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DOCTORAL THESIS

” Contributions regarding the calculation and construction of elevators in multi-storey parks”

SUMMARY

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- 2024 -

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Contents

Foreword

The research and development of solutions for constructive-functional improvement of elevators is represents the direction of the doctoral studies, completed by this doctoral thesis .

The doctoral thesis "Contributions regarding the calculation and construction of elevators in multi-storey car parks" has as its main objective, the research and development of solutions for the construction-functional improvement of the elevators these types of parking lots are being equipped with.. The theme is justified by the need to build modern parking lots, given the continuous increase in the number of vehicles in Bucharest, in relation to the relatively small number of the existing arranged parking spaces.

In this context, after completing the advanced university studies program (PPA), within the scientific research program (PCS), based on the documentation carried out and the analysis of the existing parking systems solutions, I designed the model of a double elevator, for equipping the robotic multi-storey car parks, this being the main objective of the carried out research . The proposed system, analyzed under structural, kinematic and dynamic aspects, including from the point of view of seismic demands, was achieved by making a functional model, which demonstrates the viability of the adopted solution. The scientific research activity was also valued by publishing a number of 29 works, in the volumes of some scientific events.

I express my thanks to Mr. Prof. univ.em.dr.eng.(university professor emeritus doctor engineer) Iosif TEMPEA, scientific leader, for the competent support provided, the observations, comments and proposals for improvement, formulated throughout the course of the doctoral studies. Also, I would like to thank the entire team of the Department of "Theory of Mechanisms and Robots" and especially Mr. Prof. univ.em.dr.ing.(University Professor Emeritus Doctor Engineer) Păun ANTONESCU, Dr. Eng. Prof. George ADÎR, Dr. Eng. Prof. Constantin OCNĂRESCU and Prof. Dr. Eng. Iulian TABĂRĂ, for the valuable suggestions and proposals brought during the elaboration of this doctoral thesis. I thank the management of the Doctoral School of Industrial Engineering and Robotics for the support provided. I would like to thank the academic staff from the "Constantin Brâncusi" University in Tîrgu-Jiu and the academic staff from the Department of Engineering and Management of Technological Systems (IMST) - Drobeta Turnu-Severin University Center, for the beneficial exchange of experience, permanent encouragement and trust.

Last but not least, I would like to thank my family for their understanding and support throughout the doctoral study program.

Carmen-Elisabeta Radu

Bucureşti, ...2024

Introduction

KEYWORD: robotic parking in Bucharest, the market study, the double elevator**,** the dynamics of the parking mechanism, the kinematic and kinetostatic of the parking mechanism, vibrations

The necessity, actuality and importance of the topic of the doctoral thesis

The motivation of this thesis is the research and development and study of automated parking

From recent data published in the press (hotnews.ro, etc.), it follows that the number of vehicles registered in Bucharest and Ilfov has reached almost 1.8 million. The city of Bucharest ranks 8th in the list of the most congested capitals in the world and has only 350,000 public parking spaces. This situation creates many problems for motorists who park in the capital or who cross the capital for various activities. From the Market Study, presented in chapter 2, it emerges, according to the opinion of the respondents, the need to realize as quickly as possible in Bucharest, at least one automated parking lot with as many places as possible. Due to the lack of vacant land, the optimal solution consists in the construction of multi-story parking lots, equipped with the necessary equipment to move vehicles on the different levels. The construction of robotic elevators is one of the necessary conditions for the realization of modern parking systems, corresponding to a civilized city

The objective of the doctoral thesis

The main objective of the thesis is the development of an elevator solution for equipping modern above-ground parking lots.

The research methodology is based on the application of knowledge in the field of mathematics, physics, computers and mechanics, mechanisms, resistance of materials, etc. and was realized through the following:

- Analysis of the current state of the situation, achievements and facilities in the field of road parking in the city of Bucharest and the ratio between the number of existing vehicles and the number of available parking spaces;
- Carrying out an opinion survey (market study) (https://antrepreneuroniat101.ro/model-studiu-de-piata-ghid-gratuit/), based on interviewing 107 people, car users, regarding the need, the place of location, necessary equipment for a modern, multi-storey car park in Bucharest. The obtained results were processed by the methods of mathematical statistics;
- Proposing an original solution of a double elevator for equipping a modern parking lot;
- Calculation under the structural, kinematic and dynamic aspect of the proposed elevator, taking into account at the same time the behavior of the elevator elements in case of vibrations or earthquakes,
- Realization of a functional model of the proposed elevator solution, through which its viability was highlighted.

Brief presentation of the content of the doctoral thesis

In order to achieve the main objective of research regarding **the calculation and construction of elevators in multi-storey car parks**, the doctoral work was organized in two parts:

1. – the current state;
2. - contributions regarding the proposed research field.

For this, the thesis includes an introduction and was structured in 7 chapters, to which are added a number of 3 annexes and 130 bibliographic references, in total 212 pages.
A synthetic presentation of the content of the doctoral thesis is given below.

PART ONE: THE CURRENT STAGE

Chapter 1. **ANALYSIS OF THE CONSTRUCTION AND EQUIPMENT OF THE PARKING LOT IN BUCHAREST** presents the various existing parking models in Bucharest, the advantages and disadvantages of each type of parking and the conclusions that emerge from this analysis.

PART TWO: OWN CONTRIBUTIONS

Chapter 2. MARKET STUDY REGARDING THE NEED AND POSSIBILITY OF BUILDING A ROBOTIC PARKING IN BUCHAREST presents a market study, based on which the necessity and possibility of a robotic parking in Bucharest are evaluated. A questionnaire was created, which resulted in the respondents' opinion regarding the need to build a parking lot equipped with modern elevators as quickly as possible.

Chapter 3. CONTRIBUTIONS REGARDING THE ENDOWMENT WITH ELEVATORS OF ROBOTIZED CAR PARKS presents the study from a kinematic and kinetostatic point of view, of the two main and secondary elevators, which are part of the proposed system, which we will now call the parking mechanism. The kinematic chain of the mechanism, the working mode of the elevators, the safety system adopted and the foundation of the elevator were studied. Initially, several variants of mechanisms were considered, which did not meet the requirements, due to some problems related to the stability of the elements and the possibility of blocking during operation. In a new practical approach, through comparative analyses, the version of a complex mechanism was adopted, consisting of a main elevator and an auxiliary elevator that are coupled and can be disconnected in case of need, the proposed solution representing a personal contribution. The main elevator includes a connecting rod and crank mechanism, a slide that moves in the vertical direction, and a piston that moves in the horizontal direction. The slide includes a platform at the top, on which a vehicle can park while ascending or descending to a parking floor (this parking area may have several floors, depending on the design). The piston moving in the horizontal direction is coupled with the auxiliary elevator and is positioned in a hydraulic cylinder. The auxiliary elevator consists of a translation cam that actuates a roller translation cleat, the latter supporting a platform at the top, on which a vehicle can park, during the ascent or descent to the parking floor located in this area. The parking lot served by the auxiliary elevator has only one level. Both the elements of the auxiliary elevator (cam mechanism and roller translation tach) and the component elements of the main elevator were studied. The research includes determining the important positions of the auxiliary elevator mechanism and establishing the law of displacement of the tach.

Chapter 4. RESEARCHES PERTAING TO THE BUCKLING CHECK OF ELEVATOR ELEMENTS. DIMENSIONING OF CONNECTING RODS AND BEARINGS includes the dynamic study of the parking mechanism, with reference to the component elements of the two elevators (cam follower, translation cam, connecting rods, bearings). The stresses to which the elements that make up the mechanism are subjected have been studied. The buckling of the rod of the roller tach that is part of the auxiliary elevator is investigated and the creation of a calculation model with one, two or four rods is studied. The calculation of the connecting rods, their buckling, the calculation of the mass of the cam was carried out and the radial sliding bearing of the translation tach roller is studied. In the case of the radial sliding bearing, the spindle gauge, the machine used (in the studied case lifting machine), the bearing and the lubrication of the bearing were taken into consideration. The material to be used for the bearing was determined and vibration issues were assessed in the case of the bearing.

Chapter 5. THE STUDY OF THE VIBRATIONS OF THE PARKING MECHANISM, presents the calculation of the elements of the mechanism from the point of view of vibrations is presented. The fundamental (smallest) natural pulsation and the other natural pulsations of the mechanism, which must be avoided in operation, are determined in order to avoid its destruction due to the resonance phenomenon. Various methods are used to determine the natural pulsations, such as the Dunkerley method, the Veresceaghin method, and the continuous system method. The influences of random vibrations (seismic or explosive) on the system are investigated, as well as the vibrations of the translation cam and the piston, these elements being considered as an assembly.

Chapter 6. CONCLUSIONS, ORIGINAL CONTRIBUTIONS, PROSPECTS FOR FUTURE DEVELOPMENT AND DISSEMINATION OF RESULTS includes some general conclusions drawn from the research carried out and the main original theoretical and applied contributions made by the author. The prospects for future development and mastering of the research carried out are also presented.

Chapter 7. BIBLIOGRAPHY presents the main sources of inspiration used for the realization of this doctoral thesis: research contracts, patents, scientific articles, monographs and last but not least, internet pages. It adapts to the final content of the bibliography, excluding the sources that were not used: patents, contracts, etc.

PART ONE: THE CURRENT STAGE

1 ANALYSIS OF THE CONSTRUCTION AND EQUIPMENT OF THE PARKING LOT IN BUCHAREST

1.1. Number of existing vehicles in Bucharest

In the modern world, transport is an essential element for the smooth running of economic and social activities. It is therefore neccessary to carry out a study related to the possibility of building various types of parking lots, depending on space, capacity, existing technology and financial possibilities.

From the point of view of road transport, the problems impacting Bucharest are related to pollution, the large number of vehicles circulating in the city, the low number of parking lots and the location of these parking lots in hard-to-reach areas in relation to major boulevards, job location and citizens' homes. [1]

According to data published in the press, in 2018 and 2020 the number of cars registered in Bucharest was 1106000, respectively 1151554. In 2021, Romania had 1174941 public parking spaces, compared to 1154082 spaces in 2020. With a tolerance of 10% related to the accuracy rate of municipalities' responses, the total number of parking spaces reached 1292435.

Taking into account the possibilities, the time required for documentation and execution, as well as the price, several types of parking can be considered that can be executed in Bucharest, in the Dâmbovița quay area. [2], [3], [5].

1.2. Types of parkings that can be made in Bucharest

Taking into account the possibilities, the time required for the documentation, the execution as well as the price, several types of parking can be considered that can be executed in Bucharest, in the Dâmboviței quay area.

The parking lots that can be made in Bucharest include the following types:

a) simple parkings, which can be achieved with relatively small investments compared to other types but which occupy large areas

b) multi-storey car park of the format (gf+1), thus doubling the number of parking spaces compared to the variant presented in point a). For the movement of vehicles in the area of the first floor and for their descent, an inclined plane connected to the actual building of the parking lot is used [6]

c) electrically operated parking for relatively small and narrow spaces similar to the elevator used in the case of car services and which includes parking spaces on the ground floor and on the first floor. The command of the drive motor of this parking platform can be done with the help of a card. [11]

d) the parking lot with robotic electric drive for many vehicles, made as a mechatronic system and which presents a higher efficiency than the previously presented systems from several points of view (it can be made in a closed or partially closed space, with several by an elevator or several elevators controlled by an application installed on a computer). The main problems in this case are the space required for such a construction (footprint) and the large sums for investments, with a long return period [8].

All these types of parking are presented in this work.

1.3. Parking lot with robotic operation

The achievement of the previously presented parkings involve certain absolutely necessary conditions , which are not always easy to combine. Therefore, the existence of large areas for the location of these parking lots is required, a fact that leads to the reduction of green spaces, of urban traffic areas and the possibility of using these areas for other purposes or the possibility of using limited areas as an area only for a small number of vehicles and for a reduced total mass of them, below 2000 kg.

The previously mentioned elements can be solved by using robotic parking lots, controlled with the help of applications. In this situation, a mechatronic system for industrial environments is used that can be applied in situations where multi-level parking is required, shown in figures 1, 2 and 3. [23].

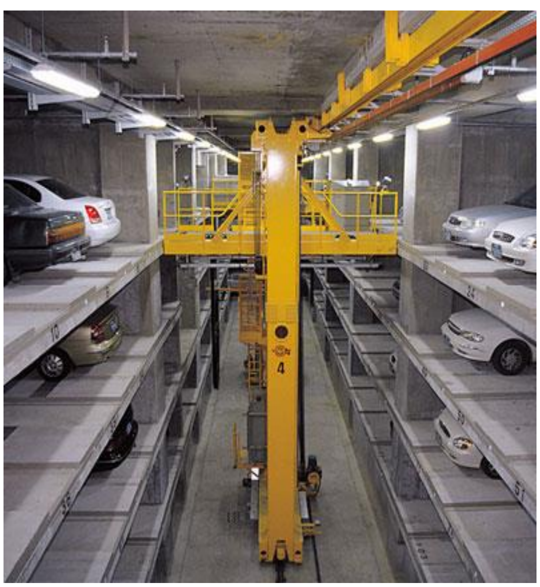

Fig. 1. Robotic parking

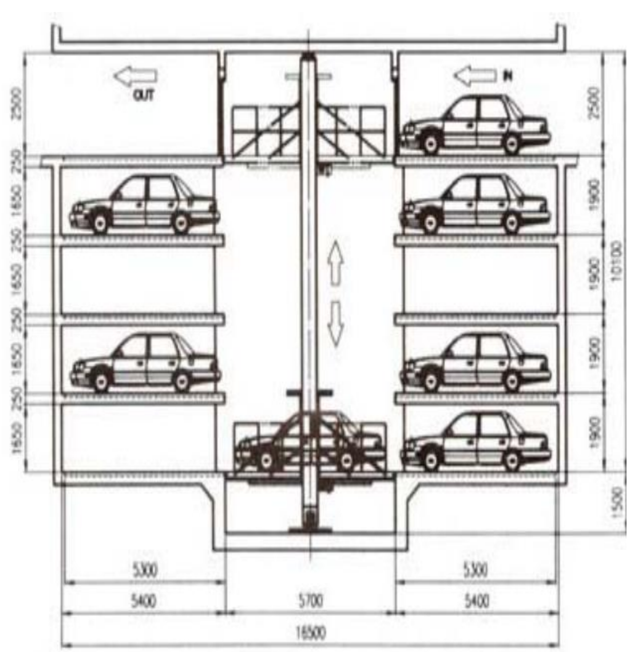

Fig. 2. Robotic parking. Operation

Fig. **3.** Moving a vehicle vertically by the elevator inside the parking lot

The mechatronic system includes in this case [36]:

- Telemonitoring and Telecontrol Center – includes a computer with telecontrol and telemonitoring software robot and router connected to the Internet
- The mechatronic subsystem – cyberspace – the control panel and soft robot, the intelligent remote control equipment, the modem and the antenna. It is linked to the Ethernet network of the respective facility
- The industrial robot – robot that includes the vehicle manipulators, the control unit, electrical connections and the interface with the computer system.

