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Numerical and experimental analysis of Jamming Phenomenon in Positioning of Circular-Section Workpiece on Horizontal Surface

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Abstract

Workpiece jamming in the fixture may cause improper positioning, damage to the workpiece, and even the fixturing elements. The present study focuses on the numerical and experimental analysis of workpiece jamming with the circular cross-section in a fixture to calculate the jamming-in travel of the workpiece. For this purpose, numerical analysis of a circular workpiece on the horizontal surface was conducted using Abaqus software. To validate the numerical predictions, an experimental setup was designed and fabricated with three circular cross-section workpieces with diameters of 40 mm, 50 mm, and 60 mm. Experimental tests were conducted to measure the friction coefficient between the circular workpiece, base plate, and palm. The jamming-in travel of the workpiece was then measured using image processing techniques, a calibrated ruler installed on the setup, and a rotary encoder. By comparing the experimental results of jamming-in travel to the predictions of the numerical model, the worst-case error values were determined as 12.4%, 6.18%, and 8.53% for workpieces with diameters of 40 mm, 50 mm, and 60 mm, respectively.

Keywords: Jamming analysis, Jamming Phenomenon, Peg in hole, Friction Coefficient, Circular workpiece, Fixture, Fixture Design, Positioning.

1. Introduction

Fixtures are one of the most important elements of a manufacturing and production process that provide and maintain accuracy in the machining, assembly, and production of industrial parts. Any factor that may cause a loss of accuracy will lead to the production of defective products and, consequently, to an increase in production costs. One of these defects is the jamming of the workpiece during its loading in the fixture.

Jamming modeling has been conducted by utilizing several case studies, including peg-in-hole, block and palm, and several other problems. In the present study, a novel problem is going to be added to these case studies. The problem of circular workpiece and palm can be considered as a case study to investigate the jamming phenomenon in the fixture [1]. In this problem, an angular movement of a palm leads to the linear movement of a circular workpiece on the horizontal surface. The workpiece gets stuck and stops moving after traveling a certain distance, due to the friction between its surface with the palm and the horizontal plate.

Several researches have been conducted in the field of analyzing the jamming phenomenon of the workpiece during its loading (or unloading) in the fixture or grasping objects in robotic applications.

Parvaz [1] proposed a mathematical model to predict the jamming-in travel of a workpiece with a circular cross-section on a horizontal surface. Zhang et al. [2] presented a strategy to evaluate the performance of the impedance control system for a dual-arm robot and checked its capabilities by performing a peg-in-hole experimental test with a robotic arm. Kim and Seo [3] proposed an analytical model to study the assembly process of an object similar to a peg in a shallow hole and determined the conditions of jamming occurrence in these systems. Parvaz [4] suggested theoretical and numerical analysis to investigate the jamming of a workpiece in the fixture using a block and Palm case study. Ortega et al. [5] proposed a strategy to evaluate jamming occurrence conditions in a dual-arm peg-in-hole assembly process using DNN coupled with a force/torque sensor. Toro et al. [6] suggested an optimization model to automate the locating layout determination process using the 3-2-1 principle.

The purpose of the present research is to calculate the jamming-in travel of the workpiece with a circular cross-section while traveling on a horizontal surface. A numerical approach is first used to calculate the jamming occurrence conditions in this problem. An experimental setup is then designed and fabricated to measure the jamming-in travel of the workpiece on the surface. The predictions of the numerical model are then validated through experimental results.

The prediction of the workpiece jamming-in travel in the mentioned mechanism may initially considered a statically deterministic problem. However, the problem would be indeterministic due to the existence of a potential rolling movement during workpiece travel on the horizontal surface. According to the background of the study and the best knowledge of the authors, no numerical analysis or experimental test has been reported in the literature to investigate the jamming phenomenon in positioning of a circular-section workpiece on a horizontal surface. Therefore, the present study is novel both in terms of experimental testing and numerical analysis.

2. Numerical analysis

Abaqus software was used to simulate the process. The mechanism of the circular workpiece and palm used in the numerical analysis was the same as the configuration presented in [1] so that the results of the numerical analysis can be compared with the theoretical results presented in the mentioned study. Figure 1 shows the model used in numerical analysis.

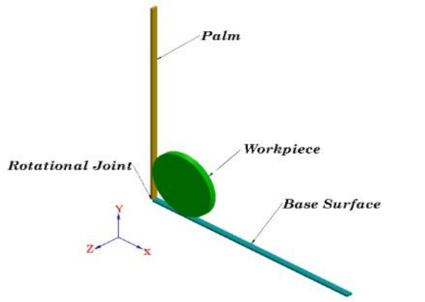

Figure 1. The model used in the numerical analysis

The important parameters of the problem were first measured by the experimental tests. The measured factors were then applied to the numerical model and the simulations were conducted for three workpieces with diameters of 40, 50, and 60 mm. The circular workpiece, the base surface, and the pin were assumed to be made of steel. The material of the palm was considered to be aluminum. The elastic properties of the model components, including density, Young's modulus, and Poisson's coefficient were defined in the software and assigned to the corresponding components. An explicit dynamic solver was used to simulate the process. The surface-to-surface frictional contacts were applied to the mated surfaces. The experimental values of the friction coefficient between the workpiece, palm, and base surface were also used in the simulations. The intensity of the force applied by the palm to the workpiece was also defined in the software. The boundary conditions were finally applied to the corresponding components. The desired element was selected as C3D8R. The numerical analysis was conducted and the jamming-in travel of the workpiece was measured in different conditions. A mesh-independency analysis was also conducted with parts with different mesh sizes to ensure the independence of the analysis results from the mesh dimensions.

