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by Andi Andi

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DEVELOPMENT OF BOOM GATE WITH DISK BRAKE SYSTEM

Abstract

Congestion at toll roads is a common problem today, this often occurs at toll booths when users are making payments. One of the causes of the congestion is the length of time the boom gate operates. To overcome the long operating time, a new boom gate mechanism was designed which can operate more quickly. The design of this boom gate uses a morphological chart as the basis for choosing a design concept. Based on the concept design selection, the boom gate was designed using the existing boom gate used on the current toll road but was added using a motorcycle disk brake system as an addition. The use of disk brakes will make the electric motor on the boom gate work better and operate faster. The application of the motorcycle disk brake function at the boom gate is assisted by the knoken brake system as the actuator in activating the disk brake function at the boom gate. Testing of the boom gate with the disk brake system was carried out directly at the toll gate. The test results show that the boom gate opening time increased by 44 percent from 567 ms to 319 ms, the closing speed also increased by 32 percent from 668 ms to 454 ms. In addition, the nominal cycles per minute of the boom gate also increased by 25 percent.

Keywords: Boom Gate, Disk Brake, Knoken Brake System

1. Introduction

Technological advancements drive toll road equipment technology to become 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] prove that contactless or without stop payments are the most effective payment methods. To support this system, a high-speed boom gate device has been developed to support smooth traffic flow at toll booths.

The boom gate operates using the principle of acceleration and deceleration which affects the opening and closing speed. Both processes require a well-designed braking system to move quickly and 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. Zhang [4] use rocker arm systems and electric motors,this system is utilized to perform the braking procedure at the boom gate. Cunico [5] created a boom gate that was powered by a DC motor. To obtain high and safe crossbar motion rates, DC motors provide a regenerative braking effect or regenerative braking on the motor during the process.

In this study, researcher created a braking mechanism at the boom gate using disk brakes and BLDC motors to reach an opening and shutting 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 DC motor in its use in the boom gate so that the DC motor can catch up with a more ideal boom gate opening and shutting speed.

2. Experimental and Procedures

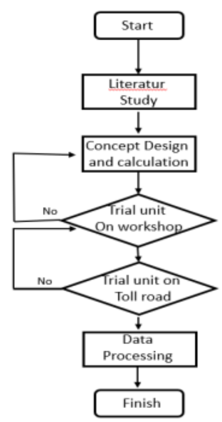

Fig. 1. Flow Diagram of this research

Research applies three stages, namely design concept, preparation of test equipment, and unit testing. Designing the concept is done using the morphological chart method. Then in the preparation stage the test equipment is applied in the form of experimental unit objects and CAD modeling. This research was conducted by modeling CAD designs in solidwork. CAD modeling is intended to minimize production errors. The use of CAD will make modeling faster and cheaper, so that the design process becomes more effective [6]. The flowchart of this research is shown in Figure 1.

2.1 *Concept Design*

This boom gate was created by improving on a prior model that was previously used on toll highways. The boom gate of the previous generation

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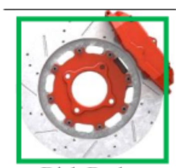
opened and closed in 0.5 seconds. The opening and shutting times are attained by employing a BLDC motor as the prime mover and the internal brake of the motor itself for the braking function. The ability to open the boom gate is a top priority because with the faster opening speed of the boom gate, congestion at toll booths can be minimized. To obtain a faster opening speed, we need a new mechanism that can fulfill this function. The additional mechanism designed is a braking mechanism with disk brakes but still uses the same driving motor. In designing the new boom gate concept, the morphological chart method is used which is shown in Table 1. Morhological Chart commonly used to overcome product variant design, the method was conducted by changing certain parameters of some features from existing design [7]. And also, morphological chart was a way to systematically restructuring component from various combination for design exploration [8]

Table 1. Morphological Chart for Boom Gate New Version

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

While using morphological chart all components considered as interdependent therefore exploring all the effects from related components must be conducted [9]. In this design, the boom gate unit uses a BLDC motor, the BLDC motor has a higher speed than other motors. The boom gate material is still made of aluminum, although carbon and fiber are lighter in weight, but their availability in the market is very rare. The researcher then chose motorcycle disk brakes for the braking system, because disk brakes produce instant and fast braking force. To replace the hand levers for motorcycles, the researchers utilized actuators in the form of ballscrew powered by BLDC motors.

