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A CASE OF SLIDER-CRANK MECHANISM SYNTHESIS

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ABSTRACT
A graphical synthesis procedure is developed for a slider-crank mechanism, in which end positions of the slider and rotation angle of floating link are specified data. The procedure is based on well known relative pole graphical method, that is somewhat changed to adapt to specified data. Application of developed procedure shows that there are numerous solutions that fulfils the main task, but encounters various functional problems. Change of movement direction of slider and floating link, existing of singular points, minor transmission angles that points out to inadequate efficiency are some of them. There is also a difference between cases where slider is an input or output link. Some of these problems are analyzed and additional phases are added to the procedure to eliminate solutions that are not satisfactory.
The procedure has all the advantages of a graphical method: it is simple, obvious and can be done without any special calculations. Obtained picture of the solution can be without difficulties subjected to various constructive limitations, which are not so easily implemented in numerical methods. All of that recommends developed procedure as a satisfactory design tool.
keywords: slider-crank mechanism, synthesis, graphical

1. INTRODUCTION

When speaking about mechanism synthesis, one often assumes a problem where certain point or link of the mechanism has to be guided through numerous prescribed positions. A number of analytical and numerical methods are developed to solve this problem. In a design process, however, an engineer often encounters another problem. Only end points of the movement are prescribed, and there are no special requirements for its parameters, as long as it is smooth and flawless. On the other hand, existing of multiple solutions for the main request means that there exists a possibility to optimize the design by incorporating some other functional, efficiency or dynamical constraints.

Graphical methods of synthesis, although generally regarded as obsolete, can offer an advantage of a clear, obvious, easily understand solution that can be quickly subjected to further examination. This is particularly true in case of simpler problems, where synthesis procedure can be easily conducted using the same computer hardware that is used for designing, without developing analytical procedures.

In a design process for a new manipulation device, we encountered a problem of a slider-crank synthesis. Although it is one of common, well studied mechanism, a synthesis procedure depends on specified data. In this case, data were end positions of the slider and rotation angle of floating link, which differs from usual analyzed problems.

This problem looks suitable for graphical solution, so, in order to supply the designer with useful graphical synthesis tool, this synthesis procedure is developed. The procedure has all the advantages of a graphical method: it is simple, obvious and can be performed without any special calculations.

2. PROBLEM DESCRIPTION

One of common case studies in manipulation inventory is presented in Figure 1a. The manipulator 1 has to rotate through prescribed angle, while sliding on a stationary guide from position a to position b. This problem can be designed in several ways: separate input devices (motors) can be implemented for rotation and sliding, manipulator can be forced to follow stationary cam that will induce its rotation while sliding etc.

One of the solutions is presented in figure 1b. In this case, link 3, which is attached to a manipulator, is a floating link of slider-crank mechanism, which also consists of slider 4 and crank 2. Prescribed movement of the manipulator can be achieved by installing an input device either on crank or a slider.

