The Structure of Modular Walking Robot MERO Displacement Systems, Support of the Heavy Load Transportation

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Abstract: The modular constructions of the walking robots led to a more suppleness and very good adaptation to any terrain surface. Some of the most significant components of the walking robots are the mechanisms of the displacement systems. The design of the leg mechanisms implies the solving of several problems regarding the static stability, the forces distribution, balancing of the gravitational forces in order to diminish the power consumption, optimization of the foot sole shape, optimization of the kinematic dimensions of the leg *etc* The advantages of legged system for off-road have been gradually recognised. One of the most important advantages is mobility. The Modular walking robots represent a special category of robots, characterized by having the power source embarked on the platform. The weight of this source is an important part of the total charge that the walking robot must transport. That is the reason why the walking system must be designed so that the mechanical work necessary for displacement, or the highest power necessary for act it, should be minimal A modular walking robot can traverses most natural terrain. Walking robots better protect the environment, as their contact to the ground is discrete, which considerably diminishes the area underwent to crushing; the robot's weight can be optimally distributed all over the supporting surface, by controlling the forces. Altering the distance to the ground, the robot can pass over young trees or other vegetation, growing in the passage area.

.*Key-Words:* - Modular Walking Robot, Static Balancing, Shifting System ,Legs, Stability margin.

1 Introduction

In order to reach areas hardly to get to, and where man's life were jeopardized, the scientific research has been tackling, during time, topics of different purposes and to achieve mechanisms, able by their skills, to cover several fields. Due to the special circumstances, regarding the vegetation and the terrain's state, and viewing the environment protection, the wheeled or the caterpillared machines, aimed at such applications, have a restrained mobility and thus, they considerably destroy the environment, the vegetation, bushes and the young trees, when passing through

Walking robots better protect the environment, as their contact to the ground is discrete, which considerably diminishes the area underwent to crushing; the robot's weight can be optimally distributed all over the supporting surface, by controlling the forces. Altering the distance to the ground, the robot can pass over young trees or other vegetation, growing in the passage area.

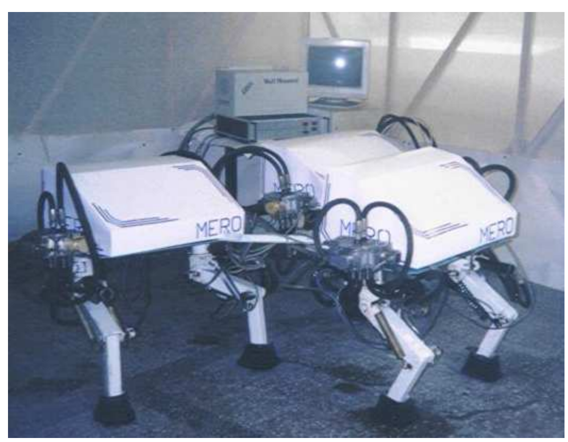

Fig. 1 Experimental model of the six legged MERO2 modular walking robot

Avoiding hurdles such as logs or tree trunks is a considerable advantage.

Likewise, the movement on an unarranged terrain, represents another advantage of the walking robot, as against the other types of vehicles.The walking robot may change the running direction within a very narrow space.

1.1 Applications of MERO modular walking robot in farming and forestry

Compared to the wheeled or caterpillared robot, the modular walking robot is a mechatronic system, its practical use requiring both the computer-assisted surveillance and the thorough checking by the movement systems [5, 6,7,8,15,16].

The locomotion using feet as a movement system was reckoned as an inefficient movement means. Nevertheless, if we take into account the infrastructure's costs to artificially create the roads for wheeled robots or own roads for the caterpillar robots, arguments for these two robot types, diminish, in some of the cases.

Here they are, the main features justifying the superiority of the modular walking robot as compared to the wheeled or caterpillared ones:

- capability to move on unarranged grounds;
- by changing its height (ground clearance) the walking robot can step over certain hurdles;modular
- the possibility to change the configuration of the modular walking robot's shift system;

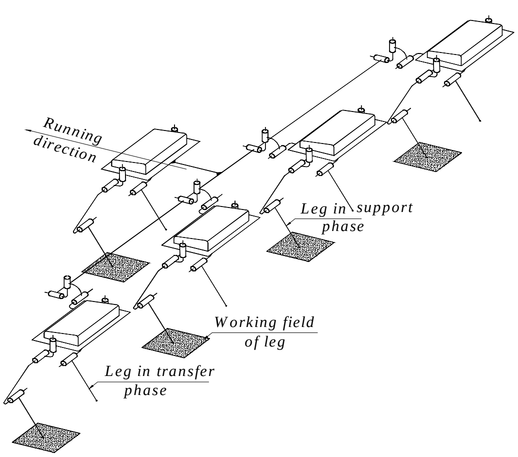

Fig. 2: Eight-legged modular walking robot; it is suggested support of technological equipments to work in farming and forestry

- feet's contact to the ground is discontinuous (it is accomplished only in the leaning phase), when a foot has the opportunity to select its contact point, while descending on the ground, contingent of the latter's surface;
- the possibility to move on a soft ground, which is sometimes more difficult for the wheeled or the caterpillar robot;
- the modular walking robot's active suspension, accomplished by setting proximity and force sensors in the outermost part of feet, enables the movement on uneven ground, under stable circumstances;
- the specific energy consumption is smaller with the movement on natural unarranged grounds as against other types of mobile robots;
- better preservation of the ground, that the robot moves on, especially in case it is made use of in specific farming or forestry activities;

By the terrain settlement, its apparent density grows higher than the normal values, namely its total porosity goes lower than the usual values.

