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A NEW ACTING SOLUTION OF A DOUBLE SCARA ROBOT

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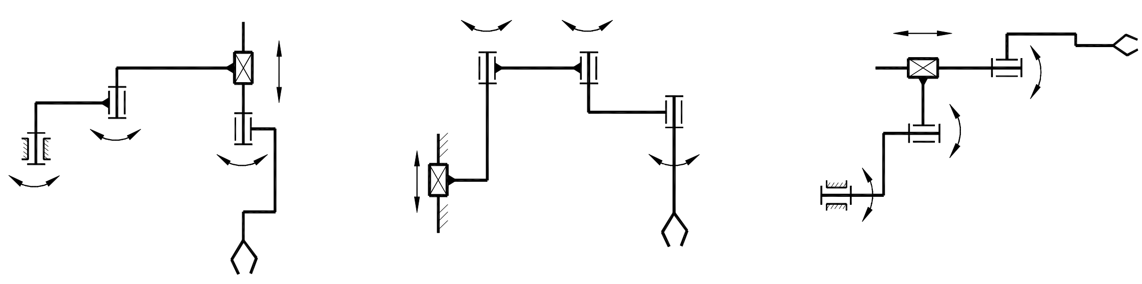
Abstract: *The traditional SCARA robot has the mechanical structure built by an open kinematical chain, articulated arm type, mounted in horizontal plane. Other than the classical solution that uses a serial structure, have appeared other solutions which are using close kinematic chains. So the double SCARA robot is using for the robot arm a five-bar closed linkage. In the paper we present the design of a double SCARA mechanism using CATIA V5 solution, where are modelled two types of five-bar mechanisms: general and degenerate, in which the distance between the joints from the frame is zero. In the second situation it is proposed a new acting solution of active joints, which is simplifying the construction of the system. This solution leads also to a simplified forward and inverse kinematics and also at a simplified control system.*
Keywords: *SCARA, robot, linkages, modelling, simulation*

1. INTRODUCTION

The SCARA is acronym for **S**elective **C**ompliance **A**ssembly **R**obot **A**rm or **S**elective **C**ompliant **A**rticulated **R**obot **A**rm. The first robot with this type of architecture has been produced in the laboratory of Yamanashi University from Kofu, Japan, by Prof. Hiroshi Makino in 1970. The traditional SCARA robot has a mechanical structure formed by the open kinematic chain articulated arm type, usually placed in horizontal plane. These robots, generally have four degree of freedom (DOF), the axis of joints (three of rotation and one of translation) being parallels. The compliance is present on the perpendicular plane on the common direction of the axis, in the time when the robot has a big stiffness, along of this direction.

The SCARA robots are used for operational pick and place or mounting. Also, due to the big velocity they can be used in the field of mounting of integrated circuits or from the other electronics components. From the construction of the first SCARA robot till now, many robot firms, like AIBO, COBRA, EPSON, KUKA, STÄUBLI, YAMAHA and others, they develop a big variety of some robots, for the handling of heavy pieces (less than 100 kilos). In fig. 1 there are presented the kinematic schemes of some robots:

- with vertical axis and translation joint, through the end-effector element (fig. 1a);
- with vertical axis and translation joint, corresponding to the actuator which allowed the vertical movement, assembling by the fixed element (fig. 1b);
- with horizontal axis, the robot has the compliance in vertical plane (fig. 1c).



a) b) c)

Figure 1: Kinematic schemes for some SCARA robots with four degree of mobility

As we can see above, the "traditional" SCARA robots are formed in compliance plane, from an open kinematic chain, with two or three degree of freedom (DOF). The end-effector element can be realised a supplementary rotation and translation movements. Relatively recently some new robot's architecture were developed, which use, for the production of SCARA motions, closed kinematic chains. Therefore, were used four-bar mechanisms [1] or five-bar linkage [3]. For the assurance of the compliance it can be used the other 2 DOF mechanisms, as it is studied in papers [2, 5], proposed as plane manipulators. Following this way, was developed the architectural modelling of SCARA manipulators, having like compliance mechanism a five-bar linkage. These manipulators were named double SCARA [3]. Using CATIA V5 solution, where are modelled two types of five-bar mechanisms: general Fig. 2 and degenerate Fig. 3, in which the distance between the joints from the frame is zero. In the second situation it is proposed a new acting solution of driving joints that simplifies the construction of the system. This solution leads to simplification of forward and inverse kinematics analysis and also to command and control.

