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ENHANCING HIGH-SPEED PERFORMANCE: MODIFICATION OF BOOM BARRIER GATE WITH PUSH BRAKING SYSTEM FOR ETC APPLICATION

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Abstract

Congestion at toll roads has become a pervasive issue in contemporary times, predominantly manifesting at toll booths during the payment process. A noteworthy contributor to this congestion has been identified as the sluggish operational speed of boom gates. In response to this challenge, a modification strategy was implemented to enhance the operational efficiency of existing boom gates. The primary modification involved substituting the conventional electric motor with a more advanced Brushless DC (BLDC) motor boasting a power rating of 660 watts. Additionally, an innovative augmentation integrated a motorcycle disk brake system into the boom gate mechanism. Replacing the original electric motor's internal brake system with the disk brake system aimed to optimize the overall performance of the boom gate. The integration of the motorcycle disk brake system was further complemented by incorporating the push braking system (knoken braking system), serving as the actuator instead of the traditional motorcycle lever handle. This strategic substitution was instrumental in activating the disk brake function at the boom gate. During peak rush hours, the modified boom gate underwent rigorous testing at both the Ciawi and Kelapa Gading toll gates. Results from the trial activities unveiled a remarkable improvement in the boom gate's operational speed. Specifically, the opening speed demonstrated an impressive surge of 51 percent, catapulting from 548 ms to 265 ms. Similarly, the closing speed exhibited a commendable enhancement of 44 percent, elevating from 602 ms to 332 ms. Furthermore, the boom gate cycle per hour experienced a notable escalation, increasing by 25 percent from 356 to 449 cars per hour. These findings underscore the efficacy of the implemented modifications in ameliorating congestion issues at toll booths.

Keywords: High Speed Barrier, Electronic Toll Collection, Push Braking System, BLDC Motor

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1. Introduction

Technological advancements make toll road equipment technology more efficient in making toll road payments more practical and ideal, allowing toll charge payments to be made via automatic or contactless services [1]. Zhang [2] proves that contactless or without-stop payments are the most effective payment methods. To support the Electronic Toll Collection (ETC) system, a high-speed boom gate device has been developed to help smooth traffic flow at toll booths. A boom gate is a portable gate with an open and close ability to prevent vehicles from passing through some restricted areas. Boom gate operates using the principle of acceleration and deceleration, affecting the opening and closing speed. Both processes require a well-designed braking system to move quickly and safely. Besides their use on toll booths, boom gates were widely used in the parking industry, too. Generally, boom gates used in the parking industry have low speeds. Meanwhile, when it comes to the toll road industry, the speed is faster enough.

The gate design was customized with the faster motor driver to make the boom faster. In case of speeding up the motor driver, the boom gate needs some braking system to reduce the high-speed reaction safely. Halim [3] creates a boom gate with an AC motor as its driving force; the AC motor also serves as a brake for the boom gate. The AC motor is usually used in the parking system, resulting in an average speed of 1.5 seconds. Zhang [4] uses rocker arm systems and electric motors; this system is utilized to perform the braking procedure at the boom gate. To speed up the boom gate, we need to maximize the motor speed, but we also have to make

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a proper braking system to decelerate the boom gate. Cunico [5] created a boom gate with 1-second speed that was powered by a DC motor. DC motors provide a regenerative or regenerative braking effect on the motor during the process to obtain higher and safer boom motion rates.

Meanwhile, nowadays, many securities barrier companies create high-speed boom gates. Dashou [6], a security tools company from China, has already built a high-speed 0.3-second version of the boom gate. Dashou's high-speed boom gate was made using rocker arm features combined with a servo motor. The Servo motor that was used was able to conduct the braking system, too, so the performance of the boom gate will be smooth and safe. Then, the Automatic System [7] also builds some high-speed 0,4-second boom gates. That boom gate uses a rocker arm and AC motor to conduct braking the boom gate.

In Indonesia, toll roads' locally fabricated boom gates commonly use Brushless Direct Current (BLDC) motors as the main power driver of the system. BLDC was chosen because of its high-speed ability and ease of maintenance. BLDC motors also have high torque characteristics to lift up heavy loads [8]. This locally fabricated boom gate on an Indonesian toll road has a 0,5 second open and close speed. Due to the increasing toll road traffic, this boom gate needs to speed up its speed. The existing model of the boom gate cannot achieve a higher speed.

In this study, the modification of the existing boom gate was conducted by changing the electric motor and creating a braking mechanism using a disk brakes system to reach an opening and closing speed of 0.3 seconds. Disk brakes are commonly utilized in motorized vehicles and have been shown in practice to be capable of braking rapidly and safely. The disk brake will replace the regenerative braking function of the electric motor in its use in the boom gate so that the electric motor can increase the boom gate opening and closing speed time.

