DEVELOPMENT OF A SEALING SYSTEM FOR A CLIMBING ROBOT WITH NEGATIVE PRESSURE ADHESION

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The non-destructive inspection of large concrete walls is still an unsolved problem. One possible technique is to use driven wheels for the propulsion and a vacuum system for the adhesion. The seals for the vacuum chambers are slipping over the rough surface, therefore it is not guaranteed that the chambers are always airproof. Especially over concrete walls a special seal construction must be found to make the adhesion more safe. On the other side the propulsion system must be able to produce enough force for carrying and accelerating the robot to a suitable velocity.

This paper will present the climbing robot Cromsci which uses the described techniques. The propulsion system consists of three omni directional driven wheels which are airproof and completely rotatable and has been presented in earlier papers before. For adhesion a vacuum system of seven controllable vacuum chambers and one reservoir chamber is used. This system including chambers and seals will be discussed in more detail. The rough and sharp-edged surface of concrete walls cause strong requirements to the sealing concerning leak tightness and attrition. Therefore, each sealing must be flexible to allow a good adaption to the ground but also let the robot slip when the wheels are turning.

Keywords: Climbing Robot, Adhesion System, Negative Pressure, Sealings.

1. Introduction

Regular inspections and repairings of concrete buildings like motorway bridges and dams are very extensive. Among high expenses in money and time the technical stuff has to work in hazardous environment by using complex access devices. For a better objectivity and reproducibility of inspections as well as for safe working conditions a climbing robot has been build up which can check the building remote controlled. During different experiments with the prototypes the importance of sealings became obvious. Although we got promising results onto smooth concrete or wooden surfaces the sealing failed on rough surfaces which can be found on every concrete building. For this the existing adhesion concept was overhauled and new sealing materials and constructions were developed.

In literature other climbing robots using negative pressure adhesion can be found, although not all of them can be used for this application [1] [2] [3] [4]. Some of them are suitable only for flat surfaces like glass or use legs for locomotion, which will result in slow movement. For climbing on concrete surfaces an active vacuum system driven by wheels seems to be the best solution because of fast continuous motion and a simple mechanical structure.

2. Adhesion Concept

The adhesion concept of our climbing robot CROMSCI[a] consists of seven single vacuum chambers which are supported by one large reservoir chamber at the top of the robot. Each chamber receives its negative pressure from the reservoir chamber which is evacuated by three suction engines and can be controlled by valves. If one or more working chambers are loosing negative pressure they can be isolated from the vacuum system to avoid the propagation of normal pressure to the other chambers which will result in loss of adhesion. The air-pressure in each chamber and the reservoir is measured by pressure sensors. These informations are given to a pressure controller which opens and closes the valves to evacuate the chambers separately depending on the actual leak tightness. The components of the adhesion system are:

- one large reservoir chamber (including valve to outside)
- three suction engines evacuating the reservoir chamber

[a]Climbing RObot with Multiple Sucking Chambers for Inspection tasks

- seven working chambers (each including valve, pressure sensor and sealing)
- electronics for low-pressure control

Beside the real adhesion mechanism a thermodynamical model has been created to simulate the airflow and pressure variation with modelled leakage areas and cracks. It shows that the usage of multiple sucking chambers are as important as a good driving strategy if the cracks are too large for the sealing. More details on the vacuum control system can be found in [5].

2.1. *New Sealing Design*

An important aspect is the concept of the sealings between the negative pressure inside the vacuum chambers and the normal pressure outside. To guarantee that the climbing-robot keeps the contact to the wall while moving on the surface, it is neccessary to develop a seal which needs to be wear-resistant, leak-proof and easy sliding. To reach this intention a prototype demonstrator has been developed which enables to apply several different sealing materials and shapes to find the optimum in friction and wear.

