Constructive Solution and the Kinetostatics of Moves Decoupling for an Orientation Robotomechanism

NICOLAE BERCAN\(^1\), VALENTIN PETRESCU\(^1\), RADU BERCAN\(^2\)
\(^1\)Faculty of Engineering Hermann Oberth
University Lucian Blaga of Sibiu
Str. Emil Cioran, Nr. 4, Sibiu
\(^2\) Faculty of Engineering in foreign languages
University POLITEHNICA of Bucharest
ROMANIA

Abstract – In this paper there is presented a constructive solution to a trimobil oriented robotomechanism that has the coupling grade equal to three, moved be tendons, with decoupling motions, proposed by the authors, for which it is provided the structural, cinematic and static analyse. It is presented a new variant of oriented robotomechanism, made of a proper orientation mechanism (A) and a decoupling mechanism (B) made itself of differential mechanisms and monomobile mechanisms with tendons.

The results obtained are useful to the inventors and designers who are working in the industrial robots’ area.

Key-Words: robotomechanism activated through wires, decoupling of the moves; coupling grade, differential mechanism with wires.

1 Introduction

The main purpose of this paper is to present a new way to decouple the moves of a robotomechanism, operated through wires. This thing is necessary, because the literature in the field of robotomechanisms operated through wires is relatively poor.

In this paper is presented the structural, cinematic and static analyse of a new three-mobile oriented robotomechanism, operated through wires, that has the coupling grade equal to three.

The objectives of this paper are:

a.) The establishing of the transmission functions for the moves, and the moments for the orientation mechanism;
b.) The establishing of the realization conditions for the mechanical decoupling;
c.) The establishing of the global functions for transmitting the speeds and the moments.

2 Notes used:

- \( M \) the mobility degree of the mechanisms
- \( M_1, M_2, \ldots \) the mobility degree of the component mechanisms
- \( L_C \) the number of the couplings between the mechanisms
- \( \omega_a \) the angle speed of an element “a” reported to the base
- \( i_{a,b} \) the transmission report from element “a” to element “b”, when the angle speed is \( \omega_a = 0 \);
- \( C \) the coupling degree of the moves;
- \( M_a \) the moment of the element “a”;

3 The structural characterization of the mechanism

The robotomechanism in this case is set out of two components: the mechanism of a proper orientation A, and the mechanism for decoupling B, represented in figure 1.

The robotomechanism of a proper orientation A, is set up through the aggregation of the mono-mobile units I = (0-1), II = (5-7), III = (4-6), IV = (8-9) and has the mobility degree

\[ M^A = M_1 + M_2 + M_3 + M_4 - L_C = 1 + 1 + 1 + 1 - 1 = 3, \]

where \( L_C^A = 1 \) represents the coupling (6-8).

The mechanism contains \( L = 6 \) exterior connections: three inputs (1,4 and 5) and three outputs (\( \alpha, \beta, \gamma \)).

Being a tri-mobile, it has three independent moves, \( (\omega_{\alpha}, \omega_{\beta}, \omega_{\gamma}) \) and for \( L - M = 6 - 3 = 3 \), three dependent moves \( (\omega_1, \omega_4, \omega_5) \), which are the transmission functions of the speeds in the direct kinematics of the mechanisms.

Therefore, the mechanism has:

\( L - M = 3 \) exterior moments (\( M_1, M_4, \) and \( M_5 \))
and three exterior moments dependent corresponding for 
\( M = 3 \), \( (M_\alpha, M_\beta, \text{ and } M_\gamma) \),
which represent the transmission functions of the moments.

The proposed mechanism has the coupling degree:
\[
C = C_\alpha + C_\beta + C_\gamma = (3-1) + (2-1) + (1-1) = 3
\]

This means that the move \( \alpha \) is coupled with \( \beta \) and \( \gamma \) and also the move \( \beta \) is coupled with \( \gamma \).