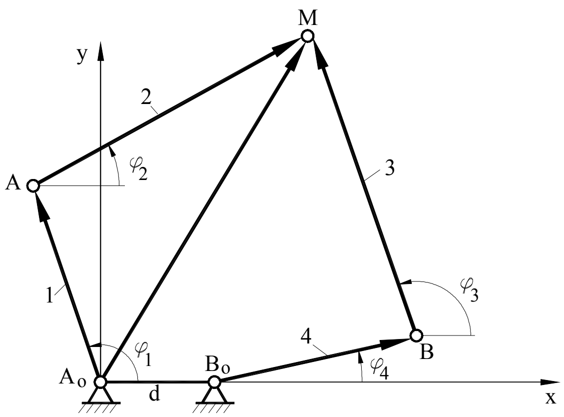


Figure 2: Five-bar general mechanism

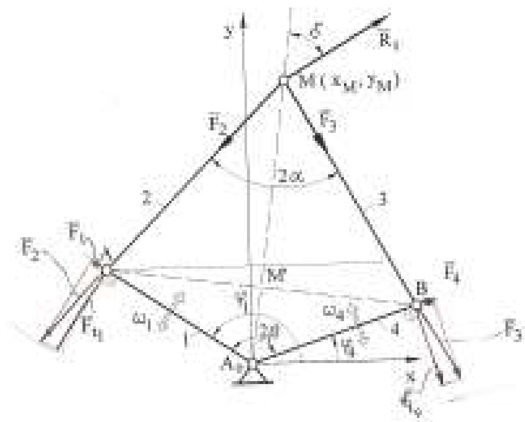


Figure 3: Degenerate five-bar mechanism (d=0)

2. MODELLING OF DOUBLE SCARA ROBOT' S MECHANISMS

To model the five-bar mechanism, the kinematic joints and the all system, we utilised CATIA V5 soft, thanks to the advantages offered by this system [6, 7]. We consider following notations (fig. 2):

$$A_0A = B_0B = l_1;\ AM = BM = l_2;\ A_0B_0 = d. \qquad (1)$$

We model the following five-bar mechanisms:

a) the case in which all the elements have the same length $l_1 = l_2 = l_3 = l_4$, for the general five-bars mechanisms $(d \neq 0)$;

b) the case $l_1 = l_2 = l_3 = l_4$, for the degenerate mechanism $(d = 0)$;

c) the case in which $l_1 = l_4 < l_3 = l_4$, for the general five-bars mechanisms $(d \neq 0)$;

d) the case in which $l_1 = l_4 < l_3 = l_4$, for the five-bars mechanisms $(d = 0)$;

For the 3D modelling, we used CATIA-Part Design product, and for the execution designs CATIA-Drafting. The assembling conditions required that the elements must be having different forms. Also, for the 1 and 4 elements in *a* and *b* cases we achieved the constructive solution (Fig. 4) and the execution design is shown in the Fig. 5.

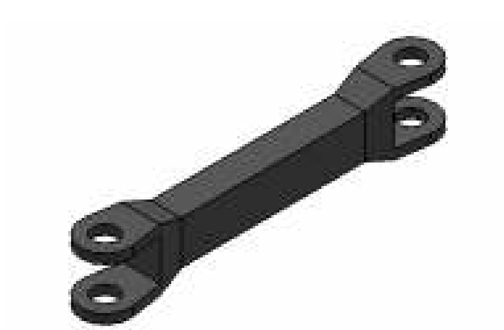


Figure 4: Constructive solution of 1 and 4 elements in *a* and *b* cases

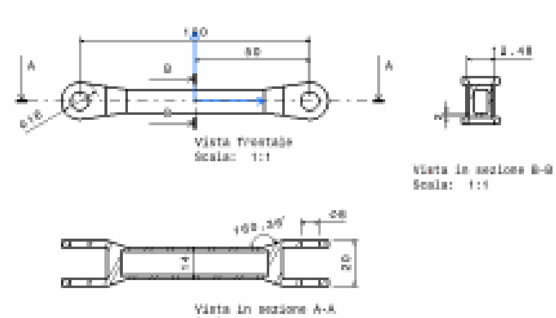


Figure 5: Execution design of 1 and 4 elements in *a* and *b* cases

For 2 and 3 elements, the constructive solution is represented in fig. 6, and the execution design in fig. 7.