In this study, the boom gate was modified to obtain faster opening and closing speeds to reduce queues at toll booths. This study designed a mechanism to accommodate the disk brake system on the boom gate so that it can function similarly to a motorcycle disk brake. Motorcycles utilize the principle of a lever to apply hydraulic brakes so that they can grip the disk. This study uses the same braking mechanism but by changing the manual lever function to automatic using an electric motor called the knoken brake system.

2.2 Equation

The boom gate has a prime mover in the form of an electric motor whose speed is limited by means of 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 power of the motor to match the characteristics of the loads [10]. In the gearbox there are gears rotation that drive output shaft to transmit the force vertically to other rotating shaft [11]. If the value of the rotation of the wheel on the driving gear is expressed by n1 (rpm) and the value of the rotation on the driven gear is expressed by n2 (rpm), the diameter of the circle distance for d1 and d2 (mm), and the number of teeth z1 and z2, the gear ratio ratio is calculated by formula (1) as follows [12]:

$$i = \frac{z_2}{z_1} = \frac{d_2}{d_1} = \frac{n_1}{n_2} \quad (1)$$

The use of disk brakes on the boom gate will be proven by calculating the braking time generated by the disk brakes on the boom gate system using the following formulas [13]:

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

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

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

Braking time calculation is analyzed based on the magnitude of the braking force on the brake pad that takes place during the deceleration process. For this reason, the linear acceleration must be found first by converting the angular acceleration of the boom gate.

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

$$v = \omega . r$$

$$\omega = \frac{2\mu}{60} . n \quad (2)$$

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

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)

2.3 *Knoken Brake System Design*

The research will improve the previously widely utilized 0.5 second boom gate. To perform the same purpose as a motorcycle, the boom gate must incorporate a braking component. Disk brake components used include disks, brake lines, and calipers. Figure 2 depicts the four supporting components. The four components are modified for placement on the boom gate under motorcycle like installation conditions. The assembly of this component was conducted in Solidworks 3D. 3D fabrication approach balance optimization process focusing on improving its design stability [14].


(a) (b)


(c) (d)

Figure 2. Brake component a) Diskbrake, b) Hose Brake c) Caliper dan d) Brake Master

The braking system is attached to the boom gate axle, which is similar to a motorbike wheel axle. The rotation of the boom gate shaft will be slowed to a halt by the caliper's grasp on the disk. This reduction of speed is caused by friction between the brake pad on the caliper and the disk.

To apply the brake mechanism to the boom gate, a mechanism is needed that can move automatically as a substitute for the brake lever on a motorcycle, which is called the knoken brake system. The knoken brake system has the same function as the brake handle or lever on a motorcycle. The components that make up the knoken brake system are shown in Figure 3 below.

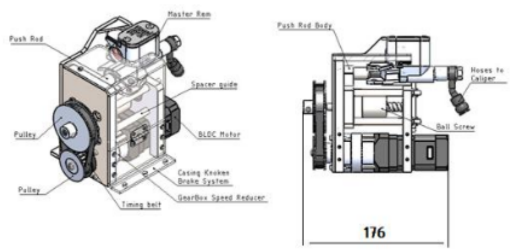

Figure 3. Component of Knoken Brake System

The knock brake system in Figure 3 transforms the bldc motor rotation which is continued through the pulley into translational motion on the ball screw. In the figure, the dimensions of the Knoken brake system also have a safe size of 176mm from the maximum limit of 186mm. The ball screw moves to carry the push rod following the existing trajectory so that later it will press the brake master. The movement mechanism of the knock brake system is shown in Figure 4. The movement displayed in Figure 4 is described in 4 steps as follows:

Step 1: The BLDC motor transmits its rotation to a speed reducer gearbox which reduces the rotation (rpm) produced by the motor but increases its torque.

Step 2: The reduced rotation is passed on to the drive pulley which is connected via a belt to the driven pulley.

Step 3: The driven pulley will rotate the shaft of the ball screw so that the ball screw will rotate and experience translational movement towards the brake master.

Step 4: The rotating ball screw also pushes the push rod towards the brake master, so that the brake master will be pressed and causes the hydraulic fluid in the brake master reservoir to flow through the brake hose to the caliper.

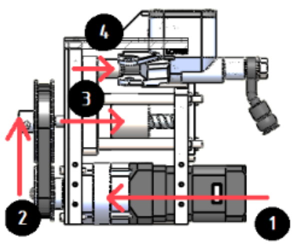

Figure 4. Knoken brake system working scheme

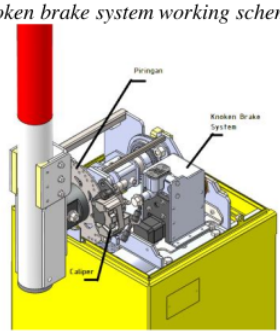

Figure 5. Knoken brake system position in boom gate

During the pressing process, the push rod will press the master brake to the maximum, and the maximum condition is achieved when the master brake is fully pressed. After the master brake is completely pressed, fluid will flow to the caliper piston and make the brake pads press against the disk and make the boom gate stop quickly. Knoken brake system specifications for disk brake system devices are shown in Table 2 below.

