Study of Material and Design of Dribbler Roller in Autonomous Soccer-Kicking Robot

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Outline

1.0 Abstract

To enable the robots to kick more accurately and score more goals, a dribbler mechanism is being developed. It is capable of centering the ball while the dribbler is rotating. This design, shown in figure 1, utilizes screw-shaped threads on the dribbler instead of using a conventional cylindrical tube (Baba, et al., 2017, p. 3-5). The dribbler is made using a 3D-printed mold. It is believed that these threads push the ball towards the center of the robot's kicking mechanism while the dribbler motor is running.

To validate this design, two experiments are carried out. The first experiment determines the best material to be used on the dribbler. Materials that are being considered are urethane and silicone of different shore hardness. The ideal material has the highest grip on the ball while minimizing ball rebound. The second experiment determines the optimal design for the dribbler. The factors being varied here are the radius and pitch of the thread. The best design can center the ball within the shortest time possible. The results of both of these experiments give us the final specifications of the dribbler.

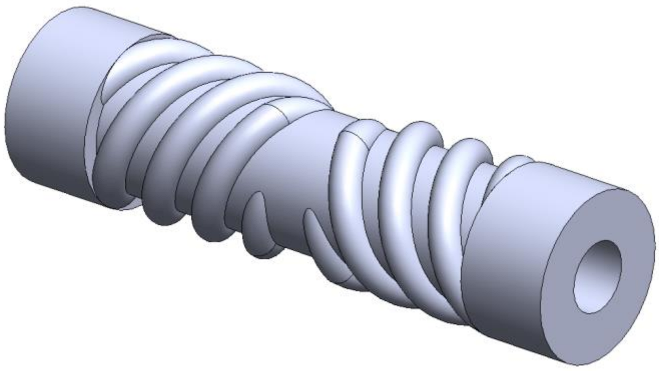


FIGURE 1: SCREW-SHAPED DRIBBLER

2.0 Objective

- To determine the material that has the highest grip on the ball.
- To determine the design that can center the ball within the shortest time possible.

3.0 Experiment Overview

3.1 Material

Due to the usage of a mold-making process to produce the complex shape of the dribbler, availability of materials that can be cast in a mold is paramount. This situation leads to only urethane and silicone being considered as they are common materials that can be easily purchased from a local shop. Two different shore hardnesses are chosen for each material, as shown in table 1. As shore hardness decreases, the coefficient of friction of the material with the ball increases, which leads to a better grip of the dribbler on the ball.

Material	**Shore Hardness**
Urethane	20A
Urethane	40A
Silicone	20A
Silicone	30A

TABLE 1: MATERIALS

There are two types of responses from this experiment: ‘successful’ and ‘unsuccessful’.

- ‘Successful’ is being defined as dribbler exerts a continuous force on the ball that causes the ball to backspin for at least 5 seconds.
- ‘Unsuccessful’ is being defined as the ball backspins for less than 5 seconds before stopping briefly or permanently, or the ball bounces off from the dribbler when it makes contact with the dribbler.

For each type of the materials above, a cylindrical dribbler is being made from a 3D-printed mold. These dribblers are shown in figure 2. Then, a simple experiment is being performed. A ball is gently pushed towards the center of the dribbler while the dribbler is rotating. This procedure is repeated for 30 times for each type of materials. The controlled variables in this experiment are the rotating speed of the dribbler which is set at around 6000 RPM and the type of carpet used.

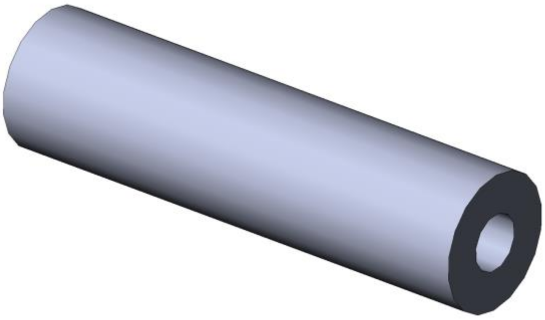


FIGURE 2: CYLINDRICAL DRIBBLER

3.2 Design

A factorial experiment with two factors is set up. The two factors chosen are the radius of the thread and the pitch of the thread. Do note that all of the designs involve multi-start thread. This is because they affect the pushing axial force that acts on the ball towards the center of the dribbler. It is believed that increasing the radius of the thread and the pitch of the thread increases the pushing axial forces. The structure of the dribbler is shown in figure 3. The factors and their respective levels are shown in table 2. The designs of the dribblers are shown in figure 4.

