RollControl

Eric Xue, Daniel Kwon, Delphine Lepeintre, William Xie

The authors are with the Department of Mechanical Engineering, Columbia University, New York, NY ex2120@columbia.edu, tk2864@columbia.edu, del2147@columbia.edu, william.xie@columbia.edu. This material is based upon work developed in the MECE E3420 / E3430 Engineering Design Courses

***Abstract*— RollControl's goal is to create an assistive walking device that addresses the lack of modularity and adaptability in most consumer off-the-shelf items. We created three separate mechanisms to improve upon issues found in push-down rollators, which are four-wheeled walkers that use springs to brake rather than rim brakes. The first novel mechanism is a spring tensioning system, which compresses the spring to various lengths to change the force required to brake. This system could support a maximum external load of 35 lbs while still being able to brake normally, with each discrete ratchet tick corresponding to an increase of 6.37 lbs. The second mechanism is a modular handle, which switches between two common walking positions found on the market. In both of these positions, the chosen material of aluminum held up to a theoretical load of 100 kg on the handles. The aluminum lock used to set the positions also withstood the same load. The last novel mechanism is a resistive wheel, which uses the concept of eddy current to induce a resistive force. With a 95% confidence interval, we observed a 10% reduction in travel distance. From our analysis, we observed an effective implementation of all three novel mechanisms, although with varying degrees of success.**

I. Introduction

Independence is of utmost importance to seniors; it allows them to navigate and overcome the challenges inherent to aging. Some tools that help seniors maintain this independence are mobility aids like walkers and rollators. In fact, as of 2012, 24% percent of seniors aged 65 and older utilize a mobility device such as a cane, scooter, walker, or rollator [1]. In this paper we will focus on push-down rollators, a type of rollator that allows user to brake by pushing down on the device. By analyzing the weaknesses of commercial off-the-shelf push-down rollators, we propose a novel rollator design that better suits the needs of seniors.

The most common rollators on the market feature rim brakes similar to those commonly found on bicycles. The user grips the handle which causes a friction brake to contact the rollator wheel, engaging the brake. However, this style of brake becomes difficult to use for users that have poor grip strength. These users could utilize a push down rollator, where instead of squeezing a handle, the user just needs to lean forward which causes a brake to contact the ground. Users that have good grip strength may also prefer push-down rollators due to the natural movement of leaning forward to brake, although traditional rollators with rim brakes continue to be the more widely used option. Both types of rollators are shown in figure 1. We have identified three primary problems with the push-down rollator, proposing solutions addressing each one and evaluating their effectiveness.

Throughout our design process we sought to maintain all functionality already present within the push-down rollator while minimizing additional complexity, weight, and cost. The stock rollator weighed 14 lbs, so we targeted a limit of 6 lbs of added weight, to keep the rollator under 20 lbs. This also meant that none of our mechanisms could interfere with key aspects of the rollator such as the ability to fold, using the chair or basket, and maintaining mobility. We also did not want to use motorized solutions to avoid the need to charge the rollator and introduce unnecessary weight, complexity, and cost. Doing so would have likely priced our modified design out of the stock rollator's cost range (from $150 to $200) and into the "smart" rollator price range ($500+). In this narrower problem space, we sought to add important and robust features to the push-down rollator that did not impede or significantly alter accessibility or the existing user experience.

Fig. 1: The traditional rollator uses rim brakes whereas the push down rollator engages the brake when the user leans forward.

A. Spring Tensioning

Current models for push-down rollators fail to account for situations in which rollators are loaded with weight such as groceries or laundry. This is of particular importance in urban environments where seniors will often walk to do grocery shopping and load their groceries on their rollator, a common situation as informed from our user interviews. Weight on the push-down rollator will cause the brake to engage so it cannot be used normally.

Our design allows users to control the amount of braking force required to engage the brake, meaning it can be used even while weighted down. The design also accommodates for a greater range of users that may want to support more or less of their body weight during normal usage.

The design functions by compressing a spring different amounts to control the braking force. To engage the brake, the wheel must push up against the spring, moving roughly half an inch upwards. The force required to move increases as the spring is pre-tensioned. A rope pulls a delrin disk against the spring, increasing the required braking force as shown in Figure 2.

The amount of tension is controlled by a handle found in the center of the rollator shown in Figure 3. By turning the handle, the user winds pulleys on either side of the rollator until the desired spring tensioning is reached. The two pulleys are connected via a live hex axle so that the tension on both sides of the rollator can be controlled simultaneously. The tension is then held in place via a ratchet that can be released to decrease the spring tension.