3. Experimental analysis

An experimental setup was designed and fabricated in the present study to verify the results of numerical analysis. Three series of experiments were conducted to measure the friction coefficients between the workpiece, palm, and base surfaces. In the first and second experiments, the pulling force required to slide the workpiece on the base surface was measured using a digital scale. The friction coefficient was then measured between the workpiece and base surface based on the workpiece weight. A similar approach was also used to measure the coefficient of friction between the workpiece and the palm.

In the third experiment, the jamming-in travel of the workpiece was measured through three methods, including imaging techniques, a calibrated ruler installed on the setup, and an angular encoder. A computer, the fabricated setup, an angular encoder (Koyo^{TM} Electronics), an Arduino board, a 12V-DC-2A adapter, a board, an interface cable, a torque meter, a video camera, and a camera holder were used to perform the test, as shown in Figure 2.

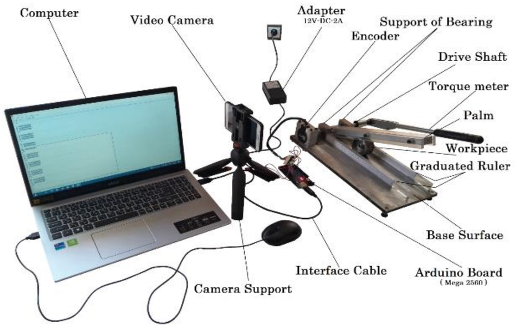

Figure 2. The experimental setup used to measure the jamming-in travel

The workpiece's jamming-in travel was first calculated using the jamming-in angle measured by the installed encoder. The measurements were then compared with the values read from the calibrated ruler. The experiments were repeated 10 times for each workpiece. The jamming-in travel of the workpiece was calculated by averaging both methods. It was calculated for each workpiece and compared with the numerical results.

4. Results and discussion

In this section, the numerical predictions are compared to the experimental results. The jamming-in travel of the workpiece was numerically predicted using Abaqus software. The jamming-in travel of the workpiece for the circular workpieces with diameters of 40, 50, and 60 mm were calculated from the numerical analysis according to the diagram in Figure

3.

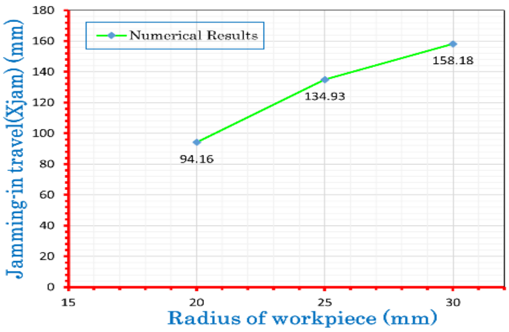

Figure 3. Numerical results of jamming-in travel of workpieces with different diameters

The numerical results of the present study were compared and matched to the predictions of the theoretical model proposed in [1]. So, the effects of the important parameters including the friction coefficient, workpiece radius, force, and angular velocity can be investigated on the jamming-in travel using the suggested numerical model.

The average coefficients of friction between the workpiece and the base surface were obtained as 0.103, 0.114, and 0.103, respectively for the diameters of 40, 50, and 60 mm. The standard deviations for these measurements were 0.0034, 0.0049, and 0.0029, respectively which shows the good repeatability of the tests. The average coefficients of friction between the palm and the workpiece surface for the diameters of 40, 50, and 60 mm were obtained as 0.102, 0.103, and 0.104, respectively, with a standard deviation of 0.0128, 0.0082, and 0.0115.

To validate the results of the numerical analysis, the jamming-in travel of the workpiece should be measured using experiments. The average value of the data gathered from the installed encoder and the calibrated ruler were used for three workpieces with diameters of 40, 50, and 60 mm. The jamming-in travel was measured for these workpieces as 105.89, 143.27, and 171.67 mm, respectively. Figure 4 represents the comparison between the numerical and experimental results.

5. Conclusion

In this research, numerical and experimental approaches were used to investigate the jamming occurrence conditions for a workpiece with a circular cross-section traveling on the base horizontal surface. The jamming-in travel of the workpiece was calculated as 94.16, 134.93, and 158.18 mm from numerical analysis using Abaqus software, for workpieces with diameters of 40, 50, and 60 mm, respectively. The numerical results obtained in the present study were in accordance with the predictions of the theoretical models of the previous studies.

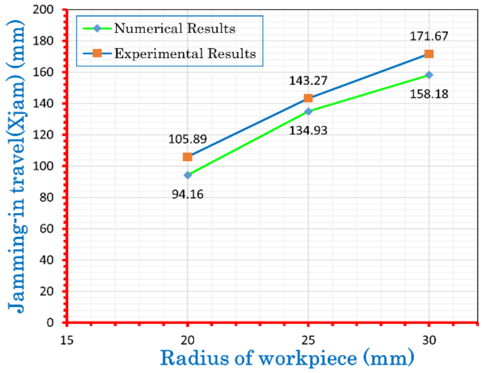

Figure 4. Comparison between the numerical predictions and experimental results

The effects of the influential parameters including the friction coefficient, workpiece diameter, force, and angular velocity were studied on the jamming-in travel using the proposed numerical model. The following conclusions were obtained:

- Increasing the friction coefficient and the diameter of the workpiece, respectively, decreases and increases the jamming-in travel of the circular-section workpiece.
- Increasing force, angular velocity, and workpiece mass do not affect the jamming-in travel of the circular-section workpiece.

The predictions of the jamming-in travel of the workpiece from the numerical analysis were validated through experimental tests. The jamming-in travel of the workpiece was measured as 105.89, 143.27, and 171.67 mm using experimental tests for workpieces with diameters of 40, 50, and 60 mm, respectively.

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