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Marian Janusz Łopatka and Daniel Sterniczuk

Concept of the Manipulators Set for Fast IEDs Neutralization

Marian Janusz Łopatka[1, a)] and Daniel Sterniczuk[2, 1, b)]

[1]*Institute of Machinery Construction, Mechanical Engineering Faculty, Military University of Technology, Gen. Witolda Urbanowicza Str. 2, 00-908 Warsaw, Poland*
[2]*Automotive Industry Institute, Jagiellońska Str .55, 03-301 Warsaw, Poland*

[a)] Corresponding author: marian.lopatka@wat.edu.pl
[b)]d.sterniczuk@pimot.eu, PhD. student mail: daniel.sterniczuk@wat.edu.pl

Abstract. In this paper, the scope of operations performed by robots to neutralize IED is presented. Next, the concept of the robot manipulators set for the quick neutralization of the IED was presented. The concept includes: kinematics, models of individual parts of the manipulators set shown on the assembly model, proposed tools and drive system. The assumptions for simulation in the MSC Adams program and results of simulations were presented. It was concluded that dynamic loads during fast work of manipulators determine the load limits of the structure. The possibility and legitimacy of the manipulator was confirmed. In this paper concept of the set of manipulators for such operations is shown.

INTRODUCTION

Manipulators are main attachment for mobile EOD (Explosive Ordnance Disposal) robots. They are used for searching, uncovering and denuding, separation and neutralization of IED (Improvised Explosive Device). There are many design manipulator solutions that many publications have been written about [1,2,3,4,5]. These devices are equipped with various types of tools that allows to perform many different operations such as gripping, lifting, throwing or opening the door [6,7,8, 9,10,11]. The drive system of manipulators can be electric, pneumatic, hydraulic or hybrid system [12,13,14,15]. The speed and precision of performed operations depend on the control system of the manipulators. The well designed ones allow to maintain intuitive operation and reliability [6,13,16,17]. The IED/EOD operations challenging specific demand for EOD robots and their manipulators.

RANGE OF EXPECTED OPERATIONS

IEDs are improvised explosive devices, often equipped with electronic detonators. Vehicle cabins, cargo spaces, ditches and road culverts are places where IEDs are most often placed. Sometimes the IEDs are buried in a dirt road. The weight of such devices reaches approx. 80 kg. Robots for fast neutralization of IEDs must perform many different operations. Tasks in these operations should be carried out quickly, one after the other. This creates the necessity to equip the robot manipulator with tools that will allow to perform various task during the operation. No need to return to the operator is preferred. The multitude of possible tasks cannot affect the intuitive control of the manipulator. Requirements for the manipulator resulting from the anticipated tasks:

- platform weight with mounted manipulator approx. 600 kg,
- the ability of observing the area from a height of 3m,
- the ability to inspect: truck chassis, cabin interiors, cargo spaces, culverts and ditches from the road crown,
- loosening the soil to the 4th category of mining difficulty to a depth of 0.2 m,
- digging in the ground to the 3rd category of mining difficulty to a depth of 0.5 m,
- the ability to take loads up to 80 kg and up to 300 mm in diameter,

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- the ability to cut electric wires,
- the ability to exchange tools, subject to the simultaneous availability of two of them,
- pulling a car weighing up to 3000 kg with an unlocked drive system,
- two manipulators in the observer-contractor layout,
- the ability of taking objects from ditches with a depth of 1 m and a slope of 50%.

CONCEPT OF THE SET OF MANIPULATORS

The structural solution consisting of two manipulators was established. The use of such set gives opportunity to use of at least two tools at one time. The serial diagram of manipulators was assumed. The kinematic scheme of the manipulator is shown in Fig. 1. The system has 9 DOF (Degrees of Freedom).

