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Model based design applied to ceramic balls grinding

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Abstract

This research uses model based design to evaluate and realize the complex motion of the lower plates that define balls motion during grinding. The Model In the Loop (MIL) was performed through the machine model generated using ADAMS and then exported to Simulink. For a prior evaluation of the machining, the grinding tracks were built through the simulation results performing Software In the Loop (SIL). The balls grinding was performed by an Arduino connected to the machine, finishing Hardware In the Loop (HIL). The technique integrated the simulation and balls grinding processes, increasing the simplicity and reducing the development time.

Keywords: model based design; ceramic balls; grinding

1. Introduction

Ceramic balls are increasingly used in bearings [1] due to the ceramic material properties, such as high hardness, low coefficient of thermal expansion, low density, and resistance to high temperatures [2].

To realize the ceramic balls grinding, several methods have been developed, and a subgroup of these methods uses a V-groove to support and move the balls and a plate with abrasives to remove material. This concept was used in the first machine for grinding metal balls for bearings [3]. Since then, many variations have been proposed in this concept, such as the V-groove division into two independent plates [4, 5], the use of eccentricity between the plates of the V-groove (lower plate) and the upper plate [6] and the use of a variable radius in the ball movement [7].

The V-groove method uses the rotational speed profile applied to the drive motors of the V-groove plates to form the resulting machining pattern on the ball surface. Previously, much work was done to predict this type of pattern from the ball equations of motion [8-10]. Other researches carried out this same study from the model of the machining region made in the ADAMS software, which uses the multibody technique [11-13]. The technique using the machining region model made in ADAMS is more advantageous because, if the machine configuration is modified or the applied motion profile is changed, the equations must be solved again or even new equations must be added [11].

Despite the time required for the building, verification and validation of the model, when ready it can be used to test the effect of various inputs applied to the system [14]. Thus, the ADAMS model can be used for the rapid verification of the effect in the balls grinding of various types of motion profile applied to the drive motors of the V-groove plates, saving material resources and time for the experiment's execution.

The model-based design approach has proven to be an effective tool for reducing development time [15], so a new approach that integrates all steps (MIL, SIL, HIL) into a single environment makes the procedure even simpler and faster. Fig. 1 shows the strategy used for simulation and ceramic balls grinding, through the use of ADAMS, Matlab and Arduino.

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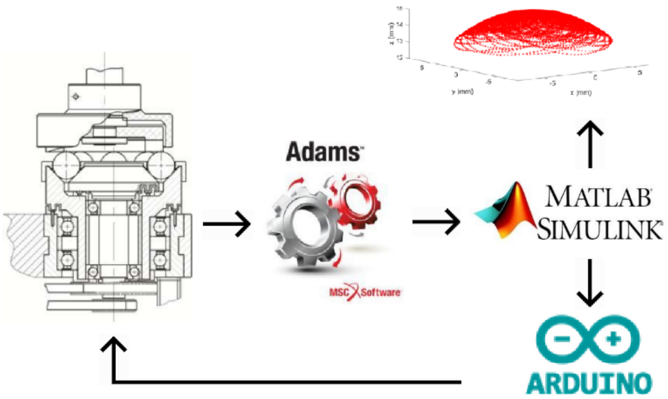

Fig. 1. Strategy used for grinding tracks simulation and to realize effective grinding of ceramic balls.

This research utilized the strategy of developing a model of the machining region through ADAMS software, exporting to Simulink (MIL) and predicting the grinding tracks generated by certain inputs applied to the drive motors of the lower plates that form the V-groove (SIL). The inputs studied in the previous simulation in the same Simulink environment were then effectively applied to the motors (HIL) using the Arduino microcontroller and the library, which allows the interaction, simplifying the grinding tracks prediction procedure and effective machining in the same environment.

2. Method

ADAMS VIEW software was used for the dynamic model elaboration, and the machining region of the balls was modeled. The inner and outer lower plates and the ball were drawn in the bodies' environment, all bodies designed as rigid bodies. In the model the original dimensions were used, as designed by [16]. The steel density was assigned to the plates for the mass definition, and, for the ball, the mass was attributed directly by measuring a pressed ball of alumina (30 g). Fig. 2 shows a wireframe view of the assembly.

