STRUCTURAL ANALYSIS AND SYNTHESIS OF A CLASS OF 2-DOF AND 3-DOF PLANAR PARALLEL ROBOTS WITH IDENTICAL LIMB STRUCTURES

PHÂN TÍCH VÀ TỔNG HỢP CẤU TRÚC RÔBỐT SONG SONG ĐỐI XỨNG 2 VÀ 3 BẬC TỰ DO PHẲNG

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ABSTRACT

Nowadays, with the development of mechanical engineering technologies in general and automation in particular, there is an increasing demand for finding various types and combination of mechanisms in machine design. This paper presents an analytical framework to analyze the relation between the mobility, the number of close loops of planar mechanisms and the structure e.g. the number of links and joints - of each close loop. A set of equations determining the structure of kinematic chains consisting of only links with Link-Value equals 2 or m is established based on the given degree of freedom (DOF) of the chains. The authors went further to synthesize structural variants of 2-DoF, 3-DoF planar parallel robot mechanisms with Identical Limb Structures by substitution and replacement position of full lower kinematic pairs from the original kinematic chains.

Key words: parallel robot, synthesis, kinematic structure

TÓM TẮT

Ngày nay, với sự phát triển của công nghệ đặc biệt là các thiết bị tự động, ngày càng đòi hỏi có nhiều nguyên lý, cơ cấu máy để phục vụ cho quá trình thiết kế. Nhằm phục vụ mục đích trên, trong bài báo này các tác giả trình bày, kết quả phân tích mối quan hệ giữa bậc tự do, số mạch vòng của cơ cấu phẳng với các phần tử (khâu, khớp) của chuỗi động học kín. Trên cơ sở đó tiến hành thiết lập hệ phương trình khâu khớp của chuỗi động học phẳng chỉ có khâu hạng m và hạng 2 đối xứng theo bậc tự do của chuỗi động. Từ đó đi đến tổng hợp các chuỗi động học gốc đối xứng 3 bậc tự do và 2 bậc tự do. Các cấu trúc robot song song phẳng đối xứng 2 và 3 bậc tự do được hình thành bằng cách biến đổi các khớp loại 5 từ các chuỗi động học gốc, nhằm tìm ra những cơ cấu có thể có từ chuỗi động được thiết kế từ hệ phương trình khâu, khớp đã thiết lập ban đầu.

I. INTRODUCTION

With the booming evolution of mechatronics and the strong demand from a wide range of industries, especially automation and mechanics, the last few decades have witnessed the increasing interest in robots in general and parallel robots in particular. As a direct result, a multitude of novel mechanisms have been researched, developed and proposed to achieve higher flexibility and to improve the effectiveness of machines with serial or parallel structures. In this paper, with analysis of the relation between the number of Degrees of Freedom (DoF) and the kinematical structure of mechanisms, the authors present a new approach to synthesize mechanisms with close-loop structures.

II. THE NUMBER OF DOF IN PLANAR MECHANISMS

As defined in [1], the number of DoF of a planar mechanism with respect to the fixed link when all links are disconnected is computed by:

$$W_0 = 3\left(\sum_{i=1}^{r} h_i - 1\right) \qquad (1)$$

The number of joints (J) in the mechanism is given by:

$$J = \frac{1}{2}\sum_{i=i}^{r} i h_i \qquad (2)$$

Moreover, the number of constraints (R_0) for all joints applied to unconnected links in the mechanism can be presented by:

$$R_0 = 3j - \sum_{i=1}^{j} a_i \qquad (3)$$

From (2) and (3), we have:

$$R_0 = \frac{3}{2}\sum_{i=1}^{j} ih_i - \sum_{i=1}^{j} a_i \qquad (4)$$

Finally, from (1) and (4), the number of DoF of the mechanism is given by:

$$F = W - R = \frac{3}{2}\sum_{i=1}^{r}(2-i)h_i + \sum_{i=1}^{j} a_i - 3 \qquad (5)$$

where :

+ h_i is the number of links with Link-Value equals i (e.g. link having i joints on it).

+ a_i is the relative DOF of the i^{th} joint connected between link i and link (i-1).

+ j is the number of joints in the mechanism.