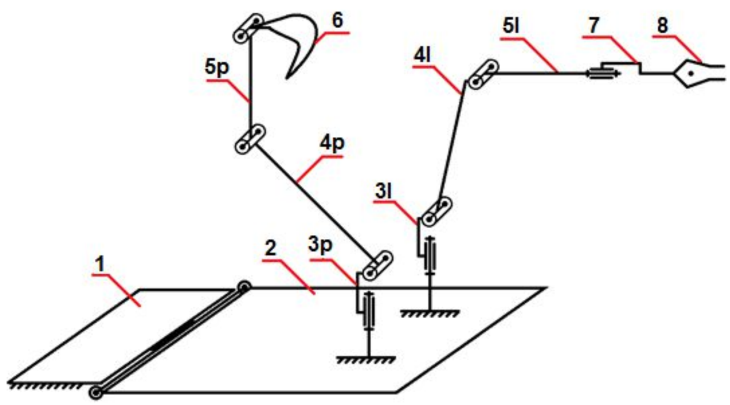


FIGURE 1. Kinematic scheme of the manipulator: 1-EOD robot platform; 2-folded base of the manipulators; 3p/3l – pivots enabling the right/left booms to be rotated; 4p/4l - right and left booms; 5p/5l - right and left arms; 6 - bucket; 7-rotary member of the left arm; 8-gripper

Using the assumed kinematic structure, the model in the CAD environment has been prepared. The 3D model including the robot platform in isometric view is shown in Fig. 2.

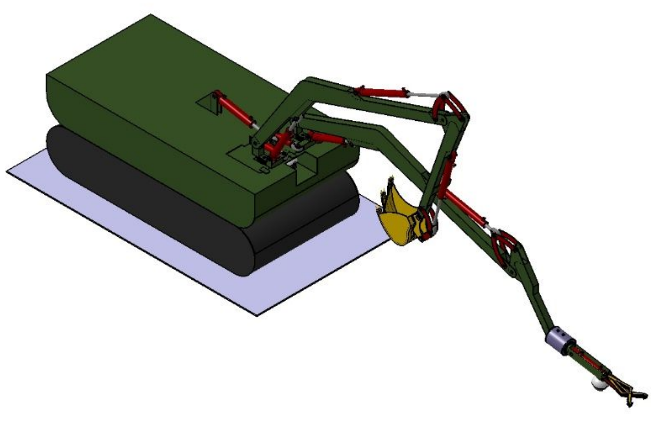


FIGURE 2. 3D model of the manipulators set with platform in an isometric view

The developed concept of manipulators design assumes the same field of work for both of them. The work area is shown on the lifting capacity curve in Fig. 3. The achieved field of work meets the requirements set for device. It allows observation of the area from a height of 4290 mm (camera placed at the end of the manipulator), inspection of passenger cars and trucks, their chassis and cargo spaces. It also allows digging, loosening the ground surface and picking up objects from ditches and road culverts.

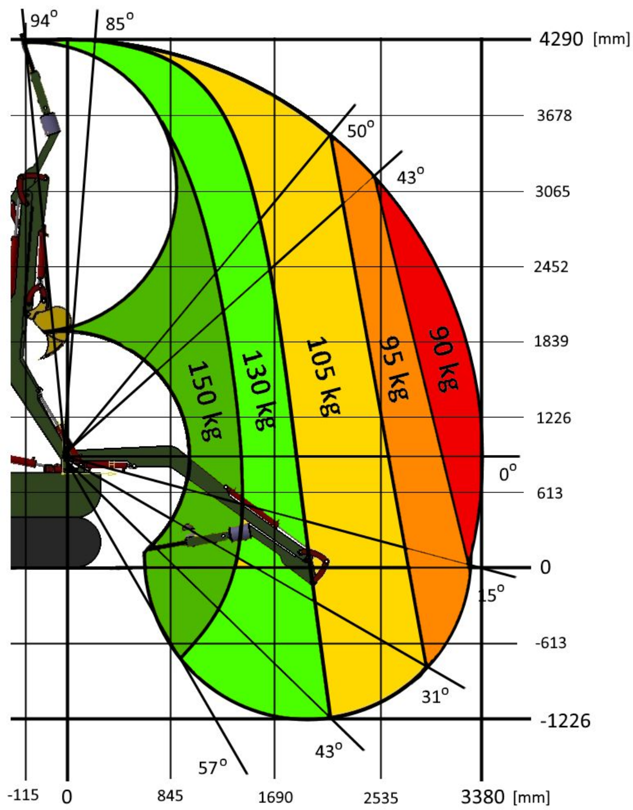


FIGURE 3. Characteristics of manipulators work area and the lifting capacity

The kinematic structure due to folding bases enables the manipulators to be in a compact transport position (Fig. 4), if necessary. It results in maintaining stability during the robot movements.