The artificial or anthropic sinking appears as the result of the heavy, insensible traffic, during the farming season, because of the transportation, or for other reasons.

The terrain settlement (compactness) is a specific process to the modern, intensive and strongly mechanized farming, and the higher the mechanization level, the deeper the sinking.

Terrain compactness has many negative effects, no matter which its nature. Thus, it diminishes the terrain's capability to keep water, it reduces the aeration, and it often considerably decreases the endurance to penetration and makes the terrain hard to plow.

As a result of the terrain's degrading, its productivity strongly drops, and the crops sometimes diminish by 50 percent as compared to that on the non-compacted terrains.

Among the drawbacks of the walking robot, here they are some worth to remind you:

- movement checking is rather sophisticated thank to the - large number of freedom degrees;
- they develop rather small speed;
--they claim bigger manufacture, maintenance and exploitation costs.

In order to achieve complex missions, the modular walking robot, designed to be autonomous, needs a hierarchically intelligent control due to its specific natural working conditions, where inaccurate descriptive information and data concerning its own movements as well as the environment are received [12, 14, 17,18,19]. The mechanical system is modular.

The experimental model of the six legged modular walking robot, built and tested in the Mobil Robots Laboratory of the POLITEHNICA

University of Bucharest is shown in Fig. 1. A module of the robot (Fig. 2) is made of a body to which two legs are joined and has got within its structure the necessary elements of the actuator system [5, 7, 18].

Walking machine represent a special category of robots, characterised by having the power source embarked on the platform. This weight of this source is an important part of the total charge that the walking machine can be transported. That is the reason why the walking system must be designed so that the mechanical work necessary for displacement, or the highest power necessary for act it, should be minimal [2, 7, 13, 14]. The major power consumption of a walking machine is divided into three different categories:

- the energy consumed for generating forces required to sustained the body in gravitational field; in other word, this is the energy consumed to compensate the potential energy variation;
- the energy consumed by leg mechanism actuators, for the walking robot displacement in acceleration and deceleration phases;
- the energy lost by friction forces and moments in kinematic pairs.

The magnitude of reaction forces in kinematic pairs and the actuators forces depend on the load distribution on the legs. For slow speed, joint gravitational loads are significantly larger than inertial loads; by eliminating gravitational loads, the dynamic performances are improved.

Therefore, the power consumption for to sustained the walking machine body in gravitational field can be reduced by using the balancing elastic systems and by optimum design of the leg mechanisms [9, 10,11,15]. The potential energy of walking machine is constant or has a little variation, if the static balance is achieved. The balancing elastic system is formed by rigid and linear elastic elements. The purpose of this paper is to presents an elastic system which can be attached to the mechanism leg to reduce the actuator forces and moments magnitudes. This system used the linear helical springs.

2.Optimization of Kinematic Dimension of Displacement Systems of Walking Robots

For the walking robot to get high shift performances on an as different terrain configurations as possible, and for increasing the robot's mobility and stability, under such circumstances, it is required a very careful survey on the trajectory's control, which involves both to determine the coordinates of the feet's leaning points, as related to the robot's body, and the calculation of the platform's location during the walking, as against a set system of coordinates in the field.

These performances are closely connected with the shift system's structure and the dimensions of the compound elements. For simplifying its mounding, it is accepted the existence of a point-shaped contact between the foot and the leaning area.

The shift system mechanism of any walking robot is built so that he could achieve a multitude of the toes' trajectories. These courses may change according to the ground surface, at every step. Choosing a certain trajectory depends on the topography of the surface that the robot is moving on. As one could already notice, during time, the shift mechanism is the most important part of the walking robot and it has one or several degrees of freedom, contingent of the kinematics chain that its structure relies on.

Considering the fact that the energy source is fixed on the robot's platform, the dimensions of the legs mechanism's elements are calculated using a multicritical optimization proceeding, which includes several restrictions. The objective function (Fox R. 1973), (Goldberg D. 1999), (Coley D. 1999) may express:

- the mechanical work needed for shifting the platform by one step ;
- the maximum driving force needed for the leg mechanism;
- the maximum power required for shifting, and so on.

These objective functions can be considered separately or simultaneously. The minimization of the mechanical work consumed for defeating of the friction forces can be considered in the legs mechanisms' synthesis also by a multicritical optimization.

The kinematics dimensions of the shift system mechanism elements are obtained as a result of several considerations and calculation taking into account the degree of freedom, the energy consumption, the efficiency, the kinematics performances, the potential distribution, the operation field and the movement regulating algorithm [4, 7, 14, 16].

