

HIGH-SPEED A PARALLEL ROBOT WITH FOUR DEGREES OF FREEDOM

OBJECT OF THE INVENTION

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The robot of the invention has the object of moving a platform carrying the corresponding tool, with four degrees of freedom (three translations and one rotation about the vertical axis), with very high accelerations and speeds in any direction.

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Another object of the invention is that the actuators of the robot are arranged symmetrically, affording homogenous performance and high rigidity in the entire working volume.

This robot is especially indicated for pick & place tasks.

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BACKGROUND OF THE INVENTION

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Parallel robots are generally made up of a fixed support or base plate on which there are assembled actuators which, through articulated arms or kinematic chains, are linked to a mobile platform which the corresponding tool is anchored to.

A robot of this type with three degrees of freedom is described, for example in US patent 4,976,582, whereas patent EP 1 084 802 describes a parallel robot with four degrees of freedom (three translations and one rotation).

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Parallel robots with four degrees of freedom are very appropriate for carrying out part handling tasks, packaging and assembly, and they have advantages over more complex parallel robots, for example with 6 degrees of freedom, in reference to simplicity, price and movement speed.

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The object of European patent 1 084 802 is a parallel robot in which all the linkages of the mobile platform are articulation-type linkages, this being a favorable factor for reaching high speeds and accelerations. This robot comprises four kinematic chains operated by means of four actuators which are fixed at one of their ends and with a specific orientation to the base plate, and at their other end to the kinematic chain. In turn, the kinematic chains are linked to the mobile platform carrying the tool, the

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mobile platform being made up of two parts or bars which are linked at their ends to the four kinematic chains and a third bar which is assembled between the first two, through two articulated linkages, this bar being the one carrying the tool.

5 The mobile platform allows a rotation of $\pm 45^\circ$ which can be amplified by means of using gear rings.

10 The specific design of the mobile platform and the use of articulated linkages leads to obtaining an isostatic configuration and forces a non-homogenous arrangement of the kinematic chains, and therefore of the actuators. This particular arrangement of the actuators combined with the isostatic configuration prevents the robot from having a homogenous performance and high rigidity in the entire working volume, which is an important disadvantage.

15 A modified configuration of the robot described in patent EP 1 084 802 is described for example in the following publication: "I4: A new parallel mechanism for SCARA motions" Proc. of IEEE ICRA: Int. Conf. on Robotics and Automation, Taipei, Taiwan, September 14-19, 2003.

20 The configuration described in this article seeks to compensate the main limitation of patent EP 1 084 802, i.e. the non-homogenous performance and low rigidity that the configuration has in the entire working volume.

25 This new configuration is essentially based on a new mobile platform design, which must solve the aforementioned problems, replacing articulated linkages with prismatic joints and the gear rings with pinions-rack. These changes imply, firstly, a considerable reduction of the risk of collision between the different parts of the mobile platform.

30 Specifically, the mobile platform is formed by three parts, two side parts and a central part, the side parts being linked at their ends to the four kinematic chains through ball joints, as in patent EP 1 084 802, whereas the central part is linked to the side parts by means of a prismatic joint. The four kinematic chains are in turn fixed to the fixed platform through the four corresponding actuators.

35 In this configuration, as in European patent 1 084 802, the rotational motors can be replaced with linear motors and the articulated linkages with universal joints. In the specific case of the new configuration described in the

mentioned article, four linear motors arranged in the same plane and aligned in the same direction are used.

Another configuration is described in the following article: "A High-Speed Parallel Robot for Scara Motions" Proceeding of the 2004 IEEE International Conference on Robotics & Automotion, New Orleans, LA, USA, April 26-May 1, 2004.

This robot is formed by four kinematic chains, linked to the mobile platform, operated by four rotational actuators, linked to the fixed base. The main differences compared to the previously described configuration are the use of rotational actuators and the design of the mobile platform. Specifically, the mobile platform is formed by two parts linked together by means of a prismatic guide and a cable and pulley system transforming the linear translational movement of the guide into the desired rotation. This mobile platform design allows the actuators to be arranged at 90° in relation to each other, which involves a symmetrical design and a homogenous performance in the entire working volume.

The main drawback of the last two configurations described is the limitation to reach high accelerations and speeds, the main requirement for pick & place applications. This limitation is due to the use of prismatic guides and more specifically to the recirculation of the balls of the rolling guides.