Figure 6: Constructive solution of 2 and 3 elements in *a* and *b* cases

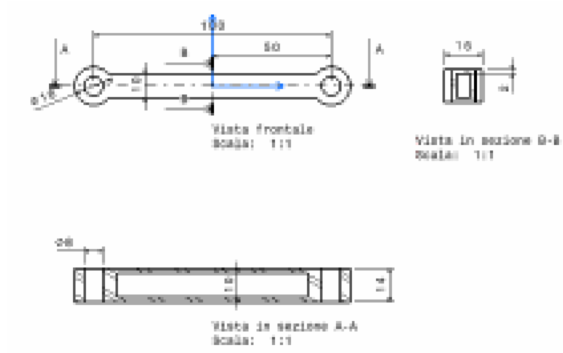


Figure 7: Execution design of 2 and 3 elements in *a* and *b* cases

The definition of kinematic joints we achieved with CATIA-DMU Kinematics product [9, 10]], obtaining the mechanism with Assembly Design (Fig. 8, 9).

Figure 8: Model of the five-bar mechanism (case *a*)

Figure 9: Model of the five-bar mechanism (case *b*)

The final mechanisms of some double SCARA robots there are shown in fig. 9 and 10, for the both cases.

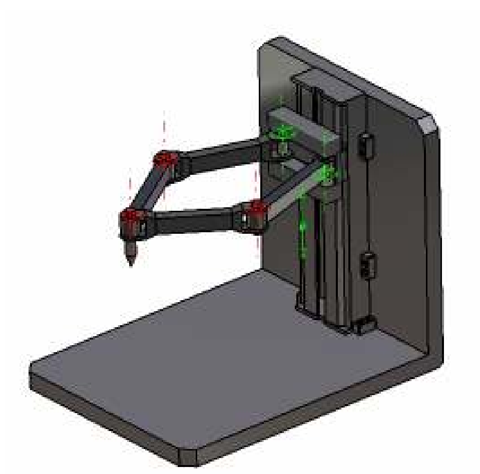


Figure 10: SCARA mechanism (case *a*)

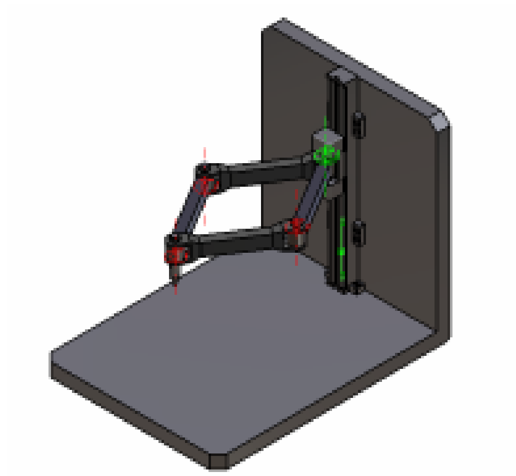


Figure 11: SCARA mechanism (case *b*)

We consider that the vertical translation movement are realised on the table frame. For the *c* and *d* cases, the realised models are shown in Fig. 12 and 13, where we considered that the translation movement is effected by the end-effector element.
The simulation of the modelled mechanisms movement, realised with help of CATIA-DMU Kinematics soft, allowed the determination of the extreme positions of the elements, in according with the their interference. In this way, we can establish the robot working space.

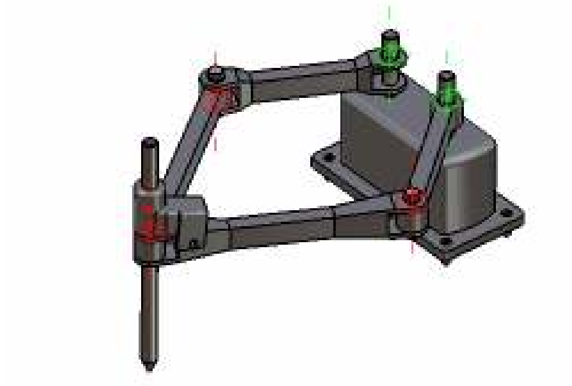


Figure 12: SCARA mechanism (case *c*)

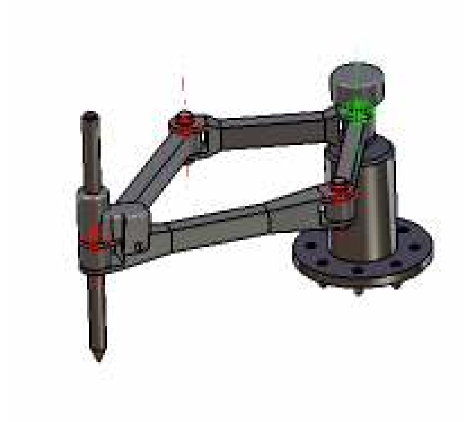


Figure 13: SCARA mechanism (case *d*)

