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1.1 ANALYSIS NONLINEARITES IN A MECHANICAL MODEL OF A CLAW DURING THE CONTACT AND IMPACT

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Abstract. *The purpose of this paper aims to obtain and analyze the dynamics of a manipulator claw, considering it as a mechanical model consisting of two simple pendulums and a material composed of parallel walls, which can be considered the mechanical characteristics with a Model mass-spring-damper. The modeling of contact and impact is very important for the dynamic simulation, particularly for modeling robotic manipulators that perform tasks involving interaction with their working environment. The impact refers to the physical phenomenon that occurs when a body collides with another, having as main characteristics: a very short duration, achieving high levels of forces of interaction, exchange and rapid energy dissipation and large accelerations and decelerations of the bodies involved .*

Keywords: *Nonlinearities, Contact, Impact*

2. INTRODUCTION

Impact event is a non-linear nature that occurs when two or more bodies suffer a collision. This phenomenon is present in several areas - machine design, robotics, multi-body analysis, these are a few examples. Impact is a complex physical phenomenon that occurs when two or more bodies collide with each other. [1] The main features are the impacts, the short duration, high strength levels achieved, the rapid dissipation and high accelerations and decelerations. These events should be considered during the design and analysis of any mechanical system [2]. Moreover, during the impact, the system can present a discontinuity in some geometry and material properties can be modified by the impact itself.

In general, two different approaches can be distinguished by impact of contact and analysis. The first approach assumes that the interaction between objects occurs in a short period of time and that the configuration of the impact of the bodies does not change significantly. The dynamic analysis is divided mainly into two intervals before and after impact, and secondary phases such as slip, bottleneck and reverse motion. To model the process of energy transfer and dissipation, there are several coefficients are employed mainly the coefficient of restitution and the relative momentum [3,4]. Applying these methods, referred to as pulse-time or discrete methods [5], has been confined mainly to the impact between rigid bodies. The extension for flexible systems, as well as extension to more general cases involving multiple contacts and intermittent contact is quite complicated.

The second approach is based on the fact that the interaction forces act in a con-tinuous manner during the impact. Thus, the analysis may be performed in the usual way, by simply adding the contact forces to the equations of motion during their action period. This al-lows a better description of the real behavior of the system, in particular, with respect to friction modeling. More importantly, this approach is naturally suitable for contact modeling and com-plex contact scenarios involving multiple contacts and bodies. This approach is referred to as continuous analysis or force based methods [5].

3. OBJECTIVE

One feature that should be taken into account when proposing simulations involving collisions is the nonlinear behavior of the phenomenon. The nonlinear behavior of the kinematic type due to large displacements, rotations and deformations that occur in a system. In general it is very common for mechanical systems may be subject to contact and impacts of these events being non-linear.

The modeling of contact and impact is very important for the dynamic simulation, in particular to the modeling of robotic manipulators that perform tasks involving interaction with their working environment. Impact refers to the physical phenomenon that occurs when a body collides with another, having as main characteristics: a very short duration, reaching high levels of forces of interaction, exchange and rapid dissipation of energy and high accelerations and decelerations of the bodies involved .

Thus, the aim of this paper aims to obtain and analyze the dynamics of a manipulator claw, considering it as a mechanical model consisting of two simple pendulums and a material composed by parallel walls, which can be considered the mechanical characteristics with a model mass-spring-damper, as shown in Figure 1.

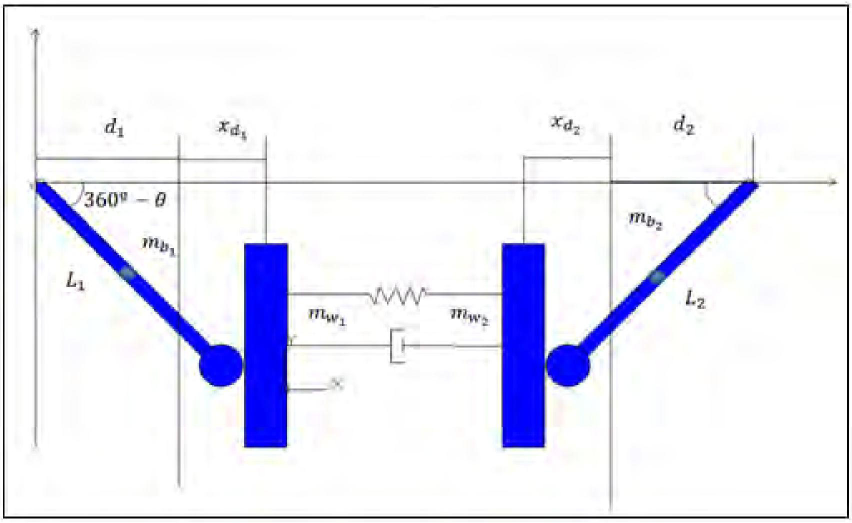

Figure 1 - Mechanical model considered.

