CILAMCE 2017
Florianópolis - Santa Catarina - Brazil

COMPUTATIONAL ANALYSIS OF AN INSTRUMENTED CHARPY IMPACT PENDULUM DYNAMICS

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Abstract. *This paper shows the analysis of the dynamic movement of a free-swinging Charpy Hammer. The analytical simulation is composed of differentials equations of a physical pendulum, which are solved by a numeric integrator. The experimental results are acquired through the Arduino microcontroller with a gyroscope sensor calibrated to be used in this assignment.*

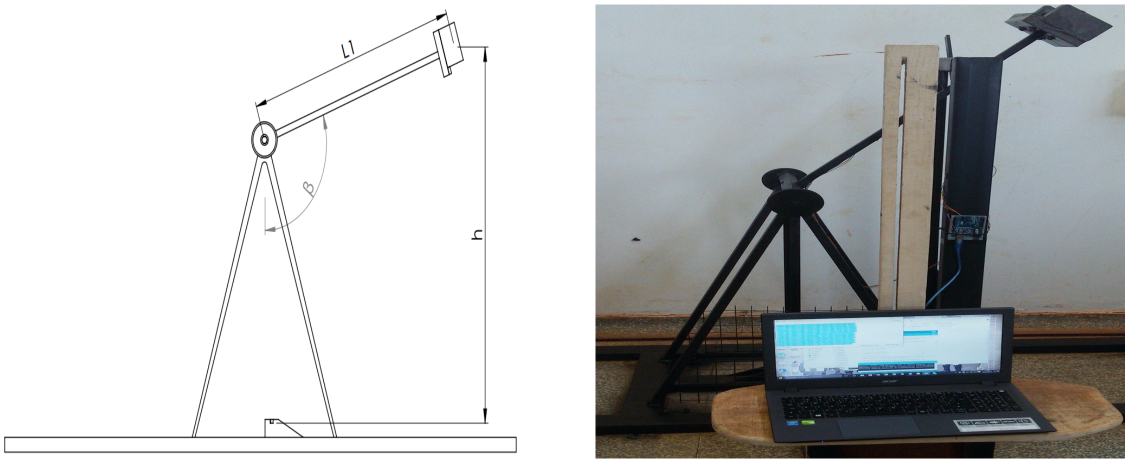
Keywords: *Dynamics, Pendulum, Charpy, Experimental Analysis*

1 INTRODUCTION

The analysis of the dynamics of machines that perform pendular movements is of extreme importance, considering the need to know their kinetic and kinematic behavior, such as the speed and amplitude of oscillation, the forces acting on the system and consequently the loads supported by the material with specific geometry as suggested by Chitolina (2013), Sahraoui (1998) and Rossoll (1999).

With respect to the design of a Charpy impact test, the modeling of the system through differential equation and finite elements is interesting since several parameters must be fulfilled according to the current norm, besides guaranteeing the physical and mechanic integrity of the system, considering the forces acting on this (Franzon, 2013 and Tóth, 2002).

In order to model the Charpy impact test already developed at the Energy Engineering Laboratory of the Federal University of Grande Dourados, is proposed the analysis of the dynamics of the apparatus, considering quantities such angular displacement and impact velocity, through analytical simulations using a high-order numerical integrator. Subsequently the results are compared with the data measured through a gyroscope sensor calibrated.



(a) Utilized Model (b) Instrumented Prototype

Figure 1: Charpy Impact Pendulum

2 METHODS

To obtain magnitudes such as the angular displacement developed by the pendulum and the impact velocity of the cleaver considering the mass, the geometry and moment of inertia, as in ABNT NBR 148, the Charpy hammer was modeled from the Differential equation of the physical pendulum. (ABNT NBR ISO 148-1,2013) and (ABNT NBR ISO 148-2,2013).

According to figure 1 (a), the term $L1$ can be defined as the distance between the rotary axis, or pivot, to the center of percussion of the pendulum, that was designed to coincide with the impact place. The term h represents the instantaneous vertical position of the center of mass, m the value of the mass of the pendulum, β, the angle with respect to the vertical, I_0 the moment of inertia, g the value of the acceleration of gravity. During the simulations, as well as the acquisition of data experimentally, the initial conditions of impact pendulum, initial velocity and launch angle were respectively defined as $v_0 = 0$ and $\beta_0 = 2,478rad$.

2.1 Analytical Simulation

With the predetermined values of the center of mass, L_{cg}, of the total width of the pendulum, L_p, and by measuring the period of oscillation, P, as recommended by the current technical norm, can calculate the center of percussion and the moment of inertia, I_0, from equations (1) and (2).

$$L1 = \sqrt{\frac{gP^2}{4\pi^2}} \tag{1}$$

$$I_0 = mL_{cg}^2 + \frac{1}{12}mL_p^2 \tag{2}$$

Applying the Lagrange equations by conserving energy, one can model the system as a physical pendulum, so that the Lagrangian, L, as a function of kinetic energy, T, and potential energy, U, is described by equation (3):

$$L(\beta, \dot{\beta}, t) = T(\beta, \dot{\beta}, t) - U(\beta) \tag{3}$$

Applying the concepts of energy balances, obtains (4):

$$\frac{\mathrm{d}}{\mathrm{d}t}\frac{\partial}{\partial \dot{\beta}}(\frac{1}{2}I_0\dot{\beta}^2) - \frac{\partial}{\partial \beta}(mgL_{cg}\cos(\beta)) = 0 \tag{4}$$

Solving (4), is obtained the moviment equation given by (5):

$$\ddot{\beta} - \frac{mgL_{cg}}{I_0}\sin(\beta) = 0 \tag{5}$$

From this, it is possible, through a numerical integrator, to solve the set of equations using Python software and the NumPy and SciPy libraries. Thus, the solution of the system of equations of (4) returns vectors of angular displacement and angular velocity.

