MULTIFUNCTION SUSPENSION OF EOD ROBOT

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Abstract

One of the applications of Unmanned Ground Vehicles (UGV) consists in conducting tasks connected to removing and disposing of Improvised Explosive Devices (IED). The tasks are often performed in hard to reach places, on off-road terrain, with weights and dimensions of explosives which require the use of work attachments of considerable lifting capacities. Due to this, it is necessary to equip the robot with suspension designed for performing such tasks. Because of variable character of the charges which are subjected to the chassis of robots, it is necessary to build a suspension with variable characteristics and examine efficiency of its action. One of the research methods that can be used for that purpose are the simulations based on the method of Multibody Systems. The paper presents a hydro-pneumatic suspension system of an EOD robot, which has been developed at the Military University of Technology, describes its model, simulation findings and the initial verification thereof based on a real object. Apart from that, special consideration is given to the quality and effectiveness of UGV suspension systems. The development of a basic platform enables the use of the platform for various purposes as a carrier of a multi-sensor system for detecting dangerous materials or for carrying other attachments.

Keywords: *Unmanned Ground Vehicle, mobility, hydro-pneumatic suspension, simulations*

1. Introduction

One of the applications of robots are tasks connected to removing and disposing of unexploded ordnance (UXO) and improvised explosive devices (IEDs) [3, 4]. It is often the case that IEDs and an UXOs are situated off-road (rubble heap, roadless tract, etc.) and their removal or neutralization requires work attachments of considerable lifting capacity (approx. 250 kg) so as to pick up the ordnance or make way for a potentially dangerous object.

The civilian, relatively cheap, robotic mini excavators and mini loaders, which are currently used for removing and disposing of dangerous ordnance are not capable of performing such tasks, which is caused by their reduced ability to negotiate ground obstacles.

The specificity of IED/EOD missions carried out by EOD robots as well as the analyses conducted at the Chair of Mechanical Engineering of the Military University of Technology (MUT) have allowed to single out three, different from one another, requirements for the suspension of a robot used in such missions:

- capability of high speeds (desired 10m/s) on surfaces with minor irregularities (2 to 5 cm), making it possible to quickly reach (distance of up to 1500 m) and survey an area which is initially deemed dangerous;
- ability to move on considerable ground irregularities (20 - 30 cm) and slopes (45%) at velocities of 2 – 3 m/s – ability to reach, as quickly as possible, ordnance located on hard to reach terrain;
- ensuring transverse and longitudinal stability reserves of the robot, in the case of significant irregularity of loads exerted on its particular axles and with speeds below 2m/s – work with attachments.

It was necessary to solve the problem of designing a robot and a suspension system enabling the former to meet all the requirements simultaneously. The MUT Chair of Mechanical

Engineering has worked out a high mobility, EOD robot of its own design for performing IED/EOD missions (Fig. 1).

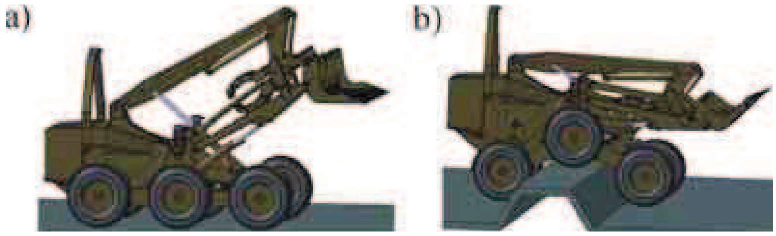

Fig. 1. EOD robot: a) general view, b) ability to negotiate ground obstacles

It is a triaxial, wheeled robot with the operating weight of ~3000kg, equipped with two attachments, i.e. manipulator-type – lifting capacity of 250 kg and loader-type – load capacity of 1500 kg. Apart from the above-mentioned requirements, the suspension, the wheels and the steering system have to ensure the robot's ability to negotiate roadside and drainage ditches, 50 cm high dykes and walls, slopes with 60 % longitudinal and 40% transverse inclination as well as low capacity terrain (minimum CI=200 kPa).

