Published by :
http://www.ijert.org

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 14 Issue 06, June - 2025

Design and Structural Analysis of an Innovative Screw-Driven Lifting Mechanism for a Tipping Trailer

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***ABSTRACT* - This article presents the design and structural analysis of an innovative lifting mechanism for a single-axle tipping trailer intended for transporting firewood. Following a review of conventional lifting systems - hydraulic and mechanical - a screw-driven solution was selected due to its low cost, simplicity, and reliability, making it particularly suitable for domestic and small-scale applications. The proposed mechanism employs a horizontally mounted, double-threaded screw working in tandem with pivoting steel arms, inspired by the geometry of a scissor jack. Detailed kinematic modeling and strength calculations were performed for all major components, including the screw, nuts, lifting arms, pins, and bearings. The lifting system can be operated manually or powered by an electric motor, with a custom-designed clutch enabling seamless switching between modes. The final design ensures safe and efficient lifting of the trailer bed, significantly simplifying the unloading of bulk materials such as firewood. This practical and robust solution offers a cost-effective alternative to traditional unloading systems for individual users.**

***Keywords*— tipping trailer, lifting mechanism, screw drive, mechanical design, unloading system**

I. INTRODUCTION

In modern households using firewood as a primary source of thermal energy, efficient transportation and unloading systems are essential. Manual unloading methods are time-consuming and inefficient, especially in small-scale domestic settings where access to professional unloading equipment is limited. The design and implementation of a compact, cost-effective lifting system can significantly enhance the usability of single-axle trailers by simplifying the unloading process.

Hydraulic jacks provide high force and precise control by using fluid pressure, but they need complex and expensive components such as pumps, reservoirs, and valves. This makes them difficult to install in passenger vehicles that do not have built-in hydraulic systems [1].

Mechanical screw jacks present an attractive alternative due to their simplicity, low cost, and reliability. These mechanisms operate by converting a relatively small input force into a significant lifting force through the interaction of a screw and nut. While mechanical jacks are generally slower and subject to frictional losses, their straightforward construction and ease of maintenance make them suitable for integration into small trailer systems. This article focuses on designing an innovative screw-driven lifting mechanism, which can be easily integrated with standard domestic trailers that increases unloading efficiency while maintaining structural simplicity and minimizing the cost of implementing a lifting mechanism in trailers [2].

II. METHODOLOGY

The design methodology employed an engineering approach, beginning with the definition of functional requirements derived from the trailer's dimensions, maximum load capacity (750 kg), and required dumping angle. The design process was guided by the need for a mechanism that is structurally sound, safe, and economical. The trailer with loading bed, shown in the Fig. 1, was taken as the basis for the design of the lifting mechanism .

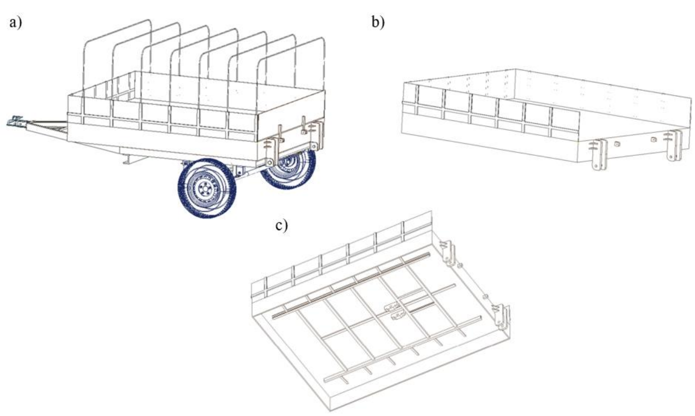

Fig. 1. a) Trailer, b) front view of loading bed, c) bottom view of loading bed.

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A double-thread screw with opposite threads on either end was chosen to drive lifting arms attached to the trailer bed, according to the kinetic structure presented in fig 2. This mechanical action enabled controlled and efficient raising of the trailer bed to the required dumping angle. The structural layout and mode of operation of the designed lifting system are, to some extent, analogous to those of a conventional automotive jack, particularly in terms of the scissor-like arm geometry and mechanical screw actuation.