3. THE GEOMETRY OF A FIVE-BAR MECHANISM OF A DOUBLE SCARA ROBOT

Between the four variants presented, the prefered solution of a double SCARA mechanism is the one from Fig. 13 (case d), which asure a bigger working space. The direct and inverse kinematics analysis of the five-bar mechanism was presented in a series of papers, for the general case (see [4, 9]). For particular case (Fig.3), the calculation formulas can be obtained, giving the condition d=0. Forward, are presented some relations required for the geometrical study of the mechanism, using the notations (2) refering to Fig. 3. Replacing $A_0M=\rho$, results:

$$\rho = l_1 \cos\beta + \sqrt{l_2^2 - l_1^2 sin^2\beta} \tag{2}$$

in which

$$\beta = \frac{\varphi_1 - \varphi_4}{2} \tag{3}$$

It can be considered for all positions: $\varphi_1 > \varphi_4$.

The coordinates of M point are:

$$x_M = \rho\ cos\emptyset;\ y_M = \rho\ sin\emptyset \tag{4}$$

Where:

$$\emptyset = \frac{\varphi_1 + \varphi_4}{2} \tag{5}$$

The relations above can serve for direct kinematics analysis of the mechanism.

For the inverse kinematics analysis, can be used the following relations [4], adapted to the studied case (d=0), with the mention that, because of the mechanism symmetry with the axis A_0M the solutions are unique:

- for $x_M > 0$:

$$\varphi_1 = \tan^{-1}\frac{y_M}{x_M} + \cos^{-1}\frac{l_1^2 + x_M^2 + y_M^2 - l_2^2}{2l_1\sqrt{x_M^2 + y_M^2}} \tag{6}$$

$$\varphi_4 = \tan^{-1}\frac{y_M}{x_M} - \cos^{-1}\frac{l_1^2 + x_M^2 + y_M^2 - l_2^2}{2l_1\sqrt{x_M^2 + y_M^2}} \tag{7}$$

- for $x_M < 0$:

$$\varphi_1 = \pi - \tan^{-1}\frac{y_M}{|x_M|} + \cos^{-1}\frac{l_1^2 - x_M^2 + y_M^2 - l_2^2}{2l_1\sqrt{x_M^2 + y_M^2}} \tag{8}$$

$$\varphi_4 = \pi - \tan^{-1}\frac{y_M}{|x_M|} - \cos^{-1}\frac{l_1^2 - x_M^2 + y_M^2 - l_2^2}{2l_1\sqrt{x_M^2 + y_M^2}} \tag{9}$$

4. FORCE TRANSFER

It is considered the technological force F_t applied in the point M, creating δ angle with the mechanism symetry axis (Fig. 3). This force is descomposed in axial components oriented on the elements 2 and 3:

$$F_2 = R_t\frac{\sin(\alpha+\delta)}{\sin 2\alpha} \tag{10}$$

$$F_3 = R_t\frac{\sin(\alpha-\delta)}{\sin 2\alpha} \tag{11}$$

For δ=0, the two forces have equal values:

$$F_2 = F_3 = R_t\frac{1}{2\cos\alpha} \tag{12}$$

It can be seen that for $\alpha = \frac{\pi}{2}$ we have $F_{2,3} \to \infty$. For the dimensioning of the mechanism longitudes, it must be evoided any singular position.
The forces F_2 and F_3 are descomposed in joints A and B having the following components:

$$F_1 = F_2 \cos(\alpha + \beta) = R_t \frac{\sin(\alpha+\delta).\cos(\alpha+\beta)}{\sin 2\alpha} \tag{13}$$

$$F_{t1} = F_2 \sin(\alpha + \beta) = R_t \frac{\sin(\alpha+\delta).\sin(\alpha+\beta)}{\sin 2\alpha} \tag{14}$$

$$F_4 = F_3 \cos(\alpha + \beta) = R_t \frac{\sin(\alpha-\delta).\cos(\alpha+\beta)}{\sin 2\alpha} \tag{15}$$

$$F_{t4} = F_3 \sin(\alpha - \delta) = R_t \frac{\sin(\alpha-\delta).\sin(\alpha-\delta)}{\sin 2\alpha} \tag{16}$$