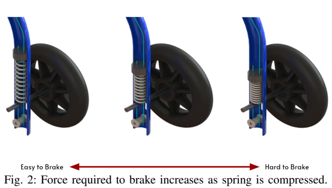
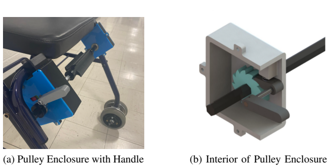


Fig. 2: Force required to brake increases as spring is compressed.



(a) Pulley Enclosure with Handle (b) Interior of Pulley Enclosure

Fig. 3: Pulley Enclosure

B. Handle Modularity

A second issue lies in the lack of flexibility that rollators offer for handle positions and posture. This is an issue that affects not only the push-down rollator, but also rollators in general. Most users utilize arched rollators, but prolonged use of arched rollators can lead to the user becoming tired and leaning forward too much. Upright rollators allow the user to stand up straight, providing the user with reduced stress and better posture. Both positions of rollators are shown in Figure 4. User interviews have shown us that users prefer the arched rollator due to its appearance but often find it tiring after extended use. Currently all rollators provide only one of these options, and do not have the option for switching between the two.

Fig. 4: Traditional walkers accommodate only either the arched or upright position.

Our design allows the user to switch between the arched and upright positions. This way if the user becomes tired, they can switch to the upright position where they are forced to maintain a better posture. Users can easily switch from one position to the other by clicking a button on the arm and rotating it until it locks in position as shown in Figure 4.

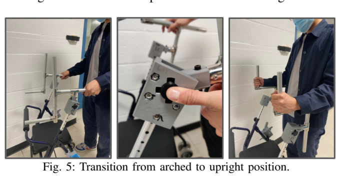


Fig. 5: Transition from arched to upright position.

C. Resistive Wheels

A final problem identified with the rollator is that it can pull users forwards while on steep hills. Gravity causes the rollator to roll faster than the desired speed of the user, potentially pulling them forward and causing them to lose their balance. This is also a problem that affects all rollators in general, not just push down rollators. In terms of prior art, the U-Step Neuro rollator has an adjustable friction brake that can apply different levels of resistance to the wheel[2]. However, while this addresses the problem at high speeds, it also affects the walker at low speeds, potentially impairing the mobility of the walker during normal use. Friction brakes will also produce wear, potentially reducing effectiveness over time.

Our design provides resistance only at high speeds by using an eddy current brake. Two magnets are positioned close to aluminum disks on the rollator wheels to create an eddy current force that resists the motion of wheel rotation. This force increases exponentially with the speed of the rollator. Thus, it is able to provide resistance at high speeds when it is needed without impacting the motion of the rollator at slow speeds. This design also does not involve any physical contact, as eddy current brakes dissipate energy through heat.

II. Methods

To ensure that our proposed rollator design is functional, it is important to evaluate the effectiveness of each subsystem on the rollator. Rollators are classified as a class 1 medical device under the FDA, meaning that the device is considered low risk and not subject to any specific standards from the FDA [3]. However, it is still essential that the device is safe to use, thus requiring it to withstand expected forces during use and effectively solve the problem that it is addressing.

A. Spring Tensioning

The spring tensioning system aims to control the amount of force required to brake, so that the rollator can be used even under common everyday loads such as laundry or groceries. To show that our mechanism is effective, it is necessary to investigate the relationship between the amount of force required to brake at the different levels of spring tensioning.

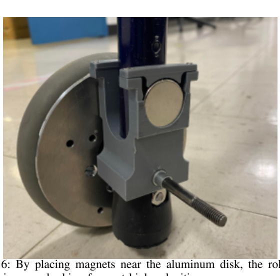


Fig. 6: By placing magnets near the aluminum disk, the rollator experiences a braking force at high velocities.

The force required to compress a spring follows the linear relationship described by Hooke's law where y is the force, k is the spring constant and x is the amount of compression.

$$y = kx \tag{1}$$

Therefore, we expect the amount of force required to engage the brake on the rollator to linearly increase with the levels of spring tensioning. The experiment was performed by setting the rollator to the lowest tensioning level and then placing a weight on the center of the rollator. The tension level was then increased until the brake was fully off the ground. Each tension level is defined as one click of the ratchet. Several trials were performed with increasing weights.

