Design of Vehicle Lifting Equipment Using Progressive Methods

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Abstract: The main objective of this article is to analyse the structural design of tire lifting equipment for tire services. To gain a better insight into the problem, several steps must be taken. The first step is to conduct a market analysis, which involves identifying all available equipment. Several types of lifting devices were distinguished within the development process, which differ from each other in terms of design and power supply. The type of structure and power unit represent the second steps in the design process. This is a critical aspect of the design since the forces necessary to move the system change as a result of these attributes. The design itself is the last step in the device's design. Passenger cars differ from each other by their weight, which is limited to 3.5 tons. Based on the weight, basic strength calculation and dimensioning of the lifting device are carried out. Based on the calculations, the scissor lift device is selected. The lower frame, scissor legs, ramp, mechanical lock, and scissors drive mechanism are five main components of the device. This type of structure is best used with a hydraulic drive unit, which is calculated in the article.

Keywords: Structural design, lifting equipment, passenger car

1. Introduction

Slovakia's automotive industry is a vital part of the country's economy. The number of cars that needs maintenance is a current and future trend, whether it is a routine tyre and engine oil change or a replacement of worn components. In Slovakia, these services are provided by numerous approved and private car repair shops, where lifting systems represent the most important piece of equipment. There is a wide variety of high- and low-quality equipment available on the market [1-3].

In the process of lifting equipment production, several specific types of lifting equipment are distinguished, which vary in terms of the structure, drive, and materials used. The five main components of the system dealt with in the article include a lower frame, which forms the foundation,

with pins connecting the scissor legs to it; an arm, which connects it to the rest of the structure; a hydraulic drive unit propelling the entire device, and a mechanical lock, which ensures safe operation. This is the most popular design on the market today [4-5].

The article focuses on the design of a lifting system that can lift cars weighing up to 3.5 tons and is mainly used by tyres service shops. Lifting system must meet several criteria. Must be met by the lifting system. First, it is the ability to lift a vehicle weighing up to 3.5 tons. This category includes smaller city cars, as well as limousines with various wheelbases, ground clearance, and vehicle width. These variables affect the device's complete shape. Another design criterion to be met is the device's minimum stroke of 600 mm, which allows the technician to operate it comfortably. Last but not least, the device safety is a top priority. These are the criteria that must be met by the device [6].

2. Lifting Device in Use

Lifting devices are used to lift loads to a height ranging from centimetres to meters in the vertical direction. Lifting devices come in a variety of shapes and sizes. They can all be put to various uses. Since the safety of their use is crucial, safety standards must be in place. STN 27 0143 is a standard that covers lifting equipment safety, maintenance, and service [7-8].

They are classified into the following categories based on the system of force transmission:

- mechanical,
- pneumatic,
- hydraulic,
- combined.

3. Dimensional Design of Lifting Device

The design must be based on the dimensions of the load to be lifted, which is a 3.5-ton vehicle. This category includes small hatchbacks, as well as SUVs and limousines. The wheelbase, ground clearance, and vehicle width are the most important factors to consider when designing the dimensions of the lifting device. These parameters are a part of the standardized vehicle data, as defined by the STN 30 0026 standard. The lowest ground clearance of vehicles, which begins at 130 mm, is a limiting factor when designing the height of the lifting device. Small cars have a wheelbase of 2500 mm, while limousines have a wheelbase of 3000 mm. The device's width, which is usually about 1500 mm, is the final parameter that affects its shape [9-12].

Figure 1 shows a hatchback car on a lifting device at the bottom dead centre with a wheelbase of 2500 mm and ground clearance of 140 mm.

Fig. 1 Car on a lifting device. Source: authors

Figure 2 shows the dimensions of the lifting device at its bottom and top dead centres. Figure 3 shows the view from above.

Fig. 2 Dimensions of lifting device: side view. Source: authors

Dimensions of the lifting device when viewed from the side:

$$h_D = 120, [\text{mm}] \quad (1)$$

$$h_H = 602, [\text{mm}] \quad (2)$$

$$z = 482, [\text{mm}] \quad (3)$$

$$L = 1980, [\text{mm}] \quad (4)$$

$$l = 1380, [\text{mm}] \quad (5)$$

$$l_1 = 300, [\text{mm}] \quad (6)$$

where: h_D , h_H , z , L , l , l_1 are dimensions of the device according to Fig 2 [mm].

Fig. 3 Dimensions of the lifting device: view from above. Source: authors

Dimensions of the lifting device as viewed from above:

$$B = 1730, [\text{mm}] \quad (7)$$

$$b = 830, [\text{mm}] \quad (8)$$

$$b_1 = 450, [\text{mm}] \quad (9)$$

where: B, b, b_1 are dimensions of the device according to Fig 3 [mm].

4. Forces Acting on the Framework

The critical factors in the design of the device includes the calculation of the forces, stresses, and reactions of the structure. The results of the calculation determine the stability, protection, and faultless operation of the entire mechanism. The lifting system is a dynamic machine, with individual components moving at different speeds and accelerating at different rates. However, only three positions of the system must be checked for load: the bottom dead centre, top dead centre, and the place where the piston must exert the greatest force to set the device in motion [13-18]. The force used to move the system is calculated in the following chapters.