When a subscribed vehicle enters the parking lot, the subscription is read, it is validated, and thus the PC makes a connection between the parking space of the owner, who has the paid parking space, and the need to move the vehicle to that place. The robot loads the car into the elevator, the command is given to move the elevator in which the car is loaded and according to the existing data in the database, the car will be raised to height h, length L at the level of the garage and floor j. At that moment, the robot takes the car from the elevator and parks it in the designated place. For more vehicles, more elevators must be built, and heavy and special vehicles must be parked on the ground or lower floors. After accessing the parking space, the owner of the vehicle descends with a special elevator or the vehicle is picked up from the entrance to the parking lot by the robot, without the need for the driver's intervention.

Multiparker automatic parking systems are made for 10-100 cars, built as vertical warehouses and available for public use.

In the same system is included an elevator with simultaneous vertical and horizontal movement, also having the option of rotating the car at the same time (fig.3.).

Access time to these elevators is very low and involves easy operation.

PART TWO: OWN CONTRIBUTIONS

2. MARKET STUDY REGARDING THE NEED AND THE POSSIBILITY OF BUILDING A ROBOTIC PARKING LOT IN BUCHAREST

The problems affecting capital cities are related to pollution, the large number of vehicles moving through the city, the limited number of parking spaces and the location of parking spaces in difficult-to-access areas in relation to major boulevards, offices, shops and citizens' homes

It is therefore absolutely necessary to create a parking lot that can provide as many parking spaces as possible and that can be built on a large number of levels in order to use as small a footprint as possible. [41]

The presented market study refers to the possibility of building a parking lot on a reinforced concrete floor above the Dâmbovița river. Until now that area is unused and represents a solution.

The advantages of using such an area are the following:

- The area is accessible in the city center compared to other areas for parking (Splaiului Independenţeii area). It should be noted that a ground-level parking lot can only be built on the outskirts of the city due to the lack of the necessary surfaces. Several parking lots of similar surface area can be created considering the existence of several straight portions of Splaiu - e.g. Ciurel-Pod Grozăvești, Pod Hașdeu-Pod Izvor).
- Influences surface public transport to a minimal extent, when vehicles enter and exit the parking lot
- There is immediate access to the metro stations, making it possible to move more easily to various points of the capital
- Immediate access is provided for employees who work in the Piața Unirii, Izvor, Hașdeu, Grozăvești areas
- The price of a parking space/hour may be lower compared to the current price for parking spaces located along the central streets of Bucharest.
- The price can be comparable to the one established when using the underground parking on two levels in the Bd. Decebal

Disadvantages of this robotic electric parking lot:

- Compared to a street-level parking lot, this solution involves research, an anti-seismic resistance study, a feasibility study and a high budget compared to a ground-level parking lot.
- The parking lot will be designed and built by a team of specialists from various institutes of mechanical engineering, architecture and construction, requiring certain materials and special technologies and may involve high execution costs.

The market study presents the social target groups [42] to which the research related to the presented parking lot is addressed, the social questionnaire, the analysis of technical risks in the course of conducting the research and the effects of the research on the community (the

purpose of the research, the objectives of the research and the results obtained as a result of the conducted research .).
The graphs of the answers to each question and the SWOT analysis are found as a conclusion of the Market Study.

2.1. Research goals

The doctoral thesis "**Contributions regarding the calculation and construction of elevators in multi-storey parking lots**" has the following main goals (Op):

- **Op$_1$**: Establishing constructive-functional improvement solutions for the elevators in multi-storey parking lots, which will contribute to the improvement of transport in Bucharest;
- **Op$_2$**: The development of an original model of a double elevator for equipping robotic multi-storey parking lots, based on the documentation and analysis of existing parking system solutions;
- **Op$_3$**: The realization of a functional model of the parking mechanism, consisting of the two coupled elevators, which proves the feasibility of the proposed model.

In order to achieve the main goals, deriving from the research and development theme of the doctoral program, the following secondary goals were formulated (**Os**):

- **Os$_1$:** The elimination of parking on sidewalks and on both directions of the streets through parking management, with the aim of increasing road safety and ensuring better visibility while in motion;
- **Os$_2$:** Reducing the need to use cars, with the aim of decongesting traffic and reducing pollution;
- **Os$_3$:** The possibility of easy access to certain places for emergency vehicles (rescue, firemen, police, etc.);
- **Os$_4$:** Comparative analysis regarding the possibilities of executing the various parking models, in the areas not used until now;
- **Os$_5$:** Critical analysis of existing parking types in Bucharest and the selection of modern solutions that meet the current needs regarding parking spaces;
- **Os$_6$:** The analysis of the efficiency of the design and execution of the intelligent parking lot equipped with an elevator;
- **Os7:** The execution of a market study regarding the need for the development of parking lots in Bucharest, the placement of new parking lots and their equipment with the help of modern tele-monitoring and remote control systems and the adopted parking model;
- **Os8:** The execution of the calculation under the structural, kinematic and dynamic aspects of the proposed elevator;
- **Os9**: The analysis of the vibration and earthquake behaviour of the elevator elements;
- **Os10**: The possibility of upgrading other existing parking lots by using the secondary elevator.

The main and secondary goals have been achieved by:

- Documentary research of the current state of construction and parking facilities;
- The execution, in its own conception, of a market study, based on an enquiry regarding the necessity of building a parking lot with modern facilities in the centre of Bucharest, to which 107 people answered;

- The proposal for the first execution of a robotic parking lot in Bucharest, which uses modern technology, involving studies regarding:
  - the space on which the parking lot is placed;
  - the connection between this space and the environment;
  - the mechanism with which the researched parking lot can be equipped and its driving system;
  - the elements of the mechanism;
  - the possibility of creating multi-storey, the maximum number of vehicles that can be parked, their dimensions and size;
  - the electrical installation of the parking lot, including the generating set with which it must be equipped and the photovoltaic cells;
  - the financial analysis of the possibilities of executing the parking lot;
  - parking lot reliability;
  - the analysis of potential problems that may occur during the use;
- The analysis of constructive versions of the parking lot's mechanism, as well as methods for its improvement;
- Validating the model of the double elevator by executing a functional replica

3. CONTRIBUTIONS REGARDING THE ENDOWMENT WITH ELEVATORS OF ROBOTIZED CAR PARKS

3.1. Mechanisms of the main and the auxiliary elevators

The work presents the possibility of creating a modern, mechatronic parking lot, which includes as many automated systems as possible and which helps achieving as many utilities as possible. This project considers:

1. The presence of as many seats as possible, on several levels in relation to the positioning of the lot in the central area of the city and for using a reduced footprint

2. The possibility for these parking spaces to be used by various vehicles (cars, vans, motorcycles, bicycles, small special vehicles)

3. Access and exit as easy as possible in and out of the parking lot to avoid road traffic jams

4. The possibility for two or more cars getting out of the parking, under special circumstances, without blocking the parking lot or removing other vehicles from the parking lot. To this end, the parking lot will be equipped with a robot that moves on a narrow rail, outside the parking lot, on a circular or elliptical trajectory, having the possibility of raising a vehicle to the maximum height of the parking lot, or lowering a vehicle to the ground.

5. Equipping the parking lot with a generator to avoid blocking the parking lot in the event of voltage drops and equipping it with photoelectric cells for power

6. Equipping the parking lot with a main elevator but also with an auxiliary elevator equipped with a reduced number of seats, coupled with the main one, for special situations. (for example all the places in the main parking lot are occupied and there are still requests, there are requests for short periods of time or there are requests for disabled people, for police cars, for

other small special vehicles for short periods of time). The auxiliary elevator will be executed as a system of translating cam-translating tappet with roller and will be able to be disconnected from the main elevator if its momentary use is not required. The distance between the two elevators will be determined according to the size of the platform on which the parking lot will be located

7. The possibility of placing a main elevator in a parking lot that is not currently equipped with an elevator

8. The two elevators will be placed on a rubber carpet to dampen the vibrations that occur during operation

Analyzing all the parking models presented in chapter 1 and all the elements that are considered, it can be concluded that the most cost-effective solution is the robotic parking that includes all the advantages presented above. The only disadvantages that can be taken into account are the high price compared to the other analyzed models and the relatively high time required for the execution of such a parking lot.

Therefore, all elements necessary for the execution of such a parking lot, which will be presented in the following chapters, are taken into account.

3.2. The adopted mechanism

In order to meet all the above mentioned requirements, an initial approach was to carry out a project that does not meet the requirements [48], [49], [50], [51]. The problems that occured during operation were the following:

- This mechanism included a piston cylinder that was not tied to the ground and was subject to vibrations during operation, these phenomena being able to lead to deformations or breakage of pipes or other elements within the hydraulic system after a certain period of use;
- The cylinder describes a balanced oscillatory movement, and the translating cam an oscillatory rectilinear movement, and their composition results in a variable stress that overworks the joint between the two elements after a variable cycle;
- Taking into account the fact that the auxiliary elevator is not in permanent use, it was considered that a cam can be used which describes a translational reciprocating movement with friction, using a lubricant between it and the guide. However, the energy consumption is too high in this case and in time the wear of the cam or the guide can increase considerably and the mechanism can get stuck during operation. In this case, much more frequent overhauls and repairs are required and consequently the maintenance costs become higher.

Evaluating all these problems, it was concluded that the following are necessary:

- Solidarization with the fixed element of the piston cylinder, to eliminate the vibrations that may occur during the operation of the piston
- Welding a rod at the end of the translating cam which should be articulated with the piston in such a way that this joint only be stressed in tension-compression, depending on the displacement of the cam
- Elimination of translational friction by using a superior rotation coupling similar to those existing in rolling mills, thus reducing the problem of wear

The mechanism shown in figure 4 resulted.

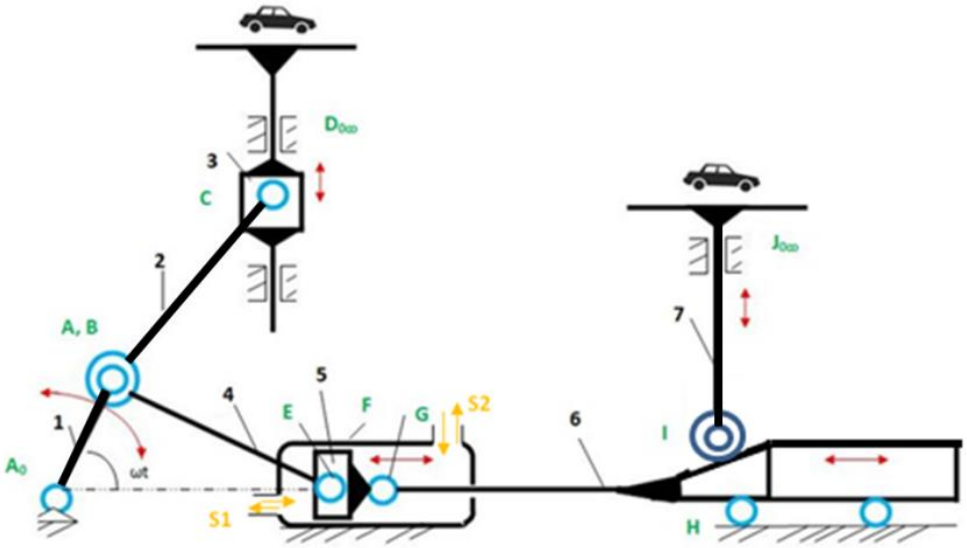

Fig.4. The mechanism of the parking lot equipped with two elevators

By the geometric arrangement of the elements and kinematic couplings of a mechanism, for a certain direction of movement, its kinematic scheme is obtained. [23]

The thesis proposes the kinematic scheme of a complex elevator consisting of the coupling of two mechanisms:

1. An articulated plane mechanism, consisting of:

   - crank (1), actuated by an electric engine, with the length $R = \frac{S}{2} = 3000$ mm

   - two dyads of the second class aspect 2, having two rotation couples R and one translation T, these being structural groups of the second class, the second order of the RRT type [16].

This mechanism can be symbolized as R-RRT-RRT, represents the **main elevator of the parking lot**.

If the electric engine that operates the crank does not work for various reasons, the function of the crank is taken over by the piston 5, the crank now becoming the driven element. As a result of the alternative translation movement of the piston 5, the element 1 becomes a rocker, oscillating around the joint A0.

The tiller 2 that actuates the slider 3, has the length L= 6000 mm

The slider 3, integral with the platform on which the vehicle driven to the parking place is parked, it can move vertically for the maximum distance h = 6 m.

The tiller 4 is identical with tiller 2.

The mass of the piston 5 is considered equal to that of the slider 3.

2. The second mechanism, with the role of **auxiliary elevator**, consists in the translation cam 6, actuating the cam roll follower 7. It supports the platform on which the vehicle actuated by the elevator is found.

The cam 6 is integral with a rod, forming an assembly that can move alternatively left - right, and the rod is coupled in (G) with the piston 5. The coupling can be disengaged when it is not necessary to use the auxiliary elevator formed by the cam 6 and the cam follower (7). The piston 5 - cylinder assembly actually represents a hydraulic engine with double action, simultaneously determining the actuation of the two elevators.

Outside the parking lot, there is an elliptical rail on which a robot circulates that can transport a vehicle from the platform of the auxiliary elevator to that of the main elevator or vice versa, at various heights, thus being able to raise or lower vehicles depending on the needs of parking places set by the application (Fig. 5)

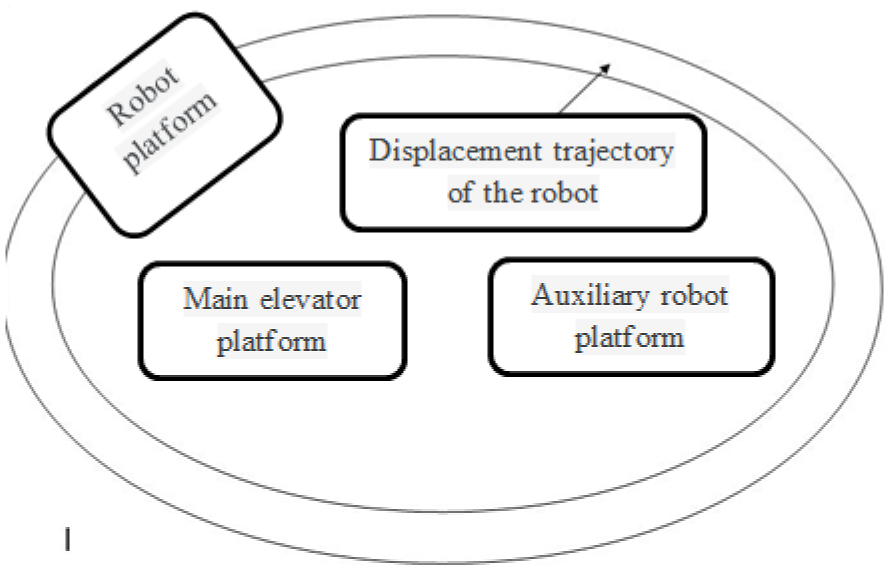

Fig. 5. The trajectory of the robot around the parking mechanism

3.3. Structural analysis of the double elevator mechanism proposed for equipping robotic parking lots

As shown above, the **mechanism of the parking lot** is a complex system consisting in two subsystems: (Fig. 4):

- Main elevator, which comes from an articulated plane kinematic chain;
- Secondary elevator, consisting in a mechanism with translation cam with translation cam roll follower.

