Design a Robotic Mechanism - Component of Low and Non-pollution Manufacturing Systems

Decoupling Movement of a Robotic Mechanism with Three Degrees of Freedom, using Couplings and Wires Transmission

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Abstract: The growing presence of industrial robots in low and non-pollution manufacturing systems requires the development of a database. This paper presents a form of robotic mechanism with three degrees of freedom, driven by wires and pulley wheels. It is necessary to present this type of mechanisms, because the literature data in the field of robotic mechanisms operated through wires are, relatively, poor. It is presented a structural and kinematic analysis of a robotic mechanism guidance, establishing equations of motion (e.g. for speeds, moments).

1 INTRODUCTION

The mechanism studied in the paper is derived from a robotic mechanism with gears and represents one important component of a (data) base of mechanisms with wires and pulley wheels, used in designing robotic mechanisms.

The solution of replacing the serrated wheels with equivalent mechanisms with pulley wheels and wires is rational and economical – with the assumptions of dealing with small and medium loads.

These mechanisms are used particularly in the nuclear industry, medicine, etc. (Coiffet, 1993), (Vertut, 2012) when low, or non-pollution manufacturing systems are involved.

2 NOTATION AND SYMBOLS

The notation and symbols used in this paper are mentioned next

- M - represents the mobility grade of the mechanisms;
- M_I, M_{II}, ...- mobility grade of each of the component mechanisms;
- L_C- number of couplings between the mechanisms;
- ω_a- angular velocity of the “a” element relative to the base;
- C- coupling grade of the motions;
- M_a- the moment of the element “a”;
- $\omega_a^{(\alpha)}=\omega_a(\omega_\alpha \neq 0;\ \omega_\beta = 0)$.
- i_{ab}^{c} - transmission ratio from the element “a” to the element “b”, when the angular velocity $\omega_c = 0$; (Dudita, 1984).

3 STRUCTURE AND KINEMATIC ANALYSES OF THE ROBOTIC MECHANISM

3.1 Structural Analysis of the Robotic Mechanism

The authors present a version of decoupling the movements by couplings, for a robotic-mechanism whose movement transmission is provided by wires.

There have been done, both, structural and kinematic analyses for the orientation mechanism I and the decoupling movements of mechanism II. Consequently, there were determined the overall functions of transmission gears and moments, as well as the conditions of release movements (see figure 1).

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In terms of kinematic and structural analysis, the proper guidance of mechanism, driven by wires through single or double pulley wheels, it has been extensively analysed by the analytical method (Bercan, 2004).

The robotic-mechanism of orientation I, is formed by combining the cinematic chain bi-mobile open A = (0 - H1 - H2) with three mono-mobile mechanisms with wires B = (1 - 3 - H2), C = (2 - 8 - H2) and D = (4 - 5 = 6 - 7 - H1). The mobility grade of the orientation mechanism is given by relation (1):

$$M_I = M_A + \ldots + M_D - L_C = 2 + 1 + 1 + 1 - 2 = 3 \qquad (1)$$

Where $L_C = 2$ represents the component between the composing mechanisms (3=4) and (8=7).

The innovative orientation mechanism I, has $L_I = 6$ external connections, three inputs (0-2-H_2) and three outputs (α, β, γ).

