

## DYNAMIC STUDY OF TORSION USING TRACKER SOFTWARE

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*Abstract.* The paper presents an experimental approach that familiarizes students with the video analysis technique. Herein we investigate the dynamic study of the torsion for a metal wire by means of video analysis method with Tracker software and a high-speed camera for data acquisition. The obtained results are in very good agreement with the theoretical calculations for the employed experimental setup.

*Key words:* dynamic study of torsion, Tracker software, video analysis, physics education.

### 1. INTRODUCTION

Aiming for a better understanding of certain physical concepts for students, a lot of new lessons based on classical physics theory and experiments [1], modern automation and monitoring technique [2, 3], modelling-based learning activities [4, 5] and video analysis software were proposed lately in the physics education research area.

Video analysis approach is considered to be an excellent teaching tool that offers students the opportunity to easily comprehend many practical experiments [6–11].

A camera is required for the later video analysis in preparing motion files – video experiments. The students can easily investigate in detail certain types of physical movements by using this high-speed camera and then by video analysis with Tracker software. Consequently, they can observe and better understand various characteristics of the movement and learn the basics of classical mechanics [12–21].

This type of method is possible by using integrated information and communication technology tools that are used for video measurements (through tracking points). Tracker is an open source software for video analysis and modeling of physical phenomena, built as Open Source Physics (OSP) [22]. It is therefore a free software designed also to be effective in educational physics, highly facilitating

the learning process of physics. This software is easy to use, being also quite intuitive. Further advantages include the possibility to run the software on any operating system (Windows, Mac, Android, IOS), without the need for a high-performance computer/hardware. Moreover, many tutorials can be found online and this can be quite helpful. Hence, this software can be successfully employed in various simple physics applications made by students (with minimal computer operating knowledge), but also in more sophisticated experiments.

There are some few simple steps you need to follow in order to properly use Tracker as a video analysis tool: initially, the physical phenomenon to be analyzed is recorded (one can use a common video camera, including here a normal camera of a smartphone); the final movie is then loaded into the Tracker software; length calibration – standard size is subsequently established, after which the software will auto-determine all the specific sizes.

A certain material point from the movie recording will have to be considered fixed and then the software will follow it throughout the entire video. Once the application is launched, it will sequentially track the movement of this material point and will automatically determine/calculate up to other 24 quantities. One can also choose to visualize the graphical representations of the physical quantities to be studied. In this way, one can picture simultaneously the recorded movement and the way the graph is drawn, which can bring forward relevant features in the understanding of any potential abstract physical concepts (Fig. 1).

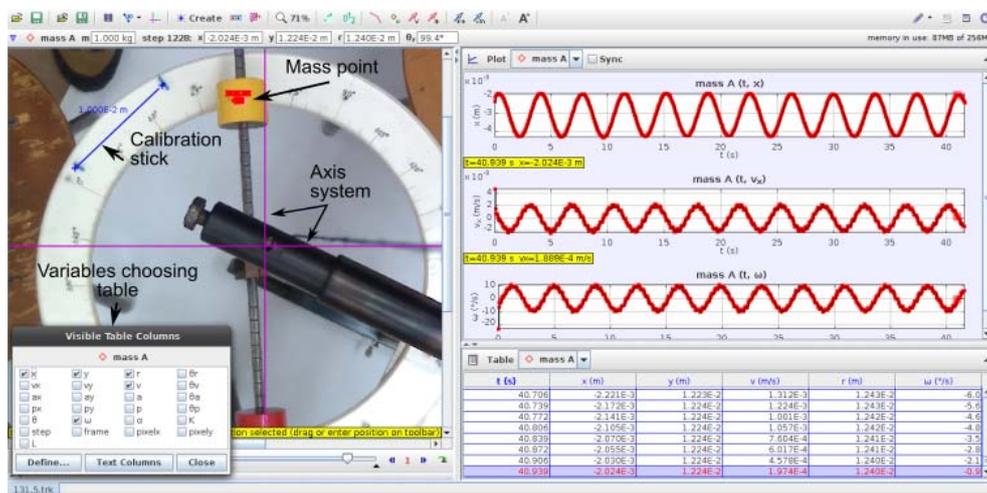


Fig. 1 – Software tracking a mass point can determine 24 physical quantities and can also plot graphs concurrently. The full color version can be accessed at <http://www.rrp.nipne.ro>.

The current paper presents a physics experiment that familiarizes participants in the video analysis procedure. It is important to help students overcome the

experimental difficulties related to the dynamic study of torsion in the physics laboratory.

