

# The Study Of Five-Bar Mechanism With Variable Topology

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## ABSTRACT

A study of complex number method of synthesis of a planar 5-bar mechanism with variable topology for motion, path (with prescribe timings) and function generating tasks is made. The tasks in Phase-I and II may be same or different. The 4-bar portions of Phase-I and II may be crank-type or double rocker type. The method reduces the job of synthesizing 5-bar mechanism of two degrees of freedom to designing a 4-bar mechanism with single degree of freedom. It is a simple method and has many advantages.

## 1. INTRODUCTION

A variable topology mechanism is a mechanism operating in two or more phases. In each phase, a link adjacent to the fixed link of the mechanism is also fixed temporarily and the remaining portion acts like a mechanism with single degree of freedom. In the next phase, the temporarily fixed link of first phase is released to move and another link adjacent to the fixed link of the mechanism is fixed temporarily and the remaining portion acts like a mechanism with single degree of freedom [1].

A planar five-bar linkage with variable topology  $O_aABCO_c$  is shown in Fig.1. Phase-I and II are shown in (Fig.2) and (Fig.3) respectively. In Phase-I, the link  $CO_c$  is temporarily fixed. So the linkage becomes a four bar mechanism,  $O_aA_1B_1C$ . Now  $O_aA_1$  is the input link,  $B_1C$  is the output link and  $A_1B_1$  is the coupler.  $O_aA_1B_1C$  &  $O_aA_2B_2C$  are the two positions of Phase-I. Note that C is a temporarily fixed pivot.

Once the mechanism  $O_aA_1B_1C$  has reached the prescribed position  $O_aA_2B_2C$ , the link  $CO_c$  is released to move and the link  $O_aA$  is fixed temporarily, thus switching on to the Phase-II. In phase-II,  $A_2B_2CO_c$  is again a four bar mechanism. link  $A_2B_2$  is input link. Link  $CO_c$  is output link, and  $BC$  is the coupler.  $A_2B_2CO_c$  & and  $A_2B_3C_3O_c$  are the two positions of Phase-II. Note that  $C$  is no more a fixed pivot whereas  $A_2$  is a temporarily fixed pivot.  $O_a$  and  $O_c$  are the permanently fixed pivots of five-bar mechanism. One may get different types of four-bar linkage mechanism in different phases depending upon the link being fixed temporarily and the link lengths.

## **2. LITERATURE SURVEY**

The following is an overview of the literature on the variable topology mechanism. Stanley Rose [2], Tsai [3] and Ting [4] dealt with the idea of variable topology mechanisms. Rawat [5] established a synthesis technique for a 5-bar variable topology mechanism operating in two phases. Joshi et al. [6] and Joshi [7] used the dyad synthesis of a 5-bar variable topology mechanism for circuit breaker applications. Balli and Chand dealt with synthesis of 5-bar variable topology function generator [8] and motion and path generator [9] with transmission angle control. Balli and Chand give 2FSP synthesis of 5-bar variable topology function generator [1] and motion and path generator with prescribed timings [10] for the motion between the two extreme positions. A general procedure to synthesize a defect-free 5-bar variable topology mechanism is suggested by Balli and Chand [11]. They suggested a method to synthesize a planar 5-bar mechanism of variable topology type free from order defect [12] and free from circuit defect [13]. Balli and Chand discussed in detail about the variable topology mechanisms in [14].

## **3. PROCEDURE OF FIVE-BAR VTM SYNTHESIS**

Following is the procedure of synthesis of 5-bar variable topology mechanism:

- i) To identify the link to be fixed temporarily and input link of mechanism in each phase of operation.
- ii) To recognize the type of four-bar portion of 5-bar mechanism in each phase

- iii) To write down the standard dyad equations for the motion between initial position and final position of Phase-I and Phase-II separately.
- iv) To identify the values to be specified, values to be chosen freely and the unknowns.
- v) To solve the equations of motion in each phase separately for the link lengths.
- vi) To retain the link lengths of Phase-I while solving the equations in Phase-II.
- vii) To find out the total number of solutions possible in all, by the method.

#### 4. EQUATIONS OF MOTION AND NUMBER OF SOLUTIONS

**Phase-I Synthesis:** Writing the dyad equation for function generation [15] (refer Fig.1),

$$Z_2(e^{i\phi^1}-1) + Z_3(e^{i\alpha^1}-1) = -Z_4(e^{i\phi^1}-1) \quad (1)$$

In case of motion and path generation (with prescribed timings), the right hand side of equation becomes the displacement of output link denoted by  $\delta_1$ .