Knoken brake system is placed on the boom gate baseplate 0.5 seconds side by side with other braking system components. The Knoken brake system will be positioned as shown in Figure 5 below. The clamping force of the brake pads against the disk transforms mechanical energy into heat energy which, when applied to the boom gate, will take place during the deacceleration process.

Table 2. Knoken Brake System Component

No	Name	Specification	Quantity
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	Alumunium	1
8	Push Rod	Alumunium	1
9	Spacer Guide	Alumunium	4
10	Brake Master	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

2.4 Experiment

Trial test conducted to see the level of success of the equipment being developed [15]. Trial unit testing was carried out at the workshop, followed by testing on actual conditions at the Ciawi, Cibubur and Bogor in Jagorawi toll booths. In addition, this test will prove the ability of the disk brake system to stop the boom gate movement in the open or closed position. The results of this test will prove that this disk brake can function as a brake for boom gate operations replacing the internal brake motor and increasing the boom gate opening and closing speed to 0.3 seconds. At each substation, the time needed to reach the cycle will be analyzed as an indication of the density of vehicle traffic.

3. Results and Discussion

3.1 Boom Gate Motor Speed Calculation

The boom gate uses a BLDC motor as its prime mover, so speed is very dependent on it. Based on the bldc motor specification data used in Table 1, the boom gate speed can be calculated using formula 2.9, but before that it will be calculated first that the motor output capability has been reduced by the gearbox. The gearbox used is a gearbox with a ratio of 1 to 17.79 and the output speed produced by the motor can be calculated using formula (1).

$$17{,}79 = \frac{3000\,rpm}{n_2}$$

$$n_2 = \frac{3000\,rpm}{17{,}79} = 168{,}5\,rpm$$

After the output rotation is known, then the angular speed of the motor will be determined using formula (2).

$$\omega = \frac{2\mu}{60}\,.\,168{,}5 = 17{,}645 \text{ x } 0{,}3 = 3.529 \text{ (rad/s)}.$$

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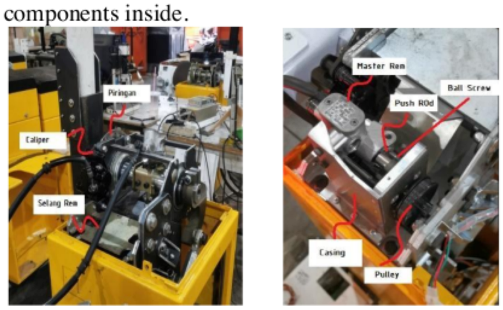
Then to find the boom gate open time formula (3) will be use, which produces.

$$t = \frac{3.529 - 0)}{(3.529)^2} = 0,28\ s = 280\ ms$$

Based on the calculation above, boom gate which using same BLDC with boom gate 0,5 second could provide open and close time within 0,3 second.

3.2 Knoken Brake System Calculation

Figure 6 (a) shows the trial unit of the disk brake system components that have been installed on the boom gate. These components include disks, calipers and brake hoses. The knock-brake system trial unit is also made as shown in Figure 6 (b) below. The Knoken brake system is equipped with a stainless steel casing to protect the supporting components inside.



(a) (b)

Fig. 6. a) Trial unit with Diskbrake Sytem; b) Trial Unit with Knoken brake system

The process of applying the knock brake system to the boom gate must go through a series of tests. The test carried out is synchronizing the brake moment with the boom gate movement. The braking moment will occur when the boom gate has passed the acceleration zone. The acceleration zone is the zone where the boom gate is accelerating. When experiencing acceleration, the knock brake system will work so that the bldc motor will rotate the pulley and push the push rod to press the brake master. The acceleration and deacceleration zones are shown in Figure 7 below.

