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A NEW PARALLEL MANIPULATOR HYDRAULICALLY ACTUATED

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ABSTRACT

The paper describes a new 6 DOF parallel manipulator named as SHOLKOR. The main properties of the new design are presented in terms of an analytical solution for direct kinematics and efficient force control of platform actions. Due to its properties, the proposed manipulator design can be used as an active support for protecting machines, buildings and other structures from disproportionate impacts. This application has been tested with a prototype by using controllable hydraulic actuator and results are reported to show the feasibility of the new design and its successful potentiality.

Keywords: Design, Parallel Manipulators, Active support, Hydraulic actuator

1 INTRODUCTION

Several parallel manipulator architectures are currently used in various fields. These manipulators have a structural topology that is similar to one of the Gough-Stewart platform [1-2]. However, most of the parallel manipulators with more than 3 degrees of freedom, show variable coordinates of the movable platform that are coupled to each other so that a movement of a drive requires simultaneous coordination with the other drives. There is not a general solution of the direct kinematic problem for parallel manipulators [3-5] and specific investigations are required for particular structures. Parallel manipulators are well understood for greater payload capability, stiffness, accuracy and dynamic performance as compared to traditional serial manipulators. Thus, parallel manipulators have attracted research interests for design and applications that can be achieved with less than 6 degrees of freedom (DOF). As shown in [6] parallel manipulator with three up to six degrees of mobility are used for guidance of the platform though three, four, five, and six points.

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The parallel structure was initially employed in the Gough machine for testing the tires of the airplane [7] and in Stewart Machine as a flight simulator [8]. CaPaMan (Cassino Parallel Manipulator) is a 3-DOF of spatial parallel manipulator, which has been conceived and built at Laboratory of Robotics and Mechatronics (LARM) in Cassino Italy [9] and [10]. Results of experimental tests have successfully proved a novel application of CaPaMan a 3-DOF spatial parallel manipulator, as a test bed earthquake simulator [11-14].

In [15] a parallel manipulator with pneumatic actuation is presented as the active controller supports, installed between the protected object and the source of sudden mechanical impacts. Thus, the idea to use parallel manipulators as active supports is substantially new.

In this paper a new parallel manipulator functionality is examined for the purpose of the substantiation of the use of parallel manipulators as an active support with six axes.

2 THE PROPOSED NEW DESIGN

The new parallel manipulator is based on a structure that has been introduced in [16]. This manipulator consists of two platforms that are connected with six connecting links (CL).

Figure 1 a) shows the structure of the proposed design of parallel manipulator whose main parts are: 1, which is the stationary platform, 2, which is the movable platform, and 3-8, which are six connecting links with a linear actuator.

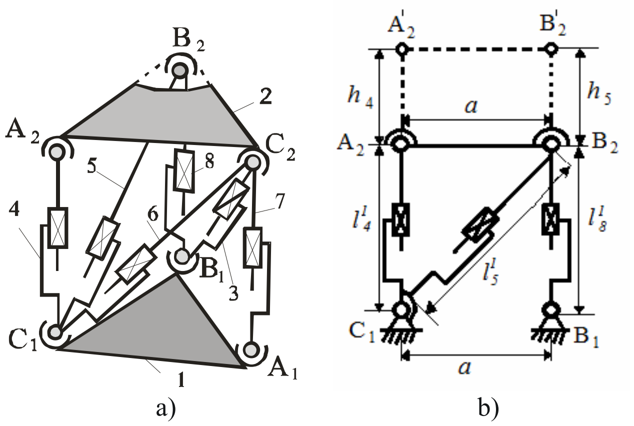

Figure 1 The proposed new parallel manipulator:
a) a scheme of the structure; b) kinematic scheme with the variables l_i.

In order to show principle of link's lengths change on figure 1 b) it is shown the part of manipulator's kinematic scheme with links l_4, l_5, l_8. Variable lengths of links are expressed as $l_i = l_i^1 + h_i$ $(i = 3,\ldots,8)$ that are the input data. Where, l_i^1 – initial length of connecting links, h_i – change in length CL due to movement which is done by actuator mechanism. It is assumed that the points of the movable and stationary platforms form regular triangles $A_1B_1C_1$ and $A_2B_2C_2$ with sides a. The lengths of the other connecting links initially are selected to obtain a platform configuration in the form of the prism. Also, accept that the lengths of the ribs $l_4^1 = l_7^1 = l_8^1 = ka$; the diagonal of the rectangles faces of the prism is also equal, therefore $l_3^1 = l_5^1 = l_6^1 = a\sqrt{1+k^2}$. Here, k – is a coefficient selected for practical reasons.

Then using the introduced initial data for the considered parallel manipulator in analytical form, it is solved the direct problem of kinematics. This uses the method of converting the coordinate system, according to the eight parameters, as reported in [17]. Mathcad is used in the formation of the matrix transformation and in operations with them.