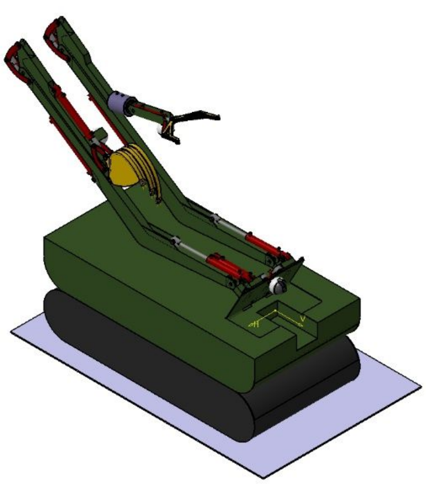


FIGURE 4. The manipulators set in the transport position

The concept of the hydrostatic drive system for manipulators set was developed. The hydraulic drive system consisting of a hydraulic pump, ten distributor sections, nine hydraulic cylinders: base, booms turning, booms, arms, the gripper and the bucket and one rotary actuator for the gripper. The scheme of the hydraulic system is shown in Fig. 5.

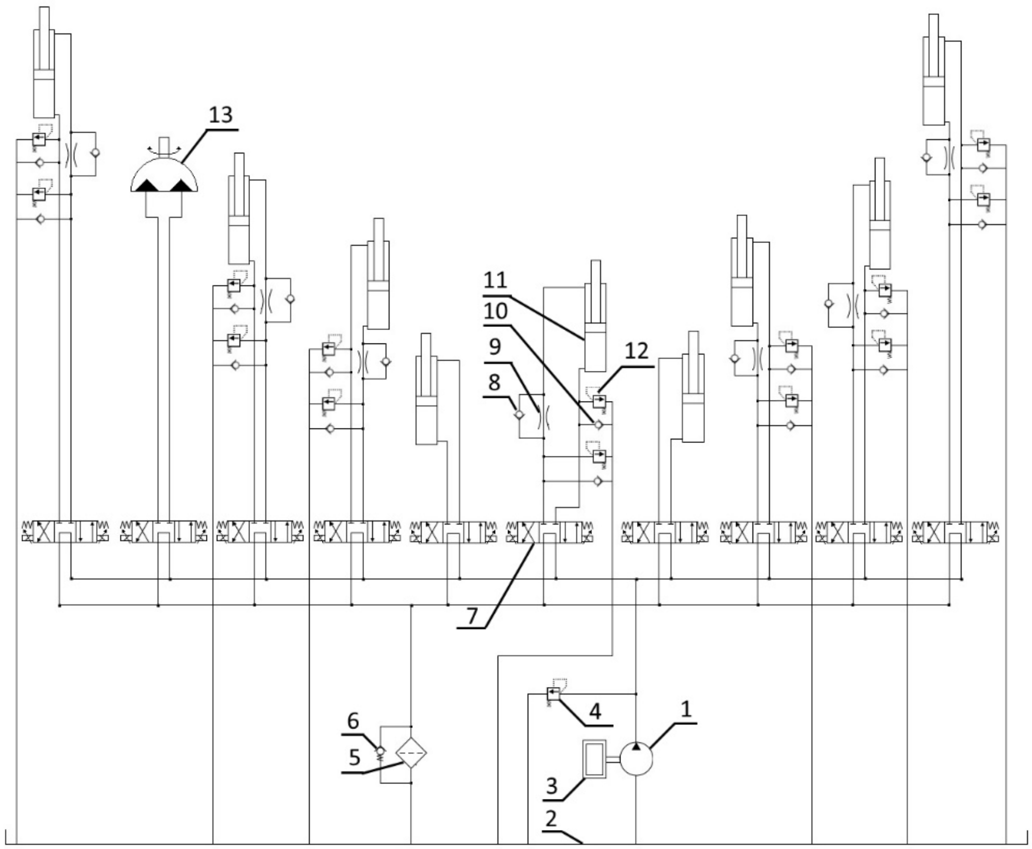


FIGURE 5. Scheme of the hydraulic system: 1-hydraulic pump; 2-hydraulic oil tank; 3-pump power source (eg internal combustion engine); 4-safety valve; 5-oil filter; 6-check valve with preload; 7-three-position four-way proportional distributor controlled by an electromagnet; 8-check valve; 9-throttle valve; 10-anti-cavitation valve; 11-hydraulic cylinder; 12-overload valves; 13-rotary hydraulic cylinder

