Effects of material characteristics and clearance size on dynamics of a slider-crank mechanism with two sliders and revolute clearance joints

Ngoc-Thai Huynh[1], Shyh-Chour Huang[1*], Thanh-Phong Dao[2,3]

[1]Department of Mechanical Engineering, National Kaohsiung University of Applied Sciences, 415 Chien-Kung Road, Kaohsiung 80778, Taiwan R.O.C.
[2]Division of Computational Mechatronics, Institute for Computational Science, Ton Duc Thang University, Ho Chi Minh City, Vietnam
[3]Faculty of Electrical & Electronics and Engineering, Ton Duc Thang University, Ho Chi Minh City, Vietnam

Email: shuang@cc.kuas.edu.tw

Abstract. This article presents influences of clearance size and material parameters on the dynamic response of a slider-crank mechanism with imperfect revolute joints in dry contacting condition. The mechanism was created by Solidworks and a finite element method in ANSYS software was used to analyze the effects which presented and discussed. The simulation results revealed that the acceleration of two sliders was obviously shaking with high peaks when the clearance size equal to 0.3 mm which differ from the ideal joint. Moreover, the smaller Young's modulus material of journals indicated the significant effects on acceleration of mechanical systems. The reasons are due to a suddenly increase of contact force when the journal impacted into the bearing in imperfect revolute joints. The simulation results for the clearance size equal to 0.1 mm, 0.2 mm and 0.4 mm were close to an ideal joint. It demonstrated that clearance size and material characteristic played an important role in dynamics analysis of mechanical systems.

Keywords: Material characteristic, slider-crank mechanism, two sliders, revolute clearance joint, dynamics.

1. Introduction

There are some significant parameters that cause low mechanical accuracy for a slider-crank mechanism with two sliders. First, a clearance in a revolute joint is inevitable due to the design, assembly, and fabrication tolerances. The clearance causes undesired vibration and abrasion of the joint which increase the clearance size. Second, the material characteristics which caused friction and lead to an abrasion and a deformation of the joint. Moreover, the clearance size causes a contact-impact force in the revolute joint, which leads to a low accuracy in the mechanical system. The impact force also causes an abrasion joint and increases the clearance size. The different driving speed influences on the dynamic behaviors. The effect of the clearance size was investigated and presented by researchers which based on some contact force models as presented in [1] , the simulation result compared with the experimental data with the different clearance size and driving speed. Besides, the flexible components and two clearance joints also were considered and presented in [2], which wear

IOP Conf. Series: Materials Science and Engineering **378** (2018) 012016 doi:10.1088/1757-899X/378/1/012016

prediction and optimization of maximum allowable wear occurs at the same number of rotation cycles for two clearance joints simultaneously. Moreover, the effect of multiple clearance joints on dynamic of planar multibody mechanical system were analyzed and presented in [3], in which it was shown three motion phases of journal: free motion, contact motion and impact motion, comparison between ideal joint and one clearance joint, two clearance, three clearance joint. In order to restrict clearance joint effects, a compliant mechanism or flexible mechanism was investigated in [4], in which Taguchi method was used in this paper. However, the different material characteristic between journal and bearing causes friction force lead to joint wear and then induced damage for mechanical systems as reported in [5], in which influences of restitution coefficient and material characteristic cannot be ignored.
The objective of this paper is to investigate effects of clearance size and material characteristic on the dynamic of slider-crank mechanism with two sliders. Dynamic simulations were analyzed by using the finite element analysis in ANSYS. The results and discussion were presented.

