SYNTHESIS OF BASIC LINKAGES FOR INPUT-OUTPUT COORDINATION

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SUMMARY: Computer-aided graphical design procedures are introduced for the synthesis of basic linkages. The two-handled block concept is utilized to illustrate the design of four-bar linkages, slider-crank mechanisms, the first inversion of the slider-crank mechanism (FISC), as well their combinations for multi-position input-output coordination. It is shown that the coordination of input-output in the resulting mechanisms is accurate, and that the error is generally less than 3% of the range.

Key Words : Blocking, computer-aided, coordination, design, graphics, handle, linkage, mechanism, synthesis.

INTRODUCTION

Virtually all machinery make use of some sort of a linkage in the production, delivery or application of power, motion, or function. A given linkage may be broken down into simpler sub linkages, or *basic linkages*, which when put together, form the linkage itself. The four-bar linkage and its inversions and the slider-crank mechanism and its inversions represent the most common of the basic linkages.

One of the applications of basic linkages arises when the motion of an output link is to be coordinated with that of an input link. Of particular interest is the multi-step coordination of four-bar linkages, slider-crank mechanisms, and FISC (first inversion of the slider-crank) mechanisms. Utilization of computer graphics permits the pragmatic synthesis of these linkages. Reasonably accurate designs are achieved after a few trials. The method itself is not complicated, and allows coordination at more than three positions.

In what follows we illustrate the procedures (1) by providing examples to the design of each of these basic linkages. A computer graphics package that utilizes the blocking concept is employed. The software must necessarily support two *handles* on the block.

THE FOUR-BAR LINKAGE

A four-bar linkage similar to the one shown in Figure 1 used in some electric typewriters. Member A_oA is rotated clockwise via a cam (not shown) such that the type slug at C is moved rapidly against a platen roller (not shown) while BB_oC rotates tawafwise (counter-clockwise). Let the required motion be specified as in Table 1, where α is a fixed angle to be determined by synthesis. Thus for given crank length A_oA and coupler length AB, the design task is to ascertain the dimensions of B_oB and α, and the determination of the position vector B_oA_o such that Table 1 is generated.

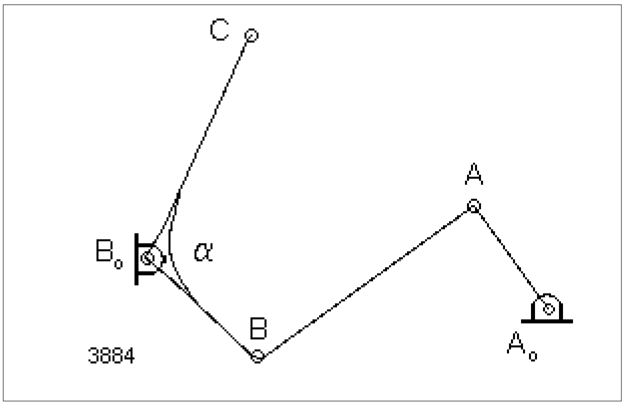

Figure 1: The four-bar linkage to be coordinated.

Procedure

Starting from a suitable point A_o, draw the five radial positions of crank A_oA (Figure 2a). Draw also five circles of radius AB, taking the tips of the rays of Figure 2a as center. Note that the circles are drawn with different line types for ease in differentiation (Figure 2b).

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Table 1: Data for the four-bar linkage.

