Enhanced Performance of a Slider Mechanism Through Improved Design Using ADAMS

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Introduction

Understanding of the influence of critical parameters in mechanical design plays a crucial role in developing a reliably performing multi-body system. This aspect gains paramount importance, particularly, when the system has dynamic interaction between the parts. Computer aided engineering tools of today are of immense help in simulating full-motion behavior of real world engineering applications through building virtual prototypes of complex mechanical systems. This eliminates expensive physical prototypes and gives confidence in the optimum design achieved through an effort, coupling CAE and physical testing.

In the current investigation, an enhancement in performance of a slider mechanism - 1 shown in Figure 1 was accomplished by conducting a dynamic analysis. On the basis of this analysis a new design (slider mechanism – 2) was recommended which is shown in Figure 2. In the case of slider mechanism - 1, fluid lubrication was needed for smooth operation over its life cycle of 300,000 cycles. In the absence of fluid lubrication, the system would start squeak and chatter. The use of self-lubricating iglide bearings with solid lubricant did not solve the problem. The challenge was to eliminate this fluid lubrication, and still maintain satisfactory functional performance.

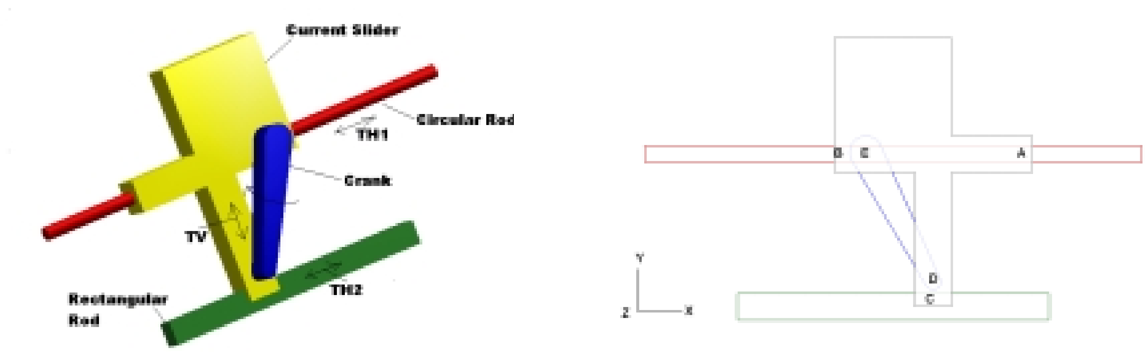
Hence, the purpose of this study was to recommend a new design, which accomplishes the following:

1. Eliminates squeak and chatter of the mechanism during its operation.
2. Eliminates fluid lubrication of the circular rod over which the mechanism slides.

Using ADAMS, reaction forces at different critical joint locations in slider mechanism –1 were examined by simulating the motion in different situations. Influence of critical parameters on the system's dynamic behavior was investigated. A new slider crank mechanism with iglide bearings (slider mechanism – 2) was designed using SOLID EDGE and fabricated. Dynamic analysis of slider mechanism – 2 was carried out and the reactions at different joints evaluated and compared with those for slider mechanism – 1. The new system experienced significant reduction in reaction forces at critical joints. The new design was tested for 300,000 cycles of operation. It performed satisfactorily when tested without using fluid lubrication.

Materials and Methods

Figure 1 shows the slider mechanism – 1. Figure 1(a) shows a three-dimensional view of the mechanism with arrows showing the translational and rotational movements at different joints. Figure 1(b) shows a schematic two-dimensional picture of the same mechanism with joints represented by letters A, B, C, D and E, which are explained below. These joints comprise of revolute, translational and, combined revolute and translational joints.



