



24th COBEM - 2017



24th ABCM International Congress of Mechanical Engineering
December 3-8, 2017, Curitiba, PR, Brazil

COBEM-2017-2773

ANGULAR CONTROL OF A ROTATING PLATFORM USING TWO REACTION WHEELS

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Abstract. *The purpose of this paper is to present an angular control of a rotating platform through the use of two reaction wheels. Space vehicles and satellites usually have reaction wheels for stabilization because this type of equipment is cheaper and more accurate than gas jet. This kind of angular control system may be used in robots as well. The platform was built using a stainless steel base and bearings, BLDC motors connected with two masses representing the reaction wheels. A torque generated by the acceleration of these motors rotates the platform, and an inertial measurement unit (IMU) measures the angular position data of platform. A Proportional Integral control algorithm was adjusted analytically and was embedded on a microcontroller in order to control the angular position of the system in a closed loop.*

Keywords: *Position Control, Angular Momentum Conservation, Reaction Wheel, Balancing System.*

1. INTRODUCTION

The quest for stability in vehicles has been the subject of studies since the nineteenth century, such as those in the search for stability of ships and cars (Schlick, 1904). In 1909 was designed a two-wheeled vehicle called Gyrocar that used a gyro and a pendulum to be stabilized (Schilovsky, 1909). Many balancing systems use the principle of gyroscope, while this work proposes the production of torque from the acceleration of wheels connected to electric motors.

The motivation of this work is the search for the feasibility of controlling a rotating platform with two reaction wheels. This type of structure can be used in variety of applications such as space vehicles and robotics.

Ge and Chen (2004) proposed to find a solution for the orientation control of a space vehicle with two reaction wheels using a genetic algorithm instead of the traditional optimal control methods used in this type of application. The motivation for using two reaction wheels instead of the classic three wheels is, according to the authors, to the possibility of failure of one of the wheels. Katsuyama, Sekiguchi and Sampei (2013) also performed a control of a space vehicle using two reaction wheels, taking into account that a vehicle with three reaction wheels could suffer a failure in one of the wheels. For this, they considered that the orientation control can be used with two wheels in which the angular momentum is zero. However, because in space this is not possible due to disturbances such as pressures due to solar radiation, the authors considered that the initial angular momentum of the vehicle was nonzero, in order to apply the proposed control.

In robotics, Kim, Kim and Lee (2014) created a bicycle robot. To balance this robot even in movement, they used a reaction wheel

The purpose of this work is to build and control a low cost rotating platform composed of three axes, two of them connected to a BLDC motor and a mass, and a central axis subject to angular perturbations using the torque produced by the acceleration of the motors.

The platform built in this work can be used for all the described applications, besides serving as a didactic tool, since it can elucidate concepts of physics, theory of modeling and dynamic systems control, and implementation of controllers through software and micro controlled systems, due to the small space occupied by the platform and components easily found.

2. EXPERIMENTAL PROCEDURE

The structure to be modeled is composed of a base and a rotating platform fixed by an axis to the base. Each side of the rotating platform has an axis, which can be called the secondary axis of the rotating platform. In each of the secondary axes there is a motor and a mass attached to them as shown in Fig. 1 which represents the 3D drawing of the idealized structure.

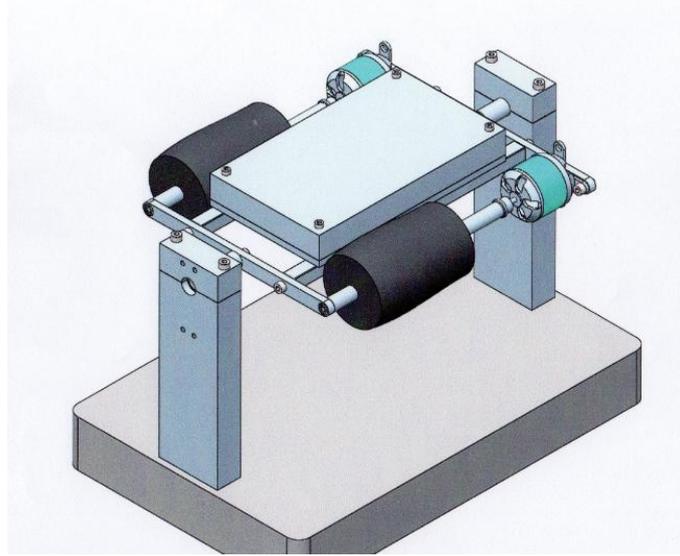


Figure 1: 3D drawing of platform

The motor on each side of the rotating platform causes the secondary axis and the masses to rotate. Following the principle of angular momentum conservation Eq. (1), if the angular velocity of the two sides is equal in modulus and opposite in direction, the rotating platform will remain immobile (considering that both sides of the platform have the same mass and moment of inertia).