Inclination of A_oA	Inclination of B_oC (Required)	Inclination of B_oC as generated by A_oBB_oC of Figure 3
0	55	54.11
10	31	30.30
20	14	13.37
30	4	2.36
40	0	-0.65

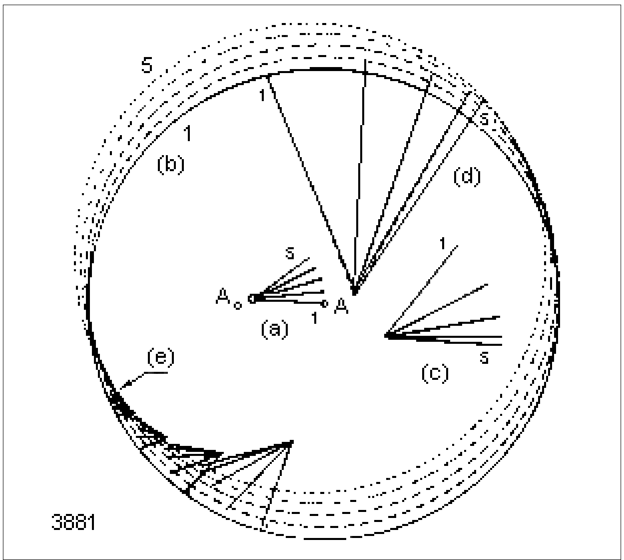

Figure 2: The procedure of synthesis for the four-bar linkage.

At a convenient location (Figure 2c) lay the five required radial positions of B_oC. Use any suitable scale for B_oC. Block the rays of Figure 2c, and set *handles* on the tips of rays numbered one and five. Set handle-1 at any point on the circumference of circle-1, and handle-2 on the circumference of circle-5, and *move* the block. Zoom if necessary. Check to see how closely the block fits. A good fit is obtained when the tip of each ray barely touches the circumference of the corresponding circle. Try setting the block at different locations until a satisfactory fit is obtained. A number of satisfactory solutions are generally possible. Figures 2d and 2e illustrate two such solutions.

The location of the vertex of the rays at the selected configuration is the location of fixed pivot B_o. The length of ray-1 is the length of *member* B_oB and its inclination (139.42°) corresponds to that of A_oA at the starting position (Table 1). The position vector from B_o to A_o determines the length and inclination of the frame member. Figure 3 depicts the crossed four-bar linkage that results from the block of Figure 2e for A_oA=0.3 and AB=1 units, where it is determined that A_oB_o=0.736, B_oB=0.05, and A_oB_o makes an angle of 41.01° with the horizontal. As B_oC is to have an initial inclination of 55° (Table 1), the fixed angle α must be 139.42-55=84.42°.

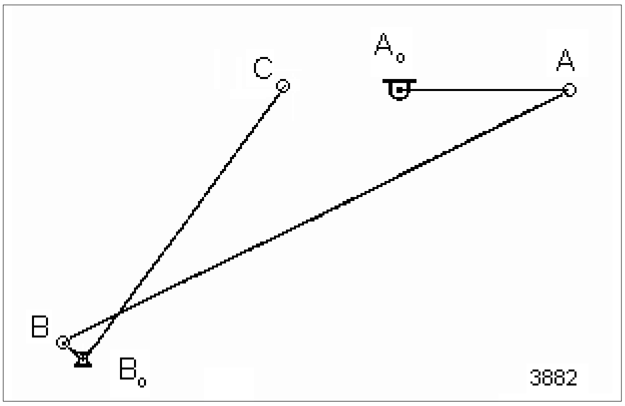

Figure 3: The resulting four-bar linkage.

Insertikon of the above data in the software package AL-YASEER (2-5) yields the output data for the mechanism of Figure 3 as listed in Table 1. It may be shown that transmission angles, within the range of interest, for the mechanism that results the block of Figure 2d are less favorable.

THE SLIDER-CRANK MECHANISM

When the motion of the slider needs to be coordinated with the rotation of the crank in a slider-crank mechanism, the blocking technique can be utilized with ease. Consider, as an example, the garage-door guiding mechanism of Figure 4, where the door AB is guided by A_oAB from its nearly vertical (closed) position until it becomes nearly horizontal (open) while crank A_oA is rotadeo tawafwise. Let it be known that AB=2.2 m, and that the variation of the x-location of the slider B with respect to an origin at A_o be given by Table 2. We wish to determine the crank length A_oA and the eccentricity l_1 to generate this motion.