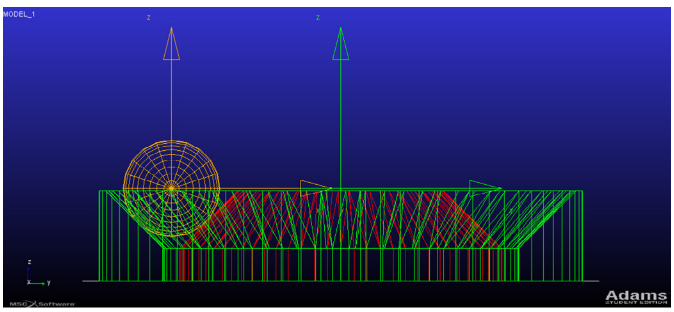

Fig. 2. ADAMS wireframe view for ball and lower plates.

Using the connectors environment, restrictions were added to the movements of the plates, using the revolution joint, which allows only the rotation of a piece around a turning axis. Thus, the lower plates can be rotated about coaxial axis. The first force considered acting in the set was gravity. In the model, the contact force between the ball and the plates was also considered, in the attribution of this force it us necessary to consider the values of static and dynamic friction coefficients between alumina and ethylene-vinyl acetate (EVA), a material used to coat the plate surface and improve ball movement through friction. Finally, a rotational movement was assigned to each joint of revolution; this rotation is considered the movement profile applied to each drive motor of each plate.

For the measurement of the friction coefficient between alumina and EVA, the procedure was performed in which a table containing the EVA specimen is movimented by a screw, while an arm with the alumina specimen is suspended on the table through a known mass. A load cell monitors the friction force between the specimens and, as the normal force is known, the friction coefficient between the two materials is calculated.

For the determination of the friction coefficient, specimens of the two materials were prepared. An EVA strip of 70 x 70 x 3.7mm was used, as well as an alumina cylinder of Ø 5.90 x 5.55mm, pressed uniaxially at 210MPa. Table 1 shows the result of the measurements for two tracks and the calculated mean value.

Table 1. Static and dynamic friction coefficients.

Track	μ_e	μ_d
1	0.821 ± 0.014	0.791 ± 0.028
2	0.821 ± 0.012	0.796 ± 0.021
Mean value	0.821	0.794

For the generation of the grinding tracks, it is necessary to describe the ball movement, that is, the description of its orientation in space. The ADAMS software defines the orientation of a rigid body through the three Euler angles ψ (psi), θ (theta) and ϕ (phi) corresponding to the 3-1-3 sequence of rotations.

When a rigid body undergoes a change in its orientation caused by a sequence of three rotations ψ, θ and ϕ a point of initial coordinates $[x_1, y_1, z_1]^t$, referring to a inertial coordinate system fixed $X_0Y_0Z_0$, has coordinates $[x_2, y_2, z_2]^t$ so that:

$$P_2 = R.P_1 \tag{1}$$

In Eq. 1, R is the rotation matrix for the sequence of the three rotations ψ, θ and ϕ. Through a rotation R_k (ψ_k, θ_k, ϕ_k.), a given point P_k of arbitrary coordinates $[x_k, y_k, z_k]^t$ come to occupy the reference position P_r, which is the contact of the ball with the upper plate, $[o,o,r]^t$, where r is the ball radius. Thus, by using the inverse of R_k one can obtain the coordinates of the point P_k, which is a point of the grinding track, as shown by Eq. 2.

$$P_k = R_k^{-1}.P_r \tag{2}$$

Therefore, given a ψ, θ and ϕ variation profile that describes the spatial orientation variation of a body, one can plot the grinding tracks, from the chart that shows all points P_k for a certain period of time.

3. Results

The ADAMS model was then exported to Simulink as a block whose inputs are the angular velocities of the lower plates and the outputs are the three Euler angles, as shown by Fig.3, so it is possible to study different types of motion profiles applied to the motors. The obtained results are the charts showing the variations of the three Euler angles; this data is the input to a Matlab code that shows which points of the ball passed through the contact with the point P_r, taken as the contact between the ball and the upper plate.