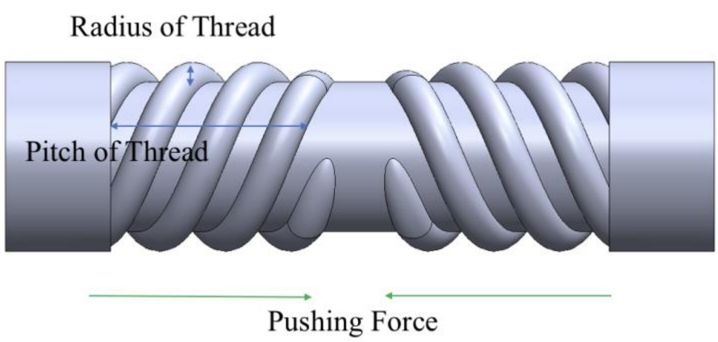
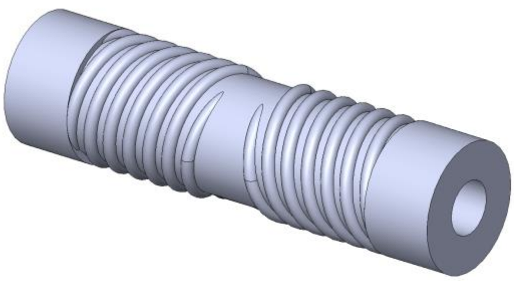


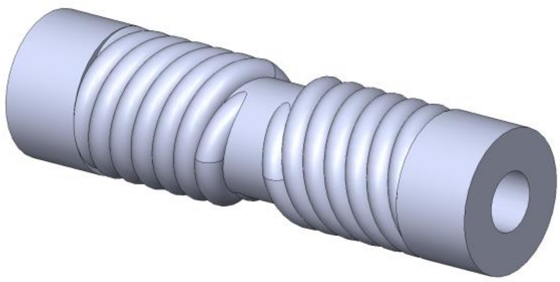
FIGURE 3: STRUCTURE OF DRIBBLER

Factors	**Notation**	**Levels**		
		-1	0	+1
radius	*r*	0.75mm	—	1.50mm
pitch	*p*	7.5mm	15.0mm	30.0mm

