Proc. of the 2017 IEEE 4th International Conference on Smart Instrumentation, Measurement and Applications (ICSIMA)
28-30 November 2017, Putrajaya, Malaysia

Kinematic Analysis of Rotary Car Parking System Mechanism

Iim Nursalim[1], Hendri Maja Saputra[2], Nanang Ismail[3], Teddy Surya Gunawan[4]

[1,3]*Electrical Engineering Department, Faculty of Science and Technology, UIN Sunan Gunung Djati*
Jalan A.H Nasution 105, Cibiru - Bandung 40614, Indonesia
[1]imnursalim@gmail.com, [3]nanang.is@uinsgd.ac.id

[2]*Research Center for Electrical Power and Mechatronics, Indonesian Institute of Sciences*
Jl. Cisitu No.21/154D Sangkuriang – Bandung 40135, Indonesia
[2]hendri_maja@yahoo.co.id

[4]*Department of Electrical and Computer Engineering, Kulliyyah of Engineering, International Islamic University Malaysia,*
Jalan Gombak, 53100 Kuala Lumpur, Malaysia
[4]tsgunawan@iium.edu.my

***Abstract*— Due to the increased number of vehicles in big cities, parking space become an inherent problem. Recent research on rotary car parking system (RCPS) showed its potential in saving space and time during parking. This paper discussed the kinematic analysis of the RCPS based on the given angle providing automatic power measurement while reducing calculation errors in the final design. The proposed RCPS is designed using six slots, in which each slot has the capability to accommodate only one car. The trigonometric approach is used to derived the equations, in which the RCPS mechanism achieved using different angle, including 0° - 90°, 90° - 166°, 166° - 180°, 180° - 194°, 194° - 270° and 270° - 360°. In this paper, two equations were derived to determine the optimum coordinate positions and the minimum power required. Simulation results showed that when all six slots were occupied, the total mechanical load is 1800 kg. The maximum power requirement is 492.73 watt for the unbalanced load.**

Keywords—kinematic; rotary car parking system; geometry design; maximum power.

I. INTRODUCTION

In the past few years, the rapid increased of number of vehicle each year is not compensated by increased number of parking space. As a result, finding parking space is nearly impossible in the metropolitan area especially during office hours. Irregular and illegal parking in the sidewalks and roadside become the norm. Moreover, the current conventional parking systems cannot provide a safe parking system, in which vehicle theft and other criminal acts were recorded every day.

There are two types of parking systems, including conventional/self-parking and mechanical/elevated parking. Conventional parking is commonly used in Indonesia. On the other hand, mechanical parking is a new type of parking system which uses mechanical and automated system with an electric power source to minimize parking space used while maximizing number of vehicles that can be parked safely. The mechanical-based parking system has several types, including rotary parking system, multilevel car parking, optima car parking, and speedy tower car parking [1]. In this paper, the parking system model used is rotary car parking system (RCPS).

The required area to design an RCPS can be calculated as three car spaces horizontally while it can accommodate six to twelve cars vertically [2]. This system consists of several platforms for vehicle storage slots and it uses a rotating elevator.

Narone et al. [1] explains about several models of the efficient vertical parking system, such as integrated car parking solution, automated car parking, multi-level parking and rotary parking system. They found that rotary parking system is the most simple and efficient parking model compared to the other methods. RCPS uses gear and chain grate on the motor to drive the car storage slot. RCPS has several advantages, including design and development are safe for a vehicle, saving time, money and fuel, minimize pollution, eco-friendly structure, and the design can adapt to environmental circumstances using modern technology [3].

Of the many advantages, RCPS requires proper positioning and power supply calculation to avoid failure. Determining the location and distance of the slot will affect motor speed and power requirements. Power and speed requirements were also affected by the amount, size, and load of each slot. Although many researches have been conducted on RCPS designs, but different RCPS design required different kinematic analysis which analyze the transformation of rotational motion into translational motion. Therefore, the objective of this paper is to conduct a kinematic analysis on RCPS and to obtain an optimum position and the minimum power requirement. The minimum power requirement will be used to select a proper motor capacity. Simulation will be conducted to verify our proposed model.

