COMPUTER AIDED ANALYSIS OF A SHEEP SHEARING MACHINE

Sham Rane, Varun Grover, Vineet Vashista, Anand Jere, and Subir Kumar Saha*
Department of Mechanical Engineering, Indian Institute of Technology Delhi
Hauz Khas, New Delhi 110 016
Email: saha@mech.iitd.ernet.in
*Presently with on-lien leave to IIT Madras (sahask@iitm.ac.in)

Abstract

A sheep-shearing machine is extensively used by the wool industry to cut hair from the sheep body. It is mainly consisting of a spatial four-bar mechanism driven by an electric motor. Rotational input is provided to the crankshaft of the machine by a flexible coupling connected to an electric motor to obtain output-rocking motion of the fork and cutter relative to the comb. In this paper, a CAD model of the sheep-shearing machine is developed using the commercial software called ADAMS (Automatic Dynamic Analysis of Mechanical Systems). The model is used to study various kinematic and dynamic parameters, e.g., angle of fork oscillations, torque required at the crankshaft, etc. The latter information is useful to estimate the power consumption of the machine. The ADAMS results were verified using separately derived analytical expressions that are programmed in MATLAB.

Key Words *Sheep, Wool, Analysis, ADAMS.*

1. INTRODUCTION

A sheep shearing machine used by wool industries to cut the hairs of a sheep is shown in Fig. 1 (Saha and Prasad, 2006). The relative motion between the cutter and comb causes the shearing action of the hair as the handheld machine is moved forward over the body of the sheep like the hair cutting in a barbershop. There is also an arrangement to vary the pressure on the cutter by turning a nut. Important features in this sheep shearing machine are the displacement of the cutter relative to the comb (cutting length), the pressure required to maintain necessary clearances between the cutter and comb, and the power consumption. Power consumption depends on the crank pin offset, hinge point location, and the friction and inertia properties.

