Parallel robots used in passive and active protection of the buildings

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***Abstract*—The paper presents some aspects related to the passive and active protection of the buildings. It is well know that Stewart platform is a mechanism with six degrees of freedom. This main property leads to the idea of its utilization in order to simulate fully the movements of earthquakes. On the other hand, from the same point of view this mechanism can be used into the passive and/or active protection of the buildings. The paper presents the main equations for these situations. Also, a virtual model and a simulation model were developed.**

***Index Terms*—Parallel robots, Earthquakes, Protection of the buildings.**

I. INTRODUCTION

Utilization of the parallel mechanisms as robotic systems it is continually increased during last period. This is more or less normal if their advantages are taken into consideration: a very good dynamics, a good ratio between the total mass and the manipulated mass, a good stiffness and also a relatively easier control of the actuators. One of the first applications of these mechanisms was to simulate the fly conditions in order to improve the training of the pilots. This paper deals with a similar idea that means utilization of parallel mechanisms as simulators for phenomena which are characterized by six independent parameters. Thus, the main goal of the paper is to develop a mathematical model for a hybrid mechanism useful in passive and / or active protection of the building during earthquakes.

II. SYNHESIS

It is well know that, from mechanical point of view, an earthquake means a complex dynamic stress for the buildings. Generally, as consequences these are damaged. Many of the buildings have no capabilities to resist at that dynamic stress. Usually, the passive systems which are provided for attenuation of the perturbations have not more that 2 or 3 degrees of freedom.

A functional analysis of the earthquakes shows that there are three characteristics which are responsible for the building behaviour during the earthquake (Fig.1a): a) of the earthquakes; b) of the system of the protection; c) of the building. These three components form together a system which will be named RES (Real Earthquake System)

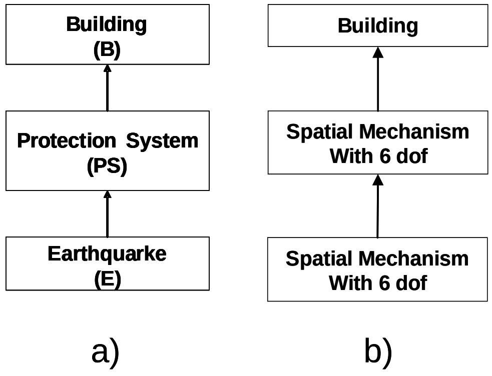

Fig. 1. a) Components of RES b) Components of MEMPS

The characteristics of the (E) are unpredictable. Anyway the most general case is when the earthquake provides all six movements (three linear displacements and also three angular displacements).

The characteristics of the (PS) must be designed according to those of (E). Of course, this is very difficult when the characteristics of (E) are unpredictable. Also, in this case a (PS) with six degrees of freedom is the best solution.

The characteristics of the buildings are known, but unfortunately these are unchangeable.

According to these remarks a mechanical substitute of RES (named MEMPS) can be developed (Fig.1b). We propose as mechanism with six dof, a parallel mechanism with six legs, and each leg with a PSU (Prismatic – Spherical – Universal) topology. It results a complex mechanism (Fig.2) formed by a serial connection of two independent 6 dof mechanisms: first of them (corresponding to E and noted with ME) with the task to provide movements similar to those of the earthquakes; b) the second one (corresponding to PS and named MPS) with the task to ensure an active or passive protection. The protection is active if the prismatic joints are actuated and passive if they are not actuated.

In order to describe easily and uniquely these mechanisms, the graph associated to each mechanism can be used. Thus, to build up the graph which correspond to a given mechanism two steps must be followed: a) each joint of the mechanism has a corresponding element into graph; b) each element of

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the mechanism has a corresponding nod into graph. The number of non intersecting interiors of the graph is equal with the number of the independent closed loops and the frontiers of these interiors are the frontiers of the closed loops. This remark it will be useful for writing independent vector equations in the frame of kinematics of the mechanism.

Figure 3 presents the graph of MEMPS mechanism.