The kinematic elements of the mechanism are: crank 1, tillers 2, 4, slider 3, rigid assembly 5-6 (consisting in piston 5 and cam 6) and cam follower 7. It results that the mechanism has m = 6 mobile elements. They are connected by 5 plane rotation couplings of the 5th class (A_0, A, B, C, E) and two translation couplings, one between the assembly piston-cam, executing a translation motion towards the fix element, with more contact zones (F = H) and another, between the cam follower and fix element (J). It results the total number of couplings of the 5th class inferior, of 5th class i = 7. The coupling between the cam and cam follower (I) is of the 4th class, s = 1. For these data, n = 6, i = 8, s = 1 according to the structural formula of plane mechanisms of the 3rd family (1.1), it results the mobility degree M = 1.

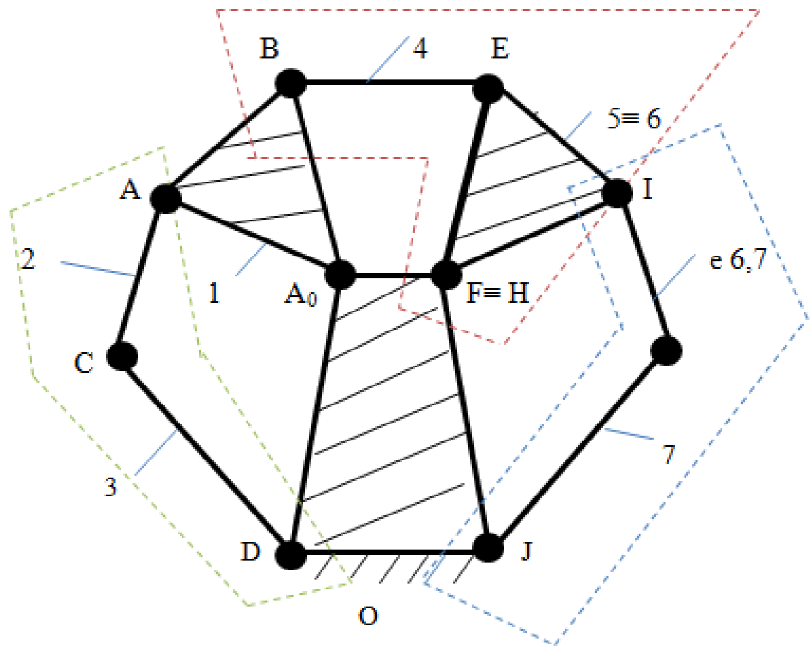

Fig. **6** The structural scheme of the mechanism of the double elevator and decomposition into kinematic groups

This means that the mechanism has a determined motion (is desmodromic) by the actuation of a single element.

The leading element is crank 1. The piston 5 actuates the mechanism only in case of need and contributes to the damping of the mechanism's movement. [37].

The Fig. 6 presents the structural scheme of the mechanism, obtained by equating the upper coupling between the cam and the cam follower, by an element and two couplings of the fifth class, according to the principles of the Science of Mechanisms. [52], [53], [54].

One of the 16 basic kinematic chains with 8 elements is obtained (Beyer, R., Technische Kinematic, Leipzig Verlag A. Barth, 1931).

The kinematic chain can be broken down into: leading element 1 (EC1) and three dyads, D (2,3), D (4,5) and D ($e_{6,7}$,7). In conclusion, the mechanism made on the basis of the studied kinematic chain is of the second class, order 2.

The number of independent cycles of the mechanism is given by the relation:

$$N = c-n, \tag{3.1}$$

n where c is the total number of kinematic couples c = i + s = 9. N = 3 is obtained. The number of independent cycles, also highlighted by the structural scheme, is of particular importance for the kinematic and kinetostatic analysis of the mechanisms, through the method of independent cycles, developed by Radu Voinea and Mihai Atanasiu. [55], [56].

3.4. The operating system of the elevators

Figure 7 shows the parking mechanism and its operation. The car arrives to the left of the main elevator at the entrance of the parking lot (1)(fig.7). After the driver had validated the access card in the parking lot, a robot with a platform (which moves in a plane perpendicular plane to the plane of the figure around the parking lot and which is not shown in figure 7.) lifts it up to a height of 3 m and deposits it on the platform of the vertical piston (2) of the main elevator. The main elevator raises it to the height corresponding to the parking place, and after that, the car is picked up again by the robot and placed on the validated parking place (in this case from fig. 7. up to the 1st floor of the main parking lot). The mechanism of the main elevator is similar to mechanism of a V-twin engine at 90 degrees.

The robot is similar to a forklift, it can lift and lower a single car from the ground floor to the top level, and it moves on a special circular or elliptical trajectory perpendicular to the drawing, so that it can serve both the main and the auxiliary lift (according figure 5.).

The solution of using a robot of this type was chosen because:

- The area where the parking lot is intended does not allow the construction of an inclined plan for the access of vehicles to several floors. If parking will be done in another area, the possibility of using other solutions, with access on an inclined plane, will also be considered;
- The robot will be able to be supplied with electricity both from the street network as well as from a generating set that must be provided, so that the phenomenon of blocking the parking lot does not occur due to the accidental lack of electricity.

The height of 3 m is chosen depending on the possibility of using these parking spaces by cars and vans that have a maximum height of approx. 2- 2.5 m and corresponds to the height of one floor of a block.

The ground floor of the parking lot is reserved for special vehicles (if absolutely necessary for the police, rescue vehicles), for motorcycles and bicycles.

When the main elevator reaches the level at which the parking space was validated by the driver, the robot takes it from the platform and deposits it in its place (in figure 8 it appears on the left side).

During the exploitation of the parking lot, certain situations may occur:

- The person wants to access a parking space only for a short period of time, without being a subscriber;
- The main parking lot is fully occupied and the person wants to access a parking space;
- The subscriber is a disabled person, who must have faster access to the vehicle. Parking spaces for disabled people will be established in this place;

- A vehicle in a breakdown must clear the roadway and must be brought into the parking lot for a short time.

For such situations, an auxiliary elevator was provided, which is connected to the main one, by means of a double-acting piston cylinder, operated by fluid through a valve system.
The car moves on a small inclined plane. The robot picks it up and places it on the tappet platform (4), after which the car is moved over the originally planned distance with the help of the cam-tappet mechanism. Then the car is taken again by the robot, picked up and deposited in the area established for the parking of these vehicles. In this area, it is considered that only one level can be created for parking.(5)

The assembly consisting of the two elevators can work both simultaneously and independently. The operation of the elevator under the action of the hydraulic element is described hereafter:

a) **Raising the two elevators**. Fluid is introduced through a valve into the compartment located to the right of the piston in the cylinder. The piston moves to the left to a certain set height and some of the fluid in the left compartment is gradually discharged through another valve. The piston moves by acting, by means of the crank connecting rod mechanism, the main elevator lifting the piston vertically. In this way, both elevators will rise simultaneously.

b) **Simultaneous lowering of the two elevators**. By introducing fluid into the left compartment and gradually evacuating the one in the right compartment up to a certain height, the two elevators will simultaneously move to the right, and thus the two platforms will simultaneously descend. The required pressures are determined according to size and needs.

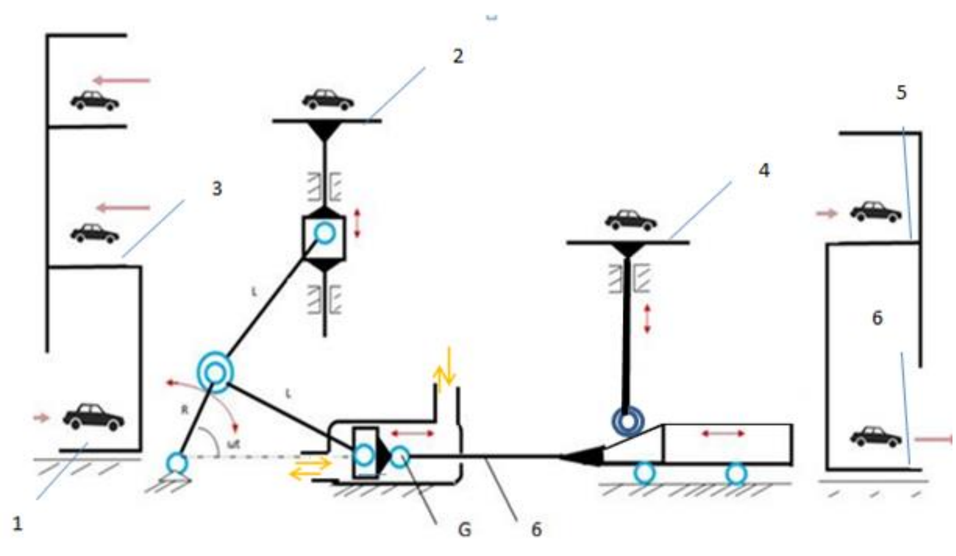

Fig. 7. Presentation of the operation mode of the parking mechanism

The movement of the main elevator will be achieved in all situations. In the event that the use of the auxiliary elevator is not required, it will be disconnected from the rest of the mechanism. To achieve this, a mechanism similar to the peripheral grasping mechanism of an industrial robot will be attached to the left end of element 6 (in joint G according to figure 8) (its kinematic diagram is shown in figure 9). [58].

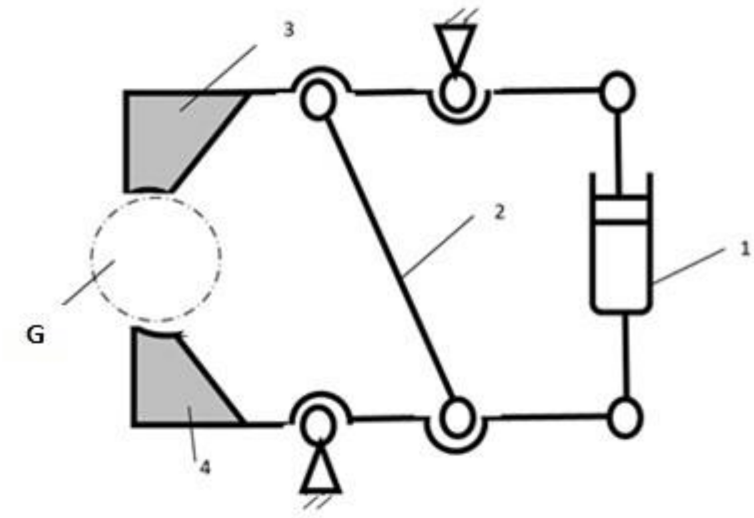

Fig. 8. The coupling-decoupling mechanism of the auxiliary elevator

In the event of the need to disengage the auxiliary elevator, it will move to the extreme right so that the platform operated by the cam is at the lower level. (see fig.7)

In the hydraulic cylinder (1) from fig.8, liquid is introduced in the upper portion so that the piston moves down. Rods (3) and (4) will release pin (5) of joint G in figure 8, thus disengaging the auxiliary elevator. If the subsequent coupling of the auxiliary elevator is necessary, the process is carried out reversing the order of the operation, introducing liquid into the lower part of the cylinder (1) in figure 8.

3.5. The safety system. The foundation of an elevator. Comparative analysis

To avoid possible accidents that may occur when using the mechanism, it is absolutely necessary that it be equipped with a safety system whose diagram is shown in figure 9. The safety system includes two completely independent components. The first component is represented by a rubber damper (I) or a set of springs placed at the bottom of the main elevator to avoid a strong shock in case of overloading the platform. The second component is a brake shoe system with electronically actuated sensors (II) that automatically blocks the elevator when the weight on the platform exceeds the permissible value, avoiding an accident.

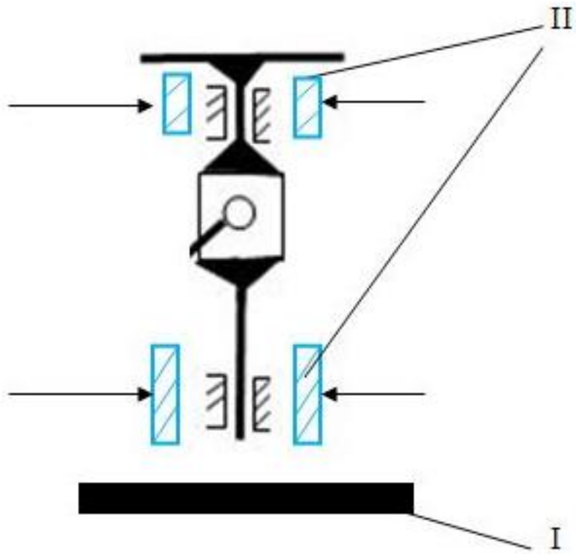

Fig.9.The safety system of the elevator

3.5.1. Elevator foundation on springs and on rubber carpet

It is considered an electric motor that operates an elevator on the platform of which a vehicle is parked. [59](pag.143, pag.368). To avoid problems related to hard shocks and vibrations produced when starting and stopping, the elevator is equipped with a safety system, which can be a spring system or a rubber shock mat. In order to be able to choose which of the two solutions is better and more cost-effective, an application made with the help of the Visual Basic program is used which takes into consideration the total mass of the electric motor, the mass of the rotor of the electric motor and its eccentricity, the speed of the motor, the percentage of the disturbing force transmitted to the foundation, the suspended mass (includes the mass of the piston and the mass of the platform) and the mass of the car existing on the platform.

According to the application made with the help of the presented Visual Basic program, the following results are obtained:

- the own pulsation imposed by adopting the reduction coefficient, the elastic constant of the suspension, the recalculated own pulsation, the arrow of the springs due to the static load, the characteristics of the used springs , the static load on a spring F, the vibration amplitude , the force in a spring due to vibration.

In the case of the foundation on the rubber mat, the modulus of elasticity of the material from which the elastic rubber mat is made and the admissible pressure on the rubber mat are taken into account, resulting in the necessary thickness of the rubber mat for achieving a static arrow identical to the one in the case of springs suspension and the area of the bearing surface.

A comparative analysis between the two systems is carried out, showing the advantages and disadvantages of each system, the data and results being presented with the help of a program in Visual Basic. The use of the rubber mat proves to be cheaper.