The maximum values of the axial forces $F_{1,2,3,4}$ can be used for the dimensioning of the mecanism elements, and the forces $F_{t1,4}$ for the determination of the motor moments, which must act upon the elements:

$$M_{M1} = F_{t1} \cdot l_1; \; M_{M4} = F_{t4} \cdot l_1 \tag{17}$$

5. A NEW ACTING SOLUTION OF A DOUBLE SCARA ROBOT

For the particular five-bar SCARA mechanisms (Fig. 11, 13) the actuators are located in fix joints, in which case there are some constructive complications. For these reasons, we propose a new acting solution of a five-bar mechanism presented in fig. 14.

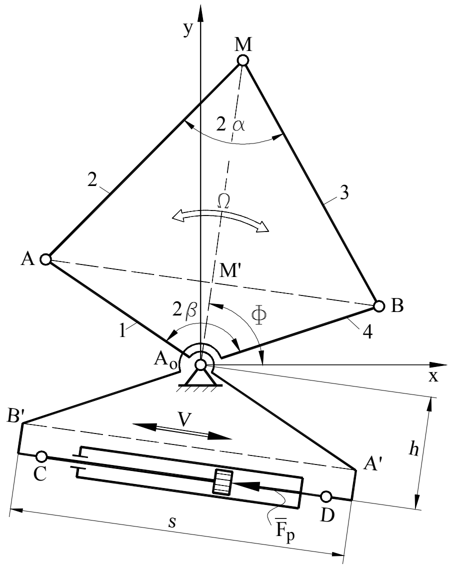


Figure. 14: A new acting solution of the mechanism from Fig. 3

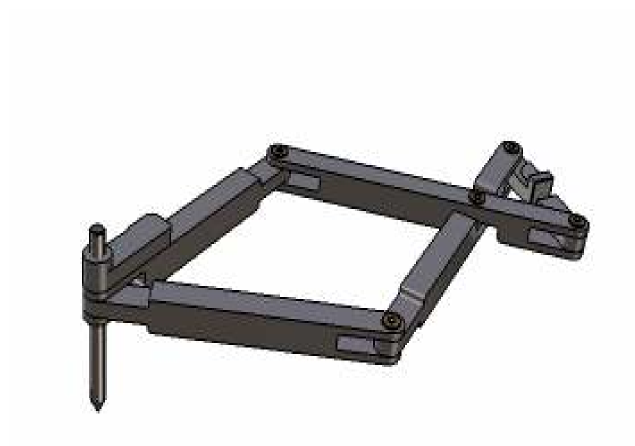


Figure. 15: CATIA's design of the mechanism

The design of this mechanism is represented in fig. 15. The mechanism act is performed in this manner:
- the distance between the joints A-B modifies thanks to the linear motor action, located between joints C-D;
- the mechanism can rotate around the joint A_0.

In this way, the motors overlap from A_0 joint can be eliminated. The command parameters are *s* and $\emptyset$. Replacing $A_0A = l$ and $\frac{A_0A}{A_0A'} = \frac{l_1}{l} = \mu$, it results $AB = \mu s$ and:

$$A_0M = \rho = \frac{1}{2}\left(\sqrt{4l_1^2 - \mu^2 s^2} + \sqrt{4l_2^2 - \mu^2 s^2}\right) \tag{18}$$

The coordinates of M point, depending on the parameters *s* and $\emptyset$ are, for the direct kinematics analysis:

$$x_M = \rho \cos\emptyset; \; y_M = \rho \sin\emptyset \tag{19}$$

For the inverse kinematics analysis, the angles φ_1 and φ_4 can be determined with the relations (6, 7, 8, 9). Folowing, it can be determined the comand parameter *s*:

$$...s = 2l \sin\beta \tag{20}$$

The forces that act above the elements, are given by the relations (10, 11, 13, 14). The intensity of the instantaneus force, developed by the liniar actuator it can be calculated with the relation (Fig. 15):

$$F_p = \frac{l_1}{h}(F_{t1} - F_{t4}) \tag{21}$$

6. CONCLUSION

This paper presents the modelling of the mechanical system of SCARA robot, with help of CATIA V5 soft. There are presented four solutions, which used as an arm of manipulators a five-bar mechanism. The acting solution of the double SCARA robot mechanism, presented in Fig. 14, 15 presents multiple advantages in point of constructive and functional aspects.

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