$$\vec{\tau} = \frac{d\vec{L}}{dt} = 0 \therefore \vec{L} = \text{constant} \quad (1)$$

Where $\vec{\tau}$ is the torque acting on the structure and \vec{L} is the total angular momentum of system.

In order for the platform to rotate in a certain direction, a resulting non-zero net torque acting on the structure is required. To do this, the motors will initially rotate with a constant average speed in opposite directions, so the angular momentum is constant, and the resulting torque is equal to zero. After this, an acceleration will be applied to one of the motors, and a deceleration of equal intensity will be applied to the other motor, causing the resulting net torque in the structure to be different from zero Eq. (2), rotating it.

$$\vec{\tau} = I\ddot{\theta} \quad (2)$$

Where I is the moment of inertia of structure about the rotation axis and $\ddot{\theta}$ is the structure's angular acceleration relative to rotation axis.

In the assembly stage were used two brushless motors (BLDC), model Turnigy D2836/8 1100KV. Two Electronic Speed Controller (ESC) Hobbyking SS 40-50 were used to drive motors. To supply the ESCs and the motors, a Turnigy lithium polymer battery with 2200 mAh electrical current supply capacity and nominal voltage of 11.1V was used. To system control it was used a Genuino 101 board that has a 32-bit Intel Curie microcontroller in addition to Bluetooth LE connectivity for serial communication with a microcomputer and an inertial measurement unit (IMU) to measure the angular position of platform. Due to vibrations caused by BLDC motors, a Kalman filter algorithm (Welch and Bishop, 2006) was used to reduce the effects of vibrations on the angular position measurements performed by the IMU.

For the system control stage, a Proportional Integral (PI) control algorithm was placed on a microcontroller to control the angular position of the rotational structure. Figure 2 shows the closed loop block diagram for control of platform.

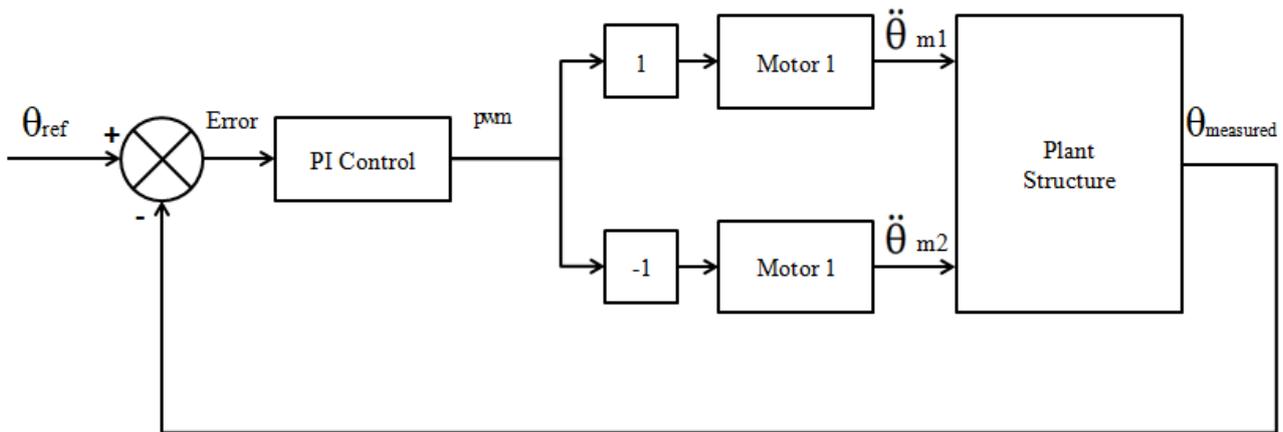


Figure 2: Closed loop block diagram of platform

The main purpose of the control is to set a reference angle for the structure to follow. The PI controller sends a Pulse Width Modulated (PWM) signal to the motors, one of which will accelerate, while the other will decelerate, causing torque, rotating the structure. The IMU measures the angular position of the structure in relation to its base, and compares it with the reference angle, calculating its error and sending this information to the PI controller, restarting the control cycle.