3.6. The parking mechanism. Quotations and displacements

3.6.1. Characteristic positions the cam and the tappet

The parking mechanism whose kinematic diagram is presented in figure 10 is taken into account

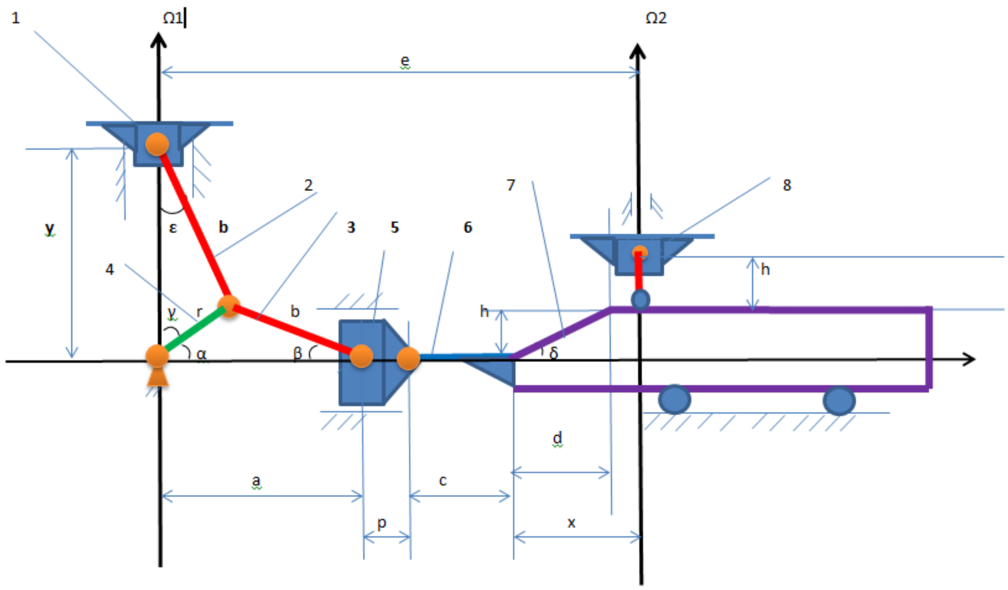

Fig.10. The kinematic mechanism of the parking lot

It includes:

1. The vertical piston 1 of length p= 2 m which moves along the vertical guide Ω1
2. Connecting rod 2 of length b= 6 m
3. Connecting rod 3 of length b= 6 m, identical to connecting rod 2
4. Crank 4 length r= 3 m
5. Horizontal piston 5 of length p= 2 m, kinematically identical to vertical piston 1
6. The coupling rod 6 of length c= 4 m, which at one end is articulated with the horizontal piston 5, and at the other end is welded or riveted with the translating cam 7. The coupling rod can be disconnected from the horizontal piston 5
7. Translating cam 7 of total length 9 m which is in connection with the translating tappet with roller 8
8. The translating tappet with a roller of length h= 3 m, which moves along the vertical guide **Ω2**
9. Between the two parallel vertical guides **Ω1** and **Ω2** the distance is 16 m.

To define the positions of the mechanism, the value of the angle **γ** between the vertical guide **Ω1** and the crank **r** is considered. All other variable elevations that define the intermediate positions of the mechanism are calculated based on this angle. [68], [69].

3.6.2. Important positions of the mechanism during operation

3.6.2.1. The characteristic position for minimum tappet elevation

In this case, the connecting rod 3 is found in the extension of the crank 4, the cam being at the extreme position on the right, and the tappet being at the minimum elevation on the area of the inclined plane of the cam (elevation 0.7 m in relation to the horizontal according to the calculation using triangle similarity theorem). (fig. 11.)

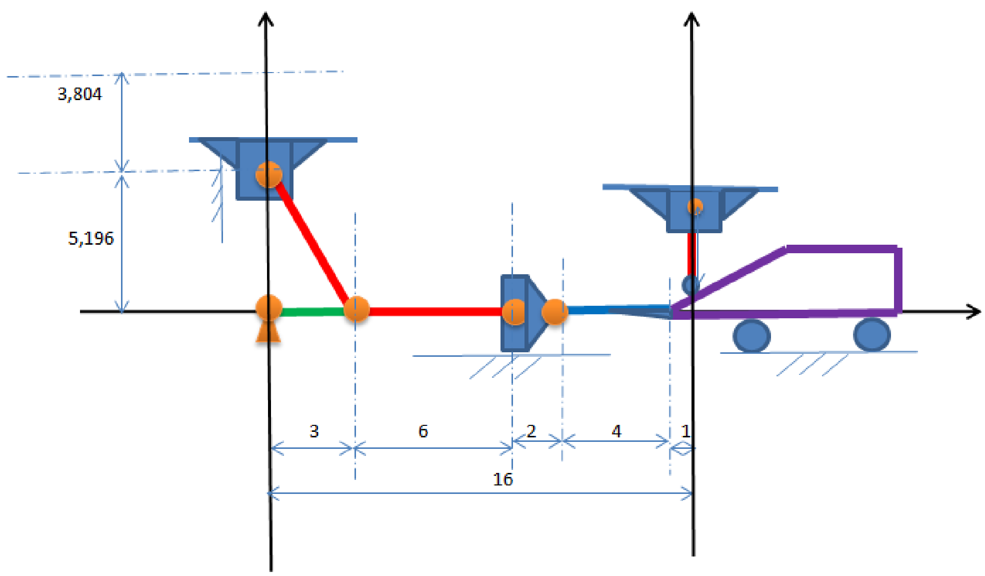

Fig. 11. Characteristic position for the minimum tapette elevation

3.6.2.2. The characteristic position for the minimum elevation of the vertical slide of the main elevator

In this case, the crank is in the lower vertical position, the vertical slide being at the minimum level h= 3 m, the level at which the robot lifts the vehicles on the platform or lowers them from the platform. The position is shown in figure 12. The tach is found at the maximum height h= 3m, characteristic of the auxiliary elevator.

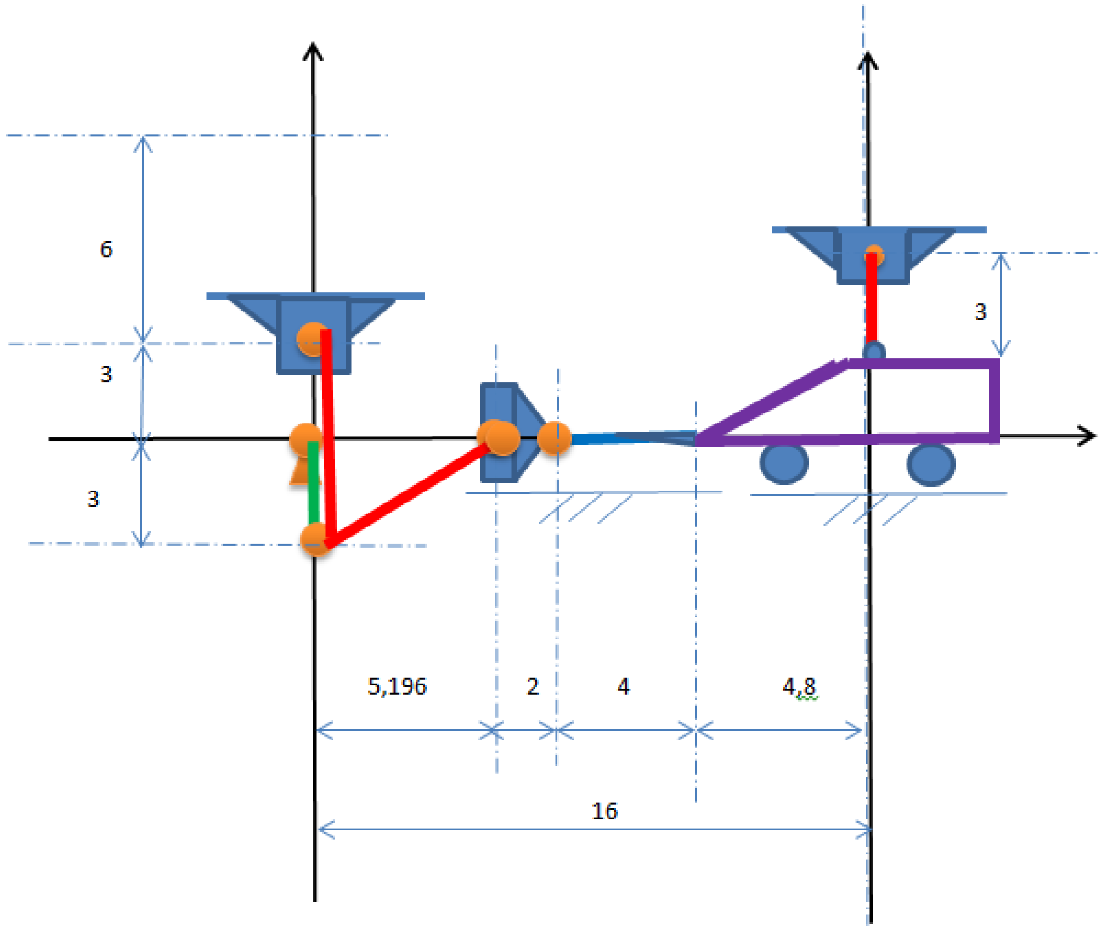

Fig. 12. Characteristic position for the minimum elevation of the vertical slide

3.6.2.3. Maximum displacement of the cam to the left

This position in figure 13. shows the maximum displacement of the cam to the left and highlights the minimum elevation that can be used to achieve the upper area of the translating cam in order not to block or damage the mechanism.

The crank is in this case in the horizontal position to the left, and the connecting rod 3 is again in this case in the horizontal position, but oriented to the left. In this case, the tappet is found at the maximum height h= 3m, characteristic of the first level of the auxiliary elevator.

It results from the calculation that during operation, the cam can move on the upper portion by a height of 2.71 m and therefore the length of the horizontal portion must be constructively at least equal to 3 m. A length equal to 4 m for the calculation of the mass of the cam shall be considered.

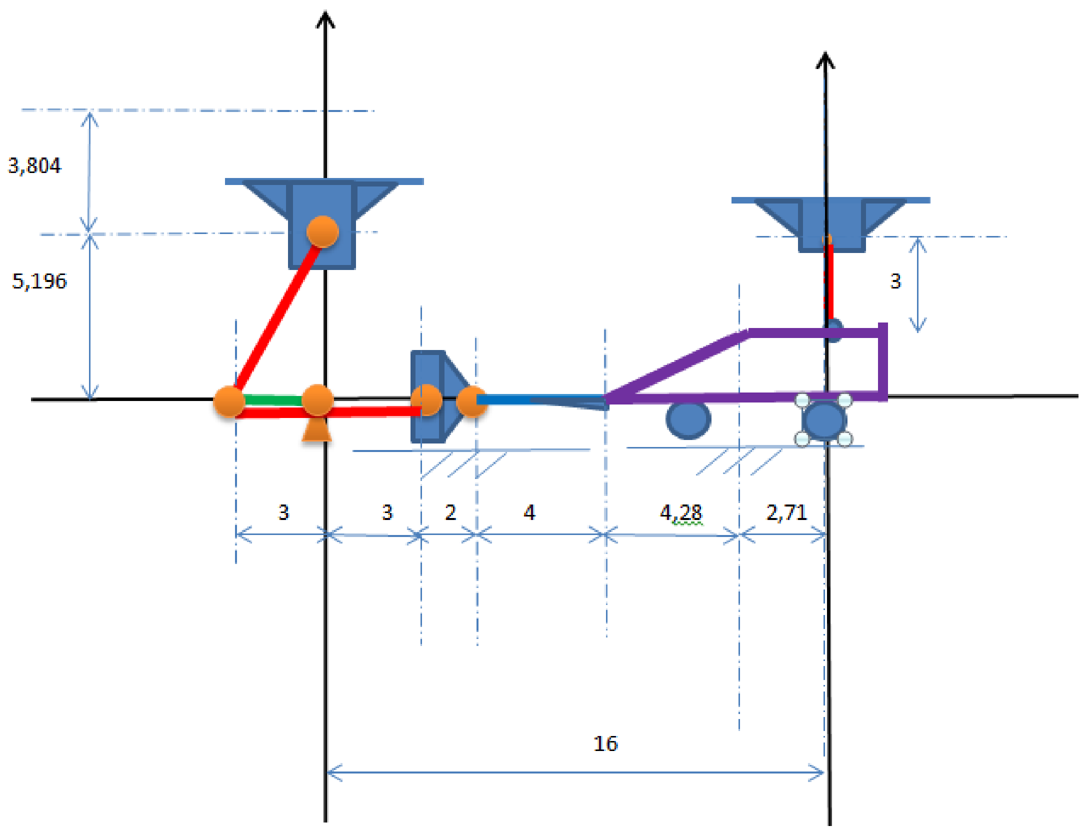

Fig. 13. Characteristic position for maximum cam displacement to the left

3.6.3. The auxiliary elevator equipped with a translational cam mechanism and a translational tach with a roller de translatie

The hereabove presented robotic parking includes the main elevator and an auxiliary elevator, coupled to the main one, the latter containing a parking lot with a reduced number of places and which is used for special situations. (requests that exceed the capacity of the main elevator or other special situations specified previously). The auxiliary elevator will be executed as a system of translating cam-translating cleat with roller and can be disconnected from the main elevator if its momentary use is not necessary or space does not allow its use. [70].

The design of a mechatronic system for the evacuation of vehicles parked in the parking lot is being considered, and the above mentioned system consists of the following elements:

- A mechanism with a translational cam and a translational tappet with a roller to raise the vehicle together with the platform on which it is parked to a certain height equal to the platform of the auxiliary parking
- A robot equipped with a platform that picks up the vehicle lifted by the cam mechanism and transports it to the main lift or outside the parking lot.

In figure 14. the component elements of the system are represented. These are the following [43].:

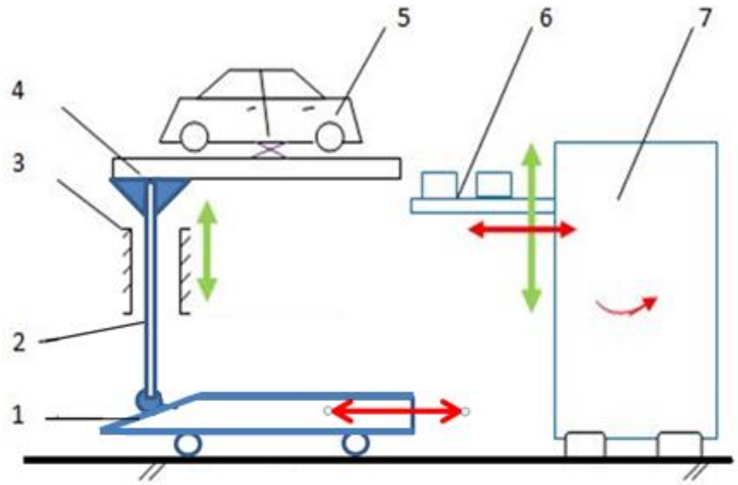

Fig. 14 .The auxiliary elevator and its operation

1) translational cam . [71].
2) the translating tappet with roller
3) the guide of the translation tappet (2) which is fixed by non-removable assembly (welding, riveting) or removable (with screws) to the metal structure of the parking lot (the structure is not represented in the figure) [31].
4) the welded platform with the translating tappet (2)
5) the parked vehicle
6) the platform of the robot that operates in the second phase the lifting of the vehicle 5 from the platform 4 by inserting the parts from the platform in the area of the thresholds of the vehicle
7) the robot 7 which moves along the circular or elliptical path perpendicular to the figure and which removes the vehicle 5 from the parking lot with the help of the platform 6

In the first phase, the cam 1 moves to the left and the translation tappet 2 moves vertically upwards together with the platform 4, thus lifting the vehicle 5 with the help of the scissor lift in the threshold area of the parking platform 4 on which it is initially located at a higher elevation greater than the height of the rubber lifting parts on the platform 6 of the robot 7. In the second phase, the adjustable horizontal platform 6 of the robot 7 moves to the left, it rises, coming into contact with the thresholds of the car and releasing the scissors from the platform 4 by the weight of the car. The plate 6 moves to the right, with the car on it, and later the robot 7 and its platform 6 move on the circular trajectory outside the parking lot, releasing the car to the ground or to another level of the main parking lot and the cam 1 moves to the right, the tappet 2 performing the descent course.