DETERMINATION OF HYDRAULIC CYLIDERS LOADS

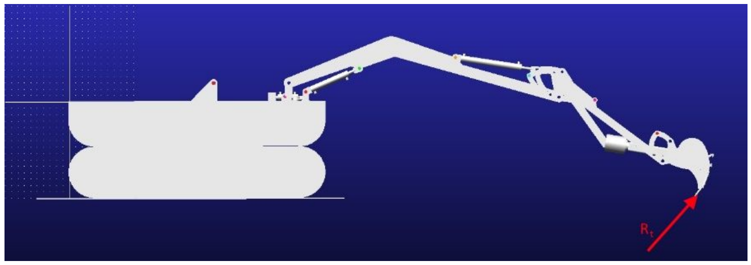
The geometric model was imported into the MSC Adams program in order to analyze the axial loads of cylinders of the system. Analyzes were carried out for the movement of the bucket while loosening the soil with their teeth. This case has been analyzed due to the anticipated heavy loads in the structural nodes. Analysis of two basic manipulator movements was also performed due to the anticipated high frequency of their occurrence:

- arm movement when digging with a bucket using an arm cylinder,
- boom movement when lifting a load from a ditch.

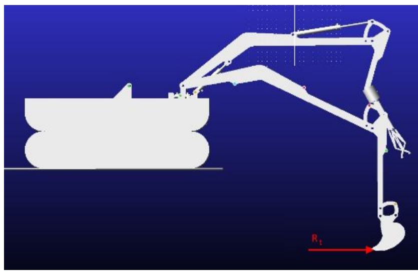
The tool end speed was assumed to be 0.5 m/s. It results from the required high speed of the device operation. Simplifying assumptions for simulation were adopted:

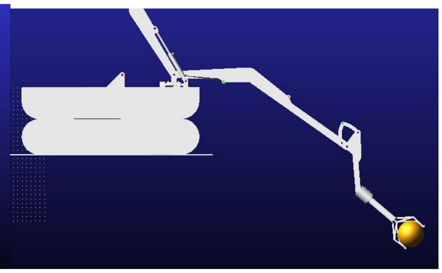
- the tangent reaction R_t of the soil as the dominant reaction is the only assumed load (R_t = 2206.5 N for the soil of 4th category of mining difficulty; R_t = 2341.6 N for the soil of 3rd category of mining difficulty),
- the lifted load is a concentrated mass weighing 80 kg.

Geometric models in MSC Adams program are shown in Fig. 6.



(a)





(b) (c)

FIGURE 6. Geometric models in MSC Adams program: (a) loosening the soil with teeth, (b) digging with a bucket, (c) lifting a load from a ditch

RESULTS

The characteristics of axial loads of actuators for the set of manipulators were made as a result of the performed simulations. The determined loads were used to select the components of the hydrostatic drive system. Characteristics of actuator load changes in case of:

- loosening of the soil with a bucket with teeth are shown in Fig. 7.,
- digging using an arm actuator are shown in Fig. 8.,
- lifting a load from a ditch are shown in Fig. 9.