2. Experimental and Procedures

Experimental research was the method used in this study. The experiment subject was an existing boom gate used on the Indonesian toll road. The research applies to three stages: design concept, test equipment preparation, and unit testing. Designing the concept is done using the morphological chart method. Then, in the preparation stage, the test equipment is applied as experimental unit objects and CAD modeling. This research was conducted by modeling CAD designs in Solidworks. Solidworks was a CAD modeling software used for structural work [9]. CAD modeling is intended to minimize production errors. The use of CAD will make modeling faster and cheaper, making the design process more effective [10]. To prove the design, a boom gate unit trial was created. The trial was conducted in some Indonesian toll road booths. Tools and materials prepared to create unit trial specimens [11].

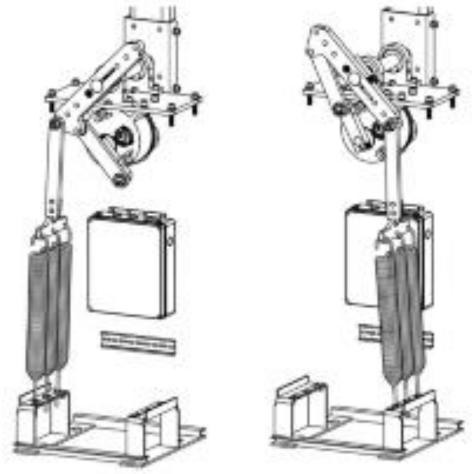

Fig. 1. Rocker arm system [6]

Table 1. Morphological chart for boom gate new version

Parts	Specifications
Motor Driver	BLDC 350W 48VDC 3000 rpm
Power Consumption	75 – 450 Watt
Boom Length	Customize (2.00 – 3.00 meter)
Boom type	Aluminum tube
Opening speed	0.5 second
Closing Speed	0.5 second

2.1 Existing Unit

Boom gate that being modified was the boom gate that commonly used in Indonesian toll road. The existing boom uses rocker arm for its mechanism and BLDC motor as its main driver. Rocker arm was a mechanism structure that allowed locking ability whenever the arm position reach the maximum level. The image of the rocker arm system is shown in Fig. 1 below. BLDC motor was used because of its high speed and easy maintain characteristic. On this model the braking system used internal motor braking. The specification of the existing model is shown in Table 1 below. This existing unit of boom gate currently being used in many tolls' road booth in Indonesia.

2.2 Concept Design

This boom gate was created by improving on a prior model that was previously used on toll

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highways. The boom gate of the previous generation opened and closed in 0.5 seconds. The opening and closing times are gained by using a BLDC motor as the prime mover and the internal brake of the motor itself for the braking function. The ability to open the boom gate is a top priority because, with the faster opening speed of the boom gate, congestion at toll booths can be minimized. We need a new mechanism to fulfill this function to obtain a speedier opening speed. The additional mechanism designed is a braking mechanism with disk brakes but still uses the same driving motor. The morphological chart method is used to create the new boom gate concept, as shown in Table 2. The morphological chart is commonly used to overcome product variant design; the method was conducted by changing specific parameters of some features from existing designs [12]. Also, the morphological chart was a way to restructure components from various combinations for design exploration systematically [13].

Table 2. Morphological chart for boom gate new version

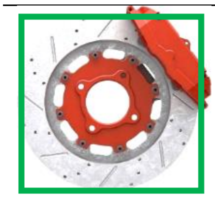
Principal Solution		
1	2	3
Motor Drive		
 Servo Motor	 BLDC Motor	 Stepper Motor
Boom Type		
 Aluminum Tube	 Carbon Tube	 Fiberglass Tube
Braking System		
 Disk Brake	 Internal Motor Brake	 Magnetic Powder Brake
Actuator for Braking		
 Ball-screw	 Leadscrew	 Solenoid

Table 3. Electric motor specification comparison

Specification	Existing Motor	Motor 660W
Voltage	48 VDC	48 VDC
Rated Power	350 W	660 W
Rated Speed	3000 rpm	3000 rpm
Rated Current	17 A	17 A
Rated Torque	1.2 Nm	2.1 Nm
Temperature	55ºC	55 ºC

In the utilization of a morphological chart for this study, a holistic approach was adopted, recognizing the interdependence of all components. The analysis of the effects of related components was meticulously conducted [14]. The choice of a BLDC motor for the boom gate unit design was a deliberate decision based on the existing model's use of a BLDC motor, thereby minimizing modification costs. Additionally, the BLDC motor's superior speed, when compared to other motor types, influenced this selection. Although alternative materials such as carbon and fiber are lighter in weight, the decision to retain aluminum for the boom gate material was grounded in their scarcity in the market.

The selection of motorcycle disk brakes for the braking system was motivated by their ability to generate instant and rapid braking force. To replace the hand levers commonly found in motorcycle systems, actuators in the form of ball screws powered by electric motors were employed. This strategic choice was made to enhance the efficiency of the braking system.

The primary objective of this study was to modify the boom gate to achieve faster opening and closing speeds, thereby mitigating queues at toll booths. The existing unit underwent modification by substituting the original electric motor with a more potent BLDC motor with a power rating of 660 watts. A detailed motor comparison, as presented in Table 2, revealed that the 660-watt motor exhibited power and torque values two times higher than its predecessor. The rationale for choosing this motor lay in its superior power within the electric motor industry, surpassing the existing motor by one power grade. Importantly, the BLDC motor 660-watt retained compatibility with the existing electric motor driver controller due to the shared voltage parameter. The integration of the BLDC motor 660-watt into the boom gate motor mounting was seamless and required no additional components, as depicted in Fig. 2 below.

