Mathematical Modeling of a Hydraulic Lifting System for the Autodock Docking Leveler

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Abstract: This paper focuses on aspects regarding the design of a universal lifting system (actuation) of the platform of a product such as hydraulically operated docking levelers, with example on the Autodock leveler, which can be found as a component of the external docking stations of logistics warehouses. Aspects regarding the configuration of this product are treated as well as functional aspects reflected through a mathematical model that describes the interdependence between the parameters that describe the movement of this mechanical system. It also describes the situation of the stresses that occur in this system during operation and how they vary depending on certain key parameters. Summarizing, an image is created on a design method that imposes a set of conditions and universal steps valid for the design of the leveler lifting system for any special configuration found in the required configuration limits. The aim of the paper is to form a clear picture of the interdependence of the parameters that shape the designed lifting system.

Keywords: docking; model; hydraulic; system; design; leveler

1 Introduction

Docking levelers are special devices installed in logistics warehouses with the aim of making the connection between the entrance to the warehouse through the docking station and the vehicle visiting the warehouse [1], [2], [3]. Loading ramps provide maximum loading speed and efficiency by building a permanent bridge between the loading area and the vehicle in areas where there is a lot of entry and exit goods shipment. The hinged loading ramp consists of two main parts:

— the main platform, which includes a ramp (hinged along its rear edge), and

— the lip, hinged at the front of the ramp [1], [2], [3].

Thanks to this simple but well–designed system, it is possible to control standard hinged ramps with a single button. Equipment and logistics machinery transits over these docking levelers, which can be found in various types and sizes.

The hydraulic oil pump, valves, pistons, and the control board move the main platform and lip properly. The paper deals with the design of the lifting system of an Autodock hydraulic leveler (1), a leveler that is installed outside the warehouse building, which supports on the edges of its frame a metal loadhouse construction (2) on which is installed a sealing device called shelter (3).

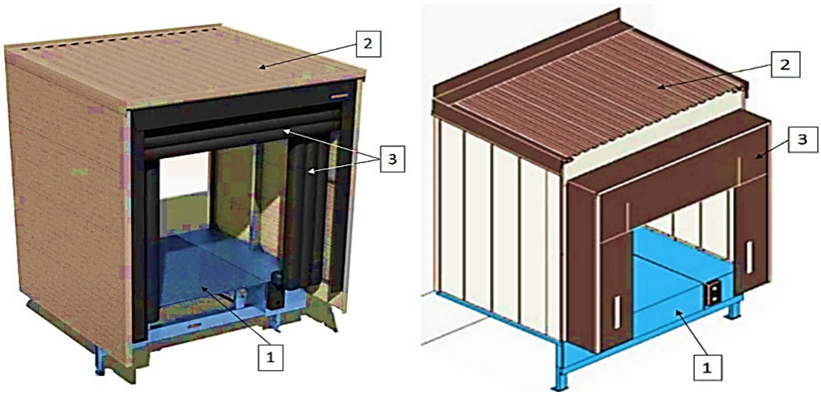

Figure 1
Docking station located outside the logistics warehouse, equipped with Autodock leveler

This is a table example: The problem of designing a docking platform lifting system is necessary due to the character of this product being found as a series product in standard configurations for newly built warehouses and as a product with special configuration for existing long–term warehouses (especially in Europe) which they have not been communized with the new regulations and standards.

At present, we used a set of linear hydraulic motors as drive systems for Autodock levelers but not only. Due to the wide range of configuration of the leveler dimensions, this platform lifting system is also influenced, which creates a need for the implementation of rules and algorithms in the design process for positioning and choosing the correct linear hydraulic motors found in this system. This paper will define a series of parameters and conditions necessary to obtain a universal solution in terms of designing this lifting system for docking levelers with example on the case of Autodock type leveler [1], [2], [3].

These automatic loading dock levelers and manual dock plates work with most types and sizes of vehicles to keep your operations running safely and smoothly [1]. Hydraulic telescopic–lip dock levellers have a movable telescopic lip, which provides a larger contact area between vehicle bed and dock leveller. Thanks to that, they can be precisely positioned on the vehicle bed for optimal load utilization and improved safety [1]. Preventive maintenance is easy and fast to secure functionality. All hydraulic telescopic–lip dock levellers are easy to operate [1].

