Molding a silicone-based shoe sole with pneumatic air-inflow for extension and flexion of the foot

Claes Gill[1]

***Abstract*— The purpose of this project was to investigate if a silicone-based pneumatic shoe sole could carry the full weight of a person while achieve extension and flexion of the foot. Since the silicone is a flexible and robust material it is interesting to see what this project can be applied to in future. It might be applicable for helping people with different foot or ankle problems or even for stabilising a robot in various terrains.**

This project demonstrate that the silicone shoe sole is strong enough to can carry a person in both the extension and flexion state.

I. INTRODUCTION

Shoes takes a big role of our daily life. Whether it is for walking or other activities the question becomes if it is possible to make the shoes adapt to our different needs by the use of technology. Today it is a large number of research-paper regarding various shoe technologies that can enhance the shoe experience. Shoe-companies like Reebok have been implementing different technologies for years. For instance was Reebok the first to implement an internal inflation mechanism to regulate the ankle support of the shoe, called the Reebok Pump that was released in 1989 [1]. It also exist newer products like the Inflasole [2] and the Inflashoe [3] that you can read more about in chapter II.

Even though there are some products on the market they all have a common problem. They are designed to be insoles. Therefore we came up with the idea to make an inflatable shoe sole made out of silicone. With a silicone-based shoe sole we are able to make air chambers expanding by applying pressure and manipulate them to behave to different terrain and surroundings. This could leave us to solve many interesting problems.

For instance we can imagine a patient that have limited ankle movement and need shoes to adapt to his or her movement behaviour. Other type of scenarios could be for energy efficiency in running-shoes. If the shoe sole could detect if there is a uphill or a downhill it could adapt and that could cause the runner to save energy. The latter would also be applicable to make a robot more stable in different types of terrain.

The main goal of this project is to lift a person minimum 1 centimetre over the ground by both extension and flexion of the foot. See the illustration of teh idea in figure 2 and figure 3. This paper focuses on the construction and testing of the shoe sole that is described further in chapter III and IV.

*This work was supported by the University of Oslo associated with the subject INF5207

[1]Claes Gill is with Faculty of Informatics, University of Oslo, 0373 Oslo, Norway claes@claesgill.com

Fig. 1. The sole in stationary state

Fig. 2. The sole in extension state

Fig. 3. The sole in flexion state

II. RELATED WORK

There is different studies done on the type of scenarios mentioned in chapter I. One of the closest products on the market is the Inflasole. Their focus has been developing a shoe insole for comfort and support for all kind of activities. The idea is similar in the sense that it has air-inflow and different air chambers to support the foot. The insole has a built-in miniature air-pump and release valve, and can adjust the air-pressure for different kind of activities. The Inflasole seems to have a good build quality and seems comfortable to use. However by making a insole instead of a shoe sole, the insole is limited to a smaller range of adjustments. This is because of the shoes tends to be tight to make a good fit of the foot. Therefore by expanding the shoe sole we do not need to be concerned by the space inside the shoe.

Another related project is the Inflashoe. This paper describes a inflatable shoe that uses a pneumatic system to inflate the shoe sole with air. As well the whole sole can be inflated it can also achieve extension and flexion of the foot. By implementing a button-system the user can easily adjust the sole by his or hers needs. This idea seems to work very well and is easy to use. Since the Inflashoe uses two inner bike tubes for the air-inflow it might not be as robust and stable as a silicone-based shoe sole. By using silicone we could make the chambers more complex. This could improve to the stability of the shoe sole.

There also exists more mechanical shoes that are made with springs both outside and inside of the shoe sole as shown in [4] [5] [6] [7] [8]. These products seems to work fine, but could be more efficient made with the a combination of electronic implementations. However we are not using any mechanical parts in this project we would be interested to explore those features in future work (chapter V).