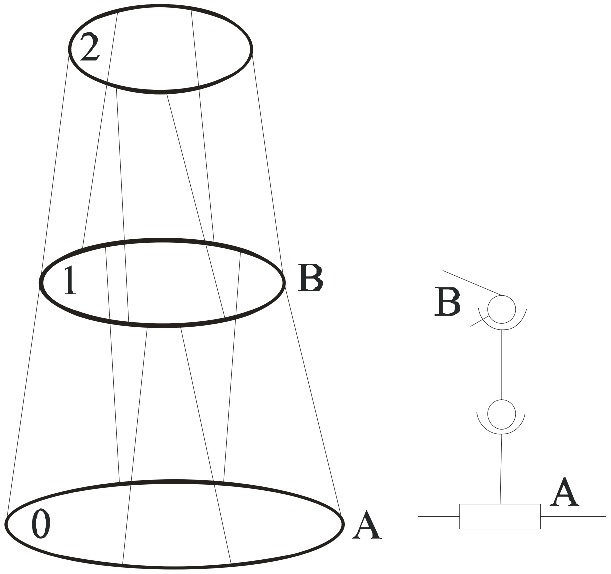


Fig. 2. The complex mechanism

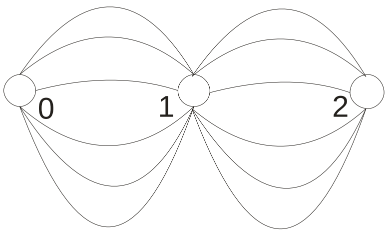


Fig. 3. The graph of the hybrid mechanism

It is important to show that from kinetic-static point of view, the six legs of the MPS are not enough to sustain a building. In this case, additional legs with the same topology can be added:

$$M = 6 + M_{add} . \tag{1}$$

where M_{add} is the number of degrees of freedom of the additional legs. According to the assumed hypothesis M_{add} is given by:

$$M_{add} = 6n - 5c_5 - 4c_4 - 3c_3 \tag{2}$$

or:

$$M_{add} = 12N_{add} - 5N_{add} - 4N_{add} - 3N_{add} = 0 \tag{3}$$

where N_{add} is the number of additional legs.

It results that any additional leg doesn't change the global number of degrees of freedom.

III. KINEMATICS

The kinematics of the parallel mechanisms with PSU topology is not complicated and, for an independent closed loop (Fig. 4), is given by:

$$\mathbf{r}_l = \mathbf{r}_r \tag{4}$$

or as matrix form:

$$\mathbf{H}_{iml} = \mathbf{H}_{imr} \tag{5}$$

where:

$$\mathbf{H}_{iml} = \prod \mathbf{A}_{il}(q_{il}) , \mathbf{H}_{imr} = \prod \mathbf{A}_{ir}(q_{ir}) , \tag{6}$$

$\mathbf{H}_{iml}$, $\mathbf{H}_{imr}$ are absolute transformation matrices and $\mathbf{A}_{il}(q_{il})$, $\mathbf{A}_{ir}(q_{ir})$ are relative transformation matrices.

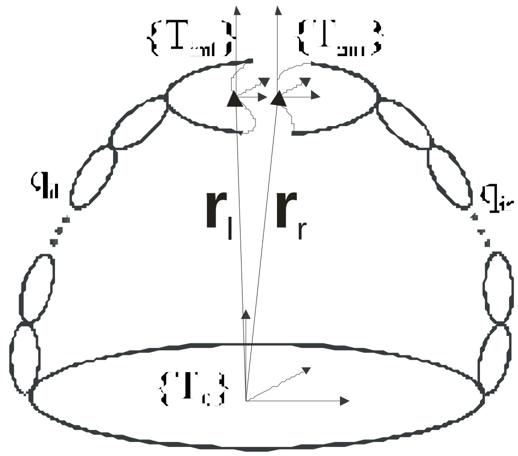


Fig. 4. Vector equations for a closed independent loop

Equations (5) and (6) define two closed vector loops, one for the right side and the other one for the left side of each independent closed loop of the mechanism (Fig.4).

Matrix equation (5) leads to six independent scalar equations. For whole parallel mechanism, a nonlinear system of equations (with 6n independent scalar equations, where n is the number of independent loops) will be obtained. This system of equations can be solved only with numerical methods and classic algorithms, e.g. Newton-Raphson, can be used in order to solve it.

It results, for the forward problem, a nonlinear system of equations and for the inverse problem a very simple linear system.

The Jacobian matrix is given by:

$$\mathbf{J}_{\mathbf{j}} = \left[\mathbf{e}_{\mathbf{I}} \times \mathbf{r}_{\mathbf{I}} \quad \mathbf{r}_{\mathbf{I}} \right] \tag{7}$$

where $\mathbf{e}_I$ is the unit vector of the leg "I"and $\mathbf{r}_I$ is the position vector of the centre of the mobile platform related to the centre of the universal joint of each leg.