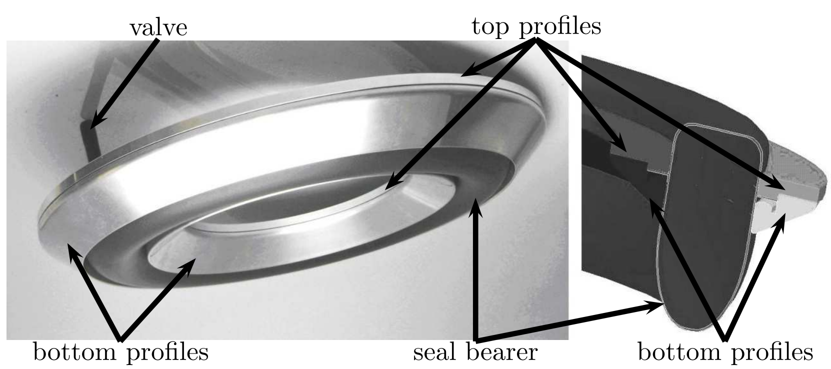

Fig. 1. Prototype and drawing of the basic construction

It is an assembly of one seal-bearer and two aluminium profiles, in which the bearer is clipped (fig. 1). It is possible to vary the height of the seal-bearer by changing the air pressure in the tube made of Butyl. Onto the surface of the tube the different samples of seal material and friction can be applied.

Another important point with regard to practical application is an easy changing of the seals if they become porous due to abrasion. With the shown sealing this replacement can be done fast and simple.

2.2. *Test Stand*

To detect the lift/drag ratio and the value of friction between the sample and the surface vis-a-vis, a Pin-on-Disc test stand is used which fulfills DIN 53516 [6]. With this test bench it is possible to adjust different velocities of the turning disk to simulate the relative movement between seal and wall. The normal force, which is affected because of the vacuum to pull the robot against the wall, can be simulated with the help of some weights, which are placed on top of the pin. The sliding friction is detected by using a beam in bending, which is coevally the reference surface for the inductive sensor to detect the amplitude of the beam. To determine the wear across the time of testing, a second inductive sensor is applied on the opposite site of the beam in bending. They are both placed on one rocker, shown in Figure 2. The sliding friction and the wear will be detected while using a dry, wet and steamed contact between pin and disk. In this way, all conditions, which appear on the seal of the climbing robot, can be simulated.

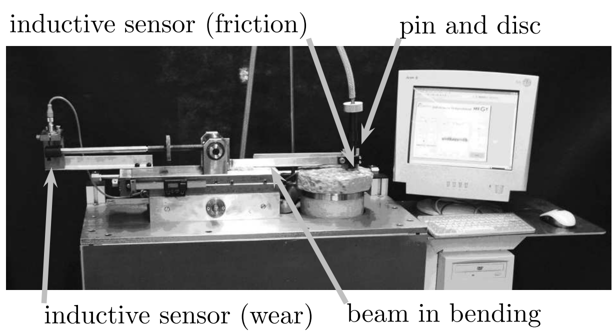

Fig. 2. Pin on Disc test stand

3. Locomotion

As already mentioned before our robot Cromsci is driven by three omnidirectional wheels which let it slip over the surface. The interaction between adhesion system and drive is important due to the fact that the robot should neither stuck to the wall nor fall down. If the sealings are too soft the robot would suck itself to the wall, if they are too hard they lose leak tightness. So we have to make a crompromise and allow controlled leakage.

To measure all occuring forces a load cell is integrated into each wheel so that the robot can recognize if the negative pressure is too high for movement or dangerously low. The drive and the adhesion system will soon be integrated into one control mechanism which allows a safe driving onto rough surfaces. More informations about the propulsion system can be found in [7].

4. Experiments and Test Results

In the first studies with the Pin on Disc stand the friction between several samples of seals are tested. In the following chart, the different parameters can be seen.

