Regenerating kinematic chains and its utilization in the innovative design for sofa bed

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Abstract. Much research on the mechanical design has been carried on. The paper is mainly based on Yan’s Creative Mechanism Design Methodology, in which the author carries out the design of the sofa bed, totally seven feasible structural schemes are obtained. In the process, some rules are brought in, and the original structure is changed for other structures with the same functions but different shapes. This paper provides the theoretical basis and reference data for the innovation of the sofa bed.

1. Introduction
In order to realize streamline and convenient sofa bed, sofa bed must be innovated.

Generally, it's not easy for the new structure to be invented. Much knowledge and experience is needed. However, the Yan’s Creative Mechanism Design Methodology makes the innovation process easily followed. The Yan’s Creative Mechanism Design Methodology is deduction with the same function by a primitive institution in accordance with a certain rule [1-3]. As a useful method for the mechanism design, the Yan’s Creative Mechanism Design Methodology has been widely used and developed in mechanical product process [4].

The innovative design process of the Yan’s Creative Mechanism Design Methodology is as shown in figure 1.

![Figure 1. The innovative design process of the Yan’s Creative Mechanism Design Methodology.](image)

2. Primitive organization and design constraint

2.1. Primitive organization
Sofa bed primal mechanism is as shown in figure 2. By the upper and sofa bed mechanism, structure diagram of the sofa bed is as shown in figure 3 [5].
The Mechanism characteristics are as follows:
(i) The total number of rods is 6. The total number of pairs is 7;
(ii) The total number of revolute pairs is 5(a, b, c, d, f). The total number of prismatic pairs is 2(e, g);
(iii) The degree of freedom of the mechanism is 1;
(iv) Include a fixed rod (member 1). A push rod (member 2).

2.2. Design constraints
According to the requirements of the movement and working characteristics of the sofa bed, design constraints are as follows:
(i) The number of rods $N$, the number of pairs $J$ and the degree of freedom $F$ remains the same;
(ii) There must be a rod as a rack;
(iii) There must be a rod as a crank;
(iv) There must be a rod as a slider.

3. Combine link rods

3.1. Principle of combining link rods
The degree of freedom of the link rods must be the same as the degree of freedom of the original mechanism, and should meet the following.

$$L_2 + L_3 + L_4 + \cdots + L_n = N \tag{1}$$

$$2L_2 + 3L_3 + 4L_4 + \cdots + nL_n = 2J \tag{2}$$

In these formulas: $N$ refers to the total number of link rods; $J$ refers to the total number of pairs.

The formula of degree of freedom:

$$F = 3(N-1) - 2J \tag{3}$$

Relations (1) and (2) are taken into the formula of degree of freedom. Get the following results:

$$F = L_2 - L_4 - 2L_5 - \cdots - (n-3)L_n - 3 \tag{4}$$

Formula(1) minus formula(4) to get the results:

$$L_2 + 2L_4 + 3L_5 + \cdots + (n-2)L_n = N - (F + 3) \tag{5}$$

3.2. Combine six-rods chain
In the six-rods chain, the value of $N$ is three, and the value of $J$ is seven. In order to meet formula (1) and (2), $n$ is less than five and the value of $F$ is one.

$$L_2 + L_3 + L_4 = N = 6 \tag{6}$$

$$L_2 + 2L_4 = N - (F + 3) = 2 \tag{7}$$
According to the formula (6) and (7), there are two schemes in total and shown in the figure 4 and figure 5.

The kinematic chain based on scheme 2, as shown in the figure 6.

4. The generalization

There are four principles for generalizations:
(i) All pairs need to be transformed into general pairs;
(ii) All components need to be converted into a general rod;
(iii) The attachment and adjacency of all components and pairs should be consistent with the original organization;
(iv) The degree of freedom should remain unchanged.

As shown in the figure 7, the sofa bed is transformed into a general chain of motion according to the below rules:
(i) The fixed rod (member 1) is generalized to three-rods (1);
(ii) The push rod (member 2) is generalized to two-rods (2);
(iii) The rotating rod (member 3) is generalized to two-rods (3);
(iv) The moving rod (member 4) is generalized to three-rods (4);
(v) The slider (member 5) is generalized to two-rods (5);
(vi) The Long rod (member 6) is generalized to two-rods (6).
5. Executable kinematic chains
The kinematic chain obtained in figure 7 is not the only proper kinematic chain with six-rods and seven-joints. There is another one chain for six-rods and seven joints as show in figure 8 after the number synthesis and type synthesis [6]. In this article, Yan’s permutation group theory is taken into the steps as an important part of graph theory [7-9].

6. Regenerate new structures
According to the design constraints known, the combined kinematic chains and the regenerated motion chains of the two kinds of six-rods mechanisms above are obtained [10-11].

(i) G is a fixed pole, C is a crank, and P is a slider;
(ii) One rod is designated as the fixed rod G, and the other is the crank C, and the crank C connect with the fixed rod G;
(iii) Designate a rod as a slider.

According to the motion characteristics of sofa bed, seven kinds of special kinematic chains can be satisfied with the constraint conditions as shown in figure 9. The final new mechanisms of sofa beds are shown in figure 10.

Figure 9. Seven kinds of special kinematic chains.

The corresponding workable actual mechanism motion diagram is shown in figure 10.

Figure 10. The corresponding workable actual mechanism motion.

7. Conclusions
The Yan’s Creative Mechanism Design Methodology is a systematized and theorized method. With the methodology, more and more new structures are produced, which is helpful in the industry. The methodology presented could be used for the creative design of all mechanisms, such as sofa bed above in the paper. In this paper, the methodology is used in the innovative of a sofa bed. After the steps such as generalization, executable kinematic chains and so on, the final 7 types of mechanisms are obtained that can meet the motion requirements of the sofa bed. In the actual design, the best scheme can be determined according to the requirements of the structure and precision.

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