Design and Fabrication of a Material Lift Machine

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Abstract

This article details the concept and design of a prototype self-propelled material lifter (MLM) capable of transporting materials to the roofs of two-story buildings. Utilizing a gravity-clamping mechanism inspired by pole-climbing robots, the MLM is designed to ensure structural integrity and maintain a kinetic non-slip grip on its track. Weighing under 60 pounds and compact enough to fit in the cargo area of an average car, the prototype can lift 200 pounds to a height of 20 feet. It is constructed from cost-effective rectangular tubing, using an A-shaped contact point to secure the load. The article concludes by discussing the MLM's benefits and potential future enhancements, such as battery operation, different carriage configurations, and a riding platform.

Introduction

Many homeowners and installers struggle to lift heavy objects onto small roofs due to bulky equipment. The Material Lift Machine (MLM) offers a compact solution, able to lift 200 lbs. up to 20 feet while fitting in a car trunk. It allows one person to safely and efficiently transport heavy items. This research explores the principles of gravity, torque, and friction, focusing on mechanical calculations and safety for small business owners and homeowners.

Background

Article 2.3 of Law 82-2010 mandates a 20% increase in the Renewable Energy Portfolio for retail energy suppliers every nine years until it reaches 100% by 2050. This law, along with installations like water heaters and air conditioners, creates a higher demand for installers accessing rooftops. Users often rely on cranes, bucket trucks, or scaffolding, resulting in storage issues and increased costs.

Problem

Small independent contractors often face challenges when transporting equipment and materials to buildings and rooftops. They frequently rely on ladders, which not only makes the process difficult but also poses a safety risk.

Figure 21
Carrying Condenser on shoulders.

Methodology

The methodology employed in this research involved the following steps:

Problem Identification: The research starts with a clear definition of what the problem is while lifting equipment and materials to buildings' rooftops and identifying what are the flaws of currently available methods.

Design Concept: Based on the problem analysis, a conceptual design for the portable lift machine (MLM) was developed utilizing Solidworks 2020 CAD . The design focused on creating a portable, one-person-operated, and self-leveling device capable of lifting heavy loads.

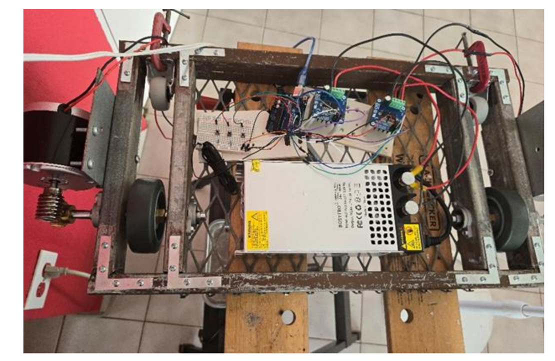

Figure 2
MLM Prototype

Mechanical Calculations: The design was analyzed using mechanical principles to ensure its structural integrity and functionality. Calculations were performed to determine the required dimensions, weight, and power requirements of the MLM.

Safety Considerations: Safety was a primary concern throughout the design process. Calculations were made to ensure the MLM would maintain a non-slip grip on the track and to evaluate the forces acting on the wood members.

Prototype Development: A prototype of the MLM was constructed using available materials and components. This prototype allowed for testing and refinement of the design.

Testing and Analysis: The prototype was tested to evaluate its performance, including its lifting capacity, portability, and ease of operation. Data was collected and analyzed to identify any areas for improvement.

OSHA Compliance: Correspondence with OSHA was conducted to determine the safety regulations applicable to the MLM. The results of this correspondence were incorporated into the final design and analysis.

By following these steps, a development of a comprehensive design was created for the portable lift machine and ensure its safety and effectiveness for the intended purpose.