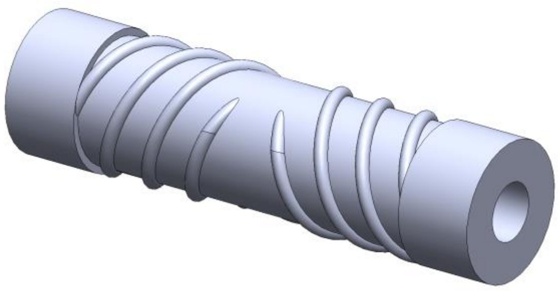
TABLE 2: FACTORS WITH LEVELS



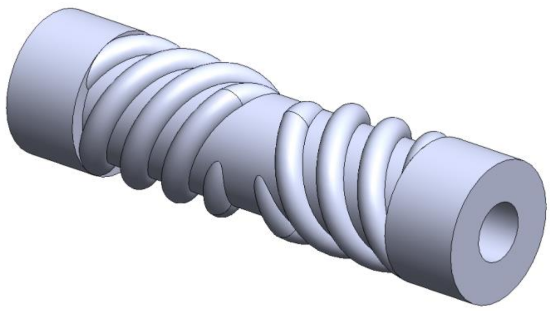
r: 0.75mm *p*: 7.5mm



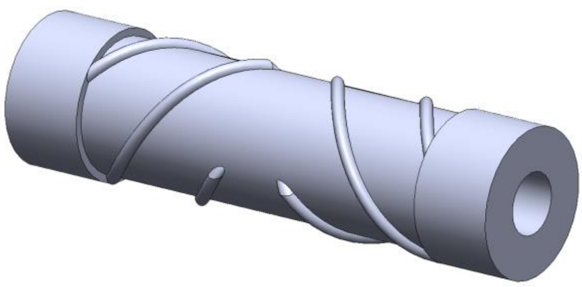
r: 1.50mm *p*: 7.5mm



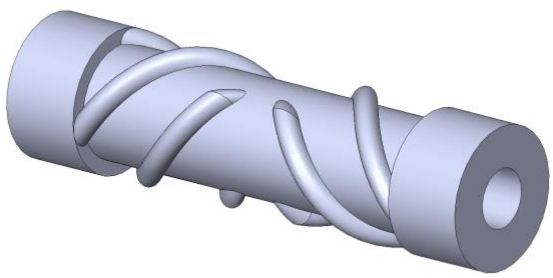
r: 0.75mm *p*: 15.0mm



r: 1.50mm *p*: 15.0mm



r: 0.75mm *p*: 30.0mm



r: 1.50mm *p*: 30.0mm

FIGURE 4: DESIGNS OF DRIBBLERS

There are two types of responses in this experiment: ‘successful’ and ‘unsuccessful’.

- ‘Successful’ response is defined as ball moves onto the center of the dribbler once it touches the rotating dribbler within 0.5 seconds.
- ‘Unsuccessful’ response is defined as the ball takes longer than 0.5 seconds to moves onto the center of the dribbler after it makes contact with the rotating dribbler, or the ball hits against the dribbler but does not stay on the dribbler, or the ball bounces off the dribbler.

In this experiment setup, a ball is being freely dropped from the top of the ramp. The controlled variables in this setup include the height *h* of the ramp at its extreme, the length *l* of the ramp from the initial position of the ball to the carpet and the distance *d* to the robot. In all cases, the same ramp is being used to ensure same frictional force is acting on the ball. Consequently, the velocity of the ball when it hits the dribbler is approximately 2.0 ms^{-1}. From the top, the ramp is being kept perpendicular to the dribbler, as shown in figure 5. The dribbler is rotating at around 7500 RPM. The two factors and their respective levels lead to 6 formulations of experiments. They are shown in table 3. For each formulation, the experiment is repeated for 30 times. The end of the ramp will be initially located at the extreme left of the dribbler with respect to the direction the robot is facing, before interchanging between both left and right sides as the experiment progresses. Experiment order is randomized to prevent bias (Ruiz, & Weitzenfeld, 2006, p. 5).

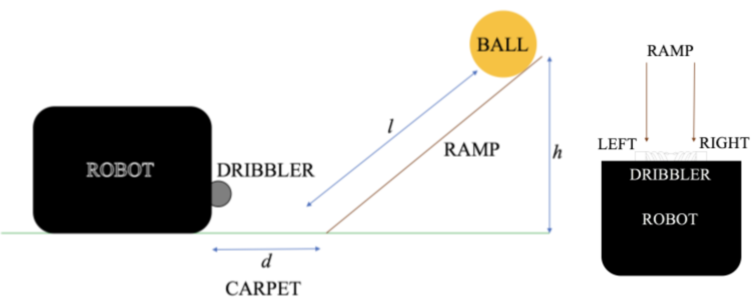


FIGURE 5: EXPERIMENT SETUP (SIDE AND TOP VIEW)

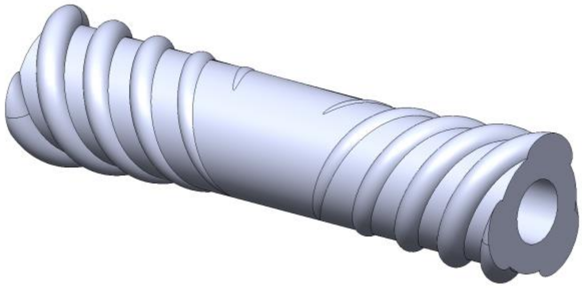
Formulation	**Factors**	
	r	θ
1	-1	-1
2	-1	0
3	-1	+1
4	+1	-1
5	+1	0
6	+1	+1