2.2 Experimental Analysis

The data acquisition was done using the Arduino microcontroller, which is an open source electronic prototyping platform, low cost and easy work environment (Bhmer,2012). The data of the pendulum dynamics was sampled from the digital gyroscope sensor on the MPU-6050 chip. These sensors can register triaxially the angular speeds through which they are subjected (Varanis, 2015).

Measurement of the angular velocity of the impact pendulum was performed in accordance with Nyquest's Theorem, whereby the highest frequency present in the signal must be at least two times less than the sampling frequency, as described by Guido (2003). According to the Nyquest or Sampling Theorem and based on the oscillation period calculated through analytical and numerical simulation, the sensor sampling frequency was set at $100Hz$.

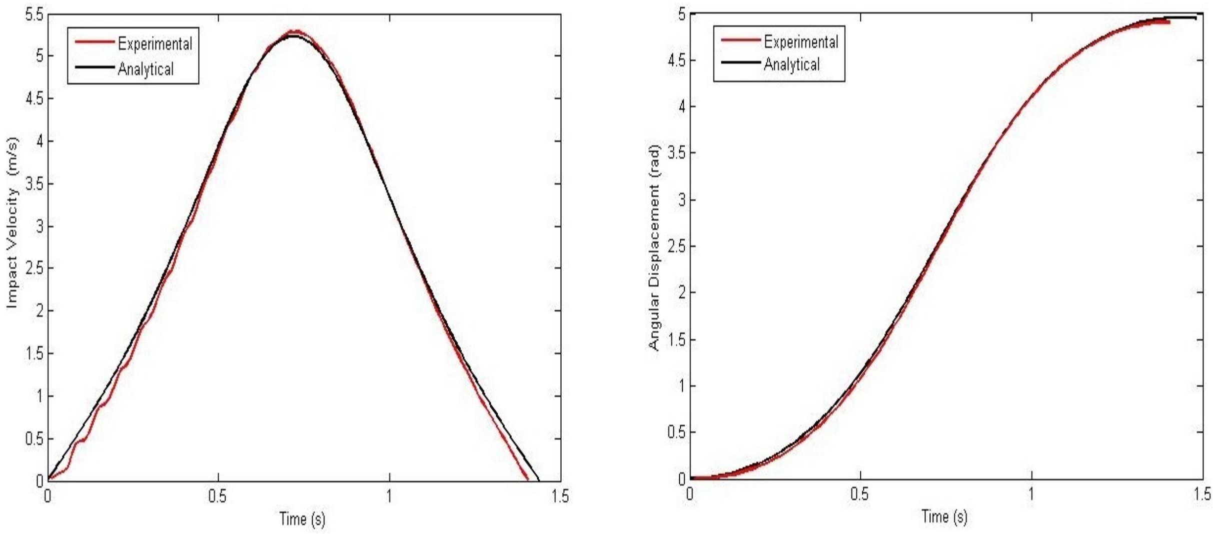
In order for the numerical values recorded by the sensor to be processed and analyzed, it is necessary that the units of measurement comply with those established by the International System of Units, S.I. Thus, it is necessary that the data acquired be multiplied by a constant defined according to measuring range programmed on Arduino software, as explained by Varanis et al. (2015).

In order to calculate the impact energy that a shape with material and geometry specified would support, it is necessary to know the maximum angular displacement of the pendulum after the fracture of the specimmens. By this way, it is necessary the numeric data integration by a software, thus obtaining an angular displacement vector,V_θ. Assuming the time increment, $\mathrm{d}t$ as $1/fs$ and V_ω as the angular velocity vector measured by the sensor and already converted to the S.I. units, it is possible to calculate the vector V_θ by Equation (6).

$$V_\theta = \int_0^t V_\omega \mathrm{d}t \tag{6}$$

3 RESULTS

In order to compare the results and experimental, tests were performed with the Charpy pendulum. Next, the impact velocity and angular displacement are compared and analyzed for each case in question.



(a) Impact Velocity

(b) Angular Displacement

Figure 2: Kinematics Analysis

Figure 2 (a) shows the impact velocity of the cleaver during the entire course of the pendulum and Figure 2 (b) shows the angular displacement resulting from the integration of the data. Between the comparison of the cleaver speed obtained analytically and experimentally there is a small divergence between the curves in the first 0.25 seconds, possibly caused by hammer interferences. However, it is notable that the data converge most of the time, including at the point of impact, where there is more interest in knowing the speed.

From Figure 2 (b) it can be observed that the convergence between the experimentally and analytically obtained curves occurs in the initial point and the overlap of the curves happens for almost all the time space analyzed. In addition, the maximum displacement of the pendulum for such analyzes are very close, varying only $0.05rad$.

The Table 1 lists the most interest values for each type of analysis

Table 1: Cinematic Data

Methods	Impact Velocity (m/s)	Total Angular Displacement (rad)
Analitycal	5.15	4.96
Experimental	5.28	4.91

4 CONCLUSION

From the data collected from Figure (2) and Table (1), it is notable that the tangential velocity of the cleaver is close throughout the time interval for both cases. Although the divergence between the period of oscillation, this shows to be some tenths of a seconds, indicating errors due to measurement uncertainties. Moreover, the impact velocity value converges, presenting only 2% for the analytical and numerical method.

As far as angular displacement is concerned, this is even more in agreement between the analytical modeling and the experimental analysis. In absolute values, it is possible to notice the proximity from the discrepancy analysis, being 1% for the presented analyses.

ACKNOWLEDGMENT

The authors thank the Federal University of Grande Dourandos for grant the Energy Engineering laboratory for the Charpy Pendulum allocation, besides the support of the technicians involved.

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