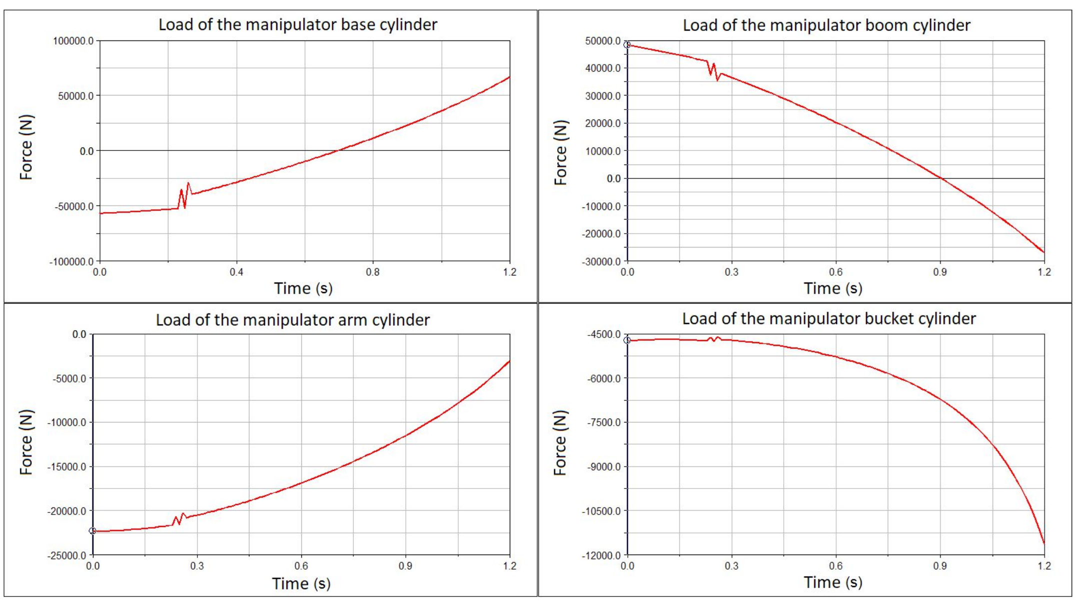


FIGURE 7. Characteristics of actuators load changes during loosening of the soil with a bucket with rippers teeth

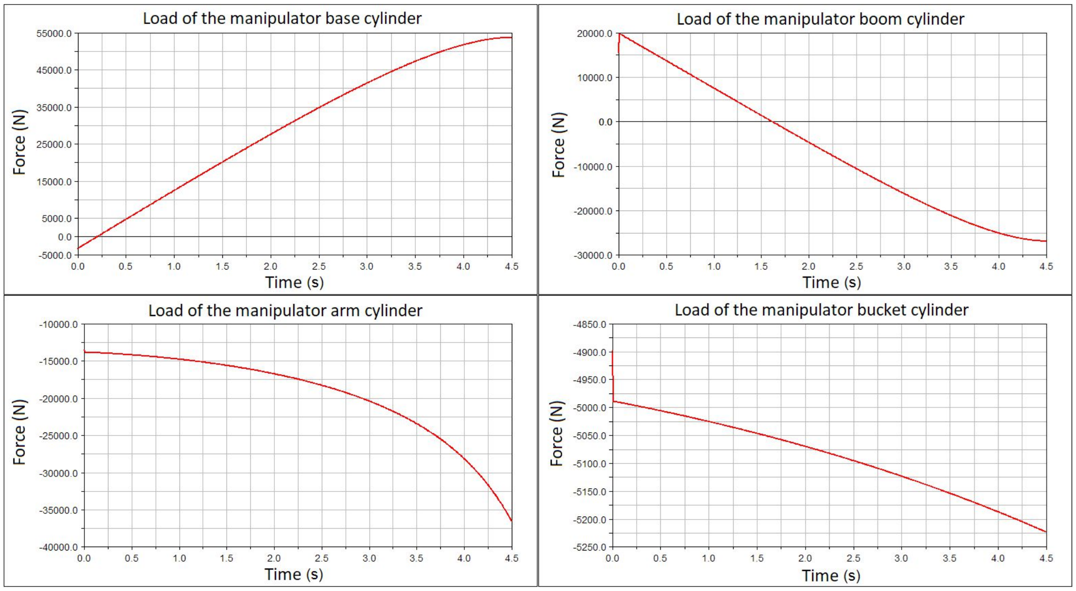


FIGURE 8. Characteristics of actuators load changes during digging using an arm actuator