(a) Three-dimensional view (b) A schematic 2-D diagram showing joints

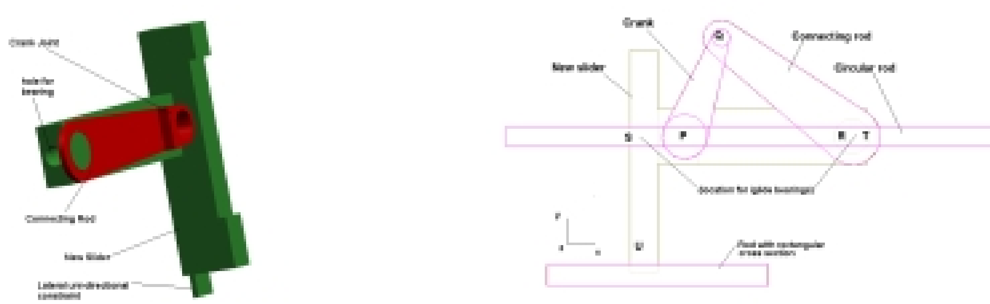
Figure 1 Slider Mechanism - 1

Current slider shown in Figure 1(a) slides back and forth along x-direction over the circular rod (CR), which passes through circular holes in the slider. Joints at A and B as shown in Figure 1(b), are two-degree-of-freedom joints with combined translation and rotation. The translation is along the longitudinal-axis of the rod in x-direction and rotation along the same axis in yz-plane. A rod with rectangular cross section (RR) at the bottom restrains the rotation of joints at A and B, through a translation joint at C (in x-direction), between the bottom portion of the slider and the rod RR. The translation joint at C is achieved through an inverted U-shaped feature incorporated at the bottom of the slider.

At D, there is a translatory joint between the outer end of crank and a vertical groove in the body of the slider. The inner end of the crank, which is connected rigidly to an electric motor shaft, constitutes a rotational joint at E. As shown in Figure 1 (a), the motor driven rotational crank motion is converted to translational movement (TH1 and TH2) of the slider over circular and rectangular cross section rods. The outer end of the crank slides in the vertical groove in the slider, in a vertical translatory movement (TV), causing the slider to perform oscillations in the horizontal direction in (along x-axis) xy-plane. An over-hanging cantilever arm connected to slider top corner above B (not shown in Figure) performs a sweeping action in horizontal plane. Application of lubricant is needed at the joints at A and B (between the slider and the circular rod) for smooth operation of the mechanism.

In order to better understand performance aspects of the mechanism under consideration, it was felt crucial to determine the forces acting at different joints under dynamic operating conditions. ADAMS (the kinematics and dynamic analysis software) was used for this purpose. Critical parameters were varied to see their influence on the dynamics of the mechanism under study. Several simulations were run for different cases, which will be discussed below.

The version of ADAMS (9.04) used in this analysis does not provide cylindrical joints with two degrees of freedom viz. translation and rotation (along X-axis in this case). Hence, through the help of a dummy part between the circular rod (CR) and the slider, simulation of cylindrical joint was accomplished. A dummy part is the one with zero mass. This can be used in cases like this without causing any change on the system. Thus a translational joint (along X-axis) between the dummy part and rod (ground) in combination with a revolute joint between the dummy part and the slider (along X-axis) was created to simulate cylindrical joint operation between slider and the ground at point A. Similar discussion holds good for the cylindrical joint at B. At C, a translational joint between slider and the rod with rectangular cross section (RR) was created. At D, there are again two joints. One is the translational joint between slider and a dummy part, and the other is a revolute joint between the dummy part and the outer end of the crank. At point E, there is a revolute joint between the inner end of the crank and the ground. All the translational joints are in XY plane. Revolute joints at D and E are in XY plane, whereas the revolute joints at A and B are in planes parallel to YZ plane.



