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THE MODEL AND SIMULATION OF A MINI ROBOT WITH ACTIVE STRUCTURE ADAPTABLE TO THE PIPE DIAMETER

In this paper, the authors present a robot for pipe inspection and exploration, which has in its structure a module for the maintenance of a constant pressure force between the robot's wheels and the inside diameter of the pipe. The paper starts with a short introduction about necessity of the presented solution followed by design aspects and finalizing with the test of the developed compliant module.

1. Introduction

The authors are developing a robot with adaptable active structure that can navigate inaccessible industrial pipes in order to check their condition and locate leakages. Different designs (Figure 1) are presented in the specialist literature. Some of the prototypes used for inspection of pipes with a large range of diameters have different types of springs in the structure to achieve contact between the wheel (caterpillar) and the pipe wall [4] [6] [10].

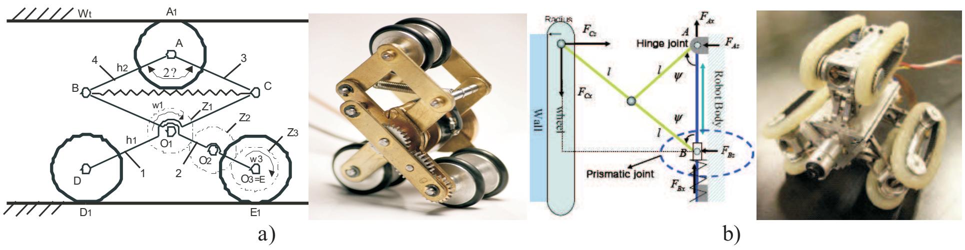

Fig. 1. Different designs of in-pipe mini robots

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If robots have structure adaptable to pipe diameters, to calculate the necessary force generated by spring the worst condition was taken in consideration, namely for the maximum diameter a priori fixed. Because of the existent springs, pressure on the pipe wall increases proportionally with the decreasing inner diameter of the pipe, influencing the speed of the robot. For the mini robot presented in the paper, we replace the spring with a DC motor and a force controller, so that the pressure on the inside wall of the pipe will be constant. The scheme from Figure 2a presents the robot structural scheme and the variation of the reduced torque to the motor shaft depending on the theta angle (Θ) (Figure 2b) [1].

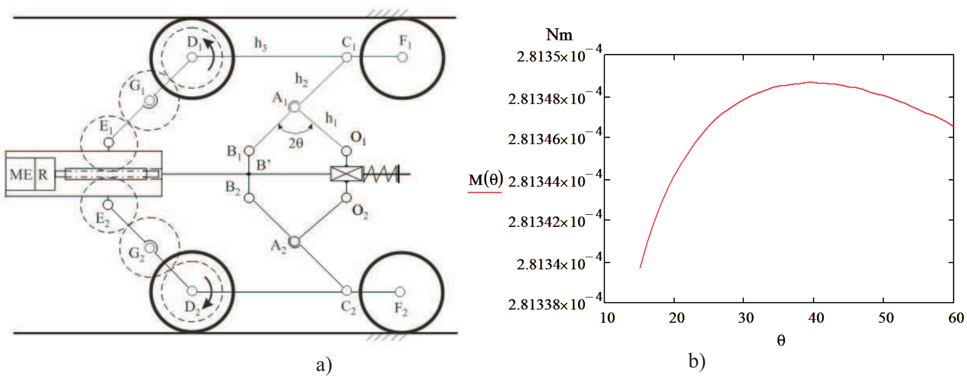

Fig. 2. Kinematic structure and reduced torque to the motor shaft

2. Proposed structure of an in-pipe robot

The proposed mechanical structure (Figure 3) is modular, composed of two main modules; one active module provides the locomotion inside the pipe, and the second one ensures adaptability of the structure to the inner pipe diameter. The structure makes it possible to mount other modules required for in-pipe inspection and exploration, such as video camera with orientation mechanism, or robotic arm for different operations. The active module is represented by a platform (1) with four wheels, powered using two DC motors with worm gears and synchronous belts transmission.

The module designed to ensure compliance (2) is composed of an articulated arm actuated by a DC motor with gearbox. In the arm structure, a force sensor is mounted, which will be used as a feedback to control the engine power (Figure 4).

