Old Main Bell – Senior Design Project

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HONR 499: Honors Thesis – Foundational Writing

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Abstract – Due to varying age and physical abilities of Alumni from Colorado State University, access to ringing the Old Main Bell was limited, in some cases requiring family members to step in for elderly Alumni. To accommodate these different skill levels of users, a ratchet system was implemented to pre-load the Bell, storing potential energy which will be converted to kinetic energy when the ratchet is released. All of this was done to preserve the historic motion of ringing the Bell while simplifying the task. Additionally, the system can be operated without the ratchet to allow for the user to choose how to ring the Bell and in doing so improve the lifespan of the rope by reducing friction applied to it.

The Honors Thesis will be a significant part of my educational career due to the ability to merge my passion for mechanical engineering and leave an impact on my community. Through this project, I was able to learn how to apply engineering concepts to complex, real-world problems. This is significant due to the variety of real-world problems and how they differ from problems that are addressed in normal educational scenarios. This experience is a testament to the growth I have felt and time to reflect on the contributions I have been able to make on the CSU campus.

Prior to any solution being pursued, testing to record the current system needed to be done. To do this, the use of a single-axis strain gauge was used as E. Weston proved to be accurate for the motion of pushing and pulling [1]. The strain gauge used in testing at the Bell was an Omega LC103B-500 S beam load cell. This cell was tied in line between the Bell and the user to measure the force required to ring the Bell. Through multiple trials of ringing the Bell, the average force applied by the team on ringing the Bell was 260-lb.

Though the task of making it easier to ring a 500-lb bell seems menial, the true problem solving came from truly delving into the root of the problem. When first awarded this project in the Spring of 2024, I thought the simplest method of making the Bell easier to ring would be to apply mechanical advantage to the pulling of the rope using pulleys. Pulleys are one of simplest mechanical advantage systems to implement and calculate due to their simple nature [2]. According to the Openstax textbook, the needed number of ropes, and thus pulleys, feeling the effects of the force can be found with equation (1).

$$IMA = N \tag{1}$$

$$Where\ N = \#\ of\ ropes\ \&\ IMA = \frac{F_r}{F_e}, F_r = Resistence\ force, F_e = Force\ excerted$$

Through this initial attempt to address the ease of ringing the Bell, there were issues that arose due to the method of force application that was being used. The use of pulleys allowed for a significant reduction in force needed to pull the Bell upwards. However, the pulleys in this case are meant to be used to lift an object. So, when the simulated Bell of 260-lb of weights was lifted, it could be lifted, but it was not allowing for a smooth reciprocal motion to proceed like is needed to keep the historical feel of ringing the Bell. Diving into the ways in which energy is stored and how it is expelled was how the final solution was decided. The pulley system followed the existing method of ringing the Bell by applying consistent kinetic (motion) energy to the Bell to gain oscillations culminating in the Bell ringing [3]. However, when gaining a deeper understanding of what the difficulty of ringing the Bell was, it was found in that initial stage of getting the Bell to a state of allowing the clapper to be in contact with the Bell was the most difficult. To address this, the storing of energy was found to be crucial to making the Bell easier to ring. Accomplishing this meant the Bell needed to be pre-loaded by tipping it up to 80-85 degrees. This angle allows for the Bell to have made contact with the clapper while also after release allowing for the Bell to ring without much input from the user if they are unable to fully exert the required force due to age or other disabilities. By applying this pre-load, the Bell was storing the potential energy needed to ring, mitigating the need for the user to apply energy to the point of ringing the Bell. To store the energy, a ratchet mechanism was used to tip the Bell to its pre-loaded stage and then released to start the oscillating motion. The ratchet mechanism was chosen due to the simple technology used in the system. With that, there is still room for improvement in the lifespan of the ratchet if it were to be used on a more repeated use case such as cycling through 24/7. As explored by V.P. Bondaletov, the pawl is the source of the most likely to fail, and a way to improve lifespan without downtime is by having replacement pawls in a successive line for rapid deployment when one fails [4]. The pawl is likely to be the first part to fail in the ratchet due to the sudden loading and unloading of force on the small surface area. This was considered in this project by ensuring there is a maintenance plan laid out for yearly checks on all parts of the system.