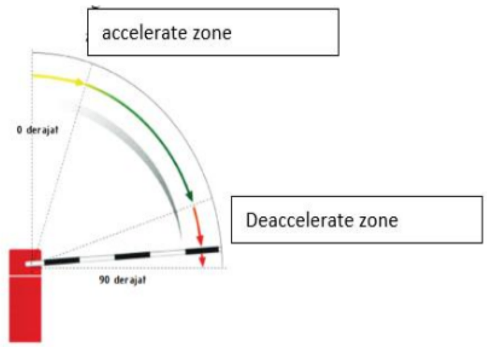
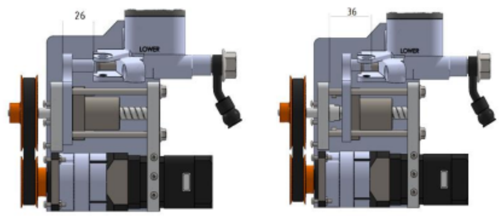


Figure 7. Accelerate and Deaccelerat Zone



(a) (b)

Fig. 8. Knoken Brake System condition a) Netral; b) Push

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 Figure 8 (a). When entering the de-acceleration zone, the motor on the knock-brake system will move and move the ball screw 10 mm so that the push rod will press the piston on the brake master as shown in Figure 8 (b).
Based on the specifications of the knock brake system, the time it takes to press the piston on the brake master 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: 9, so the output speed generated by the motor can be calculated using formula (1) as follows.

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

To fulfill one braking cycle, the push rod component must move 10 mm to press the brake master piston. The push rod moves to follow the movement of the ball screw, where the ball screw has a lead of 10mm. So, it takes one rotation of the ball screw to make the push rod press the piston on the master brake. The duration of one rotation of the ball screw is 0.18 seconds.

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After the knock brake system is active, the boom gate will enter the deacceleration zone. In order to align the brake momentum and the boom gate, an experimental test is carried out with the data shown in Table 4 below. The table shows that the total motor counter can be 124. The motor counter is a motor movement unit that is used as a reference in controlling bldc motors. The total motor counter of 124 is the total movement required to move the boom gate from 0 degrees to 90 degrees and vice versa.

Table 3. Experimental Data of Brake Point

Total Motor Counter	124
Knoken Brake System Moment	98 - 124

Based on the test results in Table 3, the braking momentum of the knoken brake 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 brake 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 Figure 9.

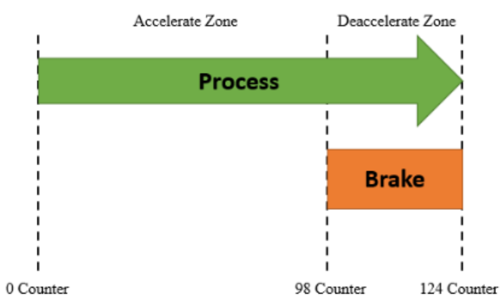

Figure 9. Brake Moment Zone

3.3 Design Trial in Toll Road

Tests were carried out on three units, each of which was placed at the Ciawi, Cibubur and Bogor toll booths. Tests on the three substations can be seen in Figure 10 below. The three tests were carried out within two months. The stages of data collection during the testing process are carried out every week, data is recorded every week for up to 10 weeks. On average every week the boom gate experiences approximately 10 thousand cycles at each tested substation.

(a) (b) (c)

Figure 10. Trial Unit in toll plaza (a) Ciawi; (b) Cibubur and (c) bogor

Data from the test results in the form of opening and closing speeds for each experimental unit are shown in Tables 4 and 5. The researcher also presents the results of the boom gate cycles per minute test in Table 6.

Table 4. Boom Gate Trial Result

Unit Status	**Existing Unit**	**Trial on Ciawi Toll Plaza**	**Trial on Cibubur Toll Plaza**	**Trial on Bogor Toll Plaza**
Average time to open	567,9 ms	325,6 ms	319,5 ms	323,2 ms
Average time to close	668,2 ms	457 ms	455,1 ms	454,4 ms

Table 5. Boom Gate Cycle Per Minute

Week	**Cycle**	**Existing Unit**	**Trial on Ciawi Toll Plaza**	**Trial on Cibubur Toll Plaza**	**Trial on Bogor Toll Plaza**
1	10000	0,82	1,046	1,03	0,93
2	20000	0,84	0,93	0,95	0,94
3	30000	0,81	1,14	1,02	0,93
4	40000	0,86	0,88	1,01	0,94
5	50000	0,73	0,97	0,97	0,92
6	60000	0,78	0,99	1	0,93
7	70000	0,86	1,14	1,03	0,93
8	80000	0,6	0,82	0,93	0,93
9	90000	0,85	1,04	1,02	0,95
10	100000	0,83	0,94	1	1,01
Average cycle per minute		0,8	0,98	1	0,94

In field testing, the three units tested had relatively the same opening speed values as shown in the graph in Figure 11. Tests on the Ciawi unit showed an average boom gate opening speed of 325.6 ms. Then the tests at the Cibubur and Bogor units produced data on opening speed of 319 and 323.2 ms. The boom gate opening speed is a very

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important thing that determines the smooth flow of traffic at the toll gate. The faster the boom gate opens, the faster the traffic flow will be and it will also reduce queues. The difference in boom gate opening times obtained is still within the tolerance range because the differences that arise are only in the range of 317 to 325.6 ms. The time difference of 8.6 ms does not affect the boom gate cycle.