Test No.	rel. Velocity $\left[\frac{m}{s}\right]$	Temp-erature $[°C]$	Lubri-cation	Contact Pressure $\left[\frac{10^{-3}N}{mm^2}\right]$	Material Pin	Material Disc
1	0,1-0,03	20	-	9,4	Rubber	Glass
2	0,1-0,03	20	-	9,4	Rubber	Marble
3	0,1-0,03	20	Dust	9,4	Rubber	Concrete
4	0,1-0,03	20	-	9,4	Carpet	Glass
5	0,1-0,03	20	-	9,4	Carpet	Marble
6	0,1-0,03	20	Dust	9,4	Carpet	Concrete

The tests no. 1 to 3 are made with rubber on glass, plane marble and plane concrete. They provide a basis to compare well known materials with the samples of carpet. In all experiments the temperature and the contact pressure were kept constant. It could be possible, that the temperature departs in a field of ± 1 kelvin but this is irrelevant for the result of the friction coefficient. It was attempted to run the test without any kind of lubrication, but this was not possible with the samples of concrete. The concrete disc wears very fast, because the pin in contact grinds the fine sand on the surface. This fine sand works like a kind of lubrication and tempers the dry friction. However all pins, which stay in contact with the concrete disc, excite this special wear, so they are comparable among each other. Three different materials were used in the Pins: rubber, carpet (short fibres) and vertofloor (long fibres) as shown in figure 3.

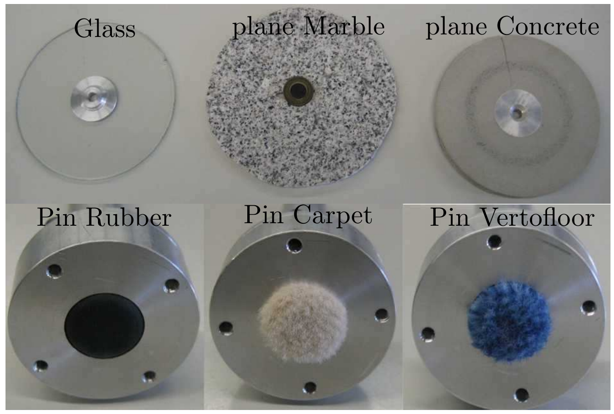

Fig. 3. Disc materials (top) and pin materials (bottom) used for the tests

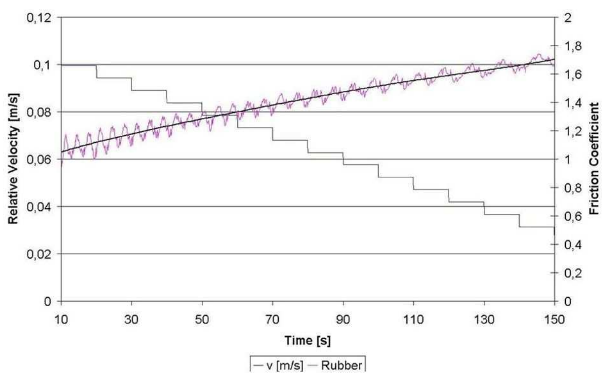

Fig. 4. Dynamic friction: rubber to glass

Figure 4 shows the graphs of the velocity steps and the value of the friction coefficient between rubber and glass. The dynamic friction coefficient starts with a value of approx. 1 at the highest relative velocity of 0,1 meters per second and rises slowly to 1,7 while the velocity decreases to 0,03 meters per second. The irregularities in the graph are generated by disturbances in the contact, resulting by the symmetry of the disc.

Figure 5 shows similar to figure 4 a friction coefficient. In opposition the current graph does not follow a clear line, so the dynamic friction cannot be clearly seen. Because of the distinctive swinging of the results, it has to be assumed, that there is more static than dynamic friction. That's why the trend line is not in the middle of the amplitudes, but on the maximums.