During the initial stages of research for the project, much of the focus was on the maximum force people can exert. According to the Ohio Bureau of Workers Compensation [5], there are different techniques in which people can exert forces in a pulling motion. In the case of ringing the Bell, both techniques of straight pulling and pulling while turning are options when ringing the Bell. In the guidelines from the State of Ohio, the ideal force is stated to be between 41-60 pounds for straight and turning pull motion, respectively. To gain a better understanding of how the human body responds to these push and pull motions, further research was done to understand how the guidelines were formed. According to E. B. Weston, there is a difference in how much a person can apply a pull force with their lumbar spine and not feel the impacts and how much their body can safely apply [6]. Weston states this state of lack of feeling to force exertion is called "psychophysical" [6]. Using these factors found in the research at the beginning of the project, the desire to pursue the pulley system was high due to being able to mechanically lower the needed force to be within these values. However, as stated above, the real-world implications of the pulley system were soon to be found not feasible to be a worthy product to make the Bell easier to ring. In addition, different postures of pulling in the sagittal plane were explored to better understand the means of a dynamic movement in the process of applying more force. S. N. MacKinnon explored the different positions of a sagittal plane pull with the one allowing for the most force to be a "free standing" position where the user is allowed to choose their positioning to achieve the maximum force [7].

As the project progressed through the testing of the pulley system described earlier, the team decided the pulley system was not going to be a design that feasibly achieved the desired goals of the project. To better accomplish the goals of the project, the team began looking at the different stages of energy. To store the energy, there were different concepts such as using a lever to pull the rope down and then place into a quick release mechanism like the ratchet design. Levers are another form of mechanical advantage and to calculate the desired length of a lever against a fulcrum, the team consulted the Math Toolbox text on Understanding Levers to ensure a full grasp of the equations needed to solve [8]. This text showed that a second-class lever would be the use case of the project. This has the load between the fulcrum and the position of effort applied to the lever. To solve for the length of lever needed, equation (2) was used to understand if the lever concept would be feasible due to the size of the lever that would be required to be approximately 17-feet [8].

$$\tau_e = \tau_l \tag{2}$$

$$where\ \tau_e = f_1 * d_1\ and\ \tau_l = f_2 * d_2$$

Another concept that was explored was the use of a spring assist to the pull to ring the Bell. This spring would be connected to a cable that would be connected, inline with, the rope leading to the Bell. This cable with the spring connected to it would have a force loading in the same direction as the pull by the user of the Bell. Essentially, the spring assist would decrease the force needed to be applied by the person because the spring would be able to fill the gap between the force levels. In the paper written by S. Jung on the implementation of spring assists to motors in a robotic orthosis, there was research done to understand how the addition of springs in line to the direction of motion made the torque needed from motors was less [9]. In the case of this project, the same concept could have been applied to the use of a person in place of the motors explored in the paper.

Further research into current methods to make ringing the Bell easier led to look into the wheel that is currently attached to the Bell. The wheel that is currently attached to the Bell is a form of a cam. As presented in Norton's textbook chapter on cam design, the path of motion, along with other derivatives, can be calculated based upon the radius of the cam [10]. In a constant radius wheel though, the motion path is constant and thus does not create any points where there is less force needed. Using a specially designed cam, the cyclic motion of the ring could be plotted to adjust the radius in points where the ring is the hardest. However, through understanding Chapter 8 on cam design, this process would require in-depth analysis that would cause the cam to be a 'one-off' design [10]. This process would go against one of the main criteria of the project in that it needs to be a simple system where the system can be easily replicated and replaced. To meet this requirement of off-the-shelf parts with minimal fabrication is the goal.

Eventually, after many different solutions were researched and investigated, the final design consisted of the ratchet pre-load with two redirection pulleys to bring the rope out of the box. The entire purpose of this project was to benefit the Alumni Community of Colorado State University as they are the only users who are allowed to ring the Bell. To create a system that allows for easier access to ringing the historic Old Main Bell is the importance of the project.

References

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