Simulation of Climbing Robots Using Underpressure for Adhesion

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1 Introduction

Applications of climbing robots using suction cups are examined in several projects worldwide. Examples are cleaning robots for windows, painting robots, inspection robots for concrete walls or climbing machine operating on steel tanks. The reliability of the used adhesion mechanisms is far away of reaching 100%. In previous research work it was shown that the concept of a wheel-driven climbing robot with a suction cup is adequate to move on vertical walls or overarm. In [3, 5] and [4] the adhesion system, the sensor system and the navigation strategy for such a robot is introduced. Still an open problem is the closed-loop control of the underpressure system because the effects of the surface conditions on the pressure in the suction cup can not be completely determined. Therefore a simulation system is developed in [9] which allows based on a thermodynamical model to test the adhesion reliability under arbitrary surface conditions.

This paper describes first the simulation based on the 1st fundamental theorem of thermodynamics. Then the results of the comparison of a simple climbing robot with one suction cup to its simulation are presented.

2 Simulation of the Underpressure System

The first part of this chapter introduces the fundamental thermodynamic equation that describes the pressure change in a control volume (i. e. underpressure chamber) because of air flow through lekages or valves from or to the outside of this volume (i.e. environment or other chamber). Furthermore the modelling of sealing leakages due to cracks in the underground surface is described. In the second part the results are applied to a seven-working-chamber climbing robot.

2.1 Thermodynamic Model of Pressure Equalisation and Sealing Leakages

From the 1st fundamental theorem of thermodynamics and BERNOULLI's equation for the steady state flow of an ideal fluid (see [1]) the change of pressure $\dot{p}$ in a control volume is given by (1) (for a detailed derivation see [2], Chap. 3.3 and [9], Chap. 3).

$$\dot{p} = \frac{\kappa RT}{V} \sum_{k} \left(\mathrm{sgn}(p_{k_0} - p_{k_1}) * A_{k_{in}} \sqrt{2\rho \Delta p_k} \right) \tag{1}$$

The parameters in this equation are as follows:

- κ – adiabatic exponent of air
- R – gas constant of air
- T – air temperature
- ρ – air density
- V – control volume
- p_k – pressure in control volume k
- Δp_k – pressure difference between two adjacent control volumes (with pressures p_{k_0} and p_{k_1})
- $A_{k_{in}}$ – area of air flow between the two volumes

The *sgn*-function delivers the sign of its argument and the sum is calculated for all volumes that are connected with the considered one through air flows.

Figure 1 shows the developed model for sealing leakages which arise from "deformations" of the underground surface: holes, grooves and cracks in a concrete wall for example. The effective leakage area A is orthogonal to the air flow paths and connects the control volume with the outside environment. For complete exactness the hatched volume must be added to the control volume. As it is unknown, it is set approximately to 0 in the simulation.

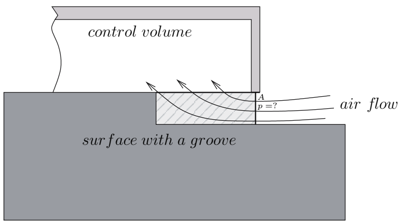

Fig. 1. Model of air flow through a leakage and corresponding flow paths. A is the effective leakage area, p is the pressure in A