A Review on Mechanisms with Variable Topology (Revisiting the Variable Topology Mechanism)

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Abstract: Simple mechanisms are used for various machines to obtain the desired motions. If the link numbers and degrees of freedom go on increasing, then the synthesis is also becoming more and more complex. The synthesized mechanisms have some limitations in satisfying the required motions. For these purpose mechanisms having multi-degrees of freedom, adjustable mechanisms and mechanisms with variable topology need to be focused on. This paper is mainly focused on the review of available literature on variable topology mechanisms in general and solution rectification of mechanisms in particular.

Keywords: Synthesis of mechanisms, Variable Topology Mechanism, Solution Rectification

1. Introduction

Kinematics is that branch of the theory of machines which will be dealing with the creation, synthesis, and analysis of mechanisms. The mechanisms are the major considerations to build machines. Synthesis of mechanisms plays an important role in the mechanical design. The process of drawing and determining the degrees of freedom of mechanism is one of the important steps in both the kinematic synthesis and analysis process. In order to meet certain motion specifications, synthesis of the mechanism is an articulated system; which can be applicable for open and closed linkages [1,2].

In a dimensionally synthesized problem, the topology of a system has to be dimensioned for an order to its workspace to get the desired task. In the early years, the planar linkages were dimensionally synthesized using the Finite-position method [3] and more recently, kinematic equations [4] are used to formulating designing equations for the complex systems. But still, this has the limitations in the solution process. Type or structural synthesis [5,6,7,8] involves a systematic differentiation of linkage-type during the synthesis process (Graph theory is the main method used in many cases) [9,10].

Hong Sen Yan [11] and F.R.E Crossley [12] showed that by the graph theory applications, the topological characteristics of variable kinematic joints have appeared with the abilities of continuity, expansibility, reversibility (Martin and Alberto [13] includes Precision Position method also), variability of degrees of freedom [14], contractibility, and joint homomorphism.

Mechanisms having multiple topologies while in operation process [15,16] like push-button locking having variable passwords [17,18], metamorphic mechanisms [19], automatically clamping and sawing of steel mechanisms [20,21] are recognized as mechanisms with variable topologies (MVTs) [22] and their corresponding chains were called as variable chains.

2. Variable Topology Mechanism:
A variable topology mechanism is a mechanism operated with two or more phases based on the DOF of a mechanism. In every phase, the adjacent link with the fixed link of the mechanism is also fixed temporarily. And the remaining portion works as a mechanism having a single degree of freedom. In the next phase, the temporarily fixed link of the first phase is released to move and another link adjacent to the fixed link of the mechanism and follows the procedure as in the previous phase.

Methodology to be followed:

- **Topology modification in Phase-I:** During the First Phase, the adjacent link(s) to the permanently fixed link(s) are temporarily fixed so that the multi D.O.F of mechanism considered becomes a mechanism with single D.O.F.

- **Dimensional Synthesis in Phase-I:** The synthesis is to be carried out to determine link lengths.

- **Consideration of Subsequent Phases:** When the mechanism in the First Phase moves to the specified position and stops. The last position is to be considered as the start of the Second Phase or Subsequent phase.

- **Topology modification according to Phase-II/Subsequent Phase:** In this position, temporarily fixed links are released to move. However, other links which are adjacent to permanently fixed links in Phase-II are to be fixed temporarily according to prior investigation and inspection.

- **Dimensional Synthesis in Phase-II/Subsequent Phase:** Next, the mechanism is allowed to move and its synthesis is to be carried out for the determination of other link lengths.

- **Other Phases:** The number phases to be considered depends on its DOF. Hence the required number of Phases is suitable considered.

- **Consideration for other Phases of synthesis:** Further, it is to be noted that, the link lengths determined in Phase-I are retained in Phase-II and so on for other subsequent phases. Thus all link lengths of the mechanism are determined.

- **Hence for a given mechanism, Phases are determined according to Degree of Freedom. Then, the phase-wise synthesis will be carried out by forming a single D.O.F in each phase. Thus, the complex nature of mechanism is synthesized using the method of variable topology concept.

- **Solution Rectification and Defect Free Synthesis:** The synthesized mechanisms with variable topology are to be tested for various defects to get a defect-free mechanism/s

2.1 Literature Survey on Variable Topology Mechanisms

The analysis of mechanisms with variable topology mechanisms (VTM) is the major concern when synthesizing the topological variations of mechanisms. Of a few noteworthy concerns, structural decomposition and also homomorphism recognition were the two commanding issues for the analysis of VTMs. Chin-HsingKuo[23] presents a paper on Structure decay and Homomorphism recognition of Planar Variable Topology Mechanisms—the orderly computational methodology for the planar VTMs.