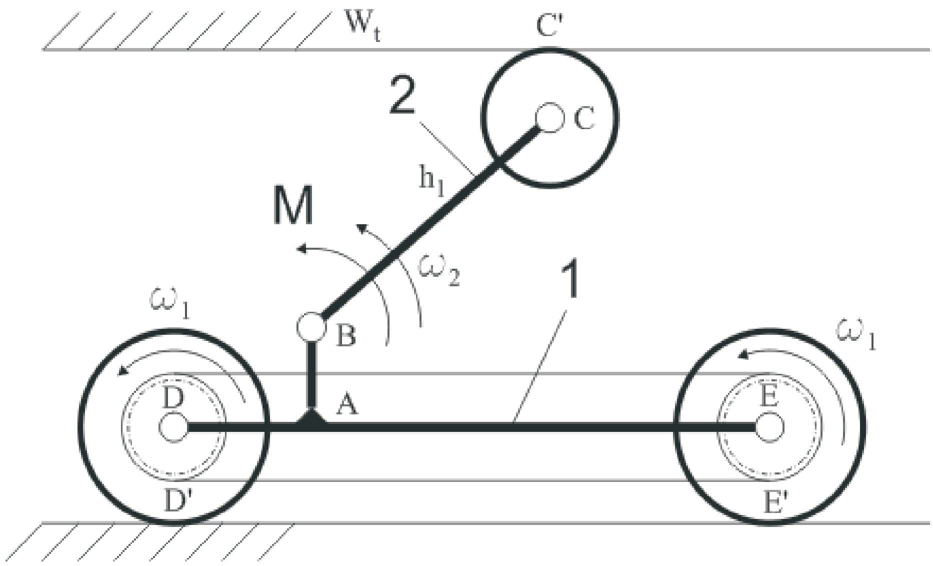

Fig. 3. Khinematic structure of the robot

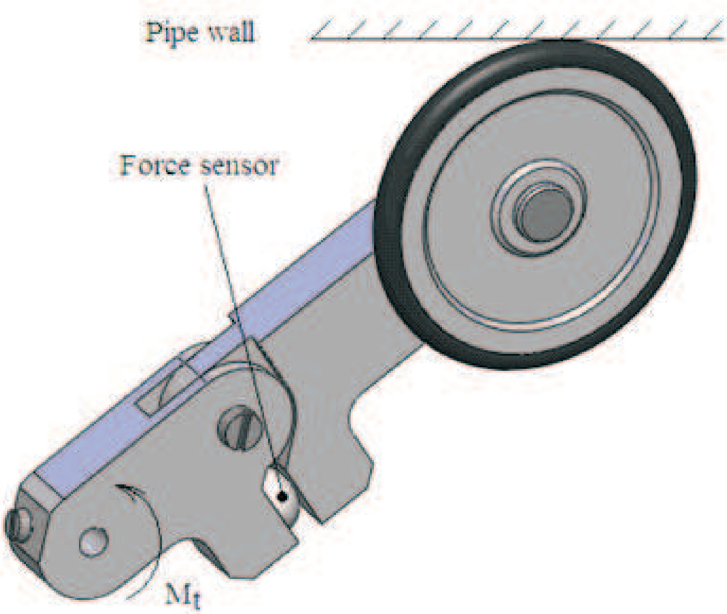

Fig. 4. Force sensor position

3. DC Motor and sensor model

3.1. The DC motor model

In this chapter, the equations which describe the electrical (1) and the mechanical behaviour (2) for a DC motor are presented:

$$\frac{di_a}{dt} = \frac{1}{L}(u_a - c_m \cdot \omega - R \cdot i_a). \qquad (1)$$

$$\frac{d\omega}{dt} = \frac{1}{J}(c_m \cdot i_a - \omega \cdot b - M_{ext}). \qquad (2)$$

where R represents the armature resistance, L the electric inductance, J is the rotor moment of inertia, c_m is the machine constant, b represents the friction coefficient and i_a is the armature current.

With the complete parameter set, equation (1) and (2) can be transformed into the graphical block model shown in Figure 5.

