2006-192: SYNTHESIS OF PLANAR MECHANISMS USING A CONSTRAINT-BASED DESIGN TOOL

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Synthesis of Planar Mechanisms Using a Constraint-Based Design Tool

Abstract

This paper discusses the use of a constraint-based design tool to design planar mechanisms. The technique has been developed for the synthesis of four-bar mechanisms and other more complex mechanisms based on the graphical approach. The constraint network provided by the 3D CAD software is used to impose relations between different members in a mechanism. In addition, the dimension animation is used to animate the skeleton form of a mechanism to study the motion. The technique developed in this study, which was proven effective in a senior-level class, will enable a designer to tackle the synthesis of planar mechanisms more quickly and accurately.

Introduction

A mechanism is a combination of two or more machine parts such as linkages, cams, and gears, which function together to perform a specific motion[1, 2]. A machine usually consists of one or more mechanisms, which must transmit and convert energy into work. Since the majority of common mechanisms are planar mechanisms that have parts moving in parallel planes[3], the focus of this study is primarily on planar mechanisms. Nowadays, 3D CAD software packages are becoming an integrated part of the engineering world as the computer technology becomes more sophisticated [4, 5]. They are widely used to perform design and engineering analysis based on solid model data[6]. With such a design tool, the synthesis of mechanisms can be quickly and accurately achieved using proper constraints provided by the software.

The constraints utilized in this study include two different groups: geometric and dimensional. The geometric constraints include those of coincidence, parallelism, perpendicularity, and location in space; the dimensional constraints include both linear and angular dimensions. With a constraint-based design tool, a designer can examine different situations quickly without the need to manually rework the graphical construction. A large number of design revisions can be made, because it's easy to change a few dimensions and watch others change accordingly. In addition, one of the applied dimensional constraints can be set as the controlled factor to animate the mechanism using a dimension animation function provided by the software[7]. Thus, it's easy to observe the motion of one member relative to others and their interference. A similar application of a constraint-based design tool had been proven effective in dealing with velocity and acceleration analysis of mechanisms[8].

The purpose of this study is to develop a constraint-based technique for the synthesis of planar mechanisms. All the synthesis in this study was completed utilizing I-DEAS on the Unix-based Sun workstation. However, the synthesis can be as effective and efficient using any 3D CAD software such as Mechanical Desktop, Pro-Engineer, Solidworks or Unigraphics on a PC, as long as it is constraint-based. In an engineering technology program that incorporates a constraint-based design tool like I-DEAS, students can learn the technique without difficulty. This technique was introduced to a computer-aided design class at Central Michigan University. Students learned to deal with the synthesis of a number of planar mechanisms using I-DEAS.

These mechanisms include two four-bars that include a slider-crank mechanism and a crank-rocker mechanism, and a more complex six-bar crank-shaper mechanism.

The Technique and Its Applications

Synthesis of a Slider-Rocker Mechanism

The slider-crank mechanism illustrated in Figure 1 consists of a crank (O_2B), a connecting rod (BC), and a slider (C). The mechanism to be designed has a stroke of 120 millimeters and a time ratio of 1.4. The time ratio is defined as the ratio of time required for the slider to complete a forward stroke to that of a return stroke. If the motor driving the crank at the fixed pivot (O_2) rotates counter-clockwise at a constant speed, it would take more time for the slider to travel rightward (forward) than leftward (return).

