Quality indices of forces transmission to planar six bar mechanisms

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Abstract. The paper represents an extension of researches in this field, started and published by authors many years ago. The central idea of these research series is notion of structural group, used in forces transmission description and also in singularities study. Thus, problems regarding forces transmission indices were presented until now referring to mechanisms containing usual structural groups: 0/2/2 (dyad type – in all their 5 aspects), 0/3/3 with revolute joints and 0/4/2 with revolute joints. For these structural groups were presented both theoretical basis and applications. Naturally, with this paper, we pass to a more complex mechanisms category – six bar planar chains Watt and Stephenson.

1. Introduction

Forces transmission quality in mechanisms is determined by reactions values in kinematic pairs. As reactions have more reduced values, with constant loads, it supposed a better quality of forces transmission. This affirmation justifies itself by fact that reactions influence directly on the friction forces, mechanical efficiency and kinematic pairs wear. Traditionally, index reflecting forces transmission quality is transmission (or pressure) angle [2 – 6]. Using transmission angle is however limited to four bar and slider-crank mechanisms [3 – 6] and attempts to extend it to six bar mechanisms [2], have not a logical support. In a series of previous papers [5 – 13], we proposed a new method to solve this problem, based on following ideas:

• Forces transmission indices are determined for each structural group and not for the mechanism as a whole.
• Forces transmission index, \( T \) defines with expression:

\[
T = \frac{D_L}{D_w},
\]

where \( D_L \) is absolute value of coefficients determinant, associated to the static analysis problem of the structural group, and \( D_w \) is a referential value, equals to its maximum value (if it is finite).

To assure a proper running of the mechanism, following condition must be fulfilled:

\[
T \geq T_a,
\]

where \( T_a \) is an admissible value of \( T \).
We show afterwards, how these indices are calculated for usual structural groups, aided by results from papers [5 – 13].

![Figure 1. Deviation angle (γ) for 0/2/2 structural group.](image)

In the case of 0/2/2 structural group with three revolute joints (RRR), (figure 1a), $T$ has expression:

\[
T = \sin \gamma,
\]

where $\gamma$ is the sharp angle between links $AB$ and $BC$, which we call deviation angle because it shows configuration deviation from the singular ones, when points $A, B, C$ are collinear, and $\gamma = 0$, $T = 0$. Relation between $T$ and $\gamma$ from figure 2, shows that in the singular positions neighbourhood their values are very close each other, so, inside this zone, $T \approx \gamma$. Nevertheless, limitation of the running domain can be done aided both parameters, $T$ or $\gamma$,

\[
T = \sin \gamma \geq \sin \gamma_s, \quad \gamma \geq \gamma_s.
\]
In the case of $RRT$ group (figure 1b), so observations made to $RRR$ group, as formulas (3) and (4), remain valid with specification that deviation angle $\gamma$ forms between link $AB$ and the perpendicular to sliding axe.

In the case of $RTR$ group (figure 1c), $D_s = d$, where $d$ is the distance between revolute joints $A$ and $B$. Because $d$ has not a finite maximum value, it is difficult to adopt a reference value $D_s$. Anyhow, limitation of the running domain can be done using relation:

$$d \geq d_s. \quad (5)$$

Representative mechanisms with four links, corresponding to the three structural groups are shown in figure 1d, e, f. It can notice that in cases of the four bar mechanism (figure 1d) and of the slider crank (figure 1d), deviation angles $\gamma$, defined before, are even well known transmission angles. A different situation occurs in the case of Whitworth quick return mechanism (figure 1f). This mechanism, although very simple and frequently used, is not treated in technical literature, under forces transmission aspect. Our conclusion, showing that limitative parameter is distance $d$, represents an element of novelty.

The $0/3/3$ structural group (figure 3a) characterises by fact that configuration and $T$ index depend on three independent parameters. This fact creates some difficulties regarding determining $T$ and adopting $T_r$. In papers [10, 12] we proposed a working procedure, consisting of followings: it determines the deviation angles $\gamma_1, \gamma_2, \gamma_3$ defined as in figure 3a.