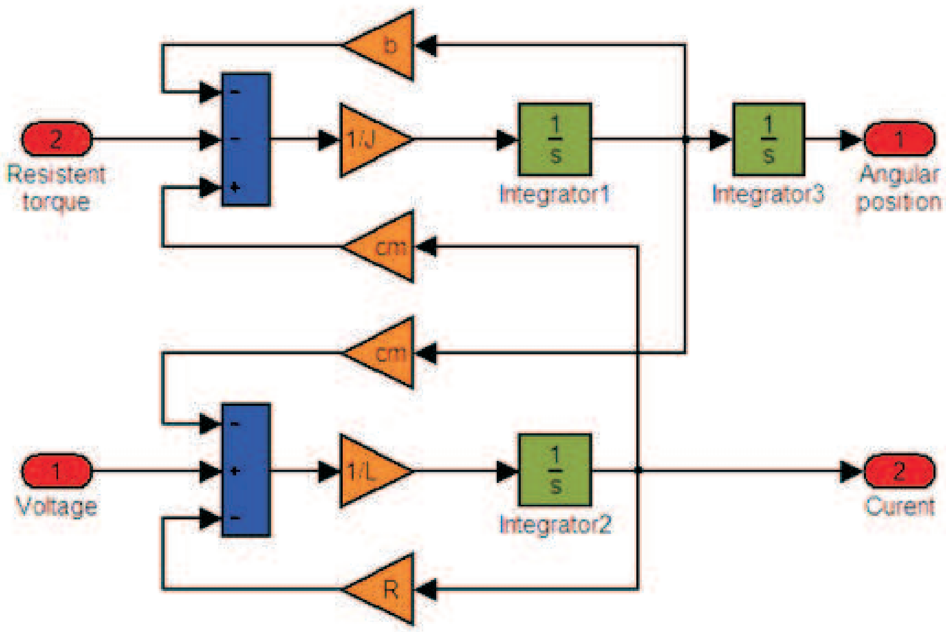

Fig. 5. DC-Motor model

3.2. The sensor model

As mentioned above, to measure the force we used a SFR force sensor type presented in Figure 6. Force sensing resistors (FSR) are a polymer thick film (PTF) device, which exhibits a decrease in resistance with an increase in the force applied to the active surface.

Fig. 6. Force-sensing resistor

For a simple force-to-voltage conversion, the FSR device is tied to a measuring resistor in a voltage divider configuration (Ffigure 7a). The output is described by the equation:

$$V_{out} = V_{in} \cdot \frac{R_{FSR}}{R_1 + R_{FSR}} \quad (3)$$

Using the setup from Figure 7a, we were able to get the following response presented in Figure 7b. The dots in the figure represent the answer given on an experimental sensor response and the continuous line represents the polynomial determined to approximate the sensor response. Polynomial coefficients were determined by interpolating the experimental results using the Matlab environment.

$$P(u) = 0.0723u^4\text{-}1.4925u^3 + 5.5329u^2\text{-}7.6492u + 5.0001 \quad (4)$$

In the shown configuration, the output voltage decreases in respect to the increasing force.

4. DC Motor torque control

To control the force of the compliant module, a control algorithm must be implemented. Due to its robustness, simplicity and ease of implementation, a PID (proportional, integrative, derivative) control strategy was chosen.

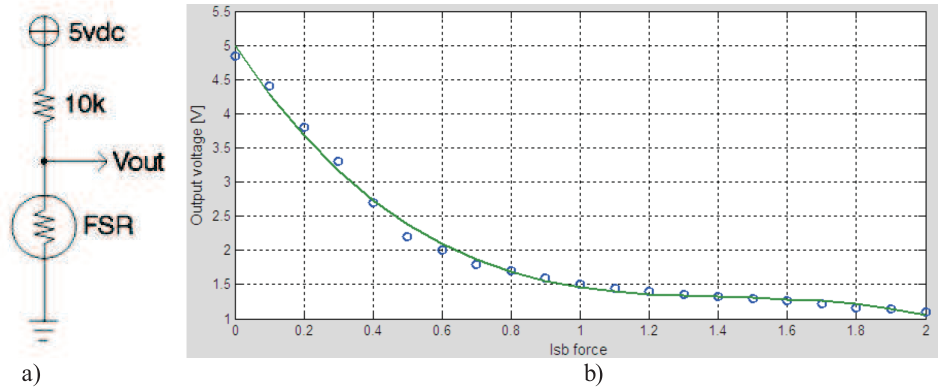

Fig. 7. FSR Voltage Divider and Sensor Output Chart

The Simulink compliant module model was created, by adding the gearbox and the force sensor to the DC motor model presented (Figure 8). A PID controller block is added together with the necessary reference generator (a step block in this case) and a scope to graphically visualize the results. The parameter tuning was made using an iterative method based on the Matlab/Simulink/Response Optimization/ Signal Constraint block (Figure 8).

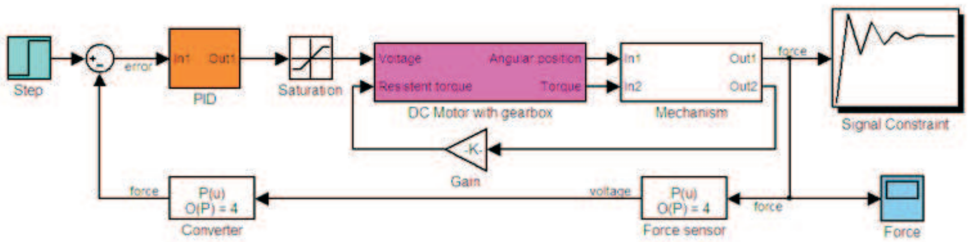

Fig. 8. Matlab/Simulink model of the compliant module

5. Electronic component design

This section describes a H-bridge electronic board developed to drive the motor using the signals from the dSPACE DS1103 board.

