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Novel Gas Cylinder Trolley with Ergonomic Lifting and Placement Adjustments

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Abstract:- The lack of features for a properly designed gas trolley has resulted in the manual handling of gas cylinder tanks during transference, a common yet inappropriate practice that is unsafe and physically strenuous. Using principles of mechanism, an innovative gas cylinder trolley was designed to maximize serviceability and effectiveness. To corroborate the design, a computer simulation was conducted and predicted the stress and strain concentrations at maximum load. After fabrication, the actual performance of the trolley was tested through actual usage where a user experience survey was administered to evaluate the performance of the trolley in terms of mobility, stability, safety, comfortability, and functionality. Based on the results of the survey, the overall weighted mean of the user's satisfaction level is 4.54 which implies that the respondents were very satisfied with the trolley design. Also, there is a significant difference in the mean satisfaction level between the existing and new designs. In terms of the force required to draw the trolley on a plane surface, the new design trolley requires lesser force (128 N) as compared to the existing design (256 N). This innovation promotes the worker's welfare and security because of features that focus on the lifting, handling, and restraining aspects. With this, safety isn't only achieved but also the worker's efficiency and productivity at work.

***Keywords**:- Gas Cylinder Trolley, Linear Ratchet Mechanism, Conchoidal Motion, Adjustable Handle, Stair-Climbing Wheels.*

I. INTRODUCTION

A trolley is a device that man invented to move big objects like gas tanks. Due to the significant loading, it has made it possible for people to work without difficulty. Additionally, it aids in easing back, waist, shoulder, and foot discomfort. People frequently suffer a severe ache in their body after raising the goods several times, regardless of how low the load may be. Therefore, at this point, people rely on a trolley, which can move objects multiple times with little effort. The importance of such systems arises from the daily simple chores that society wants to relieve discomfort with.

A properly designed mechanism for a gas cylinder trolley is a must to ensure the worker's welfare and security. It is of great importance to prioritize such features that focus on the lifting, handling, and restraining aspects when it comes to gas cylinder transportation. With this, safety isn't only achieved but also the worker's efficiency and productivity at work.

However, the most common designs of gas cylinder trolleys on the market nowadays only have features solely for transportation. There may be some products that have features for lifting but they do lack in some respects needed for a trolley to be thoroughly called safe.

Consequently, the lack of features for a proper design trolley resulted in the workers doing manual lifting and manual handling as a common yet inappropriate practice. As a matter of fact, a gas cylinder trolley weighs 15 kg to 50 kg which is difficult for a worker to lift and handle, considering the safety guidelines they must be aware of. Many workers are frequently injured causing them to experience mild to severe back pains, overexertion, imbalance, sprains, and even accidents that may lead to death. To solve these issues, several researchers have exerted efforts in improving gas cylinder trolleys.

Ravindar et al. (2018) designed and fabricated a trolley with a stair climbing mechanism to require minimal effort in lifting cylinder tanks. The model is structurally analyzed through SolidWorks and ANSYS software to determine the trend of the stress under various loads to test the device's capability in climbing the stairs. It was found that a 9800 N load can be sufficiently carried by the trolley with less effort having equivalent maximum stress of 163.51 MPa.

Ramkumar & Alagarasan (2016) concluded based on the results of the testing on their designed gas trolley that transferring the whole load plus the trolley's weight into the wheels makes an easier lift and transport for the users. It was proven effective as the weight of the structural design of the base was reduced.

Chodankar et al. (2019) designed a stair-climbing trolley with major components of wheels, bearing, and frames. During the test analysis, it was understood that the trolley can cater to lifting heavy loads of up to 100 kg without any major fractures and deformation if fabricated. With this specific load, the trolley can be able to smoothly climb the stairs and can be fully automated. However, the initial cost of the project is higher than the present ones in the market.

