Gravity Balancing Mechanism for Bus Boarding Ramp

Abhijeet Arunkumar Mishra[(1)], Jiarui Li[(1)]

***Abstract*— A mechanism is perfectly gravity balanced if the considered system is in static equilibrium at all configurations. This kind of mechanism can greatly improve the efficiency of energy consumption. Based on this concept, we design our bus boarding mechanism, which is a gravity balancing design composed of rigid links, joints, motor and springs, which is adjustable to the geometry and inertia of the weight loaded. This mechanism can unload the gravity of weight and keep it balanced in any position, it is partial gravity balanced because the spring constant are fixed and only suitable for a specific weight load. A motor can provide an additional torque for the mechanism to maintain the gravity balance when the weight changes. The goals of this report are as follows: (i) briefly review the theory for gravity balancing and present laboratory prototypes of gravity balanced machines, (ii) describe the design of the weights lifting mechanism which is designed to be gravity balanced and how it can achieve gravity balance, (iii) simulate the mechanism and show its performance by figures and report the effect on practical applications, (iv) based on the performance of the bus boarding mechanism and the outline of the design, report the future extension.**

I. Introduction

Gravity is one of the most basic and the most influential force on human activities in life. Think about an old man, it is difficult for him to quickly complete certain actions under the influence of gravity because of the decline of organ functions, such as lifting his leg, jumping and climbing a step. Their body parts, such as the waist and legs, are also prone to various problems due to gravity. It will be easier for them if they do not have to work against gravity for repetitive tasks. In such scenarios, gravity balancing of mechanisms is a good practice to adopt. For example, senior citizens or people with disabilities have trouble getting on the bus. Currently, buses either lower their entire body at stops or slide out a ramp like Fig. 1 shows. These mechanisms certainly make it easier for people to climb on to the bus, but can still be hard for certain senior citizens or people with disabilities. We therefore suggest a mechanism which will allow a very light weight setup to be attached to the undercarriage of the bus and which can open up and move passengers without them using any kind of force. Thus, we aim to design a mechanism which can replace the bus ramp and is also gravity balanced thereby reducing the need of a large motor and energy.

Fig. 1. General bus steps for elder people

A mechanism is perfectly gravity balanced if the considered system is in static equilibrium at all configurations [1,2]. The gravity balancing system can improve the efficiency of energy because it only needs little or no external force to sustain the system payloads and little work to change its position. The gravity balance of a system can be achieved by various methods like the counterweight methods and spring mechanisms [3]. Counterweight method is simple and can keep balanced at all positions easily, but it usually has a heavier weight to counter the payload and it is hard to deal with those problems in which weight is a concern. Compared with counterweight method, the spring mechanism have a more widely use for gravity balance and can well suit in any cases if we have the appropriate spring stiffness by keeping the potential energy constant. However, both methods have the disadvantage that the whole mechanism is designed only for one specific item which have unique mass and geometry parameters.

II. Design of a Gravity Balancing Mechanism

For our application, we consider that a disabled person wants to board the bus. Thus, as the bus pulls in front of him, a platform should lower to the ground. The person must be able to roll his wheelchair onto the platform. The platform must then raise the person to the level of the bus door. The person can then move ahead into the bus. An important characteristic of this mechanism is that the platform must be parallel to the ground at all times. Otherwise there is a chance that the person might lose balance and slip on to the ground.

[(1)]The authors are with Columbia University In the City of New York, New York 10027, the United States. Abhijeet Arunkumar Mishra (e-mail: aam2285@columbia.edu), Jiarui Li (e-mail: jl5188@columbia.edu)

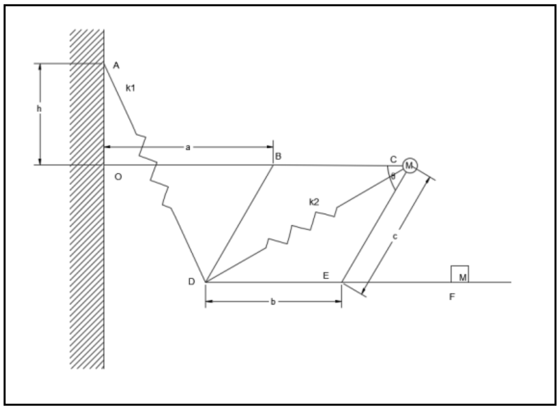

Figure 2: Diagram of the mechanism. O-B-C is the rigid arm attached to the floor of the bus. BD and CE are the swivel arms. They rotate about B and C respectively. As their lengths are equal, they form a parallel mechanism between floor DF and rigid support OC. As the angle between arms CE and OC changes, the platform DF moves in the vertical direction, always parallel to OC. Mass M is the person who gets on to the platform to enter the bus.