There are two possibilities in order to decrease the energy consumption of a walking robot. One of then is to optimize the shifting system of the robot. That could be performing by the kinetostatic synthesis of the leg mechanism with minimization of energy consumption during a stepping cycle.

A second possibility to decrease the energy consumption is the static balancing of the leg mechanism [Ebert-Uphoff I. & Gosellin C.M. 1998), (Ion I., Simionescu I. & Ungureanu M. 2001), (Simionescu I. & Ion I.2001) [3, 5, 6, 15].

The energy consumption is especially depended on the moving law of the platform, which has the biggest mass.

The simplest constructional solution for the leg mechanisms of the walking robot uses the revolute pairs only. The linear hydraulic motor has only a prismatic pair (Fig. 3). This mechanism consists of two plane kinematics chains. One of these kinematics chains is composed by the links (**1**), (**2**) and (**3**), and operated in the horizontal plane. The other kinematics chain operated in the vertical plane and is formed by the elements (**4**), (**5**), (**6**), (**7**), (**8**) and (**9**). The lengths of the elements (**6**) and (**7**), i.e. the distances *IH* and *HP* respectively, are calculated in terms of the size of the field in which the *P* point of the low end of the leg is displaced.

The magnitudes of the driving forces F_{d2} between the piston (**5**) and the cylinder (**4**) and F_{d1} between the piston (**8**) and the cylinder (**9**) are calculated with the following relations:

$$F_{d1} = \frac{Q_x(Y_H - Y_P) - Q_y(X_H - X_P)}{(X_H - X_L)\sin\varphi_2 - (Y_H - Y_L)\cos\varphi_2} + \frac{(m_7 + m_8)g(X_H - X_L) - m_7 g(X_{G7} - X_L)}{(X_H - X_L)\sin\varphi_2 - (Y_H - Y_L)\cos\varphi_2}; \quad (1)$$

$$F_{d2} = \frac{R_{69Y}(X_I - X_J) + R_{67Y}(X_I - X_H)}{(X_H - X_L)\sin\varphi_2 - (Y_H - Y_L)\cos\varphi_2} + \frac{(m_5 + m_6)g(X_I - X_G) - m_6 g(X_{G6} - X_G)}{(X_H - X_L)\sin\varphi_2 - (Y_H - Y_L)\cos\varphi_2} + \frac{R_{69X}(Y_I - Y_J) - R_{67X}(Y_I - Y_H)}{(X_H - X_L)\sin\varphi_2 - (Y_H - Y_L)\cos\varphi_2}, \quad (2)$$

where:

$$R_{69X} = F_{d1}\cos\varphi_2;$$

$$R_{69Y} = F_{d1}\sin\varphi_2 + m_9 g;$$

$$R_{67X} = -Q_X - F_{d1}\cos\varphi_2;$$

$$R_{67Y} = (m_7 + m_8 + m_9)g - Q_Y - F_{d1}\sin\varphi_2;$$

$$\varphi_1 = \arctan\frac{Y_G - Y_E}{X_G - X_E};$$

$$\varphi_2 = \arctan\frac{Y_L - Y_J}{X_L - X_J}.$$

The m_i, X_{Gi} and Y_{Gi} represent the mass and the coordinates of gravity centre of element (***i***) respectively.

The mechanical work of the driving forces F_{d1} and F_{d2}, performed in the *T* time when the robot platform advances with a step by one single leg, has the form:

$$W = \int_0^T \left(F_{d1}\frac{\mathrm{d}JL}{\mathrm{d}t} + F_{d2}\frac{\mathrm{d}EG}{\mathrm{d}t}\right)\mathrm{d}t, \quad (3)$$

where:

$$\frac{\mathrm{d}EG}{\mathrm{d}t} = \frac{1}{EG}\left[(X_G - X_E)\frac{\mathrm{d}X_G}{\mathrm{d}t} + (Y_G - Y_E)\frac{\mathrm{d}Y_G}{\mathrm{d}t}\right];$$

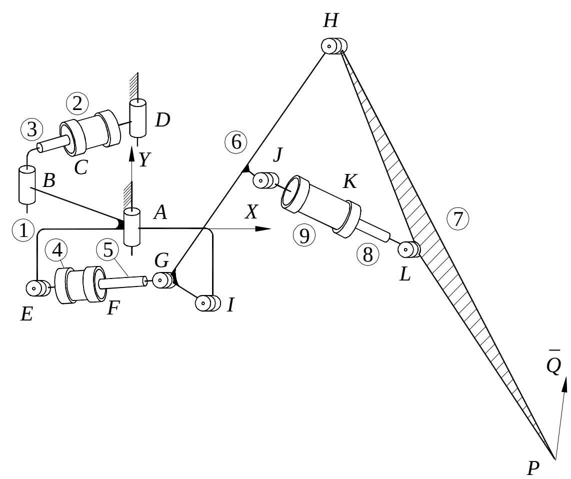

Fig. 3 Mechanism of leg

$$\frac{\mathrm{d}JL}{\mathrm{d}t} = \frac{1}{JL}\left[(X_L - X_J)\left(\frac{\mathrm{d}X_L}{\mathrm{d}t} - \frac{\mathrm{d}X_J}{\mathrm{d}t}\right) + (Y_L - Y_J)\left(\frac{\mathrm{d}Y_L}{\mathrm{d}t} - \frac{\mathrm{d}Y_J}{\mathrm{d}t}\right)\right];$$