DESCRIPTION OF THE INVENTION

The robot object of the invention has the advantages of the mentioned robots with four degrees of freedom, eliminating their drawbacks.

Specifically, the main advantages of the robot of the invention are high rigidity, high precision, homogenous performance in the entire working volume, good dynamic performance and very high speeds and accelerations in any direction.

These properties are achieved as a result of the symmetrical arrangement of its actuators, of the use of articulated linkages in the mobile platform and a new mobile platform design.

Specifically, the mobile platform of the robot of the invention is made up of four parts linked together by means of revolving joints, at least two of the parts being parallel to each other, forming an articulated mobile platform called a planar parallelogram having one degree of freedom in said plane.

The working tool is integral with any of the four parts making up the mobile platform.

The kinematic chains are formed by a spatial parallelogram made up of four bars, parallel in pairs, linked by means of ball joints.

These kinematic chains are linked at one of their ends to one of the articulated linkages of the mobile platform and at their other end, through a rotational or translational joint, to respective actuators assembled in the base plate located in the upper part of the robot, with the particularity that the actuators are positioned in the base plate with any orientation.

The actuators will preferably be symmetrically placed in a fixed structure, such that this symmetrical arrangement of the actuators and, especially, the use of a planar parallelogram in the mobile platform allows obtaining excellent dynamic performance, high rigidity and homogenous performance in the entire working volume.

By controlling the actuators the mobile platform shifts with four degrees of freedom, three translations and one rotation in relation to the vertical axis.

The degree of freedom associated to the planar parallelogram is one rotation in relation to the vertical axis affording the working tool one rotation between -45° and $+45^\circ$.

An additional mechanical mechanism by means of belt, pulleys or gears can be included to increase the rotation range of the working tool. In this case, the working tool will be integral with any of the additional mechanical parts needed.

DESCRIPTION OF THE DRAWINGS

To complement the description being given and for the purpose of aiding to better understand the features of the invention, a set of drawings is attached as an integral part of said description which shows the following with and illustrative and non-limiting character:

Figure 1 shows a perspective view of the robot object of the invention.

Figure 2 shows a plan view of a detail of the mobile platform and of its

linkages to the kinematic chains of the robot.

Figure 3 shows a plan view of the robot object of the invention.

Figure 4 shows a plan view of the mobile platform and of a preferred embodiment in terms of positioning of the actuators.

5 Figure 5 shows a perspective view of the mobile platform, including an amplification mechanism made up of two pulleys and a belt.

Figure 6 shows a perspective view of the mobile platform, including the amplification mechanism made up of a notched section and a gear wheel.

10 Figure 7 shows a perspective view of the mobile platform, including an intermediate member and an amplification mechanism made up of two pulleys and a belt.

Figure 8 shows a perspective view of the mobile platform, including an intermediate member and an amplification mechanism made up of a notched section and a gear wheel.

15 Figure 9 shows a perspective view of the mobile platform, including two intermediate members and an amplification mechanism made up of a gearbox.

20 **PREFERRED EMBODIMENT OF THE INVENTION**

The robot object of the invention, as can be observed in Figure 1, comprises four kinematic chains (1), linked at one of their ends by means of rotational joints (2), to actuators fixed to the base plate (3), and at their other end to a mobile platform (4) which the working tool (5) is assembled on.

25 Each of the kinematic chains is made up of four bars (6), (6'), (7), (7'), parallel in pairs, and linked together by means of ball joints (8). In an alternative embodiment, the kinematic chains are formed by means of a single bar with two cardan or universal joints at their ends.

Each of the four actuators is made up of a fixing support (9) for fixing it to the base plate (3), a rotational motor (10) linked to the support (9), and an arm integral with the shaft of the motor causing the rotation of the rotational joint (2). In an alternative embodiment, four linear motors arranged in the same plane and aligned in the same direction are used.

30 The mobile platform (4) is made up of four members (11), (11'), (12), (12'), linked together by means of revolving joints (13), at least two of the

members forming the mobile platform (4) are parallel to each other, to form an articulated mobile platform with one degree of freedom in the plane of the mobile platform and, more specially, one rotation in relation to an axis perpendicular to the plane of the mentioned mobile platform (4). This rotation affords the working tool one rotation between -45° and $+45^\circ$, which can increase by means of additional amplification mechanisms, which will be described below.

The tool (5) is integral with any of the members (11), (11'), (12), (12').