Thus, as we need the floor of the ramp to be parallel to the floor of the bus, we utilize a parallel mechanism between the floor of the ramp and the floor of the bus. As can be seen in Fig. 2, the floor of the bus is connected to arms attached rigidly on it. Two swivel arms are then connected to this main arm. The swivel arms are of equal length. The final ramp of the mechanism is attached to the other end of these swivel arms. Since the swivel arms are of the same length and have the same distance between them on the main rod and also the ramp, their angle with the main arm and the platform will always remain the same. Thus, they create a parallel mechanism wherein the ramp of the mechanism is always parallel to the floor of the bus.

Now, we have to gravity balance this mechanism. A method to visualize gravity balancing would be to think about this system in the horizontal plane. In such a setup, the mechanism will not be affected by gravity and will remain in whatever position it is in unless an external force is applied to it. Thus, we have to create a setup which completely negates the gravitational force in all positions of the mechanism. This means that the potential energy of the system will not change in any configuration as summation of total forces acting will be zero. However, as the mechanism moves up and down, the gravitation potential energy of the system changes. Thus, we will have to have another energy storing mechanism which either absorbs or releases energy during movement and cancels out the gravitational energy under any configuration. Springs can play a wonderful role in such a scenario. They can absorb potential energy as the platform lowers and then when the platform rises, they will release their potential energy, thereby keeping the potential energy of the entire system constant.

However, we added two springs to our setup. One spring would be attached to the frame of the bus, while the other will be attached between the two swivel arms across the bus platform and the ramp. These are all zero length extension springs. We then calculate the coefficients of the springs by assuming mass of the system and an average weight of the person climbing up.

III. MATH

The most important for a system to be gravity balanced is that the potential energy of the system does not change with respect to the configuration of the mechanism. We consider line OC to represent the zero-gravity line. θ is the angle between AE and OC. It varies between 0 and 90 degrees, where 0 degrees represents the state when system is fully closed (i.e. Mass M is at bus floor level) and 90 degrees represents the position when the mechanism is fully open (i.e. the Mass is at ground level).

Thus, potential energy of the mass at any θ can be found to be:

$$Vg = -mgc * sin\theta$$

The potential energy of the springs is directly proportional to the lengths of the springs (AD and CD):

$$AD = \sqrt{(h + c * sin\theta)^2 + (a - c * sin\theta)^2}$$

$$CD = \sqrt{(b + c * cos\theta)^2 + c^2 * sin\theta^2}$$

The total potential energy of the system is:

$$V = Vg + Vs$$
$$V = -mgc * sin\theta + \frac{1}{2}k1 * AD^2 + \frac{1}{2}k2 * CD^2$$
$$V = C1 + C2 - mgc * sin\theta + hck1 * sin\theta$$
$$-k1ac * cos\theta + bck2 * cos\theta$$

$$\frac{\partial V}{\partial \theta} = (hck1 - mgc)cos\theta + (k1ac - k2bc)sin\theta$$

Solving the above equation by making terms in bracket equal to zero, we can find the values of K1 and K2.

$$k1 = \frac{mgc}{hc} \ , \text{k2} = \frac{a}{b}k1$$

To test the validity of the system, we consider a setup. We design the system for M = 50kg, and keep all distances *a*, *b*, *c* and *h* equal to 0.5m Using these values, we simulate the system and plot the potential energy of the system in each configuration. In figure 3, it is seen that as θ varies, the gravitational potential energy and spring energy vary, however, the potential energy of the entire system is constant, implying that the system is gravity balanced.

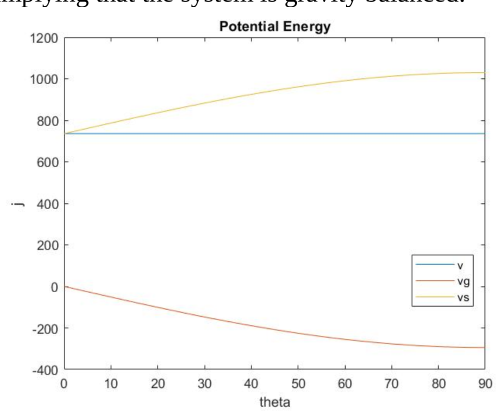

Fig. 3. Potential energy of the system at different configurations. We can see that the Total Potential Energy (v) is constant throughout.