3. RESULTS AND DISCUSSION

3.1 System Assembly

As shown in Fig. 3, the system assembly has been completed. The mechanical structure is composed of base and bearings rings made of stainless steel, ball bearings and masses made of brass. The electronic structure was built as described in the experimental procedure.

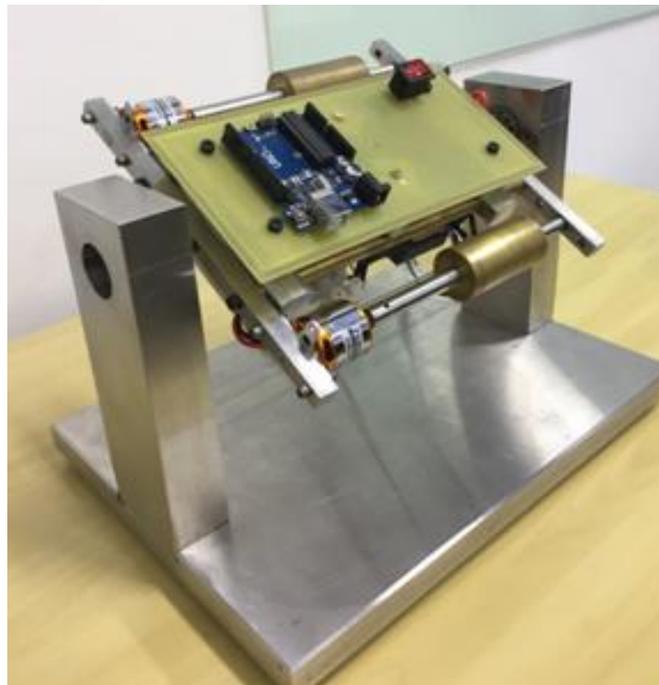


Figure 3: Platform assembled

One of the problems founded in the system assembly was the lack of precision in the alignment of the shafts with the motors and bearings, causing excessive vibration in the system. Another source of mechanical vibrations in the system was a gap between the main axis of the system and the bearing attached to the metal base. This gap appeared

because the bearing was not adequately connected to the metal base Fig. 4. With addition of bearing retainer, this problem was solved and the vibrations in the structure decreased.

