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CONCEPTUAL BASIS FOR MODELING MULTI-CORDINATE MECHATRONIC ROBOT MODULES

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Abstract*: The conceptual foundations of modeling multi-coordinate mechatronic modules of robots are considered. The use of a multi-coordinate mechatronic movement module in robots made it possible to obtain at the output of one module several linear and angular coordinates, which reduces the weight and dimensions of the robot and thereby improves its dynamic characteristics. The proposed original concept of the mathematical description of a multi-coordinate mechatronic module, which is focused on displaying their structural and operating features. A structural diagram of a developed industrial robot operating in a Cartesian coordinate system and built on the basis of a multi-coordinate mechatronic module with three output coordinates is presented. When modeling a mechatronic module, its principle of operation is displayed by logical models of its constituent elements. Structural diagrams of a composite power electromagnet and a multi-coordinate mechatronic module of an industrial robot have been constructed using the MATLAB software.*
Keywords: *multi-coordinate module, industrial robot, mechatronic module, power electromagnet.*

Аннотация*: Роботларнинг мултикоординатли мехатрон модулларини моделлаштиришнинг концептуал асослари кўрилган. Мултикоординатали мехатрон ҳаракат модулини роботларда қўллаш бир чиқишида бир неча чизиқли ва бурчак координаталарини олиш имкониятини беради, у эса роботнинг масса габарит кўрсаткичларини камайтиради ҳамда унинг динамик тавсифларини яхшилайди. Мултикоординатали мехарон модулнинг математик ёзилишини оргинал концепцияси таклиф қилинган, у унинг структуравий ва маъром хусусиятларини акс эттириш учун йўналтирилган. Уч чиқишли мултикоординатали мехатрон модул асосида яратилган ва қурилган ҳамда декарт координат системасида ишлайдиган саноат роботининг конструктив схемаси келтирилган. Мехатрон модулнинг моделлаштиришда унинг ишлаш принципи мантиқий моделлар ёрдамида ифодаланган. Модулни ташкил этувчи электромагнитнинг ва саноат роботининг мултикоординатали мехатрон модулининг структуравий схемалари MATLAB дастури асосида моделлаштирилган.*
Таянч сўзлар: *кўп координатали модуль, саноат роботи, мехатрон модуль, қувват электр-магнити.*

Аннотация*: Рассмотрены концептуальные основы моделирования мультикоординатных мехатронных модулей роботов. Применение мультикоординатного мехатронного модуля движения в роботах позволило получить на выходе одного модуля несколько линейных и угловых координат, что уменьшает весогабаритные показатели робота и тем самым улучшает его динамические характеристики. Предложенная оригинальная концепция математического описания мультикоординатного мехатронного модуля, которая ориентирована для отображения их структурных и режимных особенностей. Приведена конструктивная схема разработанного промышленного робота, работающего в декартовой системе координат и построенного на основе мультикоординатного мехатронного модуля с тремя выходными координатами. При моделировании мехатронного модуля, его принцип функционирования отображена логическими моделями составляющих его элементов. Построена структурные схемы составного силового электромагнита и мультикоординатного мехатронного модуля промышленного робота с использованием программного обеспечения MATLAB.*
Ключевые слова: *мультикоординатный модуль, промышленный робот, мехатронный модуль, силовой электромагнит.*

1. Introduction

The accuracy of the positioning and dynamics of the manipulator is mainly determined by the dynamic characteristics of the drives used. In the developed and considered [1] industrial robot (PR), one multicoordinate mechatronic module (MMM), which provides three independent linear displacements and located on the base of the robot, was used as drives. This made it possible to significantly simplify the kinematics and improve the dynamic characteristics of the PR. In order to study the dynamic characteristics of MMM, computer simulation was carried out. Computer simulation allows us to trace the nature of changes in the studied quantities and evaluate them.

2. Methodology

In the developed PR working in a rectangular coordinate system, MMM with three outputs was used (an industrial robot has three degrees of mobility). The design of the MMM with three outputs is shown in Fig. 1. and includes four of the same type of power electromagnet 1, 2, 3 and 4 armored type, anchors 16, 17, 18, 19 of which form two movable parts. Three pairs of electromagnetic couplings 7, 8, 10, 12, 11, 13 are rigidly mounted to the moving parts using strips 5, 6, covering two flexible rods 14, 15 made in the form of a closed loop (not shown in the drawing), one rigid rod 9 and gripping organs 20.