Thus, the velocities are given by:

$$\dot{\mathbf{Q}} = \mathbf{J}\,\mathbf{V} \tag{8}$$

where $\dot{\mathbf{Q}}$ is the vector of relative velocities and V is the vector of absolute velocities.

IV. DYNAMICS

Dynamics of Stewart platform is fully described by Angeles [1]. Thus, if the mobile platform (Fig. 5) is considered as free platform (under equilibrium of the acting forces and wrenches), the dynamic equations are given by:

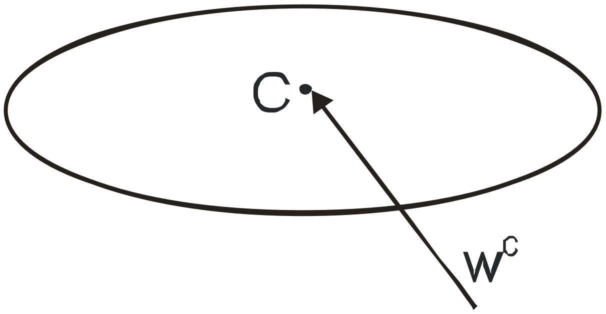


Fig.5. Mobile platform as free platform

$$\mathbf{I}\,\ddot{\mathbf{Q}} + \mathbf{C}(\mathbf{Q},\dot{\mathbf{Q}})\,\dot{\mathbf{Q}} = \mathbf{f} - \mathbf{J}^{\mathrm{T}}\mathbf{w}^{\mathrm{C}} \tag{9}$$

where I is inertia matrix of the robot, C is the matrix coefficient of the inertia terms which are quadratic in the joints rate, Q is the matrix of generalized coordinates, f is the matrix of the forces of the actuators, J is the Jacobian matrix and WC is the matrix of the constrain wrench of the legs related to the platform.

V. VIRTUAL MODEL

Based on kinematics and dynamics, a virtual model of the simulator was developed. The geometrical parameters of the fixed and mobile platforms of the mechanism, and also the distance between platforms have been considered as inputs of the virtual model. Also, the forces of the actuators are inputs in the case of direct problems and the torque and forces (given by the models of the building and of the earthquake respectively) are inputs for the inverse analysis.

The virtual model was developed using M□BILE software package. This is object orientated software, it works under Visual C++ environment and it is useful for simulation of the multi-body systems. An important characteristic of the virtual model is its modular design (Fig.6). This type of design gives the possibility to change interactively all important parameters of the robotic system.

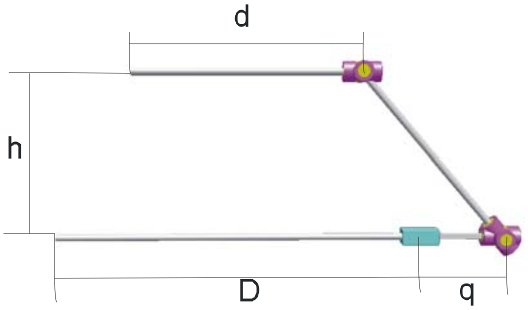


Fig.6. Modular design of the virtual model

The virtual model was developed according to both components of the MEMPS. Thus, first component is six degrees of freedom parallel mechanism, with prismatic actuators (Fig. 7). This mechanism has as functional task to provide complex movements similar to those of the earthquakes. The second component is also six degrees of freedom parallel mechanism and is serial connected to the first one. Its task is to provide protection for the building.