To determine the position of C_2 movable platform firstly we consider a pyramid $C_2A_1B_1C_1$ (Figure 2). Origin of coordinates $C_1X_1Y_1Z_1$, linked to the platform 1 is selected in the point C_1. C_1X_1 axis is directed along the A_1C_1 side of the $A_1B_1C_1$ triangle from C_1 to A_1. C_1Z_1 axis is directed perpendicular to the plane of the $A_1B_1C_1$ triangle. The position of C_2 depends on lengths l_3, l_6, l_7 of the 3, 6,7connecting links. To get the dependencies for determining the coordinates of the C_2 point in the considered pyramid, we perform a subsequent transformation of coordinate systems by three chains C_1-C_2, C_1-B_1-C_2, C_1-A_1-C_2 to match the basic coordinate system. The solution of the problem begins with the change of moving coordinate system $C_1X_6Y_6Z_6$, connected with the link 6, into the base coordinate system $C_1X_1Y_1Z_1$ by the chain C_1-C_2. Further, in this work, in order to exclude repeat of the geometric calculations the final calculations and some unique features are outlined. The transformation in (Figure 2) is worked out by a series of progressive movements of $C_1X_1Y_1Z_1$ system till complete matching with the coordinate system $C_1X_6Y_6Z_6$. The first movement is a turn of the system $O_1X_1Y_1Z_1$ at the angle θ_6 around axis C_1Z_1 until the axis C_1X_1 is located in the base plane perpendicular to the axis C_1Z_6 ($\beta = \pi/2$).

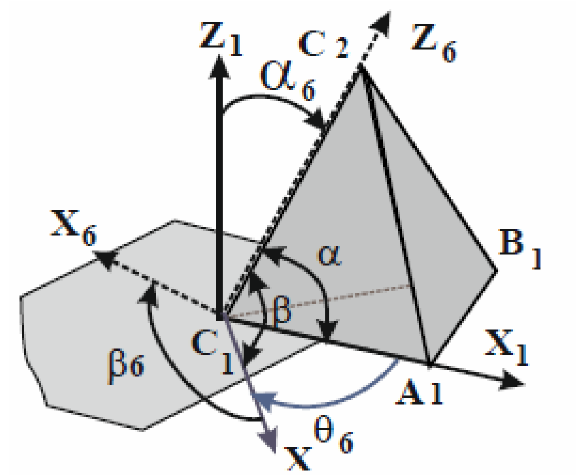

Figure 2 Main pyramid is determined by links 6, 7 and 3.

The pyramid geometry of figure 2 can be described by using the vectors as

$$\mathbf{r}_{C2}^{0} = \mathbf{A}_6^0\mathbf{r}_6 \,,\; \mathbf{r}_{C2}^{0} = (x_{C2}\, y_{C2}\, z_{C2}\, 1)^T \,,\; \boldsymbol{r_6} = (0\; 0\; l_6\; 1)^T,$$
$$\mathbf{r}_{C2}^{0} = \mathbf{A}_{03}^{0}\mathbf{A}_3^{03}\mathbf{r}_3 \,,\; \boldsymbol{r_3} = (0\; 0\; l_3\; 1)^T, \tag{1}$$
$$\mathbf{r}_{C2}^{0} = \mathbf{A}_{07}^{0}\mathbf{A}_7^{07}\mathbf{r}_7 \,,\; \boldsymbol{r_7} = (0\; 0\; l_7\; 1).$$

Manipulating equations (1) gives the coordinates of the point C_2 and angles α_3, α_6, α_7 in the form

$$\alpha_7 = Sin^{-1}\left(\frac{B\cdot a}{F\cdot B - G\cdot A}\right)$$
$$y_{C2} = -G\cdot\frac{B\cdot a}{F\cdot B - G\cdot A},\;\; z_{C2} = l_7\cdot Cos(\alpha_7) \tag{2}$$
$$\alpha_6 = Sin^{-1}\left(\frac{x_{C2}}{A}\right),\;\; \alpha_3 = Cos^{-1}\left(\frac{z_{C2}}{l_3}\right)$$

Here we introduce the auxiliary variables
$A = l_6 \cdot Sin(\theta_6)$, $B = l_6 \cdot Cos(\theta_6)$
$F = l_7 \cdot Sin(\theta_7)$, $G = l_7 \cdot Cos(\theta_7)$

The position of the B_2 can be determined from the geometry of tetrahedron Figure 3 *a* with the condition that it B_2 is situated on the surface of the sphere with the radius C_2B_2. Thus, the position of B_2can be determined by a

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matrix equation, from $\mathbf{A}_5^0, \mathbf{A}_{08}^0, \mathbf{A}_8^{08}$ matrixes that are expressed with eight parameters from

$$\mathbf{r}_{B2}^0 = \mathbf{A}_5^0\mathbf{r}_5,\ \boldsymbol{r}_5 = (0\ 0\ l_5\ 1)^T,$$
$$\mathbf{r}_{B2}^0 = \mathbf{A}_{08}^0\mathbf{A}_8^{08}\mathbf{r}_8,\ \boldsymbol{r}_8 = (0\ 0\ l_8\ 1)^T \tag{3}$$

When the condition is considered as

$$(x_{C2}-x_{B2})^2+(y_{C2}-y_{B2})^2+(z_{C2}-z_{B2})^2-a^2=0 \tag{4}$$

Solving of equations (3) and (4) gives

$$\alpha_8 = Sin^{-1}\left[\frac{a(A1\sqrt{3}-B1)}{A1\cdot D1+B1\cdot C1}\right],\quad z_{B2}=(h_8+l_8)Cos(\alpha_8)$$
$$(x_{B2})_{1,2} = \frac{-P\pm\sqrt{P^2-U1(1+k^2)}}{1+k^2} \tag{5}$$
$$y_{B2}=\frac{B1\cdot x_{B2}}{A1},\quad \alpha_5 = Sin^{-1}\left(\frac{x_{B2}}{A1}\right)$$

Here auxiliary variables used: A_1, B_1, C_1, D_1, k, U, P.