![Figure 2. Relation between $T$ and $\gamma$.](image)

$$\gamma$$

![Figure 3. Deviation parameters of the $0/3/3$ a) and $0/4/2$ b) structural groups.](image)
These angles show configuration deviation about three singular positions, when bars $AE$, $BF$ and $CG$ are concurrent. Forces transmission quality is assured if following condition is respected:

$$\min\left(\gamma_1, \gamma_2, \gamma_3\right) \geq \gamma_w.$$  \hspace{1cm} (6)

Forces transmission at 0/4/2 structural group with revolute joints (figure 3b) was analyzed in paper [14], where we concluded that condition (2) is respected if

$$d_{am} \leq d \leq d_{ad}.$$ \hspace{1cm} (7)

where $d$ is the distance between exterior joints and $d_{am}$, $d_{ad}$ limit an admissible interval.

We mention that some authors define forces transmission index, otherwise [3, 4], but in this paper we refer only to it definition, tied to reaction values.

2. Planar mechanisms with six links

Naturally, next stage of analysis for quality of forces transmission consists in approaching more complex mechanisms – those ones with six links. For each treated mechanism we will decompose it in structural groups and then, we will indicate parameters – angle or length, which must respect conditions (4), (5), (6) or (7) according to those shown in previous paragraph. We will take into consideration the six bar linkages with revolute joints only and those ones with one prismatic joint only. We chose for these mechanisms because they are more frequently used, being well known that to prismatic joint, constructive and exploiting difficulties occur. In order to identify all previously indicated mechanisms, we considered Watt and Stephenson kinematic chains ($L = 1$ and $n = 6$), with revolute joints. We emphasized all variants of base (fixed link) and driving link choosing. Structural symmetry of Watt and Stephenson kinematic chains makes that a part from these variants lead to identical mechanisms, which must avoid. Results of this operation are shown in table 1. It can notice also, that functions inversion of base and driving link leads to mechanisms with the same group structure and which can be treated once (table 1). Finally we successively substituted each revolute joint by prismatic one, taking into account here too, avoiding identical mechanisms. Results of this study are done in figure 4, 5, 6, 7, 8, to which sliding pair is written down in the same way as substituted revolute joint. The obtained mechanisms are built so, that sliding pair axis to contain centre of a proximate revolute joint. Using this mode it obtains a larger running zone and also a smaller value of $T_w$ parameter [15].

| Table 1. Synoptic overview about Watt and Stephenson mechanisms variants. |
|-----------------------------|-----------------------------|-----------------------------|
| Kinematic chaine Watt       | Base | Driving link | Figure/number of mechanisms |
| Kinematic chaine Stephenson | Base | Driving link | Figure/number of mechanisms |

| Kinematic chaine Watt       | Base | Driving link | Figure/number of mechanisms |
|-----------------------------|------|--------------|-----------------------------|
| 1                           | 2    | 4            | Figure 4/7                  |
| 2                           | 3    | 1            | Figure 6/7                  |

| Kinematic chaine Stephenson | Base | Driving link | Figure/number of mechanisms |
|-----------------------------|------|--------------|-----------------------------|
| 1                           | 2    | 1            | Figure 7/7                  |
| 2                           | 3    | 2            | Figure 8a/1                 |
| 3                           | 4    |              | Figure 8b/1                 |
Watt Kinematic chain

1 – base, 2 – driving link

Figure 4. Variants of Watt kinematic chain, with 1- base and 2 – driving link.
Watt Kinematic chain

1 – base, 4 – driving link

Figure 5. Variants of Watt kinematic chain, with 1- base and 4 – driving link.
Watt Kinematic chain

2 - base, 3 – driving link

Figure 6. Variants of Watt kinematic chain, with 2- base and 3 – driving link.
Stephenson Kinematic chain

Figure 7. Variants of Stephenson kinematic chain, with 1- base and 2 – driving link.
3. Conclusions
Method to identify forces transmission indices, proposed by us and used in this paper, are simple, does not require computing procedures and allows approaching mechanisms of any complexity.
The performed in this paper study is useful for mechanisms designers because it indicates parameters which have to be controlled in order to obtain a favourable running, regarding forces transmission. Analysed mechanisms cover almost the whole scale of planar mechanisms which can be used in practice.

Figure 8. Variants of Stephenson kinematic chain, a) with 2 – base, 3 – driving link and b) with 3 – base, 4 – driving link.
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