Regarding robots there are many interesting projects. One of them is the terrain adaptive sole for a multi-legged robot [9]. In this paper the authors has developed a adaptive sole tailor-made for their multi-legged robot, Titan VIII. It is a fully mechanical sole that get feedback from different sensors to adapt to the terrain it is in. This solution is very well done and seems to work almost seamless with the Titan VIII. However since there is a lot of mechanical parts that need to be replaced after they brake it might be a possibility to use a silicone-based sole instead. With the right construction it could be able to make the sole more flexible to various terrains as well as fewer parts to replace and give a better grip.

Since this is somewhat off topic we are not going to investigate robotic movements alongside with the human foot, but it could be very interesting for future work (chapter V).

III. The system

This system mainly contains of a microcontroller, compressor and a valve. The control system and the shoe sole design is described more into detail in section III-B and III-C.

A. Equipment

- Valve 12V
- Stationary Compressor
- Silicone Elastosil M4601 A
- Silicone hardener Elastosil M4601 B
- Table cover fabric
- Arduino Uno
- Tendon pipes
- Ultimaker 3
- Fusion 360

B. Hardware

To pump air into the chambers we used a stationary compressor witch was set at a fixed pressure of 2 bar (described further in chapter IV). To control witch chamber to be expanded we used a button to control the valve. By holding down the button and release it we controlled the pressure within the chamber.

C. Moulding

The mould is made in a CAD program called Fusion 360 and 3D-printed with a Ultimaker 3. Since the moulds should fit a size 43 foot each print had to be cut in half to fit the printer base plate. See figure 4.

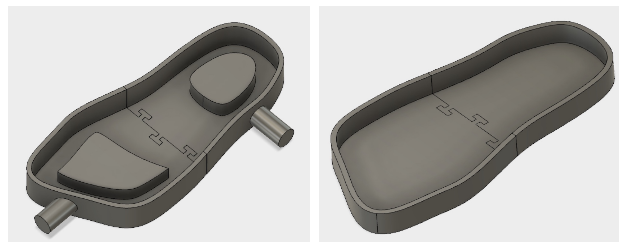

Fig. 4. Bottom mould to the left and top mould to the right.

With the use of Elastoil [10] we could achieve a silicone with a tendon strength up to $11N/mm^2$. To make the silicone as robust as possible the mixing ratio should be as seen in equation 1.

$$Mixing_{ratio} = \frac{Si_{hardener}}{Si_{mass}} \approx 0.11 \tag{1}$$

By having a small layer of fabric in the top mould before pouring the mixed silicon into it we get a more stable shoe sole. This is because when the air pressure is inflating the shoe sole the top layer do not expand along with the chambers. With the mixture poured into the two moulds we have to wait approximately 24 hours for the silicone to completely cure. This process time can be reduced with the use of a heating oven.

When the two moulds has cured we can then glue the parts together with the same mixture of silicone. We then drill a hole to each of the chambers to fit the tendon pipes. The end result is displayed in figure 5.

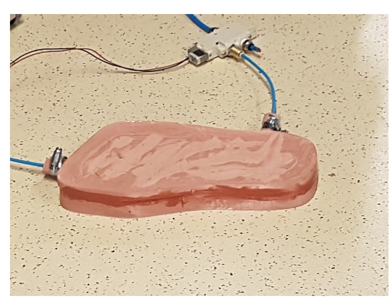

Fig. 5. The silicone prototype of the shoe sole.

IV. Experimental results

To test the hypothesis it was used a 72 kg male who the shoe sole was designed for.

By inflating air with a pressure of 1 bar, into each chamber it was possible to detect if the chambers did extrude or not. This was to make sure everything was correct connected and the silicone had no leaks.

Further testing was to check if the shoe sole could hold the weight of the test subject. With the air pressure of 1 bar the sole could not handle the 72 kg, but by increasing it to 2 bar it could hold the full weight until the pressure went below 1.5 bar. The table 1 describes the testing with different pressure states, and show whether or not it was possible to lift the test subject.