Procedure

The displacements of the slider are plotted to an arbitrary scale (Figure 5a). With each slider location as center, circles of radius AB=2.2 m are drawn (Figure 5b). The radial positions of the crank (Figure 5c) are next plotted at a suitable location and to an arbitrary scale. The rays of Figure 5c are the blocked, with handles at the tips of ray-1 and ray-5. The block is set on the circles until a satisfactory fit is obtained (Figure 5d). It is determined from Figure 5d that A_oA=1.034, and l_1=1.123 m. The resulting mechanism is displayed in Figure 6, illustrating the five positions of the garage door. The locations of slider B that are generated by the mechanism of Figure 6 are listed in Table 2.

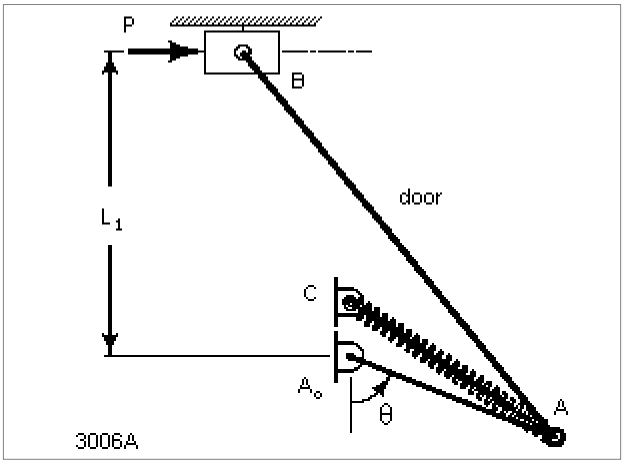

Figure 4: The garage door to be synthesized.

Table 2: Data for the garage door.

Crank angle - ^{o}	x_B (required)	x_B (generated)
277	-0.56	-0.35
320	-0.58	-0.49
3	-0.94	-0.89
46	-1.47	-1.45
89	-2.18	-2.18

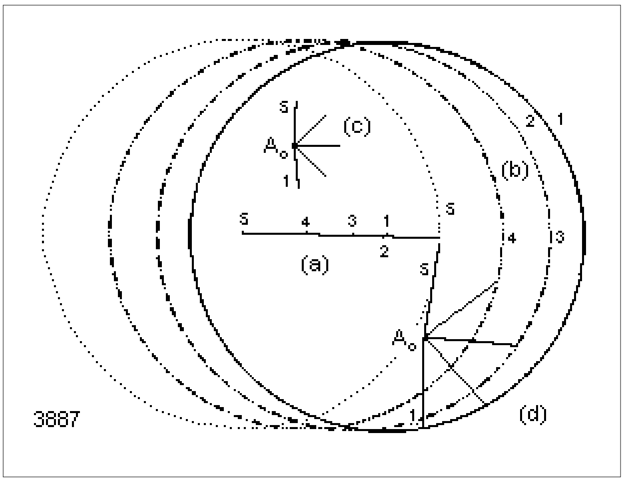

Figure 5: The procedure of synthesis for the slider-crank mechanism.

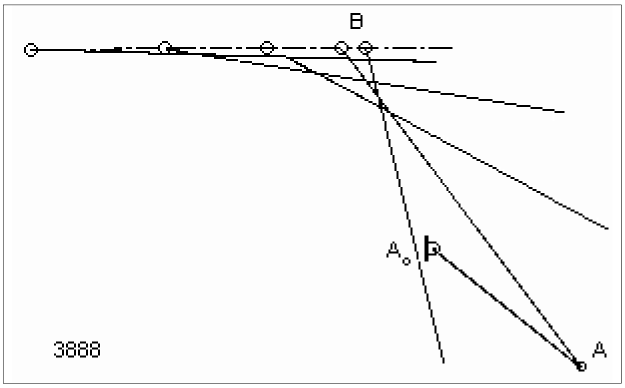

Figure 6: The resulting mechanism for the garage door, with the door at several locations.