TABLE 3: FACTORIAL DESIGN

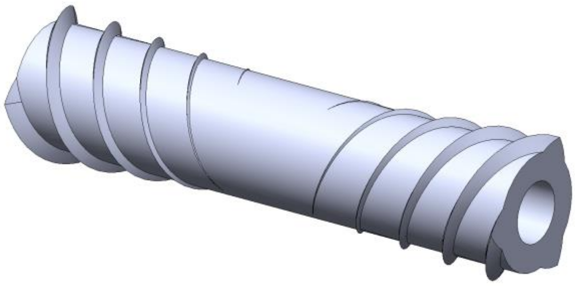
3.3 Iteration

Three new designs are introduced, using experiment setup in 3.2, as shown in figure 6. Each of them has a mix of three or four new features to investigate more features within the time constraint.

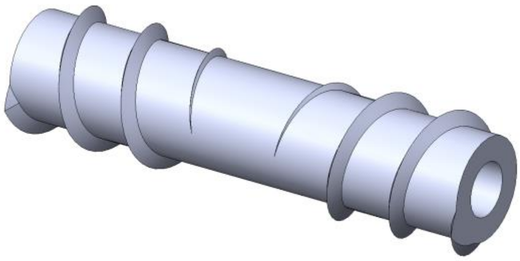
- *Chirality* : This is a crazy idea. Rather than having the screw threads pushing the ball towards the center, an opposite chirality is employed as this new chirality will spin the ball towards the center, akin to how the dribbler exerts a backspin on the ball, as shown in figure 7.
- *Material* : Urethane with shore hardness 40A is used. This is because harder material allows threads not to be compressed when the ball is in contact. More ball rebound is expected. Abrasion resistance of this material is also lower than the previous choice of material, which is silicone of shore hardness 20A.
- *Tapered* : Tapering threads towards the center is being analyzed. It is doubtful any performance gain can be obtained from this feature as the ball only rotates with its rotational axis parallel to the tangent of the tapered edges, with no tendency to move towards the center. However, no harm is done to put this feature into the test.
- *Triangular* : Triangular threads is utilized instead of semi-circular threads. Performance is unknown.



Chirality Material Tapered



Chirality Material Tapered Triangular



Chirality Material Triangular

FIGURE 6: ITERATED DESIGNS OF DRIBBLERS

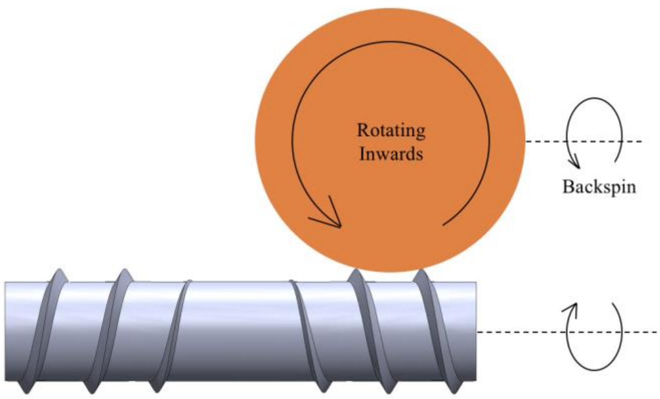


FIGURE 7: NEW CHIRALITY (TOP VIEW)

4.0 Results

4.1 Material

Material	Shore Hardness	Response	
		Successful	Unsuccessful
Control	-	30	0
Urethane	20A	30	0
Urethane	40A	30	0
Silicone	20A	30	0
Silicone	30A	30	0

TABLE 4: RESULTS TO DETERMINE BEST MATERIAL

Based on table 4, both urethane and silicone are capable of exerting sufficient grip on the ball that the ball remains on the dribbler while the dribbler is rotating. It is more beneficial to select the one with lower shore hardness as it is capable of exerting more grip and reduces ball rebound. To prevent threads not to wear off prematurely, tear strength and tensile strength are taken into account. The higher the tear strength or tensile strength, the higher the abrasion resistance of the dribbler, the more wear and tear the threads can sustain (Rubber Abrasion Resistance and the Tensile Strength of Rubber, n.d.). Based on table 5, silicone of shore hardness 20A possesses lowest shore hardness while having highest tear strength and tensile strength. Therefore, it is chosen as the best material for the dribbler.