## 2. EXPERIMENTAL SETUP AND METHOD

### 2.1. SETUP AND COMPONENTS

The experimental setup is shown in Fig. 2. It consists of a fixed support, with an attached steel wire. At the other end of the wire, we have a rod on which two identical sliding cylinders are connected. The experimental device is provided with a circular protractor necessary for measuring the angular deviations of the rod from the equilibrium position [23].

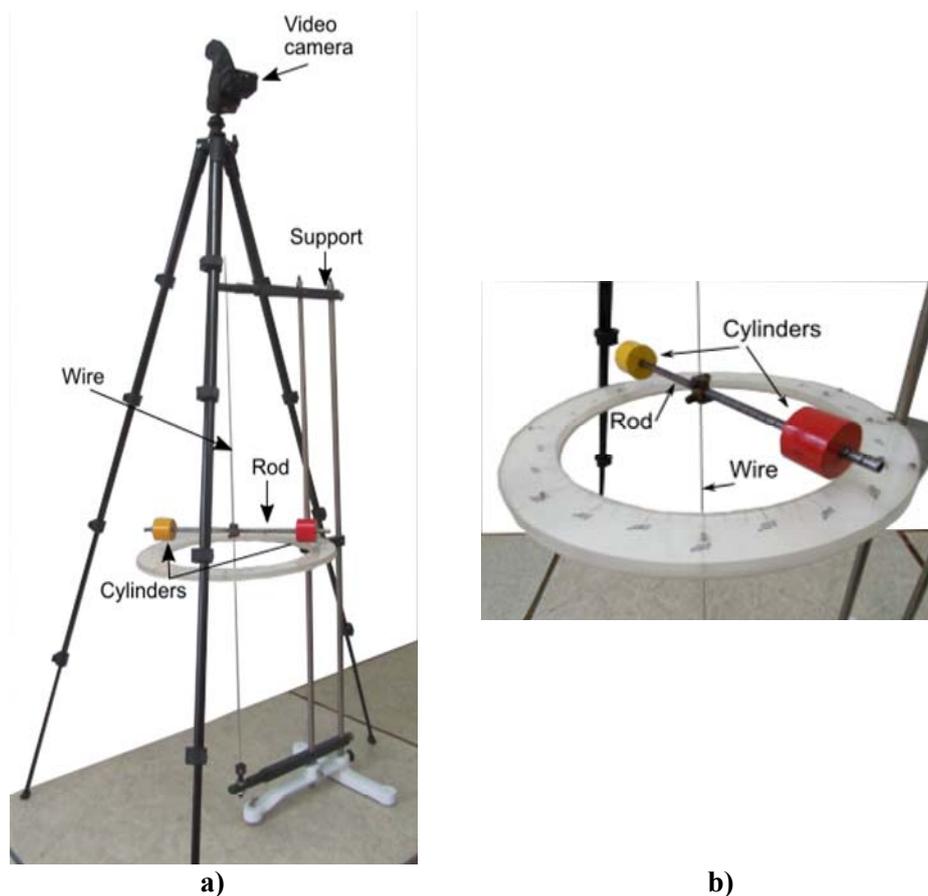


Fig. 2 – a) Diagram of the experimental device; b) inset of the metal rod and the two cylindrical weights. The full color version can be accessed at <http://www.rpp.nipne.ro>.

For the dynamic study of torsion, we used in the set-up a Sports Action Camera (with recording capabilities at 120 frames per second – fps). The camera was placed on top of the experimental device, in a horizontal position (camera lens parallel to the ground), taking care to have an accurate focus, so that the resulting recording is clear and comprehensive, without distortions. To be easily discernible as tracking points, two points are marked on the cylinders of the device's pendulum. Although a single material point is tracked, the markings are placed on both cylinders to ensure symmetry of the experimental assembly.

Special care is taken with the general placement of the camera in the experimental setup and the camera settings, for avoiding common error sources, such as reference length misplacement and incorrect camera angles that can be present in experiments involving video analysis [24].

The two metal cylinders were symmetrically placed in positions close to the axis of oscillation for the device. In order to produce torsional oscillations of the rod, it was twisted with an angle below  $5^\circ$  and then set free (the video camera that records its movement is also turned on). After performing a sufficiently large number of oscillations (so that the video material contains significant information), we repositioned the cylinders on both sides of the rod at equal distances and the procedure is repeated.

The obtained video material is subsequently analyzed using the Tracker software.

After a movie is loaded into the software, the proper size calibration is performed, by using the markings on the pendulum support. The point to be tracked is set on one of the cylinders. The analysis is adjusted to run for as long as possible, for including a larger number of complete oscillations, as shown in Fig. 3.