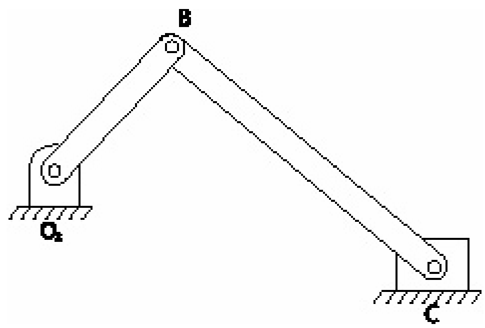
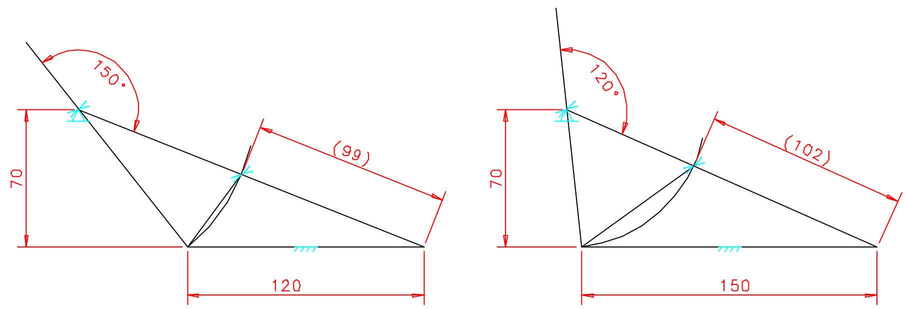


Figure 1

Figure 2a depicts the two extreme positions of the slider-crank mechanism in skeleton form. The two intersecting inclined lines represent the left and right extreme positions. The left extreme position occurs when the crank overlaps with the connecting rod. The right extreme position occurs when the crank is in line with the connecting rod. A geometric constraint of anchor that represents the fixed pivot is applied at their intersection. A horizontal ground is applied to the level line that represents range of the stroke. The arc is used to separate the segment that equals two times the length of the crank from the right extreme position using the left extreme position.

The angle of 150° is calculated based on $(360°-\theta)/\theta = 1.4$ of the time ratio. The vertical distance between the fixed pivot and the slider remains constant at 70 mm at all time. As soon as the dimensional constraints of 150° and 120 mm are applied, two times the length of the crank (99 mm in parenthesis) can be determined. Thus, the length of the crank is 49.5 mm, and the length of the connecting rod can then be made available based on this information.

The advantage of using a constraint-based design tool is that it permits the user to examine different situations quickly without the need to manually rework the drawings. For instance, in Figure 2b, the dimension of 99 mm would automatically change to 102 mm the moment the stroke is revised to 150 mm and the time ratio is revised to 2.0 (implies θ is changed from 150° to 120°). It is easy to see that a design revision can be as swift as the response of a CAD command.



(a) **(b)**

Figure 2

Synthesis of a Crank-Rocker Mechanism
Another four-bar mechanism is illustrated in Figure 3. The crank-rocker mechanism consists of a crank (O_2B), a connecting rod (BC), and an oscillating arm (O_4C). The arm oscillates when the crank rotates 360°. The length of the arm is100 mm and the horizontal distance between the two fixed pivots (O_2O_4) is 160 mm. The mechanism to be designed has a time ratio of 1.16, an oscillating angle of 75° for the arm, and an angle of 40° from the left extreme position of the arm to the horizontal.

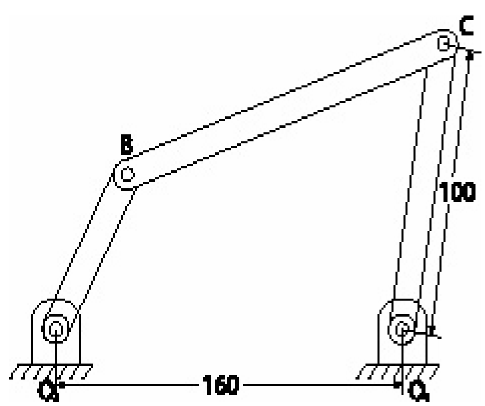
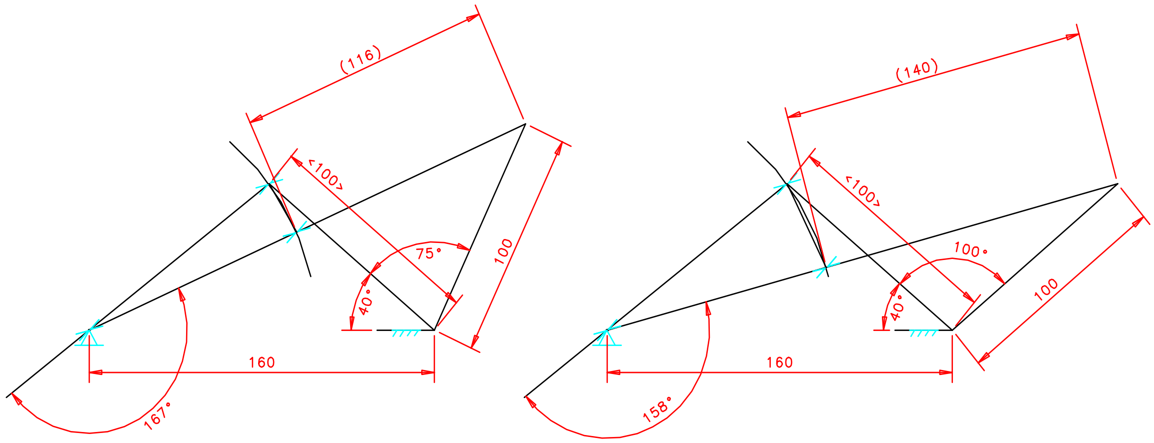