(a) Three-dimensional view (b) A schematic 2-D diagram showing joints

Figure 2 Slider Mechanism - 2

Figures 2(a) and 2(b) show the three-dimensional and two-dimensional schematic representation of slider mechanism - 2. As shown in Figure 2(a), the slider mechanism – 2 consist of new slider and connecting rod. The connecting rod is connected to the outer end of the crank (not shown). The joint details are shown in Figure 2(b). The new slider slides back and forth along x-direction over the circular rod, which passes through iglide bearings in two circular holes in the slider at S and T. The joints at S and T as shown in Figure 2(b), are two-degree-of-freedom joints with combined translation and rotation. The translation is along the longitudinal-axis of the rod in x-direction and rotation along the same axis in yz-plane. A rod with rectangular cross section at the bottom restrains the rotation of joints at S and T through a translation joint at U (in x-direction), between the bottom portion of the slider and the rod with rectangular cross section. The translation joint at U is achieved through an inverted L-shaped feature incorporated at the bottom of the slider. This L-shaped feature in the body of the new slider provides lateral restraint of the new slider in only one direction (along z-axis). A slight imbalance is intentionally created in the yz-plane by adding little extra weight on one side of the slider body, such that the unidirectional constraint at U suffice for the mechanism operation. The motor driven crank moves the new slider in an oscillatory motion in the x-direction, through the connecting rod.

Figure 2 (b) shows the details of various joints in the modified design. P, Q and R are the locations for revolute joints in xy-plane. P is the joint between the ground and the inner end of crank. Q is the revolute joint between the outer end of crank and connecting rod. R is the revolute joint between the other end of connecting rod and the new slider. U is the location of a translatory joint (along x-axis) between the bottom of new slider and the rod with rectangular cross section. S and T are the locations for cylindrical joints with two degrees of freedom viz. translation and rotation along x-axis.

All joints were associated with friction at the contact surfaces. Default static coefficient of friction of 0.4 and dynamic coefficient of friction of 0.3 was assumed at all joints to represent the case of operation without fluid lubrication in the case of slider mechanism - 1. In the case of slider mechanism - 2, the static and dynamic coefficient of friction were taken as .13 and 0.1 respectively as suggested by igus, Inc. (iglide bearings, Engineering Plastics Manual, dated 7/99, igus, inc., East Providence, RI).

Following are other details used in the study:

Material properties for plastic:

Young's Modulus of Elasticity: 9.653×10^9 N/m^2
Density : 1525.6 Kg/m^3
Poisson's Ratio : 0.4

Cycle Time: 2.88 seconds
Simulation duration: 50 seconds
Step Size: 0.1 seconds

Using function builder in ADAMS, a rotating motion for the crank was generated with 2.88 second cycle time. This motion was specified at the revolute joint between the crank and the ground. An out of plane fixation of the rectangular rod with respect to the circular rod, caused due to manufacturing tolerances, results in a torque applied at the bottom of the slider. This condition was simulated, by applying two concentrated point loads in opposite direction along z-direction at the bottom most portion of the slider body. On the basis of static finite element analysis using ANSYS, an appropriate magnitude of concentrated opposing forces applied on the slider to achieve the torque was determined. This force magnitude applied at the bottom portion of the slider was approximately 1.5 Newtons.

Both the mechanisms discussed above were simulated for 50 seconds, with a step size of 0.1 seconds. The forces acting at different joints were plotted. The joints in slider mechanism – 1, where maximum forces were encountered were selected and compared with the corresponding joints in the slider mechanism - 2.

Results and Discussion

Figures 3 to 10 show the variation of joint forces with time in X and Y direction for translatory joints at locations A, B, C and D with time for the simulations carried out for 50 seconds, for slider mechanism - 1.