2. Modeling

2.1. The slider-crank mechanism

The slider-crank mechanism with two sliders and seven revolute clearance joint was used to analyze, the model is shown Fig. 1. The mechcanism consists of the rigid links namely (1) the 1st connecting rod, (2) the 2nd connecting rod, (3) the 1st ray, (4) the 1st slider, (5) the 2nd ray, (6) crank, (7) motor, (8) Base, (9) the 2nd slider, (10) rotation of motor control, (11) DC.
In order to capture the clearance in revolute, Fig. 2 depicts a scheme of a planar slider-crank mechanism with two sliders. It includes revolute clearance joints R_1, R_2 and R_3 exist between crank, the 1st connecting rod and the 2nd connecting rod, two revolute clearance joints R_4 and R_5 exist between connecting rod 1st and slider 1, two revolute clearance joints R_6 and R_7 exist between the 2nd connecting rod and the 2nd slider, one ideal revolute joint exist between base and motor shaft, and two translations joint T_1 and T_2 exist between the 1st ray and the 1st slider, between the 2nd ray and the 2nd slider. These parameters were listed in Table 1. The crank is fixed to motor shaft. Two sliders are driven from motor shaft's rotation through the crank, the 1st connecting rod and 2nd connecting rod to the 1st slider and the 2nd slider, turn the crank's rotation into linear motion of the 1st slider and the 2nd slider.

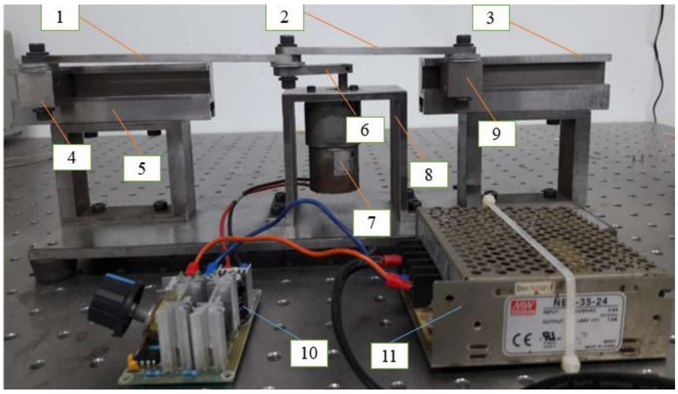


Figure 1. Rigid Sider-crank Mechanism ((1) The 1st connecting rod, (2) The 2nd connecting rod (3) The 1st ray, (4) The 1st slider , (5) The 2nd ray, (6) Crank, (7) Motor, (8) Base, (9) The 2nd slider, (10) Rotation of motor control, (11) DC

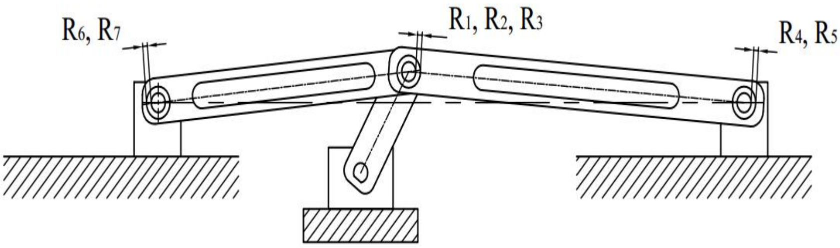


Figure 2. Planar Slider-crank mechanism with revolute clearance joint

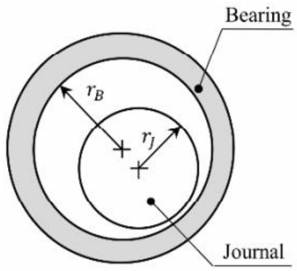


Figure 3. Revolute joint with clearance

Table 1. Simulations characteristics

Simulations characteristics	Value	Simulations characteristics	Value
Modulus of elasticity (GPa)	207	Length of connecting rod 2nd (mm)	120
Density (kg/m^3)	7850	Mass of crank (kg)	0.03
Poisson's ratio	0.3	Mass of connecting rod 1st (kg)	0.064
Initial length of crank (mm)	50	Mass of connecting rod 2nd (kg)	0.047
Length of connecting rod 1st (mm)	160	Mass of slider 1st and 2nd (kg)	0.092

