Modelling and optimization of rotary parking system

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Abstract. The increasing number of vehicles in cities is a cause of traffic congestion which interrupts the smooth traffic flow. The established EU policy underlines the importance of restoring spaces for pedestrian traffic and public communication. The overall vehicle parking process in some parts of a city takes so much time that it has a negative impact on the environment. This article presents different kinds of solution with special focus on the rotary parking system (PO). This article is based on a project realized at the Faculty of Mechanical Engineering of Cracow University of Technology.

1. Introduction
The rapid development of motorization in Poland in the second part of the 1990s generated difficulties with commuting and parking motor cars at the workplace, schools, universities, market places and also in the place of residence, both in old and modern parts of the city.

Therefore it is necessary to ensure a sufficient amount of parking space for motor cars in the close vicinity of newly erected offices, malls, edifices, residential areas and multi-storey buildings.

Much more difficult problems arise when ensuring adequate quantity of parking space for cars in the existing building is concerned [3].

The idea of construing multi-storey parks has progressively developed all over the world and its scale can be measured by, e.g. the obligation to provide parking places (1.5 parking lots per one newly built household) in some of the West European countries [2].

Nowadays the mechanized and automated multi-storey parks are adjusted to the applied system and are equipped with such elements as slide plates or ramps, transport carriages, mobile floors, lifts, elevators, turntables, etc., and also the complicated control and automation system. Actually they do not differ too much from former mechanized systems, e.g. ‘Kent’, ‘Dolly’, ‘Autosilos’, ‘Buranelli’ or ‘Pigeon’, which used to be manufactured in the interwar period.

The mechanization and automation of moving vehicles within the car park area worked out in the western countries in the interwar period only partly contributed to the lowering of cubature index of the presently built objects without reducing the index of total space per one car, because the driving lanes were not eliminated. On the other hand these changes were associated with a high capital and exploitation cost, which in turn was not outbalanced by the substitution of reinforced concrete walls and floors with light steel constructions, typical of the presently used solutions [1].

Car parks offered by specialist companies, e.g. Wöhr, Doppelmeyer, Klaus or Parktec have about 35% surface loss (and so also cubature loss) for driving lanes. As a result the cost of one parking lot in these modern objects and in traditional ones is similar, and the only advantage is partially lowered cubature because of the lowered height of particular storeys (vehicles are moved without clients’ participation) [1].
Car parks and garages are a frequent problem encountered by the designers and investors, especially when the designed and modernized objects are planned in the city centre area. The lack of sufficient space, its high cost, limitations imposed by the water and soil conditions as well as the high cost of underground cubature frequently hinder the smooth placement and designing of offices, hotels, as well as residential and sometimes production buildings. The modernization of the existing buildings also meets problems with providing necessary garage or parking lots. These problems known in developed countries for years are now more and more frequently touching Polish designers, mostly in big agglomerations [1].

2. Analysis of car parking solutions
A comparative analysis of the preferred option, i.e. rotary (optimum) parking, with elements of other parking systems, was based on a review of literature on multi-storey mechanical car parks with special emphasis on solutions involving inter-storey rotary transport of cars, i.e. rotary car parks. The comparison was supplemented by a review of characteristics of traditional multi-storey (especially indoor ones) as typical construction objects. For the simplicity's sake, the following abbreviations have been used throughout this paper:
PA – automatic car park (generally),
PP – automatic car park with inter-storey progressive transport of cars,
PO – automatic car park with inter-storey rotary transport of cars (rotary parking),
PTW – traditional indoor multi-storey car park in a building object,
OPO – optimum rotary car park, preferred solution.