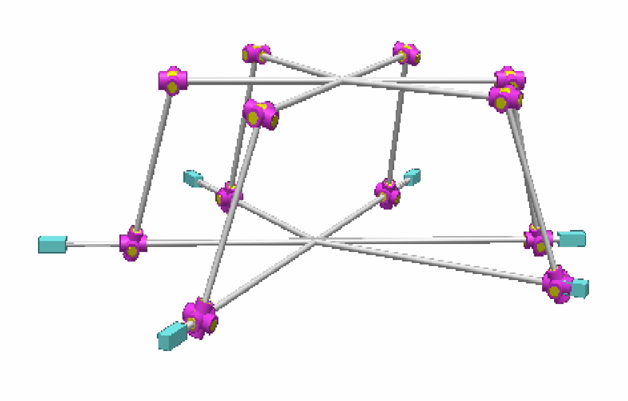


Fig.7. Earthquake simulator

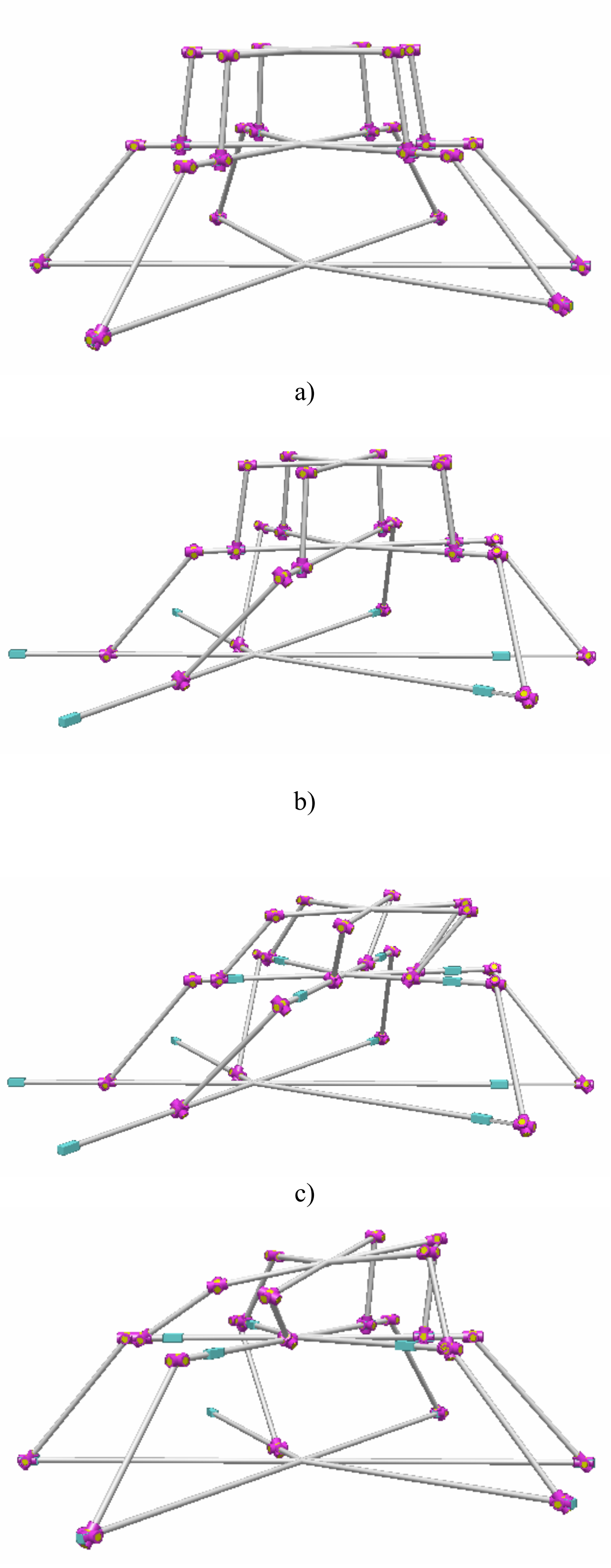
As a result of the serial connection a hybrid mechanism with 12 dof is resulting. This mechanism has decupled degrees of freedom and each component has different functional task. The connection of these mechanisms is a natural connection and is given by the real conditions of the earthquake modeling.

Figure 8 presents different positions of the resulting mechanism.

It can be observed that if an appropriate design it is used, the proposed mechanism can be used for both earthquake simulation and buildings design.

VI. CONCLUSIONS

The main goal of the paper is to develop a virtual model useful for earthquake simulation and buildings design and protection. This goal can be achieved if parallel mechanisms are used for the simulator. Thus, a serial connection of two independent six dof mechanisms was proposed. For this mechanism the basic equations of the kinematics and dynamics were presented. Based on those equations, a virtual model was developed under Visual C++ environment. This virtual model was developed into a modular manner and that leads to a higher flexibility of the model. This work can be continued in the way to consider more stiffness parameters of the building and also in the way to optimize the earthquake model.


a)

b)

c)

d)

Fig.8. Different positions of the simulator

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