Let f_u be the number of joints with u relative DoF, we have:

$$\sum_{i=1}^{j} a_i = \sum_{u=1}^{u} uf_u \qquad (6)$$

As it has already been known that a higher kinematic pair can be replaced by lower kinematic pairs (see e.g. [2], [3]), so we will only take mechanisms having merely lower kinematic pairs – also called LINKAGES (where all joints are either prismatic or rotational) as a considered object. We can then rewrite equation (6) as:

$$\sum_{i=1}^{j} a_i = \sum f_1 \qquad (7)$$

Subsitute (7) into (5), the number of DoF of a planar mechanism can be computed as:

$$F = \sum_{i=1}^{r}\frac{3}{2}(2-i)h_i + \sum f_1 - 3 \qquad (8)$$

Equation (8) is the equation for determining mobility of the planar mechanisms.

Example

Determine the number of DoF of *Watt's steam engine mechanism* in Figure 1

Putting $h_2 = 4$, $h_3 = 2$ and $f_1 = 7$ into equation (8) we will have:

$$F = \frac{3}{2}(2-2).4 + \frac{3}{2}(2-3).2 + 7 - 3 = 1$$

Reevaluating the result with Grubler-Kutzbach criterion:

F = 5.3 - 7.2 = 1

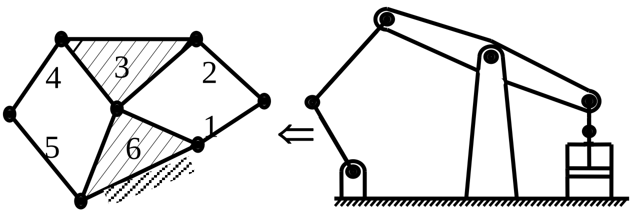


Fig. 1. Watt's Steam engine mechanism

III. RELATION BETWEEN LINKS, JOINT AND LIMBS OF PLANAR ROBOTS WITH INDENTICAL LIMB STRUCTURES

- Consider only mechanisms having links with Link-Value equals 2 or m.

- According to [8], a planar robot with identical limb structures is a mechanism in which the number of limbs equals to the number of DoF - and moreover, each limb has the same number, type and arrangement of links and joints. Therefore we can write:

m = F

$h_m = 2$

Substituting m and h_m into Equation (8) we obtain:

$$\sum f_1 = F + 3 - \sum 3(2-m) = 4F - 3 \qquad (9)$$

On the other hand, using Equation (2), the number of joints of the mechanism can be counted as:

$$j = h_2 + m = h_2 + F \qquad (10)$$

The number of links with Link-Value equals 2 can be computed from Equations (9) and (10):

$$h_2 = \sum f_1 - m = 3(F-1) \tag{11}$$

Hence we can formulate a set of equations:

$$\begin{cases} h_m = 2 \\ m = F \\ h_2 = 3(F-1) \\ j = h_2 + F \end{cases} \tag{12}$$

Finally, (12) is the set of equations determining the kinematic structure of the planar parallel robot with identical limb structure containing only links with Link-Value equals 2 or m.

IV. STRUCTURAL SYNTHESIS OF PARALLEL ROBOTS

Because of the close kinematic structure of parallel robots ⇒ there is no link with link-value = 1 (e.g. h_1 = 0). As a result, only links with Link-Value $m \geq 2$ are considered

4.1 1st case: m = 2 ⇒ F = 2

After putting m and F into (12), the set of equations can be written as:

$$\begin{cases} h_2 = 2 & \textit{(fixed \& moving platform)} \\ h_2 = 3(2-1) = 3 & \textit{(other links)} \\ j = 3 + 2 = 5 \end{cases}$$

In this case the parent mechanism is a pentagon in Figure 2.

