Team TU8AM Mechanics calculations

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1 Introduction

This document is intended to show all the relevant calculations and approximations made when prototyping the design of Team Tu8Am mechanics.

2 Spring proprieties calculations

Seeing as the unique design called for unusual springs, the springs had to be made by hand. Using 0.6 mm wire made out of 304 Steel, 8 identical springs were fabricated.

Firstly, to determine the spring constant, the wire's material has to be taken into account. Since the wire is made out of 304 Steel, the sheer modulus is equal to 10.7328 GPa [1].

Therefore, as the spring's diameter is consistent, the following formula can be used to calculate the Hooke's constant [2]:

$$k = \frac{G \cdot d^4}{8N_\alpha \cdot D^3} \tag{1}$$

Where:

- G − Sheer modulus (GPa)
- d − Wire diameter (mm)
- N_α − Number of active coils
- D − Spring diameter (mm)

Using the spring's measurements, the following calculation was made:

$$k = \frac{10.73 \text{ GPa} \cdot (0.6 \text{ mm})^4}{8 \cdot 12 \cdot (14 \text{ mm})^3} = 4.873 \text{ Nm}^{-1}$$

3 Energy transfer of step mechanism

The mechanical part of this team centers around the precise activation of several spring-powered steps. Due to the cyclical nature of designing, five different variations were made, finally settling on a feasible final version. Throughout testing, several adjustments were made.

A represenation of the final design is shown in figure 1:

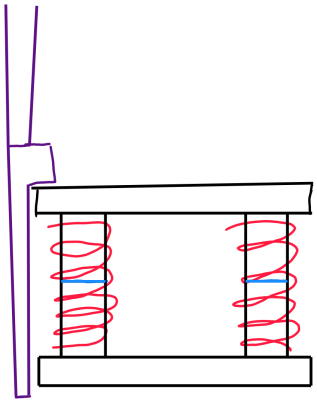

Figure 1: Side view of a single step

Probably the most important adjustment was minimising the activation energy. The final prototype is able to be activated by the ball falling 3.5 cm. Thus, the activation energy can be determined using the following formula.

$$E_{activation} = mgh \tag{2}$$

Where:

- m – Mass of golf ball
- h – Height of drop
- g – Gravitational constant

Using measured values, the following calculation can be made:

$$E_{activation} = 45.2 \text{ g} \cdot 9.81 \text{ N} \cdot \text{kg}^{-1} \cdot 3.5 \text{ cm} = 15.52 \text{ mJ}$$

Another observation is that once the step gets activated, friction does not affect the mechanism in a measurable way. Additionally, the platform and the ball remain attached until after they detach from the springs. Furthermore, the horizontal speed remains constant, which will be used to guide the ball to subsequent spring-step units.

Therefore, only the vertical energy is of interest, as it is what ensures flawless transitioning between steps. This will be determined using the principle of conservation of energy:

$$4 \cdot \left(\frac{k}{2} \Delta l^{\,2} \right) = (m_b + m_p)gh \tag{3}$$

$$h = \frac{2k\Delta l^{\,2}}{(m_b + m_p)g} \tag{4}$$

Where:

- Δl – Spring elongation
- m_b – Mass of ball
- m_p – Mass of platform
- k – Spring constant

Therefore, when plugging in the measurements, the following calculation ensues:

$$h = \frac{2 \cdot 4.873 \text{ N} \cdot \text{m}^{-1} \cdot (3.1 \text{ cm})^2}{(20 \text{ g} + 45.2 \text{ g}) \cdot 9.81 \text{ N} \cdot \text{kg}^{-1}} = 14.64 \text{ cm}$$

The final observation of note is that since further compression is limited by the spring guides, the height launch does not significantly increase with subsequent steps.

Therefore, a simple trajectory is established, as shown in Figure 2:

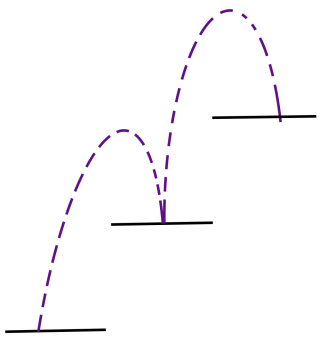

Figure 2: Visual representation of the path the ball follow

This trajectory is used to elevate the ball to the connection point between the zones. Currently, 4 steps are needed for this transfer to be achieved.

4 Spiral and guides

For both the spiral and the guides, no calculations have been made, as the movement through them is clearly slow enough, many small adjustments were made to ensure the proper path for the ball, which makes it very difficult to determine a regular shape for the path.

5 Conclusion

The calculations shown in this document have been done on the final prototype of the Proof-of-Concept phase. As adjustments still remain to be made, these will not be the final results of the calculations, however the results show feasibility in our spring-step mechanism.

6 Bibliography

References

[1] "Properties: Stainless Steel - Grade 304 (UNS S30400)." [Online]. Available: https://www.azom.com/properties.aspx?ArticleID=965

[2] "Compression Springs: Calculation Formulas." [Online]. Available: https://www.tokaibane.com/en/spring-design/compression-springs-formulas