The main part of the H-bridge board is the TC4424 Dual High-Speed Power MOSFET Drivers. One needs two signals for controlling the DC motor with the use of the developed board, one PWM signal for variable power supply and a second one, a digital signal used to select the motor direction. The maximum power supply (VSS) is up to 18 V and 3A peak output current.

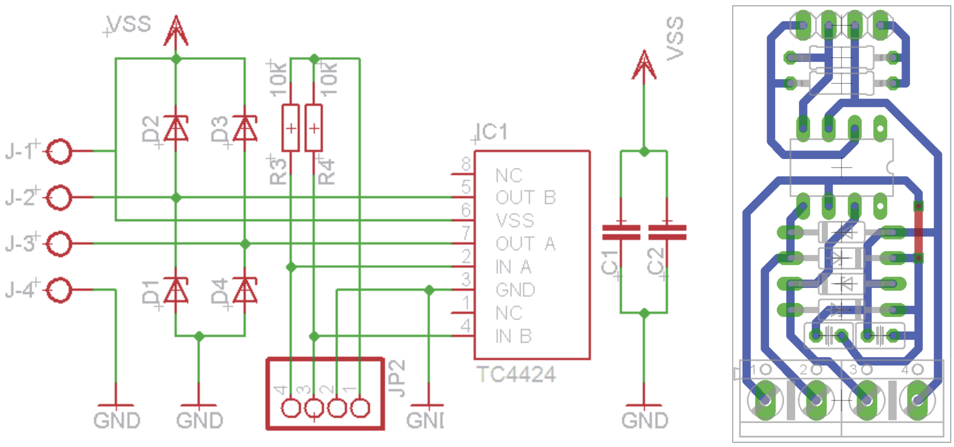

Fig. 9. H-bridge schematic and board circuit

6. Real-time model using dSPACE electronic components design

For designing and implementing in real-time a motor force controller for the developed system we used the dSPACE DS1103 [3] board. The inputs to the DS1103 include the desired force and the output of an force sensor connected in the mechanical system. The outputs from the DS1103 include a PWM signal as a input to the motor and a digital signal used for motor direction (trough H-bridge). Inputs and outputs from the DS1103 pass through the CLP1103 [2] connector panel for the DS1103 board. A general block diagram for the system is shown in Figure 10 below.

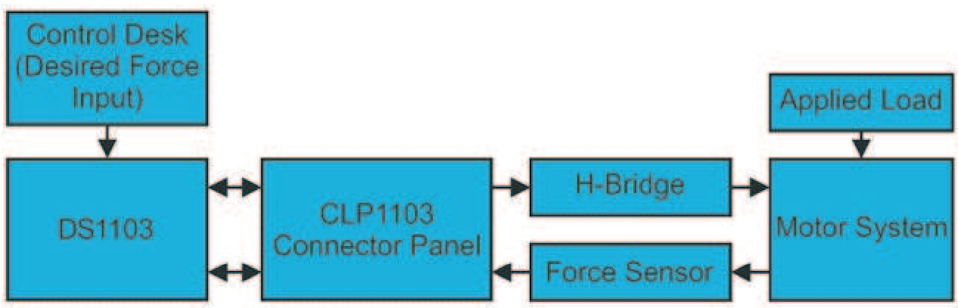

Fig. 10. Motor Force Control System Block Diagram

The analyzed system modelled in real-time Simulink is shown in figure 11. The DS1103SL_DSP_PWM3 and DS1103BIT_OUT8_GO blocks of dSPACE library [7] are used to generate the PWM signal and to set the direction for motor.

The DS1103MUX_ADC_CON1 block is used to convert analogue to digital signals from the force sensor and to display the system load in Control Desk.