This study designed a mechanism to accommodate the disk brake system on the boom gate so that it can function similarly to a motorcycle

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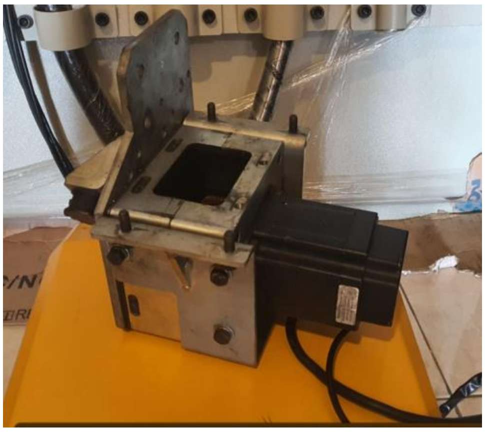


Fig. 2. Motor 660 watt attach in existing boom gate mount

disk brake. Motorcycles utilize the principle of a lever to apply hydraulic brakes to grip the disk. This study uses the same braking mechanism but changes the manual lever function to automatic using an electric motor. Later in this research, it will be called a knoken braking system that was developed by PT. Jasa Marga for high-speed barrier gate application.

The knoken braking system was an automatic lever pusher made from a combination of a ball screw and an electric motor. This tool will work when the boom gate is conducting a deceleration process, so it can still conduct braking even though the high-speed process is running.

2.3 Equations

The boom gate has a prime mover in the form of an electric motor whose speed is limited using a gearbox. The gearbox has an arrangement of gears that form a gear ratio. Gear ratio is the transmission ratio between the gearbox input and output. Gearbox transmission performs for changing the motor's power to match the loads' characteristics [15]. In the gearbox, gears rotate, which drives the output shaft to transmit the force vertically to other rotating shafts [16]. If the value of the rotation of the wheel on the driving gear is expressed by n_1 (rpm) and the value of the rotation on the driven gear is expressed by n_2 (rpm), the diameter of the circle distance for d_1 and d_2 (mm), and the number of teeth z_1 and z_2, the gear ratio is calculated by equation 1 as follows [17]:

$$i = \frac{z_2}{z_1} = \frac{d_2}{d_1} = \frac{n_1}{n_2} \tag{1}$$

The use of a BLDC motor 600-watt on the existing boom gate will be evaluated by calculating the operation time generated by the boom gate system using the following equations [18]:

$$a = \frac{(V_2 - V_1)}{(t_2 - t_1)}$$

$$t = \frac{(V_2 - V_1)}{a}$$

Where :
ɑ = Linear acceleration (m/s^2)
v = Linear speed (m/s)
t = Time (s)

To calculate the open and close speed time of the boom gate, the linear acceleration must be found first by converting the angular acceleration of the boom gate. Then, the open and close time speed can be calculated with the equations below.

$$a = \omega^2 . r$$

$$v = \omega . r$$

$$\omega = \frac{2\mu}{60} . n \tag{2}$$

$$t = \frac{(\omega_2 - \omega_1) . r}{\omega^2 . r} \tag{3}$$

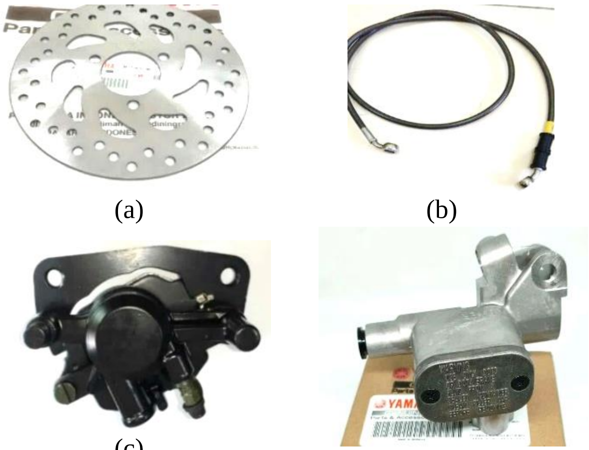
Where :
ω = angular speed (rad/s)
r = radius (m)
v = linear speed (m/s)
a = linear acceleration (m/s^2)
t = boom gate operating time (s)

2.4 Knoken Braking System Design

To enhance the braking capabilities of the boom gate, an external braking system akin to a motorcycle disk brake was introduced in this research. This addition was deemed crucial to ensure that the boom gate could achieve braking functionality analogous to that of a motorcycle. The components utilized in this disk brake system encompass disks, brake lines, and calipers. Figure 3 visually represents these four integral components, each tailored for seamless integration into the boom gate under conditions mirroring motorcycle-like installations. The modification and adaptation of these components were meticulously executed using Solidworks 3D, allowing for a comprehensive and precise assembly process.

