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DOCTORAL THESIS

ABSTRACT

Contributions to the research of inertial mechanisms

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Inertial mechanisms represent a promising area of technological and engineering research, with diverse applications in innovative propulsion systems. The field has attracted the attention of the scientific community due to its potential to provide efficient solutions and reliable alternatives for the propulsion of vehicles and appliances in situations where traditional methods become insufficient, such as moving on slippery surfaces, confined spaces or environments where traditional traction is limited.

There are numerous approaches to inertial mechanisms in the literature, from space propulsion and autonomous vehicles to specific industrial applications. Systems based on inertial mechanisms offer the advantage of generating propulsion without direct interaction with the external environment, which makes them extremely attractive for special operating conditions, such as space exploration, advanced robotics and underwater environments.

The present thesis continues the research previously initiated in the doctoral school of engineering of Babeș-Bolyai University and aims to make significant contributions to the study of inertial mechanisms, exploring the current technological opportunities in the field of advanced numerical simulation, additive manufacturing and the development of integrated mechatronic systems. Among the opportunities identified are the development of mechanisms with improved energy efficiency, reducing the negative impact of reaction moments, miniaturization of components for applications in microrobotics and the use of advanced materials to optimize the mass and strength of structures.

The opportunity of the research carried out during the doctoral studies resulted from the desire to develop new propulsion systems, as an alternative to the existing ones and to design an original system for eliminating the reaction moment, with multiple applications.

The objectives of this thesis were:

O1: Investigation of the most significant inertial mechanisms patented and developed to date;

O2: Conception and practical materialization of inertial mechanisms;

O3: Analytical study of the kinematics and dynamics of these mechanisms;

O4: Study of the influence of the main geometric elements of mechanisms on the dynamics of systems;

O5: Numerical simulation of the functioning of the mechanisms;

O6: Comparison of analytical calculations with simulation results;

O7: Comparison of the results of experimental measurements with those of simulations.

The paper is structured in five chapters that deal with distinct theoretical and experimental aspects, each developing a specific and complementary theme in the general framework of the research.

Chapter 1 "*The current state of inertial mechanism research*" analyzes patents and recent research relevant to inertial mechanisms, establishing the scientific and technological context of the work and revealing current trends in the literature.

The main conclusions that emerged from this chapter are:

- Inertial mechanisms are a topic of technological and engineering research, with diverse applications in innovative propulsion systems.
- The field has attracted the attention of the scientific community due to its potential to provide alternative and reliable solutions for the propulsion of vehicles and appliances in situations where traditional methods become inefficient.
- Although, in the last decade, more than 100 inertial mechanisms have been patented, the vast majority of them have not been practically implemented, remaining only at the patent or theoretical research stage.
- Systems based on inertial mechanisms offer the advantage of generating propulsion without direct interaction with the external environment, which makes them extremely attractive for special operating conditions, such as moving on slippery surfaces, space exploration, advanced robotics and underwater environments, where traditional traction is limited.
- Although inertial mechanisms have so far failed to impose themselves as practical means of propulsion, due to their dynamic characteristic and low efficiency, it is interesting to note the course that the human mind has followed so far and dreamed of a better future.

Chapter 2 "*Contributions to the theoretical and experimental study of an inertial linear propulsion mechanism*" aimed to make contributions to the theoretical and experimental study of a new inertial linear propulsion mechanism and to materialize it practically, using the additive manufacturing of the main components.

Even if the analytical relationships developed on this occasion highlighted the fact that the developed mechanism would be able to generate a unidirectional linear motion, and could be implemented as an alternative solution in terms of propulsion on slippery terrain, such as ice or mud, or for spaces where gravity is lacking, its practical realization demonstrated the opposite, because an important suggestion in the Machinery Parts course regarding the operation of chain transmissions was ignored, according to which "*chain transmissions work correctly if the chain is located in a vertical plane*".

At the end of the chapter, the following were summarized:

- The author of the thesis proposes a new inertial mechanism of linear propulsion, which uses the kinetic energy of several masses, placed in the articulation points of the links of a transmission chain, for the generation of linear motion.

- The masses placed equidistantly along the semi length of the chain execute a complex movement, consisting of the specific displacement of the chain elements and a rotation around an axis, which is parallel to the line that joins the centers of the chain wheels.
- After deducing the analytical equations of the geometric coordinates of the masses, the total propulsion force was calculated, the results obtained supporting the possibility that the mechanism has the ability to generate propulsion force and linear motion.
- Starting with the assembly modeling in the SOLIDWORKS work environment, most of the components were manufactured using 3D printing.
- Following this failure, the documentation continued on the concept of inertial propulsion that uses eccentric masses to produce the linear motion of a body to which they are attached.

The results obtained are presented in **Chapter 3** "*Contributions to the development of a new inertial propulsion system using eccentric masses*". This chapter proposes an original concept of propulsion of a mobile platform. The system uses the inertial force generated by two eccentric masses, which rotate in opposite directions. The verification of the kinematic parameters obtained by analytical means and the validation of the concept were performed in SolidWorks by motion simulation. Also, to demonstrate the system's ability to produce linear motion, a prototype was built and experimental tests were conducted.

The main conclusions of the chapter are as follows:

- Operating the system over five different distances, it was observed that the differences between the measured average speed of the SPI and the simulated results are less than 10%.
- The speed of the platform can be increased by increasing the speed of the engine masses.
- By doubling the speed of the driving masses (from 500 to 1000 rpm), the average speed of the platform increases by 3.99 times. This result confirmed the dependence between these two parameters deduced by analytical means.
- By increasing each engine mass by 2.5 times (from 0.18 to 0.45 kg), the speed of the platform increases by 2.28 times (from 93.72 to 214.13 mm/s). The nonlinear dependence between these two parameters has been explained by the analytical relationships previously deduced.
- The developed system is functional and capable of generating unidirectional linear motion, making it particularly suitable for driving propellerless boats or submarines.
- The proposed system is the only alternative for driving vehicles on very slippery surfaces (mud or ice), where no tire provides the necessary grip to move in such conditions.

In **Chapter 4** "*Contributions to the development of an innovative inertial mechanism for reducing the reaction moment*", an original concept of a device for reducing the reaction moment of the motor used to drive a rotary tool is proposed. The main conclusions that resulted can be summarized as follows:

- The proposed device could be incorporated into hand-supported tools, such as screw tighteners used in extreme working conditions (when assembling wind turbine blades, for example) or in motorized drill bits for digging holes.
- Implementing the concept would help reduce the risk of injury, as the system is able to reduce reaction time and minimize the possibility of the operator suffering musculoskeletal disorders in the upper limbs.
- If the polygonal effect of the chain is neglected, the additional moment generated by the device can be considered constant.
- The extra moment generated is independent of the drive power, with the system showing higher efficiency as the drive power decreases. However, there is a lower power limitation, related to the need to overcome the inertia of the system during the start-up process.
- The additional torque generated by the system can be increased by increasing the mass of the weights added to the chain, increasing the spokes of the chain wheels and increasing the drive speed.
- If, during operation, there is a sudden increase in the resistive moment at the work tool, the reaction moment that occurs at the motor is attenuated by this device, making the handling of the entire system easier.
- Disadvantages and limitations of the proposed system consist in the relatively large size, the need to take special protective measures and the operation in one direction of rotation.

Chapter 5 "*Final conclusions and personal contributions. Future research directions. Dissemination of results*" summarizes the results obtained, highlights the author's original contributions and proposes clear perspectives for future research. At the same time, details on the dissemination of research results in academic journals and national and international conferences are presented.