Compared with the prior art, the current design has the following advantages:

The invention has a simple, ergonomic, and ingenious construction design. The lifting mechanism is provided with a drive shaft that requires a small amount of input force to slide the rack into a slot. This makes it easier to lift the gas bottle which is held firmly by the bottle fastening strap connected to

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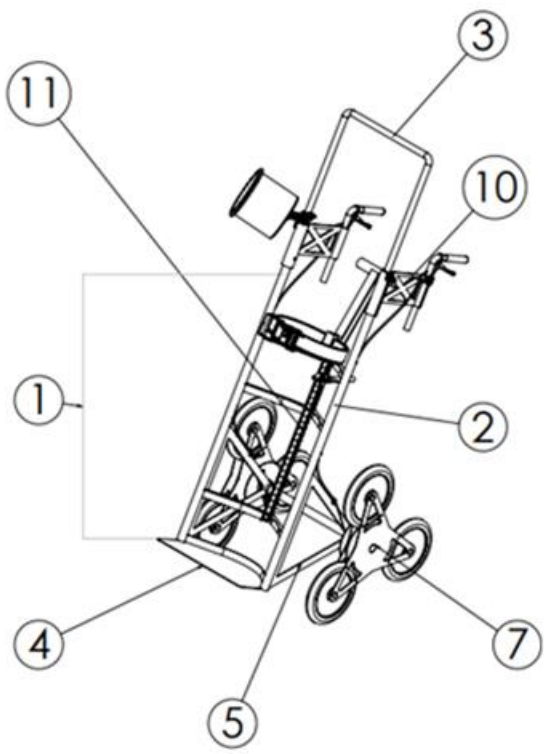
one end of the rack. The said fastening strap is rotatably connected at one end of the rack which makes it possible to easily change the orientation of the fastening strap. The braking mechanism is provided near the handle to make it easy to control the movement of the wheels while the trolley is in motion. The position of the handle can easily be adjusted depending on the height of the user.

II. METHODOLOGY

Identifying the limitations of existing designs in terms of safety and ergonomic considerations were the initial steps carried out to design the current gas cylinder trolleys. After that, new features were conceptualized to address the problem. Finite element analysis was performed on the design, and the results on the stress-strain curve, deformation, and factor of safety are collected and examined and served as the basis for the decision on whether the design is safe, functional, and satisfactorily executed. After that, the actual prototype was fabricated, tested, and evaluated.

A. *Design Concept*

Using SolidWorks, the proposed concept was drawn as shown in Fig. 1.



ITEM NO.	DESCRIPTION
1	CHASSIS
2	PARALLEL BARS
3	TRANSVERSE U-SHAPED TELESCOPIC FRAME
4	FRONT CARRIER PLATE
5	REARWARDLY DIRECTED SUPPORTS
6	TRANSVERSELY
7	PLURALITY OF WHEELS
8	LIFTING MECHANISM
9	ARC BAFFLE PLATES
10	ADJUSTABLE HANDLES WITH A BRAKING MECHANISM

Fig. 1. Isometric view of the current gas cylinder trolley

B. *Design Calculation*

The general consideration in this study is to design a trolley to cater to industrial gas cylinder sizes T, K, and S; to climb up and down the stairs; can stop or slow down during transportation through a brake mechanism; handles that can be adjusted to accommodate the varying height of the users; and can shift the position of the gas cylinder from a vertical position to a horizontal position during lifting.