The application of a 3D fabrication approach played a pivotal role in optimizing the overall design of the braking system. This approach was strategically employed to balance and enhance the stability of the boom gate, as highlighted in the optimization process [19]. By focusing on design stability improvements, the research aimed to ensure the robust performance of the braking component, thereby contributing to the overall efficiency and reliability of the modified boom gate system.

Integrating the braking system into the boom gate



(a) (b)

(c) (d)

Fig. 3. Brake component; a) brake disc, b) brake hose c) caliper, and d) master cylinder

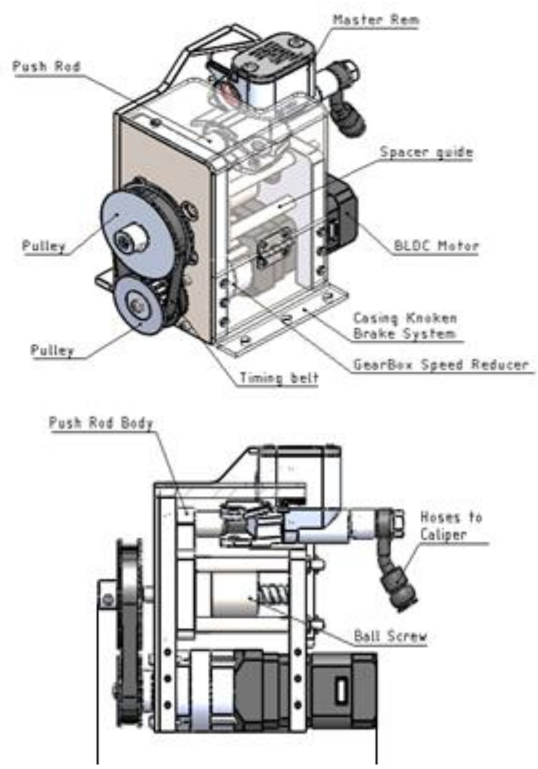


Fig. 4 Component of knoken braking system

involves its attachment to the boom gate axle, analogous to a motorcycle wheel axle. The operational principle is such that the boom gate shaft rotation is gradually halted through the caliper's firm grip on the disk. This deceleration is primarily induced by the friction generated between the brake pad on the caliper and the disk's surface.

For the practical application of the brake mechanism to the boom gate, a mechanism that can autonomously move instead of the traditional brake lever on a motorcycle is imperative. This substitute mechanism is called the knoken braking system, designed to replicate the functionality of a motorcycle's brake handle or lever. The constituent elements comprising the knoken braking system are meticulously illustrated in Fig. 4 below. The implementation of the knoken braking system ensures a seamless and automated activation of the braking system on the boom gate, aligning with the efficiency and automation goals set for this modified system.

The knoken braking system depicted in Fig. 4 undergoes a transformative process wherein the rotation of the BLDC motor is converted into translational motion on the ball screw through the intermediary pulley. In the figure, the dimensions of the knoken braking system are meticulously configured to ensure a safe size, maintaining a distance of 176 mm from the maximum limit of 186 mm. This dimensioning optimization aligns with safety considerations and operational efficiency. The ensuing movement involves the ball screw carrying the push rod along the pre-established trajectory, ultimately exerting pressure on the master cylinder. The schematic representation of the movement mechanism of the knoken braking system is visually elucidated in Fig. 5, detailing the sequence of operations in four distinct steps.

Step 1, involves the transmission of rotation from the electric motor to a speed-reducer gearbox, thereby reducing the rotational speed (rpm) produced by the motor while concurrently increasing its torque.
Step 2, sees the reduced rotation transmitted to the drive pulley, linked by a transmission belt to the driven pulley.
Step 3, the driven pulley induces the rotation of the ball screw shaft, instigating translational movement toward the master cylinder.
Step 4, culminates in the rotating ball screw compelling the push rod towards the master cylinder, resulting in the pressing of the master cylinder. This action initiates the flow of hydraulic fluid from the master cylinder reservoir through the brake hose to the caliper, facilitating the activation of the braking system.

The intricacies of these sequential steps underscore the precision and efficacy of the knoken braking system in automating the braking process for the modified boom gate.

During the pressing process, the push rod executes the action of pressing the master brake to its maximum extent, achieving the pinnacle condition when the master brake is fully engaged. After the complete compression of the master brake, hydraulic fluid is directed to the caliper piston, prompting the brake pads to exert pressure on the disk and swiftly bring the boom gate to a halt. The

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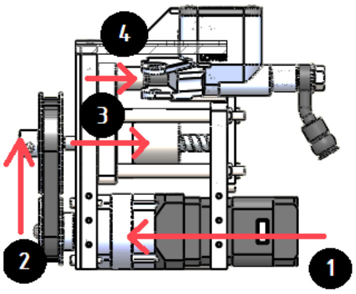