THE FISC MECHANISM

Synthesis of FISC mechanisms by the aid of computer graphics is also straightforward. Consider, as an example, the wiper mechanism of Figure 7. Let it be given that crank A_oA has a length of 5 units, and that the required variation of T_9 with T_7 is to be as listed in Table 3. We wish to determine the frame vector B_oA_o as well as length B_oB of the output member.

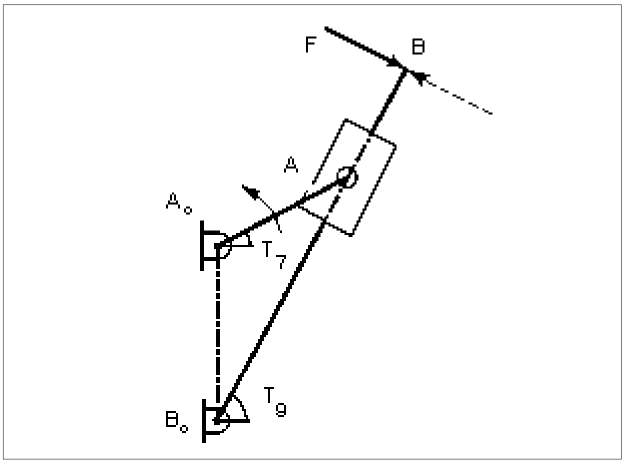

Figure 7: The wiper mechanism.

Procedure

Figure 8 outlines the design procedure that consists of plotting, to a suitable scale, the seven radial positions of crank A_oA_o (Figure 8a) and of the output member B_oB (Figure 8b). A handle is now placed at the vertex of the rays of Figure 8b, which is laid out to an arbitrary scale, and another on ray-1 at a distance of about a third the ray length from the vertex. Set two points, one at an arbitrary location, and the second point at the outer tip of ray-1 of

Table 3: Data for the wiper mechanism.

T_7-°	T_9 (required)	T_9 (generated)+1.7°
-51	66.24	66.24
-21	61.69	62.55
9	67.72	68.52
39	77.24	77.86
69	88.16	88.56
99	99.62	99.78
129	111.08	110.98

Figure 8a. The object is to have each ray of the block to barely touch the tip of the corresponding ray of Figure 8a. Move the block from location to location, zooming to increase accuracy, until a satisfactory fit is achieved. Figure 8c illustrates one such solution where it is determined that A_oB_o=8.286 units and making an angle of 97.53° with the horizontal. The length of B_oB_o is determined to be ≥13.285 units. Table 3 lists the generated output angles for this mechanism. Incorporated in the results is an addition of 1.7° due to the difference of orientation of ray-1 of the block of Figure 8c from that of Figure 8b. Figure 9 shows the resulting mechanism.

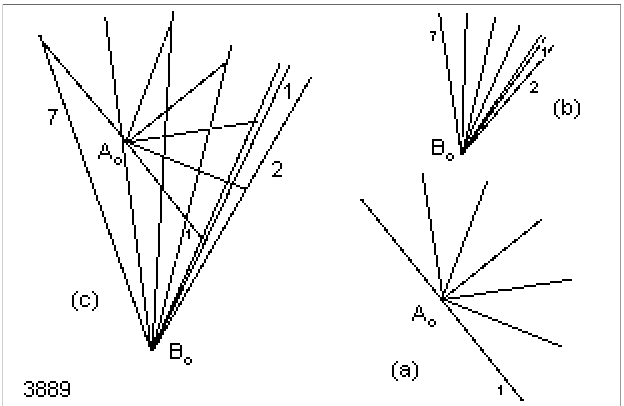

Figure 8: The procedure of synthesis for the wiper mechanism.