$$EG = \sqrt{(X_G - X_E)^2 + (Y_G - Y_E)^2};$$

$$JL = \sqrt{(X_L - X_J)^2 + (Y_L - Y_J)^2};$$

$$X_G = X_I + GI\cos(\varphi_{IH} + \beta);$$

$$Y_G = Y_I + GI\sin(\varphi_{IH} + \beta);$$

$$X_L = X_P + PL\cos(\varphi_{PH} + \alpha);$$

$$Y_L = Y_P + PL\sin(\varphi_{PH} + \alpha);$$

$$\alpha = \arccos\frac{HP^2 + LP^2 - HL^2}{2HP \cdot LP};$$

$$\beta = \arccos\frac{HI^2 + GI^2 - GH^2}{2HI \cdot GI};$$

$$\varphi_{IH} = \arccos\frac{V_1\sqrt{U_1^2 + V_1^2 - W_1^2} - U_1 W_1}{U_1^2 + V_1^2},$$

$$U_1 = 2HP(X_P - X_H),\ V_1 = 2HP(Y_P - Y_H),$$

$$W_1 = HP^2 + (X_P - X_I)^2 + (Y_P - Y_I)^2 - HI^2,$$

$$\varphi_{IH} = \arccos \frac{V_2\sqrt{U_2^2 + V_2^2 - W_2^2} - U_2 W_2}{U_2^2 + V_2^2},$$

$$U_2 = 2HI(X_I - X_H),\ V_2 = 2HI(Y_I - Y_H),$$

$$W_2 = HI^2 + (X_P - X_I)^2 + (Y_P - Y_I)^2 - HP^2;$$

$$\frac{d\varphi_{IH}}{dt} = \frac{HI}{E}\left(\frac{dY_P}{dt}\sin\varphi_{PH} + \frac{dX_P}{dt}\cos\varphi_{PH}\right);$$

$$\frac{d\varphi_{PH}}{dt} = \frac{PI}{E}\left(\frac{dY_P}{dt}\sin\varphi_{IH} + \frac{dX_P}{dt}\cos\varphi_{IH}\right)$$

$$E = HP \cdot HI \sin(\varphi_{IH} - \varphi_{PH}) \neq 0.$$

The minimization of the mechanical work of the driving forces is done with constrains which are limiting the magnitudes of the transmission angles of the forces in the leg mechanism, namely:

$$R_1 = \Psi - \delta_{\min} \geq 0;\ R_2 = \delta_{\max} - \Psi \geq 0; \quad (4)$$

$$R_3 = \Theta - \delta_{\min} \geq 0;\ R_4 = \delta_{\max} - \Theta \geq 0; \quad (5)$$

and the magnitude of the Θ angle between the vectors $\overline{HI}$ and $\overline{HP}$. This angle depends on the maximum height of the obstacle over which the walking robot can passes over, and on the maximum depth of the hallows which it may be stepped over:

$$R_5 = \Phi - \lambda_{\min} \geq 0;\ R_6 = \lambda_{\max} - \Phi \geq 0, \quad (6)$$

where: $\Psi = \varphi_{IH} - \beta - \arctan\dfrac{Y_G - Y_E}{X_G - X_E}$;

$$\Theta = \varphi_{PH} + \arccos\frac{HL^2 + HP^2 - LP^2}{2HL \cdot HP} - \arctan\frac{Y_J - Y_L}{X_J - X_L};$$

$$\Phi = \varphi_{HP} - \varphi_{IH}.$$

The Ψ angle is measured between the vectors $\overline{GI}$ and $\overline{GE}$. The dimensions HI, HP, LP, HG, IJ, JH, α and β of the elements and the coordinates X_E, Y_E X_I, Y_I, of the fixed points E and I are considered as the unknowns of the synthesis problem.
The necessary power for acting the leg mechanism is calculated by the relation

$$P = F_{d1}\frac{dEG}{dt} + F_{d2}\frac{dJL}{dt}. \quad (7)$$

The maximum power value is minimized in the presence of the constrains (5), (6) and (7).

2.1. Static Balancing of Displacement Systems of Walking Robots

The walking robots represent a special category of robots, characterized by having the power source embarked on the platform. This weight of this source is an important part of the total charge that the walking machine can be transported. That is the reason why the walking system must be designed so that the mechanical work necessary for displacement, or the highest power necessary to act it, should be minimal [1, 4, 15]. The major energy consumption of a walking machine is divided into three different categories:
- the energy consumed for generating forces required to sustain the platform in gravitational field; in other word, this is the energy consumed to compensate the potential energy variation;
- the energy consumed by leg mechanism actuators, for the walking robot displacement in acceleration and deceleration phases;
- the energy lost by friction forces and moments in kinematics pairs.

The magnitude of reaction forces in kinematics pairs and the actuator forces depend on the load distribution on the legs. For slow speed, joint gravitational loads are significantly larger than inertial loads; by eliminating gravitational loads, the dynamic performances are improved.