The mechanism for decoupling \( B \), contains too differential planetary units,
\[
V = (18-19-20-h_2), \text{ and } VI = (12-13-14-h_1),
\]
which are connected to each other and to the action engines a, b and c, through five mono-mobile mechanisms with wires:
\[
VII = (9-10), \text{ VIII } = (11-16), \text{ IX } = (7-21), \text{ X } = (8-15), \text{ and XI } = (17-22),
\]
being coupled between each other with \( L^c = 6 \) couplings:
\( (21-22), (15-16), (15-h_2), (17-18), (11-12), (10-h_1). \)

As a result, the decoupling mechanism has the mobility degree:
\[
M^B = M_V + M_{XI} - L_C = 9 - 6 = 3.
\]

Having \( M = 3 \) and \( L = 6 \) exterior connections (a, b, c, 7, 8, 9), the decoupling mechanism is characterized by
\[
M = 3 \text{ independent exterior moves } (\omega_a, \omega_b, \omega_c)
\]
and
\[
L - M = 6 - 3 = 3 \text{ dependent exterior moves } (\omega_7, \omega_8, \omega_9)
\]
which represent the transmission functions of the speeds in the case of the direct kinematics.

Implicit, the decoupling mechanism has:
\[
L - M = 3 \text{ independent moment } (M_7, M_8, M_9)
\]
and
\[
M = 3 \text{ dependent moments } (M_a, M_b, M_c)
\]
which designate the transmission functions of the moments.

4 The establishment of the transmission functions for the speeds and moments

For establishing the transmission functions for the speeds and for the moments, we are using the principle of superposing of the effects. [1, 2].

For the mechanism of a proper orientation, the transmission functions of the speeds have the following form:

\[
\begin{bmatrix}
\omega_1 \\
\omega_2 \\
\omega_{H_2}
\end{bmatrix} = \begin{bmatrix}
\omega_a \\
\omega_b \\
\omega_7
\end{bmatrix}; \quad A = \begin{bmatrix}
1 & -\frac{R_1}{R_1} & -\frac{R_1}{R_1} \\
\frac{R_2}{R_2} & 0 & 0 \\
1 & 0 & 0
\end{bmatrix}
\]

(1)

In the premise of neglecting the abrasion forces and the inertia, the transmission function of the moments can be established using the principle of the virtual mechanical powers:

\[
\begin{bmatrix}
M_\alpha \\
M_\beta \\
M_\gamma
\end{bmatrix} = -A^T \begin{bmatrix}
M_1 \\
M_2 \\
M_{H_2}
\end{bmatrix}
\]

(2)

Fig.1 Variant of robotomechanism for orientation activated through wires [3]
In the particular case known in practice, when the radius of the pulleys are equal, it will be established by using the relations (1) and (2):

\[
\begin{bmatrix}
\omega_1 \\
\omega_2 \\
\omega_{H_2}
\end{bmatrix} = \begin{bmatrix}
A_1 & \omega_\alpha \\
\omega_\beta & M_\alpha \\
\omega_\gamma & M_\gamma
\end{bmatrix} \begin{bmatrix}
M_1 \\
M_2 \\
M_{H_2}
\end{bmatrix} = -A^T \begin{bmatrix}
M_1 \\
M_2 \\
M_{H_2}
\end{bmatrix};
\]

(3)

where,

\[
A_1 = \begin{bmatrix}
1 & -1 & -1 \\
1 & 1 & 0 \\
1 & 0 & 0
\end{bmatrix};
\]

For the decoupling mechanism, the establishing of the transmission functions for the speeds and moments is being made by applying the principle of superposing of the effects, obtaining:

\[
\begin{bmatrix}
\omega_a \\
\omega_b \\
\omega_c
\end{bmatrix} = A \begin{bmatrix}
\omega_a \\
\omega_b \\
\omega_c
\end{bmatrix}
\]

(4)

where:

\[
B = \begin{bmatrix}
1 & R_{10} & R_{16} & R_{22} & 1 & R_{10} & R_{16} & 1 & R_{10} \\
4 & R_4 & R_{11} & R_{17} & 4 & R_4 & R_{11} & 1 & R_4 \\
1 & R_{15} & R_{22} & 1 & R_{15} & 0 \\
4 & R_8 & R_{17} & R_{21} & R_7 & 0 & 0
\end{bmatrix}
\]

\[
M_a = -B^T \begin{bmatrix}
M_a \\
M_b \\
M_c
\end{bmatrix}
\]

(5)

where:

\[
B^T = \begin{bmatrix}
1 & R_{10} & R_{16} & R_{22} & 1 & R_{15} & R_{22} & 1 & R_{21} \\
4 & R_4 & R_{11} & R_{17} & 4 & R_8 & R_{17} & R_{17} & R_7 \\
1 & R_{10} & R_{16} & 1 & R_{15} & 0 \\
4 & R_8 & R_{11} & 1 & R_{10} & R_9 & 0 & 0
\end{bmatrix}
\]

As a result, the aggregate formed out of the two mechanisms is three-mobile

\[
M = 3 + 3 - 3 = 3
\]

and characterized by \( L = 6 \) exterior connections (a, b, c and \( \alpha, \beta, \gamma \)).