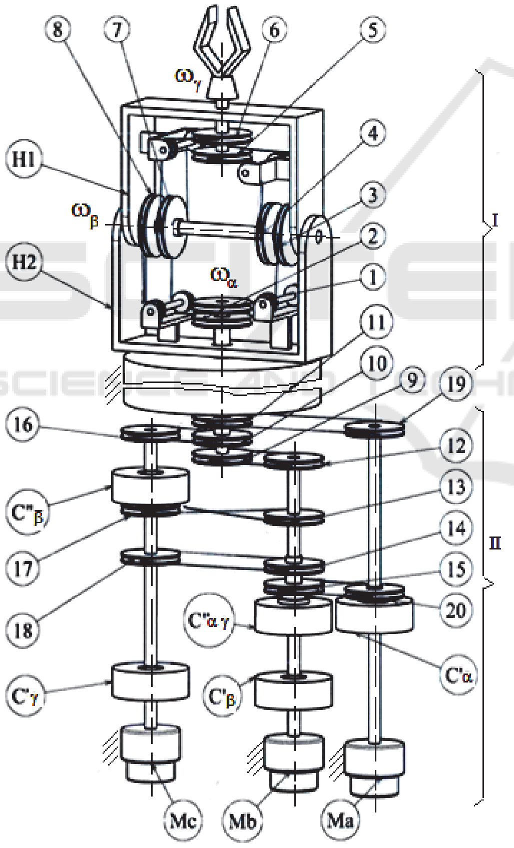

Figure 1: The robotic mechanism acted by wires.

Because the mechanism is three-mobile, it results that $M_I = 3$, as there are independent motions (ω_α, ω_β, ω_γ) and $L_I - M_I = 6 - 3 = 3$, as there are dependent motions (ω_1, ω_2, ω_{H2}).

The mechanism has $L_I - M_I = 3$ independent exterior moments (M_1, M_2, M_{H2}) and $M_I = 3$ dependent exterior moments (M_α, M_β, M_γ)

The coupling grade of the proposed orientation mechanism is:

$$C = C_\alpha + C_\beta + C_\gamma = (3-1) + (2-1) + (2-1) = 4 \qquad (2)$$

This means that the α - motion is coupled with the motions β and γ, the β motion is coupled with the motion γ, and the γ motion is coupled to the β motion.

3.2 Kinematical Analysis of the Robotic Mechanism

In order to establish the transmission functions for speeds and moments, the authors apply the principle of superposition of the effects, so that functions (3) are obtained:

$$\begin{cases} \omega_1 = \omega_\alpha - \dfrac{R_3}{R_1}\omega_\beta - \dfrac{R_3 R_5}{R_1 R_4}\omega_\gamma \\ \omega_2 = \omega_\alpha + \dfrac{R_8}{R_2}\omega_\beta - \dfrac{R_6 R_8}{R_2 R_7}\omega_\gamma \\ \omega_{H_2} = \omega_\alpha \end{cases} \qquad (3)$$

Written in matrix form, they turn into next functions, given by (4):

$$\begin{bmatrix} \omega_1 \\ \omega_2 \\ \omega_{H_2} \end{bmatrix} = \begin{bmatrix} 1 & -\dfrac{R_3}{R_1} & -\dfrac{R_3 R_5}{R_1 R_4} \\ 1 & \dfrac{R_8}{R_2} & -\dfrac{R_6 R_8}{R_2 R_7} \\ 1 & 0 & 0 \end{bmatrix} \cdot \begin{bmatrix} \omega_\alpha \\ \omega_\beta \\ \omega_\gamma \end{bmatrix} = A \cdot \begin{bmatrix} \omega_\alpha \\ \omega_\beta \\ \omega_\gamma \end{bmatrix};$$

$$where \quad A = \begin{bmatrix} 1 & -\dfrac{R_3}{R_1} & -\dfrac{R_3 R_5}{R_1 R_4} \\ 1 & \dfrac{R_8}{R_2} & -\dfrac{R_6 R_8}{R_2 R_7} \\ 1 & 0 & 0 \end{bmatrix} \qquad (4)$$

With the assumptions of neglecting the abrasion and the inertia forces, the transmission function of the moments can be determined using the principle of the virtual mechanical power, as presented by equation (5):

$$\begin{bmatrix} M_\alpha \\ M_\beta \\ M_\gamma \end{bmatrix} = -A^T \begin{bmatrix} M_1 \\ M_2 \\ M_{H_2} \end{bmatrix} \qquad (5)$$