In an embodiment shown in the attached figures, two of the members (11) and (11') are formed by arms having at their ends transverse extensions (14) provided with an inner hole in which the bars (7') of the kinematic chains (1) are housed and can rotate, whereas the arms (12) and (12') are formed by bars hingedly linked on the transverse extensions (14) of the bars (11) and (11').

As can be observed in Figure 3, the bars (7') of the kinematic chains (1) have the same spatial orientation as the output shafts of the motors (10) of the actuators, the actuators being symmetrically positioned on the base plate (3), which allows obtaining high rigidity, high positioning precision and homogenous performance in the entire working volume.

The best arrangement of the actuators, and therefore of the bars (7') of the kinematic chains and of the extensions (14) of the mobile platform (4), are 45° , 135° , 225° and 315° , as can be observed in Figure 4, although there are infinite possibilities for the arrangement of the actuators.

The mobile platform can incorporate an amplification mechanism for the rotation of the tool to increase its range of rotation. The assembly of these mechanisms in the mobile platform many times requires additional parts.

Different embodiments of the rotation amplification mechanisms are described below as they are shown in Figures 5 to 9.

In a first embodiment shown in Figure 5, the mobile platform (4) is made up of four members (11), (11'), (12), (12'), linked by means of revolving joints (13). At least two of the four members are parallel to each other. The amplification mechanism is made up of two pulleys (15), one assembled on the member (11'), and the other one (16) assembled on the

member (11) and a belt (17) arranged between both pulleys (15) (16). In this embodiment, the working tool is linked to the shaft of the pulley (16).

In a second embodiment shown in Figure 6, the member (11) has a gear ring section (18) and the member (11') has a gear wheel (19) meshing with the gear ring sector (18). In this case, the working tool (5) is linked to the gear ring and also has four degrees of freedom.

Figures 7 and 8 show alternative embodiments in which the mobile platform (4) incorporates an additional member or arm (20).

In an embodiment according to Figure 7, the mobile platform (4) is formed by five members (11), (11'), (12), (12') and (20), linked together by means of revolving joints. Four members (11) and (11'), (12) and (12') are parallel in pairs and are linked together through their ends. The fifth member (20) is placed parallel to one of the pairs of members (12), (12') and its ends are linked to the other two members (11) and (11').

Amplification of the rotation of the working member is obtained by means of two pulleys (21), (22), one of them assembled on one of the members (11), (11') and the other one on the additional member (20), and the corresponding belt (23). The working tool (5) is assembled on the pulley (22).

In Figure 8, the mobile platform (4) is made up of the same five members (11), (11'), (12), (12') and (20) of the embodiment shown in Figure 7, the amplification of the rotation of the working member being obtained by means of a gear ring sector (24) provided in one of the members (11), (11') and a gear wheel (25) assembled in the additional member (20), the working tool (5) being assembled in the gear ring (25).

In Figure 9, the mobile platform (4) is formed by six parts (11), (11'), (12), (12'), (20) and (26) linked together by means of revolving joints. The mobile platform (4) is made up of the same members as those shown in Figures (7) and (8) but comprises a sixth member (26) which is placed parallel to the pair of members (11), (11'), such that the six parts are parallel in threes. The two additional members (20) and (26) are linked at a middle point in which the working tool (5) is placed. The rotation amplification is obtained using a gearbox (28) and placing it in the intersection of the two additional parts (20) and (26).

CLAIMS

1.- A high-speed parallel robot with four degrees of freedom comprising four kinematic chains (1) linked at one of their ends to a mobile platform (4) carrying the tool (5) and at their other end, through a rotational joint (2), to an actuator integral with a base plate (3), characterized in that the mobile platform (4) is made up of four members (11), (11'), (12), (12'), linked together by means of articulated linkages (13).

2.- A high-speed parallel robot with four degrees of freedom according to claim 1, characterized in that the members (11), (11'), (12), (12') are linked together at their ends, at least two of the members being parallel to each other, forming an articulated mobile platform with one degree of freedom in the plane of the mobile platform.

3.- A high-speed parallel robot with four degrees of freedom according to claim 2, characterized in that the degree of freedom of the mobile platform is one rotation in relation to the vertical axis, with a range of -45° to 45° .

4.- A high-speed parallel robot with four degrees of freedom according to claim 1, characterized in that the actuators, which include rotational motors, are positioned in the base plate (3) in any direction.