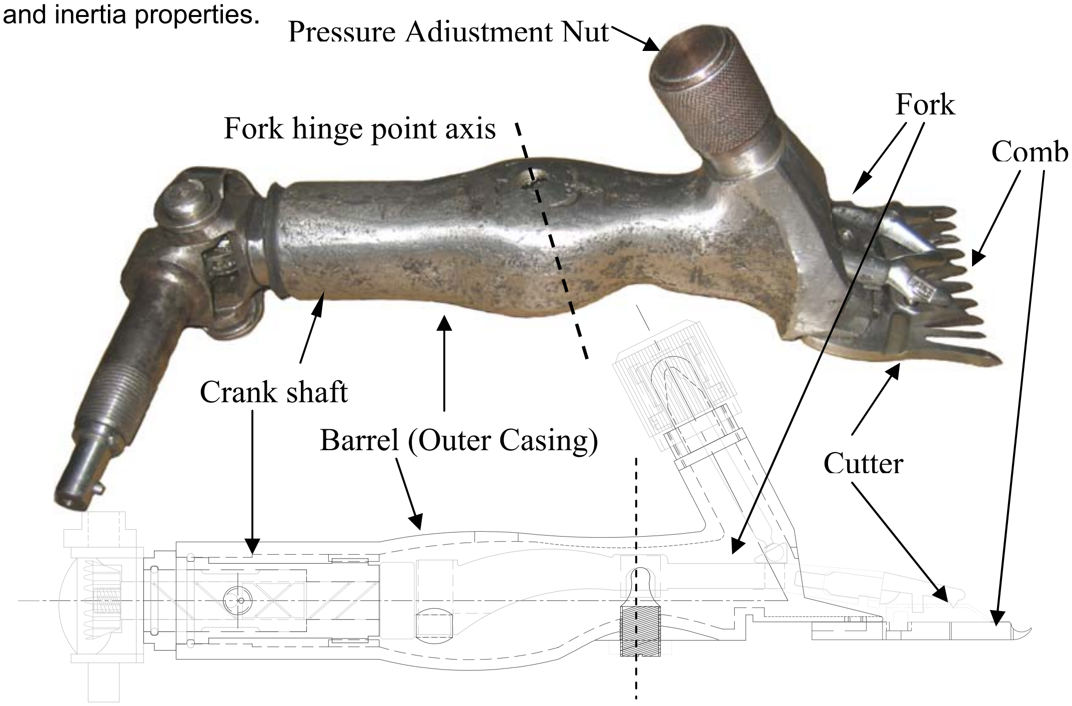


Fig. 1 Sheep shearing machine

Such devices are studied by Maloney (2005), where in-depth analysis of the comb and cutter was performed. In this paper, kinematic and dynamic behavior of the mechanism is emphasized, which are expected to improve the existing machine or come up with a better alternative device. The paper is organized as follows: Section 2 presents how to develop the model in ADAMS software, followed by the simulation results in section 3. Section 4 presents the analytical expressions used to write a MATLAB program to verify the ADAMS results. Finally, conclusions are provided in section 5.

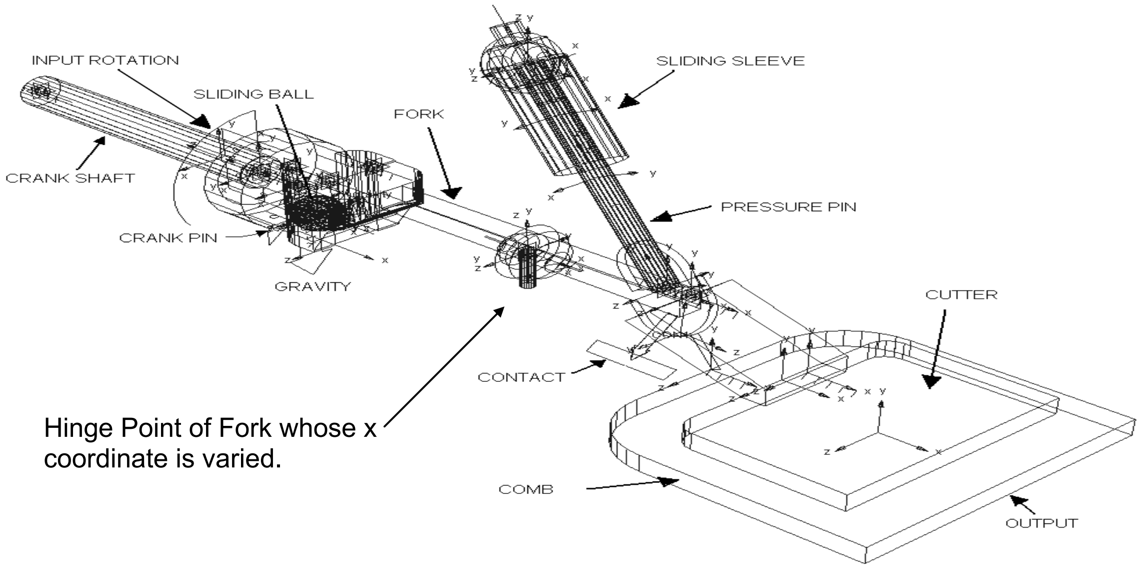


Fig. 2 Different parts in the ADAMS model

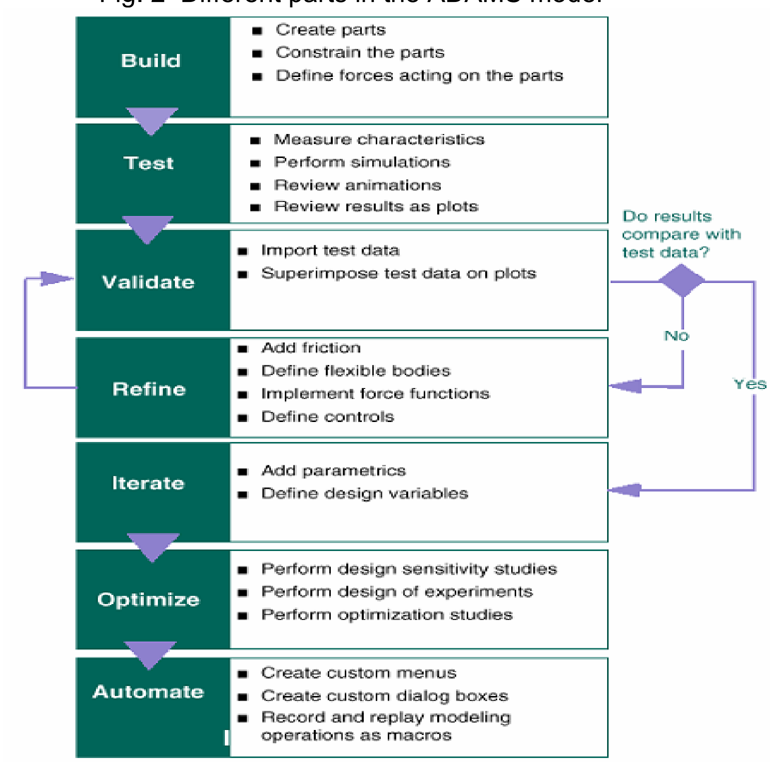


Fig. 3 Flow chart of modeling and simulation in ADAMS

2. MODELLING IN ADAMS

ADAMS (Automatic Dynamic Analysis of Mechanical Systems) is a general purpose commercial software for mechanical system simulation and is used extensively by Auto, Rail and other industries. In this paper, the software is used to analyse a rural engineering system. Different parts of the sheep shearing machine in ADAMS model are shown below Fig. 2, whereas the other aspects of the simulation are presented in the following subsections.

2.1 Modeling of the components:

The basic procedure adopted in ADAMS for modeling and simulation is shown in the following flow-chart of Fig. 3 (ADAMS, 2005). This is a very general flow chart. For the sheep shearing machine we have used the following steps:

1. We begin with the identification of different components that are required in the model. This is shown if Fig 2.

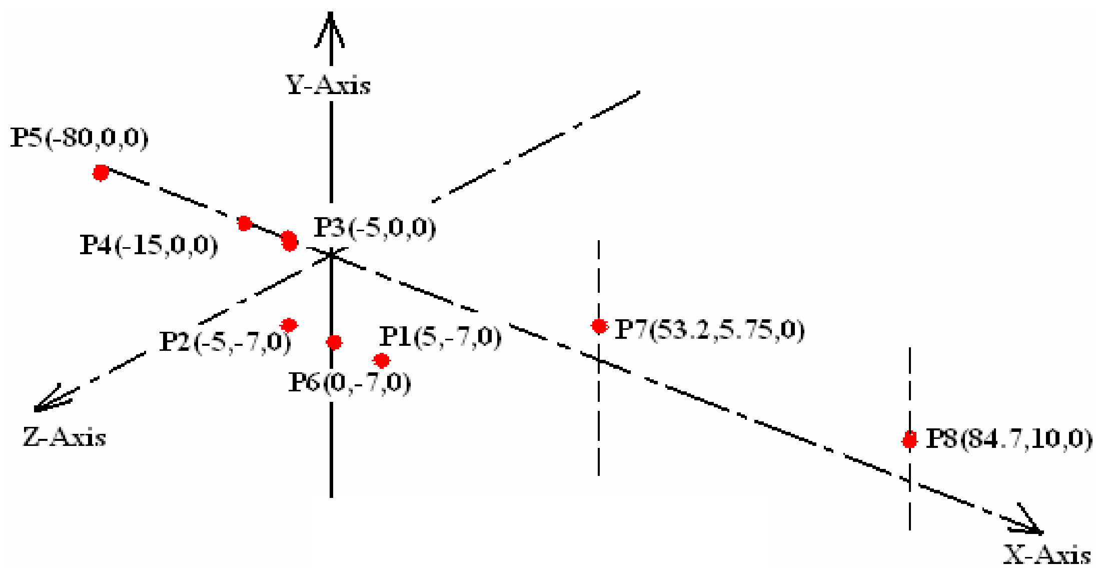


Fig. 4 Hard Point locations

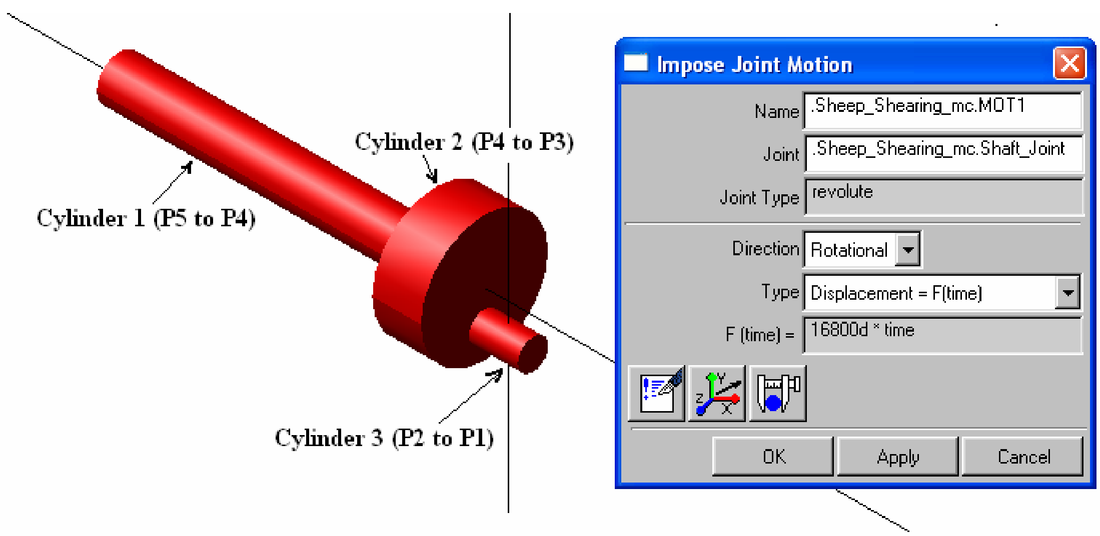


Fig. 5 Shaft with offset pin and input motion specification window

2. A layout is prepared indicating the location of various Hard Points of the model in 3D space. This is shown in Fig 4. Hard Points are the points in space such that the different links of the mechanism are positioned relative to each other in accordance with these points.

3. Solid modeling is done using ADAMS/View module of the software, which has a set of standard solid shapes (ADAMS, 2005). First the input shaft is made using a cylinder of specified diameter drawn from P5 to P4 as shown in Fig. 5. Another cylinder is added that starts from P4 to P3. A small cylinder representing the offset pin from P2 to P1 is added next on cylinder 2. A constraint of Revolute joint is then applied between the shaft (cylinder 1) and Ground. Rotational motion with displacement equal to (16800d*time) is applied to the revolute joint, where 'd' means degree. This represents the Input motion, i.e., 2800rpm. Figure 5 shows the shaft with input revolute motion specification window.

4. Using various standard solid building blocks other components are similarly developed. Appropriate joint constraints and motion constraints are applied at various locations. The sequence of creating the other components is given as follows: Shaft with offset pin, Sliding ball, Fork, Cutter, Comb, Pressure Pin, Sliding Sleeve. Figure 6 shows the complete assembly.

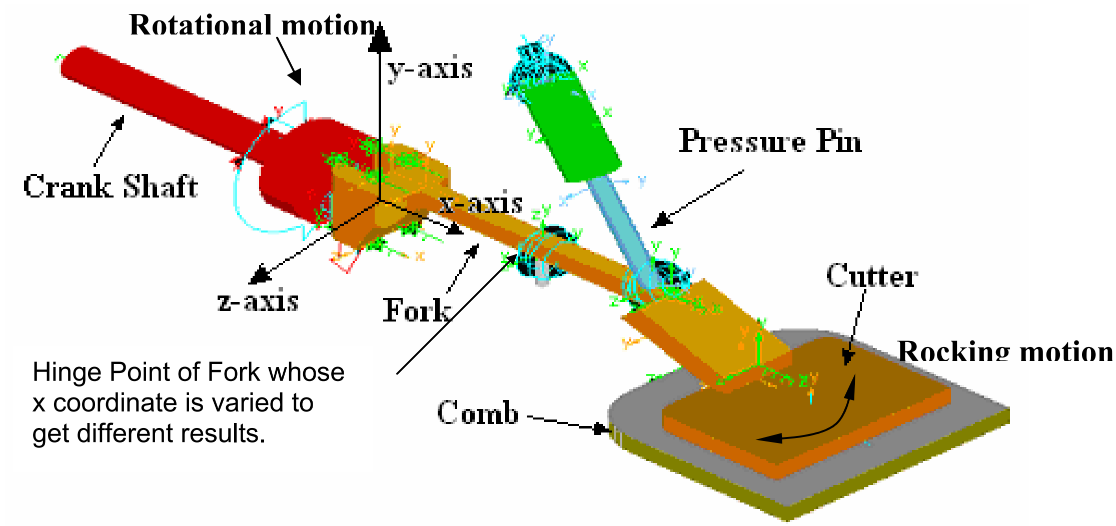


Fig. 6 Complete assembly in ADAMS

2.2 Modeling the joints

In this subsection, modeling of the joints between the interconnecting bodies is presented.

1. **Shaft with offset Pin:** Input to the mechanism is given through uniform rotation of the crank shaft (second link). In the crank shaft, the crank is at the offset of 7mm from the centre of the shaft. The stroke length of the cutter on the comb is proportional to the crank offset. The shaft has one revolute joint with Barrel (Ground for the Model) and one cylindrical joint with the Sliding ball.

2. **Sliding ball**: Sliding ball is connector between the crank and the fork. It is the third link of the model. Rotational motion of the crank is required to be converted into rocking motion of the fork, Figs. 1 and 6.

3. **Fork:** Fork is the fourth link of the kinematic chain. It has a special joint with the sliding ball. This joint has three degrees of freedom in which two are rotational and one is translational. The fork is connected to the barrel (Ground) by a spherical joint, where the pressure pin pushes the fork at the other end. A Spherical joint connects the pressure pin and the fork. At the end of the fork, the cutter is connected through the fork yokes, which are not included in the model. In the model, the cutter is made integral part of the fork.

4. **Cutter and Comb:** Comb forms the fixed link of the chain as it is an integral part of barrel. The relative motion between the cutter and the comb causes the sheep's hair to cut.

5. **Pressure pin and sliding sleeve:** Pressure pin is used to regulate the pressure between the cutter and the comb. It pushes the fork end to apply pressure on the cutter to reduce the clearance.

At its one end, there is a sliding sleeve with a cylindrical joint with the barrel. On the other end of the pin, there is a spherical joint with the fork.

3. SIMULATION

Actually the model building process involves simulating the model after every component is created. This is to ensure that there is no ambiguity involved in the new component and new constraint added. After the model is completely built the simulation results are studied in the post-processor of ADAMS (ADAMS, 2005). The post-processor can be directly accessed through the main toolbox. Duration is entered as (360/16800) in order to obtain one revolution of the shaft and study the model for one cycle. Multiples of this value will cause multiple revolutions. In the post processor various plots are obtained related to the objectives of the study.

3.1 Validation of the model

The sheep shearing machine is basically a four-bar spatial mechanism, as discussed previously while detailing the components. Its kinematic diagram is shown in Fig. 7. The degree of freedom (DOF) of the linkage can be found using the Kutzbach formula (Ghosh and Mallik, 1998) as DOF = $6(n-1) - 5j_1 - 4j_2 - 3j_3$, where, n = Number of links, 4; j_1 = Number of joints with 1 DOF, 2; j_2 = Number of joints with 2 DOF, 1; j_3 = Number of joints with 3 DOF, 1.