II. LITERATURE REVIEW

Traditional parking systems required large area, while the safety and security is not guaranteed. Using RCPS concept, the required are is around 32m^2 [2]. Figure 1 illustrates the working mechanism of an RCPS. The structure of RCPS consists of several components and pars as shown in Table I [4]. Figure 2 illustrates one slot in RCPS, where all the component and parts are integrated.

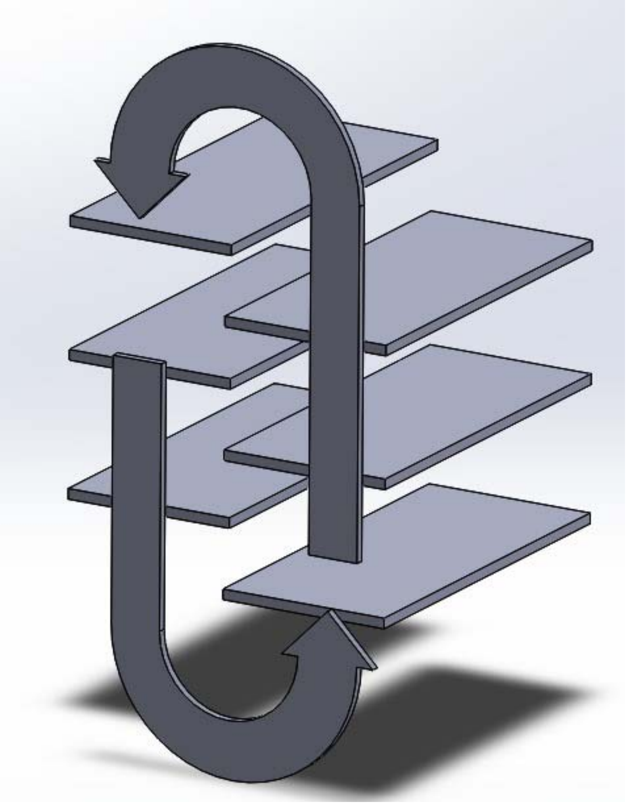

Fig. 1. Working mechanism of RCPS [2]

TABLE I. COMPONENT AND PART OF ROTARY PARKING SYSTEM

No	Component	Function
1.	*Pallet hanger*	The place for hang platform structure
2.	*Hanger bar*	Connector between bar and pallet hanger
3.	*Platform*	Base for car parking
4.	*Bar*	Connector both of pallet hanger
5.	*Frame bar*	Platform supporting structure
6.	*Support bar*	Platform supporting structure

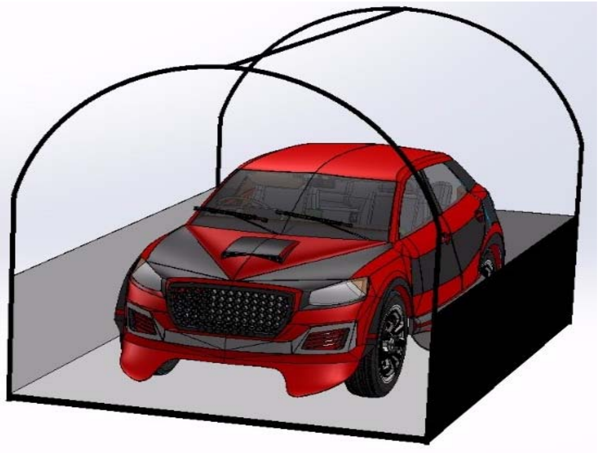

Fig. 2. RCPS parking slot

There is a kinematics inverse problem in RCPS. It is the most basic thing in mechanical control system due to the change of position and orientation. Manoca and Canny [5] explained that geometric function has two weaknesses. Firstly, the function needs a lot of time if applied practically. Secondly, geometric function is not able to find all solutions. The angle movement from the main pivot point to the slot point for each rotation will vary.