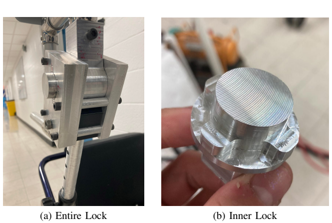
B. Handle Modularity

Modeling of the handle was carried out in order to evaluate the physical prototype and analyze the effects of an applied human load that brakes the rollator. The study calculates the vertical force applied by defining the worst possible weighted load of an elderly user in daily use, which we determined to be 100 kg. The unmodified rollator is rated for 300 pounds, and if a user were to apply 75% of their weight to suddenly brake they would apply roughly 100 kg of force. By braking on a scale, we determined braking forces during normal use to be roughly 10-15 kg.

FEA analysis was performed on the handle in the upright position and arched position. The handles are constructed out of 0.065" thick aluminum pipe. FEA analysis was also conducted on the interior of the lock. When the lock was initially 3D printed, the interior of the lock was a recurring point of failure. Later, the lock was machined entirely out of aluminum.

C. Resistive Wheels

In sourcing a magnet, we set an initial target resistance force of 10 N at a linear velocity of 2 ft/s (0.0635 m/s),



(a) Entire Lock (b) Inner Lock

Fig. 7: After the interior of the 3D printed lock repeatedly failed, it was machined out of aluminum.

which we determined to be a typical "too-fast" velocity for the rollator. We were constrained by the volume limits of the rollator leg assembly and McMaster-Carr cylindrical N52 neodymium magnets which would fit in those volumes, as the brake had to occupy the volume between each of the back four wheels with their conductive plates attached, and the leg of the rollator. Our selection was thus limited to cylindrical magnets with a maximum of 0.3125" in thickness and 1.25" diameter, but for ease of packaging we further limited magnet dimensions to a 1" diameter, 0.25" thick magnet. With these constraints in mind, we derived a magnetic field strength requirement, incorporating a flux density derivation from [4] to specify a magnet.

$$B = \frac{B_r}{2}\left(\frac{D+z}{\sqrt{x^2+(D+z)^2}} - \frac{z}{\sqrt{x^2+z^2}}\right) \tag{2}$$

Plugging in a 1" diameter, 0.25" thick magnet, with the magnet offset from the disc a conservative 0.125" (0.003175 m), we calculated via [5] an expected torque of approximately 0.101 N. This torque was dramatically lower than our target resistance, but was the theoretical maximum torque the eddy current brake would yield in our desired conditions.

$$T_d = \left(\sigma \delta B^2 A \dot{\theta} r\right) \cdot d \tag{3}$$

For confirmation of our theoretical eddy current brake output torque, we implemented a motor characterization test apparatus for the the eddy current brake. A brushed DC motor (9800 RPM theoretical free speed further reduced on a 100:1 planetary gear reduction, 0.6 A free current, I_{free}, 45 A stall current, I_{stall}, and stall torque of 0.38 N-m, τ_{stall}) was coupled with a timing belt to a 6" diameter aluminum disc with a 1.125" diameter bore and powered at 10.6V. At this voltage, we observed via video analysis a true rotational velocity of 9.3 rad/s (91 RPM), yielding a linear velocity of 2.32 ft/s.

Without the eddy current brake applied, the motor drew 1.40 A, and with the eddy current brake magnet brought to within 0.1" of the disc, the motor drew 1.55 A. Then, following the linear relationship between current draw and motor output

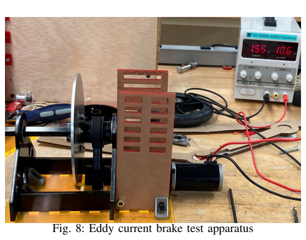


Fig. 8: Eddy current brake test apparatus

load in Eqn. 3 and multiplying by 100 to account for the gear reduction, we determined the torque of the brake on the rotating disc to be 0.122 N. This torque was consistent with our theoretical output torque, and we attributed the increased empirical value due to the increased linear velocity of the test disc, as well as to variability and imprecision in the offset distance between the brake magnet and the disc, the placement of the magnet along the radius of the disc, and tolerances in the CNC milling of the aluminum disc.

$$I_{(t)} = \frac{I_{stall} - I_{free}}{\tau_{stall}} + I_{free} \tag{4}$$

To holistically test the eddy current brake, 4.6 lbs of weight were added to the 14 lbs stock push-down rollator to equalize it with the modified rollator which weighed 18.6 lbs at the time of testing, with a mounted eddy current brake at each of the four back wheels. On the modified rollator, each magnet was a 1" diameter, 0.25" thick neodymium magnet (product 5862K253 from McMaster-Carr) offset approximately 0.1" from 4.875" diameter, 0.125" thick aluminum discs mounted to the wheels. The magnets were aligned as far along the radius of the disc as possible, with the magnet circumference approximately tangent to the disc circumference. The rollators were then set on a 36" long aluminum sheet ramp propped up by 8" (13 degree incline) and released. We recorded ten trials each in which the rollators traveled straight.

