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Measurement of Moment of Inertia Through a Bifilar Pendulum Swing Based on a Microcontroller

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Abstract

Every object has a tendency to maintain its state of motion. The concept also applies to rotating objects called moments of inertia. This experiment aims to explain the working principle and determine the magnitude of the moment of inertia of objects using a bifilar pendulum teaching aid based on the ATMEGA-16 microcontroller. The implementation method used is the experimental method. The working principle of the ATMEGA-16 bifilar pendulum microcontroller-based teaching aids uses the bifilar pendulum principle. The moment of inertia of an object can be measured using a measuring tool that works at the moment of the inertia oscillation method. The bifilar pendulum experiment consists of an object which is tied on either side by a rope and then attached to a support. Objects are deviated horizontally with a small angle to the equilibrium position and then released, the object will experience periodic oscillations. Based on the experimental results the shorter the distance of the two bifilars, the period will be even greater, and vice versa. The magnitude of the period (T) on the bifilar pendulum is inversely proportional to the root distance between the two bifilar (d). The results of experiments carried out for variations in rope length and the distance between the ropes. The moment of inertia based on experiments for variations in length of rope at 0.35 m is $(I \pm \Delta I) = (3.699 \pm 0.027)$ kg/m^2 ; 0.45 m is $(I \pm \Delta I) = (3.840 \pm 0.036)$ kg/m^2 ; 0.55 m then $(I \pm \Delta I) = (3.887 \pm 0.101)$ kg/m^2 ; 0.65 m then $(I \pm \Delta I) = (3.982 \pm 0.007)$ kg/m^2 and 0.75 m, $(I \pm \Delta I) = (4.093 \pm 0.006)$ kg/m^2. Furthermore, the moment of inertia is based on experiments for variations in the distance between the ropes at 0.1 m then $(I \pm \Delta I) = (5.30 \pm 0.69)$ kg/m^2; 0.15 m then $(I \pm \Delta I) = (5.93 \pm 0.07)$ kg/m^2; 0.20 m then $(I \pm \Delta I) = (7.17 \pm 0.15)$ kg/m^2; and 0.25 m then $(I \pm \Delta I) = (8.77 \pm 0.18)$ kg/m^2. The experimental results show that the smaller the distance between the two ropes will produce conformity to the theory of the solid cylinder using the shaft approach through the center.

Keywords: bifilar pendulum, moment of inertia, *bifilar pendulum, ATMEGA-16.*

1. Introduction

Learning in schools provides real experiences for students so that learning is more meaningful. Meaningful learning is a process that is associated with new information on relevant concepts in accordance with students' cognitive structures [1]. Real experiences can be presented through practicum while simultaneously training students' skills. Although important, not all material can be taught through practicum.

Rotational motion is often found in daily life. Rotational motion can be indicated by the rotation of the object with respect to a particular rotary axis. When an object rotates, it has a moment of inertia, because each particle has a mass and distance from its axis of rotation [2]. Moment of inertia (I) is a physical property of an object, one of which is a circular motion (rotation). As with mass (m) the inert nature of an object with respect to its translational motion, the inert moment is also the inert nature of an object with respect to its rotational motion. Every rigid body with each particle point moving around a certain reference which is different outside the object is always characterized by its moment of inertia (Giancoli, 2001).

The phenomenon of rotational motion in daily life cannot be analyzed mathematically by students because the availability of incomplete tools in the laboratory will create obstacles in practicum, it is necessary to have an innovation in making practical tools for moment of inertia material. Making the moment of inertia practicum through the ATMEGA-16 based bifilar pendulum swing can be an innovation of teachers or schools in teaching students the material moment of inertia.

Some experimental sets of moment of inertia that have been developed are still limited in automatic recording. Timing is only limited to using a *stopwatch* manually [4]. This can result in measurement data having low accuracy and accuracy. Therefore, it is necessary to develop an experimental tool set to determine the moment of inertia so that it can produce more accurate and accurate data in its measurement.