4. METHODOLOGY

The purpose of the model is to study the dynamic interaction of the contact between the impactor and the parallel walls of the block. The Euler-Lagrange equations are useful for describing the motion of a mechanical system through a set of differential equations that represent the evolution of the mechanical system over time. Restrictions on the movement position of the model are called holonomic links. When movement of a mechanical system somehow find a restriction arise also called restraining forces, i.e. the forces necessary for the restrictions are met. The determination of the forces of constraint (also called bond forces or internal forces) is not always a simple task. Thus, the Lagrangian formulation is an attractive alternative because it does not require the determination of the restraining forces to obtain the equations of motion.

Thus, we have the Lagrangian of the mechanical system is given by;

$$L = K - V \tag{1}$$

where K is the kinetic energy and V is the potential energy of the system. Then the equations of Euler-Lagrange (or simply equations Lagrange) are expressed as:

$$\frac{d}{dt}\frac{\partial L}{\partial \dot{q}_j} - \frac{\partial L}{\partial q_j} = \tau_j \tag{2}$$

Where τ_j is the generalized non-conservative force (torque or force) towards the generalized coordinate independent of q_j.

It starts here obtain the equations of motion for the system with movement restriction. The method of Lagrange multipliers allows the inclusion of internal forces in the equations of Lagrange.

The two bodies will now interact with each other. For a time, both will be in touch. When the distance between them is zero, there is a force of interaction between m_{b1} and the bulkhead. Lagrange multipliers, λ, can be interpreted as the amplitudes of the contact forces. Are considered as a new variable to the problem.Whether the system shown in Figure 1.

The kinetic energy stored in the shield is zero, so the total kinetic energy of the system is given only by the energy stored in the pendulum, ie:

$$K = \frac{1}{2} m_{b1} \dot{\theta}^2 \quad (3)$$

Thus, the total potential energy is given by:

$$V = \frac{1}{2} K_\omega x_d^2 + m_b g d_{cm} (1 - \text{sen}(360 - \theta)) \quad (4)$$

Using the equation of motion of the Bond

$$d + x_d - L_1 \cos(360 - \theta) = 0 \quad (5)$$

Thus, the Lagrange is given for;

$$L = \frac{1}{2} m_b \dot{\theta}^2 - \frac{1}{2} K_\omega x_d^2 + m_b g d_{cm} (1 - \text{sen}(360 - \theta)) \quad (6)$$

Introducing the concept of Lagrange multipliers, λ, the new Lagrangian will be written and (Routh (1960));

$$L = \frac{1}{2}\left(I_{b_1 cm} + m_b d_{cm}^2\right)\dot{\theta}^2 + \frac{1}{2} m_\omega \dot{x}_d{}^2 - \frac{1}{2} K_\omega x_d^2 + m_b g d_{cm} (1 - \text{sen}(360 - \theta)) + \lambda(d + x_d - L_1 \cos(360 - \theta)) \quad (7)$$

Where the last term is related to the constraint condition. The equation of motion for the screen when contact occurs, is given by:

$$m_\omega \ddot{x}_d + k_\omega x_d + C_\omega \dot{x}_d = \lambda \quad (8)$$

In equation (5) has two unknowns for only one equation. One of the variables should be eliminated. This is the variable x.

Making d = 0 (contact) isolating and x in Equation (5) is:

$$d = L_1 \cos(360 - \theta) - x_d \quad (9)$$

Differentiating Equation (2.26) with respect to time, one has:

The following relations are valid:

- Contactless: $d > L_1 \cos(360 - \theta) - x_d$

When there is no contact with the wall, the Lagrange multipliers is equals the zero, thus the equation of systems is given for two equations;

$$m_\omega \ddot{x}_d + k_\omega x_d + C_\omega \dot{x}_d = 0 \quad (9)$$

$$\left(I_{b_1 cm} + m_b d_{cm}^2\right)\ddot{\theta} + m_b g d_{cm} \cos(360 - \theta) = M_\theta \quad (10)$$

The equation 10, for simulation is necessary, to define a valor of the torque.