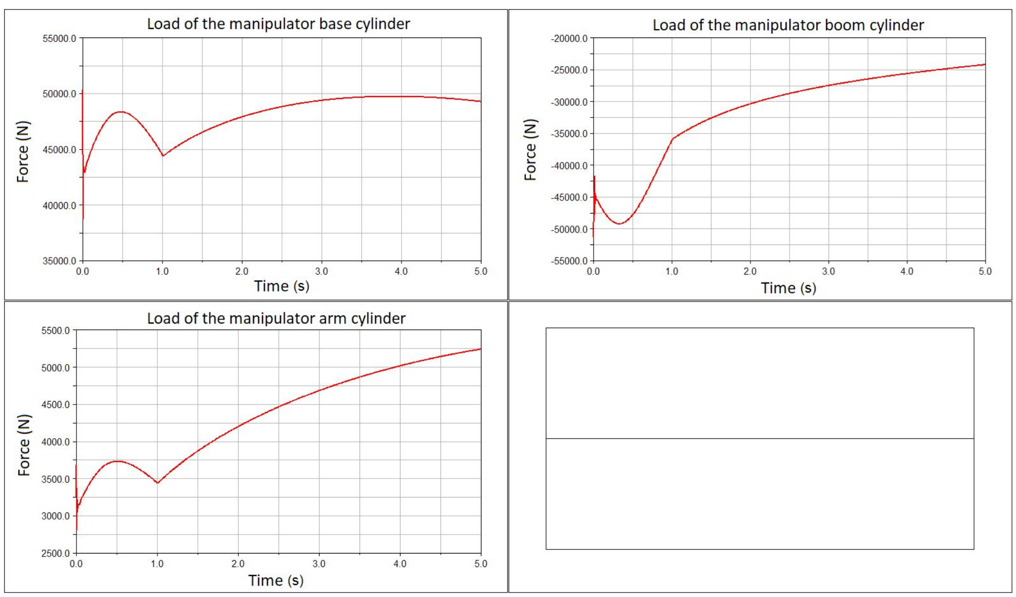


FIGURE 9. Characteristics of actuators load changes during lifting a load from a ditch

It was assumed for the simulations that the switching time of the directional valves is 0.2 s. The maximum values of actuators loads were determined from the characteristics obtained during the simulation (base cylinder – 66,8 kN, boom cylinder – 51,5 kN, arm cylinder – 36,6 kN and bucked cylinder – 11,6 kN). They show the dynamic factor during start-up movement can increase the loads about 20%. Despite this, the selection of actuators was not a problem and it was possible to select commercially available elements. Parameters of hydraulic cylinders were selected for designated loads and assumed pressure in the system equal to 20 MPa. Selected parameters of actuators are shown in Table 1. Absorptiveness of the actuators was from 9.00 to 9.80 dm^3/min for assumed stroke speed. The necessary pump capacity is 9-10 dm^3/min.

TABLE 1. Selected actuators parameters

Hydraulic cylinder	Piston diameter [mm]	Piston rod diameter [mm]	Actuator stroke [mm]	Assumed stroke speed [m/s]	Absorptiveness of the actuator [dm^3/min]
base	80	45	140	0.03	9.00
boom	80	50	260	0.033	9.95
arm	50	25	420	0.08	9.42
bucket	40	25	310	0.13	9.80

The lifting capacity characteristic was determined based on multibody simulation using the same manipulator model in MSC Adams program and it is shown in Fig.3. The assumption was the ability of lifting objects with a weight of up to 80 kg on a full reach. The set requirement has been met with a slight margin. The lifting capacity has been almost twice as high as expected value at minimum range. The simulations show that a limitation for the lifting capacity at maximum reach is EOD platform stability.

CONCLUSIONS

The proposed solution allow much faster IED neutralization thanks to the use of 2 cooperating manipulators. They allow immediate engagement of the second tool, which greatly speed up the work related to the unveiling and diagnosis of IED. The camera of the second manipulator can significantly improve the perception of the operator during work. Especially distance assessment by providing an image on the side of the active tool working field. This increases the safety and efficiency of the EOD robot in a very important way. In addition, the second manipulator can be a disruptor carrier, which enables immediate start of IED neutralization.

The developed kinematics provides a field of work that meets the assumptions. It allows for the effective implementation of a wide range of tasks related to the recognition, identification, neutralization and taking of dangerous objects type IED or UXO. At the same time, thanks to the mechanism of the folding base and a large range of boom and arm movements that provides ability to fold set to a compact size, it allows for high stability of the robot during ride. The conducted simulation tests have shown that dynamic loads can increase the load of construction nodes by approx. 20% in relations to static loads. However, the adopted manipulator kinematics allows doubling the lifting capacity while working at minimum ranges, which significantly increases the working abilities of the EOD robot.

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