By setting various control laws for electromagnetic couplings 7, 8, 10, 12, 13, it is possible to obtain independent laws of movement of the rods 9, 14, 15, namely, translational step movements.

3. Multi-coordinate meatronic module structure

By setting various control laws for electromagnetic couplings 7, 8, 10, 12, 13, it is possible to obtain independent laws of movement of the rods 9, 14, 15, namely, translational step movements.

The principle of operation of electromagnetic couplings is analogous to that described in [1] and consists in providing a firm grip of the rods with the moving parts of the MMM when they are turned on, i.e. when applying constant voltage to their windings. Electromagnetic clutches perform the functions of mechanical keys that transmit the reciprocating movements of the moving parts to the rods, the alternate switching on and off of which ensures the transformation of the reciprocating movements into translational movements of the output rods.

MMM contains four of the same type of power electromagnet 1, 3, 4, working synchronously in pairs, i.e. at one point in time, the extreme electromagnets 1, 4 are working, at another moment in time, the middle electromagnets 2, 3.

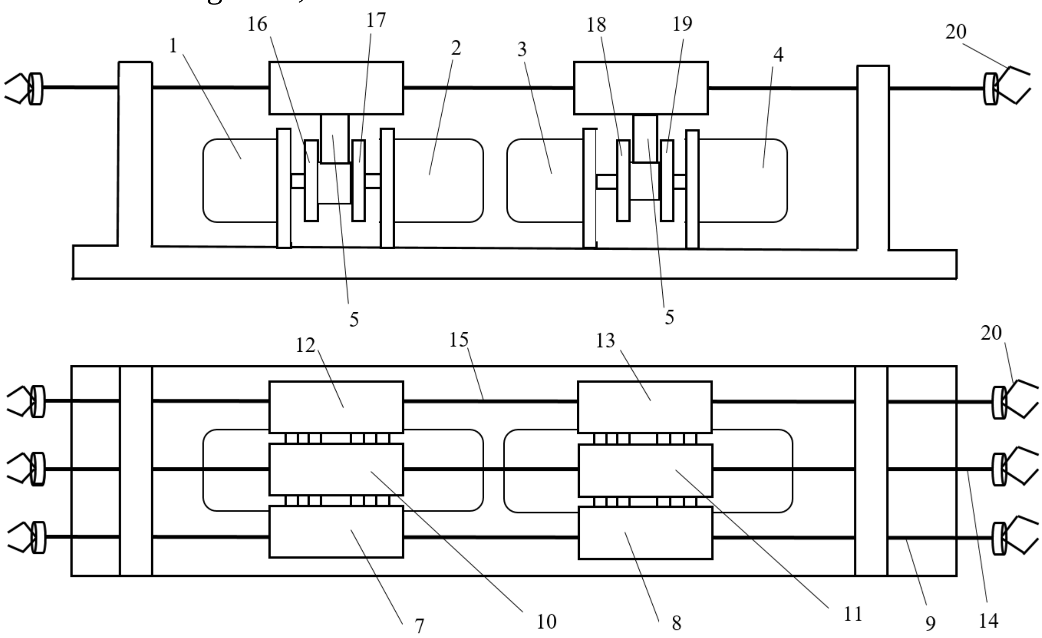


Fig. 1. ***MMM design with three outputs.***

The designs of electromagnetic clutches are also of the same type, and to reduce their response time, the windings are controlled from forcing pulses.

When modeling on a computer, structural schemes are developed in the same way, but with different signs of the output quantities X (t), v (t), f_em, depending on the direction of movement.

When the windings of the electromagnets 1 and 3 are turned on, their anchors move to the left, and when the electromagnets 4 are turned on, their anchors move to the right. When modeling MMM, we conditionally accept the positive direction of movement "to the right." The electromagnetic clutch is replaced by mechanical keys (contacts) of relay elements controlled from a pulse distributor (RI). The laws of variation of the pulse sequences of the RI determine the laws of movement of the rods of MMM. When simulating MMM, we define the following laws for the movement of rods: rod 9 moves to the right, rod 14 to the left and rod 15 to the right at a speed v / 2, v- where the speed of movement of the rods 9 and 14.