Material	Shore Hardness	Abrasion Resistance	
		Tear Strength (pli)	Tensile Strength (psi)
Urethane	20A	60 (Die C)	200
Urethane	40A	82 (Die C)	522
Silicone	20A	120 (Die B)	550
Silicone	30A	108 (Die B)	500

TABLE 5: ABRASION RESISTANCE OF DIFFERENT MATERIAL

Material Specification Charts, n.d.

4.2 Design

Formulation	Experiment Order	Response	
		Successful	**Unsuccessful**
1	4	2	28
2	6	6	24
3	1	3	27
4	3	5	25
5	2	7	23
6	5	2	28

TABLE 6: RESULTS TO DETERMINE BEST DESIGN

None of the dribblers show satisfactory performance. Based on table 6, dribblers with a radius of 1.5mm (Formulations 4, 5 and 6) show better overall performance. This is because larger screw threads exert a larger force on the ball to cause movement while smaller screw threads apply a smaller force that does not have any significant effect on the ball. Again, based on table 6, dribblers with pitches of 15mm (Formulations 2 and 5) show better overall performance. This is because this pitch allows the threads to exert sufficient pushing force on the ball, at the same time prevents the ball from slipping pass it. Iteration is required.

4.3 Iteration

Features				Response	
				Successful	**Unsuccessful**
Chirality	*Material*	*Tapered*		12	19
Chirality	*Material*	*Tapered*	*Triangular*	8	22
Chirality	*Material*	*Triangular*		22	8

TABLE 7: RESULTS TO DETERMINE BEST ITERATED DESIGN

Only the dribbler with *chirality*, *material* and *triangular* features shows satisfactory performance. This design is selected. From table 7, tapered threads significantly reduces the success rate of the dribbler. This is because as the threads tapered towards the center, the self-centering effect is also reduced, causing the ball to stop and rotate slightly off-center. Sometimes, it also causes the ball to overshoot onto the opposite side of the dribbler as smaller threads in the center cannot contain the ball as the ball is being pushed towards the center. Table 7 also proves that the three new designs show better overall performance than in 4.2, which may arise due to a combination of *chirality* and *material* features. Not much can be implied for the performance of the dribbler with *chirality* and *material* features with the same semi-circular threads.

5.0 Conclusion

The dribbler chosen has the following specifications:

- Urethane with a shore hardness of 40A
- Triangular threads with a height of 1.5mm, a pitch of 7.5mm.
- Installed with right-handed and left-handed chirality on the left and right side of the dribbler respectively, as viewed from in front of the robot.

Further explorations being suggested are as follows:

- Different combinations of height and pitch for dribbler with *chirality*, *material* and *triangular* features.
- Dribbler with *chirality* and *material* features but with semi-circular threads.
- Dribblers in 3.2 with opposite *chirality.*
- Dribbler with *chirality* feature and other types of materials or threads.

References

1 Baba, K., Horii, T., Twauchi, Y., Mizutani, S., Yamada, Y., Yoshimoto, T., & Zenji, S. (2017). OP-AmP 2017 Team Discription Paper, 3-5. Retrieved from https://www.robocup2017.org/file/symposium/soccer_sml_size/Robocupssl2017-final9.pdf

2 Ruiz, M.S., & Weitzenfeld A. (2006). Soccer Dribbler Design for the Eagle Knights RoboCup Small Size Robot, 5. ISBN: 1-4244-0537-8

3 Rubber Abrasion Resistance and the Tensile Strength of Rubber. (n.d.). Retrieved from http://www.rubbercal.com/industrial-rubber/rubber-abrasion-resistance/

4 Material Specification Charts. (n.d.). Retrieved from https://www.smooth-on.com/charts/