Kinematic analysis on four-bar mechanism model using PID Controller

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Abstract. A four-bar mechanism is used in most mechanical equipment to achieve the process or movement. Such mechanisms consist of link that move relative to one another. To identify kinematics analysis of a mechanism such as displacement and angular velocity of a four-bar mechanism in one position graphically. Therefore, an analysis conducted throughout the four-bar rotating in 360° will take a lot of time. For such cases, computer-assisted analytical is the right way of settlement. The analyses were performed using the Matrix Laboratory software, and establish a four-bar mechanism as a case of study research. Controller PID (Proportional Integral Derivative) is one type of regulator that is widely used, the characteristics of each P, I, and D controllers as well as how to use it to get the desired response. The analysis was made on the variation of rotation and crank length, while the dimension of the link and follower circuit is considered permanent. Comparison of angular velocity for varying stem lengths can conclude that if there is a change in input bar length, it will affect the angular velocity. The greater the length of the input link and so that the angular velocity would be getting lower.

Introduction
A kinematic chain is a system of linking rods in the form of rigid objects that are joined together or in a state of mutual contact so that it is possible for them to move relative to one another. If one of the links is fixed and the movement from the other connecting rod to its new position will cause each other link to move to certain positions the system is predicted to be a restricted kinematic chain. If one of the connecting rods is kept fixed from the movement of the other connecting rod to its new position, it will not cause each other connecting rod to move to a certain position that has been predicted thus the system is an infinite kinematic chain.

Analysis of the displacement and angular velocity of the four-bar mechanism, usually done graphically. To identify the displacement and angular velocity of the four-bar mechanism in one position graphically can be done simply and quickly. However, if the analysis is carried out to identify the displacement and velocity of the four-bar mechanism throughout the rotating position of the 360° input bar, graphically it will take a lot of time. For such cases, the method of analytic with the help of computers is the right solution. The four-bar mechanism is used in some mechanical equipment to achieve certain processes or movements. Such a mechanism consists of rods that move relatively one against the other. In general notation, the bar is also referred to as a link. The two links that allow
relative movement between are called joints. Thus the mechanism of the four-bar in question consists of four links that are connected by joints in such a way as to allow for relative movement between the existing links[1,2,3].

**Material And Methods**

In studying the movements of the machine elements, we usually draw these parts in the form of sketches so that only the parts that will give effect to the movement are noticed. PID Controller (Propotional Integral Derivatives) is one type of regulator that is widely used. In addition, this system is easily combined with other setting methods such as Fuzzy and Robust. To make a better regulatory system, this paper is limited to systems with the Unity Feedback System, as shown in Figure 1[4,5].

![Figure 1. Block diagrams of Unity Feedback System.](image)

First, consider the workings of the PID controller in the closed-loop system using the scheme shown above. Variable \( e \) describes tracking error, different input value \( R \), actual output \( Y \). This signal error is sent to the PID controller, and the controller will calculate the overall derivative of the integral signal error. The signal \( u \) that has passed through the controller, now equals the proportional gain \( K_p \) multiplied by the size of the error plus the reinforcement integer \( K_i \) multiplied by the size of the integral error plus the derivative reinforcement \( K_d \) multiplied by the derivation error[6,7].

\[
\mu = K_p e + K_i \int e \, dt + K_d \frac{de}{dt}
\]

Signal \( u \) will be sent to the plant and will get a new output \( y \). This new output \( y \) will be sent back to the sensor to look for new signal errors \( e \). The controller brings the new signal error and calculates the derivatives and the integrals once again. The process will run continuously as before. The proportional controller \( K_p \) will have the effect of reducing incremental time but does not erase steady-state errors. The integral controller \( K_i \) will have the effect of erasing steady-state errors, but resulting in deteriorating transient responses[8]. The derivative controller will affect increasing system stability, reducing overshoot and increasing transfer response. The effects of each controller \( K_p, K_d, K_i \) in the closed-loop system are shown in Table 1[9].

| Controller closed loop system |
|-------------------------------|
| **Closed Loop Response**      | **Incremental Time** | **Overshoot** | **Decremental Time** | **Steady State Error** |
|--------------------------------|----------------------|---------------|----------------------|------------------------|
| \( K_p \)                      | decrease             | increase      | small shifting       | Decrease               |
| \( K_i \)                      | decrease             | increase      | increase             | Shrink                 |
| \( K_d \)                      | small shifting       | decrease      | decrease             | small shifting         |