$$A1=\sin(\theta_5)\cdot l_5,\quad B1=-\cos(\theta_5)\cdot l_5,\quad C1=[\sin(\theta_8+\sqrt{3}\cos(\theta_8)]\cdot l_8,$$
$$D1=[\cos(\theta_8)-\sqrt{3}\sin(\theta_8]\cdot l_8,$$
$$U=\{z_{C2}-l_8\cdot\cos\left[\frac{a(A1\sqrt{3}-B1)}{A1\cdot D1+B1\cdot C1}\right]\}^2-a^2$$

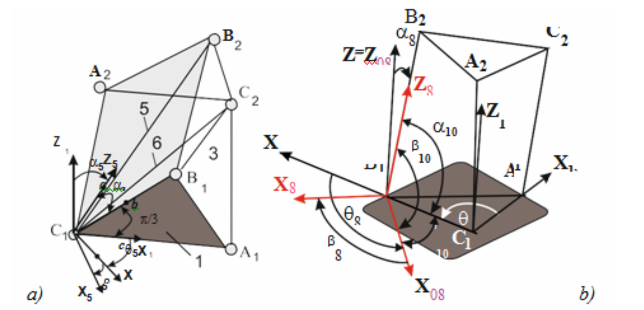


Figure 3 Geometry of tetrahedron with kinematic variables: (a) by the chain C_1-B_2; (b) by the chain C_1-B_1-B_2

Therefore coordinates of A_2 must satisfy the following three equations

$$(x_{A2}-x_{B2})^2+(y_{A2}-y_{B2})^2+(z_{A2}-z_{B2})^2-a^2=0,$$
$$x_{A2}^2+y_{A2}^2+z_{A2}^2-(l_4+h_4)^2=0, \tag{6}$$
$$(x_{C2}-x_{A2})^2+(y_{C2}-y_{A2})^2+(z_{C2}-z_{A2})^2-a^2=0$$

Solving equations (6) it is obtained

$$(z_{A2})_{1,2}=\frac{-\nu\pm\sqrt{\nu^2-4\cdot\mu\cdot\tau}}{2\mu}$$
$$x_{A2}=\frac{\frac{1}{2}(\varepsilon\cdot y_{C2}-\eta\cdot y_{B2})+(z_{C2}\cdot y_{B2}-z_{B2}\cdot y_{C2})\cdot z_{A2}}{x_{B2}y_{C2}-x_{C2}y_{B2}} \tag{7}$$
$$y_{A2}=\frac{\frac{1}{2}(\eta\cdot x_{B2}-\varepsilon\cdot x_{C2})+(z_{B2}\cdot x_{C2}-z_{C2}\cdot x_{B2})\cdot z_{A2}}{x_{B2}y_{C2}-x_{C2}y_{B2}}$$

In (7) variables used are given by

$$\varepsilon=(l_5)^2-a^2+(l_4)^2,\quad \eta=(l_6)^2-a^2+(l_4)^2,$$
$$Q=y_{C2}^2+x_{C2}^2,\quad R=y_{B2}^2+x_{B2}^2,$$
$$S=y_{C2}y_{B2}+x_{C2}x_{B2},\quad T=y_{C2}x_{B2}-x_{C2}y_{B2},$$
$$\mu=Qz_{B2}^2+Rz_{C2}^2-2Sz_{B2}z_{C2}+T,$$
$$\nu=-\varepsilon Qz_{B2}-\eta Rz_{C2}+\eta Sz_{B2}+\varepsilon Sz_{B2}$$
$$\tau=Q\,\varepsilon^2/4+R\,\eta^2/4-S\,\varepsilon\cdot\eta/2-(x_{B2}y_{C2}-x_{C2}y_{B2})^2(l_4)^2$$

Position point C_2 is determined by the variable lengths l_3, l_6, $l_7$of links 3,6,7; the position of the B_2 is determined by links l_5, $l_8$and also depends on the position of the C_2; the position of the A_2 is determined by length l_4 and depends on the positions of C_2 and B_2. Thus, using egs (1) to (7) the configuration of the platform can be computed. As an example, on the basis of obtained algorithm using Matlab made calculations and diagrams were constructed for translational (fig. 4,a), spherical (fig. 4,b) motion.

In the calculations were taken: a=580 mm; k=1.2 ; for translational motion h_4= h_7= h_8=8 mm, h_3= h_5= h_6=6 mm; for spherical motion h_3= h_6= h_7=0., h_4= h_5= h_8=8 mm; number of cycles N=5.

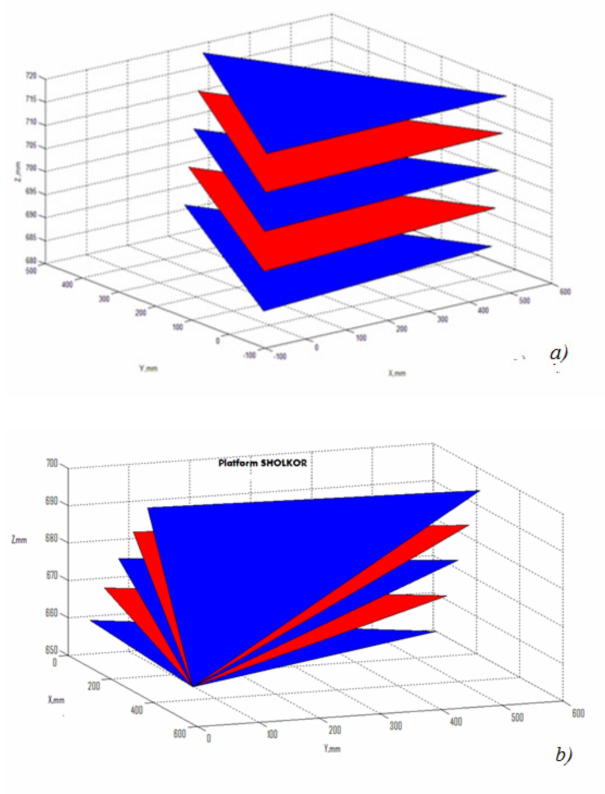
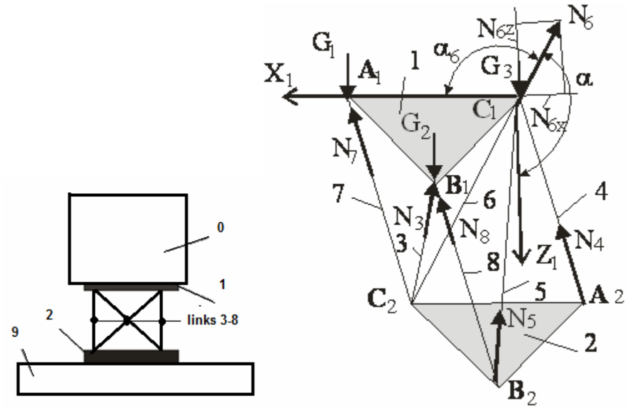