2.2. Modeling of revolute clearance Joint

In general, it is well known that two bodies are linked by joint which are called journal-bearing. In fact, the existence of clearance in journal-bearing joint is inevitable. The revolute clearance joint was depicted in Fig. 3. The difference between journal and bearing is radial clearance joint and it is defined as follows:

$$c = r_b - r_j \tag{1}$$

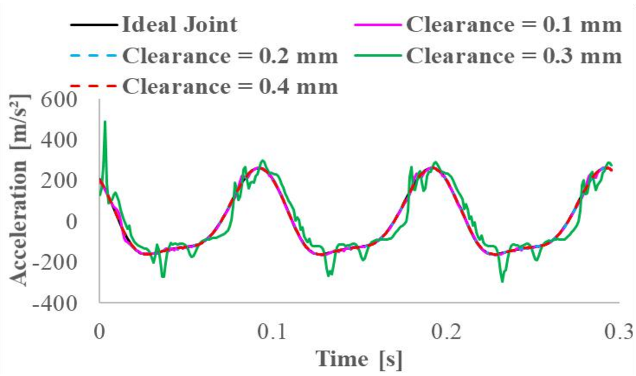
where r_b, r_j are the radii of bearing and journal, respectively.

Although, a revolute clearance joint does not restrict any degree of freedom of a mechanical system like the ideal joint, it imposes some kinematic restrictions and limiting the journal to move within the bearing. Thus, when the clearance size exists in a revolute joint, it introduces two extra degrees, which are horizontal and vertical displacements.

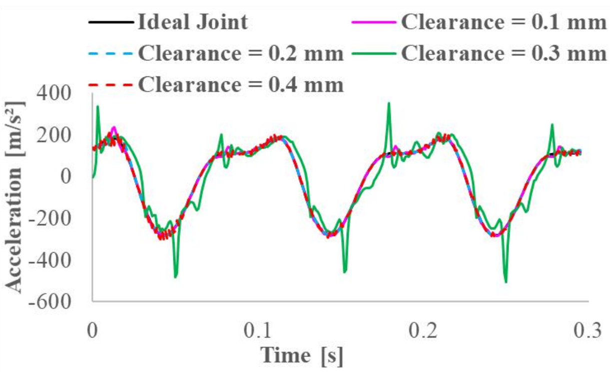
3. Results and discussion

3.1. Effects of different clearance size on dynamics

The motor shaft is a driving link and rotates with a constant velocity equal to 600 rpm with five different clearance size equal to zero, 0.1 mm, 0.2 mm, 0.3 mm and 0.4 mm, respectively.



(a)



(b)

Figure 4. Accelerations of two sliders and contact force in revolute clearance joint ((a) For the 1st slider, (b) For the 2nd slider

The slider-crank mechanism with two sliders and seven revolute clearance joints was described in section 2, using finite element analysis in ANSYS. Radius of bearing equal to 4.5 mm, radius of journal is 4.4 mm, 4.3 mm, 4.2 mm and 4.1 mm, respectively. Initialy, the journal and bearing are contact with each other, duration time simulation is 1s, time step is 10^{-4} and simulation results preseted in duration time 0.3s, in Figures. (4-5). It is identified that clearance size has significantly effected on accelerations of two sliders which oscillated with hight peaks when the clearance size equals to 0.3 mm and has silghtly effected when clearance size equals to 0.1 mm, 0.2 mm and 0.4 mm. This is because the curves of acceleration are close to the case ideal joint. At the time, accelerations have high peaks due to the journal impact into the bearing that causes the contact force strongly incereased and pointed out in Figure. 5(a)-(b)-(c)-(d). The contact force curves were different from the ideal joint case. The same phenomena can be found in [1-3]. From the simulation results were found that the clearance size cannot be ignored when analyzed dynamic of multi-body mechanical sysytems.