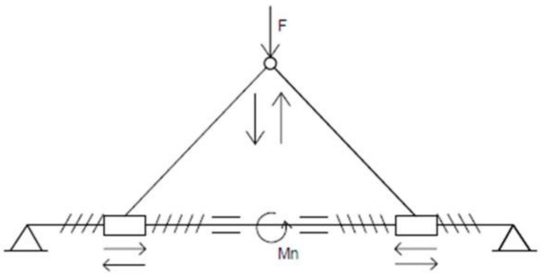

Fig. 2. Kinetic structure of lifting mechanisms.

The required angle was calculated by treating the trailer bed surface as an inclined plane, and the angle was determined using the following formula:

$$\Theta_{min} = \arctan(\mu) \qquad (1)$$

μ – wood-aluminum friction coefficient, μ = 0,5:

In the subsequent steps, a strength analysis of the mechanism was performed using analytical methods. The bending forces and moments acting specifically on the screw were calculated in detail. Due to the symmetry of the screw loading, only half of the screw was considered in the analysis. The loading scheme is shown in fig. 3. It was assumed that the load is distributed uniformly, and the self-weight of the timber was represented as a concentrated force applied at the lifting point of the trailer's bed.

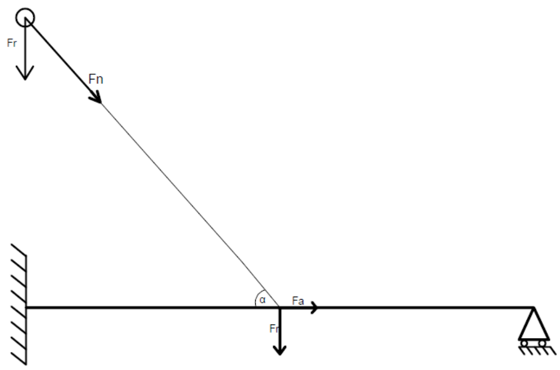

Fig. 3. Scheme of forces acting on half of the lifting mechanism.

Calculations were also performed to determine the driving torque required for the screw. This involved analyzing the forces acting on the thread and frictional effects to compute the torque needed to overcome resistance and raise the load. Based on these loads, along with the calculated allowable stresses, the material and geometry of the screw were selected to ensure adequate strength and durability. The geometry selection also took into account the self-locking property of the screw thread to ensure the mechanism remains securely in position without back-driving under load. Furthermore, additional analyses were conducted to select the geometry and materials for other components such as the nut, lifting arms, and mounting pins. The calculations were carried out for the configuration in which the mechanism experiences maximum stress. For instance, in order to determine the highest bending moment in the lifting arms, a graph (fig. 4) was developed showing the relationship between the bending moment and the tilt angle of the arms.

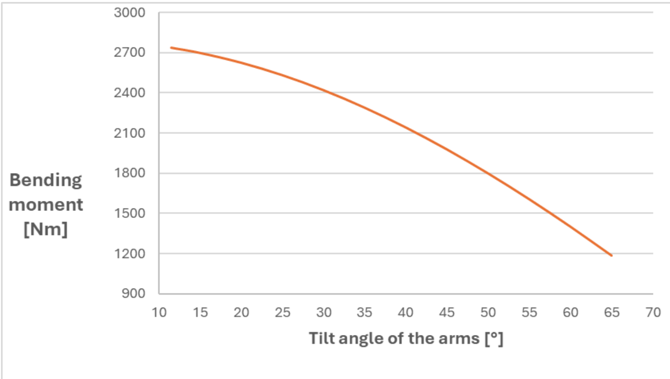

Fig. 4 Bending moment diagram as a function of the angle.

The design of lifting mechanism provided two methods of driving the lifting mechanism. The first method involved manual operation using a crank handle, where the operator applies torque directly to the screw to raise or lower the load. For this method, the recommended lever arm length has been chosen to ensure that a person is able to operate the mechanism using their own strength.

The second method employed a motorized drive, where an electric motor transmits rotational motion to the screw through a gearbox. For this approach, the driving torque of motor was calculated considering the load, frictional losses, and efficiency of the transmission system to ensure the motor could deliver sufficient power for smooth and reliable operation.