4. Mathematical analysis of multicore coordinate mechatron module

The principle of operation of RI, providing these laws of change of stocks is illustrated by the state table (table 1).

Table 1.

Status table

Power electromagnets and computers		STEPS							
		1	2	3	4	5	7	8	9
$CE1$		1	0	1	0	1	0	1	0
$CE2$		0	1	0	1	0	1	0	1
$CE3$		0	1	0	1	0	1	0	1
$CE4$		1	0	1	0	1	0	1	0
STOCK 9	M_l^7	1	0	1	0	1	0	1	0
	M_n^7	1	1	1	1	1	1	1	1
	M_l^8	0	1	0	1	0	1	0	1
	M_n^8	1	1	1	1	1	1	1	1
STOCK 14	M_l^{10}	1	1	1	1	1	1	1	1
	M_n^{10}	0	1	0	1	0	1	0	1
	M_l^{11}	1	0	1	0	1	0	1	0
	M_n^{11}	1	1	1	1	1	1	1	1
STOCK 15	M_l^{12}	1	0	1	0	1	0	1	0
	M_n^{12}	1	1	1	1	1	1	1	1
	M_l^{13}	1	1	1	1	1	1	1	1
	M_n^{13}	1	1	1	1	1	1	1	1

In table 1, the logical state "1" corresponds to the on state of the power electromagnets $CE1, CE2, CE3, CE4$ and electromagnetic couplings $M_l^7, M_n^7, M_l^8, M_n^8, M_l^{10}, M_n^{10}$, M_l^{11}, M_n^{11}, $M_l^{12}, M_n^{12}, M_l^{13}, M_n^{13}$ indices "l" и "n" mean the left and right parts of the coupling [16]. Logical state "0" corresponds to the off state.

The mathematical model of electromagnets can be expressed using a system of equations and dependencies of the form [2]:

$$\begin{cases} u = i \cdot R + \frac{d\Psi}{dt}; \\ m = \frac{d^2x}{dt} = F_{EM} - F_{np}; \\ F_{EM} = 0.5 \cdot i^2 \cdot \frac{dl}{dx}; \\ \psi = f(i, l). \end{cases} \quad (1)$$

where $u -$ is the constant voltage applied to the electromagnet winding $i -$ is the winding current, $R -$ is the resistance of the winding; $\psi -$ flux linkage, $m -$ mass of moving parts; $x -$ movement of the armature, $L -$ inductance; $F_{EM}, F_{np} -$ electromagnetic and opposing forces, respectively.

Table 2 shows the values of the initial data for modeling the MMM obtained in the calculation of the magnetic system (power electromagnet) and the load characteristic of the electromagnets (opposing forces).

The following data were used to obtain these values; voltage at the terminals of the winding of the power electromagnet $u = 26\ V$; winding resistance $R = 13\ Ohm$; mass of the movable part $m = 2\ kg$; working clearance $l = 0.4 \cdot 10^{-2}$ M; time scale $m_t = 0.001$.

Table 2.