A particular case, with practical application, is that when the radii of the wheels are equal. So, the equations (4) and (5) turn into equation (6):

$$\begin{bmatrix}\omega_1\\ \omega_2\\ \omega_{H_2}\end{bmatrix} = A_1\begin{bmatrix}\omega_\alpha\\ \omega_\beta\\ \omega_\gamma\end{bmatrix}; \quad \begin{bmatrix}M_a\\ M_b\\ M_c\end{bmatrix} = -A_1^T\begin{bmatrix}M_1\\ M_2\\ M_{H_2}\end{bmatrix}; \tag{6}$$

$$\text{where} \quad A_1 = \begin{bmatrix}1 & -1 & -1\\ 1 & 1 & -1\\ 1 & 0 & 0\end{bmatrix}$$

For the decoupling study, it is most convenient when the transmission functions of the velocity are expressed by relationship (7):

$$\begin{bmatrix}\omega_\alpha\\ \omega_\beta\\ \omega_\gamma\end{bmatrix} = A_1^{-1}\begin{bmatrix}\omega_1\\ \omega_2\\ \omega_{H_2}\end{bmatrix} = \begin{bmatrix}0 & 0 & 1\\ -\frac{1}{2} & \frac{1}{2} & 0\\ -\frac{1}{2} & -\frac{1}{2} & 1\end{bmatrix}\cdot\begin{bmatrix}\omega_1\\ \omega_2\\ \omega_{H_2}\end{bmatrix} \tag{7}$$

Kinematics and structural analysis will be done in particular for the decoupling mechanism II, when for the simplified calculation is being used general analytical method.

The decoupling mechanism II is a tri-mobile mechanism composed from six mono-mobile mechanisms acted by wires E=(11 19), F=(10 16), G=(9 12), H=(13 17), I=(14 18) and J=(15 20) together with five couplings, (C'_α, C'_β, C'_γ, $C''_{\alpha\gamma}$ and C''_β). The mechanism is driven by three stepping motors (Ma, Mb, Mc), (Bercan, 1995), (Bercan, 1999), (Stareţu, 2009).

The coupling degree of the guidance mechanism is calculated as expressed by equation (8):

$$C = C_\alpha + C_\beta + C_\gamma = (3 - 1) + (2 - 1) + (2 - 1) = 4 \tag{8}$$

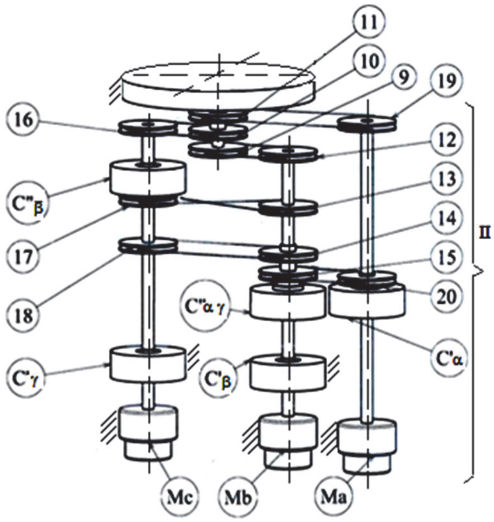

Figure 2: The α movement conditions.

To achieve the α movement, the Ma motor in running and will be locked by the stepper motor Mb and Mc (see figure 2).Under these conditions, the couplings C'α and C"α are coupled and the others are decoupled.

To achieve the β movement, the Mb motor in running and will be locked by the stepper motor Ma and Mc (see figure 3). Under these conditions, the couplings C'_β and C''_β are coupled and the others are decoupled.

To achieve the γ movement, the Mc motor in running and will be locked by the stepper motor Ma and Mb (see figure 4). Under these conditions, the couplings C'γ and C"γ are coupled and the others are decoupled.

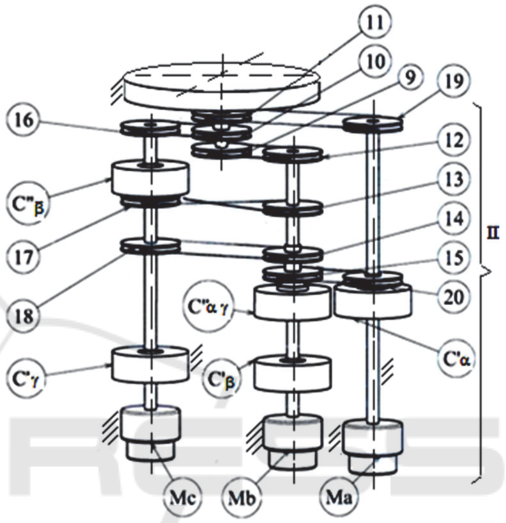

Figure 3: The β movement conditions.