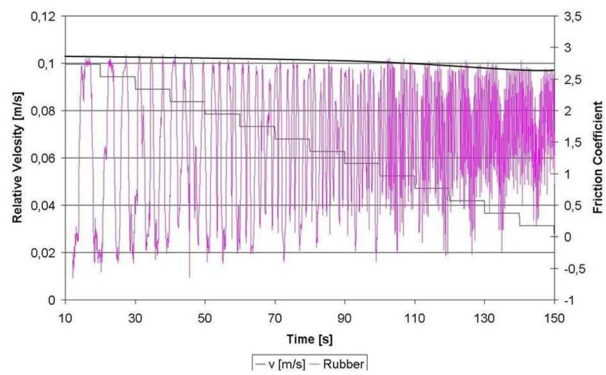

Fig. 5. Static friction: rubber to plane marble

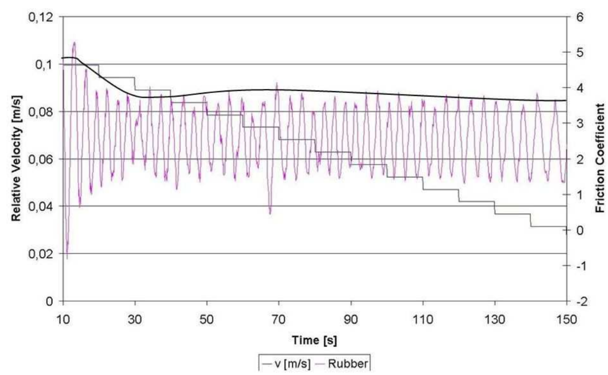

Fig. 6. Static friction: rubber to concrete

The contact between rubber and concrete (fig. 6) seems like a mixture of figure 4 and 5. The results of the experiments are also swinging, but the dynamic and frequency is much lower than in figure 5. Similar to the friction coefficient in the graph before, the dynamic friction coefficient cannot clearly be detected. Again the static friction has to be used, to get a comparable result.

The graphs in figure 7 are the first results, which can be compared to the graph in figure 4. Two distinctive differences can be seen: all values are much lower. They vary from 10% to nearly 30%. The second conspicuousness in the graph is the inverse pitch: the rubber friction rises with falling velocity, the carpet frictions are nearly constant and fall at the end of the experiences. The carpet slides much easier on glass than rubber, whereas

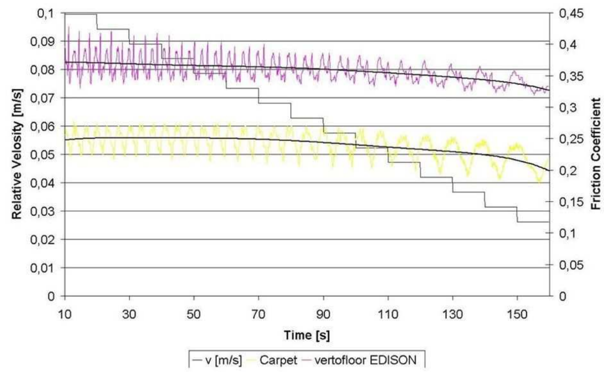

Fig. 7. Dynamic friction: carpet to glass

the carpet with the short fibers has a lower friction coefficient.

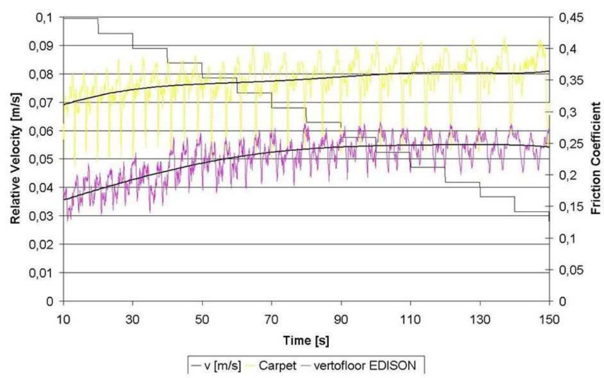

Fig. 8. Dynamic friction: carpet to plane marble

By comparison figure 5 with figure 8 the friction and the swing frequency between adhesion and sliding is much lower. With the graph in the current figure it is possible to find a dynamic friction, which is significantly lower than the static friction of the rubber in contact with the plane marble. The difference is again nearly up to 10

