Design of Portable Tyre Lifting Tool
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Abstract:
The number of automobiles has seen an alarming rise in the recent years. The main reason for this rise is the advent of mass production technologies for automobiles, making cars relatively cheap and affordable to everyone. In the year 2014, the number of road vehicles produced annually increased to 87.23 million vehicles from around 40 million in 2000. This shows that production has increased to more than twice the volume in only 14 years. Hence the auto industry is always on-the-rise. During the assembly of automobiles, be it everyday passenger cars or large commercial vehicles, tyres have to be assembled on the car chassis at some point of time in the assembly. An average tyre+rim set for a commercial car weighs around 10-12kg, and for heavy commercial vehicles it can go up to 25-45kg per tyre. Also the number of cars produced every day is very large. Almost always when the tyre has to be assembled, the vehicle is jacked i.e. it is raised to a height. Hence the tyre has to be lifted, aligned and fitted to the hub. To reduce operator fatigue, a tyre lifting tool is being designed. In this report we will focus on the design considerations, working principle and the mechanism for the said tyre lifting tool as well as the design calculations and CAD assembly.

Keywords: Finite Element Analysis (FEA), Lifting Jack, Mass Production Tools, Portable Tools, Tyre

I. INTRODUCTION

Certain important points were taken into consideration during the design process.

Lower Fatigue: Using a mechanical leverage in the tool reduces the fatigue of the operator. Also, only one operator is required to lift, align and mount the tyre on the hub. All these factors lead to increase in efficiency of the workplace.

Improved Operator Safety: The tyre lifting tools reduce the chances of accidents happening, hence operator safety at the assembly line is ensured.

Better Handling of Parts: The tools used ensure better handling of the parts. This minimises pre-assembly damages to the parts. Hence there is reduced probability of the parts being damaged.

As stated in the previous chapters, there is a great need for tyre lifting tools in the industry. The main advantages of a tyre lifting tool are as follows:

It is not possible to get electrical supply everywhere on the floor, thus a purely mechanical tool needs to be designed.

The Problem Statement is as follows:
To design a mobile tyre lifting tool. It should perform the following functions.
Tyre should be lifted off the ground
It should be rotated by 90°
After rotating it should be aligned according to hub bolts.
Operator should then be able to screw the lug nuts of tyre
The tool should be portable (set up on portable crane)
The tool should not use any kind of hydraulics and electronics.
Electric motor may be used to provide drive to move the tool i.e. the crane may have electric drive.

The specifications of the tyre are as follows:
Diameter of tyre= 794mm (31.26in)
Tyre Tread= 221mm (8.7in)
Mass of Tyre= 30kg

II. LITERATURE REVIEW

For a design of tyre lifting tool it is necessary to look into the design aspects and literature available in order to better understand the need of the industry for requirement of components and to establish the desired specifications of the required tool. The literature available has increased multifold over the past decade and multiple forms of design documents, safety parameter specifications and ergonomic considerations have come into picture.

According to NASA-STD-8719.9 SAFETY STANDARD FOR LIFTING DEVICES AND EQUIPMENT [1], the designed tool has to meet the requirements of ANSI, OHA and PCSA. Also, gearing if designed should conform to the latest AGMA Standards. The rated load of the hoist rope shall not exceed the rope’s breaking strength divided by 3.5. Also it is necessary to provide safe and adequate access to components to inspect service, repair, replace ant component during the design phase itself. Also All wire rope hoists shall be designed to have not less than two wraps of hoisting rope on the drum when the hook is in its extreme low position. Drum grooves shall be provided as recommended by PCSA Standards No. 4 and No.5. The rope ends shall be anchored securely by a clamp or a swaged terminal in a keyhole slot provided a keeper is used to prohibit the swage from moving out of the narrow slot. Other methods recommended by the hoist or wire rope manufacturer are acceptable if the rope termination anchor together with two wraps of rope on the drum will give an anchor system equal to or greater than the breaking strength of the wire rope. For the safety of the operator, it is imperative to provide two means of braking, each capable of bringing a rated load to zero speed and holding it (with and without power) for mobile cranes and derricks used for critical lifts. If the control brake and holding brake are designed to operate as a system and cannot independently stop and hold a rated load, then another means of braking is required for cranes and derricks used for critical lifts (e.g. emergency brake). For a
telescoping boom crane, the use of a counterbalance valve that locks the hydraulic fluid when the valve is in the neutral position is an acceptable braking means.