IV. Observations

We designed a system which is gravity balanced and is capable of lifting a person onto the bus. However, in the process of designing the system, we came across some startling facts which are listed below:

- We believed that the person would have load himself at a certain point on the ramp i.e. the center of gravity of the person will have to be directly above a particular point on the platform. If the person was located at another distance then, we believed that a different spring would be required for the same mass. However, upon further inspection, we found this claim to not hold true. Since the potential energy is constant and the gravitational potential energy of the system is not dependent upon the distance of the person on ramp from the hinge, we can conclude that the distance of the person from the hinge is irrelevant to selection of spring. The person will apply the same load on spring. Extra forces will be generated along the length of the platform and swivel joints. However, the frame of the system absorbs them and they do not cause a problem. Thus, the disabled person has some flexibility regarding the mounting point on the platform.

- This system is designed for one mass. Thus, if another mass, which is not equal to the designed mass, is added to the system, the system will cease to be stable. This can be a very common scenario in buses as people have different weights which means that the system will only be partially balanced. To make the system gravity balanced for all masses, we will have to add an external motor, seen in figure 1, which provides extra torque to balance the mass. To find the value of extra torque, we use the superposition theorem. If mass M = $M_{design} + M_{extra}$ needs to be lifted, we assume two masses are kept on the system. The springs completely balance the M_{design}. Thus, the motor must exert only so much torque that it can balance the M_{extra}. In this scenario, the external torque required by the motor will be equal to $M_{extra} \times g \times cos\theta$. Thus, the motor will provide positive torque if the mass is greater than M_{design} and negative torque if the mass is lesser. The toque will also be dependent on the angle between the swivel arms and floor (θ).

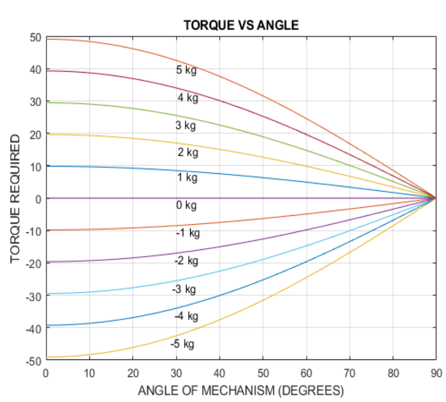

Fig. 4 The additional torque needed to maintain gravity balance if the load changes

V. Future Work

The key component of the gravity balancing mechanism is that it is designed for a specific mass. However, in our case, we since people have different masses, we will have to have an external torque source to balance the extra mass. This is a big hinderance. It will be ideal to have a system which can remain gravity balanced for a range of masses. To meet this condition, we will have to design a system which is placed on the platform. This system will sense the extra mass on the system and manipulate the length of the springs to offset the extra mass. Once the initial length of the springs has changed, the springs will be able to balance the extra mass too. Yun-Lin Chu et al. have shown a novel mechanism which causes the system to adopt to different masses in their research [4].

VI. Conclusion

The aim of the research paper was to design a gravity balanced mechanism which can replace the ramp used in buses. Senior or disabled citizens will be benefitted if rather than ramp, there was a mechanism which they can walk onto and which will pick them up into the bus. However, the mechanism must be compact, robust, and must not require active force inputs.

We have designed a system which is completely gravity balanced in any configuration while lifting the mass it is designed for. However, the system will need an external torque provider such as a motor to balance all other loads.

A key feature of the system is that the position of the mass on the platform (ramp) does not affect the spring co-efficient required in the setup. The system will always be balanced by the springs found in the design. Extra forces will be generated in the system depending upon the distance of the load from the hinge. However, they will be cancelled by the internal forces of the members of the mechanism.

This system can be used at several other places where there are large single steps. It is robust and will allow disabled people to climb the step without much effort.

Acknowledgment

The writers will like to thank Dr. Sunil Agrawal, who explained the concepts of gravity balancing and provided key insights while designing the particular system. We would also like to thanks his research students Haohan Zhang and Rand Hidayah who always extended support while working on the project.

References

[1] Nathan, R. H., “A Constant Force Generation Mechanism”, ASME J. Mech., Transm., Autom., Des., 107(4), 1985, pp. 508–512.

[2] Streit, D. A., and Gilmore, B. J., “‘Perfect’ Equilibrators for Rotatable Bodies,” ASME J. Mech., Transm., Autom. Des., 111(4), 1989, pp. 451–458.

[3] Baradat, C., Arakelian, V., Briot, S., and Guegan, S., “Design and Pro-totyping of a New Balancing Mechanism for Spatial Parallel Manipulators,” ASME J. Mech. Des., 130(7), 2008, p. 072305.

[4] Chu Y, Kuo C. A Single-DoF Self-Regulated Gravity Balancer for Adjustable Payload. ASME. International Design Engineering Technical Conferences and Computers and Information in Engineering Conference, Volume 5A: 40th Mechanisms and Robotics Conference ():V05AT07A069. doi:10.1115/DETC2016-59930