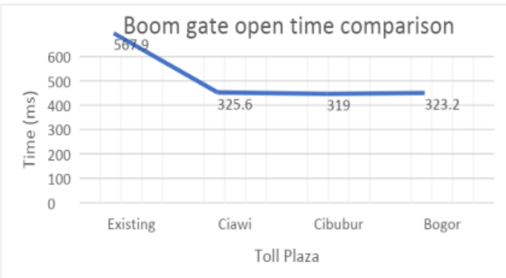

Fig. 11. Boom Gate Open Speed Comparison Chart

Figure 12 shows a graph of nominal cycle data by boom gate per minute. This assessment assumes that the boom gate will move continuously without interruption. The graph shows that the existing unit has the largest cycle in the range of 70,000 cycles with 0.86 cycles per minute and an average cycle of 0.8 cycles per minute. Then the field units tested at the Ciawi substation showed that in the 70000 range it showed the largest value of cycles per minute, which was 1.14 and the cycle average was 0.98. Then testing on the Cibubur unit showed the largest value in the 70000 range with a value of 1.03 and an average cycle per minute of 1. In the Bogor unit the test results had different values from the three previous experiments. In the Bogor unit, the largest range occurs in the 100,000 range with 1.01 cycles per minute and an average cycle per minute of 0.94.

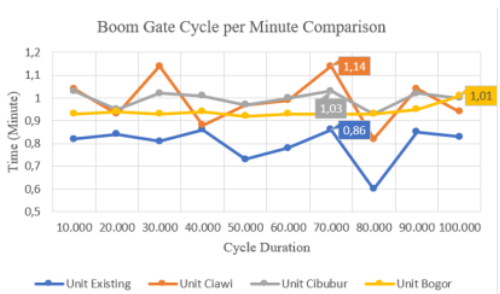

Fig. 12. Boom Gate Cycle per Minute Comparison Chart

The data proves that the boom gate experiment equipped with a disk brake system was successful. Shown by the number of cycles produced in each range from 10000 to 100000 experienced a significant difference. The existing unit installed at substation 9 Ciawi has an average number of cycles per minute of 0.8 while at substation 11 Ciawi but with a modified boom gate it shows an average value of 0.98. This difference in value clearly shortens and speeds up the queue at the toll booth. This also applies to other substations such as Cibubur and Bogor which also have a higher average value compared to the existing unit at substation 9 Ciawi.

4. Conclusions

The results of testing the Boom gate with the disk brake system indicated that the addition of the system increased the operating performance of the Boom gate. The implementation of the disk brake system on the boom gate uses the Knoken brake system tool. Knoken brake system converts the rotation of the motor into translational motion on the ball screw which in this system functions to move the push rod to push the brake master piston. The Knoken brake system works when the boom gate deacceleration process occurs by synchronizing the counter of the main drive motor of the boom gate with the drive motor of the Knoken brake system which makes the boom gate stop moving without vibration. Knoken brake system works when the main motor counter is at 98 and stops when the boom gate is at its maximum position or when the counter touches 124.

In this test the boom gate opening speed increased by 44 percent. The fastest speed in field tests was obtained from testing at the Bogor toll booth with a boom gate opening speed of 323.2 ms. In addition, the closing speed of the boom gate also increased by 32 percent. The fastest closing speed in the field test was achieved at the Bogor toll booth test of 454.4 ms.

Testing of boom gates with disk brake systems at three substations in Ciawi, Cibubur and Bogor also resulted in the number of boom gate operating cycles per minute. In the existing unit which is also installed at substation 9 Ciawi, it shows an average number of cycles per minute of 0.8. While the average number of cycles per minute test results on three units in substastion were 0.98,1 and 0.94. The three units installed at the Ciawi, Cibubur and Bogor substations received an increase in cycles per minute by 25 percent. The test data shows that the boom gate with disk brake system is proven to be able to increase the effectiveness at the toll gate substation as a result of the faster cycles handled every minute.

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