2. Suspension system of EOD robot

The above-defined requirements have led to the design of a multi-link, hydro-pneumatic suspension system, the diagram of which is shown in Figure 2.

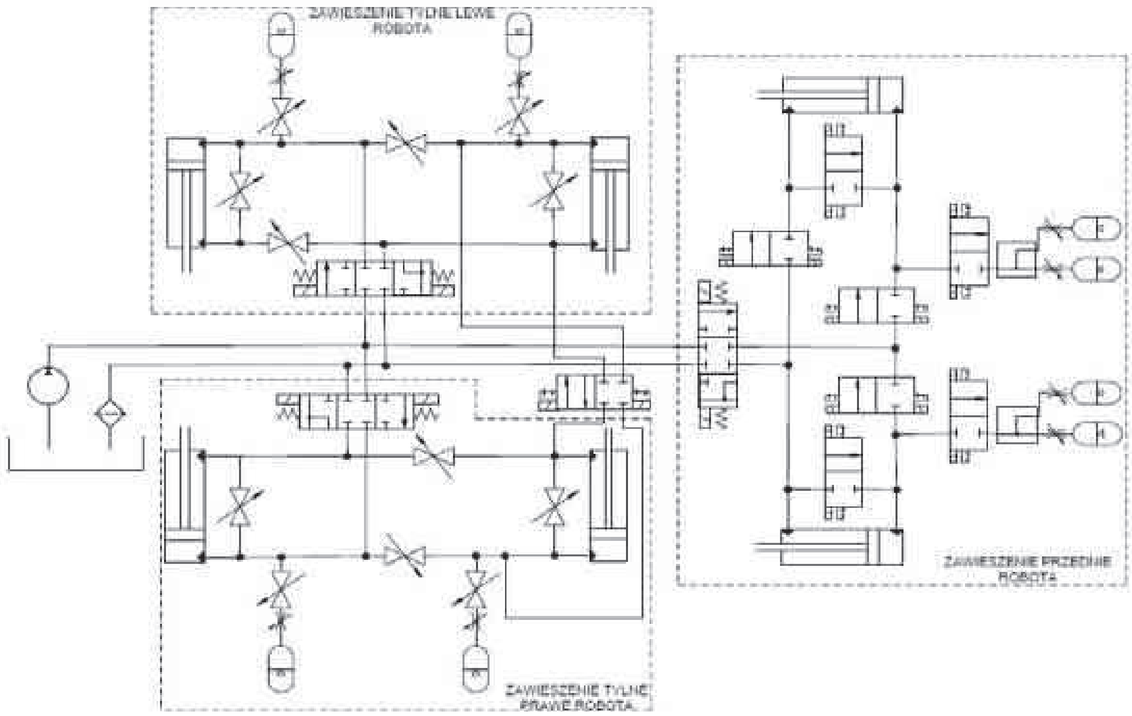

Fig. 2. Schematic diagram of EOD robot's multifunction suspension system (patent application No. P.392820)

The suspension is characterized by a much greater ability to transmit dynamic loads and better functionality than classical mechanical suspensions [1, 10]. Its work parameters can be easily modified through resetting switches or valves, without the necessity to alter the system itself.

The designed system (Fig. 2) makes it possible to obtain the desired alternative support structures of the robot (Fig. 3), which were singled out in the course of the analysis [4, 6, 7, 10], in order to adjust the suspension characteristics to the specificity of performed tasks. To ensure strong drawbar pull (regular distribution of pressure on the surface) for off-road driving, it was recommended that (hydraulic) rocker joints be applied: between the left and right wheel of the front axle (Fig. 3a.b), or between the left and right side of the middle and rear axles (Fig.3b). To ensure flexibility in the case of considerable dynamic loads (driving at high speeds), hydraulic accumulators have been applied. In contrast to structures for off-road driving, alternative suspension structures, which enable work with the use of attachments, block the movement of the front axle (i.e. the most loaded one) wheels.