In the case of the design and achievement of these systems provided with cam mechanisms, the following elements must be taken into account:

- The dynamic mode of operation
- Weight of the installation

- The allowed level of vibrations and noise
- Reliability of the installation
- Cost of the components
- Commercial accessibility to components
- Operating and maintenance conditions

Each of these factors induces one or more restrictive elements, ultimately resulting an assembly that can satisfy all the imposed requirements.

3.6.4. The mechanism with translating cam and a translating roller tappet. Component elements. The cinematic scheme. The mobility graph

Cam mechanisms are part of the category of mechanisms with upper and lower couplings and are essentially formed by a profiled element (generally leading) - the cam - which transmits through direct contact, to the driven element - the tappet - a movement whose law is determined by the cam profile.

In the analyzed case for the auxiliary elevator, is considered a mechanism provided with a translating cam and a translating tappet with a roller, as shown in figure 16 [76](pag.180).
This mechanism includes:

1 translating cam.
2- the translating tappet
3- the roll of the tappet
Between elements 1 and 3 is the upper roto-translation coupling.

To reduce the phenomenon of wear between the cam and the tappet, the contact between the elements is made through a profile with a channel.

The mobility graph [75] (pag.390) is presented in figure 16, in which
1.translating cam
2. the translating tappet
3.the roll of the tappet
0- the foundation
A- upper rototranslational coupling
B- lower rotation coupler
A0∞- lower cam translation torque
B0∞-the lower translational coupling at the tach

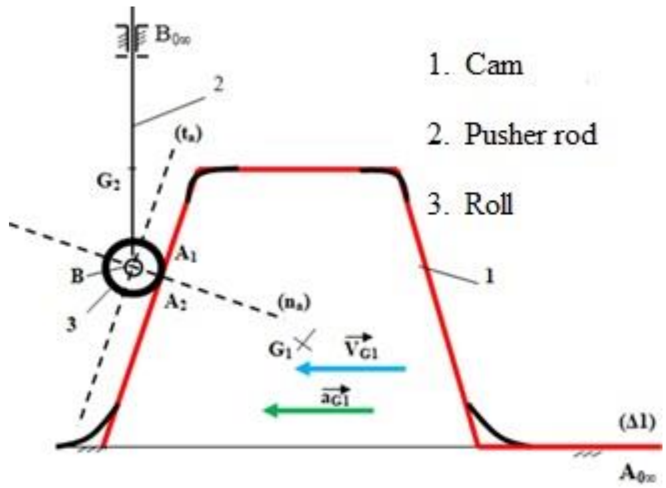

Fig.**15** Diagram of a mechanism with translating cam and translating roller tappet

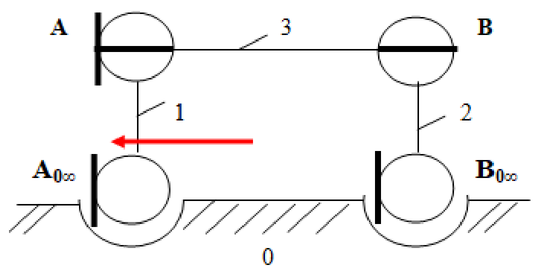

Fig. 16. Graph of the mobility of the mechanism with a translating cam and a translating roller tappet

In the case of the mechanism with translating cam and translating tappet with roller in figure 16., the roller 3 is an element with redundant movement, introduced in the construction of the mechanism to replace sliding friction with rolling friction [77]. The roller 3 can rotate around its axis without influencing the character of the movement of the mechanism, and from a kinematic point of view the roller can be removed or stiffened without disturbing the character of the movement. [75](pag 248).

When determining the mobility of the mechanism, this coupling with excess movement is excluded from the calculation.

The degree of mobility of the mechanism becomes

$$M = 3m - 2i - s = 6 - 4 - 1 = 1$$

3.6.4.1. Criteria for choosing the shape of the cam and the law of movement of the cam follower

An analysis of the stresses on the presented mechanism is considered and it can be concluded that the speed of the cam must be limited to a minimum possible value during operation.[78]
A cam mechanism works properly if there is no danger of the tappet sticking. This condition refers mathematically to the pressure angle [51], so that it is less than or at most equal to an admissible angle which generally has a value of 30...40 degrees. A pressure angle δa= 35 degrees is chosen (fig.17). To establish the law of displacement of the tappet, the mainly used displacement criteria are taken into account:

- making the inertial forces developed by the mass of the tach as low as possible;
- achieving minimal and constant forces acting from the cam on the tach;
- avoiding shocks in operation.

The first criterion is the most important [77] (pag. 27). The variation of the inertial force is dependent on the variation of the acceleration of the tappet and the type of discontinuity provided by the law of variation of the acceleration of the tappet is also of great importance. Between the points of contact between the cam and the tappet, are defined the maximum theoretical acceleration imposed by the designer on a theoretical point located on the cam in contact with the tappet considering the cam and the tappet as rigid solids and the actual maximum reduced acceleration of the same point which differs from the theoretical one due to the elasticity of the materials, the appearance of friction and play or machining tolerances. The ratio between the two accelerations is the dynamic coefficient and for charts that do not show sudden acceleration jumps it is equal to 1.

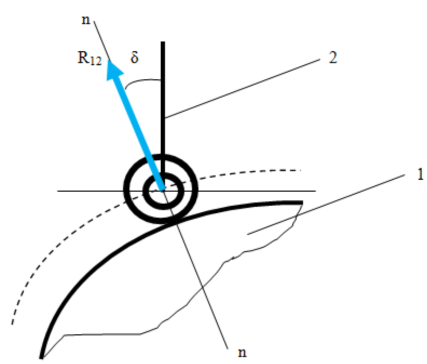

Fig.**17.** Pressure angle $\delta_a = 35^0$

3.6.4.2.*Kinematic and kinetostatic study of the mechanism with translation cam and translation cam roll follower*

According to figure 18, the cam 1 transmits directly to the tappet, by means of the upper coupling, a law of movement which is imprinted by the profile of the cam. The linear displacement law of the tappet and the cam profile which is linear, are taken into account.

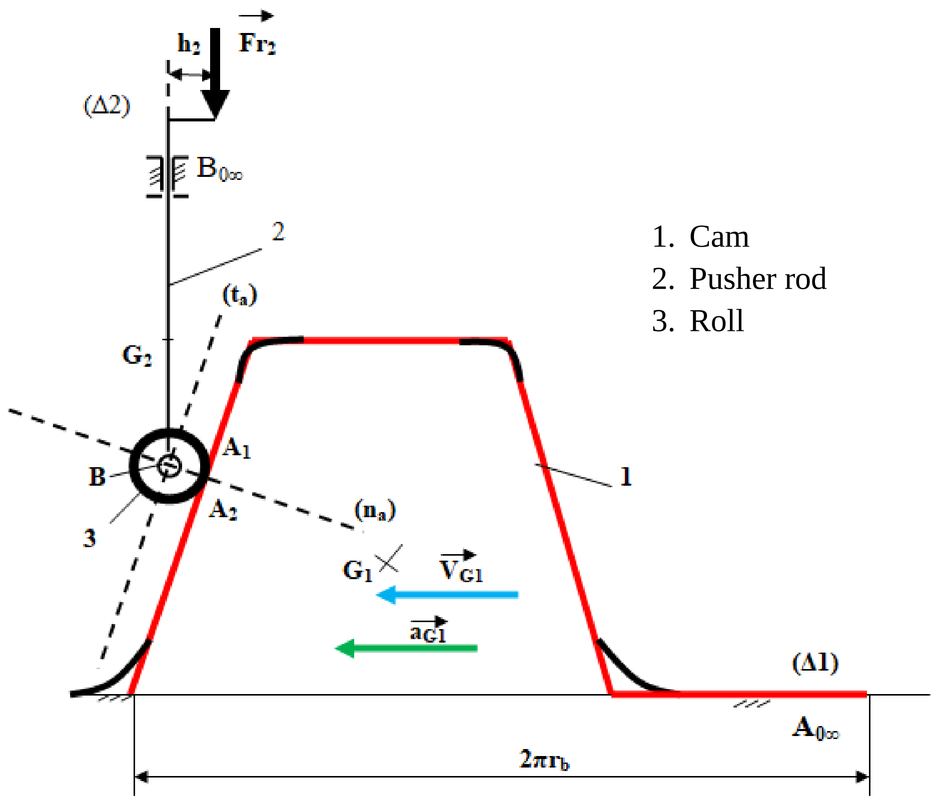

Fig. 18. Kinematic diagram of the mechanism with a translating cam and a translating tappet with a roller

3.6.5. Establishing the law of displacement of the translating roller tappet

In the case of the cam mechanism, the design theme is given in the form of the cyclogram of the movement. For example, for the mechanism with translating cam and roller tappet shown initially (for the movement up to the first floor of height h= 3m of the auxiliary elevator), the cyclogram shown in table 1 is taken into account.

Table 1. Cyclogram of the movement in the case of the mechanism with translating cam and translating roller tappet used in the auxiliary elevator

Tappet movement	goes up h=3m (one storey)	stands	goes down h=3m (one storey)	stands
Tappet displacement law	Linear			
Cam displacement (corresponding to angle)	$\varphi_1 = 60^0$	$\varphi_2 = 120^0$	$\varphi_3 = 60^0$	$\varphi_4 = 120^0$
Admissible pressure angle	$\delta_a = 35^0$			

In order to be able to adopt a certain law of movement of the tappet, a certain comparative analysis between certain laws of displacement must be carried out.

Thus, each cam displacement angle is divided into a certain number of x positions. The higher the number of positions, the closer to reality will be the plotted graphs.

Next, each tappet motion law will be taken into account to determine the transmission functions s, s', s'' (displacements, reduced speeds and reduced accelerations) for each phase.

Several laws of displacement of the tappet are analyzed, drawing certain conclusions. Finally, the linear displacement law is used, which has the following characteristics:

The tappet in this case has a uniform movement and the law is preferred for mechanisms operating at low revolutions or speeds, according to the case under investigation.

At the connection points of the lifting and lowering profiles of the tach, when changing its movement phase, the speeds make a finite jump and the accelerations make theoretically infinite jumps (in reality they are very large values) that generate hard shocks in the mechanism. To avoid these shocks, the profiles are connected by parabolic or sinusoidal connection curves. .

4. RESEARCHES PERTAING TO THE BUCKLING CHECK OF ELEVATOR ELEMENTS. DIMENSIONING OF CONNECTING RODS AND BEARINGS.

4.1. Buckling of the rod of the translantion tappet with roller in the case of the auxiliary elevator

The possibility of using a single rod for the auxiliary elevator tappet was tried initially. In this situation, the mass of the car and the mass of the rod act on the rod, stressing it in compression and buckling. In order to carry out the buckling check of the tappet rod, a calculation program was developed in Visual Basic with the help of which the presented results were obtained. .[84] ,[85](pag.340)

The data taken into account are in this case the actuation force on the rod (the weight of a large car), the length of the rod, the modulus of elasticity of the steel, the characteristic slenderness coefficient for the improvement steel, the safety coefficient, the material characteristics E, σc, σp, λ0, λ1 and a, b (from the Tetmajer-Iasinski formula).

The results were obtained with the help of a program in Visual Basic from which the following conclusions are drawn:

The chosen material cannot be used for the dimensions shown in the figure because the slenderness coefficient resulting from the calculation (λ =40.02) is lower than that characteristic of the chosen material (λ =100). If a very expensive material is used (a Cr-Mo alloy steel) the same problem results (the calculated slenderness coefficient λ =40.02 is lower than that of the material λ =55) .

The same problem manifests itself if a rod with a very large diameter is used which leads to the mechanism becoming more difficult.

The solution cannot be adopted and therefore a calculation model with several rods must be used.

In order to reduce the vertical axial force acting on the rod of the translating tappet, a system is adopted in this case consisting of several equidistant parallel vertical rods (2 or 4), each acting on the translating cam (fig.19).

The platform (1) is solidarized with the rods of the tappet (2) with the help of triangular elements to avoid their deformation or breakage during operation. An axle (3) will be inserted in the area of the tappet rollers, which will solidify the assembly. (fig. 19). The axle (3) is inserted into the assembly to avoid a different movement of the rods during the ascent or descent of the tappet on the inclined plane of the cam and is fixed laterally by means of bolted flanges that constitute an assembly. The size of this assembly will be taken into account when calculating the overall cam width.

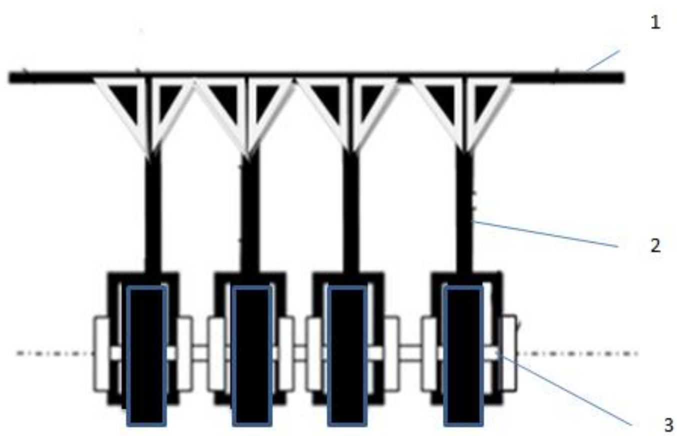

Fig. 19. The system of parallel rods acting on the translating cam

Using the system in figure 19 we get the results obtained with the help of the calculation program and which represent the optimal option for use.

4.2. Establishing the contact width between the tappet rollers and the translantion cam

The width of the cam is chosen to be greater than the minimum contact width determined by calculation multiplied by the number of cam rollers in contact with the cam and must be greater than the sum of the diameters of the cam rods acting on the cam. [79] (pag.346). Taking into account the dimensions of the rods (d=150 mm), the bronze plating of the contact area between the tappet rollers and the cam to achieve the results shown and the side dimensions required for the existing flanges shown, in this case the width B= 1000 mm is adopted .

In this case, a calculation program was developed in Visual Basic, with the help of which the presented results were obtained.

The calculation of the contact width is carried out taking into account the resistance condition of the cam to the hertzian contact stress. This calculation is performed for the version of a system with 4 rods.

The data and results are presented in the program.

4.3. Calculation of the buckling of the main elevator rod

In this case, the elevator shaft has a larger size (equivalent to two floors of the parking lot). By analyzing the model of the auxiliary elevator rod, a single-rod elevator model or a multi-rod model can be adopted in this case as well.