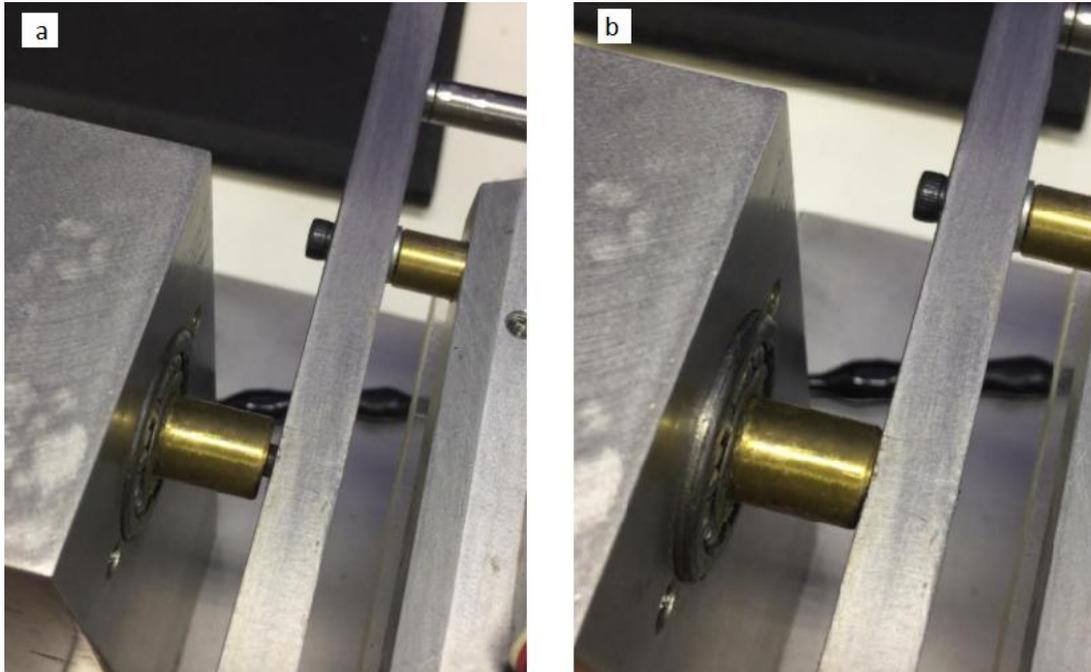


Figure 4: Clearance between axis and bearing (a) and no clearance between axis and bearing after passing bearing retainer glue (b).

3.2 System Control

The closed loop system was controlled through a PI algorithm, and the gains were adjusted to minimize steady-state error and overshoot, since the mathematical model of the structure was not validated, allowing the analytical development of the controller design.

The PI controller was programmed in C language on the Genuine 101 microcontroller. This digital controller has been designed using Tustin approximation. The data were transferred from Genuino to a computer via serial, and later processed in MATLAB software. An angle of 15° was set as the control setpoint. Figure 5 presents the control system with adjusted gains $K_p = 4$ and $K_i = 1$.

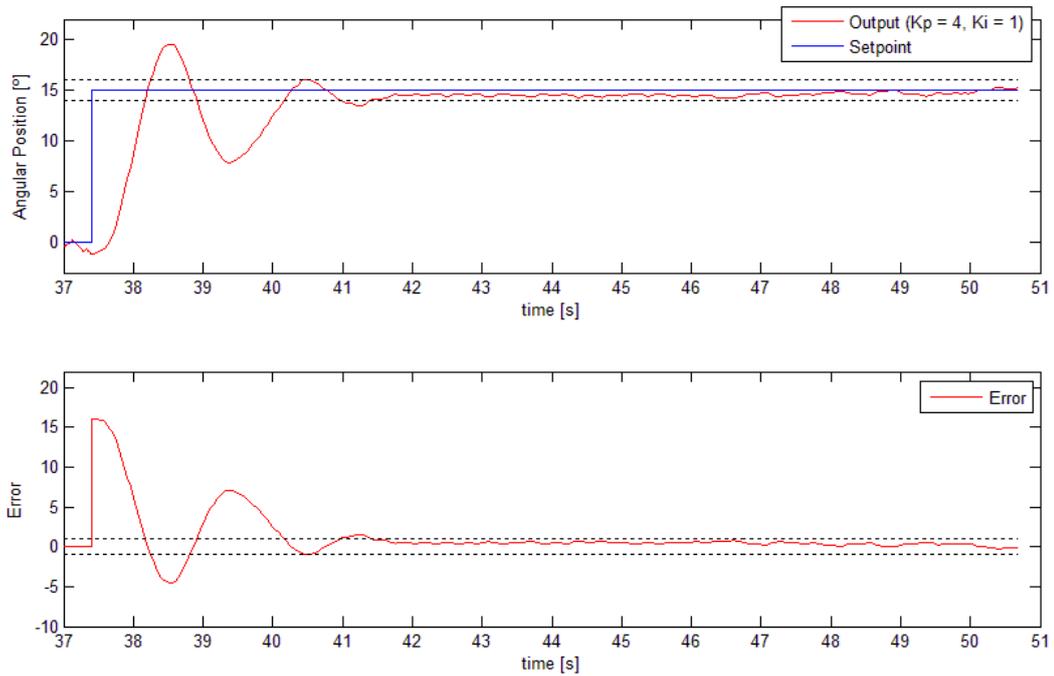


Figure 5: System response for 15° angle and its error. PI control of structure with $K_p = 4$ and $K_i = 1$

The output response Fig. 5 presented overshoot (nearly from 20°), and after 4 seconds (settling time) began to stabilize. The steady-state error remained within the range of 1°.

Figure 6 shows the system control with adjusted gains $K_p = 3.2$ and $K_i = 0.8$.