Balli and Chand have suggested a method for synthesizing the “Planar five-bar mechanism of variable topology type for motion in between the extreme positions”[24][25]; free of order defect [26,27]; and
seven-link VTM synthesis for motion in between the two dead-center positions [28]. The control of a transmission angle in between some particular range is also dealt with [29,30] and synthesis of the “Planar seven-link mechanism with variable topology” [31,32].

In these papers, the authors had developed an analytical procedure to establish links of a five-bar mechanism with variable topology. The main aim is to reduce a solution space without iterations. As a result, the time required for dimensional synthesis is also reduced.

Their investigation is also concerned with the development of analytical methods to determine the links of seven-bar variable topology mechanism and identification of possible combinations of different type’s linkages in two phases to reducing the solution space of the mechanism.

Daivagna and Balli were dealt with a “Synthesis of seven-bar mechanism using variable topology between two- dead-center positions” [32]; triad and dyad synthesis the seven-bar mechanism for function generation [33]; “FSP Synthesis of an off-set Five Bar-Slider Mechanism” includes with Variable Topology [34,35,36]; and Analytical study on variable topology mechanisms [37,38].

In these papers, the authors developed a method by writing the equations of motion with the application of dyadic complex number method and increase accuracy than graphical method [39] to synthesize a five-bar slider mechanism with variable topology. They also applied the five-bar slider mechanism with variable topology for the pick and place mechanism.

Further, they proposed an analytical method to synthesize a seven-bar slider mechanism with variable topology and dealt with tasks like path generation with prescribed timing and function generation. This method yields a simple and effective method to synthesize the mechanisms.

3. Solution Rectification:

The defects in the mechanisms may be identified as:

- Grashof’s (crank) defect [40]
- Branch defect (change point or dead center position defect) [41]
- order defect [42] (undesired occurrence in a sequence of several plane-positions of the solution)
- Circuit defect – If a linkage in a mechanism is not able to achieve all the positions, then it contains a circuit defect [43,44]. If the circuit defect presents, the mechanism cannot be achieved the desired motion. Because it will reach to a binding or lock-up position.

These defects are eliminated by the graphical methods in the ancient years. The main contribution to these techniques is by K. J. Waldron. In the year 1975 to 1977, he has proposed the graphical method to tackle the order [45] and Branch defect [46,47] of Burmester synthesizing mechanism for four finitely extreme positions. On applying a multi separated four-bar Burmester synthesis, branch defect and order defect can be eliminated on solution linkages.

In the year 1978, Waldron and Robert t. strongt [48]; improved solutions for the branch and order defects of Burmester linkage synthesis. A new technique is exhibited which resolve the problems associated with Waldron solution of the order problem by inspecting the image pole circles.

In 1988, S. Krishnamurty [49] eliminated the branching defects in planar multi-loop mechanisms. The technique comprises of three steps. Determining branching loops and sub-Jacobians of the branching loops of derivative matrices. This method requires the basic computational techniques and
effective utilization in the process of synthesis [50,51]. Later in the year 2015, Wen-Tzong Lee [52] introduced his work on Adjustable Planar Four-Bar Motion generation With Order, Branch, and Circuit defect Rectification [53].

Atul Bajpai and Steven Kramer [54] distinguish the “dyad assembly error” in the synthesis of planar mechanisms. Any single or multi DOF planar mechanism constituted by assembling of two or more dyads such that it operates smoothly over throughout range of the required motion.

In the year 1991-1995, T. R. Chase and Mirth [55, 56, 57] delivered another solution for order rectification issue by the driving dyad of planar mechanisms is exhibited. A new technique with a complex number is approached to yields the sections of Burmester curves where all four precision positions are achieved by a driving link in sequence.

Hwang and S. Bawab [58], Rectified the Synthesis of Six-Bar mechanisms Four-Position Motion Generation with Well Defined Transmission Angles. This paper represents a new system where rectification synthesis with any six-bar linkages can be achieved if the transmission angle is well defined. The new strategy eliminates the circuit defect by considering the transmission angle of the driver link.

J. C. Chuang and Pierre M. Larochelle [59] approaches a new method for Circuit and Branch Rectification of the Spatial 4C Mechanism with 2DOF kinematically closed-chains. This methodology will eliminate circuit and branch defects in motion generation tasks.

4. Conclusion:

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 reviews of papers reveal that the Variable Topology Mechanism is applied to the higher degrees of freedom mechanisms to obtain the desired motion between the links. It is also evident that there is a need for the solution rectification of these mechanisms which provides defect-free mechanisms. This work of solution rectification may be extended to the mechanisms with multi-degree of freedom with higher & lower pairs.

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