Figure 4 Computed platform position by using Eqs (1) to (7) a) translational motion; b) spherical motion.

3 KINESTOTATIC ANALYSIS

These pressures for each hydraulic drive are determined by power analysis of adaptive support's bearing platform.

In Fig. 5 it is shown a diagram of the application as an active parallel manipulator support SHOLKOR. An active support is located between the object 0 and base 9. The manipulator has two platforms 1 and 2 that are connected by six connecting links 3-8 (Fig. 5, b). The lengths of the connecting links are changed by a controlled electrohydraulic drive (Fig. 8).



a) b)

Figure 5 A model for kinestatic analysis: a) the system structure; b) a scheme with acting forces.

When a mechanical action acts on the base 9, platform 2 is moved together with the base. If the support is represented by a rigid structure, then at moving to the lower platform 2 it would move together with the upper platform 1and protected object. However, the length of the connecting links 3-8 of the active support can be varied and they compensate the movement of the lower platform. The main purpose is to provide the state of rest of the protected object. The kinestatic analysis can be as in the following.

On the platform 1 the forces of gravity G_1, G_2, G_3 of the object and platform will act at the three nodal points A_1, B_1, C_1 . On the other hand the reaction forces N_3, N_4, N_5, N_6, N_7, N_8 from the six hydraulic actuators of connectors 3-8 are directed along the corresponding links. It can be noted that these reactions depend on the inertia forces applied to the platform 2 and mechanical impact forces. Thus kinetostatics equations can be expressed as:

$$\begin{gathered}
\sum_{i=3}^{i=8} N_{ix} = 0; \quad \sum_{i=3}^{i=8} N_{iy} = 0; \\
\sum_{i=3}^{i=8} N_{iz} + G_1 + G_2 + G_3 = 0; \\
\sum_{i=3}^{i=8} M_x(\mathbf{N}_i) + y_{A1}G_1 + y_{B1}G_2 = 0; \\
\sum_{i=3}^{i=8} M_y(\mathbf{N}_i) - x_{A1}G_1 - x_{B1}G_2 = 0; \\
\sum_{i=3}^{i=8} M_z(\mathbf{N}_i) = 0.
\end{gathered} \tag{8}$$

Here the coordinates (x_{A1},x_{B1},y_{A1},y_{B1})) of A_1, B_1 points of application of vector forces $\mathbf{N}_i$ are known since they are determined from the kinematic calculations. For example, Fig. 5 *b)* shows the reaction force N_6 applied to a point C_1, which coincides with the origin of the $C_1X_1Y_1Z_1$ coordinate system. In Fig. 5 *b)* the projection force N_6 on axis C_1Z_1 and C_1X_1 are determined by

$$N_{6z} = N_6 Cos\alpha_6 \,, \; N_{6x} = N_6 Cos\alpha \tag{9}$$

In these equations angle α6 and α are determined according to Fig. 2 from equation (2). Thus in the six equations (8), the unknown variables are the quantities of the six hydraulic drives' reaction forces N_i *(i* = 3,…,8*)*. Each N_i force depends on the liquid pressure in the cavity *i* - of the hydraulic cylinder' rod P_{Ni} and the piston area S_i and is defined by the equation $N_i=P_{Ni}S_i$. Therefore by solving the equations (8) the fluid pressure P_{Ni} is determined in the hydraulic cylinder's rod cavities of six connectors. Thus, the static state of the protected object is achieved by maintaining the desired pressure P_{Ni} in hydraulic cylinder's rod cavities of six connectors.

If the forces of gravity G_1, G_2, G_3 are identified by a force sensor in 3-nodal points A_1, B_1, C_1, then the pressure in the cavities of hydraulic cylinders P_{Si} can be determined by a pressure sensor installed in each hydraulic cylinder of the pressure chamber.

4 DESIGNS AND CONSTRUCTION OF A PROTOTYPE WITH MANUAL CONTROL

A prototype which is shown in Fig. 6 is built in order to demonstrate the possibilities of the parallel manipulator positioning. Prototype consists of the lower (stationary) platform 1, the movable platform 2. Platforms of the manipulator are connected using six connecting links, the lengths of which are changed with hydraulic actuators 3 with manually operated spill valves 4.