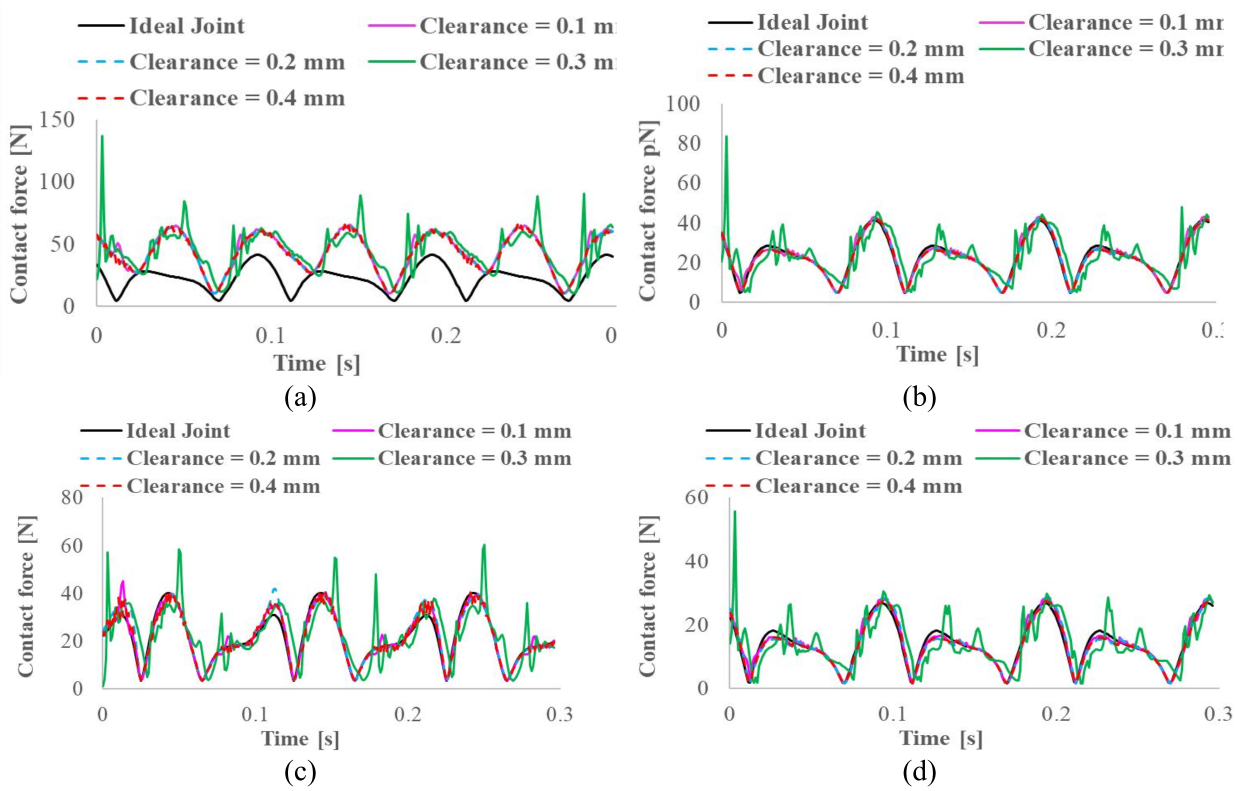
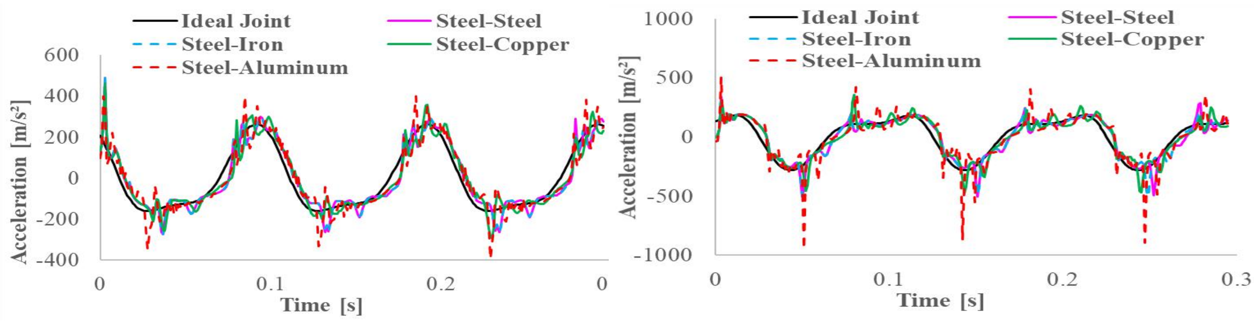