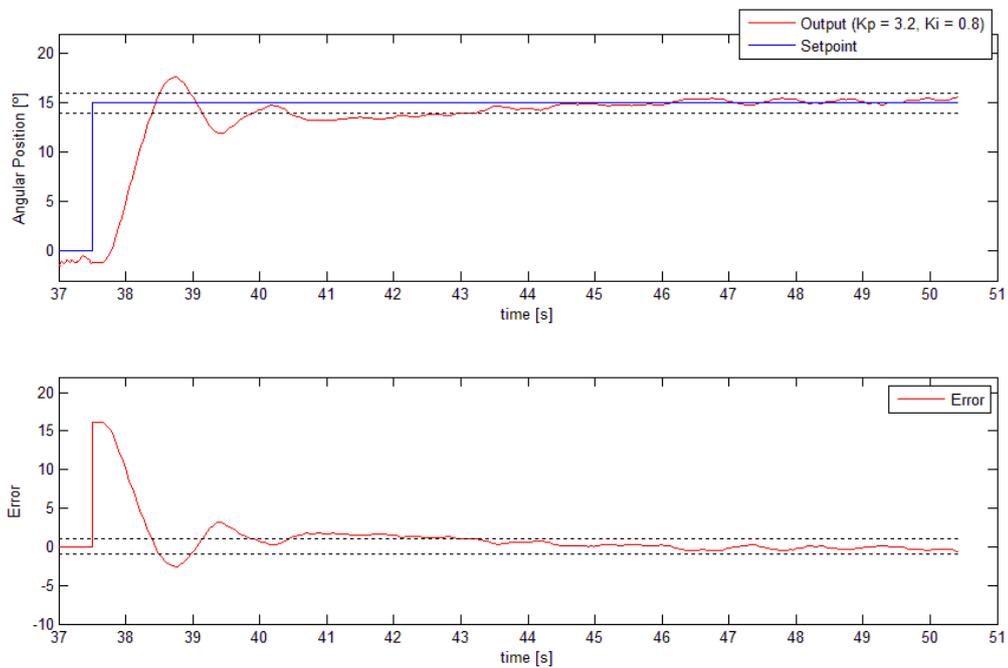


Figure 6: System response for 15° angle and its error. PI control of structure with $K_p = 3,2$ and $K_i = 0,8$

With these gains, the output response presented smaller overshoot, but the steady-state error was greater than 1° between 41 to 43 seconds.

Figure 7 presents the system control with adjusted gains $K_p = 3$ and $K_i = 0.6$.

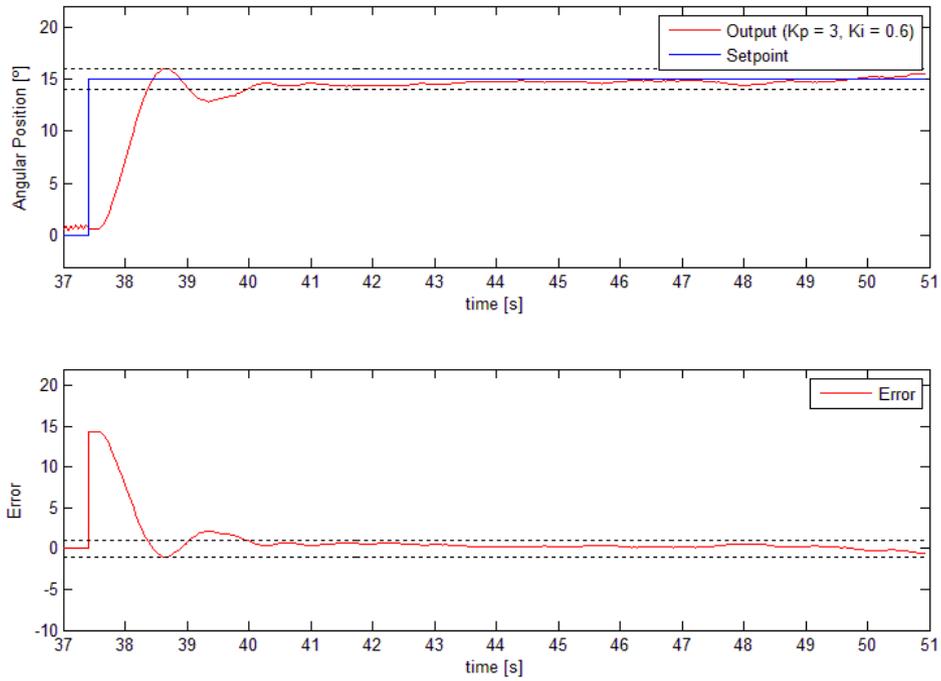


Figure 7: System response for 15° angle and its error. PI control of structure with $K_p = 3$ and $K_i = 0.6$