Figure 7 shows the specific mechanical designs of the spherical joints that are used for the construction of a prototype of the parallel manipulator with the topology of the structure shown in figure 1 *a*. In spherical three link joint (Figure 7, a) link 1 has a hollow spherical head, which its outer surface forms a spherical connection with a spherical head of link 2 and its inner surface forms a spherical relation to the round head element 3. Four link spherical joint (Figure 7,b) composed of a cardan connection with the universal-joint fork 6 and 7, in which the crossbar is made in the form of a spherical race 8, which forms a spherical connection with the links 4 and 5 is similar to spherical three link connection is shown in (Figure 7,a).

Research conducted on the prototype had helped to persuade the parallel manipulator's features, namely:

Each of the six actuators (Figure 6) can move independently. For example, it is possible to change the length of a one connecting links using the drive without changing lengths of the other connecting links, with corresponding motion.

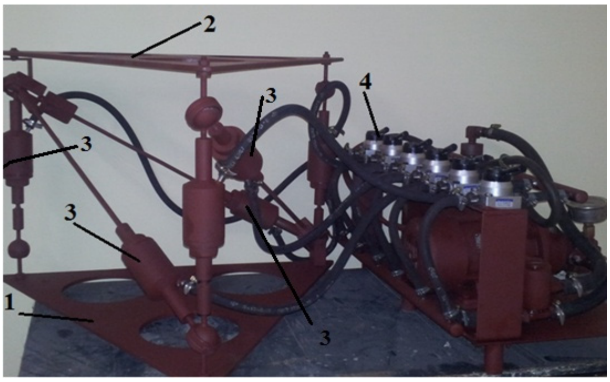


Figure 6 The prototype of the parallel manipulator Sholkor
1-stationary platform; 2- movable platform;
3- actuators; 4- regulating valve.

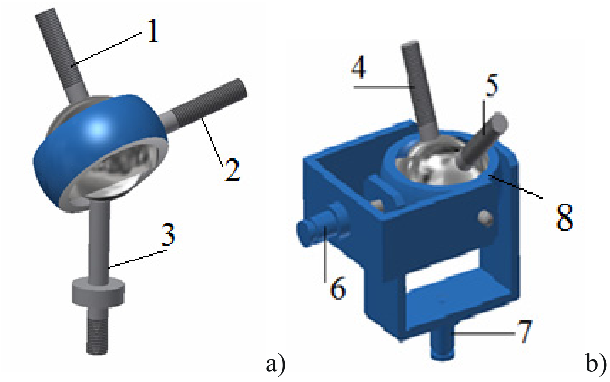


Figure 7 Multilink spherical joints: a) three link spherical joint; b) four link spherical joint.

By varying lengths of a certain set of CL in a pre-specified way, it is possible to obtain any spatial position of the movable platform or simple movements.

Each spatial position of the movable platform meets certain length of CL. From this it follows that it is possible to move the movable platform as a leading element, thus, as a consequence the length of CL will vary. Namely, due to these peculiarities, the manipulator under consideration can be used as active support, where in under the action of mechanical impact's a source, the lower platform as guide link can perform the spatial movement, relative to the upper platform, which related to the protected object.

5 THE PROTOTYPE CONSTRUCTION OF THE ACTIVE SIX AXLE SUPPORT

In order to respond to the action of source of sudden mechanical impacts and to avoid the disturbance action on the protected object between the protected object and the source of mechanical impacts, it is installed the active support. In this operation, as an active control support for large mass objects will be proposed a parallel manipulator. Therefore, the parallel manipulator must be equipped with hydraulic actuators with automatic control, operating in the mode of controlled dampers.

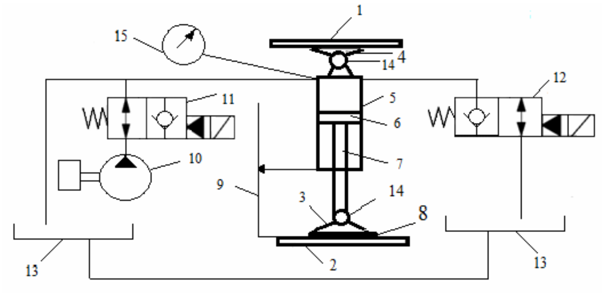


Figure 8 A scheme of an hydraulic actuator
for active support.

Figure 8 shows the system of one automatically operated hydraulic actuator of the parallel manipulator. The actuator of an active support installed between the protected object 1 and the source of impact 2 and consists of the lower (movable) 3, the upper (stationary) platform 4. Actuating motor is in the form a hydraulic cylinder of unilateral actions 5, with the piston 6 and a rod 7. The force sensor (FS) 8 determines the load on the lower movable platform. The motion sensor (MS) 9 measures the movement of a rod of a hydraulic cylinder. The hydraulic system consists of pump station 10, normally open delivery solenoid valve (NO) 11 and normally closed electromagnetic drain (bleeding) valve (NC) 12, the tank 13. The sensor (PS) 15 measures the pressure in the piston chamber. The movable and lower platforms are connected to the hydraulic cylinder by ball joints 14. Work of a controlled hydraulic actuator is to provide automatically the required pressure in the piston cavity of a hydraulic cylinder.

Dissipation mechanism of sudden mechanical impacts based on the fact, that at any given time, by controlling the pressure in the upper enclosure of six hydro cylinders can be achieved the equilibration forces, acting on the upper platform, i.e. stationary upper platform, while when the lower platform can perform unwanted movements, together with the source of mechanical impacts. In this connection the control system of each hydraulic drive should automatically provide the necessary pressure in the cylinder above the piston enclosure of hydraulic actuator. Figure 8 shows an algorithm flowchart of hydraulic actuator's control an active support.