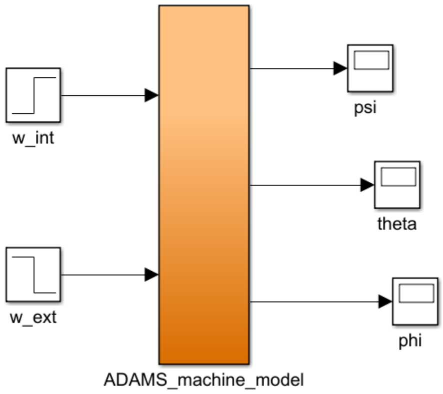

Fig. 3. ADAMS model exported as a Simulink block, with inputs (lower plates angular velocities) and outputs (ball Euler angles).

The present research considered step inputs applied to the lower plates, that is, a rotational speed of 50rpm was applied to the two plates, but in opposite directions. After a simulation of 60 seconds, the charts for the Euler angles variation are shown in Fig. 4.

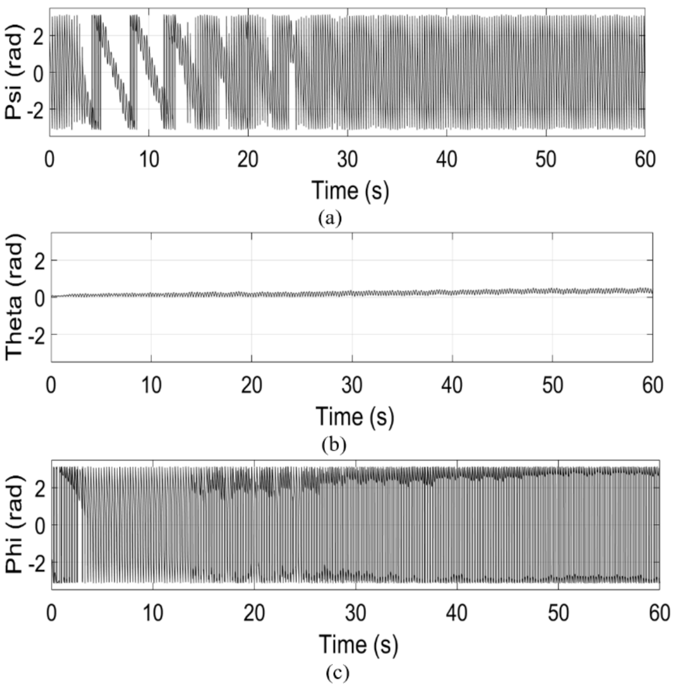

Fig. 4. Ball Euler angles as a result of Simulink simulation, in (a) ψ, in (b) θ and in (c) ϕ.

Fig. 4 shows in (a) the variation for the Euler angle ψ, the chart shows a variation of –π to π rad, which corresponds to each turn of the ball by the V-groove. The chart shown in (b) is for the variation of the Euler angle θ, we notice that there is a continuous variation, but within a narrow limit, that does not reach 30 degrees. In (c) is shown the variance for the Euler angle ϕ, and this angle exhibits a continuous variation of –π to π rad, which means that the ball is rotating continuously on its own axis, which is rotating with small oscillation around the vertical. The Euler angle variation data are then inserted into the Matlab code for plotting the chart showing the set of points of the ball which passed though the position of the upper plate, that is, the grinded surface of the ball, for the time of 60 seconds. The result is shown in Fig. 5.

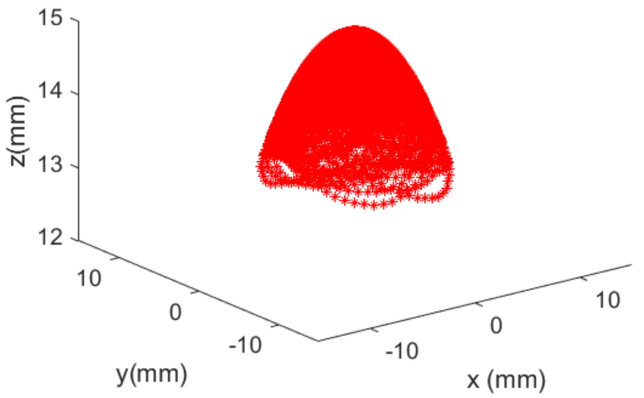

Fig. 5. Ball grinding tracks resulting from the Simulink simulation.