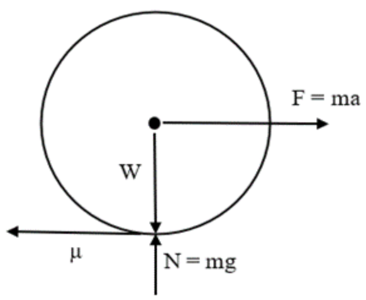


Fig. 2. Force analysis of contact wheel

The free-body diagram of the contact wheel is shown in Fig. 2. To determine the force (F_{frmax}) required to make the trolley overcome wheel and ground contact friction, Eq. 1 was used. In this equation, *m* is the mass of the design trolley, *g* is the gravitational acceleration, and μ_s is the coefficient of static friction.

$$F_{frmax} = \frac{1}{2} mg\mu_s \quad (1)$$

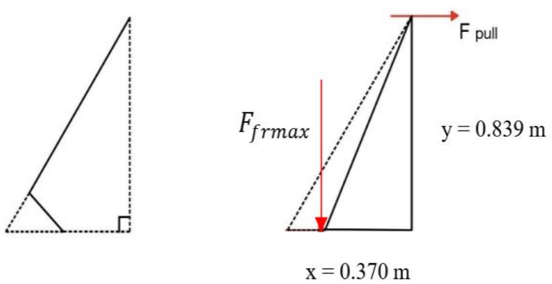


Fig. 3. Force analysis to pull the trolley

The force diagram of the pulley upon pulling is shown in Fig 3. To solve the force (F_{pull}) needed to pull the trolley with a load, Eq. 2 was used. In this equation, x is the distance where the force is applied with respect to the center of the quasi-planetary frame on the x-axis, and y is the distance where the force is applied with respect to the center of the quasi-planetary frame on the y-axis.

$$F_{pull} = \frac{x}{y} F_{frmax} \qquad (2)$$

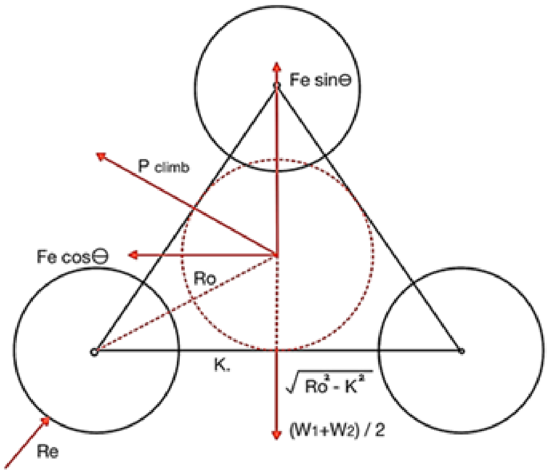


Fig. 4. Force analysis of the quasi-planetary wheels

The force diagram of the quasi-planetary wheels is shown in Fig 4. The forces acting on quasi-planetary wheels are the weight of the object to be carried (W_1), the weight of the trolley (W_2), the reaction force on one side (R_e), and the force applied (P_{climb}). Also shown in the same figure are the distance of the centroid from the center of the wheel (R_o), and the distance between the center of the wheel and the line of action of weight (K).

To determine the force required for the trolley to climb the stairs (F_{climb}), Eq. 3 was used. In this equation, ϴ is the angle of inclination of the stairs.

$$F_{climb} = \frac{F_{frmax}(with\ load)}{\cos\Theta} \qquad (3)$$

In determining the distance (D) between the centers of the quasi-planetary wheels, the Pythagorean theorem was used in Eq. 4. In this equation, a is the height of the stair step and b is the length of the stair step. Considerations in choosing the diameter of the quasi-planetary wheels are also based on the better traction and step transition of the wheels.

$$D^2 = a^2 + b^2 \qquad (4)$$

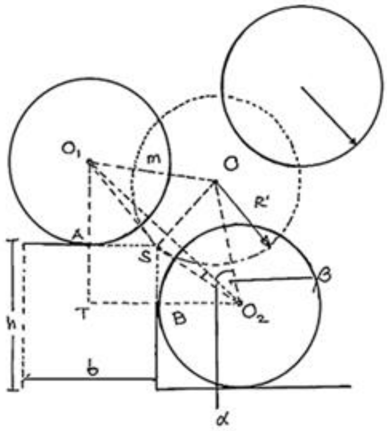


Fig.5. Free-body diagram of the quasi-planetary wheels

The free-body diagram of the quasi-planetary wheels during stair climbing is shown in Fig. 5. To determine the arm length (m) of the wheels, Eq. 5 is used. In this equation, D is the diameter of the wheels.