The purpose of this research is to explain the working principle and determine the magnitude of the moment of inertia of objects in solid cylinders on the length variation of the rope (l) and the distance between the ropes (d) using a bifilar pendulum teaching aid based on the microcontroller ATMEGA-16.

The making of practicum tools for determining the moment of inertia through a bifilar pendulum swing based on an ATMEGA 16 microcontroller can be used as an innovation in Physics learning tools to be able to determine the symptoms of rotational motion especially the moment of inertia mathematically and can reduce the systematic errors in measurement because it is equipped with IR-LED sensors and *photos diode*which has a high level of sensibility so that the measurement results are more accurate and thorough.

2. Experiments Procedure

The method in this study is to use an experimental method that results in the measurement of moment of inertia by using the bifilar pendulum swing method based on the ATMEGA-16 microcontroller. The study used a set of bifilar pendulum experimental devices consisting of: a set of supporting iron, solid cylindrical rods, ropes, a set of measuring devices and the time of the passing cylinder. This research was conducted for 2 variations, namely the length of the rope (l) solid cylinder to the buffer and the distance between the ropes (d) on the buffer**.**

In general, research is conducted in two stages, namely (1) designing and assembling devices, and (2) measuring time and vibration and conducting data analysis to determine the moment of inertia.

Design and Assembling of Tools

The bifilar pendulum practicum tools that are designed consist of an iron frame that can stand upright and be easily dismantled. The upper part that crosses the frame is a place to hang objects using two ropes (bifilar) which are then swung.

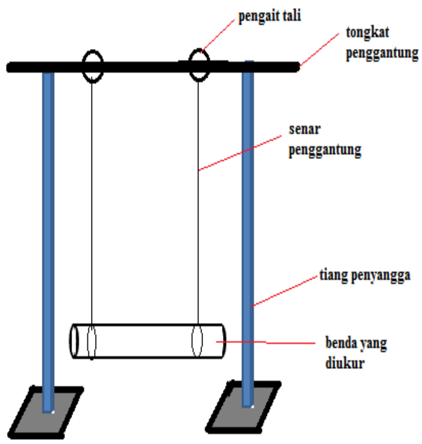

Figure 1. ATMEGA-16 Microcontoler-Based Bifilar Pendulum Tool Scheme

Figure 2. Set of ATMEGA-16-based Bifilar Pendulum Experiment Equipment

The cross section of the upper frame and the upright part is equipped with a length measurement scale to facilitate practicum. On the supporting pole there is a sensor place that can digser up and down to adjust the length of the rope. The sensor is connected to a time counter and vibration box based on the ATMEGA-16 microcontroller which is used to provide accurate measurement of time and vibration of objects. Object vibrations can be adjusted according to needs and the time counter will stop automatically when the object has vibrated to reach a predetermined vibration.

Measurement of Time and Vibration

After the tool is designed and confirmed to work properly, the researchers took measurements of vibration using a solid aluminum cylinder. The experimental steps carried out include; (1) binding the cylindrical rod with a rope attached to the cross section of the iron frame; (2) rotate the cross section to lower the object, and adjust the desired rope length; (3) connecting the adapter to the chopper to the power source; (4) adjust the number of vibrations to be chopped by pressing the right button (increasing the number of vibrations) - left (reducing the number of vibrations) on the counter; (5) turning the stem horizontally up to form a small angle of about 5°; (6) press the center button to start counting the vibration time; (7) vary the length of the rope (l) or the distance between the two ropes (d) to get the moment of inertia.