Analogous to the calculation model for the rod of the auxiliary elevator tappet, in this case only the length of the rod differs. It results in the values presented in the completed program.

In this situation, the diameter resulting from the calculation db= 104.8 < 200 mm, and the slenderness coefficient λ = hn/db = 57.2 > 55 for the chosen steel, so this material can be used. Taking into account the fact that the material for which the calculation was made is an alloy steel and therefore expensive, it is considered to make a system consisting of 2 rods, analogous to the one in the case of the auxiliary elevator.

4.4. Determination of the mass of the cam

The center of gravity of the translational cam is determined, dividing this part into two component elements[87]. The dimensions of the center of gravity are obtained with an application made with the help of the Visual Basic program.

To determine the mass of the translating cam, a model is used that includes an upper platform of length l_1, a lower platform of length l_2 a plane inclined at an angle α on which the roller of the translating tappet goes up and down, and support posts placed between the horizontal platforms. The width of the plates is l_3 and their thickness is a. The calculation is done with the help of an application in Visual Basic.

4.5. Dimensioning of connecting rods. Dimensioning of the elements of the parking mechanism

4.5.1. Crank , piston and slide

In the case of the crank, its angular velocity and its elastic constant are determined, and in the case of the pistons, their masses are adopted.

4.5.2. Sizing connecting rods taking into account strength and stiffness

The two connecting rods are dimensioned in two versions, taking into account both the strength and stiffness conditions. For dimensioning, a value of the axial force acting on the connecting rod composed of the weight of the piston and the maximum weight of a car on the platform is used. The connecting rods are identical, have circular sections and are constructed from OLC 50 heat treated steel. [84] (pag 26).

The connecting rod sizing data and results are presented in the Visual Basic program.

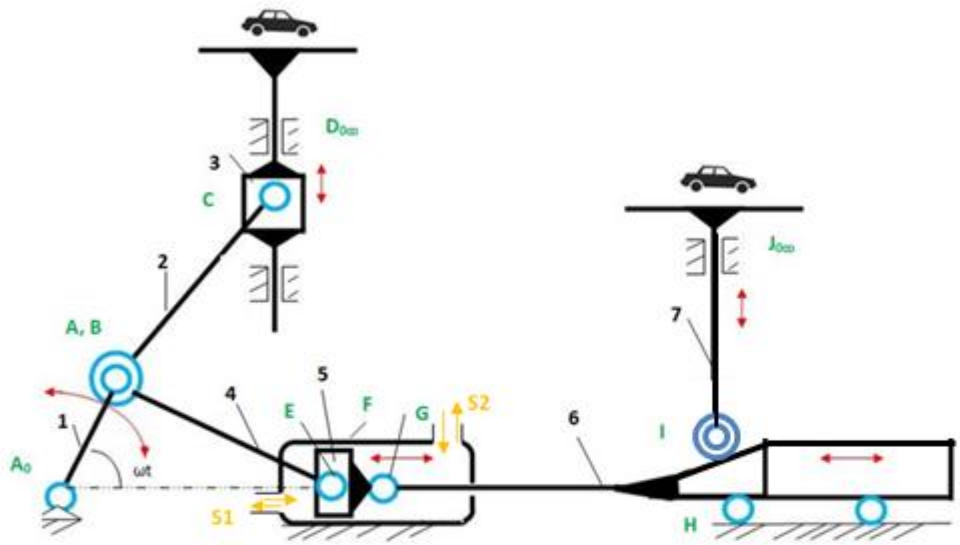

Fig. 20. The parking mechanism provided with two elevators

4.5.3. Buckling of connecting rods. Checking the buckling rods

Regarding the mechanism in figure 21, the buckling behavior of the connecting rods [85] is analyzed taking into account the following buckling verification hypotheses:

- Connecting rods are straight bars subjected to compression
- Connecting rods are slender rods (connecting rods are rods of large length compared to the cross-sectional dimensions)
- The equilibrium shape of compressed bars can be stable or unstable, using different calculation relations for each situation

The mechanism shown in figure 20 includes two connecting rods. These are considered to be straight bars that satisfy the hinged bar model at both ends (at joints A and C for connecting rod 2, respectively at joints B and E for connecting rod 4). In this case the buckling length lf = L. (L is the length of the connecting rod). Under the action of the compression forces applied to the connecting rods, they deform, and at a certain value of these forces, the connecting rods pass from the state of stable equilibrium to that of unstable equilibrium, the magnitudes of these forces representing the critical buckling forces. The data and results of the buckling connecting rods are presented in the Visual Basic program.

4.6. The radial sliding bearing of the translating tappet roll.

Consider the assembly consisting of the translating cam and the translating tappet with roller [88] , shown in figure 21.

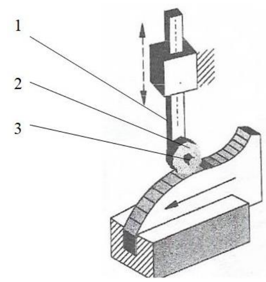

Fig. 21. The assembly consisting of the translating cam and the translating tach with roller

Between the tappet rod (1) and the translation tappet roller (2) is the axle (3) which is subject to bending.Together with the roller (2), this axle forms a radial sliding bearing, the axle representing the spindle, and inside the reel there is the roller bearing .This is a kinematic coupling where the tribological process (which includes friction, wear, lubrication and cooling) must be considered.) [108] (pag 26)

In order to be able to calculate the sliding bearing, the type of working machine, the material of the spindle (the connection axis between the roller and the rod), the diameter of the axis, the peripheral speed of the roller, the force applied to the bearing and the type of lubrication of the bearing (liquid, mixed or dry) must be taken into account. [89] (pag. 108)

In order to be able to evaluate the possibility of using a certain material in the situation of making the bearing, the use of an ARO 10 abacus chart presented in the paper is considered.

The dimensions prescriptions of the spindle (gauge coefficient), the prescriptions of the machine in use (the bearing is used in the lifting machine) and the restrictions of the bearing (kinematic restriction to avoid excessive wear of the materials of the parts, dynamic restriction in order to ensure the optimal contact pressure) are taken into account and the avoidance of lubricant expulsion and the energy restriction relating to the limitation of specific power and the avoidance of excessive heating of the material.). Bearing lubrication (dry, mixed or fluid) is considered.

Of all the materials presented in the table of materials in the ARO 10 abacus, only the one that meets all the conditions necessary to be used will be retained following the calculations, taking into account all the listed restrictions.

The data and results of obtaining a material for the sliding bearing are presented in the program.

In the situation where a sliding bearing cannot be used due to problems that may arise because of bearing materials or lubrication, a rolling bearing assembly will be used.

5. STUDY OF THE VIBRATIONS OF THE PARKING MECHANISM

5.1. Causes of the vibrations of the translating cam and of the translating roller tappet

Vibrations are alternative movements performed by the mechanical system in relation to the reference state, being caused by disruptive forces whose sizes, directions or application points vary over time [89], [90].

Auxiliary elevator mechanism is a complex system that performs a series of alternative movements around the equilibrium position. When startingping and stop, it passes through transient operating regimes, causing vibrations in operation.

The total movement displacement of the secondary elevator mechanism (t_t) comprises a start phase, a regime phase and a stop phase.

During the starting phase(tp), the speed of the leading element increases from zero to a characteristiv value of the regime phase.

During the regime phase (t_r), the speed of the leading element varies around a constant medium value (v_m) characteristic to this phase.

During the stopping phase (t_o), the speed of the leading element decreases from the medium value of the regime phase to zero.

The graph of the variation of the speed of the driving element as a function of time represents the tachogram of the movement and is shown in the figure 5.1.[91] .

The causes of vibrations found in machines and equipments are very diverse [92] . These are related to:

- the inertial forces that occur during the operation of the mechanisms
- variable forces at start-stop and shocks
- inaccuracies in execution or assembly
- wear and tear or malfunctions

An elastic system is determined when the following are known:

1. system mass
2. the elastic properties of the system which are given by the elastic characteristics of the deformable elements in the system. If the relationship between the deformation of the elastic element and the stress causing it is proportional, then the elastic element is linear and can be characterized by an elastic constant

The auxiliary lift is a complex system that alternately performs a series of movements around a balance position. When starting and stopping the system, it goes through transient operating regimes, thus causing vibrations in operation.

5.2. Models used for determining the own pulsations in case of free and forced vibrations of the translating tappet of the robotic parking lot

5.2.1. Calculation of the first own pulsation of the translating tappet for the mass-spring system model

The simplest vibrating system consists of a mass attached to a linear spring, according to figure 22 . When the movement can be described by a single coordinate, the system has only one degree of freedom. Using this simple model, basic concepts such as natural frequency and resonance can be introduced. During vibrations, the mechanical energy is dissipated by damping. This limits the amplitude of the movement at resonance, decreases the amplitude of free vibrations, and introduces phase shifts between response and excitation. Measuring damping is important because it cannot be calculated like the other two properties, mass and stiffness. [102] [103].To calculate the own pulsation of the system consisting of the cleat rod and the total mass of the system with the help of this model, the section of the rod, the modulus of elasticity of the rod, the length of the cleat rod and the total mass of the system (the rods, the parking platform of the vehicle and the mass of the vehicle) must be known. .

The result is the elastic constant of the rods and the system's own pulsation, according to the model in figure 22.

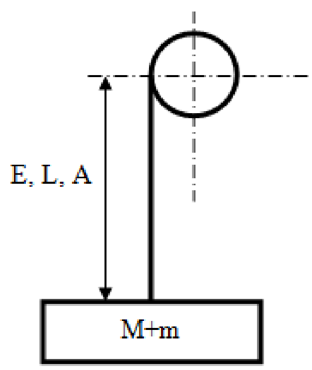

Fig. 22. The elevator model of system with one autonomy degree

5.2.2. Calculation of the first own pulsation of the translating tappet using the Dunkerley method

Unlike the previous method, with the Dunkerley method [105] (pag.194) the system is decomposed into two different elements, being closer to the real case according to figure 23.

The system's own pulsation results.

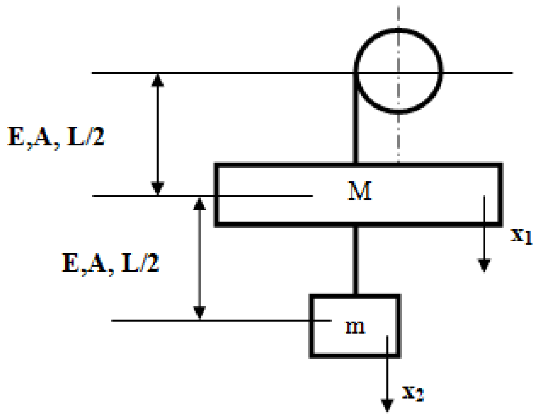

Fig. 23 The model of the elevator used in the calculation with the Dunkerley method

5.2.3. Calculation of the first own pulsation of the translating tappet using Vereşceaghin's method in the case

The vibrations produced by an elevator during operation are transmitted in the form of elastic waves.

To determine the own pulsation, the method of inertial forces can be used with the help of the flexibility matrix.

Consider the elevator as a bar embedded at the bottom, modeled as in figure 24. The unit diagram is shown on the right side of the figure. [106] (pag 84) .

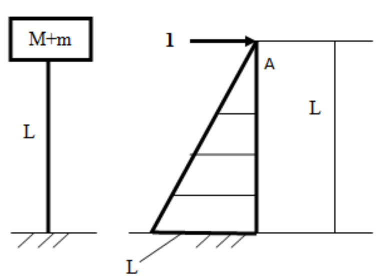

Fig.24. The model used in the calculation of the first own pulsation with the Veresceaghin method

The modulus of elasticity, the length of the rod, the mass of the rods and rollers, the mass of the vehicle, the exterior diameter of the rod, the interior diameter of the rod, the ratio between the interior and the exterior diameter, the area of a section of a rod are taken into account.

For the 4 rods of inelar section, the section consisting of 4 rods is presented in fig.25. For the calculation of the moment of inertia of the system from the OY vertical from fig.25, the 4 rods are considered tangent.

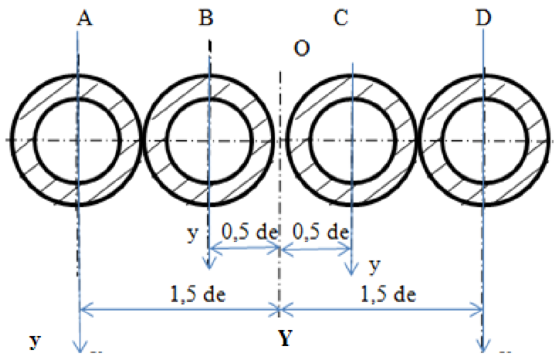

Fig.25.The section of the 4 rods that actuate the tappet in order to calculate the moment of inertia.

The system's own pulsation results.

5.2.4. The model of the continuous system in the case of the translating tappet

Unlike previous models that identify the system as consisting of concentrated masses, this model is approximated as a continuous system, the inertial forces being distributed throughout the entire volume and not just at the points where the masses are concentrated. A model is made for the lift mechanism of the Multiparker car park, considered to be composed of a continuous and homogeneous bar of length L, modulus of elasticity E, section S and density d , on itembedded at the base. The elevator moves on it in a vertical direction, raising and lowering the car of mass m, considered as concentrated mass located at the upper end of the bar (fig. 26). The advantage of this method is that several own pulsations can be determined in the case of free vibrations for this bar.[104]

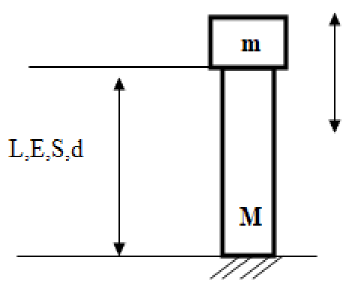

Fig. 26. Model of the continuous system for determining the own pulsation of the main elevator

The model used in the Seismic Design Code or the model for attaching a vibrator are also used as possibilities for determining the first own pulsation of the translating tappet system.

The own pulsations determined using the continous system model are obtained using a program in Visual Basic.

5.2.5. The behavior of the translating tappet under the action of a load of the nature of an explosion or an earthquake

Consider a force exerted by an explosion or an earthquake of the form shown in fig. 27. To make the calculation easier, it is considered that the auxiliary elevator mass mtot is subjected to a force determined by an initial burst of force that varies linearly, from the maximum value F_0 at time t = 0 to the value F= 0 at time t_0, so that the areas defined by the two curves are equal. [105] (pag 83).