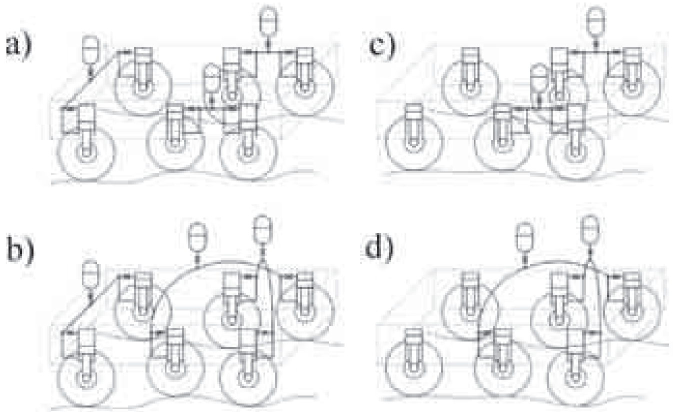

Fig. 3. Designed suspension structures of EOD robot : a,b) off-road driving , c,d) work with attachments

Additionally, the designed system (Fig. 2) enables the achievement of flexible, independent suspension for each wheel, which is desired for driving at high speeds on terrain with minor irregularities.

The suspension kinematic system (Fig. 4) was designed for the purpose of obtaining the required 500 mm vertical movement of each one of the wheels, as well as to ensure that the robot's static balance clearance was 250 mm.

a) b)

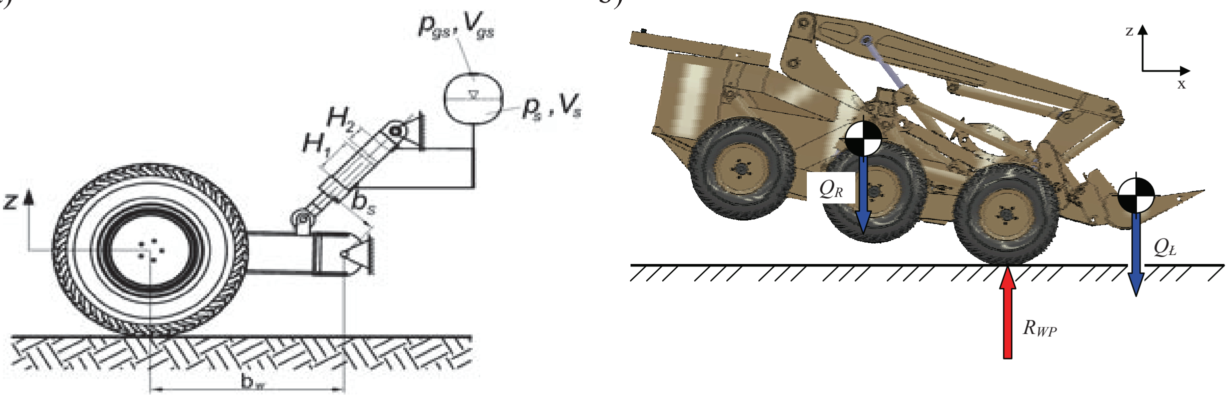

Fig. 4. Suspension design of EOD robot: a) front wheel suspension system in static balance position; b) exclusive load on one axle

The sizes of suspension actuators (piston diameter 80 mm, rod diameter – 56 mm) were defined for the robot supporting on one axle exclusively (Fig.4b) and for the loader equipment with a 2400 kg load (tipping load).

3. Simulation testing of hydro-pneumatic suspension

To select hydraulic accumulators, simulation tests of particular suspension arms [5], based on the dynamic model (Fig. 5), were performed.

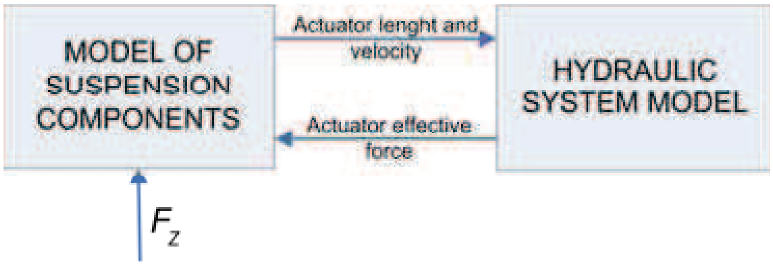

Fig. 5. Flowchart of robot suspension model

The model consists of interlinked modules: mechanical and hydraulic. The mechanical module includes kinematic links (rotational and linear) which connect its particular elements whereas the hydraulic module includes the hydraulic installation of the suspension. The mechanical model of the suspension arm (Fig. 6a) was created by means of multibody systems (MD ADAMS View suite). For the purpose of simplification, the modelling was performed according to the following assumptions:

- the distribution of the robot's weight on particular wheels is regular;
- the surface is undeformable;
- there is excitation under the wheel in the form of the F_z vertical force (Fig. 6a) generated by the robot's weight;
- the fixing point of the A suspension arm constitutes its pivoting point;
- the radial stiffness of the tyre (static deflection 0.03m) and the dimensionless damping factor ξ=0,1 were both taken into account;
- the unsprung weight is : 156,5 kg, including the combined weight of the wheel and the hydraulic engine m_k=78 kg, weight of the suspension arm m_w=51kg, that of the actuator cylinder m_c=18kg, and the weight of the rod m_t=9,5 kg.

Variations in the length L and velocity of the actuator $\frac{dL}{dt}$ under the effect of the F_z force constituted output parameters of the mechanical module linked to the hydraulic system module (modelled in the Easy5 program) (Fig.6b), in which they constituted input parameters.

a) b)

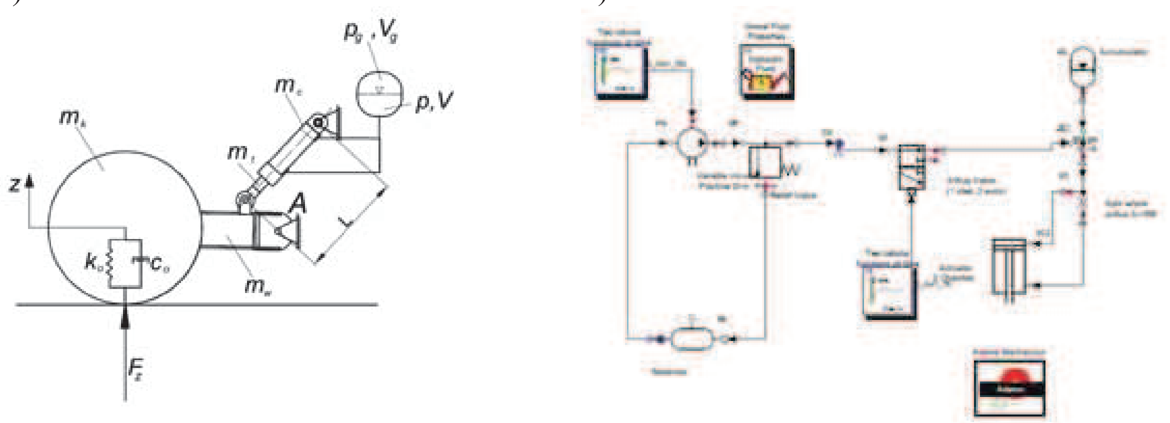

Fig. 6. Suspension model of robot's suspension arm: a) mechanical module diagram, b) hydraulic module diagram

Additionally, for the hydraulic system model, the following assumptions were made:

- no heat transfer between the system and the environment and the work of the accumulator in the adiabatic process:

$$p_{g1}V_{g1}^{\kappa} = p_{gs}V_{gs}^{\kappa} = p_{g2}V_{g2}^{\kappa} = const\,, \qquad (1)$$

where: p_{g1}, V_{g1} – pressure and volume, respectively, of the gas in the accumulator, with the down position of the wheel, p_{gs}, V_{gs} – pressure and volume, respectively, of the gas in the accumulator, in the static balance position, p_{g2}, V_{g2} – pressure and volume, respectively, of the gas in the accumulator, with the up position of the wheel, κ - adiabatic exponent (κ=1,4), the elasticity of hydraulic hoses and the dynamics of switching valves were not taken into account.