4.1 Forces Acting on the Structure with Inclined BD Arm, $\alpha=13^\circ$

Fig. 4 Device position when the arms are inclined. Source: authors

$$l_R = 1370, [mm] \quad (10)$$

$$\frac{l_R}{2} = 685, [mm] \quad (11)$$

$$AB = 1266,681, [mm] \quad (12)$$

where: l_R, AB are dimensions of the device according to Fig 4 [mm].

$$F = 17167,5, [N] \quad (13)$$

where: F is force [N].

$$\sum M_{iA} = 0 \rightarrow -F \cdot \frac{l}{2} + B_y \cdot AB = 0 \rightarrow B_y = \frac{F \cdot \frac{l}{2}}{AB} \rightarrow B_y = 0,512 \cdot F = 8789,760 [N] \quad (14)$$

where: B_y is force in Y direction [N].

$$\sum F_{iy} = 0 \rightarrow -F + A_y + B_y = 0 \rightarrow -F + 0,512F + A_y = 0 \rightarrow A_y = 0,512 \cdot F = 8789,760 N \quad (15)$$

where: A_y is normal force in Y direction [N].

$$A_y = -D_y \quad (16)$$

$$B_y = -C_y \quad (17)$$

4.2 Static Balance Conditions of BD Arm

To simplify the calculation, it is sufficient to relax forces on one arm only. This is due to the symmetry of the structure. For this purpose, the BD arm was chosen. In Figure 5 below, the forces acting on the arm are represented by red arrows, green arrows represent reactions.

Fig. 5 Forces on the BD arm. Source: authors

Static balance conditions:

$$\sum F_{ix} = 0 \rightarrow P_x - F_x = 0 \rightarrow F_x = P_x \rightarrow F_x = P \cdot \cos\beta \quad (18)$$

where: P_x, F_x , are forces in the X direction [N], β is angle [$^\circ$].

$$\begin{aligned} \sum F_{iy} = 0 &\rightarrow -D_y + P_y - F_y + B_y = 0 \rightarrow F_y = P_y + B_y - D_y \rightarrow F_y = \\ &= P_y + 0,512F - 0,488F \rightarrow F_y = P \cdot \sin\beta + 0,024F \end{aligned} \quad (19)$$

where: D_y, P_y, F_y, B_y are forces in the Y direction [N].

Rotation around point B:

$$\begin{aligned} \sum M_{iB} = 0 &\rightarrow D_y (l \cdot \cos\alpha) - P \cdot \sin\beta \left[\left(\frac{l}{2} + a \right) \cos\alpha \right] + \\ &+ F_y \left(\frac{l}{2} \cos\alpha \right) - P \cos\beta \left[\left(\frac{l}{2} + a \right) \sin\alpha \right] + F_x \left(\frac{l}{2} \sin\alpha \right) = 0 \end{aligned} \quad (20)$$

where: P is force in the X direction [N], α is angle [$^\circ$].

Equation 8 can be used to calculate the necessary force of the piston at any point by determining the system of equations:

$$P = \frac{\frac{F}{2}(l \cdot \cos\alpha)}{a \cdot \sin(\alpha + \beta)} \quad (21)$$

Based on the derived formula for calculating the AE piston force and the known angles of the BD arm and AE piston from the geometry, Table 1 was compiled, where the forces of the piston AE

at individual inclinations of the arm BD are defined. Figure 6 shows a graphical representation of the development of piston force [19-21].

Table 1 Piston forces at various inclinations of BD arm. Source: authors

Angle α of the BD arm [°]	Angle β of the piston AE [°]	Piston force [N]
3	7.9	0
5	13	0
7	18	22398.602
9	22.7	35807.995
11	27.2	45419.092
13	31.4	53085.423
15	35.3	47841.020
17	38.9	43389.614
19	42.3	41075.039
21	45.7	38816.194
23	48.3	37031.032
24	49.6	36276.123

Fig. 6 Piston force development. Source: authors

Figure 7 shows the final solution and configuration of the lifting system. The calculated forces acting on the structure were used to design the individual components of the unit. The system is made up of five basic components that are connected together by pins. The lower frame, to which the scissor

system is attached, forms the lower part. The device's upper part consists of a ramp that supports the elevated ramps. The device is propelled by pistons. The device's safety is ensured by a mechanical lock that closes the scissor system mechanically and prevents it from moving downwards [22-25].

Fig. 7 The lifting device's description. Source: authors

5. Conclusion

The objective of the article is to design of a lifting device weighing up to 3.5 tons, primarily for tyre service shops. Prior to designing, it is important to conduct market research to determine what choices and alternatives the market can offer. The survey has shown there are several devices that vary in terms of design or drive. Scissor structure is selected after consulting with the tutor and using personal judgement. Since it outperforms other drives, the hydraulic drive was chosen [26-28].

Prior to the design itself, the basic dimensions of the lifting device, such as the wheelbase, ground clearance, and width of the device, must be determined. The lifting device's dimensions are determined by the parameters defined by the standard STN 30 0026. The length of the ramp is determined by the vehicle's wheelbase. It is variable thanks to the adjustable approach platforms, and thus will suit vehicles with both short and long wheelbases. Another critical consideration in the design is the device's height. The operator must be able to handle the lifting device comfortably, which is enabled by the 600 mm lift.

The safety of the device is a top priority. Although the hydraulic piston mechanism is effective, the device still requires a mechanical lock. The lock is intended to keep the unit safe when in use. The mechanical lock's manual operation is easy and comfortable [29].

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