To determine the decoupling conditions of the oriented movements, there is proceeded like in previous cases, so that there are obtained the following transmission ratios equals:

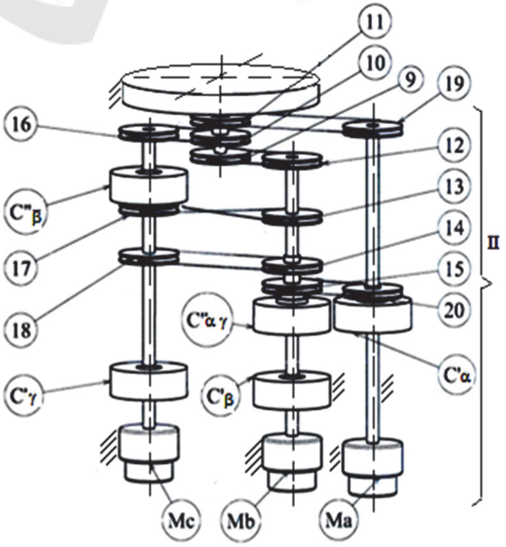

Figure 4: The γ movement conditions.

- for decoupling movements γ - β:

$$i_{9\text{-}c}=i_{10\text{-}c};$$

$$\text{where:}\quad \begin{aligned} i_{9\text{-}c}&=i_{9\text{-}12}\cdot i_{14\text{-}18}=\frac{R_{12}R_{18}}{R_9R_{14}}\\ i_{10\text{-}c}&=i_{10\text{-}16}=\frac{R_{16}}{R_{10}}\end{aligned} \tag{9}$$

- for decoupling movements β - γ:

$$i_{9\text{-}b}=-\,i_{10\text{-}b};$$

$$\text{where :}\quad \begin{aligned} i_{9\text{-}b}&=i_{9\text{-}12}=\frac{R_{12}}{R_9}\\ i_{10\text{-}b}&=i_{10\text{-}16}\cdot i_{17\text{-}13}=-\,\frac{R_{16}R_{13}}{R_{10}R_{17}}\end{aligned} \tag{10}$$

- for decoupling movements α – (β and γ) (see equation 11)

From relations (9), (10) and (11) we obtain the conditions for decoupling, given by equation (12).

$$i_{11\text{-}a}=i_{10\text{-}a}=i_{9\text{-}a};$$

$$\text{where :}\quad \begin{aligned} i_{9\text{-}a}&=i_{9\text{-}12}\cdot i_{15\text{-}22}=\frac{R_{12}R_{20}}{R_9R_{15}};\\ i_{10\text{-}a}&=i_{10\text{-}16}\cdot i_{18\text{-}14}\cdot i_{15\text{-}30}=\frac{R_{16}R_{14}R_{20}}{R_{10}R_{18}R_{15}};\\ i_{11\text{-}a}&=i_{11\text{-}19}=\frac{R_{19}}{R_{11}}\end{aligned} \tag{11}$$

$$\begin{cases} \dfrac{R_{16}}{R_{10}}=\dfrac{R_{12}R_{18}}{R_9R_{14}}\\ \dfrac{R_{12}}{R_9}=\dfrac{R_{16}R_{13}}{R_{10}R_{17}}\\ \dfrac{R_{19}}{R_{11}}=\dfrac{R_{16}R_{14}R_{20}}{R_{10}R_{18}R_{15}}\end{cases} \tag{12}$$

These relationships are fulfilled in the particular case of equal radii: $R_9= ... =R_{20}$.