Fig. 9: Roll test for eddy current brake

III. Results

A. Spring Tensioning Results

The following results were obtained after testing the spring tensioning level required to support different weights placed on the seat of the walker, where braking was still possible afterwards. Tension level 1 was defined as the tension level required to lift the brake with no load applied. It was observed that at tension level 6, the spring was close to its full compression and full braking could not be applied with a 40 lb load. Thus, tension level 5 is the maximum tension level that can be used with the walker.

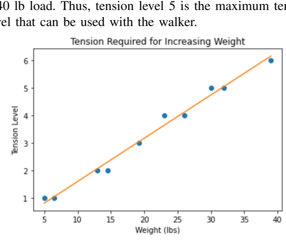


Fig. 10: Results from Spring Tensioning Experiment

The best fit line for the data was determined to be as follows:

$$\text{Tension Level} = 0.157 \cdot \text{Weight} + 0.03$$

Taking the reciprocal of the slope, we determine that increasing the tension level allows the rollator to support an additional 6.37 lbs of load. From this we can easily determine our spring constant. The string compressing the spring is spooled around a one inch diameter pulley that is connected via a live axle to our ten tooth ratchet. We observe that spinning the pulley once results in a change in string length of $1\ \text{in} * 2\pi = 6.28$ in. Since we have 12 teeth on our ratchet, changing the tension level results in one tenth of a turn of our pulley. Therefore our spring constant is equal to:

$$k = 6.37/(6.28/12) \approx 12\ \text{lbs/in}$$

B. Handle Modularity Results

Modeling was conducted using finite element analysis (FEA) with a SolidWorks CAD model to analyze physical phenomena in terms of tensile and yield strength. Multiple trials were run at increasingly smaller mesh sizes until results leveled out. An example for the trials run at different mesh sizes for the arched frame configuration is shown in Part D of the appendix.

1) Arched Frame Handle: In Figure 11, we can observe that in the arched frame configuration, the maximum stress is roughly 102 MPa, which is less than the yield strength of 125 MPa.

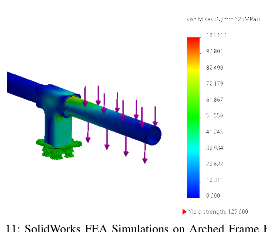


Fig. 11: SolidWorks FEA Simulations on Arched Frame Handle

2) Upright Frame Handle: In Figure 12, we can observe that in the upright frame configuration, the maximum stress is roughly 103 MPa, which is less than the yield strength of 125 MPa.

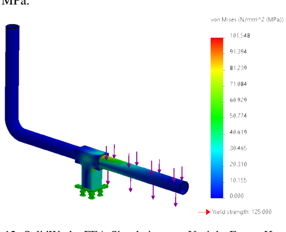


Fig. 12: SolidWorks FEA Simulations on Upright Frame Handle

3) Inner Lock Button Analysis: When subject to the 100 kg load in Figure 13, the interior lock reaches a maximum stress of 82 MPa, which is less than the yield strength of 125 MPa.

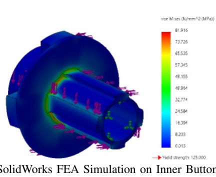


Fig. 13: SolidWorks FEA Simulation on Inner Button System.

C. Resistive Wheels Results

We observed a 10.0% decrease in travel distance from the rollator with eddy current brakes attached. Table I shows the data from our ten trials with both the stock and modified rollator, where the measuring tape used to record distance had a bias uncertainty of 0.06 inches.