Appropriate bearings selection for the screw was also carried out, supported by an analytical analysis of bearing life expectancy. As in the case of force analysis, due to the symmetry of the system, only one half of the screw support was analyzed, and a corresponding calculation diagram (fig. 5) was developed. Given the substantial length of the screw shaft, the design incorporates a floating bearing to compensate for thermal expansion and prevent excessive axial constraint.

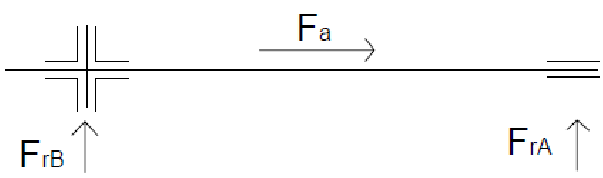

Fig. 5. Calculation diagram of bearings.

The analytical calculations and 3D model were further validated through calculations and modeling performed using Autodesk Inventor.

III. RESULTS

The final prototype consists of a horizontally mounted trapezoidal-thread screw supported by radial and spherical bearings. It uses dual-threaded nuts connected to pivoting arms, enabling synchronized lifting. The screw was manufactured from 25CrMo4 alloy steel. The maximum equivalent stresses within the Tr40x3 trapezoidal thread were calculated, assuming a safety factor of 3. Under the most critical loading scenario, the resulting equivalent stress was determined to be 102.8 MPa, which remained well within the allowable limits.

Following the estimation of thread friction and resistance torque during full compression of the lifting mechanism, a geared motor unit from SEW-EURODRIVE was selected, rated at a nominal torque of 51 Nm. To increase the output torque and exceed the minimum required actuation torque of 123 Nm, an additional spur gear transmission with a 1:3 gear ratio was incorporated into the drive system.

A non-standard C-channel profile (86×55×15 mm) was selected for the lifting arms, and its strength was verified through stress analysis. The resulting stress did not exceed 82 MPa, which, combined with the use of C40 structural steel, ensured a safety factor of at least 3.

In addition, the selected spherical roller bearings demonstrated a calculated service life exceeding 800 operating hours, which guarantees long-term operation of the lifting mechanism without significant risk of mechanical failure.

The 3D model of the trailer (fig. 6), including the lifting mechanism, served to visually represent the complete scope of the design work. The motor was mounted on a specially designed bracket, transmitting power to a shaft, which in turn drove the screw via a spur gear transmission. On the opposite side of the shaft, a manual lever can be attached, enabling the trailer bed to be raised and lowered by hand.

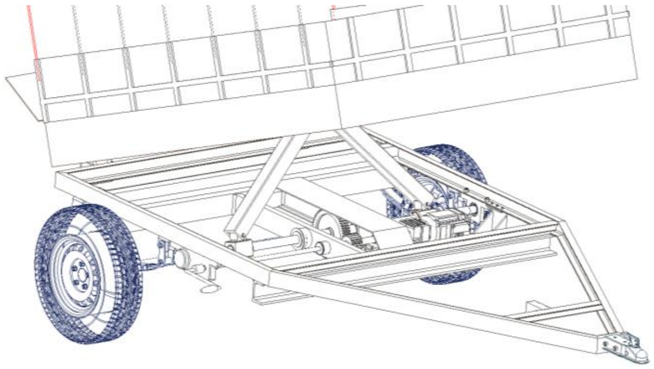

Fig. 6. 3D model of the trailer with screw lifting mechanism.

IV. CONCLUSION

The screw-driven lifting mechanism designed for a single-axle tipping trailer successfully meets the functional and structural requirements established at the outset of this project. The system offers a reliable, safe, and low-cost solution for domestic users requiring manual or motor-assisted unloading of bulk materials such as firewood.

Through comprehensive analytical and structural calculations, the design has been validated for long-term use with a high safety margin. The mechanism ensures operational efficiency while maintaining mechanical simplicity and ease of assembly.

This solution is particularly well-suited for small-scale agricultural operations, household use, forestry work, and other contexts where compact trailers are used and conventional hydraulic systems are not feasible. The project demonstrates that a robust and accessible lifting mechanism can be achieved using widely available components and conventional materials.

The proposed screw-driven lifting mechanism represents an innovative and competitive alternative to conventional hydraulic systems, offering comparable functionality without the associated complexity and cost.

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