The simulations with the use of the multi-body system method had been preceded by the initial simulation research [5], with the aim of determining dynamic loads exerted on particular axles of the robot negotiating 0.05 and 0.3 m high ramp-shaped obstacles at the velocity of 10 m/s. The loads were expressed in the form of the dynamic surplus coefficient k_d, which determines variations in the F_Z force, i.e. the one generated by the weight of the robot and exerted on a single wheel, according to the following correlation:

$$k_d = \frac{F_{Zi}}{F_Z}, \tag{2}$$

where: F_{zi} – value of the vertical reaction on the wheel while negotiating unevenness, F_z – static value of the vertical reaction on the wheel.

The highest value of the k_d coefficient was recorded for the front axle and it was 1.3. In the case of the middle and rear axles, the value of the dynamic surplus coefficient was 1.1. It made it possible to define the timing of the variation in the F_z force, whose static value of 5000N was increased every 0.1 s by the coefficient of 1.3 (front axle) and by that of 1.1 (middle and rear axle) to the values of 6500N and 5500N, respectively, and which was then reduced to 0N (no contact between the wheel and the surface) so as to determine the operating range of the hydraulic accumulator and the travel of the suspension actuator. In the course of the simulation the accumulator nominal volume V_0 was modified, in accordance with the HYDAC (0.4, 0.7, 1.4, 2.4 dm^3) diaphragram accumulator type of series, setting pressure of the initial filling with gas at the level ensuring that the volumes of gas and oil in the accumulator were equal to each other.

In order to enable the suspension to fully utilize its travel, the selection of the accumulator nominal volume V_0 was made, by means of simulation, on the basis of the previously determined k_d coefficient, with the use of the pressure-based approach.

$$k_d = \frac{p_{g2}}{p_{gs}}. \tag{3}$$

In the case of a properly selected accumulator, the value should be close to 1.3 (front axle) and 1.1 (middle and rear axles). The simulation findings are shown in Tab. 1 and 2.

Tab. 1. Front suspension simulation findings

	V_0 [dm^3]			
	0.4	0.7	1.4	2.4
p_{gs} [bar]	56	56 56		56
p_{g2} [bar]	92.6	84.2	70	62
k_d	1.65	1.50	1.25	1.10

Tab. 2. Middle and rear axle suspension simulation findings

	V_0 [dm^3]		
	0.4	0.7	1.4
p_{gs} [bar]	56	56	56
p_{g2} [bar]	67.8	61.5	58.2
k_d	1.21	1.10	1.04

On the basis of the performed simulation tests, the front suspension actuators were matched with the accumulator volume of V_0=1400 cm^3, with p_0=25 bar, whereas the middle and rear axles with an accumulator of V_0=0,75dm^3 and p_0=25 bar.

4. Exploratory research on robot suspension

The simulation tests enabled the construction of a real multi link suspension system for the hydropneumatic suspension of the EOD robot, ensuring the achievement of all the expected and required structures (Fig. 3). The use of alternative suspension structures (on one research object) makes it possible to verify their usefulness for particular requirements and to examine the suspension effect on the robot's working capability. For the purpose of initial evaluation of the simplifying assumptions made during the modelling process and that of the simulation findings, exploratory research into the suspension (Fig. 7, 8) was conducted on the demonstrator of the EOD robot technology.

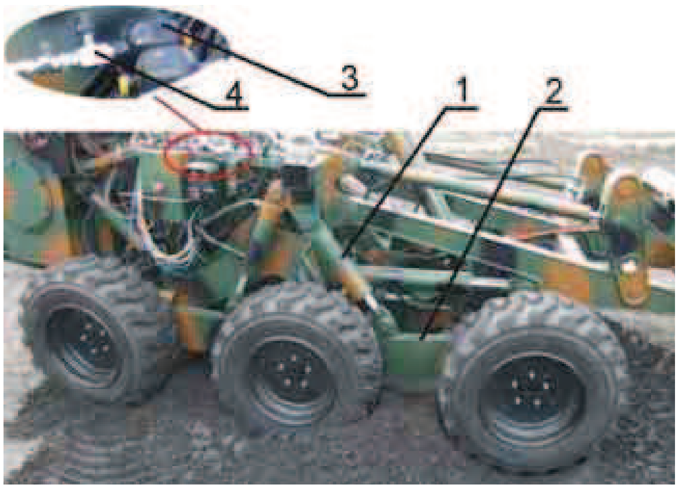

Fig. 6. Main elements of hydropneumatic suspension covered with the demonstrator of the EOD robot technology : 1-suspension actuator, 2-front suspension arm (to be pushed), 3-hydraulic accumulator, 4-throttle valve