Therefore, the power consumption to sustain the walking machine platform in the gravitational field can be reduced by using the balancing elastic systems and by optimum design of the leg mechanisms. The potential energy of the walking machine is constant or has a little variation, if the static balance is achieved. The balancing elastic system consist of by rigid and linear elastic elements.

2.2 Synthesis of Static Balancing Elastic Systems

The most usual constructions of the leg mechanisms have three degree of freedom. The proper leg mechanism is a plane one and has two degree of freedom (Fig. 4). This mechanism is articulated to the platform and it may be rotated around a vertical axis. To reduce the power consumption by robot driving system it is necessary to use two balancing elastic systems. One must be set between links (**2**) and (**3**), and the other - between links (**3**) and (**4**). Because the link (**3**) is not fixed, the second balancing elastic system can not be set. Therefore, the leg mechanism schematized in Fig. 4 can be balanced partially only (Streit, D.,A. & Gilmore, B.,J. , 1989).
It is well known and demonstrated that the weight force of an element which rotate around a horizontal fixed axis can be exactly balanced by the elastic force of a linear helical spring (Simionescu I. & Moise V. 1999). The spring is jointed between a point belonging to the element and a fixed one.

The major disadvantage of this simple solution is that the spring has a zero undeformed length. In practice, the zero free length is very difficult to achieve or even impossible. The opposite assertions are theoretically conjectures only. A zero free length elastic device comprised a compression helical spring. In the construction of this device, some difficulties arise, because the compression spring, corresponding to the calculated feature, must be prevented from buckling. A very easy constructive solution, which the above mentioned disadvantage is removed, consists in assembly two parallel helical springs, as show in Fig. 4. The equilibrium of forces which act on the link (**3**) is expressed by following equation:

$$(m\,BC\cos\varphi_{3i} - m_{7F}X_F - m_{8I}X_I - m_2X_{G2})g - F_{s7}\,BF\sin(\varphi_{3i} - \psi_{1i} + \alpha_1) - F_{s8}\,BI\sin(\varphi_{3i} - \psi_{2i} + \alpha_2) = 0,\quad i = \overline{1,12}, \qquad (8)$$

where:

m is the mass of distributed load on leg in the support phase, including the mass of the link (**2**) and the masses of linear helical springs (**7**) and (**8**), concentrated at the points H and J respectively;

m_{7F} and m_{8I} are the masses of springs (**7**) and (**8**), concentrated at the points F and I respectively;

$$\psi_{1i} = \arctan\frac{Y_{F_i} - Y_H}{X_{F_i} - X_H};\ \psi_{2i} = \arctan\frac{Y_{I_i} - Y_J}{X_{I_i} - X_J};$$

$$X_{F_i} = BF\cos(\varphi_i + \alpha_1);\ Y_{F_i} = BF\sin(\varphi_i + \alpha_1);$$

$$X_{I_i} = BI\cos(\varphi_i + \alpha_2);\ Y_{I_i} = BI\sin(\varphi_i + \alpha_2);$$

$$F_{s7} = F_{07} + k_7(HF_i - l_{07});\ F_{s8} = F_{08} + k_8(JI_i - l_{08});$$

$$\alpha_1 = \arctan\frac{y_{3F}}{x_{3F}};\ \alpha_2 = \arctan\frac{y_{3I}}{x_{3I}};$$

$$HF_i = \sqrt{(X_H - X_{F_i})^2 + (Y_H - Y_{F_i})^2};$$

$$JI_i = \sqrt{(X_J - X_{I_i})^2 + (Y_J - Y_{I_i})^2}.$$

The equations (8), which are written for twelve distinct values of the position angles φ_{3i}, are solved with respect to following unknowns: x_{3F}, y_{3F}, x_{3I}, y_{3I}, X_H, Y_H, X_J, Y_J, F_{07}, F_{08}, l_{07}, l_{08}. The undeformed lengths l_{07} and l_{08} of the springs given with acceptable values from constructional point of view.

The masses m, m_1, m_2, m_7, m_8 of elements and springs, and the position of the gravity center G_2 are assumed as knows. In fact, the problem is solved in an iterative manner, because at the start of the design, the masses of springs are unknowns.

The angles φ_{3i} must be chosen so that, in the positions which correspond to the support phase, the loading of the leg is full, and in the positions which correspond to the transfer phase, the loading is null. The static balancing is achieved theoretical exactly in the positions defined by angles φ_{33i}, $i = \overline{1,12}$. Between these positions, the unbalancing is very small and may be neglected.

If a total statically balancing is desired, a more complicated leg structure is necessary to used. In the mechanism leg schematized in Fig. 5, the two active pairs are superposed in B.

The second balancing elastic system is set between the elements (**2**) and (**5**).