Fig. 5. Knoken braking system working scheme

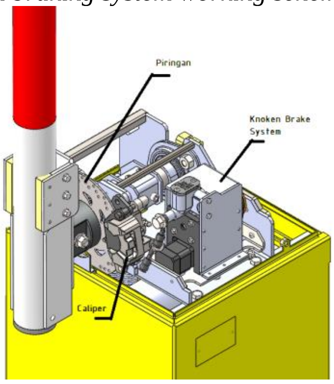
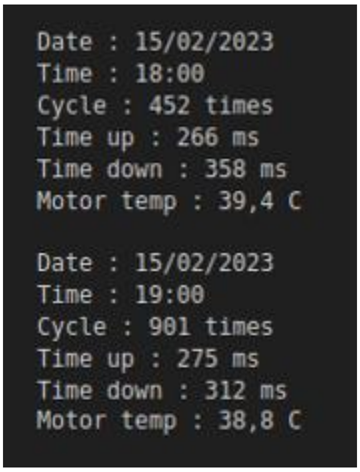


Fig. 6. Knoken braking system position in boom gate



```
Date : 15/02/2023
Time : 18:00
Cycle : 452 times
Time up : 266 ms
Time down : 358 ms
Motor temp : 39,4 C

Date : 15/02/2023
Time : 19:00
Cycle : 901 times
Time up : 275 ms
Time down : 312 ms
Motor temp : 38,8 C
```

Fig. 7 Boom Gate driver controller data output

specifications of the knoken braking system, integrated to the disk brake system, are comprehensively outlined in Table 4, providing essential parameters for understanding its operational characteristics.

The placement of the knoken braking system on the boom gate baseplate is a critical aspect of the overall braking system configuration. Positioned in tandem with other braking system components, the knoken braking system finds its designated location, as illustrated in Figure 6. The clamping force exerted by the brake pads against the disk translates mechanical energy into heat energy. This conversion, occurring during the deceleration process, plays a pivotal role in ensuring the effective and controlled stoppage of the boom gate. The alignment and integration of the knoken braking system within the braking system framework contribute to the modified boom gate's seamless and efficient braking performance.

2.5 Experiment

A trial test was systematically executed to assess the efficacy of the developed equipment [20]. This trial unit testing was conducted under real-world conditions at the Ciawi and Kelapa Gading toll booths, both renowned for their high-traffic nature. The choice of these toll gates was deliberate, considering their heavy traffic conditions, and the trials were specifically scheduled from 5 PM to 7 PM, corresponding to peak traffic hours.

The trial unit was engineered by modifying the existing boom gate, incorporating the BLDC motor with a power rating of 660 watts, and integrating the disk brake system. The testing protocol involved comparing the existing boom gate units and the modified units at the toll gate booths. Both types of boom gates underwent testing simultaneously at the exact location and time, ensuring a consistent evaluation environment.

This trial aimed to validate the modification system's capability to arrest the boom gate movement swiftly and safely in both open and closed positions. The test outcomes also substantiate the disk brake system's suitability as a replacement for the internal brake motor in boom gate operations. The analysis at each substation focused on assessing the cycle per hour as an indicative measure of the reduction in vehicle traffic. To obtain data on the speed of opening and closing, as well as cycle count, boom gate driver data, as illustrated in Fig. 7, was employed for a comprehensive evaluation of the

Table 4. Knoken braking system component

No	Name	Specification	Qty
1	Motor BLDC	63W 3000 rpm 24VDC 3.44 A	1
2	Gearbox Speed Reducer	Ratio 1: 9	1
3	Driver Pulley	24 teeth	1
4	Driven Pulley	32 teeth	1
5	Timming Belt	100 xl	1
6	Ball Screw	Lead 10mm, Diameter 10mm	1
7	Push Rod Body	Aluminum	1
8	Push Rod	Aluminum	1
9	Spacer Guide	Aluminum	4
10	Master cylinder	Brand A Original	1
11	Brake Hose	Brand A Original	1
12	Brake Caliper	Brand A Original	1
13	Outer Case	Stainless Steel 201 Hairline Finish	1

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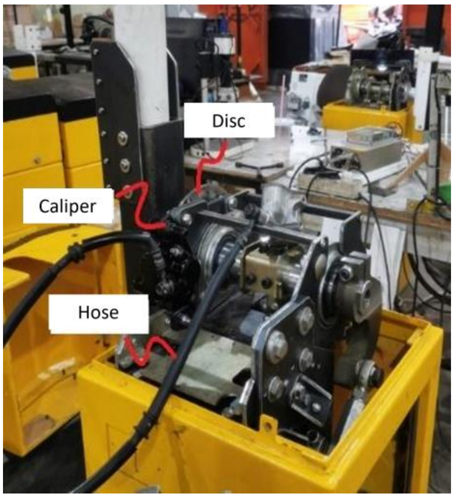
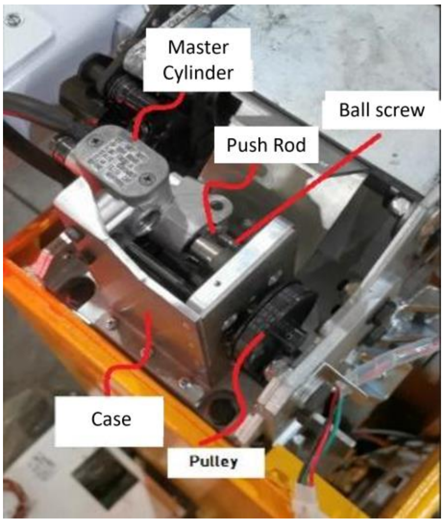


(a)



(b)

Fig. 8. a) Trial unit with disk brake system; b) Trial unit with knoken braking system

modified boom gate's performance.