The research was conducted on a robot test track constructed on the premises of the Chair of Mechanical Engineering. The exploratory research had been preceded by an initial evaluation of the robot's performance for various configurations of suspension structures and by the decision to conduct the research with the structure shown in figure 3, i.e. the one with cut off accumulators of the middle and rear axles. In the course of the research the robot was driven, at a speed of ~5kph, across the following ground obstacles:

a) 12 cm high dyke of hexagonal paving slabs (Fig. 7);
b) 0.5m deep transverse ditch with a 50% inclination of slopes (Fig. 8a,b).

Fig. 7. EOD robot attempting to drive across dyke of hexagonal paving slabs

The test involved the recording of hydraulic oil pressure in the suspension system of the front actuator, between the actuator and the damping valve, with the latter being fully opened during the test.

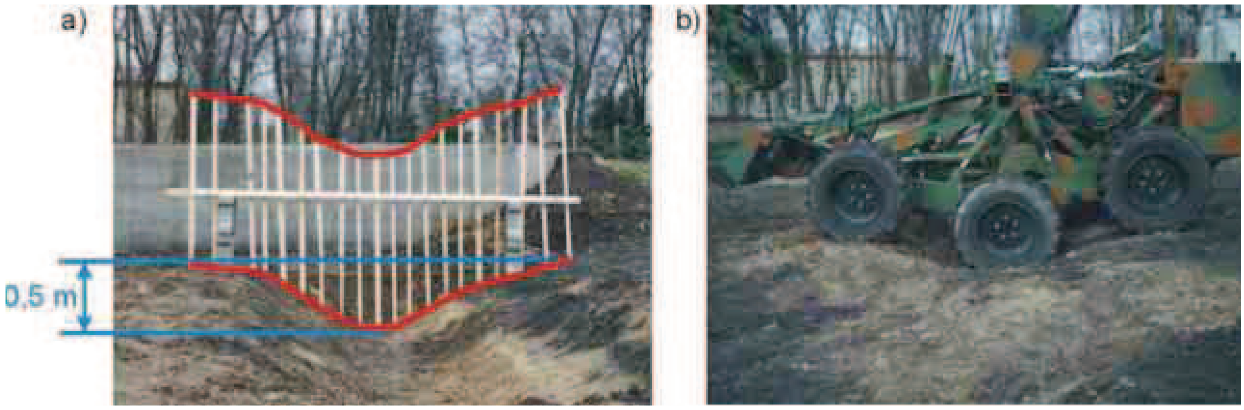

Fig. 8. Attempt at driving across transverse ditch: a) side view of the obstacle; b) robot in the course of passing through

Figure 9 shows exemplary timing of pressure variations measured during the test.

The findings of the exploratory research on the suspension of the front suspension arm (Fig. 9) are to a great extent similar to the simulation findings (chart 1). It was determined that, using the pressure approach, the dynamic surplus coefficient k_d was similar for both obstacles. Its maximum value was recorded during robot's drive across the ditch and it was 1.34.