3. Result and Discussion

Performance Specifications of the Moment of Inertia Experiment Sets

Specifications on the experimental set are identification of the decomposition of the arrangement in a system. The experimental tool set is designed to be able to carry out physical measurements of the determination of the moment of inertia automatically through the calculation of periods and vibrations displayed on the LCD in the time counter box. The results of the design are as follows:

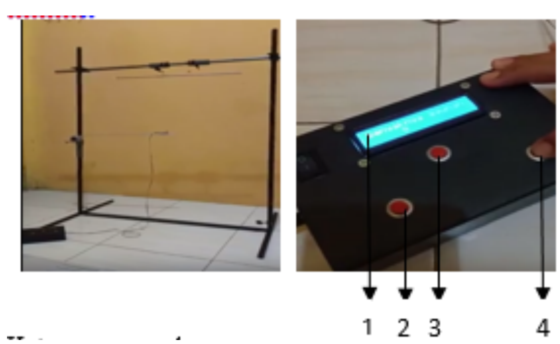

Figure 3. Results of Inertia Moment Experiment Set Design

Caption:

1: LCD time and vibration counter

2: vibration amount reduction button

3: time and vibration counter start button

4: vibration number increase button

Based on Figure 3, the moment of inertia experimental set consists of a support pole measuring 1.5 mx 1 m and its use can be adjusted. On the pole there is an IR LED sensor and photo diode that is used to count the amount of time and vibration, the reduction button and the increase in the amount of vibration is used to adjust the desired amount of vibration as needed. The start time and vibration counter button is used to adjust the start vibration and the time of the cylinder is solid from the start of the swinging process. The use of this experimental set is very easy and can be designed and removed on its own without any special mechanical assistance

Specifications Design Moment of Inertia Experiment Set

1. The Accuracy of Experimental Sets

The accuracy of experimental sets of moment of inertia is obtained by comparing the results of manual measurement tools. Measurement of time produced by the instrument is compared with the results of measurements using a stopwatch. The stopwatch and time counter on the experimental set of moment of inertia are used together and the results are compared. The average relative accuracy in time measurement is 98.7%. As well as measuring the number of vibrations based on the experimental set and using manual calculation theory is to produce the same number of vibrations.

2. Precisson of Experiment Sets

Precission of measuring measurements comes with the repeated measurement method. Variations were carried out for two experiments, namely variations in the length of the rope (l) and the variation in the distance between the ropes (d). Each variation in the experiment was measured 5 times. Based on the data obtained can be obtained the average value, measurement error and the percentage of accuracy. Analysis of the data used in this experiment are :

$$T = 2\pi\sqrt{\frac{IL}{mgb^2}} \quad \text{So,} \quad I = \frac{T^2 mgb^2}{16\,\pi^2 L} \qquad (1)$$

where:

I : moment of inertia (kg / m^2)

m : object mass (kg)

T : oscillation period (s)

g : acceleration of earth's gravity (m / s^2)

b : the distance between the ropes (m)

L : length of the ropes (m)

and the calculation for the measurement uncertainty is:

$$\Delta I = \frac{1}{N}\sqrt{\frac{N\sum I^2-(\sum I)^2}{N-1}} \qquad (2)$$

The uncertainties in the repeated measurements of the results are determined based on the measurement results obtained, while all measurement results should reflect the sample data from the object being measured. Repeated measurements involve average measurements, deviations from mean values, average deviations and standard deviations [5].

The results of the experimental set of moment of inertia for variations in the length of the rope can be seen in table 1. Based on table 1, the experiment used a variation of the length of the rope for 5 times the variation in the length of the rope, and for each variation of the length of the rope repeated experiments repeated 5 times. Based on the experimental results obtained, the magnitude of the period on the solid cylindrical rod during swinging will be greater in proportion to the length of the rope. Thus, the greater the length of the rope (L) will be directly proportional to the magnitude of the cylinder period [6]. This is in accordance with equation (1) that the length of the rope is proportional to the period (L ~ T).

Table 1. Results of Experiments with Rope Length Variations.

Length of rope (L) (m)	Period (T) (s)	Average Period ($\bar{T}$) (s)
0.35	3.238	3.228
	3.200	
	3.200	
	3.246	
	3.256	
0.45	3.766	3.729
	3.774	
	3.718	
	3.690	
	3.698	
	4.962	
0.55	4.194	4.147
	4.204	
	4.196	
	4.212	
	3.928	
0.65	4.562	4.564
	4.556	
	4.564	
	4.580	
	4.560	
0.75	4.970	4.970
	4.964	
	4.984	
	4.972	
	4.962	

The results of the experimental set of moment of inertia for variations in rope length can be seen in table 2.