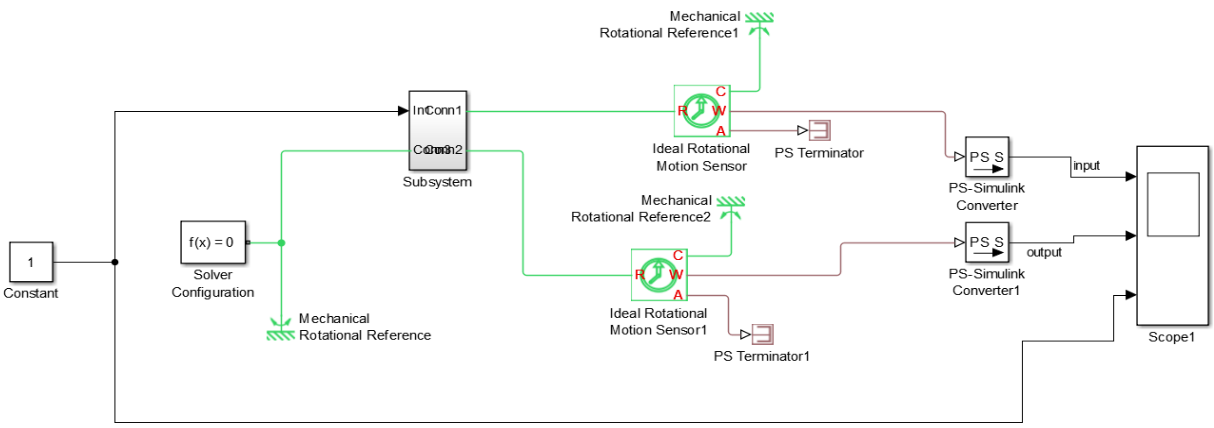
Source Data Values

$X \cdot 10^2 M$	0	0,08	0,16	0,24	0,32	0,36	0,4
L, F_H	0,4	0,52	0,65	0,89	1,45	2,15	4,23
$1/L, 1/\Gamma_H$	2,5	1,92	1,54	1,12	1,69	0,47	0,24
$dL/dx, F_H$	14	7,7	12,8	25,1	69,1	150	620
$F_{np}(x), H$	3	6	10	20	60	140	200

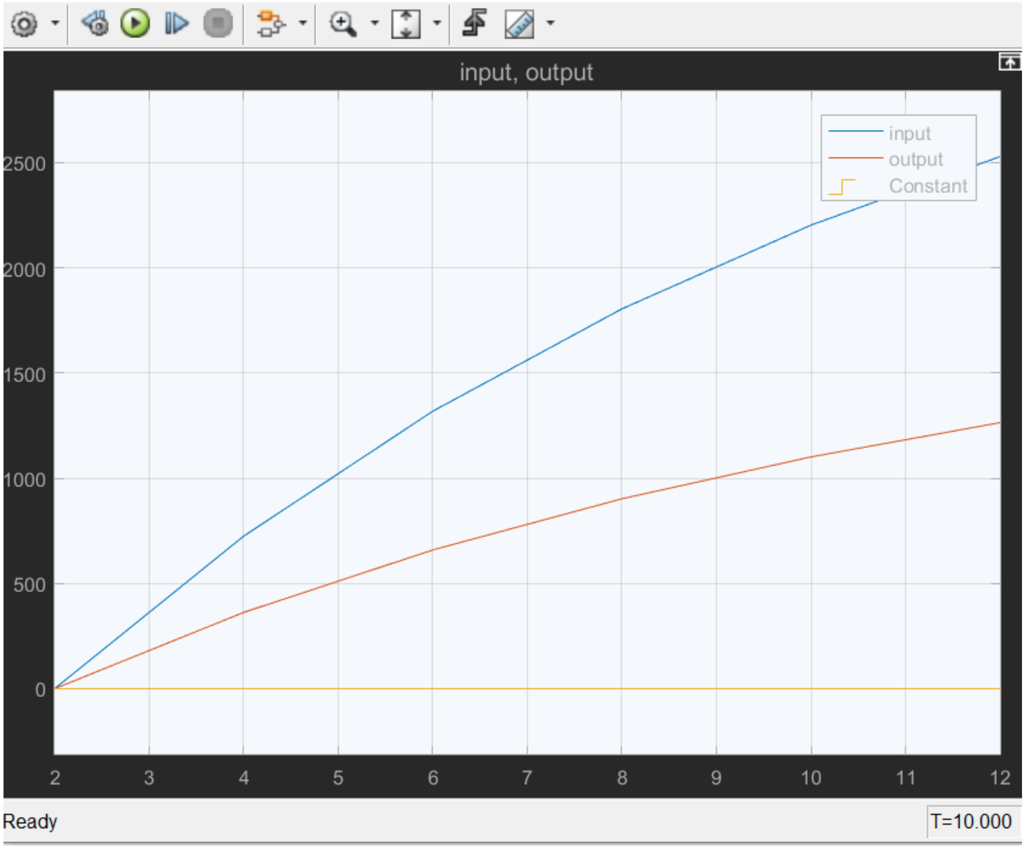
5. Modeling of multi-coordinate electronic module structure

By choosing the scale of the variables, the coefficients of the MMM model were calculated.