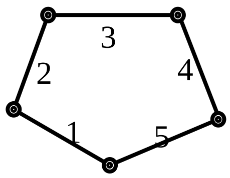


Fig 2. Parent Mechanism 2 Dof

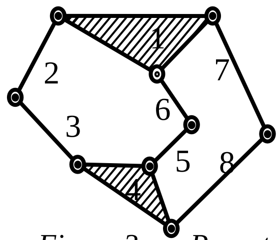
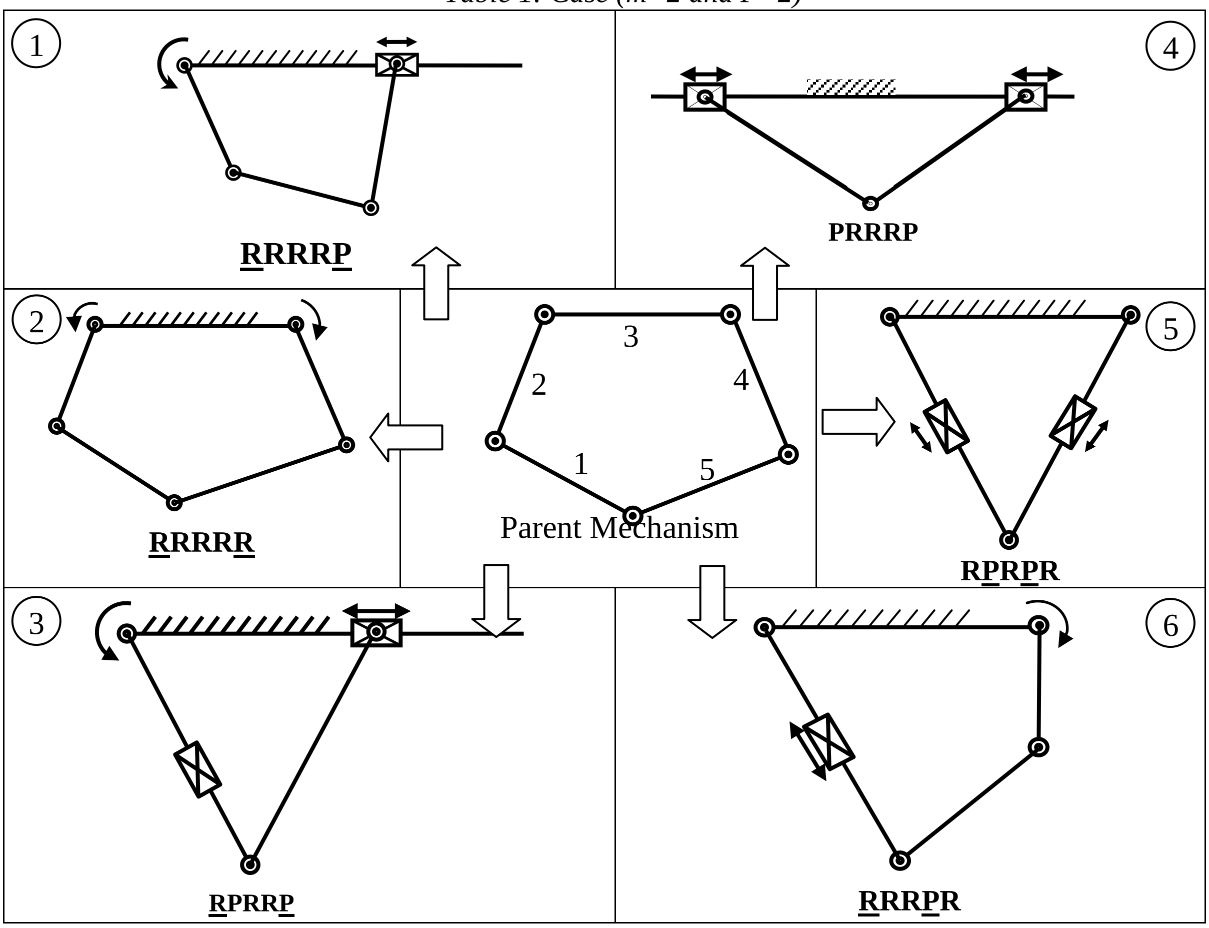


Fig 3. Parent Mechanism 3 Dof

Table 1: Case (m=2 and F=2)



We can therefore synthesize six variants (see table 1 bellow)