5.- A high-speed parallel robot with four degrees of freedom according to claim 4, characterized in that the actuators are positioned in the base plate (3) symmetrically.

6.- A high-speed parallel robot with four degrees of freedom according to claim 5, characterized in that the actuators are positioned in the base plate (3) at 45° , 135° , 225° and 315° .

7.- A high-speed parallel robot with four degrees of freedom according to claim 1, characterized in that the actuators include linear motors arranged in the same plane and aligned in the same direction.

8.- A high-speed parallel robot with four degrees of freedom according to claim 1, characterized in that each of the kinematic chains (1) are made up of four bars (6), (6'), (7), (7'), parallel in pairs, which are linked together by means of ball joints, being linked to the mobile platform (4) and to the actuators (2), such that the linking bar (7') to the mobile platform (4) has the same orientation as the corresponding actuator.

9.- A high-speed parallel robot with four degrees of freedom according

to claim 1, characterized in that some or all of its kinematic chains (1) are formed by means of a single bar with two cardan or universal joints at its ends, being linked to the mobile platform (4) and to the actuators (2).

5 10.- A high-speed parallel robot with four degrees of freedom according to claim 1, characterized in that the mobile platform (4) incorporates an amplification mechanism for the rotation of the working tool (5).

10 11.- A high-speed parallel robot with four degrees of freedom according to claim 10, characterized in that the amplification mechanism is made up of two pulleys (15) (16), one of them (15) assembled in one of the four members of the mobile platform (4), and the other one (16) linked to another one of the members of the mobile platform, and a belt (17) arranged between both pulleys (15) (16) the working tool (5) being assembled on the shaft of the pulley (16).

15 12.- A high-speed parallel robot with four degrees of freedom according to claim 10, characterized in that the amplification mechanism is made up of notched section (18) provided in one of the members of the mobile platform (4), a gear wheel (19) provided in another one of the members of the mobile platform, the working tool (5) being linked to the gear wheel (19).

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25 13.- A high-speed parallel robot with four degrees of freedom according to claim 1, characterized in that the mobile platform additionally comprises an intermediate member (20) arranged between two of the members of the mobile platform (4), by means of articulated linkages, the working tool (5) being assembled on the intermediate member (20).

30 14.- A high-speed parallel robot with four degrees of freedom according to claim 13, characterized in that the members forming the mobile platform (4) are arranged parallel in pairs and the intermediate member (20) is assembled parallel to one of the pairs of arms (12,12') making up the mobile platform and is linked to the other two members (11,11') in its central part.

15.- A high-speed parallel robot with four degrees of freedom according to claim 14, characterized in that it incorporates an amplification mechanism for the rotation of the working tool.

16.- A high-speed parallel robot with four degrees of freedom according to claim 15, characterized in that the amplification mechanism is made up of two pulleys (21) (22), one of them (21) assembled on one of the four members of the mobile platform (4) and the other one (22) linked to the intermediate member (20), and a belt (23) arranged between both pulleys (21) (22), the working tool (5) being assembled on the shaft of the pulley (22).

17.- A high-speed parallel robot with four degrees of freedom according to claim 15, characterized in that the amplification mechanism is made up of notched section (24) provided in one of the members of the mobile platform (4) and a gear wheel (25) provided in the intermediate member (20), the working tool (5) being linked to the gear wheel (25).

18.- A high-speed parallel robot with four degrees of freedom according to claim 1, characterized in that the mobile platform (4) additionally comprises two intermediate members (20), (26) linked to the mobile platform (4) by means of articulated linkages.

19.- A high-speed parallel robot with four degrees of freedom according to claim 18, characterized in that the members forming the mobile platform (4) are arranged parallel in threes, with one of the intermediate members (20) assembled parallel to one of the pairs of arms (12,12') forming the mobile platform (4) and linked to the other two members (11,11') in its central part, whereas the second intermediate member (26) is assembled parallel to the second pair of arms (11,11') of the mobile platform (4) and linked to the other two members (12,12') at its central part, the two intermediate members (20) and (26) being linked together at a point (27) where the working tool (5) is placed.

20.- A high-speed parallel robot with four degrees of freedom according to claim 19, characterized in that the mobile platform includes an amplification member for the rotation of the tool.

21.- A high-speed parallel robot with four degrees of freedom according to claim 20, characterized in that the amplification member comprises a gearbox (28), assembled in the linking point (27) of the intermediate members (20) and (26).