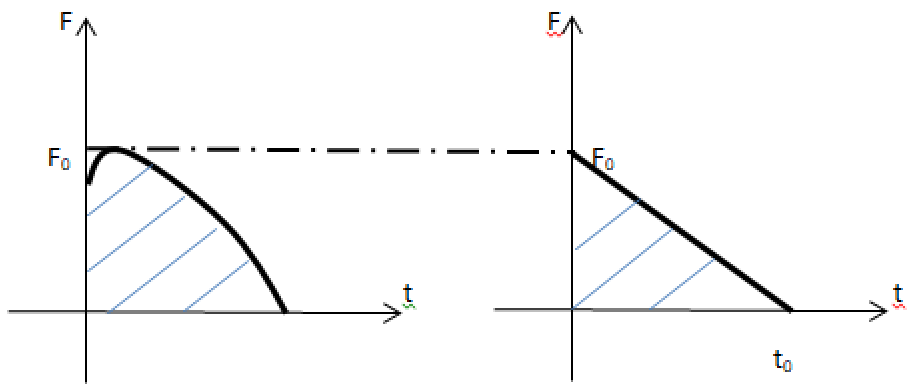

Fig. 27. Equating the driving force of an explosion with a linear model

It results in an impulse response function, i.e. a displacement of the mass of the form **x(t)**, function of the mass $\mathbf{m_{tot}}$, the own pulsatition $\boldsymbol{\omega_0}$, $\mathbf{t_0}$, which is of the form shown in figure 28. The graph shows when the maximum displacement of the elevator occurs during the action of the disturbing force relative to the equilibrium position in relation to the explosion, what is the amplitude of this displacement, the fact that that the signal is periodic and how it varies in time.

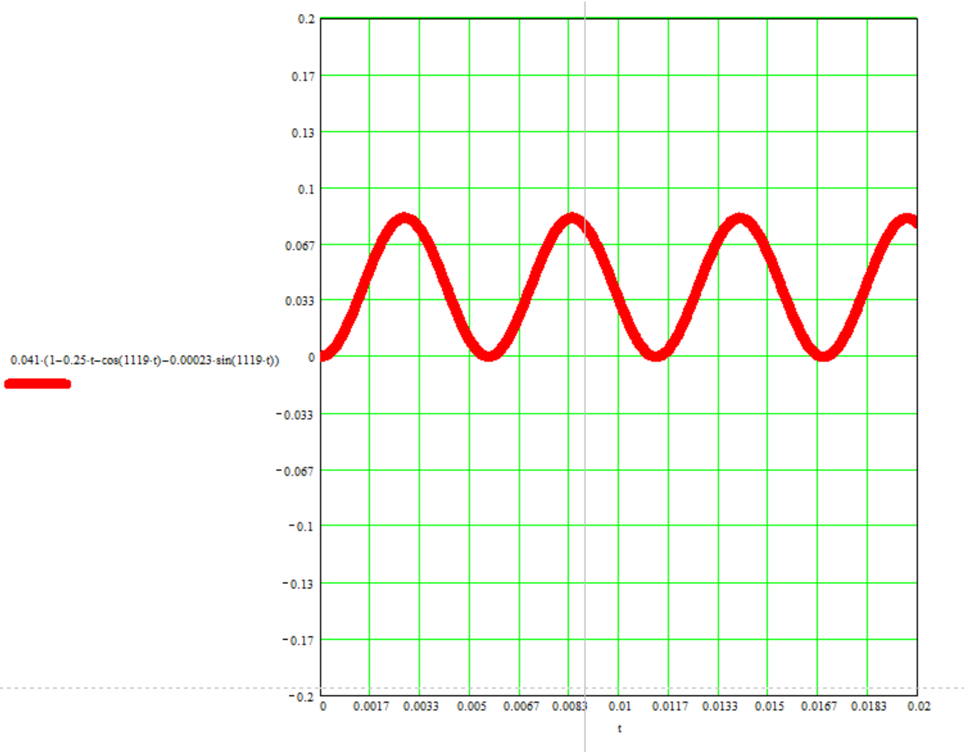

Fig. 28. Graph of the impulse response function

The values for the main elevator are also determined analoguously.

5.2.6. Conclusions related to the vibration of a system. Comparative analysis

The conclusions regarding the use of several models for the determination of own pulsations are as follows:

- The determined own pulsations are greatly influenced by the model adopted for the system. No own pulsation can be considered accurate for the system because the model does not include all the elements in reality.
- The Versceaghin model and the seismic analysis model refer to empirical formulas and the results obtained are the lowest and can be taken into account in the case of an experimental research to avoid resonance
- The continuous system model is the closest to the constructive reality for a homogeneous structure and offers the largest number of own pulsations. This is the closest to reality in the calculation to avoid resonances.
- It can be considered that the values closest to reality are those resulting from the calculation using the mass-spring, Dunkerley, continuous system model.
- Passing through resonance must be done quickly. The parking lot will be designed and operated in such a way that in normal operation it does not generate noise or

vibrations likely to affect the health or tranquility of the users of the neighboring buildings (over the limits allowed in the technical regulations).

5.3. Bending vibrations of connecting rods

All elements included in the parking mechanism are elastic systems. The connecting rods perform various lifting or lowering movements, passing from the equilibrium positions to those of plane-parallel movement. Due to these plane-parallel movements, under the action of disturbing forces, when starting and stopping, oscillatory movements appear outside the equilibrium zone called bending vibrations. All these elements of the mechanism are subject to vibrations, including the hydraulic fluid in the cylinder.

For the adopted circular section of the connecting rods, the following calculation quantities are taken into account:

- connecting rod diameter
- connecting rod length
- steel density
- longitudinal modulus of elasticity of the used steel
- damping constant

It results:

- connecting rod mass for circular section
- the polar moment of inertia
- elastic constant for circular section
- the own pulsation of the connecting rod

The data and the results of the calculation in the absence of damping (c=0) are presented in the Visual Basic program.

5.4. Vibration of the translating cam

The translational cam performs alternate movements of back and forth, when starting or stopping, thus passing from the stationary position to the moving position with different accelerations or decelerations.

In these situations, inertial and frictional forces are disruptive factors that lead to the appearance of vibrations in the system consisting of a cam and a translational tappet with a roller.

In order to reduce wear and the negative influence of vibrations due to frictional forces, wheels are used between the cam and the drum on which it moves, thus reducing the coefficient of friction by changing from sliding friction to rolling friction.

The data and calculation results are presented in the Visual Basic program. .

5.4.1. Vibration of the translational cam and horizontal piston during operation

During the operation of the entire mechanism, both the translating cam and the piston located in the liquid cylinder participate in the rectilinear alternative movements. It thus becomes necessary to determine an own pulsation of the system formed by the two elements, considering the following working hypotheses:

a) The two platforms on which cars are located do not always work simultaneously
b) The lifting or lowering speeds of the platforms (the vertical piston and the translating tappet with the roller) are very low (5 cm/s)
c) The masses of the systems are large (over 1 ton)

In order to be able to determine the lowest natural pulsation of the system, Dunkerley's method is used. [105] (pag.194).The model presented in figure 29 is considered.

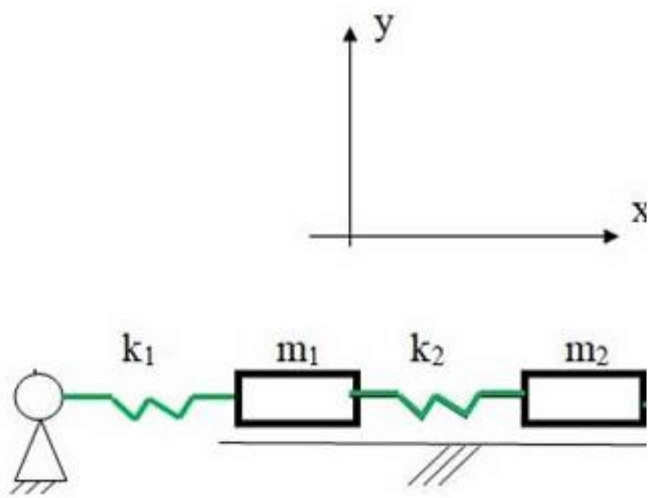

Fig. 29. The model adopted to determine the own pulsation of the horizontally moving system

Taking into account the mass of the piston, the mass of the translating cam together with the mass of the coupling rod, the elastic constant of the equivalent spring and the viscous damping coefficient, it results, in the case of adopting a horizontal system identical to the one shown in figure 29, the own pulsation of the relative movement of the system and the critical value of the damping coefficient. As the viscous damping coefficient increases, the pulsation of the damped oscillation of the system decreases. [112].

5.4.2. The action of a random vibration on a main elevator rod

We consider the action of a vertical wave further to the action of an earthquake that produces a disturbance of the form shown in figure 30.

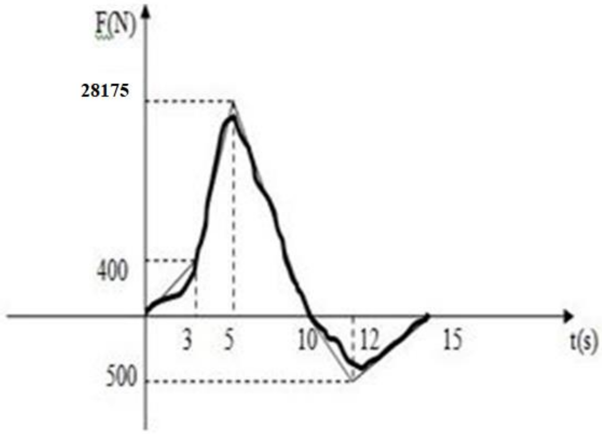

Fig. 30. The action of a force of the nature of an earthquake on an elevator - the real form

Considering the complicated form of the disturbance, in the form of a random vibration, it is considered, for simplification, its approximation with a sum of linear functions of the form shown in figure 31.

The impulse produced by the force on the elevator (the numerical value of the impulse response function) is calculated based on the approximation of the integrals using the trapezoidal method.

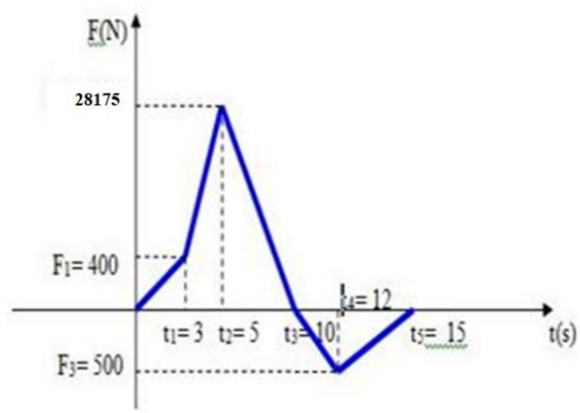

Fig. 31. The action of a force of the nature of an earthquake on an elevator - linearized model

For simplification, the variation of the earthquake force can be equated with a straight line having the shape of the one in figure 32, the time t_0 being determined so that the areas defined by the two signals are equal, the amplitude module (peak-to-peak value) F_0**,** being the same in both situations . [105] (pag. 83).

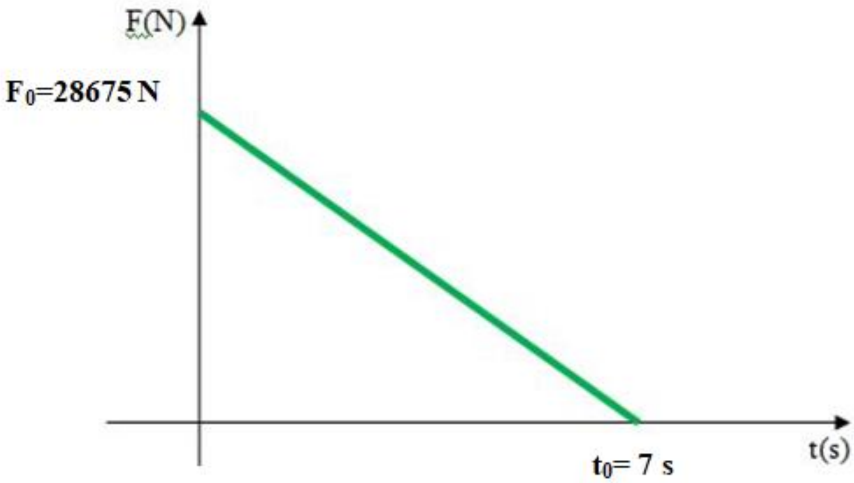

Fig. 32. Variation of earthquake force for simplification. Determining the action time of the earthquake

It results in an impulse response function of the form shown in fig. 33.

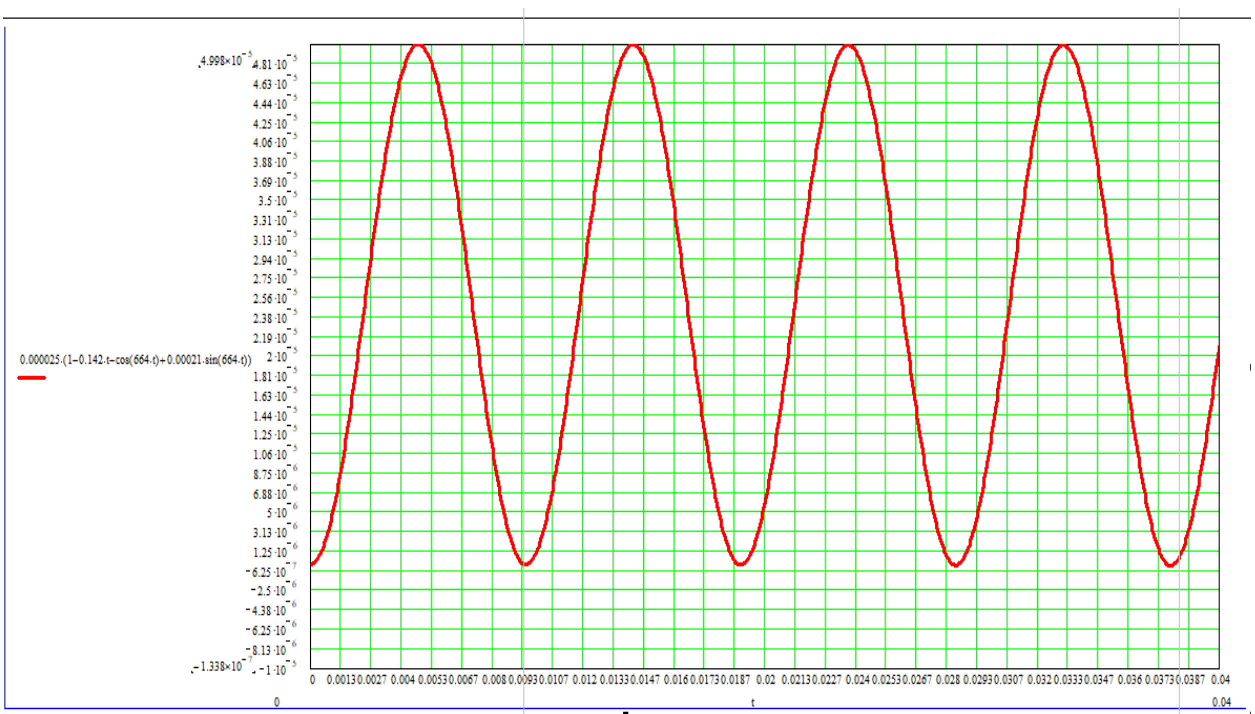

Fig. 33. Displacement in case of main elevator considering the force as input signal

6. CONCLUSIONS, ORIGINAL CONTRIBUTIONS, SUBSEQUENT DEVELOPMENT PERSPECTIVES AND RESULTS DISSEMINATION

6.1. General conclusions. Beneficiaries of the research

The main objective of the research developed within this doctoral thesis is the creation of parking lots on the territory of Bucharest, equipped with mechatronic systems, for the movement and positioning of vehicles in the parking lot, in complete safety conditions.