The course of the graphs in figure 9 shows a distinctly static friction. It is necessary to use the maximums of the amplitudes to compare it with figure 6. The course of the friction for both kinds of carpets is approx. from a third up to a quarter. Summary of results:

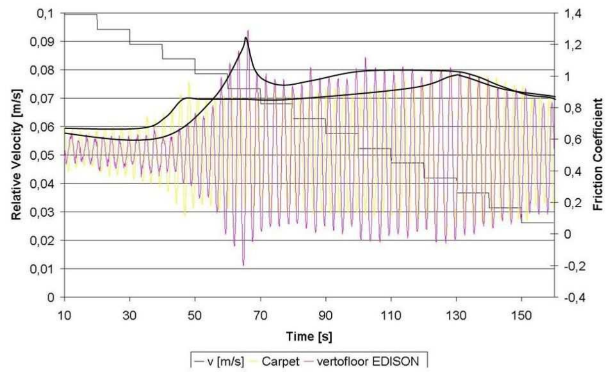

Fig. 9. Static friction: carpet to concrete

Test No.	Static Friction	Dynamic Friction
1 rubber	-	1,1 - 1,7
2 rubber	2,3 - 2,7	-
3 rubber	3,7 - 4,9	-
4 carpet	-	0,33 - 0,37
4 vertofloor	-	0,20 - 0,25
5 carpet	-	0,17 - 0,25
5 vertofloor	-	0,32 - 0,37
6 carpet	0,70 - 1,00	-
6 vertofloor	0,60 - 1,22	-

5. Conclusion

In this paper we introduced a novel sealing system which meets high demands. A sealing prototype is presented and different applicable facings have been tested concerning friction and abrasion onto several surfaces like concrete or glass. These experiments pointed out, that the sliding characteristic strongly depends on the facing material and will have a high influence on robot movement and adhesion.

Future Work mainly consists of experiments under real conditions. For this the adhesion system of our robot CROMSCI (see figure 10) has to be completed so that it will cling to the wall. Furthermore more experiments concerning the leak tightness of the sealing facings have to be carried out. These results will be compared with simulated experiments and evaluated to achieve best adhesion attributes.

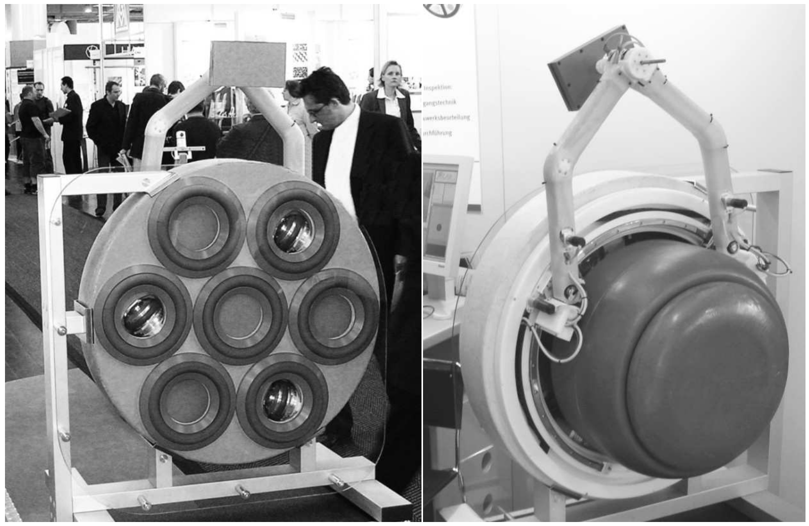

Fig. 10. CROMSCI platform as presented at the Hannover Messe 2007 with seven vacuum chambers, mounted sealings (left) and reservoir chamber (right).

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