3. Justification of optimum type of car park OPO as a solution to the car parking problem
The OPO type car park (for a PO 10 model, i.e. for 10 cars as the smallest for this type of unit) was selected because of the following properties and parametric comparison with before mentioned car park types:
1) Coaxial, modular, increasing of the parking volume (up to 120 or more, thanks to which comparison analyses could be performed); the assumed direction of car entry/exit is rectangular to the drum,
2) No waste gases emission, making PTW (according to calculations in point 4) an 'environmental benefit' as compared to the OPO and all PA car,
3) about 50 percent energy savings as compared to the parking discussed in point 3 thanks to the smaller resistance in the rotational movement of the drum than in the progressive movement of the platforms, thanks to which the installed capacity can be increased twice,
4) about 60 percent shorter time of car retrieval than in a parking presented in point 3 (90 instead of 230 sec); shorter inner driving lanes and a bigger number of entry/exit stands,
5) object surface index 2.8 m$^2$/l lot generating about 22% and 86% saving as compared to car parks listed in points 3 and 4, respectively,
6) object volume index 48 m$^3$/l lot generating about 17% and about 47% saving on space as compared to car parks mentioned in points 3 and 4, respectively,
7) unit investment cost of 30,000 PLN/l lot generates about 60% and about 75% saving on capital cost in serial production as compared with car parks listed in points 3 and 4, respectively,
8) shortcomings of car parks PO and MP-750, presented in point 2.2, were eliminated by making the following design assumptions;
   - leveling of platforms with two prismatic guides (shape of a circle section), giving the openwork structure some lightness and possibility to support the drum on both sides,
   - the drive is shifted from the axis to the circumference of the side of the drum with the use of a cycloidal chain gear, which apart from minimizing the size of the drum bearing also provides full self-attenuation of its movement,
   - lowered depth of the trench to about 1/3 of the surface part, i.e. parameter conditioning rational assumption of self-acting (gravity-based) onward motion of parking cars (car enters on one side and leaves on the other),
   - the way in which cars enter and leave the parking eliminates driving lanes and access paths, thus reducing the terrain and space losses,
- modular multiplication of the parking space, limiting the consequences of potential break-downs of the system to one module only.

4. Description of rotary parking
The presented technical variant of a multi-storey automated car park is an avant garde solution meeting the goals discussed in this paper. And so, [1]:

- The capital cost of a parking lot in this solution is several times lower;
- The total space index is lowered;
- The average time of parking in and out is shortened;
- Its reliability increases;
- The cost of exploitation of the parking is lowered.

Generally, this car park, as visualized in Figure 1, resembles the Vienna 'Riesenrad or Chorzów 'Devil's Wheel' (Poland), where the carriages for people were substituted with parking platforms for cars. This car park rotates around the horizontal axis. There are no internal driving lanes or paths because each car goes directly to its parking lot. There are no roofs, carrying walls, poles and the gravitational transport of vehicles makes use of the existing slope of the drive-in way and does not require any mechanical aid or drives. This system is simple, cheap and reliable [3].

Depending on the size of the car park, the platform with hangers, installed rotationally on the sides of the drum, can be single or multi-storey, and each of the levels comprises two cars side by side. The size of the drum also depends on the number of arms with platform hangers [3].

The drum, fixed on two supports, rotates whereas the drive in and out is realized in the plane perpendicular to the rotation axis, at half of the drum's height. Accordingly, the car park is partly located in the ground and part of it is exposed on the surface [3]. An exemplary rotary car park solution has been presented in Figure 1.

![Figure 1. Rotary car park – exemplary solution.](image-url)

5. Model of a rotary car park – computer simulation and optimization of parking parameters
The car park was modelled at two stages: control automation and automation of mechanical part.

5.1. Model optimization of control automation – computer simulation
The automation of the drive in-park-drive away parking was based on a modelled control presented in Figure 2.
The automation tasks were realized with the use of a controller, e.g.: sensor Omron CJ1, providing 2560 signals of digital ins and outs, which in the case of the extended car park should extension of controller capacities. The software package Omron-CX-Programmer V4.0 was used for writing the program (Figure 2).

The program was divided into sections, which was facilitated by programming and easier use of the program. Each section is responsible for particular elements of car park control, as in the table below:

Section 1  Entry to platform no. 1
Section 2  Entry to platform no. 2
Section 3  Exit from platform no. 1
Section 4  Exit from platform no. 2
Section 5  Initial conditions
Section 6  Major problem
Section 7  Activate sub-programs
Section 8  Check out the parking for free lots
Section 9  Calculate weights
Section 10 Select position on platform no. 1
Section 11 Select position on platform no. 2
Section 12 Calculate angle of parking rotation on entry
Section 13 Realization of parking rotation
Section 14 Start counting the parking time
Section 15 Select position of exit
Section 16 Calculate angle of parking rotation on exit
Section 17 Realization of parking rotation
Section 18 Stop counting the parking time.

5.2. Description of optimization program
The assumed optimization program could be used more intensely, therefore authors presented fragments of the program controlling the operation of the car park responsible for finding an optimum...
solution for work: cost, access lane and efficiency. An exemplary solution of a drive-in and drive-away from the platform have been presented in Figure 3 and in Figure 4, respectively.

Figure 3. Algorithm of determining ‘enter’ position [2].
Figure 4. Algorithm of determining 'exit' position [2].