Testing Considerations have been defined by ANSI. According to these considerations, three types of tests need to be carried out i.e. proof load test, rated load test and operational tests. The proof load and operational tests are to be performed prior to use of new, extensively repaired or altered tools and cranes. Repairs or alterations to secondary, non-lifting components do not require a load test although a complete service check is mandatory. All load and operational tests should be performed by qualified personnel according to technically approved procedures by contractor safety representatives. The design shall provide for visual and physical accessibility. This inspection shall include NDE of components that are suspected to be cracked or otherwise affected by the test. The rated load test requirement may be fulfilled by a concurrently performed proof load test. Before first use, all new, extensively repaired, extensively modified, or altered cranes and derricks shall undergo a proof load test. A proof load test also should be performed when there is a question in design or previous testing. Mobile cranes and derricks shall be tested at the minimum working radius with a load as close as possible, but not exceeding 1.10 times the rated load. Proof load tests conducted by the manufacturer prior to delivery are acceptable if the necessary test certification papers are provided to verify the extent and thoroughness of the test on that specific item.

Tool design (weight, shape, fit to the user and the task), workstation design (size, shape and layout), and the way tasks are scheduled are all key factors in making hand tool use safe and risk-free. An effective prevention strategy must address all aspects at the same time. As an example, the design of handle of the tool can be considered. With the exception of tools for precision work (e.g., watchmaking, microsurgery, carving), the handles and grips of hand tools should be designed for a power grip. Tools with straight handles are for tasks where the force is exerted perpendicular to the straightened forearm and wrist, for instance, when the force must be applied vertically. Shaped tools such as bent-handle tools are effective where most of the tasks are done in the same plane and height as the arm and hand and when only one or two other tools are used. Also, a handle that is too short can cause unnecessary compression in the middle of the palm. It should extend across the entire breadth of the palm. Tool handles should be not less than 100 mm (4 in) to reduce the negative effects of any compression exerted. Handles around 120 mm (5 in) are generally recommended. The use of gloves requires longer tool handles. To ensure a good grip on a handle, sufficient friction must exist between the hand and the handle. This is particularly important where a considerable force must be applied with a sweaty hand. Hand tools should be made of non-slip, non-conductive and compressible materials. For example, textured rubber handles provide a good grip, reduce the effort needed to use the tool effectively, and prevent the tool from slipping out of the hand. Glossy coatings and highly polished handles should be avoided.

### III. DESIGN APPROACH

The basic design approach followed by us has been tabulated below:

<table>
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<th>What To Do</th>
<th>How to do it</th>
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<td>Rotating the tyre Placed on ground through 90°</td>
<td>Manual Lifting</td>
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<tr>
<td>Placing the tyre on tool</td>
<td>Tyre supporting rollers</td>
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<td>Lifting the tyre to required Height</td>
<td>Power Screw attached to lifting platform through scissor-links</td>
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<tr>
<td>Rotating the tyre about its axis and aligning it with the hub.</td>
<td>2 rollers</td>
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Initially the tyre is placed on the ground. The operator rotates the tyre by 90deg with his hands. After that the spring in the top plate is released. The spring is attached to the spur gears and the gear is attached to the tyre bar on which the tyre will rest. When the spring is released due to restoring force of the spring, the tyre bars will snap inwards and grip the tyre. Hence the tyre can then be lifted to the required height using the further lifting mechanism.