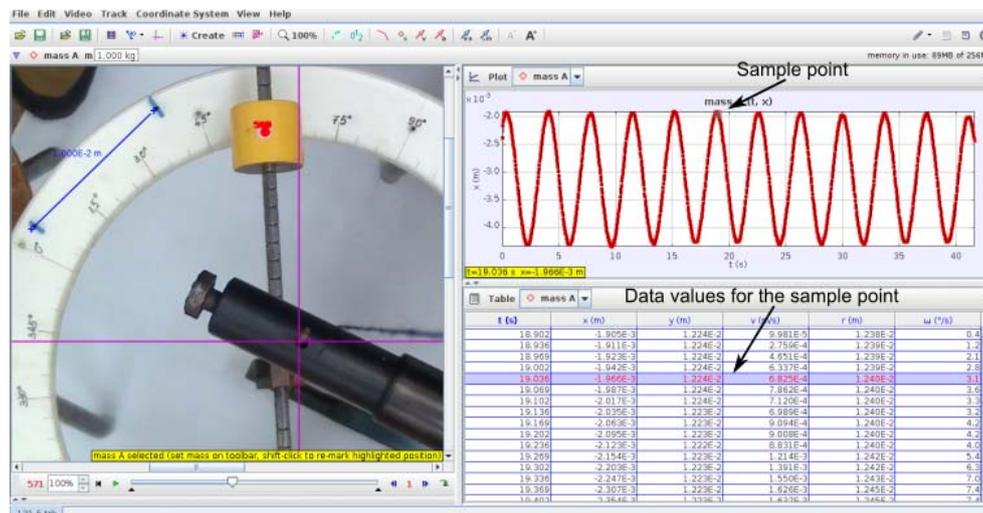


Fig. 3 – The periodicity of the oscillatory movement analyzed with the Tracker software for the dynamic torsion experiment. The full color version can be accessed at <http://www.rpp.nipne.ro>.

In order to determine the oscillation period two points with the same phase are selected, at the maximum possible distance and the period is then calculated by dividing the total duration of the process by the number of complete oscillations. The software allows identifying the points with a precision of several hundredths of a second (120 fps), providing detailed information in both the value tables and information windows that appear at the click on the point on the graph, thus allowing the accurate identification of the points in phase and of the necessary moments of time during the experiment.

## 2.2. THEORETICAL BACKGROUND

If the rod is slightly twisted, torsion in the wire will be induced, generating a restoring torque that comes from the elastic fibers deformations [25]. The magnitude of the torque is proportional with the torsion angle of the wire [25, 26]:

$$M = -C\theta, \quad (1)$$

where  $C$  is the torsion constant of the wire.

In case of small angle deviations, the rod's equation of motion is the equation for harmonic oscillator having the period:

$$T_0 = 2\pi\sqrt{\frac{I_0}{C}}, \quad (2)$$

where  $I_0$  is the moment of inertia of the rod about an axis defined by the suspension wire which coincides with the axis passing through the center of the rod. Considering  $m_0$  and  $l$  the mass and respectively the length of the rod, the moment of inertia becomes [25–27]:

$$I_0 = \frac{1}{2}m_0l^2. \quad (3)$$

With the two cylinders attached to the rod (each at distance  $d$  from the center of oscillation), the moment of inertia of the ensemble is [23]:

$$I = I_0 + 2I_c + 2m_c d^2, \quad (4)$$

where  $I_c$  is the moment of inertia of a cylinder relative to its center. The cylinders are hollow pipes of inner and outer radii  $r$ , respectively  $R$ , length  $l_c$  and mass  $m_c$ , thus [26]:

$$I_c = \frac{1}{4}m_c \left( r^2 + R^2 + \frac{1}{3}l_c^2 \right). \quad (5)$$

Since the centers of the cylinders are at distance  $d$  from the center of oscillation, the parallel axis theorem was used in equation (4).

If we consider the case where the cylinders are situated at distances  $d_1$  and respectively  $d_2$  from the center of rotation, the ratio of the periods calculated from equation (2) becomes:

$$\frac{T_2^2}{T_1^2} = \frac{I_2}{I_1} = \frac{I_0 + 2I_c + 2m_c d_2^2}{I_0 + 2I_c + 2m_c d_1^2}. \quad (6)$$

The quantity  $Z = I_0 + 2I_c$  can be obtained from the above equation if we measure the oscillation periods for the two distances:

$$Z = 2m_c \frac{T_1^2 d_2^2 - T_2^2 d_1^2}{T_2^2 - T_1^2}. \quad (7)$$

If we take the ratio between the oscillation periods of the rod with cylinders situated at a certain distance, say  $d_2$  and the oscillation periods of the rod without cylinders, we get:

$$\frac{T_2^2}{T_0^2} = \frac{I_2}{I_0} = \frac{I_0 + 2I_c + 2m_c d_2^2}{I_0} \quad (8)$$

and afterwards we can obtain the moment of inertia of the rod:

$$I_0 = \frac{T_0^2}{T_2^2} Z + 2m_c d_2^2. \quad (9)$$

The value for the moment of inertia of the rod is used in equation (2) to calculate the torsion constant of the wire.