**Phase-II Synthesis:** Writing the dyad equation for function generation [15] (refer Figs.2),

$$Z_5(e^{i\beta^2}-1) + Z_4 e^{i\phi^1}(e^{i\phi^2}-1) = -Z_3 e^{i\alpha^1}(e^{i\alpha^2}-1) \quad (2)$$

In case of motion and path generation (with prescribed timings), the right hand side of equation becomes the displacement of output link denoted by  $\delta_2$ .

Table-1 gives the summary of the Phase-I and II synthesis for various task combinations. If the task to be performed is function generation in Phase-I and any one of the tasks (function/path/motion generation) in Phase-II, the number of solutions will be  $\infty^4$ . If the task to be performed is motion generation in Phase-I and any one of the tasks (function/path/motion generation) in Phase-II, the number of solutions will be  $\infty^3$ . If the task to be performed is path generation (with prescribed timings) in Phase-I and any one of the tasks (function/path/motion generation) in Phase-II, the solutions will be  $\infty^2$ . Thus from Table-1 it is evident that the different task combinations and different types of 4-bar portions of variable topology mechanism in Phase I and II don't have any bearing on number of solutions. It is the number of positions of synthesis, which determines the number of solutions. However, when the conditions like motion between extreme positions or the motion between the dead center positions are laid down, the number of solutions vary because some of the angles are well defined at these positions. For

example, i/p angle in case of crank type mechanisms is zero or  $180^\circ$  at extreme positions [8, 9] and the transmission angle is equal to  $180^\circ$  in case the 4-bar portion (at its extreme position) of 5-bar variable topology mechanism is a double rocker [1,10].

### **5. AN UNIQUE, NON-ITERATIVE AND AN UNIFIED METHOD**

The method of variable topology mechanism synthesis makes use of complex number for the mathematical modeling and analysis. Thus, all the advantages and limitations of complex number mathematics have also crept into this synthesis method. It may be stated that it is a unique and non-iterative synthesis method that provides a unified approach for motion, path and function generations for 2 or more FSP, ISP and MSP synthesis of multi link mechanisms with two or more degrees of freedom acting in more than one phase.

### **6. ADVANTAGES OF THE 5-BAR VTM SYNTHESIS METHOD**

\* The mechanism may be designed for one task in one phase and for a different task in the other phase.

\* The method yields infinite solutions. To obtain practically useful mechanisms, it is necessary to prescribe limits on quantities like transmission angle [16] and max. to min. link length ratio. The condition such as equal deviation of transmission angle at two design positions from the ideal  $90^\circ$  may be used as one of the synthesis criteria. Then by determining the angle between the two specified positions of links yielding the optimum range of transmission angle of mechanism and solving the equations of displacement, one may get the optimum mechanism. The requirements like the tracing point or some link to be moved in a particular fashion (direction) reduce the solution space. If one link length is prescribed, the solution space is reduced by  $\infty^2$  solutions and if one angular motion of link is prescribed, the solution space is reduced by  $\infty$  solutions.

\*The variable topology mechanisms may prove to be more appropriate mechanisms to suit applications like pick and place, locking devices, circuit breakers and on-off switching mechanisms. These methods could be considered to simplify the synthesis process of multi-link, multi DOF mechanism operating in multi-phases which otherwise might be more complicated, laborious ones.

\* The authors have extended the technique of Sandor and Erdman [15] to identify optimal mechanisms in terms of limits on transmission angles [1,8-10]. The method reduces the job of synthesizing five-bar mechanism of two degrees of freedom to designing a four-bar mechanism with single degree of freedom in two phases.

## **7. LIMITATIONS OF THE 5-BAR VTM SYNTHESIS METHOD**

- The proposed method is applicable only to complex number approach.
- The mechanism synthesized by the method may suffer from order, branch, Grashof or circuit defects, which can be rectified separately.
- The method can't be adapted for more than five prescribed position synthesis.
- While solving the simultaneous equations, it is difficult to find good initial guesses for all possible solutions (free choices).

## **8. CONCLUSIONS**

The method reduces the synthesis of five-link, two degree of freedom mechanism to the synthesis of a 4-bar, single degree of freedom linkage mechanism in two phases. The method is simple and straightforward. The designer has an infinite number of possible solutions at his disposal (depending on free choice and combinations of types of mechanism). He can look up a number of solutions and decide upon a particular solution that suits the space or transmission angle requirements.

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