Finally we have the force of contact between the pendulum and the wall is given by the Lagrange multiplier.

$$\lambda_1 = \frac{-m_\omega L_1 sen\theta}{I_{b_1 cm} + m_b d_{cm}^2 m_\omega L_1{}^2 sen^2\,\theta}\left[M_\theta - m_b g d_{cm} \cos\theta - m_\omega L_1^2 sen\,\theta \cos\theta \dot{\theta} - C_\omega L_1^2 \dot{\theta} + k_\omega L_1^2 sen\,\theta \cos\theta - k_\omega d L sen\theta\right] - m_\omega L_1 \cos\theta\,\dot{\theta} - C_\omega L_1 sen\,\theta\,\dot{\theta} + k_\omega L_1 \cos\theta - k_\omega d \quad (9)$$

The same procedure is performed for other pendulum, the same equation for obtaining the second pendulum.

$$\lambda_2 = \frac{-m_\omega L_1 sen\theta}{I_{b_1 cm} + m_b d_{cm}^2 m_\omega L_1{}^2 sen^2\,\theta}\left[M_\theta - m_b g d_{cm} \cos\theta - m_\omega L_1^2 sen\,\theta \cos\theta \dot{\theta} - C_\omega L_1^2 \dot{\theta} + k_\omega L_1^2 sen\,\theta \cos\theta - k_\omega d L sen\theta\right] - m_\omega L_1 \cos\theta\,\dot{\theta} - C_\omega L_1 sen\,\theta\,\dot{\theta} + k_\omega L_1 \cos\theta - k_\omega d \quad (10)$$

3.1 Coefficient of restitution

The coefficient of restitution given by:

$$\epsilon_x = -\frac{v_{P1_x}^{depois} - v_{P2_x}^{depois}}{v_{P1_x}^{antes} - v_{P2_x}^{antes}} \quad (11)$$

However the event contact represents a major challenge because before contact, the angular velocities of the pendulums are attached only to their own pendulums, as the dynamic equations. This implies that the velocity at impact, need to be recalculated taking into account the coefficient of restitution.

Thus we have, making the substitutions speeds;

$$\epsilon_x = -\frac{L_1\,\omega_b^{depois} cos(\theta - 270°) - v_{\omega_x}^{depois}}{L_1\,\omega_b^{antes} cos(\theta - 270°) - v_{\omega_x}^{antes}} \quad (12)$$

Whereas $\epsilon_x = 0$, we have;

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$v_{\omega_x}^{depois} = L_1\, \omega_b^{depois} cos(\theta - 270°)$ (13)

Substituting (7) into equation (8) thus has;

$$\left(I_{b_1cm} + m_b d_{cm}^2 cos^2(\theta - 270°) + m_\omega L_1^2\, cos^2(\theta - 270°)\right)\omega_b^{depois} = (I_{b_1cm} + m_b d_{cm}^2 cos^2(\theta - 270°)\omega_b^{antes} + m_\omega L_1^2\, cos(\theta - 270°)$$

Isolating ω_b^{depois} then we obtain the equation (12), as follows:

$$\omega_b^{depois} = \frac{(I_{b_1cm} + m_b d_{cm}^2 cos^2(\theta - 270°))\omega_b^{antes} + m_\omega L_1^2\, cos(\theta - 270°)}{\left(I_{b_1cm} + m_b d_{cm}^2 cos^2(\theta - 270°) + m_\omega L_1^2\, cos^2(\theta - 270°)\right)} \quad (14)$$

That will be used to calculate the new velocities during contact.

3.2 Numerical Simulation (system-restricted)

The values for the parameters used in the numerical simulations are given in Table 1. Three different cases are considered, varying only the value of the spring stiffness bulkhead, k1.

For numerical integration, the numerical integrator called Runge-Kutta fourth order is used. The integration step is considered 0.0001s.

Table 1- Table with the values of the parameters considered

PARAMETERS USED TO THE NUMERICAL SIMULATION	
Wall mass	1 Km
Constant Elasticity of spring	10 N/m
Damping constant of	5 m/s
Stem length	1 m
Value of torque is	1.6 $N.m$

In the Figure 2 is possible verify the displacement of the pendulum 1, of according the conditions initials. The pendulum 2 also will be displaced the same way, because of synchronism.