Note that the correlation relationship may not be entirely accurate, because \( K_p, K_i \) and \( K_d \) are mutually independent. Changing one variable an change the other two. For this reason, Table 1 above is only used as a reference when we determine the values for \( K_i, K_p, \) and \( K_d \). From table 2, it is known that the proportional controller \( K_p \) reduces incremental time, increases overshoot and reduces steady-state errors[10]. The closed-loop transfer function of the system above with proportional control is;
The stages of the simulation model begin with making a PID diagram in the Matlab software. Overall, the display of the PID diagram in the four-bar mechanism Simulink can be seen in Figure 2. In Figure 2, we see a four-bar mechanism, in which we have to display the Simulink menu located at the top of the menu when the Matlab software opened. After Simulink appears, we select File >> New >> Blank Model.

\[
\frac{X(s)}{F(s)} = \frac{K_p}{s^2 + 10s + (20 + K_p)}
\]  

(2)

To get information regarding the solution to this problem, a literature study was conducted. Information regarding this problem was obtained from books and journals relating to the four-bar mechanism in general obtained from various sources. At this stage, a data analysis mechanism for the four-bar is made[11,12,13]. The method of this research is the study of kinematics on the four-bar mechanism. Supported by establishing data used to execute numerical commands in Matlab of the four-bar mechanism includes:

a. Input data in the Windows command. Matlab Command windows/edit is a window that is opened when Matlab is run, in the windows command the commands entered are typed and can be saved using the command record.
b. Simulink mechanism for four-bar. The mechanism of the four bars in Matlab can be seen using Simulink, in the corner Simulink of the four-stem mechanism that we analyze, the data released is in the form of moving images.
c. Data analysis. Data analysis in Matlab can be seen by outputting the graph with the help of windows figures. Output data can be in the form of a graph.
d. The output from Matlab Analysis. The output from Matlab can be Simulink and graph.

Result And Discussions
In this study, a simulation was performed for variations in the speed and crank length and then analyzed the kinematic response of the four-bar mechanism. Simulation is a technique that imitates operations or processes that occur in a system with the help of computer devices and is based on certain assumptions so that the system is studied scientifically. By making a model of a system, it is expected to be easier to carry out an analysis. This is a modeling principle, namely that modeling aims to facilitate analysis and development. Modeling is one way to study the system and the model itself and also the differences in behavior, as shown in Figure 3.Subsequent, we will compile a four-bar PID diagram. First, we have to look for the Simulink Library, in the Simulink library there are various kinds of items to design the PID controller[14].
To enter the PID block diagram into the Simulink blank model, it is done by dragging the block with the crucible and directed to the blank Simulink model. In this stage, we will analyze the model in each of the links above by changing the size of the crank length and the variation of rotation. The modified data is contained in the block parameters in each link. The output is in the form of a graph, so we can compare the output graph with different input data. For standard sizes on each link must be set, if the link size does not match the standard, then Simulink cannot operate normally. The standard size for the link can be seen in Table 2.

Table 2. Standart properties and sizes of each link with variation

| Block Parameter   | Input Link    | Coupler Link  | Output Link   |
|-------------------|---------------|---------------|---------------|
| Link Density      | 10 ~ 12 kg/vol| 10 ~ 12 kg/vol| 12 ~ 14 kg/vol|
| Link Length       | 8 ~ 12 cm     | 18 ~ 22 cm    | 12 ~ 16 cm    |
| Link Width        | 2 ~ 6 cm      | 2 ~ 6 cm      | 2 ~ 6 cm      |
| Link Thickness    | 0.5 cm        | 0.5 cm        | 0.5 cm        |
| Hole Radius       | 0.5 cm        | 0.5 cm        | 0.5 cm        |

If standard sizes and variations have been set, Simulink can move normally. Following that, we can also see the output window in the analysis table model of the four-bar mechanism from the input link, coupler link and output link, as seen in the graph of Figure 4.

When we know the angular velocity, we can determine the linear velocity of the input rod. And the linear velocity for this input link is constant. The following in Figure 5 is a trajectory velocity simulation model for the four-bar mechanism with the number of cycles 14, 16 and 19 in the input link[1,2,8].
Conclusion
From the mechanism that has been simulated by the PID controller method, it is obtained that the angular velocity value of the mechanism for the link length varied is; for the input rod length of 8 cm, the angular velocity is 119.38 rad/s and the linear velocity is constant at 95.44 cm/s. Whereas for the input rod length of 10 cm, the angular velocity is 100.48 rad/s and the linear velocity is constant at 100.4 cm/s. Meanwhile, for the input rod length of 12 cm, the angular velocity is 87.92 rad/s and the linear velocity is constant at 105.48 cm/s. So from the ratio of angular velocity to varying rod length, it can be concluded that if there is a change in the length of the input link, it will affect the angular velocity. The larger the input link length, the lower the angular velocity.

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