The equilibrium equation of forces which act on the elements (**3**) and (**5**) respectively are:

$$BC(R_{34Y}\cos\varphi_{3i} - R_{34X}\sin\varphi_{3i}) + (m_{7F}X_F + m_{8I}X_I + m_3X_{G3})g + F_{s7}\,BF\sin(\varphi_{3i} - \varphi_{7i} + \alpha_1) + F_{s8}\,BI\sin(\varphi_{3i} - \varphi_{8i} + \alpha_2) = 0;$$

$$BE(R_{56Y}\cos\varphi_{5i} - R_{56X}\sin\varphi_{5i}) + (m_{9N}X_N + m_{10L}X_L + m_5X_{G5})g + F_{s9}\,BN\sin(\varphi_{5i} - \varphi_{9i}) + \alpha_3) + F_{s10}\,BL\sin(\varphi_{5i} - \varphi_{10i} + \alpha_4) = 0,\ i = \overline{1,12},$$

where: $\alpha_3 = \arctan\dfrac{y_{5N}}{x_{5N}}$; $\alpha_4 = \arctan\dfrac{y_{5L}}{x_{5L}}$;

$$F_{S9} = F_{09} + k_9(ML_i - l_{09});\quad F_{S10} = F_{0,10} + k_{10}(QN_i - l_{0,10});$$

$$R_{34X} = \frac{U(X_D - X_E) - V(X_C - X_D)}{W};$$

$$R_{34Y} = \frac{V(Y_D - Y_C) - U(Y_E - Y_D)}{W};$$

$$U = g[m_4(X_{G4} - X_D) - m(X_P - X_D)];$$

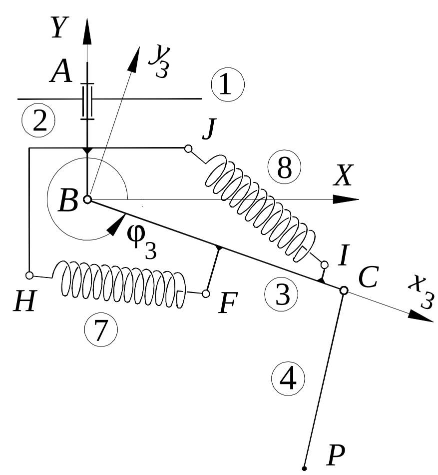

Fig. 4 Elastic system for the discrete partial static balancing of the leg mechanism

$$V = g[m_6(X_{G6} - X_D) - (m_4 - m_6 - m)(X_E - X_D)];$$

$$W = Y_D(X_C - X_E) - Y_C(X_D - X_E) - Y_E(X_C - X_D);$$

$$R_{56X} = -R_{34X};\ R_{56Y} = (m_4 + m_6 - m)g - R_{34Y}.$$

The magnitudes of the angles φ_{3i} and φ_{5i} are calculated as functions on the position of the point P. The variation fields of these, in support and transfer phase, must not be intersected. In the support phase, the point P of the leg is on the terrain. In the return phase, the leg is not on the terrain, and the distributed load on the leg is zero.

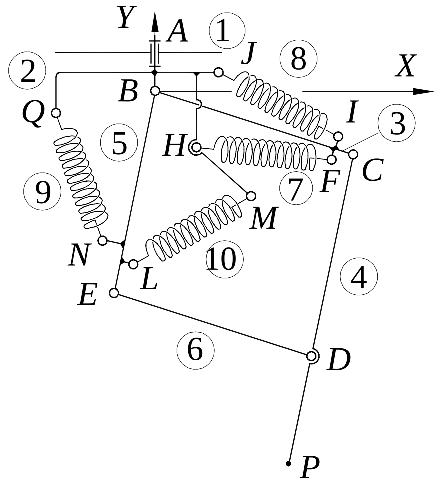

Fig.5 Elastic system for the discrete total static balancing of the leg mechanism

The not intersecting condition can be easy realized for the variation fields of angle φ_3. If the working positions of link (**4**) are chosen in proximity of vertical line, the driving force or moment in the pair C is much less than the driving force from the pair B. This is workable by the adequately motions planning. In this manner, the diminishing of energy consumed for the walking machine displacement can be made by using the partial balancing of leg mechanism only.

The static balancing is exactly theoretic realized in twelve positions of the link (**3**), accordingly to the angle values φ_{3i}, $i = \overline{1,12}$, only. Due to continuity reasons, the unbalancing magnitude between these positions is negligible.
In order to realize the theoretic exactly static balancing of the leg mechanism, for all positions throughout in the work field, it is necessary to use the cam mechanisms. In Fig. 6 is shown a elastic system for continuous balancing, consist of a helical spring (**7**), jointed on the link (**3**) and the follower (**8**), which slides along the link (**2**). The cam which acted the follower, by the agency of role (**9**), is fixed on the link (**3**). The parametrical equations of directrices curves of the cam active surface are:

$$x_2 = Y_D \sin\varphi_3 \mp \frac{R\left(\dfrac{dY_D}{d\varphi_3}\cos\varphi_3 - Y_D \sin\varphi_3\right)}{P};$$

$$y_2 = Y_D \cos\varphi_3 \pm \frac{R\left(\dfrac{dY_D}{d\varphi}\sin\varphi_3 + Y_D \cos\varphi_3\right)}{P},$$

where R represents the role radius, and:

$$P = \sqrt{\left(\frac{dY_D}{d\varphi_3}\right)^2 + Y_D^2}\ ,$$

The ordinate Y_D of point D and its derivative $\dfrac{dY_D}{d\varphi_3}$ are calculated as solutions of following differential equation which expressed the equilibrium condition of force system which are taken into consideration:

$$g(BC\, m + m_3 BG_3 + BF\, m_{7F})\cos\varphi_3 + F_{s7}\, BF \sin(\varphi_3 - \psi) + Y_D R_{93} \sin\alpha = 0, \qquad (9)$$

where the reaction force R_{93} between cam (**3**) and role (**9**) has the expression:

$$R_{93} = [F_{s7} \sin\psi + (m_8 + m_9 + m_{7F})\, g] \cdot \frac{P}{Y_D},$$

and: $X_F = BF \cos\varphi_3$; $Y_F = BF \sin\varphi_3$;

$X_H = 0$; $Y_H = Y_D - DH$;

$$\alpha = \arctan\frac{\dfrac{dY_D}{d\varphi_3}}{Y_D};\ \psi = \arctan\frac{Y_H - Y_F}{-X_F};$$

$F_{s7} = F_{07} + k_7\,(FH - l_{07})$;

$$FH = \sqrt{(X_F - X_H)^2 + (Y_F - Y_H)^2}$$

The mass m_7 of the helical spring (**7**) is assumed as concentrated in joints H and F, m_{7F} and m_{7H} respectively. The masses m, m_1, m_2, m_3 and m_4 of the bodies, dimensions BF, BC, DH and helical spring characteristics F_{07}, l_{07} and, k_7 are considered knows.

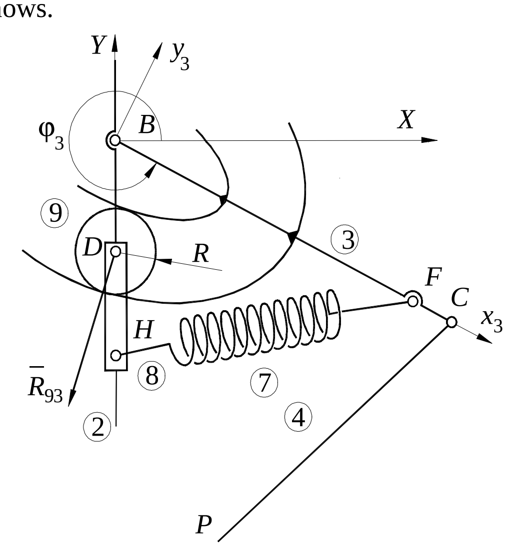

Fig.6 Elastic system for the continuous partial static balancing of the leg mechanism VARIANT I

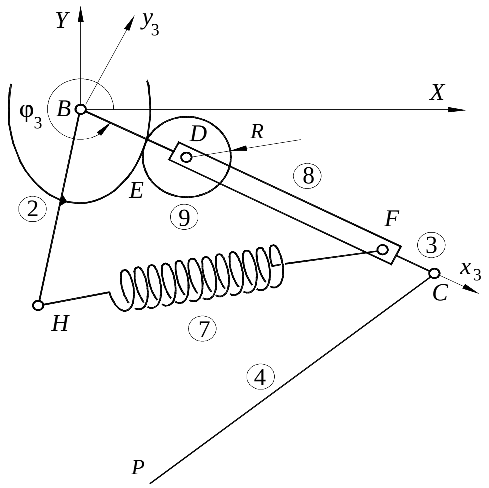

Fig.7 Elastic system for the continuous partial, static balancing of the leg mechanism VARIANT II

The initial conditions, which are necessary to integrate the differential equation (9) are considered in a convenient mode, adequate to a known equilibrium position.

In Fig. 7 is schematized another elastic system for continuous balancing. The balancing helical spring (**7**) is jointed with an end to the follower (**8**) at the point *F*, and with the other one to link (**2**), at point *H*. The cam is fixed to the link (**2**). The follower (**8**) slid along the link (**3**). The parametrical equations of directrice curves of the cam active surface are:

$$x_2 = X_D \mp \frac{R\left(\frac{\mathrm{d}BD}{\mathrm{d}\varphi_3}\sin\varphi_3 + X_D\right)}{Q},$$

$$y_2 = Y_D \pm \frac{R\left(\frac{\mathrm{d}BD}{\mathrm{d}\varphi_3}\cos\varphi_3 - Y_D\right)}{Q},$$

where: X_D = BD cosφ_3, Y_D = BD sinφ_3, and

$$Q = \sqrt{\left(\frac{\mathrm{d}X_D}{\mathrm{d}\varphi_3}\right)^2 + \left(\frac{\mathrm{d}Y_D}{\mathrm{d}\varphi_3}\right)^2}.$$