The angle movement in RCPS involves kinematic movement. Kinematic analyzes position, speed, and acceleration of all link calculated regardless of the forces that cause movement. The mechanism of kinematic RCPS can be divided into two types, including forward and reverse kinematic. Forward kinematic analyzes motion to obtain its coordinate position (x, y) if the rotation angle is known. While reverse kinematic analyzes motion to obtain its rotation angle if the coordinate position (x. y) is known [6]. Trigonometric equation could be used for this purpose.

Motor rotation is affected by torque. Electric torque is the strength of motor rotation related with voltage and current, as shown in Eq. (1).

$$\tau_e = \frac{(P\eta 60)}{(\omega 2\pi)} \tag{1}$$

where τ_e is electic torque, P is the amount of power generated (watt), ω is the rotaional speed of the motor (rpm), and η is the motor efficiency. In RCPS, not only electric torque, but mechanical torque presents as well. The mechanical torque is related to the force, car mass, and slot mass, as shown in Eq. (2).

$$\tau_m = w \times r = m \times g \times r \tag{2}$$

where τ_m is the magnitude of mechanical torque (Nm), w is the weight of the load (N), r is the relative position of the fall point of w to the center of the circle, and g is the gravitaional force (9.81 ms^{-2}). The illustration to determine the r value, i.e. x_{max}, can be seen in Fig. 3.

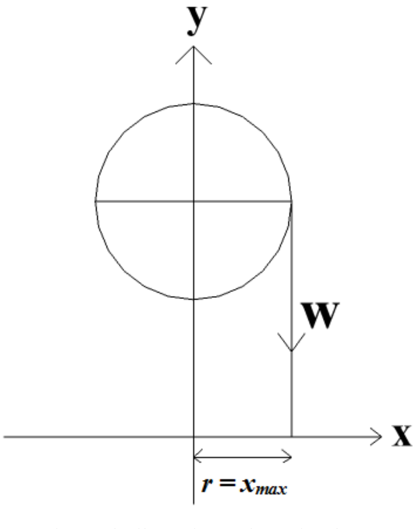

Fig. 3. The ilustration to determine the r

III. METHODS AND MEASUREMENTS TECHNIQUES

The model used in kinematic analysis to produce an RCPS mathematical model is shown in Fig. 4. It is assumed that one slot can only be occupied by one car. In the parking system mechanism as shown in Fig. 3, there are angles θ and slot positions in coordinates (x, y).

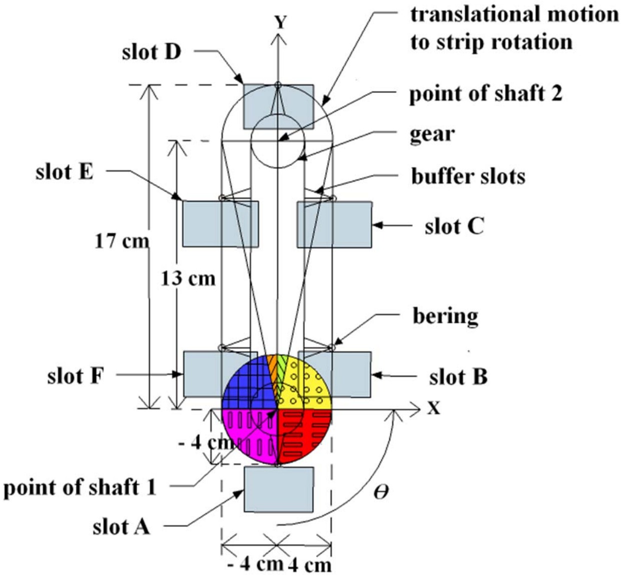

Fig. 4. RCPS scheme

The RCPS divides its angle into six parts, i.e. (0° - 90°), (90° - 166°), (166° - 180°), (180° - 194°), (194° - 270°), and (270° - 360°). The division is based on the change of the rotational motion to the translational motion, vice versa.