$$\frac{D}{\sin(120°)} = \frac{m}{\sin(30°)} \qquad (5)$$

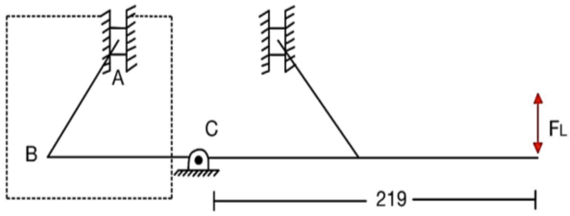


Fig.6. Free-body Diagram for Linear Ratchet Mechanism

Figure 6 shows the force analysis (F_L) in determining the needed force to be applied for the lifting ratchet mechanism which is expressed in Eq. 6. In this equation, z is the length from point A to C and M is the moment occurring at Point C.

$$F_L = \frac{M}{z} \qquad (6)$$

The design specification can be summarized in Tab. 1.

TABLE I. DESIGN SPECIFICATIONS

The average weight that a man can pull	49 kg
Weight of the trolley	28 kg
The average weight of the gas cylinder	59 kg
F_{pull} without Load	137.34 N
F_{pull} with Load	376.38 N
F_{pull} to climb with Load (considering minimum tilt angle)	480.69 N
Minimum angle to which the user can pull the trolley while climbing the stairs	62.4994°

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C. Fabrication Procedure

➢ *Fabrication of Quasi-Planetary Wheel Set-up*

The fabrication of the gas cylinder trolley began with the quasi-planetary wheel set-up. The Quasi-Planetary clamp was used for connecting the three wheels together. Since it will be difficult for a trolley to move upward and downward using a single wheel in a flight of stairs, hence, a quasi-planetary wheel mechanism was employed. The quasi-planetary clamp was fabricated mainly using the cutting process. The three wheels were connected to each of the arms of the clamp and this quasi-planetary wheel rotates when it is at the edge of the stairs. The wheels were placed in the middle of the two clamps and were attached through nuts and bolts.

➢ *Fabrication of Shaft Assembly*

The pair of quasi-planetary wheel set-ups were connected at the ends of a shaft to make a quasi-planetary wheel and shaft assembly. The shaft was made from hollow circular pipes and the quasi-planetary wheel set-up was fixed at the opposite ends of the shaft by welding.

➢ *Fabrication of Frame*

Once the material selection and the dimensions for the frame have been decided, the fabrication for its assembly then commenced. Hollow circular pipes were used. All the other parts of the trolley were assembled in the frame. This also included the base of the trolley which was made of a flat metal plate. The base or platform was welded to the vertical frame.

➢ *Fabrication of Handles*

The handles were cut out from a bicycle handle since it was made from hollow circular tubes, and it was bent already. They were made perpendicular to the body of the trolley to allow free inclination of the trolley at any angle. Since the handles can be adjusted depending upon the preferred height of the users, they were not welded at any fixed position to the frame.

➢ *Fabrication of Linear Rack Ratchet*

A linear rack ratchet was used to elevate the cylinder tank gradually which will be appreciated once the tank is transferred or loaded into a vehicle. Manual cutting was used to fabricate its parts. This was then attached to the back of the frame of the trolley.

➢ *Fabrication of Conchoidal Mechanism*

The conchoidal mechanism was fabricated after the linear ratchet. This was used to shift the position of the load; thus, it was connected to the upper part of the linear ratchet so the user can easily access it.

➢ *Fabrication of the Brakes*

The brakes of the trolley were hand-operated using a lever attached to the handles. The adjustable handle brake lever and the links used were sourced out from a bicycle while the brake ring, brake ring link, and brake ring link extension were machined.