Figure. 5. The contact force in revolute clearance joint ((a) Contact force of R_1, (b) Contact force of R_2, (c) Contact force of R_3, (d) Contact force of R_4)

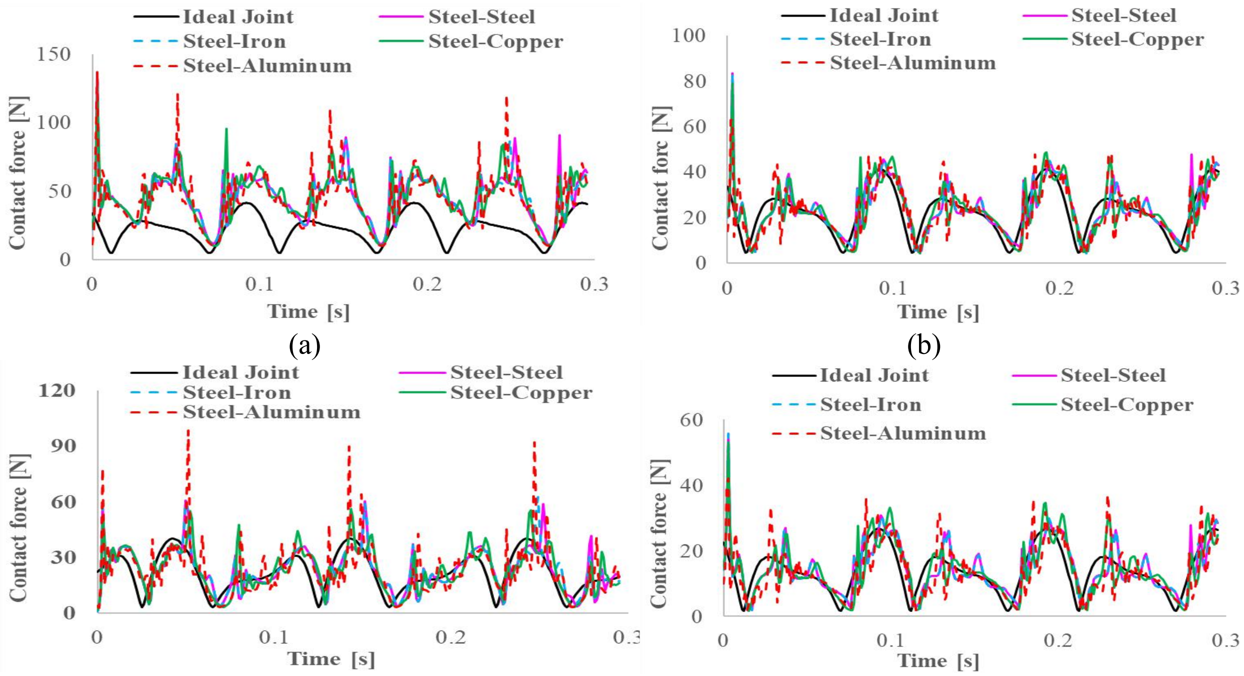
3.2. Effects of different material characteristics on dynamics