The division of these angular values is based on manual measurements due to the shape of the system mechanism that changes from the rotational motion into translational motion and otherwise repeatedly. Using the trigonometric approach, we can determine the position of the joint slot point for each of the angle groups using Eq. (3) and (4). These equations has been validated manually using ruler and protactor.

$$x = \begin{cases} x_1 = x_{max} \sin\theta & (0 \le \theta \le 90°) \& (270° \le \theta < 360°) \\ x_2 = x_{max} & (90° < \theta < 166°)\ (194° < \theta < 270°) \\ x_3 = y_{max} \sin\theta & (166° \le \theta \le 194°), \end{cases} \tag{3}$$

$$y = \begin{cases} y_1 = y_{max} \cos\theta & (0 \le \theta \le 90°) \& (270° \le \theta < 360°) \\ y_2 = -y_{max} \cos^5\theta & (166° \le \theta < 194°) \\ y_3 = y_{max} \sin\theta & (90° < \theta < 166°) \& (194° < \theta < 270°) \end{cases} \tag{4}$$

To estimate the power requirements to hold RCPS slot statically, Eq. (5) is derived by subtituting Eq. (2) to Eq. (1).

$$\tau_e \ge \tau_m \Leftrightarrow \frac{P.\eta.60}{\omega.2\pi} \ge m.g.r \tag{5}$$

By assuming that the values of ω, g, π, η are constant, and m_c is a variable, then Eq. (5) could be derived to further calculate the minimum power requirement to hold RCPS, as shown in Eq. (6).

$$P \ge m_s g \omega 2\pi \frac{(m_{cA}r_A + m_{cB}r_B + m_{cC}r_C + m_{cD}r_D + m_{cE}r_E + m_{cF}r_F)}{\eta 60} \tag{6}$$

where ω is the rotational speed of the motor (rpm), m_s is the slot mass, m_{cI} is the car mass in the slot I, and r_I is x value of the gravity drop point for each position of the slot joint I with $I = \{A, B, C, D, E\}$. Slot B and C have $r = x_{max}$, i.e. 4 cm, slot E and F is -4 cm, and slot D is 0 cm.

Table II shows the simulation parameters for Eq. (6). The example value of the car mass (m_c) and the rotational speed (ω) were taken from [3], while the mass of slot (m_s) and motor efficiency (η) was obtained based on our own assumption.

TABLE II. SIMULATION PARAMETERS

No	Parameter	Value
1	Mass of cars (m_c)	1800 kg
2	Mass of slot (m_s)	300 kg
3	Rotation speed (ω)	0.1 m/s
4	Motor Efficiency (η)	90%

IV. RESULTS AND ANALYSIS

Based on Table II, we conducted extensive simulation. Eq. (3) and (4) were used to obtained the position of slot joint coordinates (x, y). The coordinate positions are obtained from the angle rangingin from 0° to 360°. The calculated values are then plotted and compared to the manual trajectory. Fig. 5 shows the simulation error.

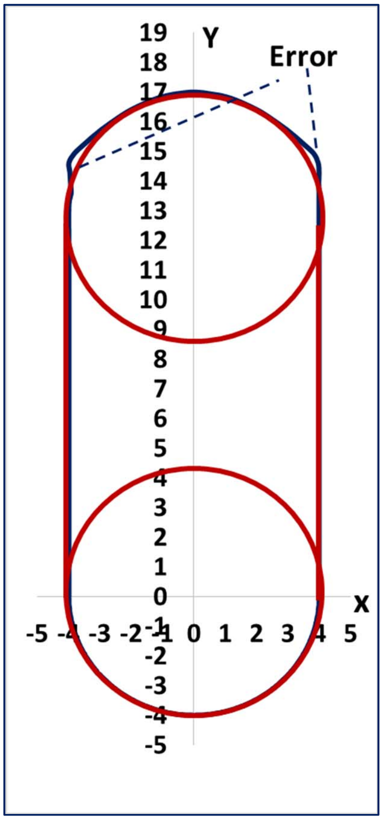

Fig 5. Simulation Error

Fig. 5 shows that Eq. (3) and (4) are valid.The red line is the manual trajectory, while the black line is obtained from Eq. (3) and (4). There are two small error visible, which is the error in the positive x-axis in the range of 163° to 175°, and the error in the negative x-axis in the range of 185° to 197°, as highlighted in Fig. 6 and 7. Maximum error of 9.3 % occurs at the angle of 194°.