Fig. 5 shows the trajectory pattern formed. Although it is a small region with contact with the upper plate, the trajectories are close. As the values of the Euler angle vary, the points are distributed over an area, after reaching the steady state of the movement.

For the simulation validation, the test bench was assembled with the Arduino Mega 2560 microcontroller and TB 6560 drivers for control of KTC 401 stepper motors that drives the V-groove lower plates. The upper plate utilized was an aluminum disk with a flexible polyurethane coated with abrasive particles of silicon carbide with dimensions between 125 to 150µm. The upper plate was utilized to remove material of the balls and was driven by DC motor, connected to the voltage source. Fig. 6 shows the test bench.

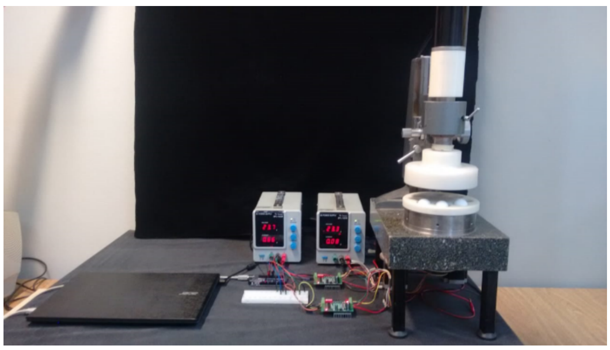

Fig. 6. System for realizing the ball grinding using Arduino.

For the stepper motors control, Simulink software was utilized with the communication library with Arduino; in this library there are own blocks for driving the stepper motors, to be controlled in real time. Fig. 7 shows the Simulink blocks utilized.

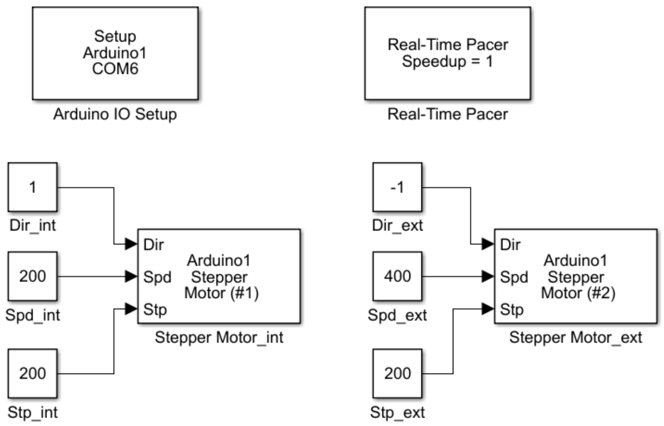

Fig. 7. Simulink model for driving stepper motors through Arduino.

For the test, a rotational speed of 50rpm was applied to the lower plates with counter-rotating directions and the alumina ball with 30mm of diameter was machined for 60 seconds. Fig. 8 shows the ball after machining.

Fig. 8. Machining pattern resulting from the application of inverted angular velocities to lower plates.

Fig. 8 shows that only a limited area of the ball has been grinded, as indicated by the simulation. Fig. 8 shows that the grinded area is larger than the one of the simulation due the presence of the upper plate that realizes the material removal and modifies the ball movement.

4. Conclusion

The simulation strategy proved to be effective for the study of the influence of a step input applied to the drive motors of the lower plates in the ball grinding. After the construction of the model in the ADAMS software and export to the Simulink environment, different inputs can be compared for the effect on the ball grinding, by applying a Matlab script that uses the results of the previous simulation. Also, in the Simulink environment, through the library that communicates with Arduino microcontroller, the inputs analyzed in the simulation were applied directly to the machine, which makes the simulating and machining realization process extremely fast and simplified.

Acknowledgements

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