Dynamics of underwater inspection robot

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Abstract: In this article authors present the problems connected with the dynamics modeling mobile robot with crawler drive. The description of the robot's dynamic is based on the energetic method based on Lagrange equations. In order to avoid modeling problems connected with decoupling Lagrange multipliers Maggi equations are used. During the analysis and motion simulation takes into account such parameters as: slipping track-dependent deformation of the substrate and claws, strength, buoyancy robot located in the liquid, the hydrodynamic resistance force depending on the environment in which the robot works and the strength of the rolling resistance of track. Simulations of the dynamics parameters have been made and the results are shown.

Keywords: mobile robot, kinematics, inspection robot, underwater robot

1. Introduction

The project of robot for inspection and diagnostics of tanks with liquids is constructed at the Department of Robotics and Mechatronic AGH. It's created in cooperation with the Municipal Enterprise of water supply systems and sewage system. Its aim is to develop the original construction of inspection machine enabling to determine the technical condition of concrete construction of storage liquid tanks (most often water). The design fundamental assumption: work in conditions of souse in liquid at depths up to several.

Fulfilling this assumption will have a fundamental influence on the reduction costs of the inspection procedure, because existing methods require most often emptying tanks, what carries behind long (about one month) stoppages. It next burdens the company budget, which is forced to turn off the tank/s from use.

Fig. 2. Tanks for storing water – MPWiK Cracow
Rys. 2. Zbiorniki do magazynowania wody pitnej – MPWiK SA Kraków

Other advantages of replacing traditional methods of thaw inspection robot are: faster inspection, greater work security and wider range of available inspection methods. The article presents one element of the structural-research procedure that is drawing the model of kinematics along in with numerical verification.

2. Description of the robot construction and working space

The inspection robot is constructed from tubular elements allowing for the wheelbase change. Crawler track tracks were used to the drive with developed transmission gears and propellers, their structure allows for works up to 30 m underwater. Additionally the robot is equipped with the diagnostic-monitoring module used for observation the tank above the robot height. Equipped is with 3 cameras (2 for observation, 1 for the docking with home station), 2 rotating drives and sensors laser.

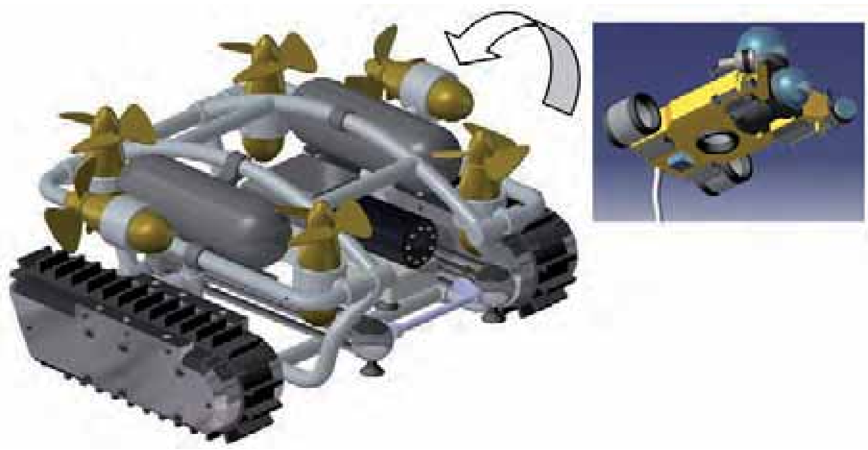

Fig. 1. Inspection robot with the diagnostic-monitoring module
Rys. 1. Robot inspekcyjny z modułem diagnostyczno-obserwacyjnym

The inspection robot is intended for diagnostics and observation of tanks with liquids. Cooperation with MPWiK SA in Cracow [7] enables verifications and testing the constructed robot in real terms. Cracow water supply systems have a dozen of tanks for storing water (among others – the biggest in Europe, with diameter of 34 m). They require repeated reviews and expert opinions, applying the constructed robot

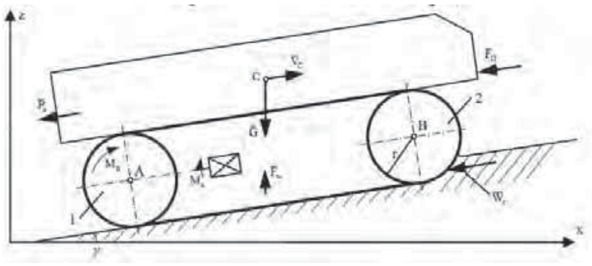

Fig. 3. The dynamic model of the robot
Rys. 3. Model matematyczny robota

will enable to streamline these activities and will reduce the costs of these type actions.

3. Modeling of the dynamics inspection robot

In the dynamics description we expand descriptions of the robot on forces acting but still considering the some characteristic points on the structure (fig. 3).