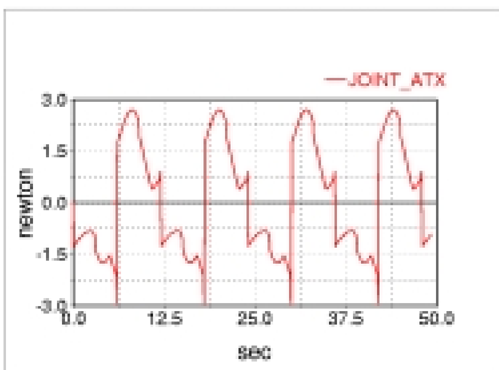


Figure 3 Variation of force in x-direction at joint A (Slider mechanism-1)

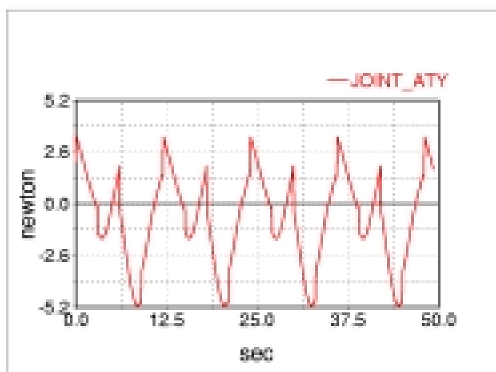


Figure 4 Variation of force in y-direction at joint at A (Slider mechanism-1)

Figures 3 and 4 show the variation of force in x and y-direction at joint location at A (translatory joint). The magnitude of force in y-direction seems to be higher than the magnitude of force in x-direction. A similar trend can be seen for the forces in x and y-direction for the translatory joint at location B (Figures 5 and 6).

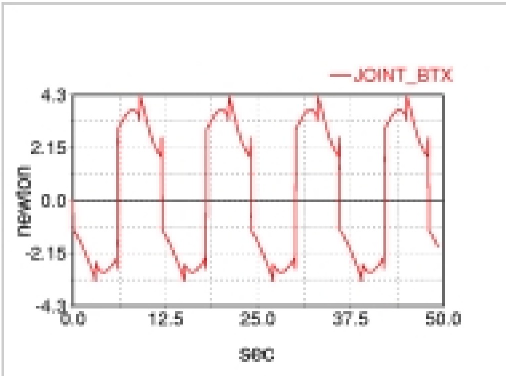


Figure 5 Variation of force in x-direction at joint B (Slider mechanism-1)

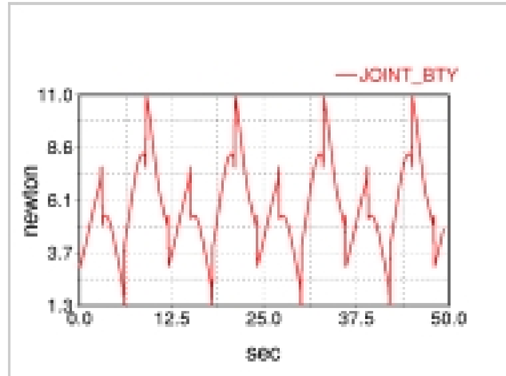


Figure 6 Variation of force in Y-direction at joint at B (Slider mechanism-1)

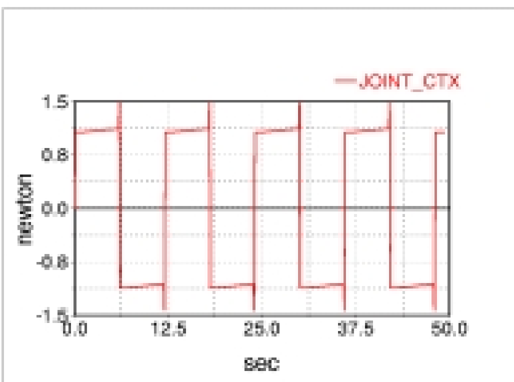


Figure 7 Variation of force in x-direction at joint C (Slider mechanism-1)