3. Results and Discussion

3.1 Boom Gate Operation Speed Calculation

The operational speed of the boom gate is intricately tied to the performance of its prime mover, the BLDC motor. A critical aspect of assessing the boom gate speed involves a comprehensive analysis of the BLDC motor's specifications, particularly the 660-watt variant, as detailed in Table 3. Before calculating the boom gate speed using Equation 3, it is imperative first to determine the reduction in motor output capacity induced by the gearbox. A ratio of 1 to 18 characterizes the gearbox employed in this system. The output speed generated by the motor, post-gearbox influence, can be accurately computed using Equation 1. This preliminary step is crucial in establishing a precise understanding of the motor's effective output and subsequently enables a more accurate estimation of the boom gate speed.

$$n_2 \quad = \frac{3000\,rpm}{18} \quad = 166\,rpm$$

Following the determination of the output rotation, the angular speed of the motor was subsequently computed utilizing Equation 2.

$$\omega \quad = \frac{2\mu}{60}\,.166 \quad = 17{,}374 \text{ x } 30\% = 5.212 \text{ (rad/s)}.$$

Subsequently, to ascertain the formula for the boom gate open time, Equation 3 was employed, yielding insightful results.

$$t \quad = \frac{5.212 - 0)}{(5.212)^2} \quad = 0{,}19\,s \; = 190\,ms$$

The calculations presented above affirm that the modification implemented on the boom gate has significantly enhanced its operational speed compared to the existing boom gate, reducing the opening time from 0.5 seconds to an impressive 0.19 seconds. This noteworthy improvement underscores the efficacy of the modified boom gate in delivering high-speed operations, thus contributing to the efficiency and expediency of its functioning.

3.2 Knoken Braking System Design

In Figure 8(a), the trial unit of the disk brake system components installed on the boom gate is depicted. This configuration encompasses essential elements such as disks, calipers, and brake hoses. Concurrently, Figure 8(b) showcases the trial unit of the knoken braking system, a critical component in the braking mechanism. The knoken braking system is strategically encased in stainless steel to safeguard the integral components housed within. The implementation of the knoken braking system on the boom gate necessitates a rigorous testing process, ensuring its seamless integration and functionality.

A pivotal aspect of the testing involves synchronizing the brake moment with the movement of the boom gate. The initiation of the braking moment is strategically timed to coincide with the boom gate's traversal of the acceleration zone. This acceleration zone denotes the phase during which the boom gate is in the process of accelerating. The knoken braking system comes into operation precisely at this point, where the electric motor rotates the pulley, propelling the push rod to engage the master cylinder. The delineation of the acceleration and deceleration zones is elucidated in Fig. 9, providing a visual representation of the critical phases in which the knoken braking system

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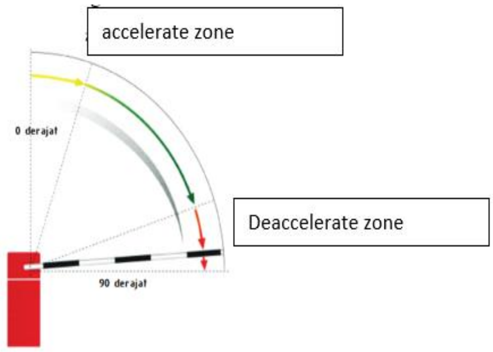
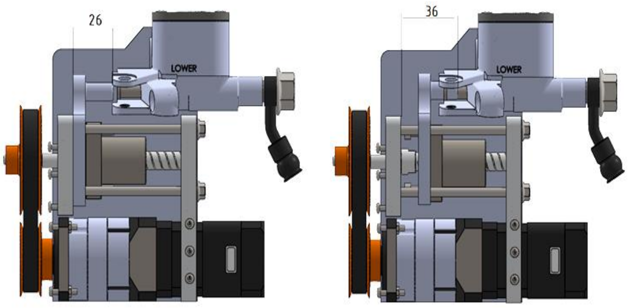


Fig. 9. Accelerate and deaccelerate zone



(a) (b)

Fig. 10. Knoken braking system condition a) netral; b) push

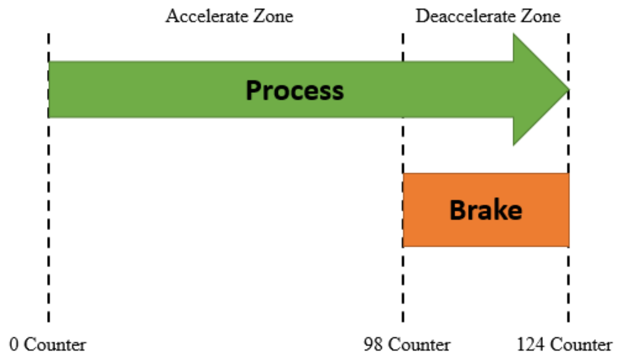


Fig. 11. Brake Moment Zone

functions to optimize the boom gate's braking performance.