For the robotic mechanism with decoupled movements (see figure 1), we obtain the functions of velocity transmission, as follows:

1^0 for $\omega_\beta=0$ and $\omega_\gamma=0$ => $\omega_b=0$ and $\omega_c=0$

$$\omega_\alpha=\omega_a\cdot i_{\alpha\text{-}a};\ \text{where :}\ i_{\alpha\text{-}a}=i_{11\text{-}19}=\frac{R_{19}}{R_{11}}$$
$$\Rightarrow\quad \omega_\alpha=\omega_a\cdot\frac{R_{19}}{R_{11}} \tag{13}$$

2^0 for $\omega_\alpha=0$ and ω_γ => $\omega_a=0$ and $\omega_c=0$

$$\omega_\beta=\omega_b\cdot i_{\beta\text{-}b};$$
$$\text{where :}\ i_{\beta\text{-}b}=i_{8\text{-}2}\cdot i_{10\text{-}16}\cdot i_{17\text{-}13}=-\,\frac{R_2R_{16}R_{13}}{R_8R_{10}R_{17}}$$
$$\Rightarrow\quad \omega_\beta=-\,\omega_b\cdot\frac{R_2R_{13}R_{16}}{R_8R_{10}R_{17}} \tag{14}$$

3^0 for $\omega_\alpha=0$ and $\omega_\beta=0$ => $\omega_a=0$ and $\omega_b=0$

$$\omega_\gamma=\omega_c\, i_{\gamma\text{-}c}$$
$$\text{where :}\ i_{\gamma\text{-}c}=i_{6\text{-}7}\cdot i_{8\text{-}2}\cdot i_{10\text{-}16}=-\,\frac{R_7R_2R_{16}}{R_6R_8R_{10}}$$
$$\Rightarrow\quad \omega_\gamma=-\,\omega_c\cdot\frac{R_2R_7R_{16}}{R_6R_8R_{10}} \tag{15}$$

The velocities functions of overall transmission for the robotic mechanism with decoupled movements are expressed by the matrix form presented in equation (16):

$$\begin{bmatrix}\omega_\alpha\\ \omega_\beta\\ \omega_\gamma\end{bmatrix}=\begin{bmatrix}\dfrac{R_{19}}{R_{11}} & 0 & 0\\ 0 & -\dfrac{R_2R_{16}R_{13}}{R_8R_{10}R_{17}} & 0\\ 0 & 0 & -\dfrac{R_7R_2R_{16}}{R_6R_8R_{10}}\end{bmatrix}\cdot\begin{bmatrix}\omega_a\\ \omega_b\\ \omega_c\end{bmatrix} \tag{16}$$

In the case of equal values for radii, the relationship (16) turns into (17):

$$\begin{bmatrix}\omega_\alpha\\ \omega_\beta\\ \omega_\gamma\end{bmatrix}=\begin{bmatrix}1 & 0 & 0\\ 0 & -1 & 0\\ 0 & 0 & -1\end{bmatrix}\cdot\begin{bmatrix}\omega_a\\ \omega_b\\ \omega_c\end{bmatrix} \tag{17}$$

Under the assumptions of neglecting the abrasion and the inertia forces, the transmission function of the moments can be expressed by equation (18).

$$\begin{bmatrix}M_a\\ M_b\\ M_c\end{bmatrix}=\begin{bmatrix}-1 & 0 & 0\\ 0 & 1 & 0\\ 0 & 0 & 1\end{bmatrix}\cdot\begin{bmatrix}M_\alpha\\ M_\beta\\ M_\gamma\end{bmatrix} \tag{18}$$

4 CONCLUSIONS

The mechanism studied in this paper is derived from a robotic-mechanism with gears and represents one important component of a (data) base of mechanisms with wires and pulley wheels, used in designing robotic mechanisms.

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. This type of mechanisms, beyond being silent and with good maintenance, do not need lubricants while working and do not develop thermal energy.

This solution is also relevant for industrial robots in low and non-pollution manufacturing systems (Iliescu, 2015).

The determined transmission functions are applied in programming the robotic-mechanisms, as well as in their design calculi. They are also used in the studies of mechanical decoupling for orientation movement.

Further development of this study aims the analysis of the mechanism from the kinematical and dynamic points of view of, as well as the fatigue behaviour by computer aided programs, CAD software.

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