Results and Discussion

The initial calculation aimed to determine the conditions that prevent slipping and the factors that control the state. Starting with the principles of statics, an object is in equilibrium if the net force acting on it is zero. As shown in Figure 1, the forces acting on the MLM are the Load, the normal reactions, and the tangential force. To achieve a non-slip condition forces must cancel each other. Normal reaction forces at each contact point are equal in magnitude but opposite in direction and the same happens with vertical forces Load and Tangential. Table 1 shows calculations supporting that a kinetic non-slip condition was achieved. Since the input speed and torque are known data, the following known relation

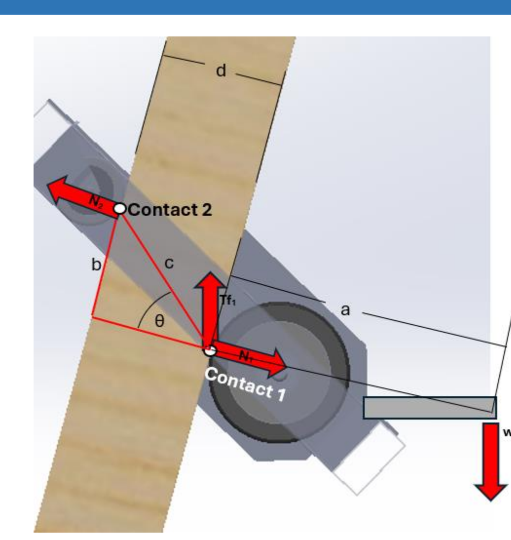

Figure 3
Acting Forces on MLM

Table 1
Kinetic Non-slip Calculation Lifter to Wood Members.

Non-slip Condition Calculation lifter To Wood Members					
Given:				Imperial Measurement System	
Static Coefficient of Friction	μ_s	0.9			
Kinematic Coefficient of Friction	μ_k	0.7			
Wood Member Thickness	t	0.0889	m	**3.55**	**in**
Segment Contact 1-wg	a	0.3003	m	**12.00**	**in**
Contact 1 to Contact2	c	0.1200	m	**4.80**	**in**
Height Contact 1-Contact2	b	0.085	m	**3.40**	**in**
Mass	m	119.048	kg	**8.16**	**slug**
Gravity	g	*9.81*	m/s^2	**32.20**	ft/s^2
Calculations (Governing Equations):					
Weight	W	1167.86	N	**262.55**	**lbf**
Tangential Force	Tf	1167.86	N	**262.55**	**lbf**
Theta Angle	θ	45	degrees		
Normal Force 2	Nf2	4125.98	N	**927.56**	**lbf**
Normal Force 1	Nf1	4125.98	N	**927.56**	**lbf**
Sum of Torques at Contact 1 $mga\cos(\theta)$	=	338.76	Nm	Approx 3% error	
$C\sin(\theta)N_2$	=	350.10	Nm		
Static Non-slip $W_1 \leq \mu N_1$	➡	1168 ≤ 2761			
Kinetic Non-Slip Indicator					
$a \geq \frac{c\tan(\theta)}{\mu_k}$ and $\theta = arccos\left(\frac{t}{c}\right)$	Green = Succeeded, Red = Failed			Succeeded	

$\frac{\omega^1}{\omega^2} = \frac{n^1}{n^2} = \frac{d^1}{d^2} = \frac{T^1}{T^2}$ was utilized to determine the output gear speed, where ω is the angular velocity, n is gear speed, d diameter, and T is for number of teeth. The law of gears states that in gear train the output to input torque ratio is also constant and equal to the gear ratio (Gear Ratio $= \frac{d^1}{d^2} = \frac{\tau_{out}}{\tau_{in}}$) where τ is for torque. With the parts on hand the resulting gear ratio was 64:1 and the torque being inversely proportional to speed resulted in 701 Lb.in and 42 RPM respectively. The motor and the Gear train were selected based on the speed and torque calculations in Table 1. The sum of the parts weight totaled 59.36 lbs. The MLM has dimensions of 33 in. wide, 15 in. deep, and 5 in. tall, making it compact enough to fit an average car trunk space.