The values for the parameters of our experimental setup are summarized below [23]:

- length of the rod:  $l = 358 \pm 1$  mm;
- mass of the rod:  $m_0 = 150 \pm 0.5$  g;
- mass of a cylinder:  $m_c = 350 \pm 1$  g;
- length of the cylinder:  $l_c = 35 \pm 1$  mm;
- outer radius of the cylinder:  $R = 20 \pm 0.05$  mm;
- inner radius of the cylinder:  $r = 3.95 \pm 0.05$  mm.

From equation (3) it follows that the moment of inertia of the rod is  $I_0 = 1.602 \cdot 10^{-3}$  kg·m<sup>2</sup> and from equation (5) one obtains that the moment of inertia of a cylinder relative to its center  $I_c = 0.072 \cdot 10^{-3}$  kg·m<sup>2</sup> and finally  $Z = I_0 + 2I_c = 1.746 \cdot 10^{-3}$  kg·m<sup>2</sup>.

### 3. RESULTS AND DISCUSSIONS

Using the experimental setup described in the previous section, we determined the oscillation period of the rod with cylinders situated at different distances from the oscillation axis represented by the wire.

As we already indicated in the preceding section, in order to calculate the oscillation period, a point situated at the beginning of the data set is chosen and Tracker gives its coordinates, as in Fig. 4. After 10 complete oscillations, we look for a point on the graph with the same  $x$  coordinate (for which the time is determined by the software). For a more precise determination, the coordinates are also read from the data table and the period is calculated as the ratio between the time interval and the number of oscillations. The time interval can also be obtained by slow motion playback of the recorded movie. The resulting periods ( $T$ ) determined by these two methods have the same value.

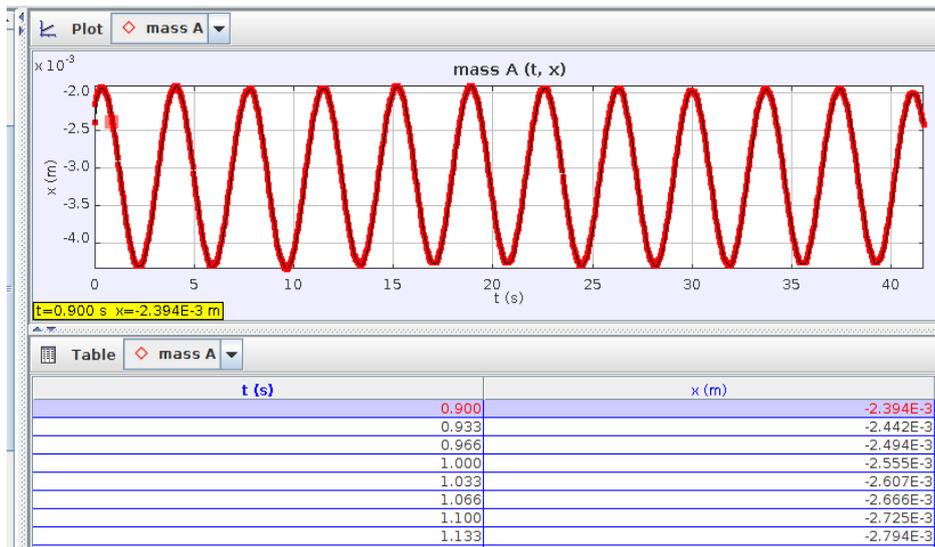


Fig. 4 – Data set used to extract the experimental data. The full color version can be accessed at <http://www.rrp.nipne.ro>.

Using equations (2) and (4), we find that the dependence of the square of the oscillation period on the square of the distance of the cylinders to the oscillation axis is linear:

$$T^2 = \frac{4\pi^2}{C}(Z + 2m_c d^2). \quad (10)$$

From the experimental data, we plotted the dependence of  $T^2$  on  $d^2$  and we obtained that the graph is linear (Fig. 5).