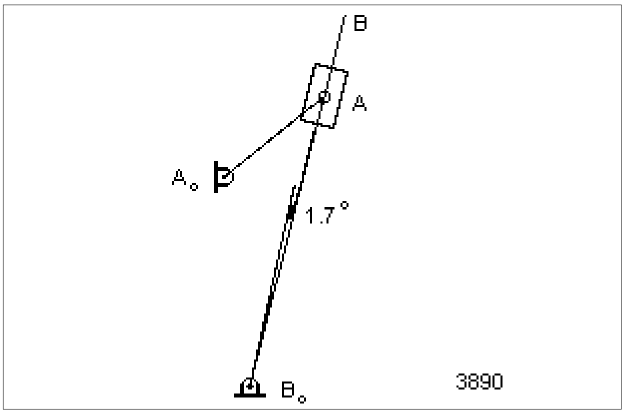

Figure 9: The resulting mechanism for the wiper mechanism.

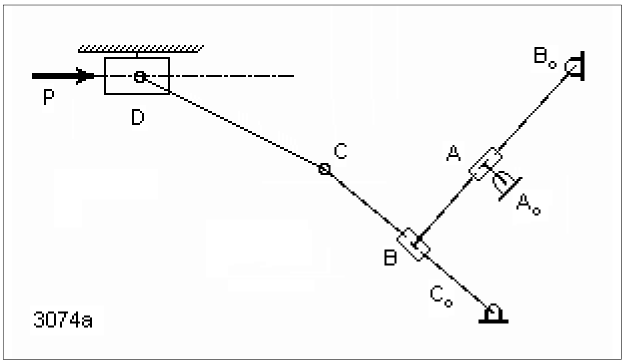

Figure 10: The hack-saw mechanism.

Table 4: Design data for the hack-saw mechanism.

Input- °	Output (required) Units	Output (generated) Units
-80	-8.42	-8.59
-50	-6.79	-7.11
-20	-9.74	-9.81
10	-14.98	-14.78
40	-16.28	-16.04
70	-16.18	-15.94

BASIC MECHANISMS IN TANDEM

The process of synthesis of mechanisms that involve more than one basic linkage proceeds essentials as outlined above for individual basic linkages. To illustrate, consider the hacksaw mechanism of Figure 10. We observe that the mechanism consists of three basic linkages, i.e., FISCs A_oAB_oB and B_oBC_oC, and the slider-crank mechanism C_oCD. Let it be required to design this mechanism to achieve the coordination listed in Table 4, where input is the angle of crank A_oA, and output refers to the displacements, relative to point C_o, of the blade at D.

Procedure

Starting with input crank A_oA, additional design information may be provided, or rational estimates may be made by the designer himself. Thus let the length of A_oA be 3 units, and the input and the output for FISC A_oAB_oB (Figures 10 and 11) be given by Table 5. Figure 12 outlines the corresponding procedure. It is found thus that A_oB_o=8.422, B_oB>11.422 units, and T_6=197.33°. We let B_oB=12 units. The output generated by this mechanism is also listed in Table 5.

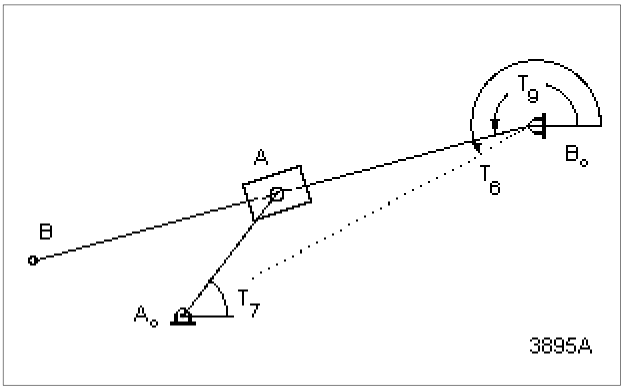

Figure 11: The first FISC of the hack-saw.

Table 5: Data for the FISC A_oAB_oB.