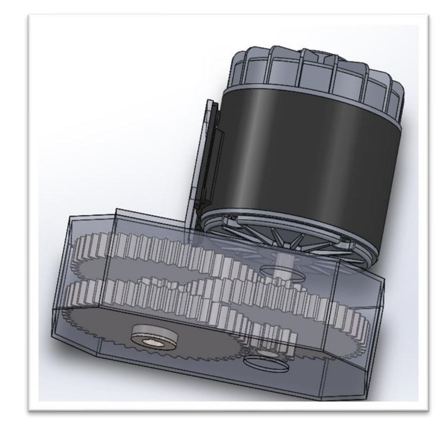

Figure 4
Motor and Gear Train

Table 2
Gear Train Reduction

Gear Train Reduction		
Input		
Speed	2700	RPM
Torque	10.94767593	Lb.in
Power	350	W
Number of teeth		Gear Ratio
Driver Gear	15	4
Idler 1	60	
Idler 2	15	4
Idler 3	60	
Idler 4	15	4
Driven Gear	60	
Resultant Ratio		64
Output		
Speed	42.1875	RPM
Torque	700.6512593	Lb.in

Table 3
Non-slip Calculation Footing to Ground

Non-slip Condition Calculation Footing to Ground			
Given:			
Static Coefficient of Friction Rubber on Wet Concrete	µs	0.7	ratio
Weight Loaded	WL	550	lbs.
length of Wood Members	l	240	in
% of Length for Carriage Position	x	97.35%	
Reactions			
Wall Reaction	Bx	258.3893	lbs
Floor Reaction	Ay	369.1275	lbs
Friction			
Force of friction at floor	Ffa	258.3893	lbs
Force of friction at wall	Fjb	180.8725	lbs
Tangent(θ)	tan(θ)	1.3722	Rads
Minimum Angle from the floor	θ	**54**	^{0}

Table 3

- Normal forces acting on a max loaded MLM 258.39lbs between the two sides.
- Floor reaction forces of loaded MLM 369.13 total.
- Recommended angle 75^0 from the floor, Minimum angle of inclination to sustain a nonslip condition on wet concrete is 54^0.

Figure 5
MLM prototype with 25 gallons of water approximately 200 lbs.

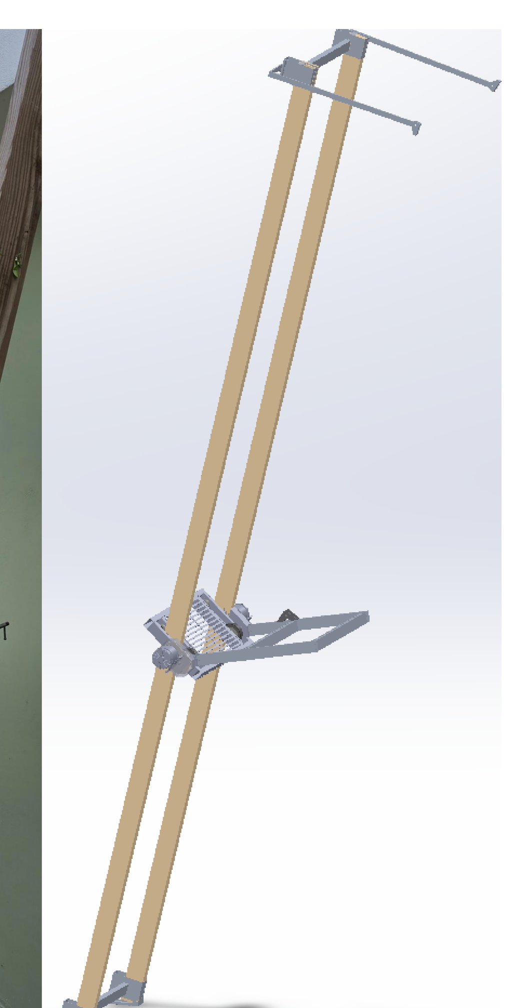

Figure 6
MLM model.

Conclusions

This research presented a new application to climbing robot technologies to provide a solution for individuals looking to lift material and equipment to their two-story buildings. The governing mechanical principles have been calculated and described and proved to be a viable solution. The non-slip condition is dependent on the geometry of the contact points and the coefficient of friction but not on the center mass.

Future Work

Later configuration will include all components as designed to lower cost and weight and upgrade performance. More capabilities can be added like battery operation, different carriage basket configurations, and ride on capabilities.

Acknowledgements

I would like to express my heartfelt appreciation for Professor Julio Noriega Motta, the dean of the mechanical engineering department. His exceptional patience and wisdom have been invaluable. He guided me in viewing this endeavor as a manageable journey, inspiring confidence along the way. He consistently embodied the spirit of knowledge sharing and the drive to make a meaningful impact. Thanks to his commitment to the Material Lift Machine project,

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