2 Leveler Description

The Autodock docking leveler is composed of 3 large subassemblies that are found everywhere in the construction of hydraulically operated docking levelers, namely: frame, platform and lip. Figure 2 shows the main components of the docking Autodock type leveler, they can be found in several combinations of types and sizes, depending on the configuration of the leveler, imposed by the operating situations and other technical factors derived from the docking process.

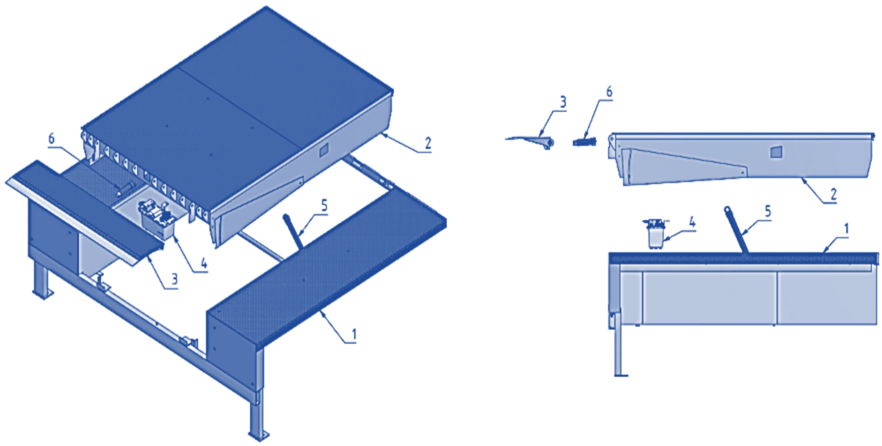

Figure 2
Autodock docking leveler components

According to Figure 2, the following constructive components that make up the leveler can be described:

1. The frame – represents the support structure both for the other components of the leveler and for the loadhous that is installed on its side wings. The frame is supported at the front by two support legs and at the other end by a profile behind the frame, which is welded at installation by a metal support embedded in the foundation of the building outside which the leveler is installed.
2. The platform – is made of striped sheet plate reinforced by L profiles, made of sheet metal, arranged longitudinally below it. The role of the platform is to be transited by logistics equipment, at the same time it supports other elements and accessories that are found in the composition of the leveler. It is installed in the frame by hinges located on the back of it and at the other end being installed the lip and two side guards to cover the space between the platform and the frame that appeared during the operation of the leveler.
3. The lip – has a double role, makes the transition between the leveler platform and the logistics vehicle visiting the docking station, the second role is supporting the platform during the resting position of the leveler when the platform is supported in the rear hinges and lip. The lip can be of two types, the

case of the articulated lip performing a rotational movement (with platform hinges) or telescopic, in which case it performs a translational movement and support on the support legs.

4. The hydraulic unit – consists of a hydraulic pump, motor and oil tank, it has the role of supplying and taking oil from the hydraulic system.
5. Hydraulic lifting motors – are linear hydraulic motors with simple action and are mounted in the supports on the frame and those on the platform, having the role of raising and lowering the platform to bring it into operation. These are found one on the right and one on the left inside the frame.
6. Hydraulic lip drive motor – is a single linear hydraulic motor with single action in the case of the articulated damper and with double action in the case of telescopic lip, has the role of extending or retracting the lip to bring the leveler into operation or of resting position.

The docking levelers are generally found provided with 3 operating positions and in the case of the Autodock leveler, they are represented in Figure 3. The leveler is considered at rest (Figure 3, A) when the platform is found in the horizontal plane, the articulated lip resting on the supports provided on the transverse front profile of the frame. During the resting position the leveler cannot be crossed by the logistics equipment and the hydraulic systems are in a depressurized state [1], [2], [3].

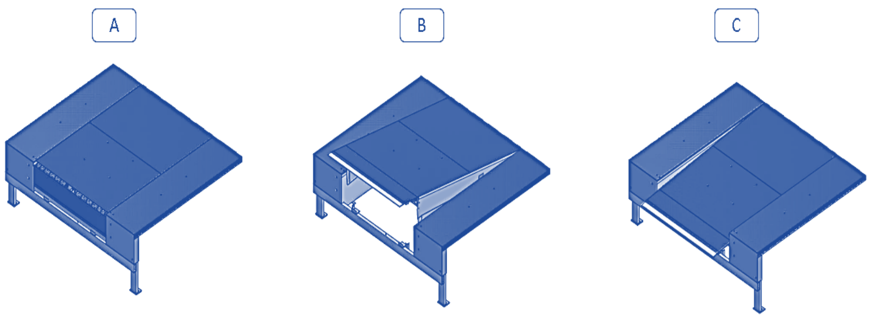

Figure 3
Autodock leveler operating positions

The operating position of the leveler is considered when the lip is in the extended position and supported on the platform of the vehicle visiting the docking station. Two operating positions are considered in the upper position (figure 3, B) when the vehicle level is higher than that of the leveler and lower position (figure 3, C) when the vehicle level is lower than the leveler level. During the operating position, the hydraulic systems are also depressurized, which facilitates the continuous adaptation of the platform according to the level variations of the vehicle platform due to its suspensions.

The hydraulic systems are pressurized in the transition phases of the ramp from the resting position to the operating position and vice versa. It is possible to self–pressurize the hydraulic system due to the accidental fall of the platform due to the disappearance of the possibility of supporting the damper which may be due to the accidental advancement of the vehicle. In the case of self–pressurization, the system is provided with a safety valve that stops the discharge of hydraulic fluid from the two linear hydraulic motors intended to drive the platform.

The operating sequences of the leveler starting from the rest position are raising the platform to the upper maximum point, operating the lip to full extension and lowering the platform until the lip comes into contact with the platform of the vehicle in the docking station. The retraction to the rest position is performed in reverse order.

3 Defining the Lifting System

Taking into account the configuration parameters of the Autodock docking leveler, the aim is to determine the technical characteristics that define the linear hydraulic motors with simple action intended for lifting the platform.

The first technical specification considered is the useful force developed F [kN] its magnitude is given by formula (1):

$$F = \frac{\text{the load capacity of the leveler}}{2} \cdot k_s \cdot k_d \tag{1}$$

where: k_s − safety factor, considered 1.5;

k_d − dynamic load coefficient, considered 1.4.

The coefficients k_s and k_d are in accordance with standard EN 1398:2009 [4].

It is also necessary to determine the dimensional limits of the hydraulic motor such as the minimum length L_{min} [mm], the maximum length L_{max} [mm] and the stroke of the piston St [mm] given in formula 2:

$$St = L_{max} - L_{min} \tag{2}$$

An important feature of the hydraulic motor is also the inner diameter D_i, which is required by the design input data to be 40mm and the outer diameter D_e in the value of 50mm. Another feature to consider is the speed of the piston V_p which can be adjusted from the hydraulic unit by varying the flow of the pump [5], [6].

$$V_p = Q_p \cdot \frac{\pi \cdot D_i^2}{4} \tag{3}$$

where Q_p [l/min] is the pump flow from the hydraulic unit.

The main parameters used in the configuration of the docking ramps are presented in Table 1 where are shown the intervals between which they can be found.

Table 1
Autodock docking leveler configuration parameters

Description	Parameter notation	UM	Range	
			Minim	Maxim
Load capacity of the leveler	–	kN	60	150
Nominal length	NL	mm	2000	4500
Nominal width	NWAD	mm	3300	3750
Nominal height	DH	mm	800	1500
Frame thickness	LH	mm	600	950
Lip width	NW	mm	2000	2500
The length of the lip	LL	mm	350	1000
Maximum opening	Ls	mm	500	200
Minimum opening	Li	mm	400	150

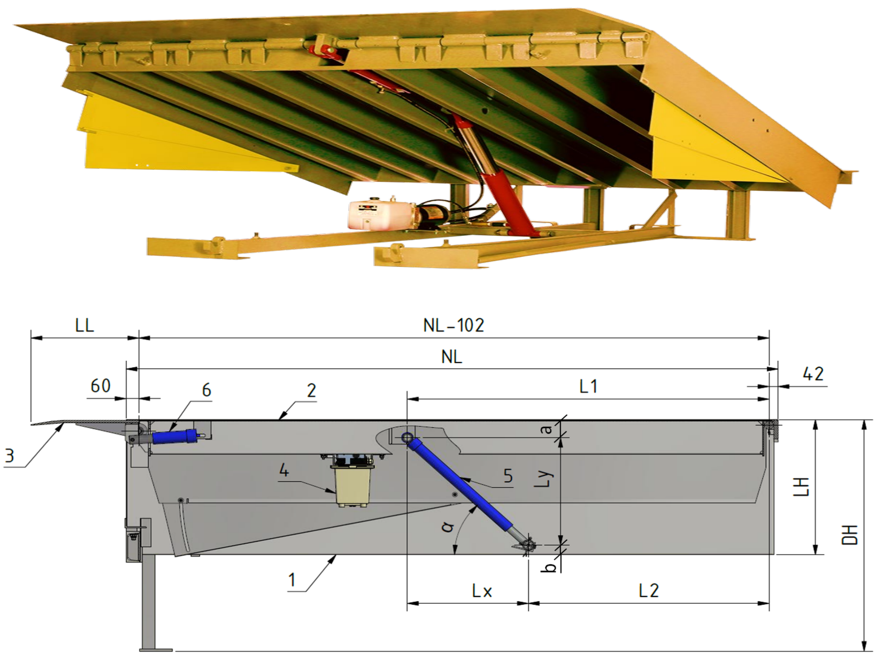

Figure 4
Constructive parameters of the lifting system designed for the Autodock docking leveler

Figure 4 shows the parameters that influence the lifting system of the hydraulic ramp, it can be seen that the hydraulic motor 5 is fixed in two articulated supports forming the angle of inclination α which is considered 45 degrees always when the leveler is stationary, in this case the other 2 parameters L_1 and L_2 describe the position of the fixing articulated supports with respect to the center of the hinge that forms the rear joint of the leveler. The parameters L_x and L_y are influenced by the length of the hydraulic motor during the rest position.

$$L_x = L_y = LH - a - b \quad (4)$$

Considering the position of the center of gravity extracted according to the 3D model of the platform and lip assembly as 55% of the NL parameter, measured from the center of the rear hinge to the lip, the formulas for determining the fixed dimensions L_1 and L_2 can be considered:

$$L_1 = 0{,}55 \cdot NL \quad (5)$$

$$L_2 = L_1 - L_x \quad (6)$$

It is also possible to calculate the length L of the hydraulic motor in the resting position state of the leveler, this being given by formula 7:

$$L = \frac{L_y}{\sin\alpha} = \frac{L_x}{\cos\alpha} \quad (7)$$

When choosing the type of hydraulic motor it is necessary to respect the condition (8) in order to have a sufficient stroke of the piston necessary when lowering the platform of the docking leveler below the level of the horizontal.

$$L > 0{,}35 \cdot L_{max} \quad (8)$$

At the same time, a 50 mm reserve of the piston stroke is required in the minimum operating position of the leveler. This condition is due to the fact that the fluid supply of the hydraulic motor is made without the existence of an ante filling chamber with fluid, the supply being made by an orifice with a section much smaller than the active surface of the piston. In this case, the possibility of locking the hydraulic motor may occur due to its inability to develop the useful force required to lift the platform.

These dimensional parameters being determined it can be considered that the lifting system of the platform are completely defined from a constructive point of view in the resting position of the docking leveler [7].

4 Mathematical Modeling of the Lifting System

The determination of the maximum opening L_s according to Figure 5, which the linear hydraulic motor can offer for the different configurations of the Autodock leveler is made by elaborating a mathematical model describing the relations between all the parameters that vary during the actuation of the platform.

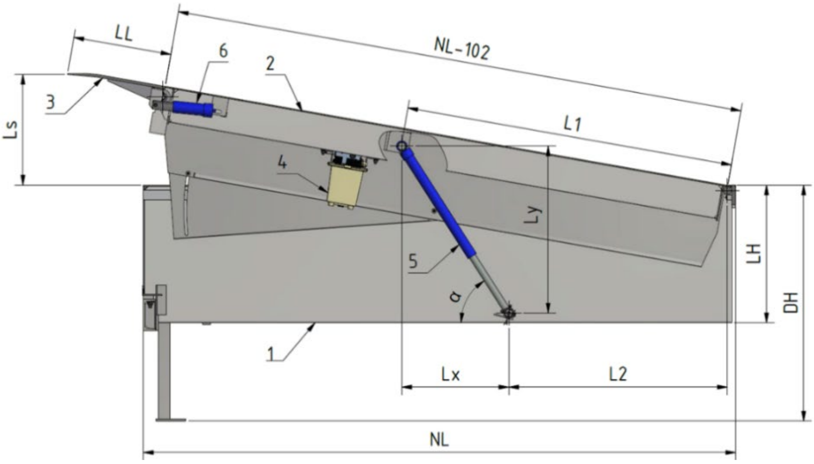

Figure 5

The parameters of the platform lifting system in the upper operating position of the leveler

The main parameters that describe this path of the platform movement are the inclination angle of the hydraulic motor α, the inclination angle of the platform β and the elevation that describes the vertical movement of the lip tip L_s.

Figure 6 shows the diagram describing the kinematic parameters of the route traveled by the platform and the extension of the hydraulic motors that drive it.

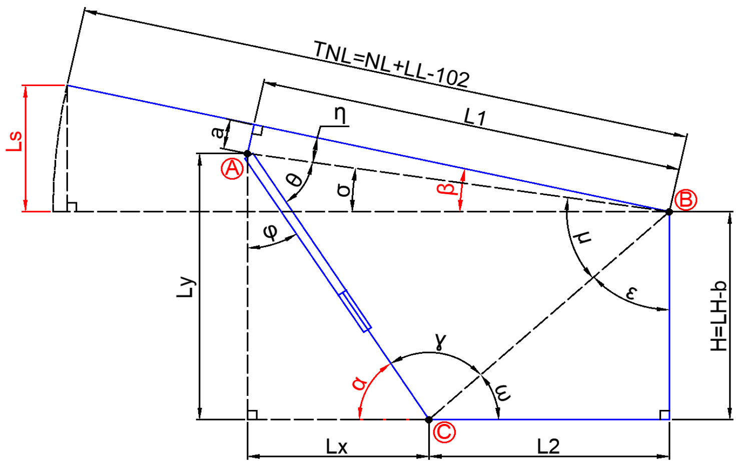

Figure 6

The scheme of the parameters involved in the mathematical model of the platform movement

Points A, B and C are joints that allow the rotational movement, points B and C being fixed and mobile point A, also the constructive parameters H, L1, L2, a and TNL are considered the parameters established according to the ramp configuration and are not considered variables in this analysis of movement.

The order of the scheme for the mathematical determination of each parameter is as follows:

$$BC = \sqrt{L_2^2 + H^2} \tag{9}$$

$$\omega = \cos^{-1}\left(\frac{BC^2+L_2^2-H^2}{2\cdot BC\cdot L_2}\right) \tag{10}$$

$$\varepsilon = 90 - \omega \tag{11}$$

$$\gamma = 180 - \alpha - \omega \tag{12}$$

$$\varphi = 90 - \alpha \tag{13}$$

$$BA = \sqrt{L_1^2 + a^2} \tag{14}$$

$$\theta = \sin^{-1}\left(\frac{BC\cdot \sin\gamma}{BA}\right) \tag{15}$$

$$\mu = 180 - \gamma - \theta \tag{16}$$

The parameter AC represents the length of the extended linear hydraulic motor for a certain value of the parameter α. The additional parameters L_x and L_y can also be determined:

$$AC = BA + BC - \sqrt{2 \cdot BA \cdot BC \cdot \cos\mu} \tag{17}$$

$$L_x = AC \cdot \sin\varphi \tag{18}$$

$$L_y = AC \cdot \sin\alpha \tag{19}$$

$$\eta = \cos^{-1}\left(\frac{L_1^2+BA^2-a}{2\cdot L_1\cdot ba}\right) \tag{20}$$

$$\sigma = \varepsilon + \mu - 90 \tag{21}$$

Knowing the parameter β that characterizes the inclination of the platform can determine the maximum opening of the leveler L_s.

$$\beta = \sigma + \eta \tag{22}$$

$$L_s = TNL \cdot \sin\beta \tag{23}$$

Knowing all these relationships, it can be considered that the lifting system of the platform has a path that is clearly defined from a mathematical point of view, covering the configuration range of the Autodock docking leveler product [8], [9].

In case of lowering the platform below the horizontal level, the lower limit must be $\alpha > 30^o$. This limitation is due to the avoidance of the appearance of a too small vertical component of the useful force developed by the hydraulic motors, necessary to lift the platform, which leads to the impossibility of lifting the platform. The second risk that may occur is that the horizontal component of the force (much greater than that required to lift the platform) developed by the hydraulic motors has a destructive character by inducing stresses in various frame components or even in the support joints of hydraulic motors.

5 The Balance of the Forces Developed within the System

Regarding the demand developed within the lifting system of the docking platform, the situation is represented schematically in Figure 7. The main force acting during the lifting of the platform is the gravitational force G which is divided on the two linear hydraulic motors, acting on each one separately the component G_L.

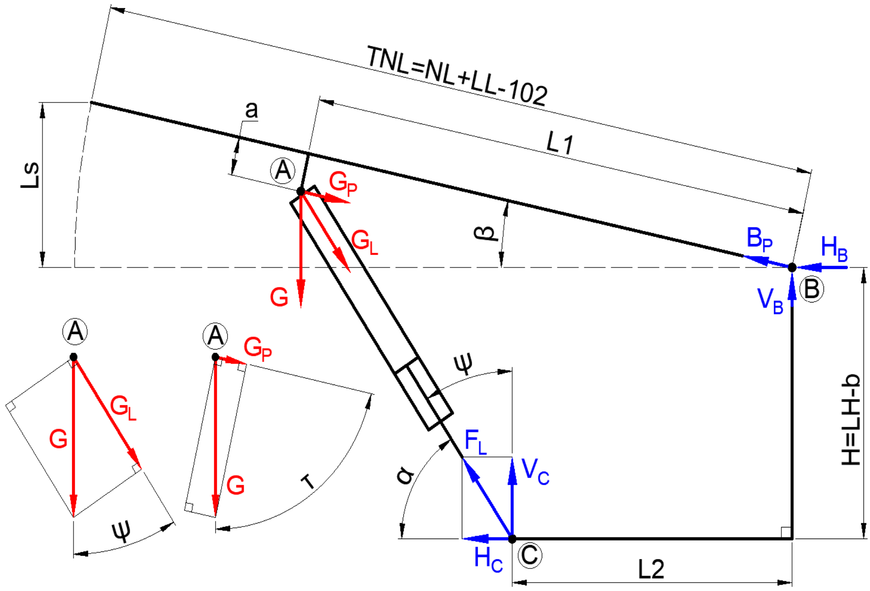

Figure 7

Distribution of forces within the designed leveler lifting system

The reaction forces present in the joints with fixed position in the system, represented by points B and C are highlighted in Figure 7 in blue, among which are components in the vertical direction V_B and V_C respectively components in the horizontal direction H_B and H_C.

The component G_P acting along the platform is compensated by the reaction force B_P which develops in the fixed joint B.

In the case of the component G_L of the force of force G acting on the linear hydraulic motors this is canceled by the reaction force F_L during the stationary stage of the leveler in stationary position when $G_L = F_L$. If the platform performs a lifting movement then the condition $G_L < F_L$ is met and during the descent of the levelers the reverse $G_L > F_L$ takes place [10].

The mathematical determination of the stresses is performed by a series of successive determinations starting with the angles appeared due to the decomposition of the main forces on components:

$$\Psi = 90 - \alpha \quad (24)$$

$$\tau = 90 - \beta \quad (25)$$

Knowing these angles can determine the components of the weight force acting on a single hydraulic motor G_L and G_P acting on the platform on a single hinge of the joint located in the back of a the leveler:

$$G_L = \frac{G \cdot \sin(90 - \Psi)}{2} \quad (26)$$

$$G_P = \frac{G \cdot \sin(90 - \tau)}{2} \quad (27)$$

For the steady state of the platform it is considered that the mobile joint A becomes fixed by respecting the following condition:

$$F_L = G_L \quad (28)$$

The relations by which the magnitude of the vertical and horizontal reaction component forces related to the fixed joint C can be determined are:

$$V_C = F_L \cdot \sin \alpha \quad (29)$$

$$H_C = F_L \cdot \sin \Psi \quad (30)$$

In the case of the fixed joint B the relations that describe the reaction forces developed in it are the following:

$$B_P = G_P \quad (31)$$

$$V_B = B_P \cdot \sin \beta \quad (32)$$

$$H_B = B_P \cdot \sin(90 - \beta\beta) \quad (33)$$

According to these relations, the pressure required in the hydraulic installation for lifting the platform can be determined according to the relation:

$$P_L = \frac{F_L}{D_i};\ F_L > G_L \quad (34)$$

These relations presented in the balance of forces are necessary for the strength sizing calculations of the different constructive components of the joints and other constructive components [11].

The gravitational force G acting on the platform can be found under two scenarios:

1) When the leveler is not subject to external stresses (it is not crossed), the situation of maneuvering the leveler to bring it into different operating positions. In this case, the weight force G is specific to the weight of the platform and the other components that are supported by it.

2) When the leveler fall safety system is activated and it is crossed by the machines. In this case, the force G is considerably higher than in the first case, having also a dynamic stress character where the leveler and the joints together with the lifting system must withstand the stress F in the relation (1).

The dimensioning of the leveler and the joints of the lifting system is performed for scenario 2 and the lifting capacity of the hydraulic motors must be dimensioned according to scenario 1 taking into account a safety factor between 1.2–1.4 in order not to encounter problems in operation.

Conclusions

The efficient flow of products in and out of facilities is critical in today's highly competitive world. Special attention must be given to the loading dock area design for this to happen. A number of factors must be considered when coordinating dock heights and door sizes, and when selecting the proper loading dock equipment. Hydraulic swing–lip dock levellers are designed to enable a safe and efficient loading and unloading while reducing downtime to a minimum. The result is exceptionally high safety for the transfer of goods, preventing any injuries or damage to equipment. Dock levelers bridge the gap and height difference between the dock and the trailer. They also compensate for the up and down float of the trailer bed during loading. They use fully powered raise and lip extension functions with hydraulic cylinders and hydraulic pump and motor stations. Hydraulic levelers are considered the safest loading dock choice.

The process of designing the Autodock docking leveler lifting system starts from knowing the destination of the product and defining its configuration range. For a good functioning of the system, the following constructive conditions are established and imposed:

— The platform of the leveler must be driven by linear hydraulic motors with simple action in the platform center of gravity.

— The angle of inclination α of the hydraulic motors while the leveler is in the resting position must be worth 45 degrees.

— For the sustainability of the lifting system and the leveler, it is necessary to have a reserve of the piston stroke of 50mm for the hydraulic motors that operate the platform.

A mathematical model was developed to determine the variation of the L_S dimension and the β angle as a function of the α angle. The balance of the forces appeared in the lifting system of the platform was made, depending on these, the sizing calculations of the different components of the leveler and from the lifting system will be carried out.

Today's workplace will not tolerate unsafe work practices. Planners must ensure that the loading dock area is not just efficient, but also safe. Installing loading dock safety equipment is just the first step towards minimizing hazardous and costly accidents. A dock leveler is a fixed bridge designed to permit the safe and efficient flow of goods into and out of a building. In order to accomplish this, a dock leveler must be able to support extremely heavy loads and service a wide range of truck heights. Hydraulic units, although initially more costly, require less routine maintenance than mechanical units, and offer many long–term benefits. Heavy load, high usage, and severe condition applications are best suited to hydraulic dock levelers. Besides increasing efficiency and safety, it also generates energy savings by restricting thermal losses through open doors, ultimately improving hygiene and working conditions.

The innovative and unique docking control system implemented in our unit offers complete control of the dock leveller, dock shelter and door, all in one control unit. With very few self–explanatory buttons on the control unit, the system is easy to operate for all operators. Separate steering (control) units and complex wiring systems are no longer needed. The innovative and unique docking control system offers complete control of the dock leveller, dock shelter and door, through a single control unit.

Lifting system for the docking leveler are designed to enable a safe and efficient loading and unloading while reducing downtime to a minimum. It is the standard solution in general industry applications. Its swing lip safely bridges the gap between the ramp and the vehicle bed. The result is exceptionally high safety for the transfer of goods, preventing any injuries or damage to equipment. Maintenance is easy and fast to secure functionality.

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