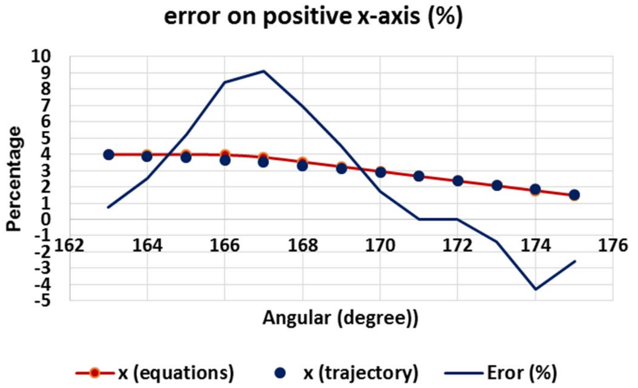

Fig 6. Error in the angle range of 163° to 175°

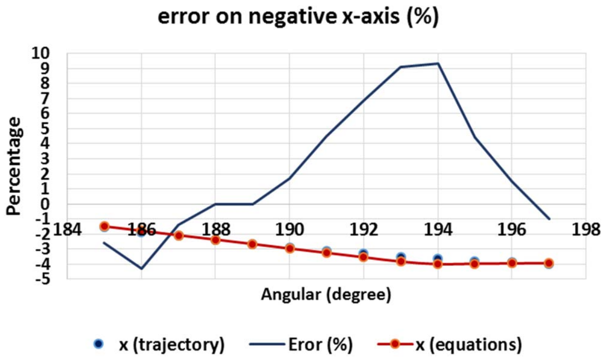

Fig 7. Error in the angle range of 185° to 197°

The next simulation is to find minimum power required. The required power is related to the electric torque (τ_e) and the mechanical torque (τ_m) as described in Eq. (5). Simulation is conducted by varying number of parking slots occupied. This simulation only evaluates the instantaneous power required to hold RCPS statically, and not during the rotation. Table III shows the simulation of power requirements when the number of parking slots, car mass (m_C), and the value of x gravity drop point for the slot joint position (r) are varied. The parking slot A, B, C, D, E has the value of 1 if the particular slot is occupied by a car.

Based on the minimum power requirement simulation, there are four position of highest values, i.e. 492.73 watt, highlighted by red circle in Table III. The highest power required is obtained when each parking slot is occupied by car with weight of 1800 kg. The unbalanced mechanical position causes the power requirement to be higher, while the balanced position requires power of 0 watt. In summary, the number of occupied slot and the position of the slot will affect the power required to withstand the mechanical load.