The push rod on the knock brake system is installed directly on the ball screw body so that its movement is in line with the movement of the ball screw itself. When in the acceleration zone, the ball screw is in a neutral position, which is 26 mm from the wall, as shown in Fig. 10 (a). When entering the deacceleration zone, the motor on the knoken brake system will move and move on the ball screw 10 mm so that the push rod will press the piston on the master cylinder, as shown in Fig. 10 (b).

Based on the specifications of the knock brake system, the time it takes to press the piston on the master cylinder will be calculated. But before that, the researcher will first calculate the motor output capability that is reduced by the gearbox. The gearbox used is a gearbox with a ratio of 1 to 9, so the output speed generated by the motor can be calculated using Equation 1 again as follows.

$$n_2 = \frac{3000\ rpm}{9} = 333\ rpm = 5{,}5\ rps$$

To complete one braking cycle, the push rod component must traverse a distance of 10 mm to engage the master cylinder piston. This movement is synchronized with the motion of the ball screw, possessing a lead of 10 mm. Consequently, a single rotation of the ball screw is required to facilitate the push rod's compression of the master brake piston. Notably, the duration of one rotation of the ball screw is quantified at 0.18 seconds, providing crucial insights into the temporal dynamics of the braking system.

Following the activation of the knoken braking system, the boom gate transitions into the deceleration zone. An experimental test was conducted to ensure optimal alignment between the brake momentum and the boom gate movement, and the resulting data is elucidated in Table 5. This table delineates that the total motor counter, amounting to 124, is a reference for controlling BLDC motors. The entire motor counter 124 signifies the cumulative movement required to shift the boom gate from 0 to 90 degrees and vice versa. This experimental data is instrumental in refining and calibrating the knoken braking system to effectively synchronize with the boom gate's movement during the crucial deceleration phase.

Table 5. Experimental data of brake point

Total Motor Counter	124 motor counters
Knoken braking system Moment	98 – 124 motor counters

Based on the test results in Table 5, the braking momentum of the knoken braking system is optimal and makes the boom gate able to stop at an angle of 90 degrees or vice versa with no vibration. It can start when the BLDC motor counter is at 98. The brake moment occurs when the counter motor has reached 98, then the brake moment on the knoken braking system stops when the BLDC motor counter has stepped on 124 or when the boom gate position is at 0 or 90 degrees. The scheme for the braking moment is shown in Fig. 11 below.

3.3 Design Trial in Toll Road

Tests were carried out on the existing boom gate unit and the modified unit, which were placed at the

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Fig. 12 Trial Unit in toll plaza (a) Ciawi; (b) Kelapa Gading

Ciawi and Kelapa Gading toll booths. Tests on both toll booths can be seen in Fig. 12 below. The tests were conducted in 3 days in the rush hour session from 5 PM until 7 PM. In each toll booth, a test of the boom gate was conducted within the same line.

Data from the test results of opening and closing speeds for the existing unit and modified unit are shown in the tables below. The researcher also presents the results of the boom gate cycles per minute test as a parameter to know the effectiveness of changing the boom gate design.

Table 6. Existing boom gate trial result in Ciawi

Date & Time	**Cycle per Hour**	**Open Speed (ms)**	**Close Speed (ms)**	**Motor Temp. (C)**
Day 1 5-6 PM	365	548	608	44,6
Day 1 6-7 PM	352	541	595	42
Day 2 5-6 PM	351	554	586	43,4
Day 2 6-7 PM	374	562	626	41,5
Day 3 5-6 PM	338	543	588	40,7
Day 3 6-7 PM	358	540	612	42,8
Average	356,3	548	602,5	42,5

Table 7. Modified boom gate trial result in Ciawi

Date & Time	**Cycle per Hour**	**Open Speed (ms)**	**Close Speed (ms)**	**Motor Temp. (C)**
Day 1 5-6 PM	452	269	328	38,6
Day 1 6-7 PM	446	272	325	39
Day 2 5-6 PM	438	254	346	38,7
Day 2 6-7 PM	462	258	326	38,5
Day 3 5-6 PM	452	266	358	39,4
Day 3 6-7 PM	449	275	312	38,8
Average	449,8	265,6	332,5	38,8

Table 8. Existing boom gate trial result in Kelapa Gading

Date & Time	**Cycle per Hour**	**Open Speed (ms)**	**Close Speed (ms)**	**Motor Temp. (C)**
Day 1 5-6 PM	354	542	600	41,6
Day 1 6-7 PM	350	540	555	40,3
Day 2 5-6 PM	341	544	571	40,7
Day 2 6-7 PM	344	552	566	40,2
Day 3 5-6 PM	348	563	575	40,9
Day 3 6-7 PM	358	550	605	41,8
Average	349,1	548,5	578,6	40,9