TABLE I: Distance Travelled By Rollators

	Stock Rollator (in)	Modified Rollator (in)
Trial 1	107.00 ± 0.06	113.25 ± 0.06
Trial 2	113.50 ± 0.06	113.00 ± 0.06
Trial 3	106.50 ± 0.06	108.88 ± 0.06
Trial 4	106.50 ± 0.06	110.75 ± 0.06
Trial 5	103.13 ± 0.06	114.50 ± 0.06
Trial 6	104.75 ± 0.06	117.75 ± 0.06
Trial 7	105.65 ± 0.06	122.50 ± 0.06
Trial 8	102.75 ± 0.06	118.75 ± 0.06
Trial 9	107.00 ± 0.06	123.25 ± 0.06
Trial 10	102.38 ± 0.06	116.50 ± 0.06

These trials resulted in an average distance of 115.91 ± 3.41 inches for the stock rollator and an average distance of 105.92 ± 2.59 inches for the modified rollator. The uncertainty calculations can be found in Part C of the appendix.

IV. Discussion

A. Spring Tensioning

From our experiment investigating the relationship between spring tensioning level and the load supported by the rollator, we determined that by increasing the tensioning level by one, the rollator can support an additional 6.37 pounds. We also determined that the rollator can support a maximum of roughly 35 pounds and still functional normally with braking, since this is the amount supported at tension level 5. Although the rollator could theoretically support more weight at higher tension levels, the spring then becomes fully compressed and braking stops being functional. In the future this could be remedied by selecting a longer spring or a spring with a higher spring constant. However, if we assume a typical bag of groceries weighs 20 pounds, our rollator would be able to easily accommodate it.

Nevertheless, there will always be some point at which the spring will be completely compressed, impacting the braking functionality. We plan to introduce a hard stop on the ratchet such that the user can never tension the rollator above a certain point. We observe from our data that it only requires 5-6 tension levels (or clicks of the ratchet) to reach the full range of weight we aim to support. Since our ratchet currently has 12 teeth, this means it requires less than one rotation. Thus, we can conclude that our pulley diameter is of an adequate size.

As expected, we also determined that the relationship between tension level and the amount of weight supported is linear, which allowed us to calculate the spring constant as 12 lbs/in. The current spring utilized is the same spring from the original unmodified push down rollator. Knowing this value will allow us to compare the functionality with this spring compared to other springs in the future.

It is important to note that the accuracy of the results from this analysis is limited by the fact that the tension levels and that the weight can only be changed by discrete amounts. However, the clear linear relationship between the tension level and the weight allows us to say that the spring constant is 12 lbs/in. Since this spring constant will only be used to compare against other springs, further precision is not needed.

B. Handle Modularity

Initially, our handle prototype was constructed out of PVC pipe and the lock at the handle's rotation point was 3D printed. However, in order to create a robust product, everything was later constructed out of aluminum. From our FEA analysis we observe that for both handle positions and the inner lock, the observed stress under a load of 100 kg is less than the yield strength of aluminum. Thus, the aluminum pipes and aluminum lock are suitable material choices for the device.

The accuracy of our FEA analysis is dependent on the accuracy of our assumptions. In our analysis we assumed the handle to be a continuous beam that bent, when in reality it is constructed out of multiple pipes that are mounted together using aluminum pipe fittings. Further FEA testing would be required to ensure that the introduction of pipe fittings does not lead to a failure point.

Another consideration is the added weight of the aluminum lock. The lock assembly weighed 1.6 lbs and with just one lock mounted, and the modified rollator weighed 19.6 lbs, so two locks would have put the rollator over our 20 lbs target maximum. Further designs of the lock should minimize weight without sacrificing strength, at the cost of increased design and machining complexity.

C. Resistive Wheels

The effect of the eddy current brakes on slowing the rollator was statistically significant, but we initially wanted a much greater stopping force. Within the existing mechanical design, we could replace the aluminum disc with a more conductive copper disc, move the magnet closer to the disc, and use a larger magnet, all of which would increase the strength of the brake.

Our test measurement accuracy was dependent on our operator precision in releasing the rollator on the ramp, as well as mechanical properties of the rollator. There was inherent slop on the axles of the wheels because they rode on spring suspensions, and because the magnets were mounted on cantilevers, vibrations to the wheel assembly may have variably offset the distance between magnet and the discs.

Future iterations could utilize a reverse gear transmission between the wheel and the disc so that the disc rotates much faster than the wheel, thereby multiplying the eddy current brake force. Keeping the rollator lightweight is also pertinent, as the increased weight increases the momentum and roll-time of the rollator, independent of the resistive wheels.