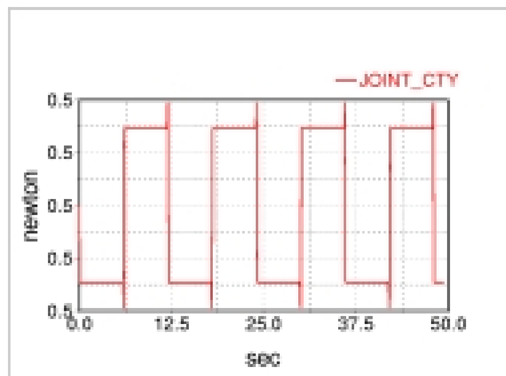
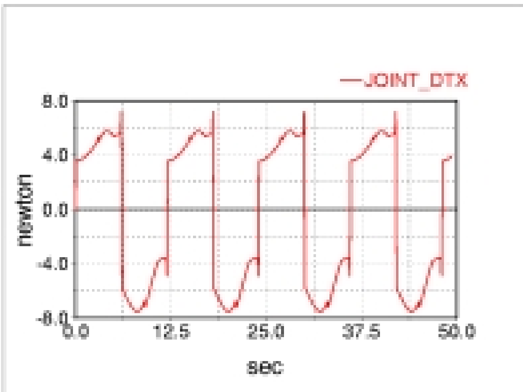


Figure 8 Variation of force in Y-direction at joint C (Slider mechanism-1)



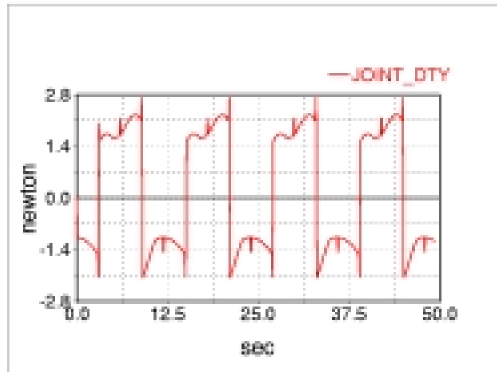
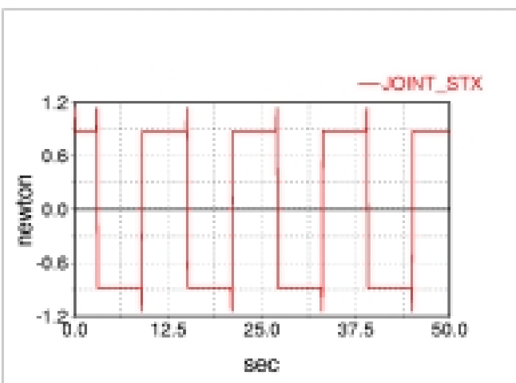


Figure 9 Variation of force in x-direction at joint D (Slider mechanism-1)

Figure 10 Variation of force in y-direction at joint D (Slider mechanism-1)

Whereas, in Figures 7 to 10, the magnitude of force in x-direction is higher than the magnitude of force in y-direction. The reason for this is the change in direction of translation at location D.



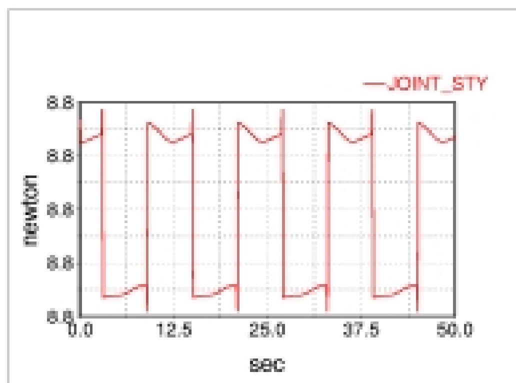


Figure 11 Variation of force in x-direction at joint S (Slider mechanism-2)

Figure 12 Variation of force in y-direction at joint S (Slider mechanism-2)

Figures 11 to 14 represent the plots pertaining to the variation of joint forces at the translatory joints at the locations S and T, in the slider mechanism - 2. As it can be seen from these Figures, the magnitudes of maximum joint forces at locations S and T in the slider mechanism-2, was significantly reduced as compared to the forces in slider mechanism-1 at the corresponding locations B and A. The maximum forces experienced in the slider mechanism-2 was at location S. Its magnitude in x and y-directions was 1.2 newtons (-JOINT_STX) and 8.8 newtons (-JOINT_STY) respectively, as compared to

4.3 newtons (-JOINT_BTX) and 11 (-JOINT_BTY) newtons in the slider mechanism-1 at location B. The forces experienced in slider mechanism – 2 in y-direction at joint T were higher than the forces in x-direction as shown in Figures 13 and 14.