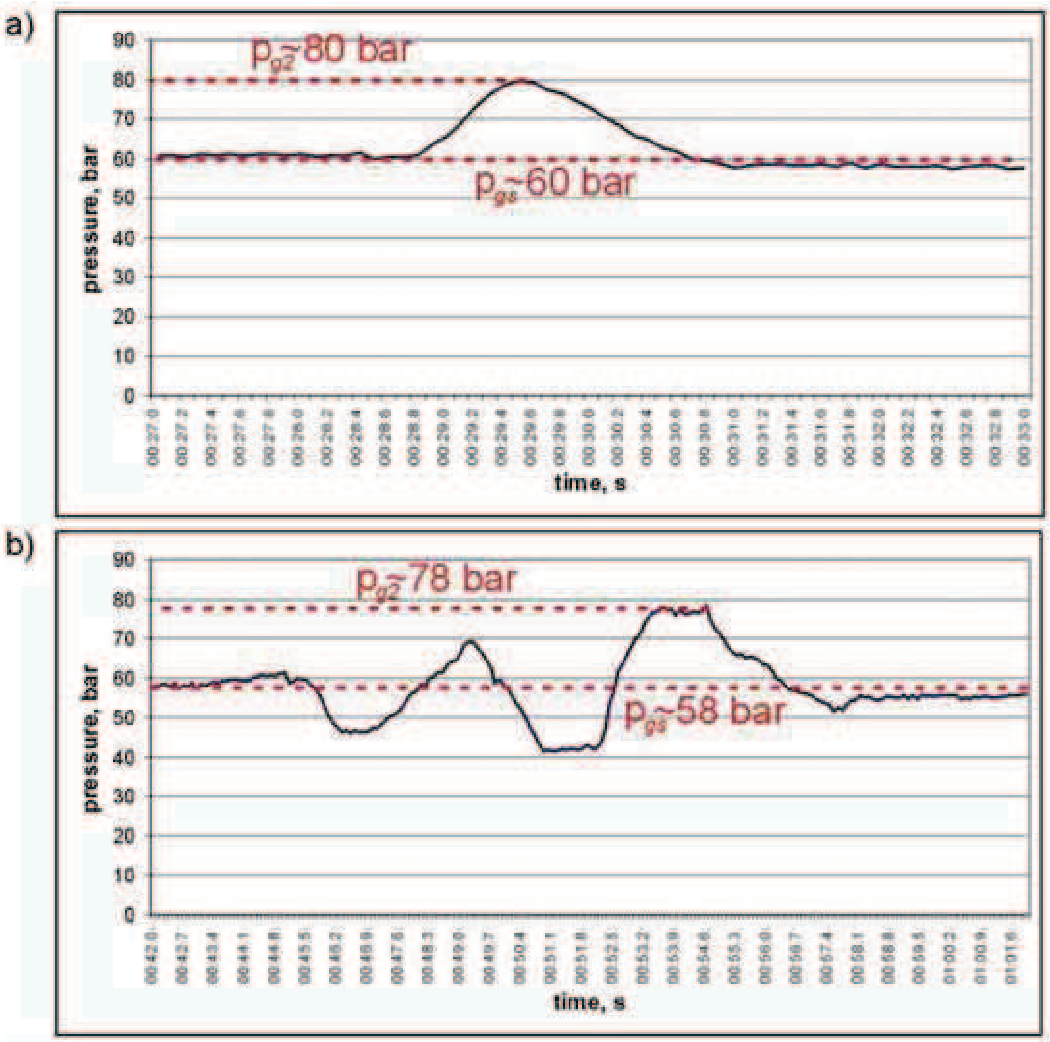

Fig. 9. Timing of pressure variations in the suspension system of the front suspension arm during: a) robot's drive across hexagonal paving slabs, b) drive across transverse ditch

5. Summary

Due to the fact that the character of driving and work of the EOD robot is different (remote control) from that of classical vehicles and equipment, there arose the necessity to work out a new suspension solution. The established requirements (which are often mutually exclusive for mechanical suspension systems) concerning the performed functions determined the application of hydropneumatic suspension.

The developed model enabled the selection of hydraulic accumulators on the basis of the initial criterion for its assessment (k_d coefficient) as well as the construction of the suspension system on a real object. The findings of the exploratory research on the suspension system confirmed conformity between the k_d coefficient value and the simulation findings.

It is recommended that simulation investigation of the robot's performance be conducted with the above suspension characteristics and that it should be followed by the verification of the findings on a real object. However, it is also recommended that new rules for their assessment be developed, which is due to the fact that the existing methods described in the literature, based on the driver's comfort criterion (vertical acceleration values, pitching, etc.), or on that of the operator, may not be directly used for the assessment of the robot's suspension since it does not have occupants.

The development of a basic platform, equipped with an effective suspension increasing its mobility and working capabilities will enable the use of the platform for various purposes, eg. as a carrier of a multi-sensor system for detecting dangerous materials or for carrying other attachments.

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