		Supported the weight	
Weight (kg)	Pressure (Bar)	Flexion State	Extension State
36	1	Yes	Yes
36	1.5	Yes	Yes
36	2	Yes	Yes
72	1	No	No
72	1.5	No	No
72	2	Yes	Yes

TABLE 1. Testing with different weight and pressure. The red mark indicates the shoe sole could not hold the weight.

With the pressure of 2 bar we can observe in figure 8, that we did not get a high lift. Although all lifts were higher than our goal we clearly see that there were some design issues to the front chamber. By comparing the measured height of each state in table 2 we can see that the extension state had a overall better expansion and could lift the test subject the highest.

		Maximum height	
Weight (kg)	Pressure (Bar)	Flexion State (cm)	Extension State (cm)
0	2	5	11
36	1	0	0
36	1.5	1	10
36	2	1	10
72	1	0	0
72	1.5	1	10
72	2	1	10

TABLE 2. Measurements of the maximum height.

The following figures shows the testing in the different states.

Fig. 6. The sole in stationary state with no pressure

Fig. 7. The sole in extension state inflated with 2 bar at full weight

Fig. 8. The sole in flexion state inflated with 2 bar at full weight

V. Conclusions

In this project we developed a shoe sole that can expand two chambers by inflate air into them. With the use of a compressor we could see that it was possible to inflate the chambers with a god amount of pressure and still see that it was strong enough to not rip apart. Although there was some trouble with the flexion state of the shoe sole we can conclude that the goal of lifting a person minimum 1 cm of the ground was reached. Regarding future work we have a couple of suggestions.

Since the shoe sole have a simple design it could be a good idea to make the chambers more complex as well as more support around the chambers. This would also give the chambers a less balloon-like form. We would also implement different types of sensors such as gyroscope, accelerometer and elastic sensor. These could be useful for a more complex control for the movement of the shoe sole.

We also want to improve the portability. By switching out the stationary compressor with portable motors would be a more ideal solution. It have also been discussed whether or not it is possible for the chambers to inflate air into each other.

As mentioned in chapter I and II it would be interesting to make a combination of springs and electronics as well as apply the shoe sole to a robot. Both applications demands a complete remake of the shoe sole, but could have various advantages such as flexibility and grip.

ACKNOWLEDGEMENT

The author would like to thank the University of Oslo for providing laboratory for prototyping and the associate professor Mats Erling Høvin for the guidance and motivation to write this paper.

REFERENCES

[1] R. Jake, "Adjusted for inflation: A history of the reebok pump," *Mental Floss*. [Online]. Available: http://mentalfloss.com/article/69922/adjusted-inflation-history-reebok-pump

[2] (2018) Inflasole. [Online]. Available: http://www.inflasole.com/index.html

[3] K. Baousi, N. Fear, C. Mourouzis, B. Stokes, H. Wood, P. Worgan, and A. Roudaut, "Inflashoe: A shape changing shoe to control underfoot pressure," in *Proceedings of the 2017 CHI Conference Extended Abstracts on Human Factors in Computing Systems*, ser. CHI EA '17. New York, NY, USA: ACM, 2017, pp. 2381–2387. [Online]. Available: http://doi.acm.org/10.1145/3027063.3053190

[4] (2018) Enko running shoes. [Online]. Available: https://enko-running-shoes.com/en/

[5] (2018) Spira running shoes. [Online]. Available: https://spira.com

[6] (2018) Joe singer shoes. [Online]. Available: http://www.joesingershoes.com/

[7] (2018) Bionic boot. [Online]. Available: http://www.bionicboot.com/

[8] (2018) Crazy coil shoes & insoles. [Online]. Available: http://crazycoil.com/

[9] S. Ohtsuka, G. Endo, E. F. Fukushima, and S. Hirose, "Development of terrain adaptive sole for multi-legged walking robot," in *2010 IEEE/RSJ International Conference on Intelligent Robots and Systems*, Oct 2010, pp. 5354–5359.

[10] "Solid and liquid silicone rubber material and processing guidelines," Wacker Chemie AG, München, Germany.