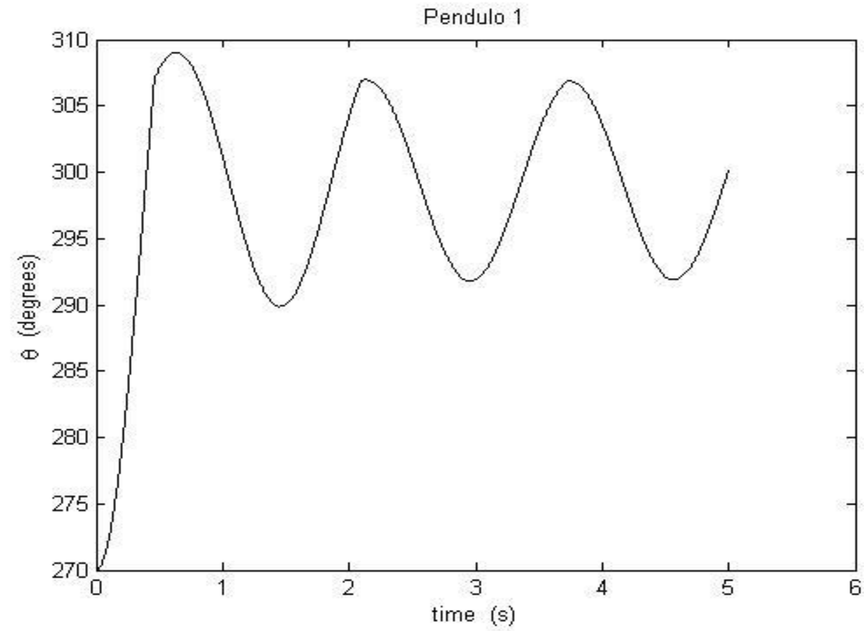

Figure 2 - The displacement of the pendulum.

ISSN 2176-5480

In the Figure 3 is possible to verify the angular velocity of the pendulum 1, the angular velocity of pendulum is bigger in the start, because there is not contact.

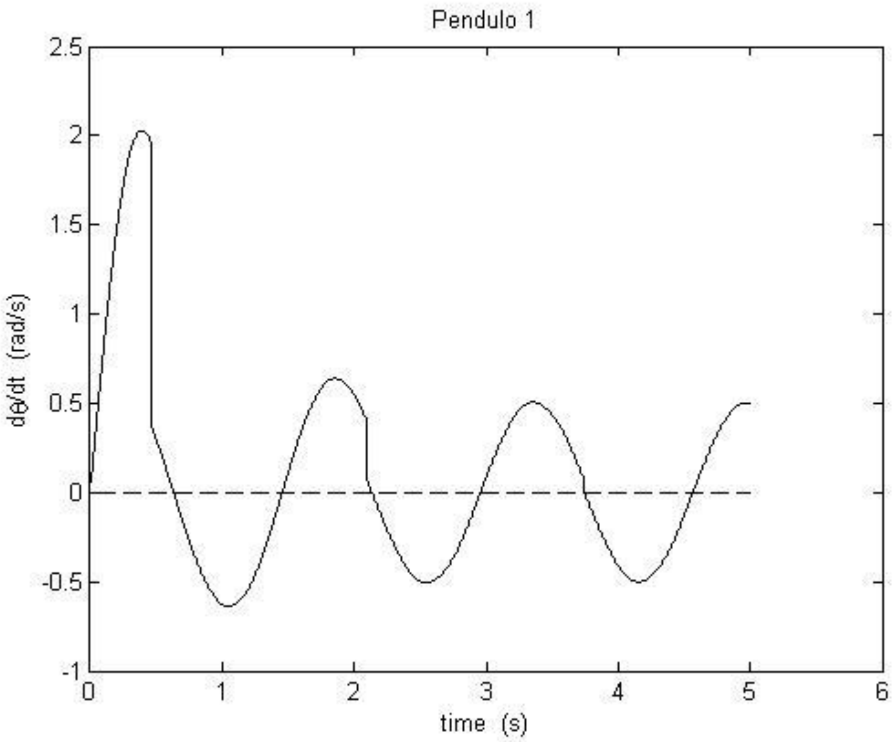

Figure 3 - The angular velocity of the pendulum.

In the Figure 4 is possible to verify the linear velocity of the wall, the linear velocity of wall is bigger in the start, because there is not contact.