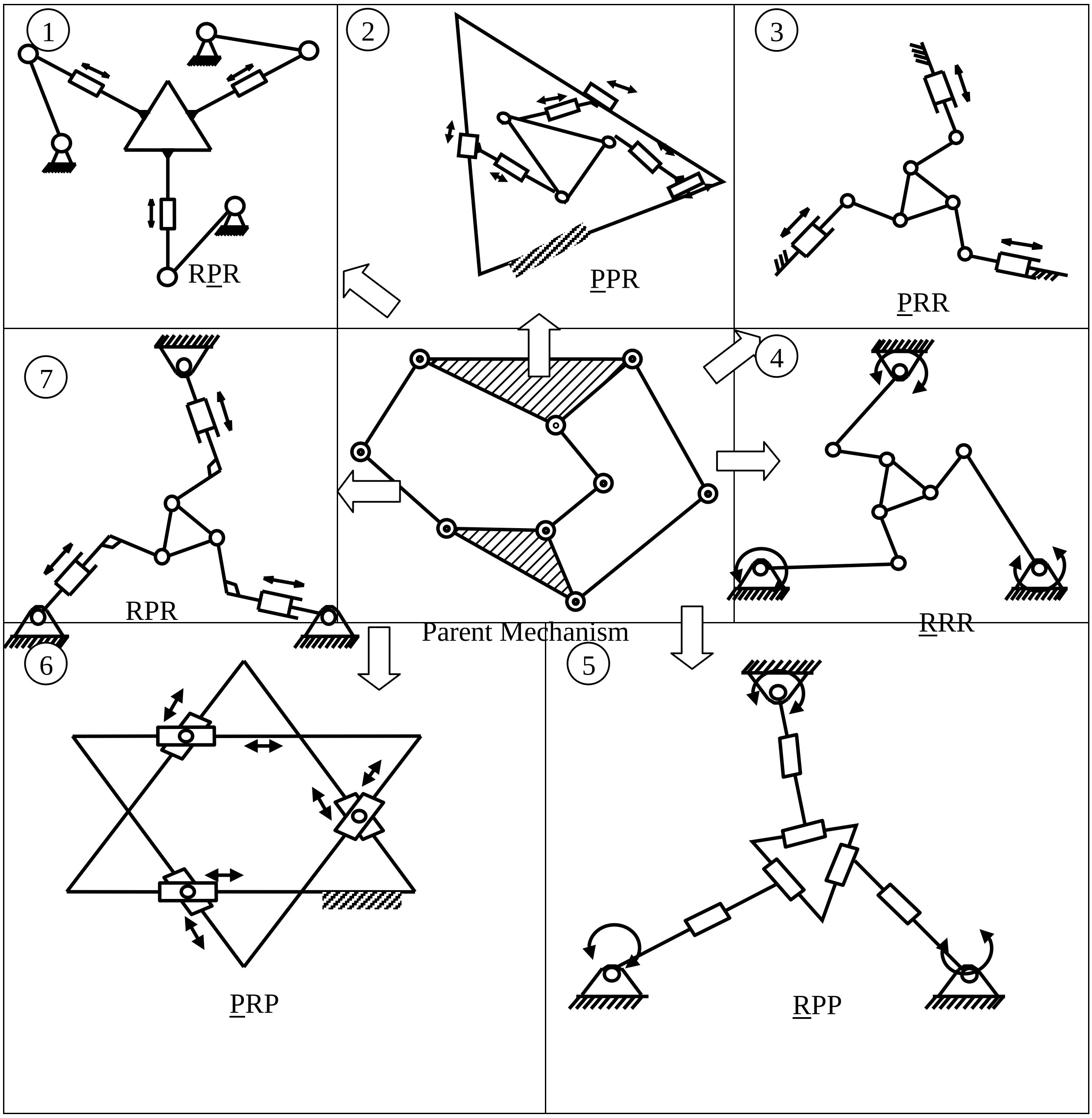
4.2. *2nd case:* m = 3 ⇒ F = 3

In this case, the set of equations (12) is written as follow:

$$\begin{cases} h_3 = 2 \\ h_2 = 3(3-1) = 6 \\ j = 6 + 3 + 9 \end{cases}$$

Therefore, we can obtain the parent mechanism shown in Figure 3. In the table bellow we can see seven variants of 3-DoF planar parallel robots obtained by re-arranging the location of each revolute and prismatic joints in the limbs (combination PPP is excluded as three joints are not independent) see table 2 bellow.

Table 2. Case m=3 and F=3



V. CONCLUSIONS

The paper presents a method using the number of joints, links and link-value to determine the mobility of robots in particular and of mechanisms in general. The new approach to synthesize structures of the planar parallel robot with identical limb structures is also presented. The results can be applied in researching, analyzing and synthesizing mechanisms for further design-machine proces.

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