Once the tyre has been rotated, it has to be lifted to the required height. This is to be done using a power screw. The power screw is used due to its self-locking feature. In a power screw when the load is raised along a power screw, it does not come down due to its self-weight if the lead angle of the screw is more than the friction angle of the screw material. This property is called the self-locking ability of the screw. The power screw is designed with this self-locking ability and manufactured strictly according to the design parameters. Accurate manufacturing of the screw is critical as the self-locking ability of the screw depends on it. The screw has both right hand and left hand threads cut then the nut will move only in one direction on the screw. As the entire top assembly is supported on the nuts the entire assembly would move to one side of the bottom plate, leading to imbalance in the system. Such imbalance could cause toppling of the system. Hence to avoid such condition from arising we cut both right and left handed screw threads on the screw and mate corresponding right and left handed nuts on them. Due to this when the screw is rotated both nuts move inwards or outwards in tandem and hence the assembly stays centralised on the bottom support plate and imbalance is avoided. The accurate manufacturing of mating nuts of the screw is just as necessary. The screw is kept fixed and supported on the plunger blocks and the nuts are moving. The rotation of nuts is constrained with the help of roller wheels attached to the nuts via metal brackets. This provides linear motion to the nuts when the screw is rotated. A top plate is attached to the nuts on which brackets are welded. Now the links are assembled using fasteners. These links are assembled in such a way that they resemble a scissor. When the nut is raised via rotation of the screw, the links are raised along with the nut. A top plate is attached to the topmost links with the help of rollers moving in guide-ways. The tyre holding arrangement is kept on top plate. Hence the entire arrangement is raised and lowered through usage of links.

Now that the tyre is lifted up to the desired height, it needs to be aligned with the hub of the vehicle. Generally vehicle hubs have press-fitted bolts in them or have integral shanks with threading. They may also have threaded holes and bolts may be fitted after fitment of the rim. Hence the holes on the rim of the tyre need to be matched with the hub. This is done with the help of...
rollers. The tyre while being lifted is supported on pin shafts having freely moving rollers attached to them. When the tyre is lifted to the desired height the operator has to rotate the tyre along its axis until the holes in the rim are aligned with the holes/bolts in the hub. The tyre will be freely rotating over the rollers.

The friction angle of the screw is 11° and the helix angle is found out to be 4.2°. Hence as the friction angle is more than the lead angle of the screw, the screw is self-locking. The screw will be having square threads. The force required to rotate the screw to raise the required load is 150N. Hence the torque required is calculated and found out to be 1.5Nm. In one rotation of the screw the nut advances by only 5mm. Hence a large number of rotations are required to raise the load by an appreciable height. Hence to reduce the number of rotations to be done by operator as well as reduce the time a reverse reduction of 0.333 is given with the help of chain sprocket arrangement.

The assembly of links is the main component in the entire working assembly. The links are responsible for converting linear converging motion of nuts on the screw into upward motion of the top plate. Design procedure is as follows:

Max weight of tyre is 40kg and maximum upward acceleration is taken as 2.5m/s². Hence downward accelerated force is calculated as:

\[ F = m(g + a) \]

\[ F = 40 \times (9.81 + 2.5) = 500N \]

Hence entire system is designed to sustain 500N load. Worst case loading scenario will occur when whole system is constrained due to some reason and tyre is placed on the tool. This will lead to stress development. Two identical sets of links have been used and hence load on each link will be 250N. In each set, the load will be simultaneously applied on two links, hence take load on each link as 125N. Hence downward accelerated force is calculated as:

\[ F = \frac{500}{\pi \times 20^2} = 1.591 \text{ MPa} \]

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### V. FINE ELEMENT ANALYSIS

Finite Element Analysis is a numerical technique for finding approximate solutions to boundary value problems for partial differential equations by subdivision of a whole problem domain into simpler parts, called finite elements. Variational methods from the calculus of variations are used to solve the problem by minimizing an associated error function. FEA as applied in engineering is a computational tool for performing engineering analysis. It includes the use of mesh generation techniques for dividing a complex problem into small elements, as well as the use of software program coded with FEM algorithm. In applying FEA, the complex problem is usually a physical system with the underlying physics such as the Euler-Bernoulli beam equation, the heat equation, or the Navier-Stokes equations expressed in either PDE or integral equations, while the divided small elements of the complex problem represent different areas in the physical system.
Meshing is the process of converting a solid body into an assortment of nodes and elements. Nodes are singular points on the body of the component. Geometrical entities created by joining of nodes are called elements. All required calculations by the software are made at the nodes. The values obtained at nodes are interpolated throughout the entire element. For example for a quad element the interpolation function is:

$$u = a_0 + a_1x + a_2y + a_3xy$$ (1)

**METHODOLOGY**

**A. FEA of Link:**

The Boundary conditions for a FEA problem is basically the points of application of the constraints as well as the forces on the component. The boundary conditions depend mostly on the geometry of the component. For the link, the constraint was applied at one end and force applied at the other end. The link was modelled in SOLIDWORKS. Accurate application of loads, moments and constraints is very important for proper analysis results.