Based on table 3, the experimental results are obtained for variations in rope length (L). In accordance with the experiment for each rope length has a relative error in the range 1.78% to 11.2%. It can be concluded that for the cord length variation can produce a large moment of inertia approach to the theory that is equal to 4.167 x kg / m2. This value assumes that the cylindrical axis through the center of mass.

Table 4 explains the results of the experiment for variations in the distance between the ropes (d). In accordance with the experimental results, the relative error for each variation is from 1.31% to. with 2.05%. Experiments using variations in the distance between the ropes with the assumption that the smaller the distance of the quarter (d) close to the kenol, the greater the moment of inertia will approach the theory using a solid cylindrical rod with calculations $I = \frac{1}{12} m L^2$ [8]. This corresponds to the results of the experiment using the experimental set of moment of inertia of the bifilar pendulum method. The results of the moment of inertia in the experiment will be smaller for the distance between the bifilary smaller.

Table 2. Experimental Results with Variations in Distance between Ropes

Distance between Cords (d) (m)	Period (T) (s)	Average Period ($\bar{T}$) (s)
0.1	4.323	4.283
	4.367	
	4.277	
	4.231	
	4.218	
0.15	3.153	3.086
	3.043	
	3.097	
	3.081	
	3.057	

Table 3. the experimental results are obtained for variations in rope length (L)

Rope Length (l) (m)	Moment of Inertia (I ±ΔI) (kg/m²)		KR (%)
	Theory	Experiment (10^{-3})	
0.35	4.167×10^{-3}	(3.699 ± 0.027)	11.2
0.45		(3.840 ± 0.036)	7.84
0.55		(3.887 ± 0.101)	6.72
0.65		(3.982 ± 0.007)	4.44
0.75		(4.093 ± 0.006)	1.78

The principle of work in the set of experimental moment of inertia uses the principle of physical pendulum. This experiment causes harmonious vibrations in oscillating objects with small amplitude, so that it has a period whose value depends on the magnitude of the moment of inertia [9]. Experiments on the set of experimental moments of inertia through the bifilar pendulum method consisting of objects namely solid cylindrical rods, both sides bound with a rope and hung on a support pole. If the rod is turned horizontally with a small deviation angle and then released, the rod will experience periodic oscillations.

Table 4. Results of Data Analysis of Moment of Inertia for Distance Variations between Times (d)

Distance between Cords (d) (m)	Moment of Inertia (I ± ΔI) (kg/m²)		KR (%)
	Teory	Experiment (10^{-3})	
0.1		(5.30 ± 0.69)	1.31
0.15	4.167	(5.93 ± 0.07)	1.18
0.2	$\times 10^{-3}$	(7.17 ± 0.15)	2.09
0.25		(8.77 ± 0.18)	2.05

4. Conclusion

The working principle in the set of moment of inertia experiments using the bifilar pendulum method is an experiment that causes harmonic vibrations in objects that oscillate with small amplitude, so that it has a period whose value depends on the magnitude of the moment of inertia. Moment of inertia based on experiments for variations in the length of the rope at 0.35 m are (I ± =I) = (3.699 ± 0.027) kg/m^2; 0.45 m then (I ± ΔI) = (3.840 ± 0.036) kg/m^2; 0.55 m then (I ± ΔI) = (3.887 ± 0.101) kg/m^2; 0.65 m, (I ± ΔI) = (3.982 ± 0.007) kg/m^2; and 0.75 m, (I ± ΔI) = (4.093 ± 0.006) kg/m^2; Furthermore, the moment of inertia based on experiments for variations in distance between the ropes at 0.1 m, (I ± ΔI) = (5.30 ± 0.69) kg/m^2; 0.15 m then (I ± ΔI) = (5.93 ± 0.07) kg/m^2; 0.20 m then (I ± ΔI) = (7.17 ± 0.15) kg/m^2; and 0.25 m then (I ± ΔI) = (8.77 ± 0.18) kg/m^2.

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