T_7 - °	T_9 (required)- °	T_9 (generated)- °
-80	216.45	216.45
-50	218.75	218.64
-20	214.72	214.55
10	201.76	201.80
40	185.78	186.2
70	177.31	177.92

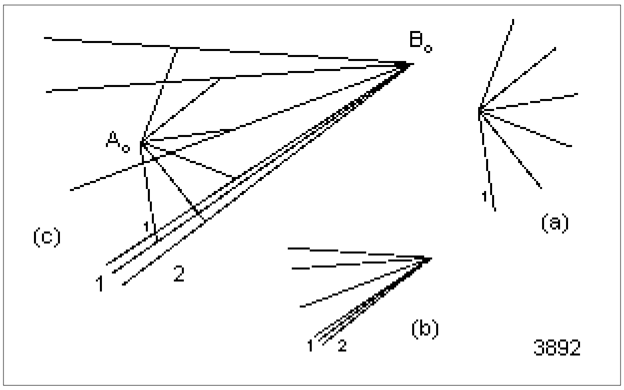

Figure 12: The procedure of synthesis for the first FISC.

Taking up the FISC B_oBC_oC next, where B_oB is now the crank, let it be given that the relationship of T_9 and T_2 (Figure 13) is given by Table 6. Figure 14 presents the design procedure whereby it is determined that C_oB_o=14.78, $C_oC \geq$10.13 units, and T_6=40.53.

The synthesis of slider crank mechanism C_oCD (Figure 15) depends on the data provided by Tables 1 and 6, as outlined in Table 7. Letting the length of the connecting rod CD be equal to 15 units, and following the design procedure outlined in Figure 16 we find that l_1=9.183 and C_oC=12.317 units.

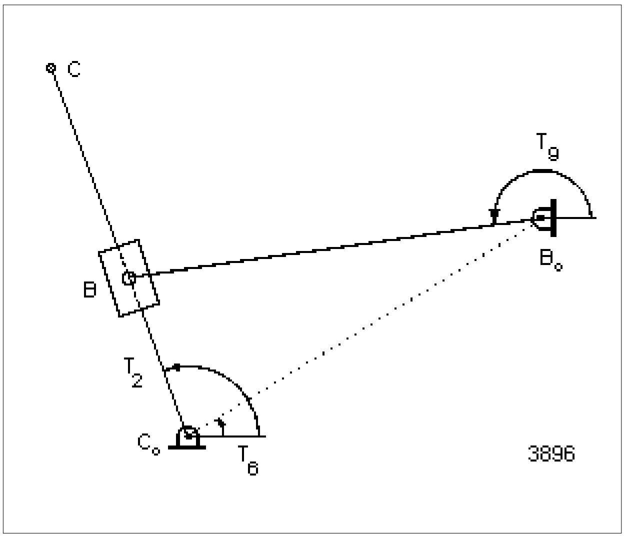

Figure 13: The secondFISC of the hack-saw.

Table 6: Data for the FISC B_oBC_oC.

T_9- °	T_2 (required)- °	T_2 (generated)- °
216.45	58.67	59.00
218.64	48.63	50.18
214.55	66.28	65.82
201.80	91.73	90.55
186.22	96.64	96.36
177.92	95.83	95.89

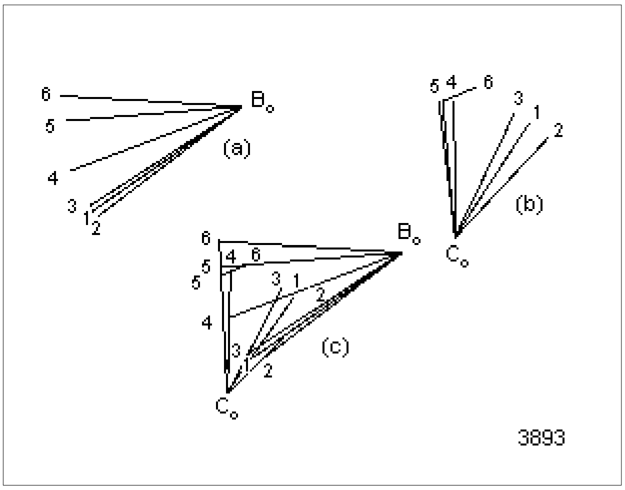

Figure 14: The procedure of synthesis for the second FISC.