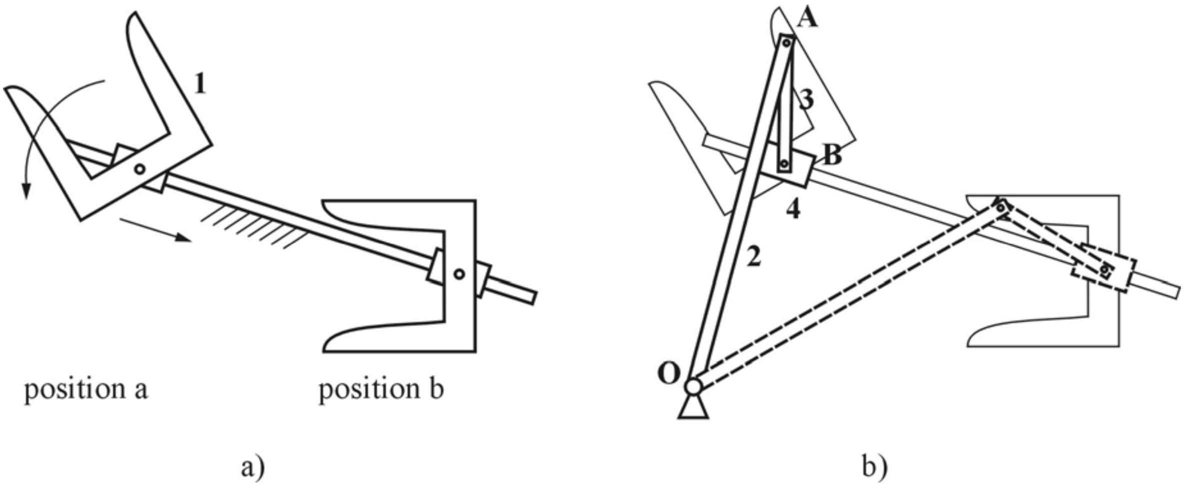

Figure 1a. General problem description; 1b. Problem solution with slider-crank mechanism

Presented solution has design advantages in regard to previous mentioned. It is cheaper because it those not need two input devices and do not impose additional weight on slider, and is much simpler than solution with cam. On the other hand, it has disadvantages in occupying additional space for the crank and in fact that sliding and rotating movements are not independent. However, for a particular case it might not present a problem, and therefore it is quite a favorable solution.

3. GRAPHICAL SINTHESIS

3.1 General disposition of the solution

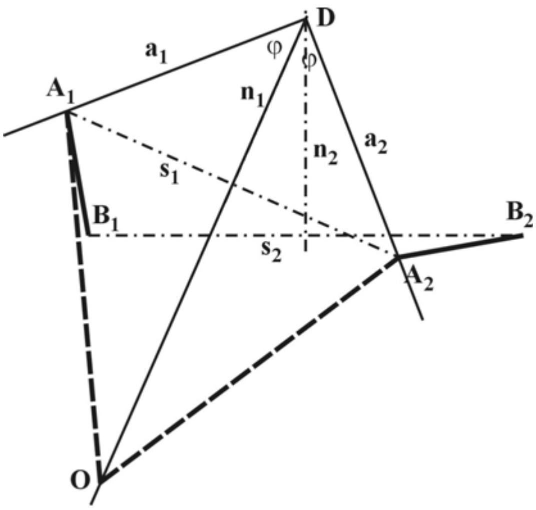

Figure 2. General disposition

Figure 2 shows general disposition of graphical synthesis for slider-crank mechanism in two prescribed positions. Points A_1, B_1, A_2 and B_2 presents first and last positions of points A and B – endpoints of floating link 3. They define lines s_1 and s_2. Their axes of symmetry, n_1 and n_2 respectively, define point D. Point O, fixed pivot of the crank OA (link 2) is also positioned on line n_1. Points A_1 and A_2, as well as all other possible solutions for the end of link 3 are positioned at lines a_1 and a_2. Those lines start at D and form angle $\pm\varphi$ with n_1.

It is important to notice that point D has unique position, depending only of link 3 angle on rotation - 2φ and sliding movement – s_2 and not on the other parameters of the mechanism.

3.2. Synthesis procedures

Synthesis procedures depend on prescribed data. As mentioned before, functional demands define angle of rotation of the manipulator - 2φ and its sliding movement – s_2. In this way, number of solutions is infinite and some other parameters must also be adopted. Looking from the designer's point of view, it is logical to adopt: position of fixed pivot of the crank (link 2), length of the crank, and position of joints A and B on the manipulator. Any of these parameters can be adopted according to specific demands of the design. Mathematically, we can define following parameters (see Fig. 2):

- position (initial) of the link 3 (A_1 B_1) – angle α
- length of link 3 – L_3
- position of point O
- length of link 2 – L_2

Analysis of synthesis procedures for different specified data leads to following conclusions:

Specified position of point O

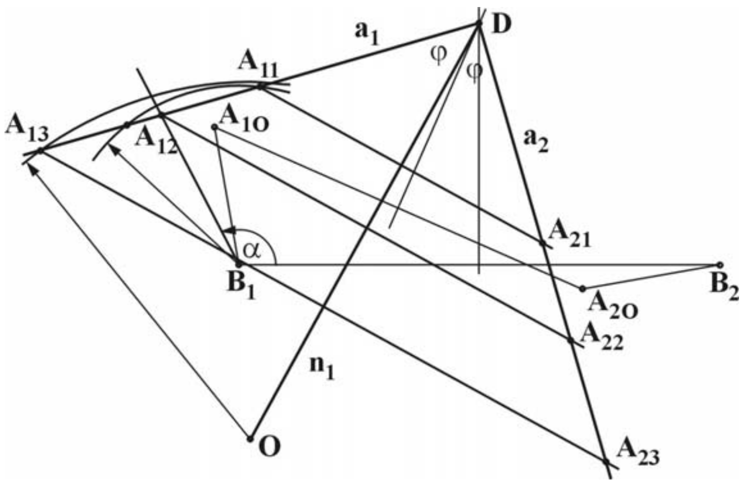

Figure 3. Synthesis procedure in case of specified point O

In this case, presented on figure 3, it is possible to find point D according to arbitrary data for link 3 (assumed A_{10} and A_{20}). Since the position of point O is known, line n_1 can be drawn. Constructing angles $\pm\ \varphi$ according to n_1 at point D, lines a_1 and a_2 can be drawn. Those lines are loci of all points A_1 and A_2, respectively. In this way, we have a possibility to easily adopt point A_1 according to other requirements (that will be discussed later). According to A_1, A_2 can be easily constructed, drawing s_1 that is perpendicular to n_1.

If we adopt any other parameter beside point O, a possibility for optimization no longer exists. If angle α is adopted, unique solution for A_1, denoted A_{12} is found at intersection of line a_1 and line with angle α to slider guide (B_1B_2). If length L_3 is adopted, there exist two solutions, at the intersection of a_1 and circular arc of radius L_3 constructed from B_1. One of solutions is denoted A_{11}. If length L_2 is adopted, there exists two solutions, at the intersection of a_1 and circular arc of radius L_2 constructed from O. One of solutions is denoted A_{13}. In these cases, it is only possible to check the solution according to additional requirements.

Nonspecified position of point O

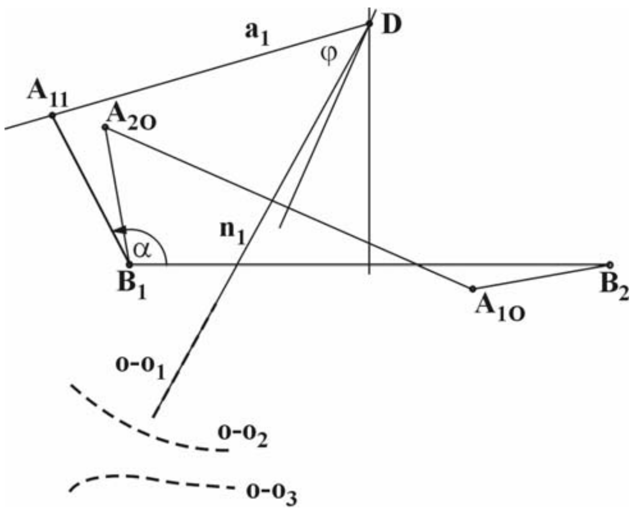

Figure 4. Synthesis procedure in case of nonspecified point O

In this case, it is necessary to specify two of remaining three parameters. The easiest way is to specify positions of joints – angle α and length L_3 which means that position of A_1 (denoted A_{11}) is known. After constructing point D, in the way presented before, it is easy to draw a_1, connecting D and A_{11}. Upon it, line n_1 is drawn, with angle φ between a_1 and n_1. Line n_1 is the locus of points O (denoted o-o_1), so it is easily possible to perform optimization and choose point O according to additional requirements.