According to the algorithm, the active support in the form of parallel manipulator is set to the initial position. At each position, nominal values at step 1 are set by scanning the sensors. Upon detection of impact the controller will consider the sensor data, step 1. With the known position of the platform (by position sensor) the value of pressure is determined at step 2. At step 3 the calculated pressures in enclosure of the hydraulic cylinders are compared with the sensed pressure and are fed to give a binary signal on one of the valves to proceed to step 4. When the pressures are equal, then the state of valves is not changed. At step 4, as depending of the condition PH>PD a signal will be give to open or close the valve in order to keep controlled the object position.

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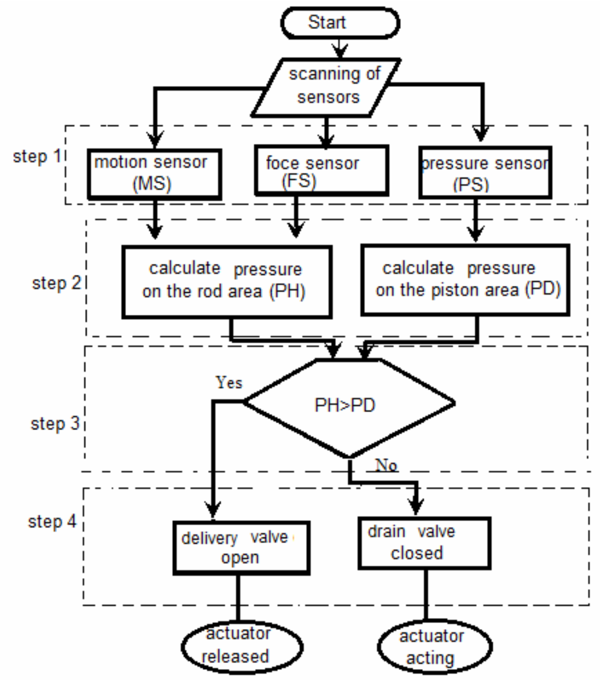

Figure 9 A flowchart of the control algorithm for the generation of active support at each position.

In order to investigate the possibility of using parallel manipulator as a six axle active support in the work created a prototype active controlled support (Figure 10).

Each hydraulic actuator in this parallel manipulator has a hydraulic circuit diagram shown in figure 7. Each hydraulic drive is equipped with pressure sensors 3, movement sensors 2, force sensors 1 between the movable platform and three connecting points. Actuators are six delivery valves 4 and six drain solenoid valves 5. The hydraulic system of actuators an active support is powered by a hydraulic pump 6.

To perform the operation of the parallel manipulator as active support, the control system (CS) shown in Figure 11 was designed. The Figure 10 displays the same notation as in Figure 7, except for number 16 that indicates Mitsubishi FX3U - 16MR/ES industrial controller.

The controller 16 (Figure 11) processes the signals from the pressure sensors 15, motion sensors 5 and the force sensor 8. The algorithm is implemented as a program for controller FX3U - SCADA visualization system displays 16mr / ES in algorithmic language C. Current system parameters and modes of valves operation on the computer screen (Figure 12).

6 AN EXPERIMENTAL CHARACTERIZATION

An active control support must react promptly to the action of contingencies action's sources and prevent the effects on the protected object by harmful disturbances. In this way the effectiveness of the active support's functioning in a large extent is determined by its motor reaction.

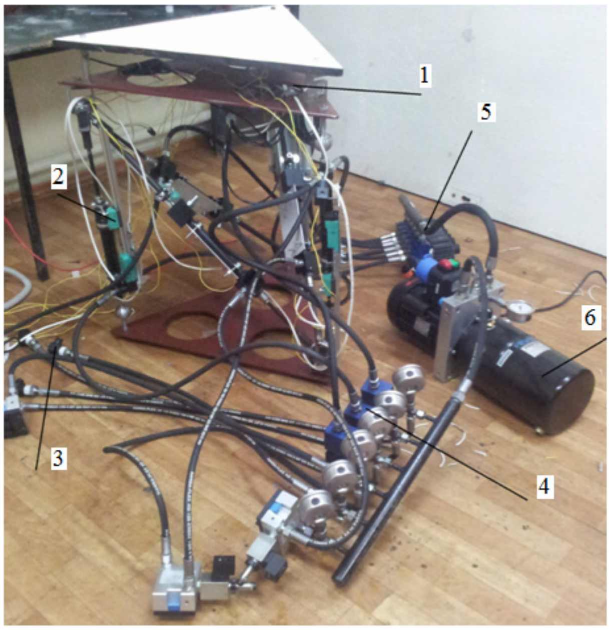

Figure 10 A prototype of active support of the parallel manipulator: 1-force sensor; 2- movement sensor; 3- pressure sensor; 4- delivery valve; 5-drain solenoid valve; 6- hydraulic pump.

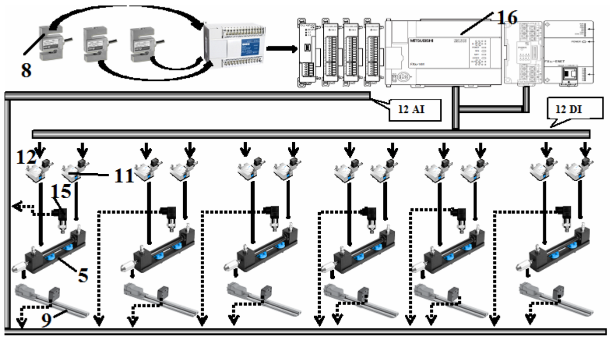

Figure 11 Components of the active support control system for prototype in Figure 10
8- force sensor; 9- piston sensor; 11, 12- valves of cylinders; 15- pressure sensor; 16- controller.