TABLE III. THE EFFECT OF TOTAL MASS AND SLOT POSITION TO THE MINIMUM POWER REQUIREMENT

No	Car Mass (mc)						P (watt)
	A	B	C	D	E	F	
1	1	1	1	1	1	1	-
2	1	1	1	1	1	0	246,365
3	1	1	1	1	0	1	246,365
4	1	1	1	1	0	0	492,730
5	1	1	1	0	1	1	-
6	1	1	1	0	1	0	246,365
7	1	1	1	0	0	1	246,365
8	1	1	1	0	0	0	492,730
9	1	1	0	1	1	1	(246,365)
10	1	1	0	1	1	0	-
11	1	1	0	1	0	1	-
12	1	1	0	1	0	0	246,365
13	1	1	0	0	1	1	(246,365)
14	1	1	0	0	1	0	-
15	1	1	0	0	0	1	-
16	1	1	0	0	0	0	246,365
17	1	0	1	1	1	1	(246,365)
18	1	0	1	1	1	0	-
19	1	0	1	1	0	1	-
20	1	0	1	1	0	0	246,365
21	1	0	1	0	1	1	(246,365)
22	1	0	1	0	1	0	-
23	1	0	1	0	0	1	-
24	1	0	1	0	0	0	246,365
25	1	0	0	1	1	1	(492,730)
26	1	0	0	1	1	0	(246,365)
27	1	0	0	1	0	1	(246,365)
28	1	0	0	1	0	0	-
29	1	0	0	0	1	1	(492,730)
30	1	0	0	0	1	0	(246,365)
31	1	0	0	0	0	1	(246,365)
32	1	0	0	0	0	0	-
33	0	0	1	1	1	1	(246,365)
34	0	1	1	1	1	0	246,365
35	0	1	1	1	0	1	246,365
36	0	1	1	1	0	0	492,730
37	0	1	1	0	1	1	-
38	0	1	1	0	1	0	246,365
39	0	1	1	0	0	1	246,365
40	0	1	1	0	0	0	492,730
41	0	1	0	1	1	1	(246,365)
42	0	1	0	1	1	0	-
43	0	1	0	1	0	1	-
44	0	1	0	1	0	0	246,365
45	0	1	0	0	1	1	(246,365)
46	0	1	0	0	1	0	-
47	0	1	0	0	0	1	-
48	0	1	0	0	0	0	246,365
49	0	1	1	1	1	1	-
50	0	0	1	1	1	0	-
51	0	0	1	1	0	1	-
52	0	0	1	1	0	0	246,365
53	0	0	1	0	1	1	(246,365)
54	0	0	1	0	1	0	-
55	0	0	1	0	0	1	-
56	0	0	1	0	0	0	246,365
57	0	0	0	1	1	1	(492,730)
58	0	0	0	1	1	0	(246,365)
59	0	0	0	1	0	1	(246,365)
60	0	0	0	1	0	0	-
61	0	0	0	0	1	1	(492,730)
62	0	0	0	0	1	0	(246,365)
63	0	0	0	0	0	1	(246,365)
64	0	0	0	0	0	0	-

V. CONCLUSONS

This paper has presented the kinematic analysis of rotary car parking system. Mathematical equations have been derived systematically to relate the electric torque with the mechanical torque. Subsequently, the minimum power required to rotate and withstand a mechanical load has been successfully derived. The maximum error has been found to be 9.3% at the angle of 194°. Maximum power requirement of 492.73 watts occurs when there is unbalanced load. This estimate could be used further to determine the motor capacity.

ACKNOWLEDGMENT

The authors gratefully acknowledge the support provided by the Indonesian Institute of Sciences and Department of Electrical and Computer Engineering, International Islamic University Malaysia. We also like to thank Mr. Mufid Ridho for the fruitful discussion, and Ms. Sinta for her helps.

REFERENCES

[1] S. G. Narone, S. S. Chabukswar, S. A. Valyal and R. B. Hirapure, "Vertical Car Parking – A Prototype," *Int. J. Emerg. Technol. Adv. Eng,* vol. 5, no. 4, p. 199–203, 2015.

[2] P. Raman, A. Kumar and R. P. Kushwaha, "Rotary Automated Car Parking System," *Int. J. Sci. Eng. Technol. Res,* vol. 5, no. 5, pp. 1788-1791, 2016.

[3] P. Pashte, V. Narkhede, S. Nade and S. More, "Design and Analysis of Rotary Automated Car Parking System," *Int. J. Sci. Res. Dev.,* vol. 4, no. 4, pp. 28-31, 2016.

[4] N. Nasir, H. Rashid, A. H. Abdullah, M. Azzeim and a. M. Jusoh, "Rotary Car Park (Pallet Design) Computer Aided Design Analysis Study," *IEEE Symp. Business, Eng. Ind. Appl - IEEE Symp. Business,* pp. 512-515, 2011.

[5] D. M. a. J. F. Canny, "Efficient Inverse Kinematics for General 6R Manipulators," *IEEE Trans. Robot. Autom,* vol. 10, no. 5, pp. 648-657, 1994.

[6] W. Budiharto, Modern Robotics - Theory and Implementation (in Bahasa Indonesia), vol. Robotika Modern, Yogyakarta: Andi Publisher, 2014.