Using the functional capabilities of the computer, it is possible to build an imitation model of an MMM-powered electromagnet built on the basis of the MatLab program, and its structural scheme is shown in Fig. 2 (a and b).



a)



b)

Fig. 2. ***Block diagram of a power electromagnet MMM.***

In this model for the acquisition of non-linear dependencies

$$\left(\frac{1}{L}\right) M = f(X_m), \left(\frac{dl}{dx}\right) M = f(X_m) \text{ и } F_{np\ M} = F(X_m)$$

accordingly, functional blocks 5, 9, 8 are used.

Based on the structural model of the power electromagnet, the MMM model was developed (Fig. 3) with three outputs, the laws of the movement of the rods of which are presented in Table 1, where the electromagnetic couplings are represented by the contacts of electromagnetic relays 2, 1, 3, 4, 5, 6 with external equations from Fm, which provide the dependence $X = X_{\Delta M} + x$ where the translational movement of the rod is $\Delta X -$ step, M is the number of steps, X is the instantaneous movement of the last step.

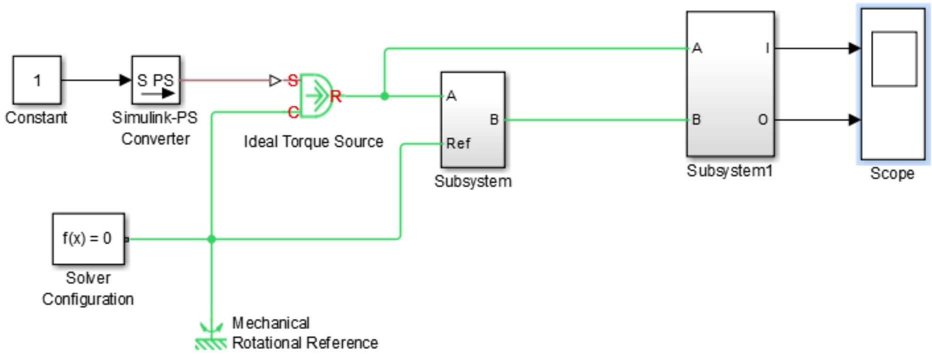


Fig. 3. ***MMM block diagram.***

Three signals $X, -X, \frac{1}{2}X$; are observed simultaneously on the computer monitor; which are shown in Fig. 4.

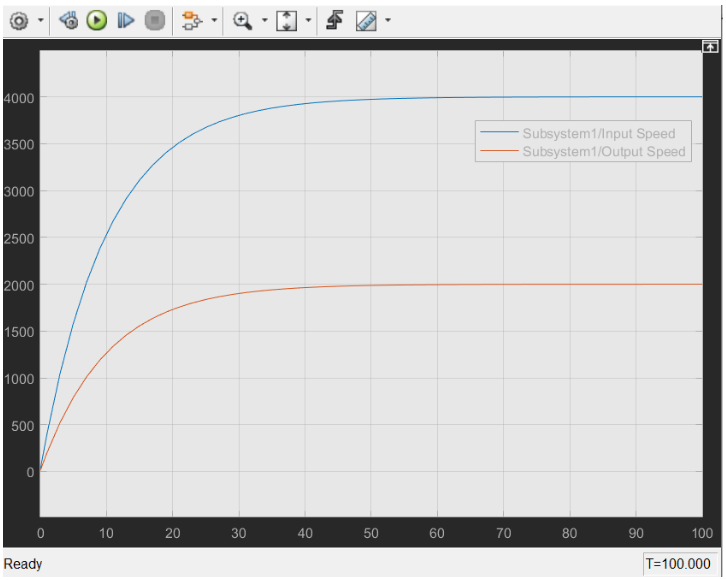


*Fig. 4. **Time characteristics MMM.***

6. Conclusion

Thus, the conceptual foundations of modeling multi-coordinate mechatronic modules of robots reflects the features of modeling mechatronic modules on a computer. At the same time, the positioning accuracy and dynamic characteristic mechatronic modules of industrial robots robots in various coordinate systems are evaluated. A structural scheme of a multi-coordinate mechatronic module with three output coordinates is also proposed, and its simulation is carried out on a computer.

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