Knowing the number of cars and the distance of platforms from the centre of the car park, one can calculate the coordinates of the centre of gravity \( x_{cc}, y_{cc} \). The sub-program is used for calculating lengths of sections as a function of centre of gravity for each platform. Then the weights of mass of each of the platforms are defined on the basis of these lengths. After calculating the length of sections connecting the centre of gravity with each platform, the program sorts them out decreasingly, ascribing weights to each of them, where 1 corresponds to the platform staying closest to the center of gravity and 10 to the most distant one. In this way the number of the platform, onto which a given car should drive in to make the centre gravity closest to the centre of the car park, is established.

5.3. Verification of InTouch program

Now the process visualization systems are a very powerful and dynamically developing branch of automatic control. The visualization in the project have been realized with the versions of the InTouch 8.0 program. InTouch consists of three major programs: Application Manager, WindowMaker and WindowViewer [10].

The Application Manager of InTouch is used for managing created applications. It is also used for configuring WindowViewer as an NT service, configuring Network Application Development (NAD), both for client and server architectures, configuring Dynamic Resolution Conversion (DRC) and/or dispersed alarming. From the level of the Application Manager we can also activate database tools DBDump and DBLoad.
The WindowMaker program is an editing environment with object-oriented graphics used for creating anonymous windows and keys. These windows can be connected with industrial IN/OUT systems and also other applications of Microsoft Windows [10]. The WindowViewer is an Environment, where windows created with WindowMaker are displayed. WindowViewer performs scripts of InTouch. QuickScript collects archival data, processes alarm signals, generates reports, may work as a client or server, both for DDE communication protocol or for SuiteLink [10].

6. **Model optimization of construction part – computer simulation**

The computer simulation of the rotary car park was performed with the use of program C Robot BAT, thanks to which the construction nodes could be defined and the static and dynamic strength calculated. The forces acting on the prototype in real conditions could be determined. The static models create possibility of determining elements and nodes of the parking.

![Figure 5. Exemplary numeration of nodes.](image)

The results were presented in the form of plots. The curve of probability that a given momentum G was exceeded (M > Mk) has been presented at the assumed probability of drive-in/drive-out (Mode). The considered value: Mode={17, 33, 50, 67, 83}*100%. The number of trials in simulation MaxTrial = 10 000 was assumed on the basis of a comparison of results presented in Figure 6.
The computer simulation of the car park allowed for defining significant construction nodes. By assuming real conditions of the car park in the ROBOBAT program, attempts could be made to perform strength calculations (exemplary calculations provided). This extends the scope of the discussed problem and creates possibilities of further realization, i.e. construction of a prototype.

7. Concluding remarks

A car park model was worked out and some constituent systems selected on the basis of the project. The rotary car park model PO – 10 was designed as a reduction model in scale 1 ÷ 12.5 (to fit in the available car models in this scale). Prior to the building of the model, computer simulations of the nominal model, as well as the construction and exploitation analyses were realized. Then the model was construed. It consisted of a general description, function and limitations, design project with documentation, electronic project with documentation, design project with documentation of the model. The model consists of a mobile part with platforms where the cars are parked, electronic part, i.e. drive of the drum with regulated rotational velocity, automatic part allowing the cars to automatically drive-in to the parking lot and then exit. An original and characteristic way of entering and leaving the parking lot is based on the gravity motion generated by the inclination of the parking lanes, being the parking places.

The experiments on the gravity-based car movement (entering and leaving the parking) were performed.

The model experiments revealed that a 2° inclination of the parking lanes on exit and entrance was sufficient. This inclination also suffices to stop the car before entering the platform and then after entering the platform in the place of parking.

The tests were performed in real conditions (on 5 cars of different weight) for the 2° - 4° angle of inclination of the drive lane revealed that the inclination of 2° was sufficient.

The drive of the model drum was solved by a gear with toothed belt and electronic change control of rotation velocity (In real conditions – figure: ‘Drive of drum in a prototype of rotary car park PO-10” – further in the text). The rotation of the drum is activated by the drive system, where the motor drives the chain gear through the Nord flexible reducer. The pin chain is fixed in many points on the outer side of the drum. The total drivetrain \( i = 2550 \), which gives rotations of the drum \( n = 0.57 \) rpm.

Moreover by using the inverter to the electrical motor the rotations of the drum can be accelerated or slowed down.
The analysis of the reduction model, especially the reliability of the car movement within the car park area, necessitated seeking for technical solutions to the blocking problems. A construction solution of the drive in and out from the parking platform was also provided.

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