Analysis influence of journal radius and length of bearing on dynamics of a slider-crank mechanism with two sliders and revolute clearance joints

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Abstract. This article investigates influence of clearances, journal radius and length of bearing on the dynamic response of a slider-crank mechanism with two sliders and imperfect revolute joints in dry contacting condition. The mechanism was designed by Solid Works and analyzed by finite element method in ANSYS. The simulation results revealed that the velocity of two sliders were oscillated and acceleration of two sliders were obvious shaky with high peaks comparing with the ideal joint when clearance size is equal to 0.3 mm and at different length of bearing and journal radius. This reasons are due to a suddenly increase of contact force when the journal impacts into the bearing in imperfect revolute joints. It demonstrated that clearance, length of bearing and journal radius play an important role in dynamics analysis of mechanical systems.

1. Introduction

The clearance in revolute joints is the most important parameters for a slider-crank mechanism with two sliders. It is inevitable because of the design, assembling, and deformation of material, wear and manufacturing errors. It causes vibration and joint abrasion.

This problem was stated by several researchers. The clearance and driving speed effects on dynamic of mechanism were presented by Onesmus Muvengei et al [1]. In order to estimate accuracy clearance effect in dry contact condition with friction, a hybrid contact force model of the Lankarani-Nikravesh model was utilized by Bai and Zao in [2]. Because of unwanted effects of clearance joint, Dao and Huang designed pseudo-rigid-body for flexible slider-crank mechanism [3]. There are some contact force models were presented and selection the suitable contact force model was so important which was stated in [4] by Bai et al. Influences of clearance also optimized by Varedi et al. [5] using particle swarm optimization (PSO). Li et al. [6] also were used the elastic foundation model with hysteresis damping, nonlinear spring-damp and flexibility of harmonic gear to optimize dynamic design and analysis of a planar slider-crank mechanism. Chen et al [7] carried out the experiment to investigate effects of high driving velocity and heavy load on a planar slider-crank mechanism with clearance joint and was compared with the simulation result using Adam software. Moreover, the
length of bearing, restitution coefficient and material characteristics also causes oscillation for mechanical system, which were investigated by Xupeng et al. [8].

The influence of journal radius has not studied yet. The aim of this paper is investigating effects clearance size in revolute joint in dry contact, length of bearing and journal radius on the dynamic of slider-crank mechanism with two sliders and revolute clearance joints. Dynamic simulations are executed by using a finite element analysis in ANSYS.

2. Modelling

2.1. Description of a slider-crank mechanism with two sliders and revolute clearance joints
The slider-crank mechanism with two sliders and seven revolute clearance joint was used to analyze, as presented figure 1. The mechanism consists of rigid links namely the 1st ray; the 1st connecting rod; the 2nd connecting rod; the 2nd ray; The 1st slider; Crank; Motor; the 2nd slider.

In order to capture the clearance in revolute joint, figure 2 depicts a scheme of a planar slider-crank mechanism with two sliders. It includes the seven revolute clearance joints namely R₁, R₂, R₃ exist between crank, the 1st connecting rod and 2nd connecting rod, two revolute clearance joints R₄, R₅ exist between the 1st connecting rod and the 1st slider, two revolute clearance joints R₆, R₇ exist between the 2nd connecting rod and the 2nd slider, one ideal revolute joint exist between base and motor shaft, and two translations joint T₁, T₂ exist between the 1st ray and the 1st slider, between the 2nd ray and the 2nd slider. These parameters were listed in table 1.

![Figure 1. Rigid Slider-crank Mechanism.](image1)  
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.](image2)
2.2. Revolute clearance joint model

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

\[ c = r_B - r_J \]  (1)

where \( r_B, r_J \) are the radii of bearing and journal, respectively.

![Figure 3. Revolute joint with clearance.](image)

Although, a revolute clearance joint does not restrict any degree of freedom from the mechanical system like the ideal joint, it imposes some kinematic restrictions, limiting the journal to move within the bearing. Thus, when clearance is present in a revolute joint also introduces two extra degrees, which are horizontal, vertical displacements. In figure 3, \( r_B, r_J, l_B(L) \) and \( d_B \) are radius of bearing, journal radius, and length of bearing and diameter of bearing, respectively.