The dynamic [1–6] description of the robot is based on energetic method based on Lagrange equations. In order to avoid modeling problems connected with decoupling Lagrange multipliers Maggi equations are used. The final form of the dynamic motion equations based on Maggi formalism has been presented as follows:

$$\left(\frac{r}{2}[\ddot{\alpha}_1(1-s_1)+\ddot{\alpha}_2(1-s_2)]\cos\gamma\right)(m_R+2m)\frac{1}{2}r(1-s_1)\cos\gamma+$$
$$\left(\frac{r}{2}[\ddot{\alpha}_1(1-s_1)+\ddot{\alpha}_2(1-s_2)]\sin\gamma\right)(m_R+2m)\frac{1}{2}r(1-s_1)\sin\gamma+I_y\ddot{\alpha}_1=$$
$$M_{s1}\eta i+(-0,5P_u-0,5F_D-0,5G\sin\gamma+0,5F_w\sin\gamma-0,5W_{t1})r(1-s_1) \quad (1)$$

$$\left(\frac{r}{2}[\ddot{\alpha}_1(1-s_1)+\ddot{\alpha}_2(1-s_2)]\cos\gamma\right)(m_R+2m)\frac{1}{2}r(1-s_2)\cos\gamma+$$
$$\left(\frac{r}{2}[\ddot{\alpha}_1(1-s_1)+\ddot{\alpha}_2(1-s_2)]\sin\gamma\right)(m_R+2m)\frac{1}{2}r(1-s_2)\sin\gamma+I_y\ddot{\alpha}_2=$$
$$M_{s2}\eta i+(-0,5P_u-0,5F_D-0,5G\sin\gamma+0,5F_w\sin\gamma-0,5W_{t2})r(1-s_2) \quad (2)$$

where: α_1 – angle of rotation for wheel 1, α_2 – angle of rotation for wheel 2, m_R – frame mass, m – track mass, W_t – the force of resistance of the rolling track, P_u – pulling force, F_w – hydrostatic force, F_D – hydrostatic resistance force, I_y – inertia moment for the robot frame, s_1 – skid for wheel 1, s_2 – skid for wheel 2, G – gravity force, η – efficiency.

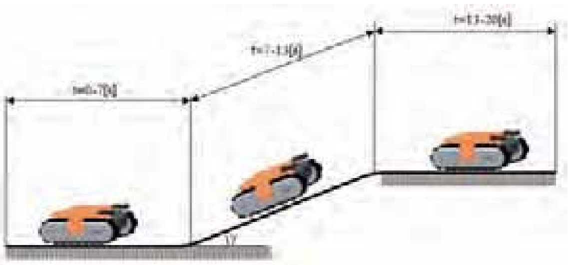

Fig. 4. The straight trajectory assumed for the simulation
Rys. 4. Trajektoria przyjęta podczas symulacji

4. Simulation on the basis of the robot description

With the use of kinematics and dynamics description of the robot the simulations have been carried out in order to fit construction parameters to optimal work conditions by the robot. In many cases the work environment of the inspection robot is not limited to horizontal surfaces. Sometimes the robot has to overcome the height difference and, therefore, to obtain a more comprehensive analysis of the robot's movement must also be performed in case of motion on the hill.

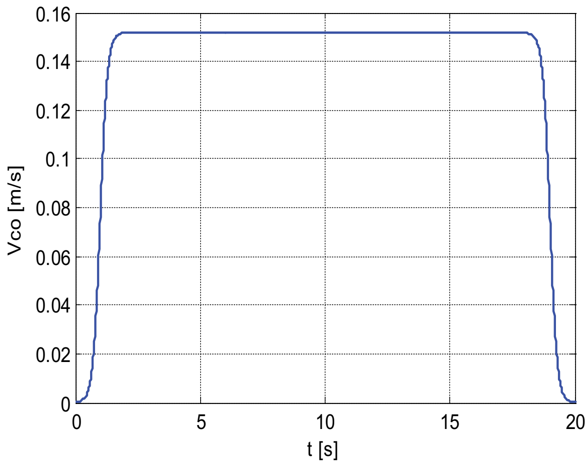

Fig. 5. Calculated velocity of the point C
Rys. 5. Zadana prędkość punktu C

In the analyzed case the robot moves on the ground with a slope $\gamma = 20°$ (fig. 4) and $V_C = 0.15$ m/s, where the track carrier segment length is equal $L = 0.322$ m, the quantity of clutches on truck equals $n = 9$, $\Delta l' = 0.0005$ m the deformation of the clutch, the radius of the driving wheel of truck $r = 0,05$ m and the distance $H = 0.306$ m.