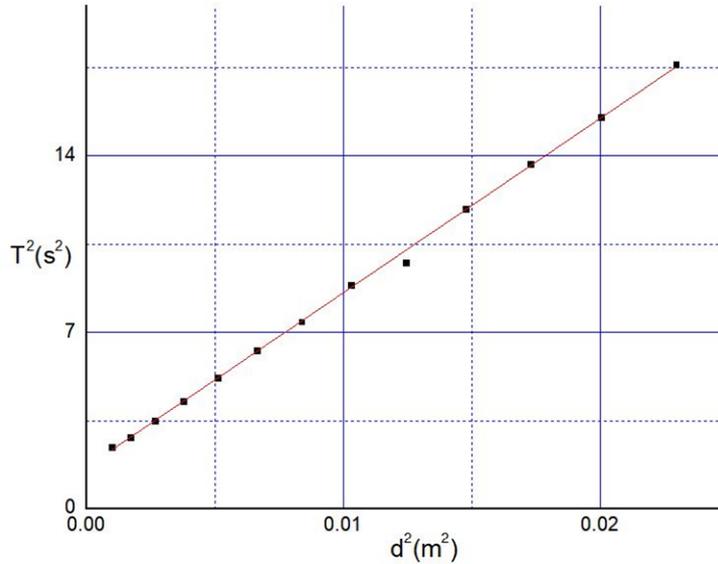


Fig. 5 – Dependence of the square of the oscillation period on the square of the distance of the cylinders to the wire.

The linear fit of the curve in Fig. 5 gives us the slope  $a = 691.748 \pm 6.257 \frac{\text{s}^2}{\text{m}^2}$  and using the mass of the cylinder in equation (10) we obtain the torsion constant of the wire  $C_1 = 3.990 \cdot 10^{-2} \text{ N} \cdot \text{m} / \text{rad}$ .

For comparison, we determined the oscillation period of the rod without cylinders ( $T_0 = 1.258 \text{ s}$ ) and using the moment of inertia of the rod in equation (2), we obtained  $C_2 = 3.990 \cdot 10^{-2} \text{ N} \cdot \text{m} / \text{rad}$  which is identical with the value  $C_1$  determined from the graph.

The linear fit of the curve in Fig. 5 also provides the intercept  $b = 1.657 \pm 0.075 \text{ s}^2$ . Using the obtained result for  $C_1$ , we determine  $Z_1 = 1.678 \cdot 10^{-3} \text{ kg} \cdot \text{m}^2$ , a value that is almost identical to the theoretical value calculated from parameters of the experimental setup.

Moreover, we take two values from the data set, namely  $d_1 = 5.15 \text{ cm}$  (when  $T_1 = 1.87 \text{ s}$ ) and  $d_2 = 12.15 \text{ cm}$  (when  $T_2 = 3.45 \text{ s}$ ) and we then calculated  $Z$  from equation (7). We obtained  $Z_2 = 1.673 \cdot 10^{-3} \text{ kg} \cdot \text{m}^2$ , which is in good agreement with the result for  $Z_1$  achieved from the graph in Fig. 5 and the theoretical value.

Additionally, the quantity  $Z_2$  was employed to calculate the moment of inertia of the rod from equation (9), obtaining  $I_{01} = 1.598 \cdot 10^{-3} \text{ kg} \cdot \text{m}^2$  which is matching to the value calculated for the rod using the values from [23].

#### 4. CONCLUSIONS

Accurate experimental results were obtained by using the video analysis method with Tracker software for the dynamic study of the torsion. The method is shown to produce far better results than employing the traditional routine (such as the stopwatch practice). Moreover, the experiment is very interactive, as students can real-time modify the oscillatory movement of the rod by moving the cylinders along it. The experiment can also be in depth re-analyzed at any later moment by using the recorded movies and the capabilities of the software to show/process the video in slow-motion.

On the other hand, the experimental setup and the video analysis software are suitable to quickly generate reliable and reproductive data results. The method/experiment itself is also straightforward and inexpensive because it includes simple devices; data acquisition (recordings) can be done even by means of a smartphone camera and the analysis software is free.

This manuscript represents an approach to STEM (Science, Technology, Engineering and Mathematics) and IBL (Inquiry Based Learning) integration using access to a computer-based learning environment. The integration of the Tracker software into the experiment generates exploratory experiences, where students construct models of physical quantities and apply them to the processing of experimental data within a classroom instructional environment [17, 18].

Based on the IBL, the method broadens experimental students' activity while helping them to understand and explain the physics phenomena when watching the video and analyzing the acquired data *via* Tracker software.

In our opinion, these types of approaches can be employed in several teaching environments, by including real life physical examples.

Video analysis and modeling technique help students in better comprehending the physical principles and phenomena, further developing their abstract thinking, projection skills and their perception, while offering them the opportunity to immediately discuss the results of the planned experiment.

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