In other two cases, when one of parameters for link 3 (L_3 or α) and length L_2 is specified, situation is somewhat more complicated. In these cases, it is necessary to perform numerical or graphical calculation in which, specifying different values for remaining link 3 parameter (α or L_3), different solutions for A_1 is obtained. Starting with particular A_1, respective A_2 is constructed. Respective O is found as intersection of circular arcs with radius L_2 drawn from A_1 and A_2 (not presented on fig. 4). In this way, a curve that presents the locus of points O is found (general appearance of curves in two cases is presented on fig. 4 and denoted o-o_2 and o-o_3). Solution of point O should be chosen from these curves. As construction of these curves is not an easy task, it is apparently more complicated problem, not suitable for simple design purposes, and should be avoided if possible.

4. ADDITIONAL REQUIREMENTS

Described synthesis procedures provide a solution that assures positioning of the manipulator in two prescribed positions. But it is not enough for proper functioning of the manipulation system. There are additional requirements that can be grouped in two batches: functional and efficiency.

4.1 Functional requirements

Two additional functional requirements are

- Rotation direction of the manipulator must not be changed during the movement.
- Sliding direction of the manipulator must not be changed during the movement.

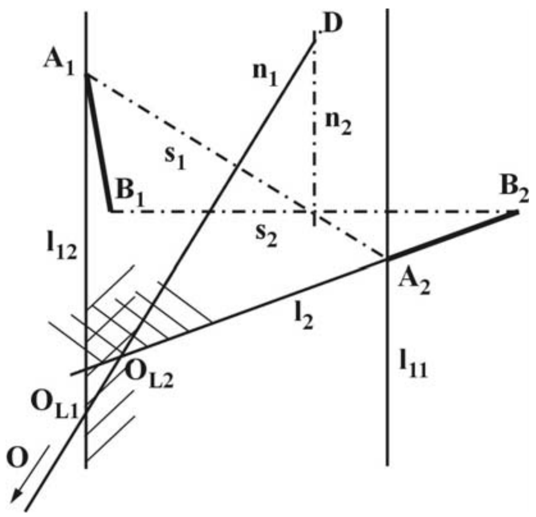

Figure 5. Limiting positions of point O

Implementation rules of these requirements can be found performing instant centers analysis [1]. Results of this analysis show that the manipulator rotation will change the direction when crank (link 2) reaches the position perpendicular to the guide. It is the case that we should avoid. In order to do so, as presented on fig. 5, two lines – l_{11} and l_{12} are drawn from points A_1 and A_2, perpendicular to line s_2. Position of point O must not be in the region between these two lines (one boundary position is denoted O_{L1}).

Also, results of this analysis show that the manipulator sliding will change the direction when crank (link 2) reaches the position coaxial with the floating link (link 3). In order to avoid this, as presented on fig. 5, a line – l_2 is drawn coaxial with A_2B_2. Intersection of l_2 and n_1 is boundary position of point O (denoted O_{L2}). Distance of point O from the point D must be longer or equal to DO_{L2}.

Adopted position of point O must fulfill both mentioned requirements.

4.2 Efficiency requirements

Synthesized mechanism must also have sufficient efficiency to avoid great values of reaction forces at joints and required input power. In order to do so, we must perform analysis of transmission angles and mechanical advantage [1]. This analysis will also give some additional constraints, but will not be shown in this paper. Let it only be mentioned that these results depend on adopted input motion. Namely, the same function can be performed either by driving the slider or the crank.

5. CONCLUSION

In this paper, a graphical procedure is presented, that is developed for synthesis of slider-crank mechanism with specific task, namely, when angular displacement of the floating link and displacement of the slider are specified. A procedure is suitable for design purposes. It is simple, obvious and can easily be subjected to design limitations. It does not require special software or hardware assets. Special attention is paid to different additional specified data, and to constraints raised upon satisfactory functioning of the mechanism.

6. REFERENCES

[1] Norton, R.: Design of machinery, McGraw-Hill Inc., 1992