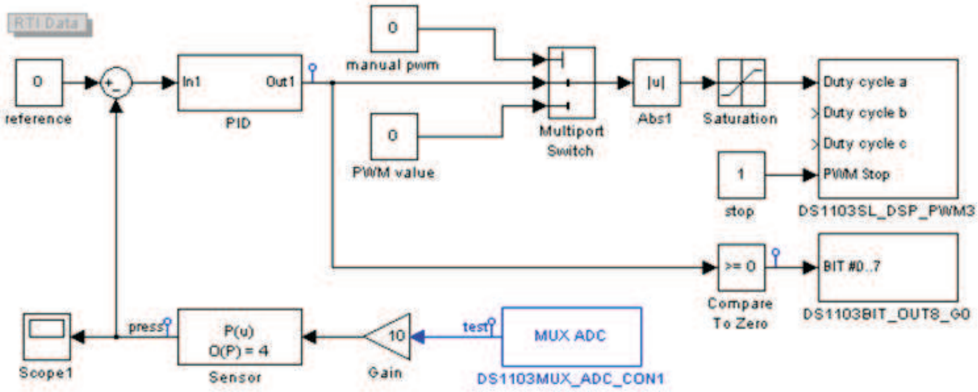

Fig. 11. Real-time Simulink model

7. Conclusion

On some pipelines, it is easier to use remote visual inspection equipment to assess the condition of the pipe. Robotic crawlers of all shapes and sizes have been developed to navigate the pipe. The video signal is typically fed to a truck where an operator reviews the images and controls the robot.

In the usage of only one actuator instead of a spring, the maintenance of a constant pressure force, regardless of the pipe diameter, is permitted.

In the functioning conditions where slippage appears, the actuator permits the growth of the pressure force between the wheel and the pipe over the limit value of the spring. The disadvantage of this system is caused by imperfection of the sensor, the energy consumption and the complexity of the system.

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REFERENCES

[1] CIREBEA C.I, DONCA R., TĂTAR M.O., ALUŢEI A.: “Rapid Control Prototyping for an In-Pipe Inspection Robot”, Poster Sessions Workshop IOHIS – Interoperabitity in healthcare

information systems 2010 IEEE lnternational Conference on Automation, Quality and Testing, Robotics AQTR2010, pg. 148.
[2] Connector and LED Panels, *Catalog 2008*, Germany: dSPACE GmbH, 2008, p. 302.
[3] Control Desk Experiment Guide For Control Desk 3.2, Germany: dSPACE GmbH, 2008, Release 6.1.
[4] CHOI H.R., RYEW S.M.: Robotic system with active steering capability for internal inspection of urban gas pipelines, Mechatronics, Vol. 12, pp. 713-736, 2002.
[5] "DS1103 PPC Controller Board", Germany: dSPACE, July 2008.
[6] JUN C., DENG Z., JIANG S.: Study of Locomotion Control Characteristics for Six Wheels Driven In-Pipe Robot, Proceedings of the 2004 IEEE International Conference on Robotics and Biomimetics, Shenyang, China, 2004.
[7] Real-Time Interface (RTI and RTI-MP) Implementation Guide, Germany: dSPACE GmbH.
[8] ROH S.G., CHOI H.R.: Differential-drive in-pipe robot for moving inside urban gas pipelines, IEEE Transactions Robotics, Vol. 21, No. 1, pp. 1-17, 2005.
[9] TĂTAR M.O, STAN S., MANDRU D.: The modular robotic systems, PAMM Volume 8, Issue 1, pp. 10311-10312, WILEY-VCH Verlag GmbH & Co. KGaA, Weinheim (Special Issue: 79th Annual Meeting of the International Association of Applied Mathematics and Mechanics (GAMM), Bremen 2008).
[10] TĂTAR M.O., ALUŢEI A., MÂNDRU D: Driving module for modular robotic system, in vol. Machine Design 2009, Ed. S. Kuzmanovic, University of Novi Sad, 2009, pp. 147-150.
[11] TĂTAR M.O., ALUŢEI A., MÂNDRU D., LUNGU I.: Minirobots with Adaptable Structure - Chapter 21 in DAAAM International Scientific Book 2009, pp. 187-196, B. Katalinic (Ed.), Published by DAAAM International, ISBN 978-3- 01509-69-8, ISSN 1726-9687,Vienna, Austria, DOI: 10.2507/daaam.scibook.2009.21.
[12] TĂTAR M. O., ALUŢEI A., MÂNDRU D.: In-pipe Modular Robotic Systems for Inspection and Exploration, Solid State Phenomena Vol. 164 (2010) pp 425-430, Trans Tech Publications, Switzerland doi:10.4028/www.scientific.net/SSP.164.425.

Model i symulacja minirobota o aktywnej strukturze dostosowującego się do średnicy rurociągu

S t r e s z c z e n i e

Artykuł zawiera opis minirobota przeznaczonego do inspekcji i eksploatacji rurociągów, którego aktywna struktura pozwala na utrzymanie stałej siły nacisku między kołami robota a wewnętrznym obwodem rury. Artykuł rozpoczyna się krótkim wstępem o celowości przedstawionego rozwiązania, następnie omawia się aspekty projektowania, a w zakończeniu opisuje test opracowanego modułu sterowania.