Figure 3

Figure 4a depicts the two extreme positions of the mechanism. Similar to the slider-crank mechanism, the extreme positions of a crank-rocker mechanism occur when the crank overlaps and is in line with the connecting rod. The first two inclined lines from the left hand side in Figure 4a represent the left and right extreme positions of the crank and the connecting rod. Just like the previous example, a geometric constraint of anchor that represents the fixed pivot is applied at their intersection. And an arc is used to divide the right extreme position, so the segment that equals two times the length of the crank can be determined.



(a) **(b)**

Figure 4

At the moment the given parameters of 160 mm, 100 mm, 75°, 40°, and 167° (based on time ratio of 1.16) are applied as dimensional constraints, the dimension of 116 mm (in parenthesis) that equals two times the length of the crank can be obtained. The length of the connecting rod is therefore from the anchor to the midpoint of 116 mm. Figure 2b shows the same advantage of examining different design versions quickly without the need to manually rework the drawings. In this figure the dimension of 116 mm would automatically change to 140 mm, as soon as the time ratio is revised from 1.16 to 1.28 (implies θ is changed from 167° to 158°) and the oscillating angle of the arm is revised from 75° to 100°.

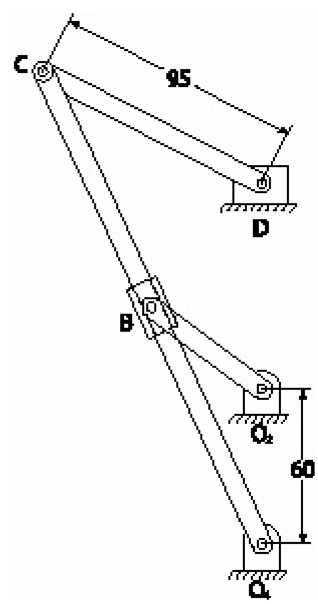
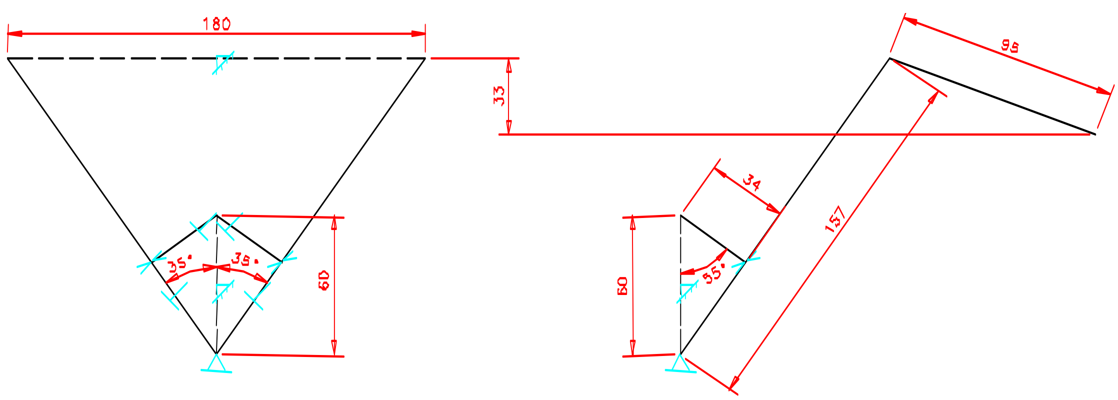