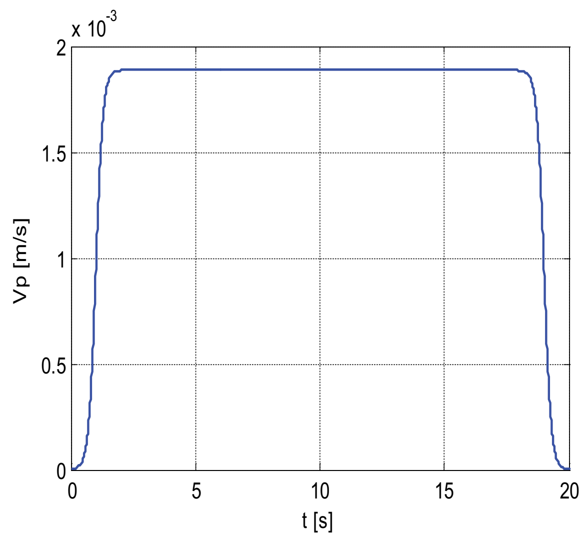

Fig. 6. The skid velocity
Rys. 6. Poślizg

After assumption of the velocity of characteristic point C we are receive the kinematic parameters as follows:

As can be observed, for the simulation, for ever-greater inflicted on a single horizontal ground deformation, slip velocity increases its value (fig. 5, fig. 6). The velocity of point C shell obtains increasing value to ensure the speed of the set point. However, this speed increase is in fact limited by the driving system (speed, power the drive motor), which leads to the fact that the robot starts moving with lower speed ever lost to the slip velocity [5, 6].

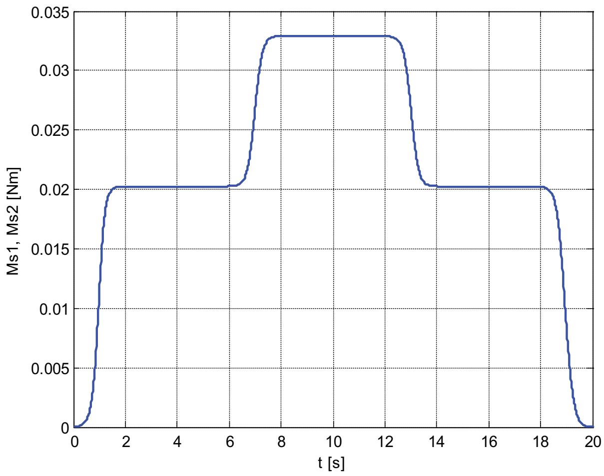

Fig. 7. The Driving moments before gearbox

Rys. 7. Momenty napędowe na osiach silników napędzających gąsienice poprzez przekładnie

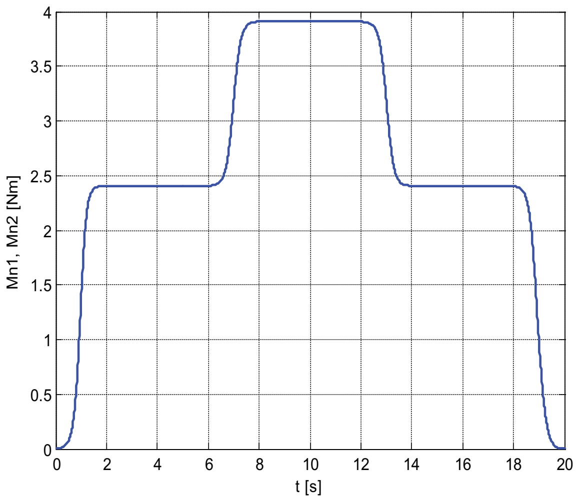

Fig. 8. The Driving moments after gearbox

Rys. 8. Momenty na kołach napędzających gąsienice

In the dynamics simulation (fig. 7 and fig. 8) we receive time courses in which during the robot motion, after a start-up and determining the speed, driving moments have constant value. Change in the moments happens when the robot encounters a hill on its way, and must overcome it with the same speed. When the robots has driven down the hill the value of the moments return to the previous value and then decline to zero in the 20 s of recording time when the robot stops.

5. Summary

The analysis of the dynamics and motion simulation takes into account factors such as slipping track-dependent deformation of the substrate and claws, strength, buoyancy robot located in the liquid, the hydrodynamic resistance force depending on the environment in which the robot works and the strength of the rolling resistance of track. This approach will be used for more detailed analysis taking into account additionally the turning of the robot. This will also be necessary during the identification and control this type of object.

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Dynamika podwodnego robota inspekcyjnego

Streszczenie: W artykule przedstawiono zagadnienia związane z modelowaniem dynamiki robota mobilnego z napędem gąsienicowym. Do opisu dynamiki robota wykorzystano równania Lagrange'a. W celu wyeliminowania mnożników Lagrange'a z równań ruchu, posłużono się formalizmem Maggiego. Przeprowadzając analizę dynamiki oraz symulacje ruchu, uwzględniono takie czynniki jak: poślizg gąsienic zależny od podłoża i odkształceń szponów, siłę wyporu robota znajdującego się w cieczy, siłę oporu hydrodynamicznego zależną od środowiska, w którym pracuje robot oraz siłę oporu toczenia gąsienicy. Otrzymane wyniki zaprezentowane zostały w postaci równań matematycznych oraz wyników symulacji obrazujących parametry dynamiczne ruchu robota.

Słowa kluczowe: mobilne roboty, dynamika, roboty inspekcyjne, roboty podwodne

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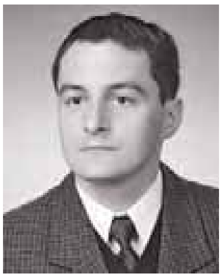

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