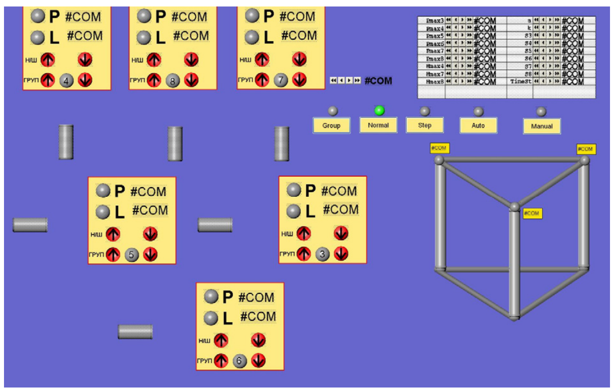

Figure 12 Screen programs in SCADA system

It is known that under consideration motor reaction we understand the time of the quickest answer, done by simple and well known in advance movement to the signal, which appears suddenly, but which is well known. The motor response of active support depends on the motor reactions of controlled hydraulic actuators. In this connection, it is given an experimental investigation of the motor reactions of controlled actuators by applying the prototype of the active support (Fig. 10).

For carrying out experiments on the movement platform of the parallel manipulator freight of the set weight of 15 kg settled down. Sensors of the movement were installed in the initial situation when rods are in a starting position. Using force sensors and sensors of pressure values of the efforts operating on a rod and pressure in working cavities of hydraulic cylinders were defined. The controller processed these values and used by the program of the managing director of the parallel manipulator. Then, according to the set sequence, the control unit exercised to control the movement of a platform of the parallel manipulator. The controller processed the received data from the information and measuring system according to the set program, and the graphs of the dependence of movement of a rod and pressure in a hydraulic cylinder of the drain valve were displayed on the SCADA monitor. It should be noted that in the prototype of active support generally is available on three hydraulic actuators of a look 7 and 3 which differ in that in a hydraulic actuator 7 diameter of the d1 piston = 20 mm., and in a hydraulic actuator 3 diameter of the piston of a hydraulic cylinder of d2 = 16 mm., also in a hydraulic actuator 7 the piston has choking openings, and a hydraulic actuator 3 – there are no choking openings. However, all hydraulic actuators are unilateral with a returnable spring.

On the graphs (Figure 13) received for a hydraulic actuator 3 as a result of measurements during t=4s. Experimental data give the chance to measure a time interval of delays of which motive reaction of a concrete hydraulic actuator is formed. Indeed, the schedules constructed for a hydraulic actuator 3 that after the command for closing off the drain valve forcing of working fluid in a hydraulic cylinder cavity begins. The pressure in a cavity of a hydraulic cylinder starts changing through Δ_1=0.37s time and after Δ_2=0.37s the movement of a rod of a hydraulic cylinder starts. Thus, movement reaction of a hydraulic actuator to the team of promotion of a rod by closing off the drain valve makes up Δ_{ON}=074s. The same schedules allow determining time intervals of a delay on team lowering of a rod. The team of lowering of a bar is realized by the opening of the drain valve. Thus, working fluid pressure in a cavity of a hydraulic cylinder falls, and the rod under the influence of a returnable spring descends. As it can be seen from the results of the experiment (Figure 13), after opening the drain valve before reduction of pressure in a cavity is observed a temporary delay of Δ_3=0.25s. Then from the moment of reduction of pressure before the movement of a rod passes Δ_4=0.25s time interval. Thus, motor reaction to the return trip of a rod makes Δ_{Off}=0.5s.

Similar test studies were conducted with the hydraulic actuator 7 with choking channels. These data were captured during the time frame t=4s (Fig. 14) and carried out with the purpose to determine movement reaction of the drive with a choking on the execution of the command of promotion of a rod.

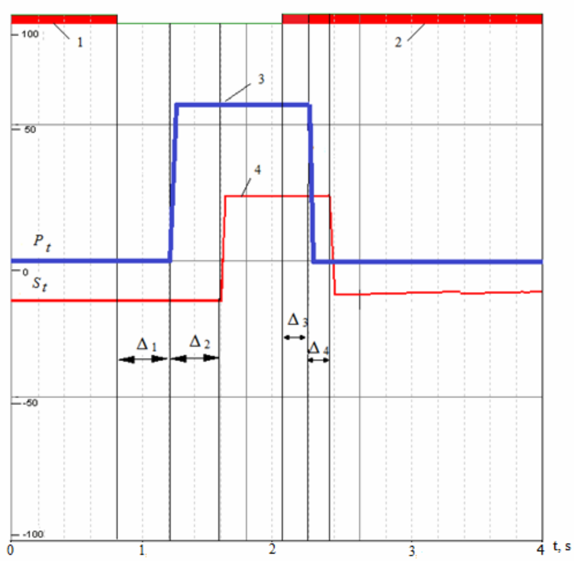

Figure 13 An experimental curve of hydraulic actuator 3 on the pressure and displacement with time
1,2 – schedules for a phase of opening of the drain valve;
3 – schedule of change of pressure in a rod plenum;
4– schedules of change of movement of a rod

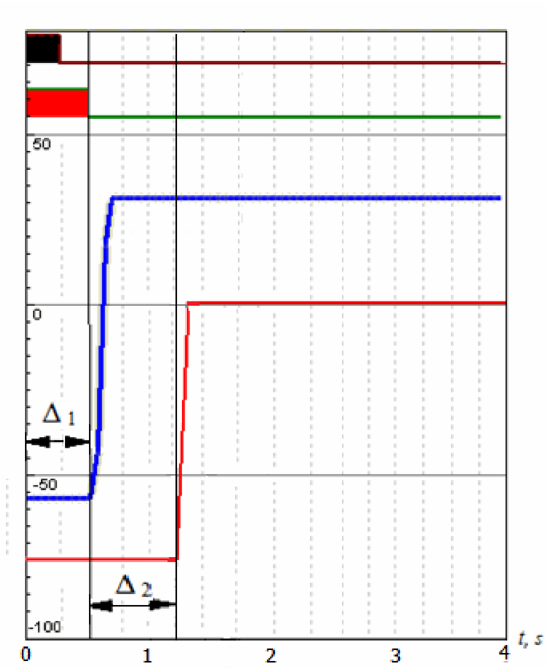

Figure 14 An experimental curve of hydraulic actuator 7 on the pressure and displacement with time.