So we have:

\[
M = 3 \) exterior independent moves \( (\omega_\alpha, \omega_\beta, \omega_\gamma) \) and
\]

\[
L - M = 3 \) dependent moves
\]

which represent the functions of global transmission of the speeds.

These speeds are obtained by coupling the transmission functions of the component mechanisms A and B, respecting the conditions.

As a result, we acquire:

\[
\begin{bmatrix}
\omega_a \\
\omega_b \\
\omega_c
\end{bmatrix} = A_1^{-1} \begin{bmatrix}
\omega_a \\
\omega_b \\
\omega_c
\end{bmatrix} = A_1^{-1} B C \begin{bmatrix}
\omega_a \\
\omega_b \\
\omega_c
\end{bmatrix}
\]

(6)

where:

\[
C = A_1^{-1} B = \begin{bmatrix}
R_{21} & 0 & 0 \\
R_7 & 1 & R_{13} & R_{22} & 1 & R_{15} & 0 \\
2 & R_8 & R_7 & 2 & R_8 & 2 & R_8 \\
1 & R_{10} & R_6 & R_{22} & 1 & R_4 & R_{22} & 1 & R_{10} & R_{16} & 1 & R_5 & 1 & R_4
\end{bmatrix}
\]

The analyze of the transmission function for the speeds shows that the decoupling of the orientation moves \( (\alpha, \beta, \gamma) \) can be realized if the following conditions are fulfilled:

\[
\begin{bmatrix}
R_{21} \\
R_7 \\
R_{15} & R_{22} \\
R_8 & R_{17} \\
R_{15} & R_{22} \\
R_8 & R_{11}
\end{bmatrix}
\]

(7)

also known as decoupling conditions.

It can be seen that these conditions are also fulfilled in the particular case preferred in applications where:

\[
R_7 = 2R_{21}, \quad R_{15} = R_8, \quad R_{10} = 2R_9,
\]

\[
R_{11} = R_{16}, \text{ and } R_{19} = R_{22},
\]
In the particular reminded case, the global transmission function of the speeds, specific for the kinematical analysis, becomes:

\[
\begin{bmatrix}
\omega_a \\
\omega_b \\
\omega_c
\end{bmatrix} = C_1 \cdot \begin{bmatrix}
\omega_a \\
\omega_b \\
\omega_c
\end{bmatrix}
\]

(8)

where:

\[
C_1 = \begin{bmatrix}
-1 & 0 & 0 \\
0 & -\frac{1}{2} & 0 \\
0 & 0 & -1
\end{bmatrix}
\]

Analog with the previous situations, with the premise of neglecting the rubbing and the inertia, for the functions of global transmission of the moments , we come to the following result:

\[
\begin{bmatrix}
M_a \\
M_b \\
M_c
\end{bmatrix} = -C_1^T \cdot \begin{bmatrix}
M_a \\
M_b \\
M_c
\end{bmatrix} = \begin{bmatrix}
-1 & 0 & 0 \\
0 & 1 & 0 \\
0 & 0 & 1
\end{bmatrix} \begin{bmatrix}
M_a \\
M_b \\
M_c
\end{bmatrix}
\]

(9)

5 Conclusions

It has been carried out a structural, cinematic and static analyze of a new three-mobile oriented robotomechanism, operated through wires, that has the coupling grade equal to three.

In order to do that, there had to be solved problems dealing with:

- establishing of the transmission functions for the moves, and the moments for the orientation mechanism;
- establishing of the realization conditions for the mechanical decoupling;
- establishing of the global functions for transmitting the speeds and the moments.

The solution of replacing the serrated wheels with equivalent mechanisms with pulley wheels and wires is rational and economical under the circumstances of dealing with little and medium charges.

The established functions, of transmission of the speeds, of the moments and the mechanical decoupling of the moves, assures the simplicity of the commanding programs.

When checked into practice, there has been proven that the obtained mathematical relations, resulted in good precision of movements and moments - for the studied orientation robotomechanism type.

References:


