To design a belt drive scissor lifting table

Corrado Andrea[#], Polini Wilma[#1], Canale Luca[*], Cavaliere Costanzo[*]

[#] Department of Civil and Mechanical Engineering, University of Cassino and Southern Lazio
via Gaetano di Biasio 43, 03043 Cassino, Italy

[1] polini@unicas.it

[*] CIEM S.p.a.
via Cerro Tartari, 03043 Cassino, Italy

Abstract—**The present work deals with the design of a belt drive scissor lifting table to be install on platforms, called skillet, that constitute a typical line of handling on which the operator can stay and proceed to assembly, with times established by the product manufacturing.**

The aim of this work is to design a new lifting table with the cheapest actuation commercially available, simple and able to respond to the functional requirements, in order to replace two commercial lifting tables actually in use on the skillets along the handling line. In order to satisfy these requirements, the design has involved two different analysis: a dynamic motion analysis and a structural analysis.

Keyword- scissor lifting table, belt drive, dynamic motion analysis, structural analysis

I. INTRODUCTION

Scissors lifting table is a device that employs a scissors mechanism to raise or lower goods and/or persons. Typically, lift tables are used to raise large, heavy loads through relatively small distances. Common applications include pallet handling, vehicle loading and work positioning, automatic production lines, distribution lines and so on. Lift tables are a recommended way to help reduce incidents of musculoskeletal disorders by correctly re-positioning work at a suitable height for operators. They can work in hostile environments, be used indoor or outdoor with a considerable extensive space, be manufactured in stainless steel and have equipment like conveyors, turntables, barriers and gates easily added to their deck plates.

The scissors mechanism is one of the most important components of the lifting table, whose capability influences directly the performance of the whole equipment, therefore identifying the structure's dimensions is one of the most critical aspects. Other critical aspects to design a table are to identify the scissors posts, the bottom car and the upper platform, and above all to define the actuation mechanism for lifting. In fact, in the last half century many kinds of actuation mechanism for lifting have been developed and implemented in scissors lifting platform in order to have scissors lifting table with higher and higher loading capability, faster and faster speed and more and more stability at the beginning and the end of the stroke.

The first scissor platforms have been built around 1950 by the Jervis B. Webb Corporation [1], although improvements have been made in materials and safety, since then, the basic design is still often used. The concept is ideally suited, since it offers portability and efficiency. Moreover, those industrial platforms retracts to the smallest possible size when they are completely closed. In its first application it has been driven by a hydraulic system and it has had a simple structure. Later, a scissors lifting table has been proposed with a screw drive that has been placed at the bottom of scissors lifting table. The horizontal configuration of the actuation mechanism for lifting requires a high driving force, since the direction of the actuation force is perpendicular to the load direction that is difficult to be provided mechanically. The successive researches have studied the kind of the actuation mechanisms to lift the platform by trying to solve the main problems due to the forces developed in the system, the no constant speed during the vertical movement and the need of electric motors with high power and performance in according to the applied loads.

The evolution of the main actuation kinds used in the scissors lifting tables, briefly shown in Fig. 1, underlines that the most advanced kinds of drives are the push chains, the spiral lifters and the flat belts when considering the advantages and disadvantages in comparison with the previous actuation mechanisms.

The push chain uses a particular chain that is guided to move vertically by a specific linear actuator, that is connected by joints to the electric motor; in this way it forms a rigid column along which the load to lift is directed. It is one of the most innovative products and it is still subject to research in order to improve its performances, since two chains are needed to stabilize the platform [2], [3].

The spiral lifter is a linear actuator that uses a particular spiral motion to form a rigid column able to lift heavy loads. This mechanism is maintenance-free, but it turns out to be quite expensive and it is not recommended for applications with a high utilization factor [4]-[6].

The flat belts exploit their elastic properties and are suitably wrapped between the arms of the scissor lift to the operating tension. The tension is regulate by a suitable winder shaft on which the belt is fixed, it allows to open or to close the scissors with the consequent vertical movement of the platform. The mechanism has a constant speed of the load, it uses a reduced power, but it requires a high number of safety devices to prevent the uncontrolled fall of the platform [7]-[9]. The main advantages of flat belts' actuation are its cost that is lower than any kind of actuator, and its easy maintenance in case of failure. Those advantages have addressed the design towards a new lifting table driven by flat belts in this work.

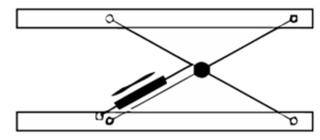
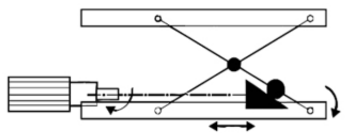
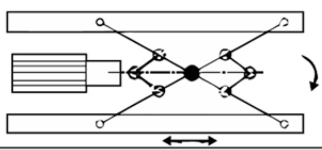
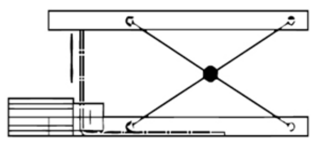
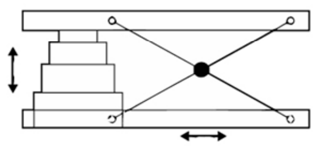
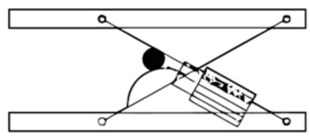
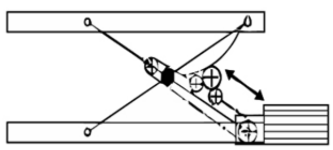
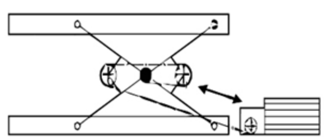
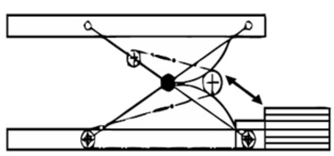
Description	Picture of table	Advantages	Disadvantages
Hydraulic scissor lifting table		- simple design	- needs oil -piston sealing needs maintenance - no constant level
1st ball screw table		- constant level - no oil	- complicated design - high forces in the lifting system
2nd ball screw table		- reduced forces in lifting system	- speed is “not constant” - large amount of bearings
Advanced “push chain” table		- advanced chain with reduced wear out - constant speed	- at least 2 chains necessary to stabilize the platform
1st spiral lifter		- constant speed - direct carried load	- at least 2 cylinders necessary to stabilize the platform
1st ball screw table with cam		- constant speed - less power required - small geared motor	- ball screw needs maintenance - high inner forces because of cantilever situation
1st timing belt table		- constant speed - low maintenance - less power required	- high inner load because of cantilever situation
Different solutions in flat belt design		none	- no constant speed - more power required - safety against breakage < 6
Advanced flat belt table additional deflection pulley “at scissor leg”		- constant speed - low maintenance - less power required - low inner forces - safety against breakage > 8	- none

Fig. 1. Evolution of main actuation mechanisms for scissors lifting tables (courtesy [1])

The present work has focused on the design of a belt drive scissor lifting table to be install on platforms, called skillet, that constitute a typical line of handling on which the operator can stay and proceed to assembly, in order to replace two commercial lifting tables in use with a device capable to satisfy new functional requirements. The adopted design approach uses a concurrent logic that aims to identify any critical aspect from the view's point of motion and mechanical strength, in order to anticipate any issues [10]-[12]. It has involved two steps: a dynamic motion analysis and a structural analysis. It has allowed to design a profile of the cam and, more generally, a lifting table that meets all the table functional requirements.

The paper is organized as follows: in Sec. 2, the case study and the methodology to design a belt drive scissor lifting table capable to satisfy new functional requirements are presented. In Sec. 3, the dynamic motion analysis is described in detail and the derived design choices are presented. In Sec. 4, the structural analysis is described in detail. In Sec. 5, the results of analysis are discussed and the new belt drive scissor lifting table is presented.

II. Case Study and Design Methodology

In a typical production plant, it is possible to observe, along the line of handling, the platforms on which the operator can stay and proceed to assembly, with times established by the product manufacturing. Those platforms are called skillet and, thanks to their versatility and modularity, they may be used in different quantities according to the production rate. A skillet has a tubular structure that supports any elements needed to move the platform and to make the operator able to carry out properly the assembly operations. Fig. 2a and Fig. 2b show the handling line with men at work and a CAD model of the lifting table that permits to lift car chassis.

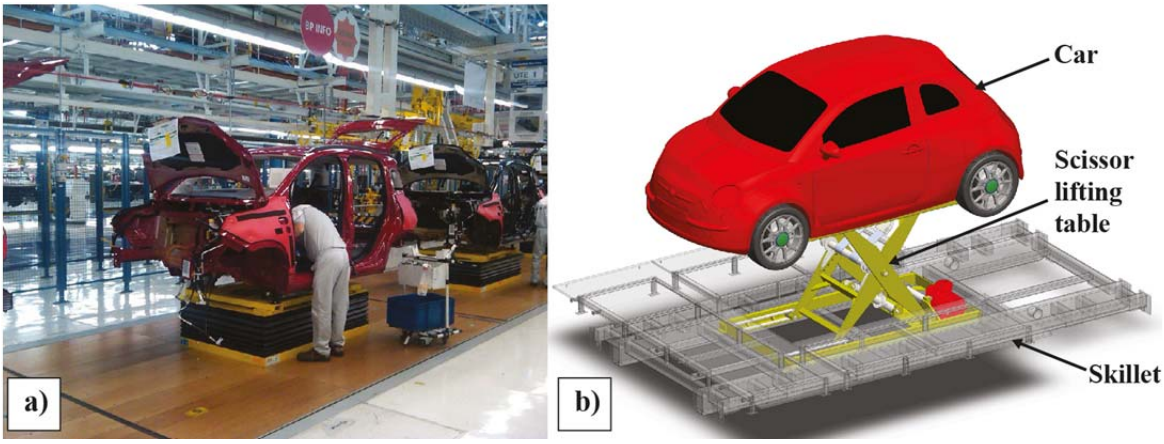


Fig. 2. Handling line: a) Men at work; b) CAD model of the scissor lifting table

The aim of this work is to design a new lifting table with the cheapest actuation commercially available, simple and able to respond to the functional requirements, in order to replace two commercial lifting tables actually in use on the skillets along the handling line. The main characteristics of two commercial lifting tables and the functional requirements of new table are shown in Table 1.

Two commercial lifting tables are PRO HUB-Hebetechnik products [13] and they are made up, as shown in Fig. 3a, mainly of a top frame, a bottom frame, a scissors mechanism, flat belts, a horizontal anti-fall device and a spreader element with a double scissors mechanism, power unit. Two commercial products are similar into the structural design but are different in terms of encumbrance, lifting time, maximum stroke, height of close table, as shown in Table 1.

TABLE I
Functional requirements of the scissor lifting table

Functional requirement	1st commercial lifting table used [13]	2nd commercial lifting table used [13]	Aims for new lifting table
Carrying capacity	1000 kg	1000 kg	100 kg
Height of close table	290 mm	360 mm	< 340 mm
Stroke	350/420 mm	700/800 mm	1000 mm
Table encumbrance	1700x1100 mm^2	2100 x 1200 mm^2	2100 x 1200 mm^2
Lifting time	6 s	11 s	< 15 s
Weight	950 kg	970 kg	< 1200 kg
Engine power	1.1.kW	1.1 kW	< 1.5 kW
Assembly rate	20 p/h	20 p/h	20 p/h

In order to design a lifting table capable to meet the new functional requirements required, a design methodology, shown in Fig. 4, has been followed to achieve those requirements. The design methodology foresees the parts modelling, the dynamic motion analysis and the structural analysis of the lifting table. After each analysis, there is a check to verify the achievement of the functional requirement.

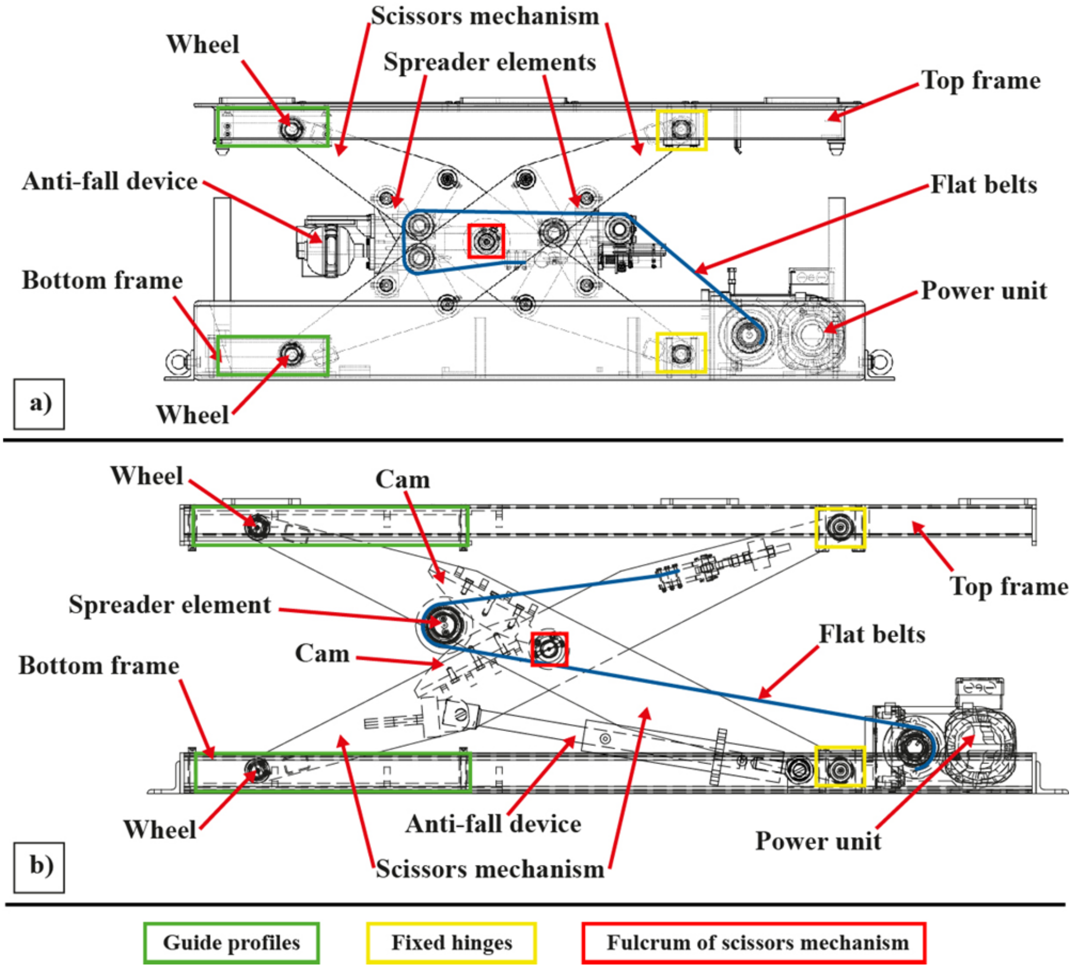


Fig. 3. Scissor lifting tables: a) commercial lifting table, b) new lifting table

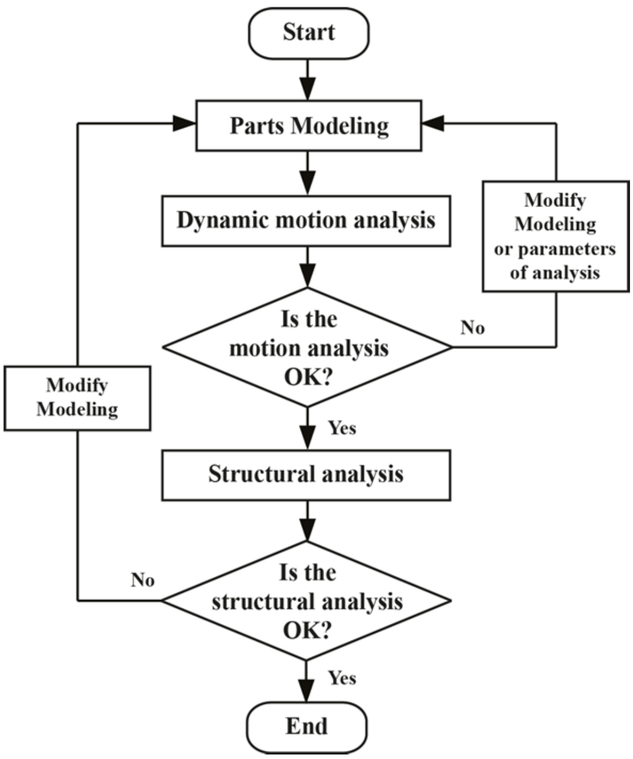


Fig. 4. Design methodology

The first modelling of the parts forming the lifting table has been carried out starting from the parts' dimensions of the second commercial lifting table because it has the same encumbrance dimensions of new table and has to provide the same carrying capacity. To provide a greater stroke, the scissors mechanism has been extended and re-designed. To realize a lifting table constructively simple and economic, offering the functional requirements, it was decided to use a belt drive to move the scissors mechanism on which four cams are installed. The first representative modelling of the new lifting table is shown in Fig. 3b.

III. Dynamic Motion Analysis

The motion analysis has been performed by means of SolidWorks Motion that uses the assembly mates along with part contacts and a physics-based solver to accurately determine the physical movements of an assembly under load. It allows to carry out two types of motion analysis, kinematic and dynamic. Kinematic analysis studies how the part moves due to forces and motions drivers applied to the assembly. The key results of interest are the assembly range of motion, velocity and accelerations. Dynamic motion analysis evaluates the forces generated by movement, as well as the movement itself.

The package of dynamic motion analysis has a limit, since it is not able to manage opened flexible elements that wrap on a system of fixed or mobile pulleys. To overcome this limit, all simulations have been carried out by considering the flexible belt element as a rigid element and only a fixed pulley (winding shaft driven by the power unit). In this way the designed case, shown in Fig. 5a, is different from the simulated case of Fig. 5b. In the simulated case, the belt is not wrapped because it is a rigid element; therefore, it is connected at one end to the spreader element and at the other to the winding shaft that takes the rotary motion from the power unit. The connection with the winding shaft is the type rack-pinion, where the belt is the rack and the shaft is the pinion. In this way the belt is able to pull the spreader element allowing the opening of the lifting table.

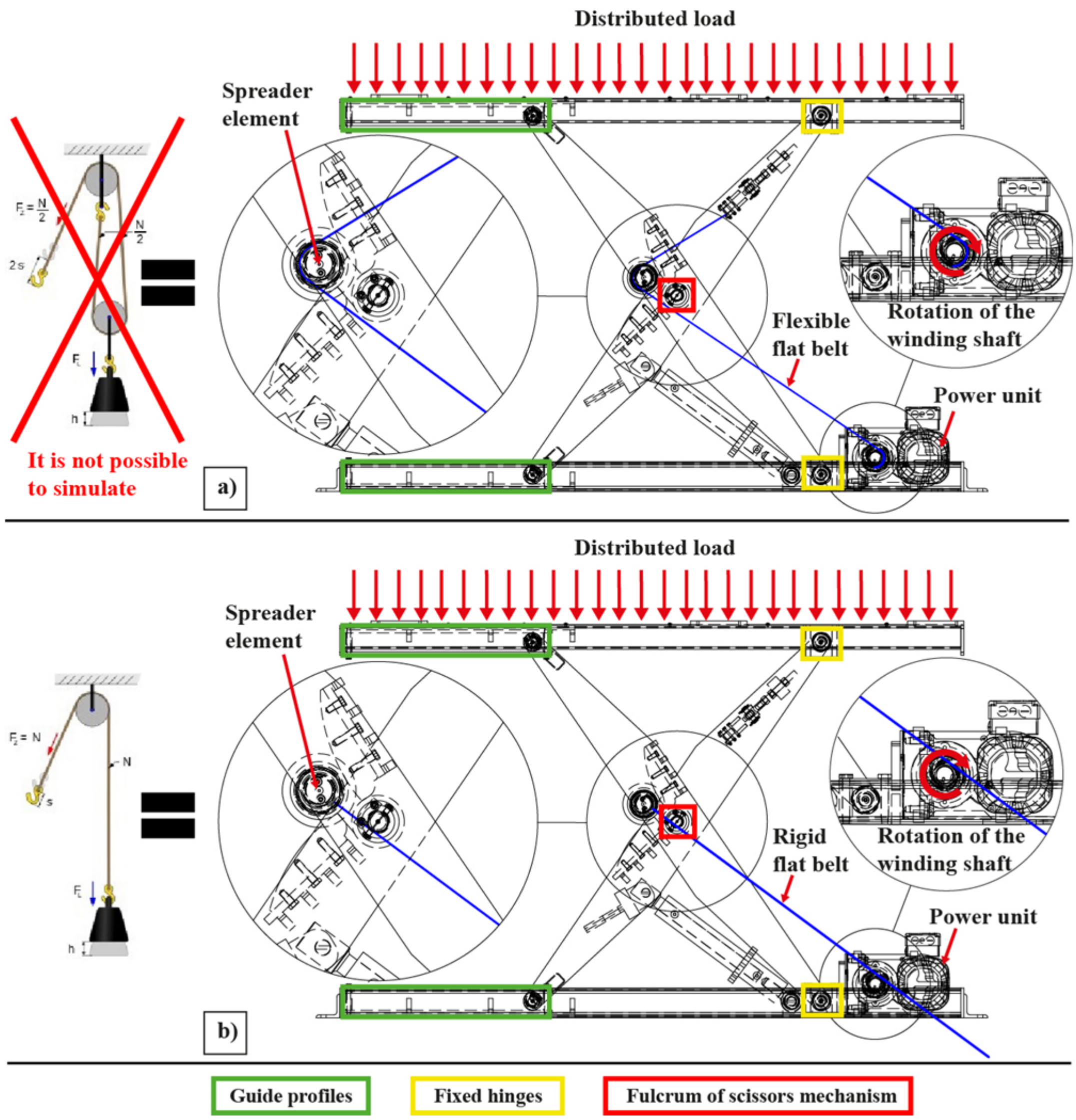


Fig. 5. Scissor lifting table: a) the design case, b) the simulated case

In order to apply this simplification, it was necessary to perform all the simulations with a number of revolutions of the winding shaft equal to half of those that are specified and carried out by the engine. In this way, the load is lifted of the same quantity as if it were simulated the design case.

The simulations have been carried out by starting from the closed table configuration (height of 320 mm) with a distributed load of 1000 kg, with a rotation speed of the winding shaft of 14 rev/min and without considering the presence of friction in the fixed hinges, in the fulcrum of scissors mechanism, between the wheels and guide profiles, between cams and the spreader element and between the different bodies in contact generally (see Fig. 5).

The belt drive scissor lifting table involves the use of non-symmetrical cams installed on both arms of the scissors. The cam profile has been designed by means of an iterative approach that has been carried out through the package SolidWorks Motion. The results of this approach are shown in Fig. 6. The cam profile that assures a low and constant power to lift, whose maximum value does not exceed 1150 W, is shown in Fig. 6c. Moreover the cam profile provides a constant speed to lift, whose maximum value does not exceed 88 mm/s, see Fig. 7a, thereby cancelling accelerations, see Fig. 7b, which would cause the rise of dynamic loads. The cam profile assures a simulation time of 11.70 s that is the actual time the lifting table employs to reach the height of 1320 mm.

The results, due to dynamic motion ideal analysis, do not take into account the frictions. Therefore, the motor to lift the table should provide a power higher than that of ideal analysis (equal to 1.15 kW), it should be probably next to 1.5 kW.

With the motion analysis has been possible to evaluate the strength to pull the belt for lifting the distributed load, as shown in Fig. 7c. Knowledge of the force value has allowed to dimension the belts required to lift the table; two flat belts with a width of 120 mm and a thickness of 3 mm are required to lift a load of 1000 kg [14].

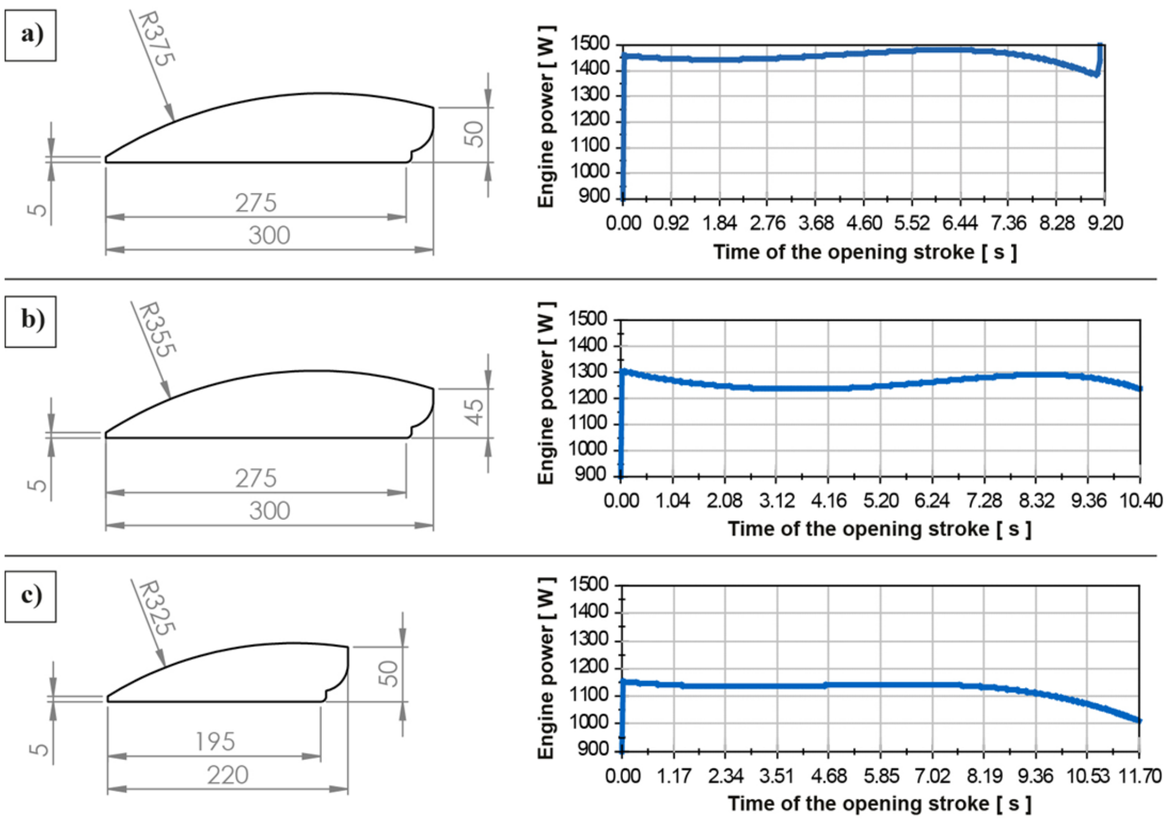


Fig. 6. Results of the iterative approach to design the cam profile

IV. STRUCTURAL ANALYSIS

A static analysis has been carried out. The material of the lifting table is the structural steel Fe430C and each part has been processed as a deformable solid body; only the sliding wheels have been considered rigid and non-deformable, since they have to transfer the weight on the bottom frame. The structural analysis has been carried out considering both the open lifting table and the close lifting table. For these two configurations the structure of lifting table has been considered as a rigid structure and not as a mechanism, this means that the parts of lifting table have been considered as bodies joined to each other rigidly.

The loads have been applied to the table as shown in Fig. 8. The nominal load (1000 kg) has been increased by 40% and applied on the top frame uniformly; the lateral load, equal to 10% of the nominal load, has been applied according to the reference standard EN 1570 [15]. The re-action force of the safety system, called the anti-fall device, has been considered; it varies depending on the stroke of the lifting table as shown in Fig. 7d. In fact, when the table is fully open, the security system exerts a very low force (of about 20 kN) on the structure, because of its favourable position; on the contrary when the table is closed, the system exerts a very high force (of about 100 kN). A load of 100 kN to simulate the re-action of the anti-fall device has been applied to the close lifting table, while a load of 60 kN has been applied to the open table. To carry out the structural analysis CAD-embedded SolidWorks® Simulation has been used.

The results of the structural analysis have been the equivalent stress, the displacements and the safety factors, as shown in Fig. 9 and in Fig. 10. The safety factors have been calculated as the ratio between the obtained values of the stress and the yield strength or the ultimate strength resulting by a tensile test on the material constituting the part.

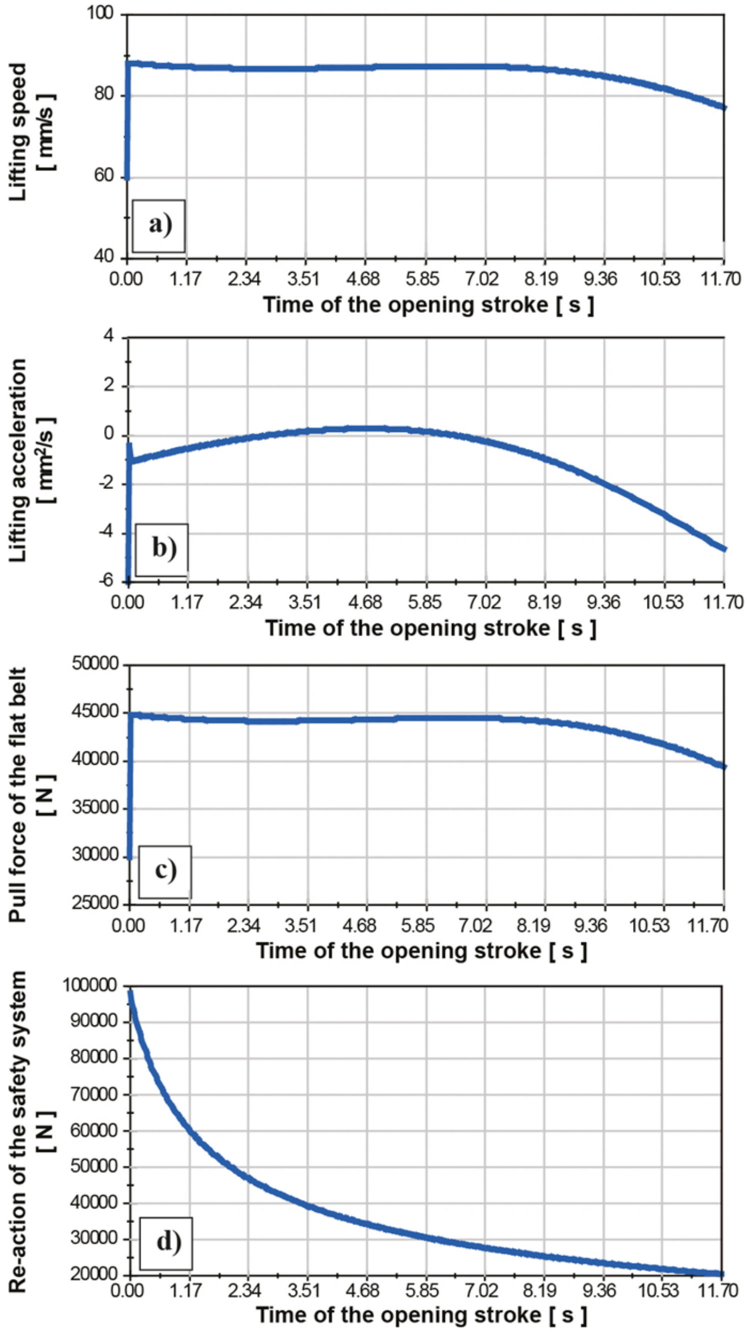


Fig. 7. Results of dynamic motion analysis

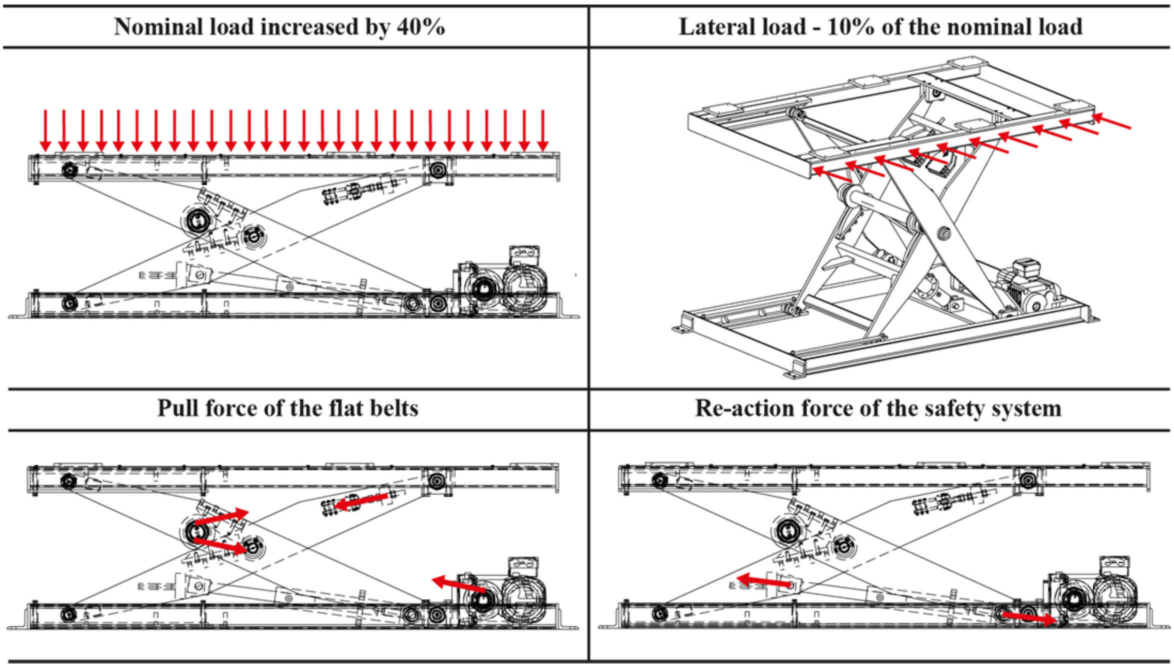


Fig. 8. Loads applied to the scissor lifting table in the structural analysis

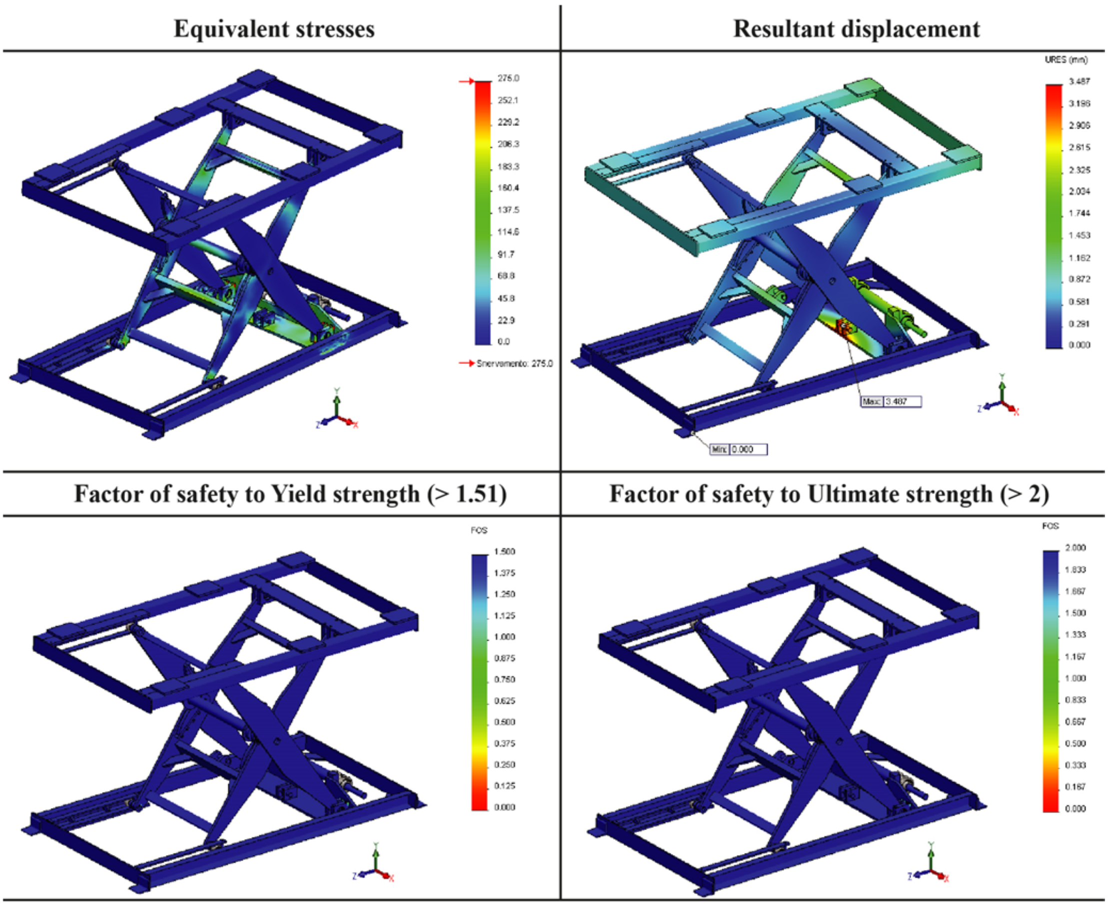


Fig. 9. Results of structural analysis for the open lifting table

It has been possible to detect the stress value point by point, by means of the probe tool, and the trend has been detected by means of a scale with maximum limit equal to the yield stress (275 MPa). The reached maximum value of stress has been 130 MPa and 200 MPa for open and close lifting table respectively. The reached maximum value of the resultant displacement has been of 3.487 mm and 2.851 mm for open and close lifting table respectively. The most stressed area is where the safety device is connected.

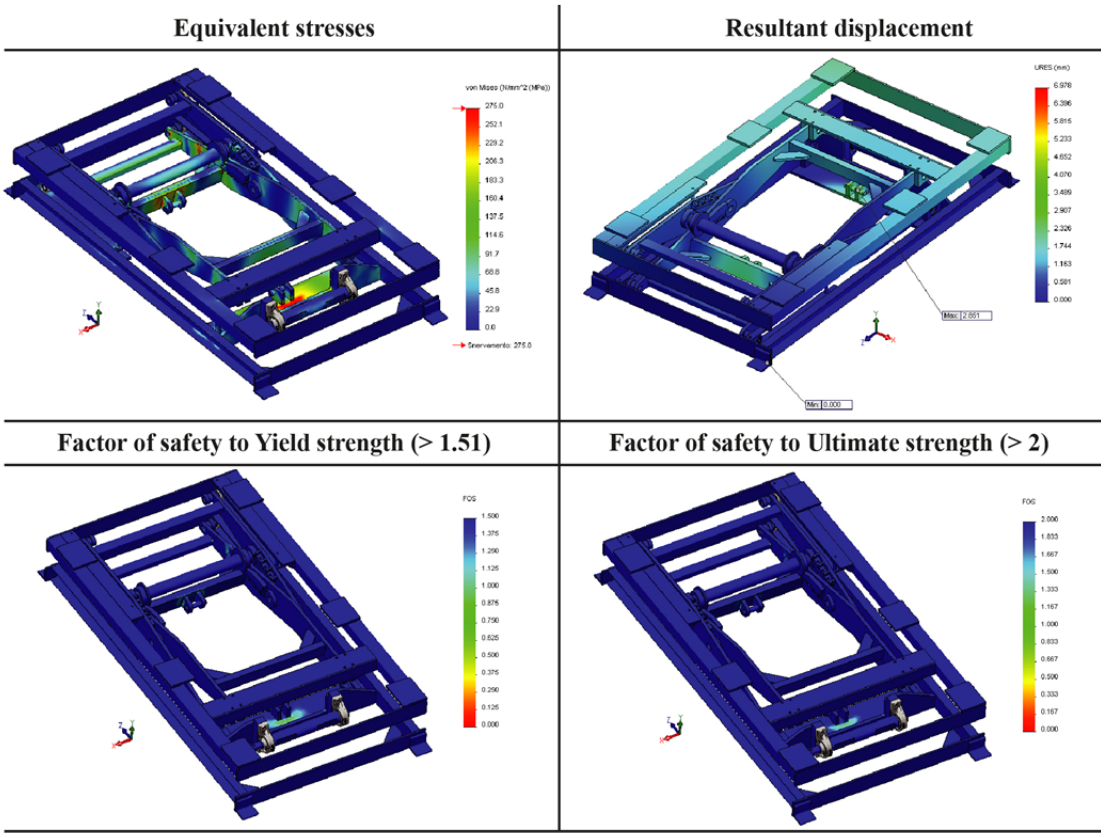


Fig. 10. Results of structural analysis for the close lifting table

The results show that the applied stress is much lower than the yield strength of the material, the deformation of the structure is negligible and the safety factors required by the standard have been evaluated both for the open lifting table and for the close lifting table. In fact, the standard EN 1570 [15] defines that in normal operating conditions, the stresses should not exceed 0.66 times the yield strength and 0.50 times the ultimate strength of the material used in any part of the lifting table.

V. Design Result: A New Belt Drive Scissor Lifting Table

The design result has been a lifting table constituted by five macro-parts: the top frame, the bottom frame, the scissors, the cams and the safety system, as shown in Fig. 11a.

The top frame, considering new encumbrance described in Table 1, consists of two tubular with a section of 80x80 mm^2 and two plates welded together, six plates to mount the car chassis, one plate to connect the fixed hinges and two guide flat profiles to make the wheels of the arms to slide on the scissor.

The bottom frame consists of two C-profiles and two plates welded together, a crossbar to connect the electric motor and the winding shaft of the flat belts, one plate to connect the fixed hinges and two guide flat profiles to make the wheels of the arms to slide on the scissor.

The scissors are constituted by a pair of internal arms, whose length is equal to 1610 mm that are welded together through some rectangular crossbars of length equal to 690 mm; a pair of external arms that are joined by a single rectangular crossbar of length equal to 800 mm. The scissors are achieved by keeping together the arms with bushings and pins that are placed in the central holes of the arms.

The movement of the table is ensured by opening of the scissor system. This system can be opened by the spreader element which slides on the cams installed on the scissors by the action of the flat belts, as shown in Fig. 11b. The cam profile was obtained by dynamic simulations and allows to better manage the parameters of the lifting table, such as power, lifting speed, acceleration, as deeply described previously. The platform is equipped with a safety device (an anti-fall device), which prevents the fall of the top frame in case of failure. It is a piston-cylinder system that is used in case of failure of the electric motor and of breakage of the belts in order to exert the pressure required to lock the platform avoiding the uncontrolled fall. The lifting table also presents many electromechanical limit switches that have the task of controlling the ascent and descent of the top frame.

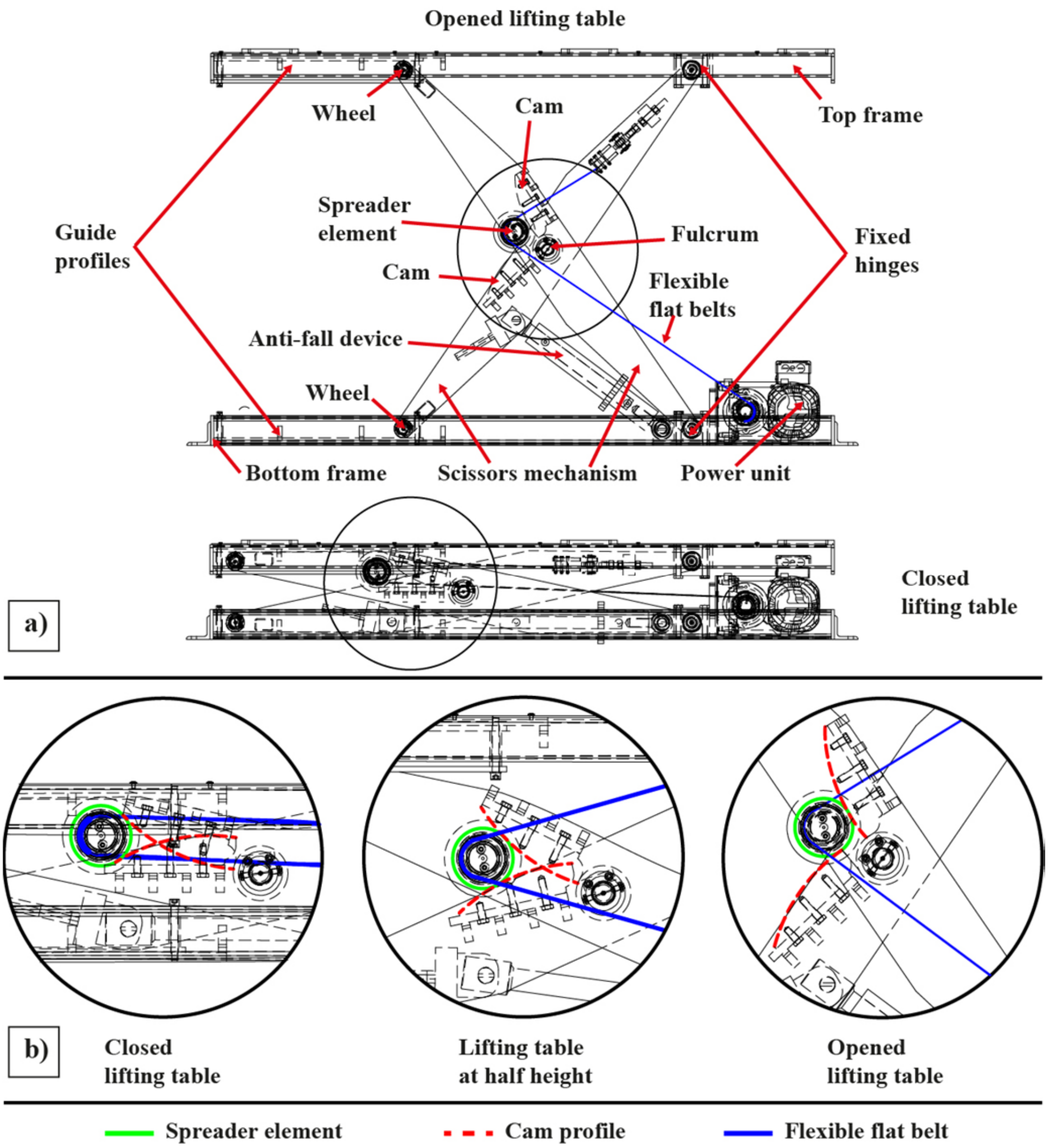


Fig. 11. a) The belt drive scissor lifting table, b) The scissor mechanism movements of the new table

VI. CONCLUSION

The present work has focused on the design of a belt drive scissor lifting table to be install on a platforms that constitutes a typical line of handling on which the operator can stay and proceed to assembly, in order to replace two commercial lifting table in use with a device capable to meet the new functional requirements required. The design result has been a lifting table constituted by five macro-parts: the top frame, the bottom frame, the scissors, the four cams and the safety system.

The motion analysis has provided the motor power and the strength to pull the belt for lifting the load without breaking. Knowledge of the force value has allowed to dimension the belts required to lift the table; two flat belts with a width of 120 mm and a thickness of 3 mm are required to lift a load of 1000 kg. Moreover, the load of 1000 kg is lifted in 11.70 s and a stroke of 1000 mm is travelled.

The structural analysis has underlined that the stress is much lower than the yield strength of the material, the deformation of the structure is negligible and the safety factors, required by the standard, are satisfied for both the open and the close lifting table. The weight of the structure is about 1100 kg, lower than the fixed limit.

The designed table uses the cheapest actuation commercially available, simple and able to answer to all functional requirements.

ACKNOWLEDGMENT

Special thanks to CIEM S.p.A. (AIDA project to bring innovation in small and medium firms of Frosinone district, Italy) for providing materials and in particular to Ms. Umberta Vizzaccaro.

REFERENCES

[1] To see a brief history of scissors lifting tables used in automotive. [Online]. Available: www.heckert-engineering.com.
[2] Linear telescopic lifting columns. [Online]. Available: www.serapid.com.
[3] P. Novack, "Column for lifting load", U.S. Patent 4,875,660, 1989.
[4] Linear telescopic actuators. [Online]. www.pacospiralift.com.
[5] P. Gagnom, and P. Laforest, "Push actuator", U.S. Patent 4,875,660, 1989.
[6] P. Laforest, "Linear actuator with releasably interlocking bands", U.S. Patent 7,213,796 B2, 2007.
[7] G. L. Coad, and J.C. Carter, "Scissor lift and drive mechnism therefor", U.S. Patent 3,875,462, 1974.
[8] G. Heckert, "Scissor-type lifting table", U.S. Patent 6,705,238B1, 2004.
[9] A. Lopez Alba, "Scissor lifting table", U.S. Patent 6,742,768 B2, 2004.
[10] T. Hongyu, and Z. Ziyi, "Design and simulation based on PRO/E for a hydraulic lift platform in scissors type", Procedia Engineering, vol. 16, pp. 772-781, 2011.
[11] H. Rashida, M. K. A. Mohd Ariffin, M. H. Mohd Noh, A.H. Abdullah, A. H. A. Hamid, M. A. Mat Jusoh, and A. Othman, "Design review of scissors lifts structure for commercial aircraft ground support equipment usign finite element analysis", Procedia Engineering, vol. 41, pp. 1696-1701, 2012.
[12] M. Walter, T. Breitsprecher, G. Gruber, and S. Wartzack, "Simulation based generation of an initial design taking into account geometric deviations and deformations", in Proceedings of the 18th International Conference on Engineering Design (ICED11). Impacting Society through Engineering Design, 2011, vol. 10, paper DS 68-10.
[13] PRO HUB-Hebetechnik GmbH. [Online]. www.pro-hub.com.
[14] Power Transmission Group, The new generation: CONTI POLYFLAT PU Flat Belts. [Online]. www.contitech.de.
[15] UNI EN 1570, Safety requirements for lifting tables-Part 1: Lifting tables serving up to two fixed landings.