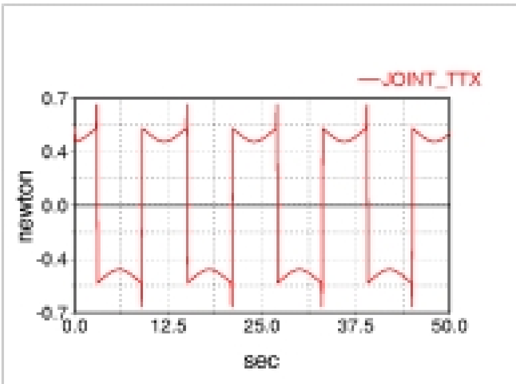


Figure 13 Variation of force in x-direction at joint T (Slider mechanism-2)

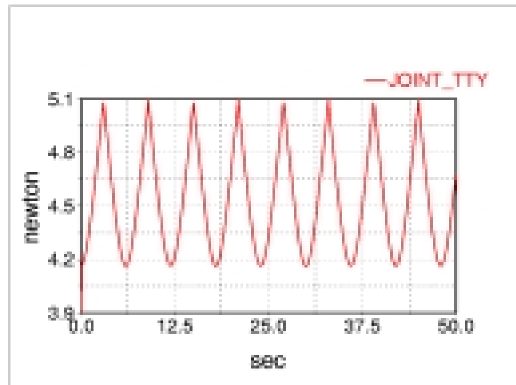


Figure 14 Variation of force in y-direction at joint T (Slider mechanism-2)

The slider mechanism – 2 was tested for 300,000 cycles. After running for 220,000 cycles, the movement of the mechanism became slightly rough. A dead weight (a rectangular block as shown in Figure 15) was added to the slider mechanism-2 for the purpose of balancing. The slider mechanism performed satisfactorily for more than 300,000 cycles.

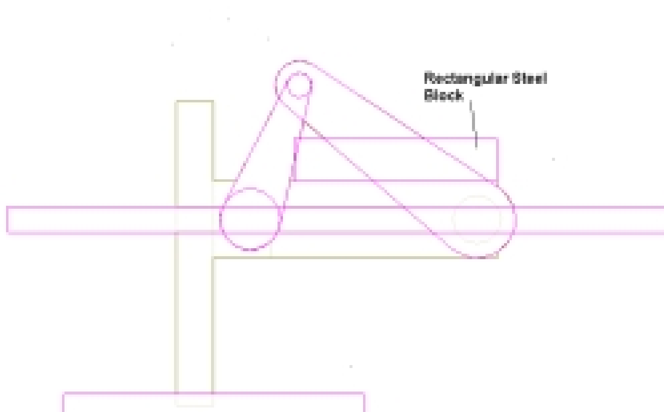


Figure 15 A schematic 2-D diagram of modified slider mechanism showing rectangular steel block

Conclusions

Design modifications were made to a slider crank mechanism –1, on the basis of dynamic analysis carried out by ADAMS software, resulting in slider mechanism – 2, with enhanced performance. A comparative study of the reaction forces at the critical joints of both designs showed a significant reduction in the magnitude of joint reaction forces in slider mechanism – 2 as compared to that in slider mechanism - 1. Fluid lubrication, which was a requirement in slider mechanism – 1, to avoid squeak and chatter, was eliminated in the slider mechanism – 2, through the use of iglide bearings. Slider mechanism – 2 was tested for its life of 300,000 cycles, and was found to perform satisfactorily.