➢ *Fabrication of the Valve Cap Assembly*

The valve cap was purchased. On the other hand, the magnets and the cable integrated into it were sourced from the scraps in the machine shop.

➢ *Fabrication of the Ratchet Strap*

A normal strap was purchased from the hardware however, it was quite glossy. The researchers anticipated that there will be a great chance that the gas tank will slip from it. To counter this, a strip of leather was sewn on the side of the strap facing the gas tank.

D. Performance Evaluation

An experimental setup was done to check if the objective has been met specifically wherein the proposed gas cylinder trolley with ergonomic lifting and placement adjustments can climb up and down the stairs (based on the National Building Code of the Philippines (NBCP) Residential Decree No. 1096 the minimum rise and run of 200 millimeters).

Fig. 7. The prototype climbing the spiral stairs with a 150 mm rise

Also, the performance of the lifting mechanism was tested up to a height of 1100 mm. On the other hand, the adjustable handles can accommodate up to 1064 mm to 1214 mm.

Fig. 8. Rack gear levelling with the height of a common gas cylinder truck (810 mm)

E. End User's Satisfaction Survey

A survey was administered to measure the end user's satisfaction in using the prototype in terms of mobility, stability, safety, comfortability, and functionality. The data collected from 20 respondents were analyzed using paired sample t-test. The respondents are personnel handling transference of gas cylinder from a gas cylinder retailing company.

III. RESULTS AND DISCUSSION

A. Theoretical Calculation Results

Using the equations found in the methodology, a regular trolley was compared to the current design in terms of the force requirements. As shown in Tab. 2, it is evident that it takes more force to move the regular trolley on a plain surface compared to the current design. It is safer, however, to use the regular trolley on an inclined surface because it takes a lot of force to make the trolley wheels slip. To overcome this concern on wheel slippage at the inclined surface, a brake mechanism was installed on the current design.

TABLE II. COMPARISON OF THE FORCE REQUIREMENTS BETWEEN THE REGULAR AND THE CURRENT DESIGN

	Regular design	**Current design**
Force applied to pull the trolley at a plane surface	256 N	128 N
Minimum force to pull the trolley up the ramp at 18°	269 N	135 N
Maximum Force applied at the inclined surface for the wheels to slip (18°)	730 N	339 N

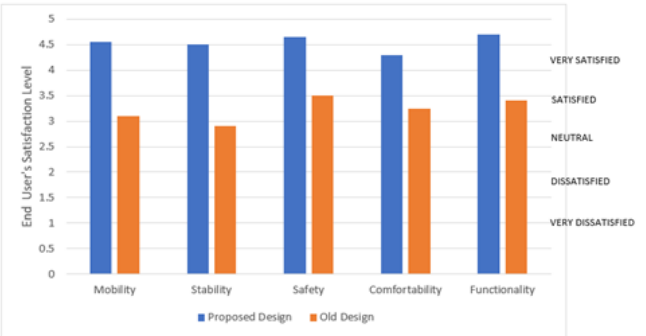

Fig. 9. Comparison of the regular design and the current design

B. End User's Satisfaction Survey Results

Using A Likert Scale with was used to evaluate the end user's satisfaction. The overall weighted satisfaction rating of the respondents is 4.54 which can be interpreted as "very satisfied". The breakdown of the result is as follows: mobility (4.55, very satisfied), stability (4.5, very satisfied), safety (4.65, very satisfied), comfortability (4.3, very satisfied), functionality (4.7, very satisfied). Abbreviations and Acronyms

C. Regular vs Current Design

Using a paired Sample t-test, it was determined that there is sufficient evidence to say that there is a significant difference in the mean of the satisfaction level between the regular and the current design. The summary of the result is shown in Fig. 9.

IV. CONCLUSION

The current trolley's actual performance both in testing and end user's actual usage showed its leverage over the regular commercial trolley in terms of its mobility, stability, safety, comfortability, and functionality.

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