With these gains, the output response presented smaller overshoot (16°), and after 2.5 seconds (settling time) began to stabilize. The steady-state error was the smallest of the three experiments.

Figure 8 shows the system response for the three gain settings.

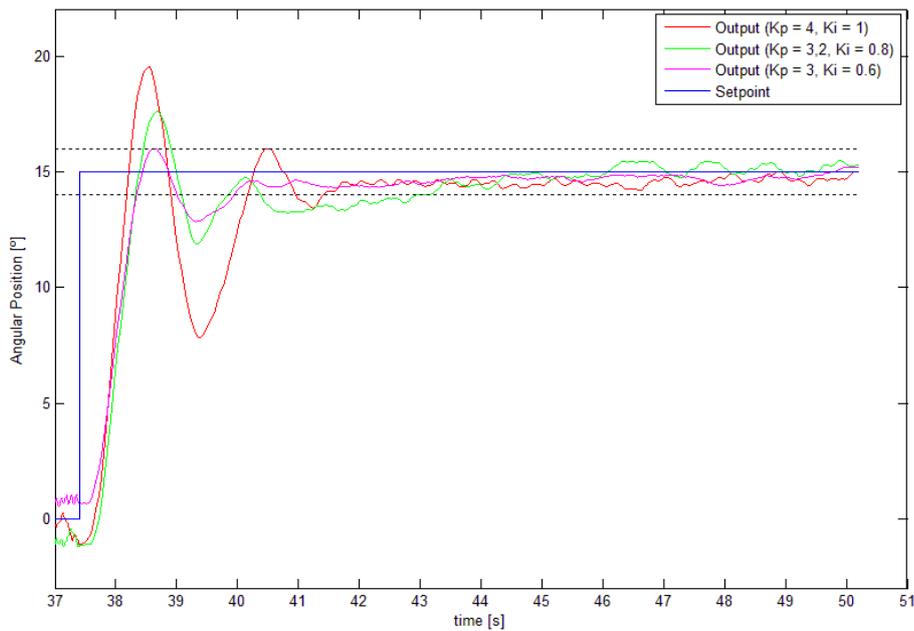


Figure 8: System response for 15° angle.

4. CONCLUSIONS

The study present in this paper is a first approach of control in this kind of structure. It is a first step to build more complex structures as space vehicles or robots. This structure also can be used in basic Control classes, or until in Digital Control classes due to it reduced size and weight.

Some of the objectives were achieved, such as the assembly of a rotational structure that uses two reaction wheels with low manufacturing cost, using components that could be easily found. Some points can still be improved in the system assembly, such as better precision in the fit of the parts and bearings, making the decreasing of the mechanical vibration.

PI control algorithm was programmed in the microcontroller of the system, and its gains were adjusted to minimize steady-state error and overshoot. It was possible to control the angular position of the structure with accuracy of 1° around the setpoint when the system is in steady state. Since the output variable of the PI controller is a PWM signal sent to the motor, there is no accuracy of their speed. For the next steps of research, a closed loop control could be applied for the speed of the brushless motors, therefore, the output of the controller would be the speed of the motors, making the response of the system faster, more accurate and closer to the input signal.

For the next steps of this research, also it is necessary to validate the mathematical model of the system, so it can be simulated and compared to the experimental control and other control techniques besides PI can be used. In addition, other types of input can be used beyond the step input, such as a square wave or a sine wave, for example.

5. ACKNOWLEDGEMENTS

This work was supported by Instituto Federal de Educação, Ciência e Tecnologia de São Paulo, LCA – Laboratório de Controle Avançado and CNPq (Edital 17).

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