As appears from these experiments after closing the drain valve before the pressure increases time frame of Δ_1=0.5s passes in a cavity of a hydraulic cylinder and further after the beginning of the rise in pressure before the movement of a rod Δ_2 time frame = 0.82s. passes. Thus, motor reaction of the given hydraulic actuator to the command of a rod movement makes Δ_{ON}=1.32 s.
Thus, the technique for definition the motor reactions of drives on experimental samples are obtained. The received results characterizing components of motor reactions of two types of hydraulic actuators allow us to make the following conclusions: the working fluid ways are the reason of delays of Δ_1; motor reaction of Δ_{ON} of a hydraulic actuator with choking channels is more than in a hydraulic actuator without choking. It means that improvement of motor reaction of the drive requires joint execution in a hydraulic actuator of actuation mechanisms and control equipment's, i.e. application of the mechatronic hydraulic actuators is necessary to exclude the impact of the working fluid ways. On the other hand, experiments showed that application of the choking elements in hydraulic actuators in the parallel manipulator used as active supports decreases their motor reaction.
Results of the test studies showed that it is possible to achieve the required figures of motor reactions so that the parallel manipulator hydraulically actuated could be used as an active controlled support.

7 EXAMPLE OF THE ACTIVE SUPPORT APPLICATION AS A SEISMIC ISOLATION SYSTEM

As an example we shall consider the implementation of combined technology of seismic protection consisting (Figure 15) of active and passive seismic systems, between the ground part of the building 1 and foundation 2 with the bottom part of base 3 are to be installed passive seismic isolation devices, for example, such as kinematic foundations 4. On the sides of the base of the building for liquidating horizontal inertial forces are installed systems of active seismic protection, composed of eight parallel manipulators 5 [18].
Some parallel manipulators depends on the construction area. Calculations for the first option of the combined system, as per bearing capacity, by average values in the hydraulic system of 35 bars and piston diameter of 250 mm show that one parallel manipulators installed for every 220 sq.m. of the building area. The practice shows that approximate weight of 1 sq.m. of the building is ten kN. There are a lot of areas in which the use of active supports is of vital necessity.

CONCLUSION

In this article in the analytical form is solved the direct problem of parallel kinematic's manipulator with a new topology structure. The solution of the direct problem of kinematics, and also the prototype of the parallel manipulator had shown that the parallel manipulator has got the functional possibilities which enable to use it as the active control support.
To substantiate the possibilities of using the parallel manipulator as active support is created the prototype of the active six axle support. The scheme of automatically controlled hydraulic drive is developed. The algorithm of drive's control in the mode of active support is created.
From the results of experimental investigations of the motor reactions value in hydraulic actuators follows, that for improving the drive's motor reaction it is necessary to use the mechatronic hydraulic actuators without the throttling elements.
The value of the motor reaction, equal to 0.74 c., which is derived for hydraulic drive without throttling apertures which indicates that the parallel manipulator can be used as an active controlled support.
A diagram of a seismic protection system shows the possibility of application in the future the parallel manipulators as active controlled support.

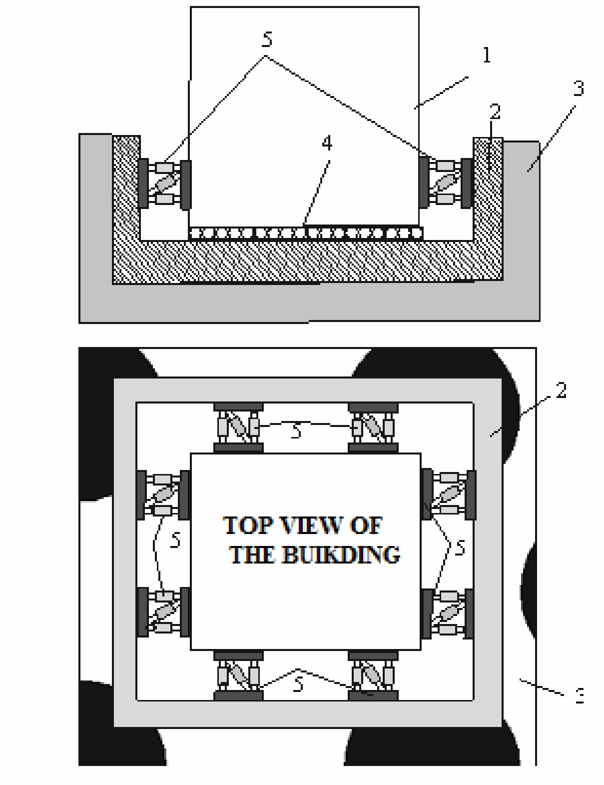

Figure15 An example of active isolation seismic systems with parallel manipulator
1-the ground part of the building; 2-foundation; 3-the bottom part of the base; 4-kinematic foundations; 5-parallel manipulator isolation units.

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