3. Results and discussion

Initially, the centre of journal and bearing are concentric. The crank is fixed into motor shaft and is set up at horizontal position. The distance from the motor shaft centre to the centre of two sliders is equal to 20 mm. Two sliders are driven from motor shaft’s rotation through the crank, the 1\(^{st}\) connecting rod and 2\(^{nd}\) connecting rod to the 1\(^{st}\) slider and 2\(^{nd}\) slider; turn the crank’s rotation into linear motion of the 1\(^{st}\) slider and 2\(^{nd}\) slider. The motor shaft rotates with constant rotation velocity 600 rpm, and radius of clearance is also constant 0.3 mm in simulation duration 1 second and time step \(10^{-4}\)s. Friction coefficient in revolute clearance joints \( R_1 \) to \( R_7 \) are equal to 0.01.

3.1. Effect of different length of bearing

In this section, length of bearing for three case as following \( L = 5 \) mm, \( L = 10 \) mm and \( L = 15 \) mm, radius of journal and bearing are equal to 9.7 mm and 10 mm respectively for three case. The simulation results were illustrated in figures (4-6). Figure 4 identified the velocity graph of two sliders oscillated around the velocity graph of two sliders of ideal joint and increase when length of bearing reduces from 15 mm to 5 mm. These same phenomena were sated reference [1,3]. The acceleration graphs of two sliders depicted in figure 5. It can be concluded that the clearance size has significantly affected on the acceleration of two sliders and increased when length of bearing reduces from 15 mm
to 5 mm. The acceleration of two sliders was strongly shaky with high peaks. This problem is due to journal impact into bearing, it caused contact force in revolute clearance joint, and caused unbalancing mechanical system. The curve of contact force in revolute clearance joints and contact force in translation joints pointed out in figure 6. It revealed clearance size has important influenced on contact force in revolute clearance joints and increased when length of bearing decreased from 15 mm to 5 mm. The same phenomena are presented in references [1-4].

**Figure 4.** Velocity of two slider ((a) The 1st slider, (b) The 2nd slider).

**Figure 5.** Acceleration of two sliders ((a) The 1st slider acceleration, (b) The 2nd slider acceleration).
3.2. Effect of different radius of journal

Figure 6. The contact force in revolute clearance joins and translation joint ((a) For R₁, (b) For R₂, (c) For R₃, (d) For R₄, (e) For R₅, (f) For R₆, (g) For R₇, (h) For T₁, (i) For T₂).

Figure 7. The velocity of two sliders ((a) The 1ˢᵗ slider velocity, (b) The 2ⁿᵈ slider velocity).

Fixed length of bearing is 10 mm, at different journal radius as following 4.7 mm, 7.2 mm and 9.7 mm and clearance size of 0.3 mm. The simulation results were demonstrated in figures (7-9). The velocity graph of two sliders as shown in figure 7, it indicated that velocity of two sliders were vibrated by radius of clearance size and increased when radius of journal reduced from 9.7 mm to 4.7 mm.
Moreover, the acceleration of two sliders were also seriously affected by clearance size and reduced when radius of journal increase from 4.7 mm to 9.7 mm as shown in figure 8. The same phenomenon was drawn out in the contact force graph and shown as figure 9. The problem was due to contact force suddenly increased with high peaks that caused mechanical system unstable. These same phenomena investigated in references [5-8].

![Figure 8](image1.png) ![Figure 9](image2.png)

**Figure 8.** The acceleration of two sliders ((a) The 1st slider, (b) The 2nd slider acceleration).
4. Conclusions

The influences of non-ideal revolute joints on the dynamic behaviour of a slider-crank mechanism with two sliders were analyzed using the Finite element method. The velocity of two sliders different from ideal joint case at different length of bearing. The accelerations of the two sliders were shaky with high peaks due to journal suddenly impact in to bearing cause the contact force in the revolute clearance joint when clearance size equal to 0.3 mm and length of bearing reduced. However, the contact force was different from ideal joint case. Further, different journal radius has important effect on dynamic response of slider-crank mechanism with two sliders and imperfect revolute joints when clearance size equal to 0.3 mm. The problem will cause quickly joint wear and induced damage for mechanical systems.

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Figure 9. The contact force in revolute clearance joins and translation joint ((a) For $R_1$, (b) For $R_2$, (c) For $R_3$, (d) For $R_4$, (e) For $R_5$, (f) For $R_6$, (g) For $R_7$, (h) For $T_1$, (i) For $T_2$).