The motor shaft is a driving link and rotates with a constant velocity equal to 600 rpm. Various materials are used being manufactured for the journal. For example, Young's modulus of structure steel, iron, copper and aluminum Al-6061-T6 is 207 GPa, 173 GPa, 106 GPa and 69 GPa, respectively. Poisson's ratio of the corresponding materials is 0.3, 0.3, 0.324 and 0.33, respectively. The radius of bearing and journal equals to 4.5 mm and 4.2 mm, respectively. The clearance size equals to 0.3 mm and at the initial time, journal and bearing contacted with each other. The material of bearing is steel, the material of journal in ideal joint is SS-304 with Young's modulus 193 GPa and Poisson's ratio is 0.3. The simulation results pointed out in Figures (6-7).



(a) (b)

Figure 6. Accelerations of two sliders and contact force in revolute clearance joint ((a) For the 1st slider, (b) For the 2nd slider



(a) (b) (c) (d)

Figure 7. The contact force in revolute clearance joints with clearance size 0.3 mm (a) Contact force of R_1, (b) Contact force of R_2, (c) Contact force of R_3, (d) Contact force of R_4)

In Fig. 6(a)-(b), it is clear that the accelerations curves of two silders with steel-aluminum, steel-copper has obvious shaking with high peaks compared with steel-steel and steel-iron. Meanwhile, the result of steel-aluminum has slighter delay than that of steel-copper, and steel-iron's results have slighter delay than steel-steel's. The reason for this phenomenon is that according to the material combination of steel-steel, steel-iron, steel-copper and steel-aluminum, the contact stiffness is gradually decreased. The same phenomena can be found in the contact force curves as depicted in Figure. 7 (a)-(b)-(c)-(d). The results was in line with present in reference [5].

4. Conclusions

The influences of non-ideal revolute joints on the dynamic behavior of a slider-crank mechanism with two sliders were analyzed using the Finite element method. the accelerations of the two sliders were obviously shaking with high peaks due to the sudden impact of journal into bearing that causes contact force in the revolute clearance joint suddenly increase when clearance size equal to 0.3 mm. When the clearance size equals to 0.1 mm, 0.2 mm and 0.4 mm has slightly affected on the accelerations of two sliders and it is close to ideal joint. But the contact force was different from ideal joint. Further, different material characteristics have important effected on dynamic response of slider-crank mechanism with two sliders when the clearance size equals to 0.3 mm. Material has Young's modulus smaller cause high peaks for the accelerations and contact force. So that, it will cause the joints wear quickly and induce damage for mechanical systems.

5. Acknowledgments
The authors acknowledge and thank the Ministry of Science and Technology of the Republic of China for their partial financial support of this study under Contract Number MOST 105-2221-E-151-016.

6. References
[1] J. Ma, L. Qian, G. Chen, and M. Li, "Dynamic analysis of mechanical systems with planar revolute joints with clearance," *Mechanism and Machine Theory,* vol. 94, pp. 148-164, 2015.
[2] Y. Li, G. Chen, D. Sun, Y. Gao, and K. Wang, "Dynamic analysis and optimization design of a planar slider–crank mechanism with flexible components and two clearance joints," *Mechanism and Machine Theory,* vol. 99, pp. 37-57, 2016.
[3] Z. F. Bai and Y. Sun, "A study on dynamics of planar multibody mechanical systems with multiple revolute clearance joints," *European Journal of Mechanics - A/Solids,* vol. 60, pp. 95-111, 2016.
[4] S.-C. H. Thanh-Phong Dao, "Design and Analysis of Flexible Slider Crank Mechanism," vol. 8, pp. 836-843, 2014.
[5] X. Wang, G. Liu, S. Ma, and R. Tong, "Effects of restitution coefficient and material characteristics on dynamic response of planar multi-body systems with revolute clearance joint," *Journal of Mechanical Science and Technology,* vol. 31, pp. 587-597, 2017.