We now apply the loads and constraints on the previously meshed model and solve it. The mesh model for the link includes 2513 nodes combining to form 7986 elements. Also the meshed model clears the element checks of aspect ratio, skew, warpage and tet collapse and hence we can be confident of an accurate result. We now perform stress and displacement analysis on the link by applying the various loads and constraints as calculated above. They were applied as singular loads as well as a combination of loads and moments to simulate real time conditions. The results were obtained as follows:

The analysis was done using Altair Hypermesh. Maximum stress was found out to be 85MPa. Hence factor of safety was calculated to be 2.7. Hence we can say that the component is overdesigned. Hence there is scope for weight reduction without sacrificing structural strength and integrity. The displacement is coming out to be 0.429mm which is well within limits. We know that the created model of the link is overdesigned. Hence now we can think about reducing its weight. Hence Weight Optimization Study was done. The software used for weight optimization is solidTHINK INSPIRE V9. Same loads as previous were applied and results provided by the software were as follows:

This result obtained from INSPIRE showed the parts of the link from where material could be removed without disturbance of internal stress flow patterns within the material. This result was taken as reference and a new revised design of the link was created. The material was considered same as that of the original link i.e. Mild Steel. Weight reduction of 28% per link was observed after the study.
Hence max stress was found out to be 104MPa which gives a Factor of Safety of 2.0. Hence even though there is significant weight reduction the design is safe. The maximum displacement was found out to be 0.789mm which is also well within acceptable limits.

VI. PROTOTYPE MANUFACTURING

The initial assembly of the components was done. Initially, the links were fastened to each other with the means of nuts and bolts (M6 Bolt and hex nut). Washers were included between two mating links to act as a spacer between the links. These washers did not allow contact of links with each other by creating space between them and hence reducing surface friction.

The nuts were assembled on the screw. Ideally, when the screw rotated, the nuts will rotate along with the screw. So, to prevent that, the rolling of nuts is constrained to move along the length of the screw by attaching rollers with the help of brackets welded to the nuts. Hence as the rotating tendency of the nuts is constrained, the nut will advance along the screw threads when the screw is rotated.

Also, the power screw has both right hand and left hand threads. Hence, when the nuts are advancing along the threads they are actually moving closer to each other. A plate is welded on the top of the nuts and brackets are welded on the plate. This acts as starting points of the links. The first link is connected on the brackets. There are four brackets on each nut (2sets of 2).

The power screw is supported between two plunger blocks attached to the base plate. There are spacers provided between the plunger blocks and the base plate to provide height adjustment to the plunger blocks. One end of the screw shaft is extended and a keyway is provided on the shaft. This is for the attachment of the output sprocket i.e. sprocket with 13 teeth.

VII. TESTING OBSERVATIONS

The prototype was thoroughly tested and validated after completion. The various minor assembly issues were identified and isolated.

The major issue during assembly of the prototype was the instability of the upper links as the assembly is lifted. As there is major weight of the tyre, the tyre holding bars, gears, top plate etc. on the links, the links tend to sway during operation of the tool. When the links reach a certain height, and the assembly sways, there is a moment acting on the tool due to displacement of C.G of tool, and this may cause the tool to topple.

Also there is friction acting at assembly interfaces such as between roller and plate and also contact friction between individual links at points of fastening. Hence the force required is much more than the calculated force.

There are compliances in the systems which reduce the overall efficiency of the system. Due to inaccurate dimensional tolerances in mating parts like bolts and links, compliance arises in the system which contributes to wobbling and instability of the system. Also, additional operator effort is required to counter the effect of compliance.

VIII. CONCLUSION

Hence the tyre lifting tool for the required tyre has been designed. Using this tyre lifting tool a single operator can rotate, lift and align the specified tyre with a minimal force of 33N applied at the handle without use of hydraulics, pneumatics.

REFERENCES

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