The mechanism that resulted from the current synthesis is shown in Figure 17. The output generated by this eight-bar linkage is summarized in Table 7.

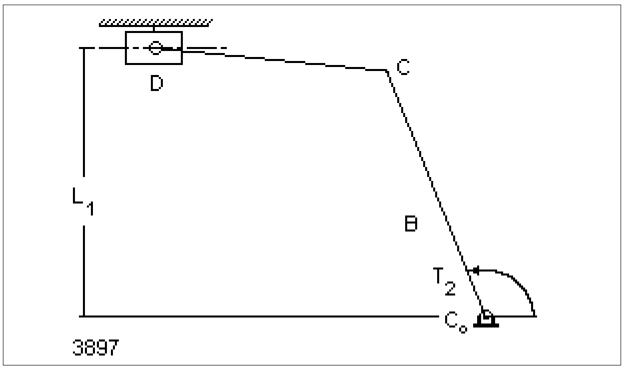

Figure 15: The slider-crank mechanism of the hack-saw.

Table 7: Data for slider-crank mechanism C_oCD.

T_7	T_2	x_D (required)	x_D (generated)
-80	59.00	-8.42	-8.59
-50	50.18	-6.79	-7.11
-20	65.82	-9.74	-9.81
10	90.55	-14.98	-14.78
40	96.36	-16.28	-16.08
70	95.89	-16.18	-15.95

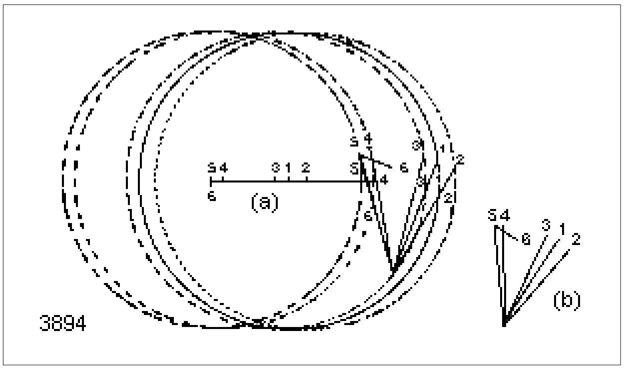

Figure 16: The procedure of synthesis for slider-crank mechanism of the hack-saw.

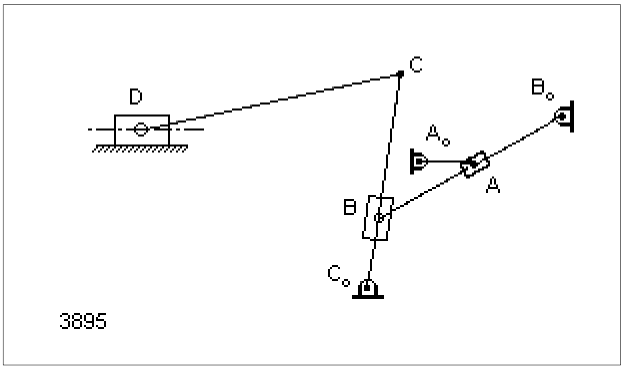

Figure 17: The resulting hack-saw.

CONCLUSIONS

The two-handled blocking method introduced here possesses the potential to become a powerful technique for the computer-aided graphical design of mechanisms. The method allows the rapid determination of linkage dimensions. Powerful tools of modern design packages such as zoom and intersect are effectively used to achieve highly accurate designs. One outstanding feature of the approach is that the designer is able to synthesize for input-output coordination without losing sight of the physical situation. The results are relatively accurate, the resulting coordination errors beign generally below 3% of the range.

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