \).

f. Frame the rigid triangle \( \triangle A'C_0C' \) which is similar to \( \triangle KB'C' \).
Since KD* moves at the angular velocity of the fixed link A_oB_o, a six-bar mechanism is obtained having a translating rod. The resulting mechanism is indicated by the full-drawn lines of Fig. 11.

The sixth and last solution to the problem is illustrated in Fig. 12. This translating mechanism may be obtained by using the design instructions of the just-mentioned 5th translating six-bar, while interchanging the functional characters A and B. (One may remark, finally, that all solutions generate the same parallel moving plane 0' and that all points of this plane describe the same coupler-curve as produced by the source mechanism, which is the arbitrarily chosen four-bar A_oABB_o with coupler-triangle ABK.)

4. The design of a translating platform attached to the coupler-point (summit-point) of a level-luffing jib-crane

Most European level-luffing cranes, used in shipbuilding and cargo handling, feature a double-rocker mechanism. With these jib-cranes the motion of the jib-lever is identical to the motion of the coupler-plane of the double-rocker mechanism and the motion will be controlled by some luffing gear attached to the foremost leg of the crane. The hoisting rope of such a crane passes over a single pulley at the jib-head (A), and then over another single pulley at the end (K) of the jib-lever, directly to the lifting hook attachments.

In order to move the suspended load inwards or outwards along a level path between maximum and minimum position of the jib-lever, one aims to move the coupler-point K of this lever along a horizontal path. This objective may be approached in letting K coincide with Ball’s point (or undulation point) of the jib-lever in the midposition of the jib [4].

In this paper, however, the main features of such a jib-crane will be taken for granted. The principal objective of this paper is to find the means of moving a platform attached to the coupler-point (K) parallelwise, destined to hold a loadcell for measuring suspended loads in a vertical position during the motion of the crane.

Should the loadcell be attached to the coupler-plane (KA), in a manner as shown in Fig. 15a, the equilibrium of forces on the coupler-point K would cause the loadcell to stand the varying force $G \cos \varphi$ instead of some constant force proportional to the load force $G$. Here, the angle $\varphi$ is the varying angle between the moving jib-line KA and the horizon. Therefore, a translating platform is necessary.

The design of the additional mechanism may be carried out in several ways. One of these may be obtained through the next sequence of design instructions (see Fig. 13):

a. The jib-crane consists of the double-rocker A_oABB_o and the jib-lever (coupler-triangle) ABK.

b. Form the linkage-parallelogram A_oB_oBB_o.

c. Turn the four-bar A_oABB_o about A over the angle $\alpha = \angle BAK$ and multiply the four-bar by the factor $f_a = KA/BA$.

(One thus obtains the four-bar EAKF which is similar to $\triangle A_oABB_o$)

d. Frame the rigid triangle A_oAE which is similar to the rigid coupler-triangle BAK.

Fig. 10. Fourth Watt’s six-bar with translating bar.

Fig. 11. Fifth Watt’s six-bar with translating bar.

Fig. 12. Sixth Watt’s six-bar with translating bar.
Choose a turning-joint $Q$ on the diagonal $FA$ of the four-bar $EAKF$ in the neighbourhood of jib-head $A$.

f. Turn the four-bar $EAKF$ about $A$ over $n$ radians and multiply the four-bar so as to obtain the four-bar $RAPQ$. (Thus $\square A_0A_1BB_0 \sim \square EAKF \sim \square RAPQ$.)

g. Attach turning-joint $R$ to the foremost leg $A_0A$ of the crane.

h. Attach turning-joint $P$ to the jib-lever $ABK$. (So the dyad $PQR$ is added to the crane of which $PQ$ moves parallel to the frame.)

i. Choose a random turning-joint $S$ in the neighbourhood of jib-head $A$ and frame the rigid triangle $PQS$ (see also under $k$).

j. Form the linkage-parallelogram $PSTK$. (Then $TK$ controls the motion of the parallel moving platform ²) and is rigidly attached to it.)

k. In order to keep the varying angle $TSP$ in the neighbourhood of $\pi/2$ rad during luffing, it is advisable to choose the angle $TSP \approx \pi/2$ in the midposition of the jib-lever. (This may be done in choosing the turning-joint $S$ accordingly.)

l. The crane and adjoined linkage are indicated in Fig. 13 by solid lines.

m. The fastening of the loadcell to the platform is indicated in the motion of the platform $K'$ on the platform.

Any point $K'$ of this platform describes the same coupler-curve or load-trajectory as the coupler-point $K$ of the jib-lever.
Fig. 15. Arrangement of loadcell for weighing purposes.
a. Inadequate solution; b. Correct solution.

Fig. 15b. The measuring will then be proportional to the loadforce \( G \) and is independent of the position of the jib-lever. Another method in securing the parallel motion of the platform may be obtained through following the next altered design-instructions (see Fig. 14):

e. Choose a turning-joint \( Q \) on the diagonal \( EK \) of the fourbar \( EAKF \) in the neighbourhood of the end (K) of jib-lever \( ABK \).

f. Multiply the four-bar \( EAKF \) geometrically from \( K \) by the factor \( \frac{QK}{EK} \). (Thus the four-bar \( QPKR \) is obtained which is similar to \( EAKF \) and \( A_0ABB_0 \).)

g. Attach turning-joint \( P \) to the jib-lever \( ABK \). (Then \( RK \) moves parallel to the frame as long as \( PQ \) moves parallel to the leg \( A_0A \).

h. Choose a random turning-joint \( S \) in the neighbourhood of coupler-point \( K \) while making the angle \( SPA \approx \frac{\pi}{2} \) rad in the midposition of the jib-lever.

i. Frame the rigid triangle \( PQS \).

j. Form the linkage-parallelogram \( SPAT \).

k. Fix turning-joint \( T \) to the leg \( A_0A \) and fix the platform to the link \( RK \).

l. The crane and adjoined linkage are indicated in Fig. 14 by solid lines.

m. The fastening of the loadcell to the platform is indicated again in Fig. 15a and b. The electrical measuring equipment attached to the loadcell may then measure the load in any luffing position of the crane.

References