Figure 5

Synthesis of a Crank-Shaper Mechanism

Figure 5 displays a crank-shaper mechanism that consists of a crank (O_2B), an oscillating arm (O_4C), a collar (B), and a slider (D). The oscillating arm slides against the collar as it rotates with the crank. The distance between the two fixed pivots (O_2O_4) is 60 mm. The length of the connecting rod can be any convenient length (95 mm in this case). The mechanism to be designed has a stroke of 180 millimeters for the slider and a time ratio of 2.27.

Figure 6a exhibits the two extreme positions of the crank-shaper mechanism. Each of the left and right extreme positions occurs when the crank is perpendicular to the oscillating arm. A perpendicular constraint is applied to force this relationship. The two fixed pivots are connected with a dotted vertical line, and the two extreme positions of point C are connected with a dotted horizontal line that is the same as the stroke of the slider. Once the dimensional constraints of 60 mm, 180 mm, and 55° (based on the time ratio of 2.27) are in place, the dimension of 34 mm and 157 mm that represent the lengths of the crank and the oscillating arm, respectively, can be obtained as demonstrated in Figure 6b. The dimensional constraint of 55° in Figure 6b is identical to that of 35° in Figure 6a, because one is the complement of the other. The dimensional constraint of 33 mm, which is arbitrarily selected, doesn't affect the design outcome. Just as proven in the previous examples, the design revision of this more complex mechanism can also be swiftly achieved with the use of proper constraints.



(a) **(b)**

Figure 6

Dimension Animation

One other major advantage of using a constraint-based design tool for synthesis is that the motion of the mechanism can be easily studied using the CAD command of "drag". For instance, the position of the oscillating arm and connecting rod can be determined as soon as the crank is rotated (dragged) to a new position. With the similar idea, the animation of the mechanism may be carried out using the CAD command 'dimension animation'. Figure 7 shows such an example. With the angular dimension between the crank and the dotted vertical line (55^{o}) as the controlled parameter, the crank will rotate completely around the fixed pivot if its range is set between zero and 360° as one of the entries in the dimension animation window.

Other entries include speed and number of cycles. Figure 7 shows dimension animation at work. It portrays how different members of the mechanism react to the motion of the crank.

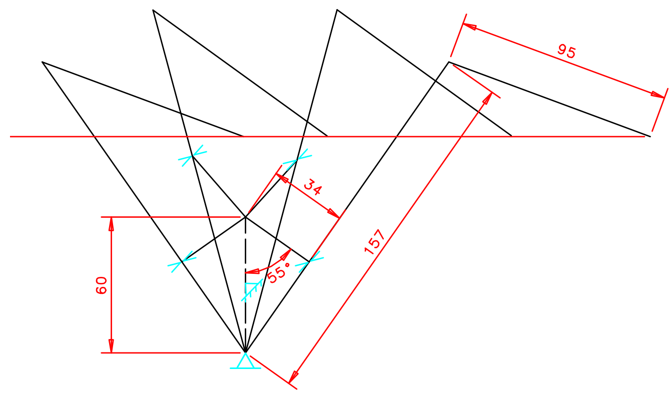


Figure 7

Conclusion

With the use of a constraint-based design tool, it saves a tremendous amount of time by eliminating laborious manual construction required for the traditional graphical approach. The user can examine different situations quickly and deal with as many design revisions as necessary. This is because it's easy to change design specifications and watch the required conditions change accordingly. Students became very appreciative when they realized how much time could be saved using this technique with a design tool like I-DEAS. Although I-DEAS and other similar constraint-based design tools were developed for the application in solid modeling, they have been proven to be very useful in synthesis of planar mechanisms in this study. This approach can be considered as a preliminary study, prior to a more thorough investigation of mechanism design in a solid model provided by the very same software.

Bibliography

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