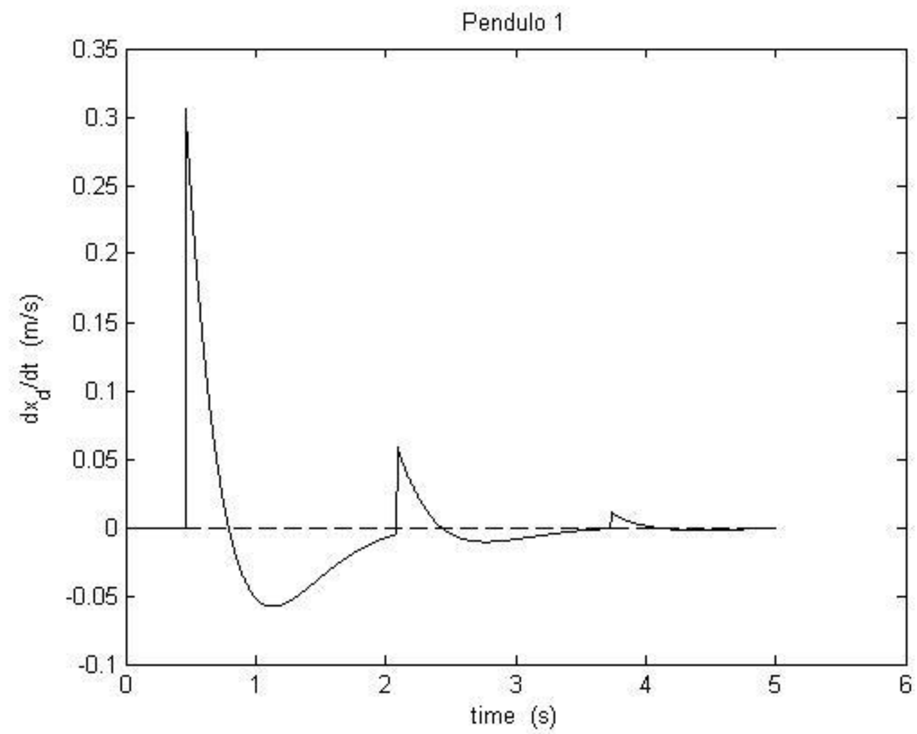

Figure 4 - The linear velocity of the wall.

ISSN 2176-5480

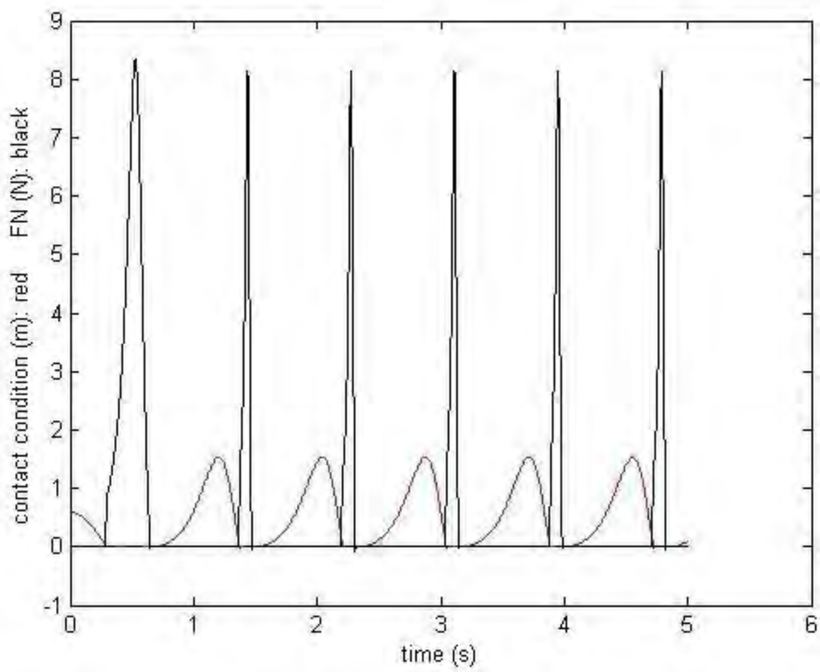

Figure 5 - The contact condition in red and the contact force in black.

In the Figure 3 is possible to verify the displacement because of the contact condition, represented in the picture as curve red. The curve black shown the values of Langrange multiplier, when there is not contact the value of Lagrange multipliers is 0, this conclusion can be verified in this figure.

5. CONCLUSION

The nonlinear behavior of the kinematic type due to large displacements, rotations and deformations that occur in a system. In general it is very common for mechanical systems may be subject to contact and impacts of these events being non-linear. The modeling of contact and impact is very important for the dynamic simulation, in particular to the modeling of robotic manipulators that perform tasks involving interaction with their working environment. Impact refers to the physical phenomenon that occurs when a body collides with another, having as main characteristics: a very short duration, reaching high levels of forces of interaction, exchange and rapid dissipation of energy and high accelerations and decelerations of the bodies involved .

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7. RESPONSIBILITY NOTICE

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