Table 9. Modified boom gate trial result in Kelapa Gading

Date & Time	**Cycle per Hour**	**Open Speed (ms)**	**Close Speed (ms)**	**Motor Temp. (C)**
Day 1 5-6 PM	432	252	319	36,1
Day 1 6-7 PM	443	256	321	37,4
Day 2 5-6 PM	433	267	336	36,9
Day 2 6-7 PM	442	248	346	38,1
Day 3 5-6 PM	445	261	341	37,4
Day 3 6-7 PM	440	259	329	37,4
Average	439,1	257,1	332	37,2

In actual testing, existing and modified units had relatively different opening speed values, as shown in the graph in Fig. 13. The Modified unit on the Ciawi showed an average boom gate opening speed of 265.6 ms. Then, the tests at the Kelapa Gading units produced an opening speed of 257,1 ms on the modified unit. Meanwhile, the existing unit only results in half of the limited unit speed. The boom gate opening speed is critical to determine the smooth traffic flow at the toll gate. The faster the boom gate opens, the faster the traffic flow will be, and it will also reduce queues.

Fig. 13 shows a graph of nominal cycle data by boom gate per hour. This assessment indicated the

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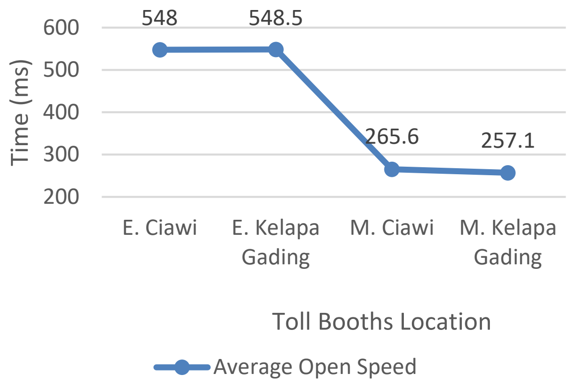

Fig. 13 Boom gate open speed comparison chart

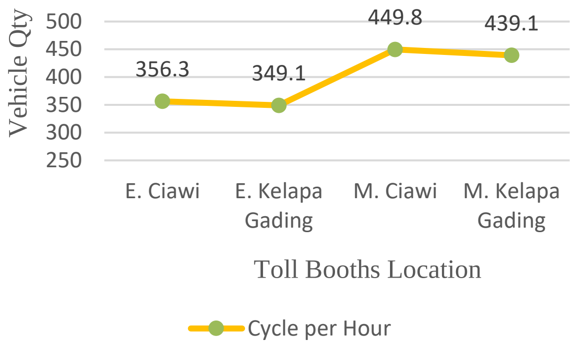

Fig. 13. Boom gate cycle per minute comparison chart

quantity of vehicles that pass through the boom gate. The graph shows that the existing unit in Ciawi and Kelapa Gading has 356,3 and 349,1 cycles per hour. Meanwhile, the field-modified units tested at the Ciawi toll booths resulted in 449,8 cycles per hour. Then, testing of the modified unit on the Cibubur unit showed 439,1 cycle per hour.

The data proves that the modified boom gate equipped with a BLDC motor 660-watt and motorcycle disk brake system was successful in increasing the boom gate operation speed and cycle per hour.

4. Conclusions

The testing outcomes of the modified boom gate, featuring the BLDC motor 660-watt and disk brake system, demonstrate a substantial enhancement in the operational performance of the boom gate. The integration of the BLDC motor 660-watt elevates the ideal operating speed to an impressive 0.19 seconds, a notable increase supported by the effectiveness of the disk brake system as the braking tool. The implementation of the disk brake system is further facilitated by the knoken braking system, which translates motor rotation into translational motion on the ball screw, subsequently driving the push rod to press the master cylinder piston. The synchronized operation of the knoken braking system during the boom gate's deceleration process ensures a smooth and vibration-free cessation of movement. Specifically, the knoken braking system engages when the main motor counter reaches 98 and disengages either when the boom gate reaches its maximum position or when the counter hits 124.

Field tests conducted at Ciawi and Kelapa Gading toll booths substantiate the superior performance of the modified unit compared to the existing one. The opening speed of the boom gate increased by an impressive 51 percent, with the Kelapa Gading toll booth achieving the fastest average opening speed of 257 ms. Similarly, the closing speed witnessed a commendable 44 percent increase, with the Kelapa Gading booth test achieving the fastest closing speed of 332 ms. The assessment of boom gate operating cycles as an indicator of increased vehicle operation value further reinforces the success of the modification. The modified unit in Ciawi demonstrated an average number of cycles per hour at 449.8, reflecting a significant 26 percent increase. Concurrently, the Kelapa Gading test resulted in an average cycle per hour of 439, indicating a 25 percent increase. These results affirm that the modified boom gate significantly enhances vehicle efficiency in toll booths, addressing traffic concerns through faster cycle handling every hour and improving overall boom gate performance.

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