V. Conclusion

RollControl set out to create an assistive walking device which increases the sense of independence and modularity that was lacking in other rollators on the market. Three novel mechanisms were implemented that improves upon issues identified in push-down rollators. The first of these mechanisms is a spring tensioning system which compresses the braking springs at certain intervals, retaining the settings with a ratchet. We observed that each ratchet interval corresponded with an 6.37 lbs of external load that the rollator could withstand while still retaining normal braking functionality. This trend continued until an external load of 40 lbs, when the rollator could no longer brake normally. The second mechanism of handle modularity was initially designed with PVC, before switching to aluminum for better structural integrity. FEA done on the aluminum handles and locking mechanism showed that they could withstand a theoretical concentrated load of 100 kg. The third mechanism is a resistive wheel with eddy current brakes installed at each of the rollator's four wheels. Through multiple trials, we saw that the stock rollator had an average travel distance of 115.91 ± 3.40 inches in our test, while the novel rollator had an average travel distance of 105.92 ± 2.58 inches in our test. With a 95% confidence interval, this result showed a statistically significant decrease in travel distance using the eddy current wheel. While all three mechanisms achieved some sort of improvement, there are still large improvements to be had. The braking springs can be swapped out to increase the range of possible braking forces. The handle's geometry and material could be modified even further to increase the possible load that they can withstand. The eddy current brakes could also increase in effectiveness through stronger magnets, a more conductive disk, a thicker disk, a larger interfacing surface area, or a tighter distance between the magnet and the disk.

VI. Appendix

A. Moment Force Analysis

$$M = \vec{r_1} \times \vec{F}$$

$\vec{r_1}$: radius vector w/ origin at the back wheel (m)
$\vec{F}$: downward force applied for brake activation (N)

B. Eddy Current Drag Force

$$B = \frac{B_r}{2}\left(\frac{D+z}{\sqrt{x^2+(D+z)^2}} - \frac{z}{\sqrt{x^2+z^2}}\right) \tag{5}$$

B : Magnet flux density (T)
Br : Remanence field, independent of the magnet's geometry (T), set to 1.48 T
z : Distance from a pole face on the symmetrical axis (m), 0.125" (0.003175 m)
D : Thickness (or height) of cylindrical magnet (m), set to 0.25" (0.00635 m)
x : Radius of the cylinder (m), set to 0.50" (0.01270 m)

$$T_d = \left(\sigma \delta B^2 A \dot{\theta} r\right) \cdot d \tag{6}$$

T_d : Eddy Current Drag Torque (N)
σ : Plate conductivity (S/m), for aluminum, 3.7 10E7 S/m
δ : Thickness of the plate (m), 0.125" (0.003175 m)
A : Area of the magnet $\left(m^2\right)$, for a 1" diameter magnet, 0.00051 m^2
$\dot{\theta} r = v$: Tangential velocity, set to 10 rad/s for a 3" radius disc, 0.635 m/s
d : distance from center of plate to pole face, set to 0.125" (0.003175 m)

C. Eddy Current Testing Uncertainty

$$P = t_{\alpha/2,\nu} \frac{S}{\sqrt{N}} \tag{7}$$

P : Precision Uncertainty
α : 0.05 (95% t-test)
ν : 9 degrees of freedom
N : 10 trials
S_{old} : 4.75 inches
S_{new} : 3.20 inches

$$U = \sqrt{P^2 + B^2} \tag{8}$$

U : Total Uncertainty
B : Bias Uncertainty (± 0.06 in)
Average distance of stock rollator: 115.91 ± 3.40 in
Average distance of modified rollator: 105.92 ± 2.58 in

D. FEA Mesh Sizing

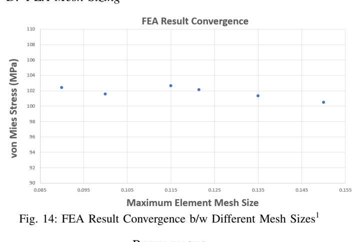


Fig. 14: FEA Result Convergence b/w Different Mesh Sizes[1]

References

[1] A. Z. L. T. M. M. Nancy M. Gell, Robert B. Wallace and K. V. Patel, "Mobility device use among older adults and incidence of falls and worry about falling: Findings from the 2011–2012 national health and aging trends study," *National Library of Medicine*, 2012.
[2] "Ustep neuro," 2022.
[3] FDA, "Product classification: Walker,"
[4] supermegnete, "Formula for cylinder magnet flux density," *The International Journal of Robotics Research*, 2022.
[5] D.-M. M. Jaw-Kuen Shiau, "The design of eddy-current magnet brakes," *Transactions- Canadian Society for Mechanical Engineering*, 2011.