The distance BD and its derivative $\frac{\mathrm{d}BD}{\mathrm{d}\varphi_3}$ are calculated as solutions of following differential equation

$$F_{s7}\frac{Y_H(BD+DF)\cos\varphi_3}{FH} - R_{29}BD\cos(\varphi_3-\alpha) - g(m_3BG_3 + m_{4A}(BD+DF) + m_8(BD+DG_8))\cos\varphi_3 = 0, \qquad (9)$$

where:

$$R_{29} = \frac{g(m_8 + m_9 + m_{7F}) - F_{s7}\cos(\varphi_3 - \psi)}{\cos(\varphi_3 - \alpha)};$$

$$\alpha = \arctan\frac{\frac{\mathrm{d}BD}{\mathrm{d}\varphi_3}}{BD}.$$

3. The control system of the *MERO* modular walking robot

The robot is controlled by a computer that has been configurated for this application, and which operates four or six legs with hydraulically actuators. Each leg has three articulated joints, equipped at their lower end of the lower arm with the force
measuring sensor

There are 18 analog outputs and 12 analog inputs of 18 bits each to adjust the $3 \times 6 = 18$ axes as well as to record the information supplied by the six force measuring sensors.

The control system was developed around the CP303 – 34×86 processor board from compact PCI – PEP modular computers, with QNX real time operating system. The control system contains four sub-parts: path planner, path-traking controller, legs servo-controllers and position estimation including issues regarding the robot platform stability. The control structure is actually a classical one. For testing of the modular walking robot, an integrated virtual environment aiming to study the stepping process, detection/recognition of the obstacles and avoiding collision will be developed.

The simulation will use for testing both navigator and pilot level for the mobile robot.

Walking robots may have a lower or higher autonomy degree. This autonomy has in view the power source's supply capability but also orientation and perception capabilities as regards the terrain configuration. The movements planning is necessary only for the walking robots with a low autonomy degree and which move according to a previously scheduled program. The walking robots having a high autonomy should benefit from appropriate driving programs and obviously from high-speed computers. In order to control the walking robot shift in more or less structured environments, the following specifical functions are needed:

- the environmental perception and shaping using a multi-sensorial system for data acquiring;
- data collecting and defining the field configuration;
- movement planning;
- analysis of the scenes;

- control over the handling of the objects, if any.

The control system of the walking robot is modularly, the blocks named *leg controllers* and the aggregate conceived, as shown in and fig. 8. The basic elements are conversion modules. The other elements can be considered as auxiliary, and they are passive elements, but essential to the system's good functioning.

One can find the program guiding the movement, the keyboard operability and the walking sequels in the computer's memory and stored on its hard disk as executable files and they fulfill the following functions: - edit and memorize the movement and adjustment parameters in the form of real time files;

- operate the robot's movement, launch or stop some movement sequences by the keyboard;
- main parameters can be visualized in real time, as they are required to elucidate, test and adjust the system as a whole;

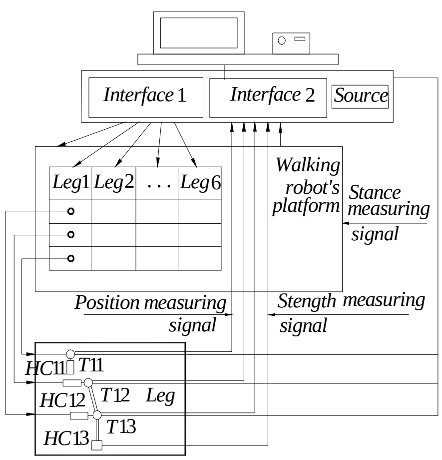

Fig.8. Data acquiring system block scheme

- calculate and check the movement control, regulate the position, its force sensors detect the steps, automatically generates the movement laws (space, speed, acceleration), real time interpolation, automatic estimation of the offset servo-valves, convert direct and indirect coordinates systems, attached to the walking robot's elements [5].

The mechanical, hydraulic, electrical and conducting systems are functionally inter-connected and they cooperate in fulfilling the duties the operator claims. Nevertheless, a precise and stable functioning requires that the axis position be automatically maintained according to the internal position reference in the computer's memory, so that the robot's axes could precisely and repeatedly carry out the movement laws generated by the robot's guidance program. As it is shown, in the computer's memory records two automatically run functions, namely those of the off set adjustment, estimation and compensation.

The multi-sensor system consists of :

sensors to survey the system components (parameters of the actuating, supplying and distributing system);

sensors to survey and control forces, positions, speeds, accelerations and targets;

sensors to scan route, proximity, to video control in order to acquire images, as well as the computerized system needed for image analysis, parameter extraction, coordination of the navigation systems etc.

The system of the information transfer and processing will consist of the module for data transmission and the controller of the data and images transmission and reception.A proper work and functioning of the autonomous motion systems implies the existence of a careful coordination between motion planning, environment perception and control performance, in order to get a suitable behavior within loosely structured environments.

6. Conclusions

The *MERO* modular walking robot made by the authors is a multi-functional mechatronic system designed to carry out planned movements aimed at accomplishing several scheduled tasks. The walking robot operates and completes tasks by permanently inter-acting with the environment where there are known or unknown physical objects and obstacles. Its environmental interactions may be technological (by mechanical effort or contact) or contextual ones (route identification, obstacle avoidance, etc)

The successful fulfillment of the mission depends both on the knowledge the robot, through its control system has on the initial configuration of the working place, and by those obtained during its movement.

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