Following the studies and documentation carried out, a series of conclusions resulted, from which we present the following:

- The continuous increase in the number of vehicles owned by the inhabitants of Bucharest, to which are added those that are temporarily stationed on the territory, imposes as a first necessity, the construction of modern parking lots, which ensure the freeing of the roadway from some illegally parked vehicles.
- Parking lots must comply with the following conditions [114];
  - the safety and reliability of its construction;
  - placement in an accessible area;
  - it should have as much capacity as possible;
  - the ventilation of the parking lot should be possible;
  - the levels of noise and vibrations should not affect the activity in the area;
  - ensuring electricity supply in any situation;
  - reduced footprint, taking into account the available spaces.
- Taking these considerations into account, it is considered that the location of some parking lots above and along Dâmboviţa river is part of the urban development of Bucharest.
- To ensure the parking of as many vehicles as possible, the construction of multi-storey parking lots is recommended.
- Taking into account the requirements manifested worldwide, these parking lots must be equipped with mechatronic equipment, an important role within them is represented by the multi-functional elevators.

The beneficiaries of the execution of such parking lots, are:

- Car owners;
- Design companies;
- Public authorities;
- Research institutes in the field of constructions;
- Institutes with a profile in the field of architecture;
- Universities with mechanical, construction and architecture profile;
- Companies manufacturing construction materials;
- Companies selling construction materials.

6.2. Original contributions

Among the **original contributions** brought by the doctoral thesis, the following can be listed:

- Critical analysis of the existing types of parking lot in Bucharest and the selection of a modern solution that corresponds to the large number of vehicles, which is constantly increasing;
- Conducting for the first time, a survey based on interviewing a number of 107 respondents, regarding the need to develop the vehicle park in Bucharest, the location of new parking lots and equipping them with modern remote monitoring and remote control systems;
- The performance of a comparative analysis regarding the possibilities of creating various types of parking lots, in areas unused until now, evaluating the advantages and disadvantages of each model separately
- Based on the study of the various constructive versions of the mechanisms that can be included in the equipment of modern parking lots, the original solution of a double elevator has been proposed, hereinafter called the parking mechanism, consisting of two systems: the main elevator and the secondary elevator, which can be connected or disconnected depending on the situations that may arise;
- The possibility of realizing this system in various areas was studied, for example on a concrete platform, built above the river Dâmbovița, or in a storied area that allows this.
- The proposal to modernize some existing parking lots by using the main elevator for this purpose;
- Calculation for the dimensioning of the elements of the two elevators, to ensure the functional role;
- Performing a study of the vibrations of the elevator elements, taking into account the phenomenon of resonance, which may appear due to the periodic movement of the system;
- The consideration of additional system demands, as a result of seismic waves, or caused by explosions;
- Development of programs with the help of the Visual Basic language, to solve the problems of dimensioning and variation of the elements of the parking mechanism;
- The execution of a functional model of the parking mechanism consisting of the two coupled elevators, which proves the feasibility of the proposed model (Annex 1)

6.3. Subsequent development perspectives

PROSPECTS FOR FURTHER DEVELOPMENT

Future development perspectives

According to the needs identified at the field level, the project will meet the following needs:

Research

- The development of concepts for the realization of a multi-storey car park equiped with an elevator and a robot for the movement of vehicles.
- For the operation of the elevator, the energy obtained through cogenaration can be used, being a modern solution, in order to comply with the EU indications of zero emission
- Cogenaration defines the simultaneos production of heat and electricity, with the same installation(heat engine -electric generator group turbine)

- Through the cogeneration systems, the reduction of polluted emissions is obtained, protecting the environment, as well as the reduction of thermal production costs[115]
- The study regarding the improvement of the advantages of such a mechanism model with energy recovery
- The processing and improvement of existing constructive options

Education

- Tehnical and technological training of engineers for the design and exexutiin of madern parking lots
- Practice base for students of architecture, construction, mechatronics, masters and doctoral students from specialized research institutes universities.

The results of the studies performed within the doctoral thesis can be extended further, in the following directions:

- **Research**
  - The development of concepts for the execution of a multi-storey parking lot equipped with an elevator and a robot for the movement of vehicles;

Education

Results dissemination

During the elaboration of this doctoral thesis, the research performed have been valued through a number of 29 articles published in magazines and bulletins, 8 communications in national and international symposiums. These are presented in the Annex 2. At the same time, the articles presented in works [1], [3], [16], [48], [50], [65], [70], [74], [80], [93], [104], [106], [115] were used in the paper.

7. Bibliography

1. [1] Rășchitor, E., Radu, C.,E.(2017) Parcări supraetajate deasupra râului Dâmbovița, SMART START- UP EDIȚIA II, Polytechnic University of Bucharest, December 5
2. [2] https://egea.ro/constructii/parcari-supraetajate
3. [3] **Radu, C., E**., Rășchitor, E., Tempea, I., The Need of Developing the parking system in the Bucharest Municipality,Fiabilatate și Durabilitate , No. 1/2018, Editura ”Academia Brâncuși”, Tîrgu Jiu, p. 316 -319
4. [5] indrumari-juridice.eu- cate locuri de parcare trebuie sa asigure dezvoltatorul imobiliar
5. [6] https://evmarket.ro/utile/foto-este-gata-parcarea-supraetajata-din-pantelimon-a-durat-11-ani-26196/ 18 mai 2022
6. [8] (http://www.starelevators.ro/produse/multiplicator-auto-model-a3/)
7. [11] (gabaritul+unui+elevator+model+ptj+201-27&qpvt)
8. [16] **Radu, C.E**., Rășchitor, E., Tempea, I, (2018*), Elevator-Type Parking Lots*, 11th Symposium, Durability and Reliability of Mechanical Systems ,SYMECH 2018,Tg-Jiu, Gorj,11-12 may 2018, - Fiability & Durability No 1-/ 2018 Editura “Academica Brâncuşi” , Târgu Jiu, pp. 80-86, ISSN 1844 – 640X
9. [23] Legendi, A., Pavel, Cr.- Mecanisme cu destinație restrânsă Editura MATRIX ROM, București 2014
10. [31] Moise, V, Analiza si simularea mecanismelor, Editura. Printech .-pag. 41
11. [36] Gheorghe, Gh. Contribuții originale și științifice la dezvoltarea sistemelor cyber-mecatronice pentru medii industriale, economice și societale - Revista TechnoMarket - februarie - martie - aprilie - mai 2017
12. [37] http://www.sistemedeparcare.ro/html-parcari/multiparker-710-720.htm
13. [41] Ziarul Gândul din 20.06.2022
14. [42] Dimitrescu, A.- Marketing industrial- Note de curs-2020
15. [48]. **Radu, C., E.,** Rășchitor, E., Tempea, I, *Calculation of the Collapsing Critical Load of a Translating Cam Mechanism and Roller Translating Follower Actuating an Elevator*, Advanced Engineering Forum Vol. 42, pp 99-106 Revised: 2021-03-19, © 2021 Trans Tech Publications Ltd, Switzerland
16. [49] Tempea, I., Martineac, A., Mecanică și mecanisme, Editura Printech, 2000
17. [50] **Radu, C., E,** Rășchitor, E., Popescu, V., Tempea, I., *Vision And Strategy Regarding The Parking Lots With Elevators*, Fiability & Durability No 1/ 2022, Editura “Academica Brâncuşi” , Târgu Jiu, pp. 141- 146, ISSN 1844 – 640X
18. [51] Adîr, G., Adîr, A., Adîr, V., Ungureanu, L., Dudici, L., *Mecanisme. Teorie şi aplicaţii*, Ed. Printech, ISBN 978-606-23-0096-8, cod CNCSIS 54, 2013
19. [52] Manolescu, N., I., Tempea, I., Analiza şi sinteza numerică şi structurală a lanţurilor cinematice şi mecanismelor, Litografia I.P.B., 1967
20. [53] Tempea, I., Antonescu, P., IFToMM-SYROM Symposia on TMM: an Historical Overview, International Symposium on History of Machines and Mechanisms, Proceedings HMM-2000, Kluver Academic Publisher, p.223-239, 2000.
21. [54] Tempea, I., Popa, Gh., - Mecanisme plane articulate, Lito IPB, Bucureşti, 1978.
22. [55] Voinea, R., Voiculescu , D., Ceauşu, V., Mecanică, Editura Didactică și Pedagogică, Bucureşti, 1983
23. [56] Voinea, R., Atanasiu, M., Metode analitice noi în teoria mecanismelor, Editura Tehnică, Bucureşti, 1964
24. [58] Ocnarescu, C., Bogdan, R., Roboți industriali , editura printech , Bucuresti, 1997

25. [59] Buzdugan , Ghe, Izolarea antivibratorie a mașinilor- Editura Academiei 1980- pag.143, 368
26. [65] Rășchitor, E., **Radu, C., E.**, Tempea, I., *Anti-Vibration Insulation Possibilities Of The Overground Parking Over The Dambovita River. Antiseismic Protection Systems*, Annals of the „Constantin Brancusi" University of Targu Jiu, Engineering Series , No. 2/2019
27. [68] Adîr, G., M., Adîr, A., Adîr, A., Mecanisme.Teorie și Aplicații.Editura Printech, 2013
28. [69] Luca, L., Popescu, I., Rădulescu, Ct.- Structure and kinematics of a mechanism with stop- Journal volume&issue Vol 1 , no.15, pp.21-28, May 2015 , Fiability &Durability,ISSN 1844-640X, Academia Brancusi , Tg.JIU
29. [70] **Radu, C.,E**, Rășchitor, E.,Tempea, I., Auxiliary elevator activated with a translanting cam mechanism used for serving an overground smart parking lot above the Dambovița river.calculation of the buckling critical load of a rod pertaining to a roller traslating follower, Publishing House "Academica Brancusi" ISSN 1842-4856 , Engineering series no. 2/2019, ISSUE 2/2019, pg. 42-46
30. [75] Popovici, M.,M. , Staicu ,Șt., Mecanica tehnică- Cinematica și aplicațiile ei tehnice-Editura tehnică București 1982
31. [78] Legendi , A.,Pavel, C. - Dinamica mecanismelor – Editura MATRIX 2007 pag.158-159)
32. [79] Popovici , M.,M., Sinteze mecanice- Editura AndorTipo- București 2006
33. [80] **Radu, C., E**., Rășchitor, E., Tempea, I , System Made Up Of An Elevator Actuated By A Translating Cam And An Auxiliary Robot For Being Used In Overground Or Underground Parking , 12th Symposium Durability and Reliability of Mechanical Systems , SYMECH 2019,Tg-Jiu, Gorj,11-12 may 2019, Fiabilitate si Durabilitate No 1/ 2019- Editura "Academica Brâncuşi" , Târgu Jiu, pp. 50-55, ISSN 1844 – 640X
34. [84] http://www.mec.legacy.tuiasi.ro/RM2/capitole/Cap1.html
35. [85] Buzdugan, Gh., Rezistența materialelor, Editura Academiei-București 1986
36. [87] Popovici, M.,M., Mecanica tehnică- Statica și aplicațiile ei tehnice, Ed. Tehnică 1980-pag.170
37. [88] Alaci,S., Mecanisme cu came, Matrix Rom București 2016- pag.8
38. [89] Rădulescu, O., Sinteze optimale în construcția de mașini, Editura tehnică 1984
39. [90] https://mec.tuiasi.ro/wp-content/uploads/2023/05/curs-vibratii.pdf
40. [91] Legendi, A. - Mecanisme- Editura CONPRESS 2002].
41. [92] Deutsch, I., Rezistența materialelor, Editura Didactică și Pedagogică- București 1979-pag.412
42. [93] **Radu, C., E.,** Rășchitor, E., Tempea, I . , Identifying The Inherent Pulsation Of The Follower And Critical Resonance Speed For The Translating Cam Mechanism And Roller Translating Follower ,12th Symposium Durability and Reliability of Mechanical Systems , SYMECH 2019,Tg-Jiu, Gorj,11-12 may 2019, Fiabilitate si Durabilitate No 1/ 2019- Editura "Academica Brâncuşi", Târgu Jiu, pp. 44-49, ISSN 1844 – 64
43. [102] Benaroya,H., - Mechanical Vibration, Prentice Hall, 2001
44. [103] Meirovitch, I., - Elements of Vibration Analysis, McGraw-Hill Book Company, Inc.19
45. [104] **Radu, C., E.,** Rășchitor, E., Tempea, I , Evaluation of Own Pulses in the Event of FreeVibrations of a Multiparker Type Parking Machine Lifting Machine- ADEM 2018, Drobeta Turnu Severin 2018 «5th Conference of ADVANCES IN ENGINEERING & MANAGEMENT» November 1 th November 2 st , Management And Industrial Engineering pp. 57 ,,Advanced Engineering Forum - ISSN: 2234-991X, Vol.34, pp.137-142 https://www.scientific.net
46. [105] Magheți, I , Savu, M., Teoria și practica vibrațiilor mecanice- Editura didactică și pedagogică- 2007-

47. [106] **Radu, C., E.,** Rășchitor, E., Tempea, I, Studies On Optimizing Lifting Mechanisms. Evaluating The Behavior Of A Lifting Mechanism At An Elevator During An Earthquake, National Scientific Conference With International Participation "CONFERENG 2018" ,November 23th – 24th 2018, Târgu Jiu ,ROMANIA, Analele Universităţii „Constantin Brâncuşi" din Târgu Jiu Annals of „Constantin Brâncuşi" University of Târgu Jiu Seria Inginerie Engineering Series NR.2/2018 ISSUE 2/2018- Editura „Academica Brâncuşi" PUBLISHER, pp. 82 - 88, ISSN 1842-4856
48. [108] https://ftp.utcluj.ro/pub/users/chisalita/StudiiAprofundate/Structuri/Determinarea pulsatiilor proprii si a formelor proprii de vibratie-2012.pdf
49. [112] Vescan, S., D., Fodor, R., Șt.,Arghir, M., A XIII-a Conferință Națională Multidisciplinară de participare -Prof. Dorin Pavel- SEBEȘ 2013
50. [114] Normativ pentru proiectarea și execuția parcajelor pentru autoturisme, indicativ NP 24-97, din 28.11.1997. Publicat în Broșură nr. 1 din 28 noiembrie 1997. Formă aplicabilă la 01 octombrie 2019
51. [115] **Radu, C., E**., Rășchitor, E., Tempea, I., *The Adaptability Of Using A Cogeneration Installation When Actuating An Elevator*, Annals of „Constantin Brâncuşi" University of Târgu Jiu Seria Inginerie Engineering Series NR.3/2018 ISSUE 3/2018 - Editura „Academica Brâncuşi" PUBLISHER, pp. 48- 54, ISSN 1842-4856