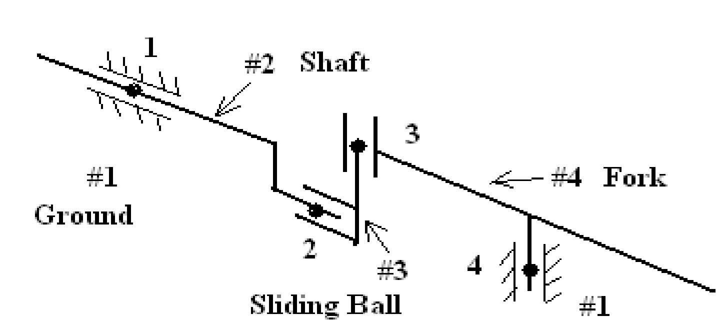


Fig. 7 Kinematic diagram

Hence, DOF = 1, which is the input rotational motion. In order to check if the model is developed correctly or not, two simple comparisons are given in Table 1. The Z-displacement of the fork, as indicated in Fig. 8 is calculated as, **z** = (61.5*7*2) / 53.2 = 16.18mm---7 being the pin offset---, whereas the angular displacement is obtained as, **α** = $\tan^{-1}(16.18 / 2 * 61.5) = 7.496^{o}$.

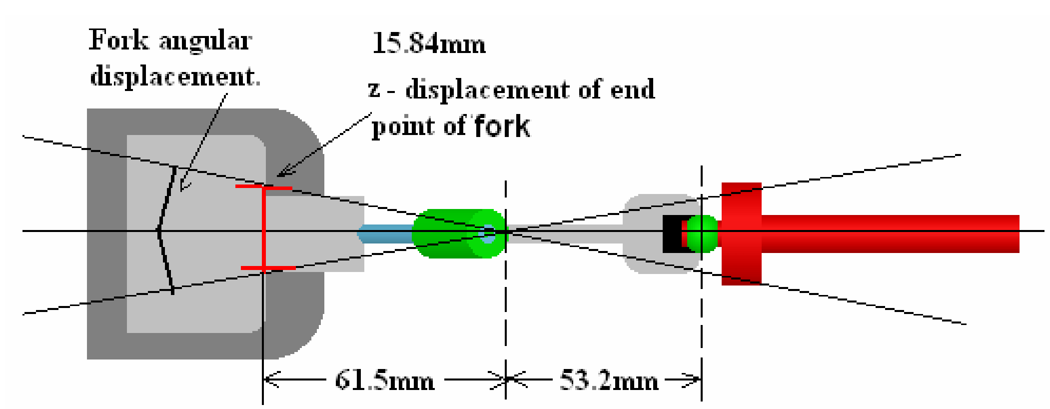


Fig. 8 Measured data

Table 1 Comparison of results

No	Parameter	Calculated value	ADAMS plots
1	Z-Translation displacement.	16.18mm	16.231mm
2	Fork angular displacement.	7.496^o	7.5^o

The differences in the results of Table 1 are mainly due to the joint clearances in actual machine.

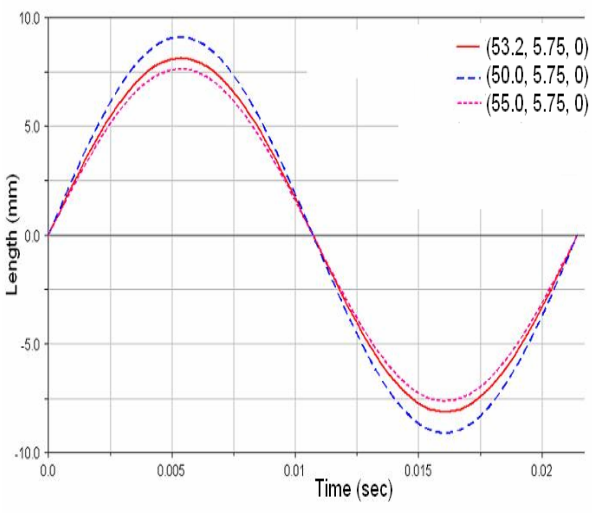


Fig. 9 Z-Displacement of cutter vs. time

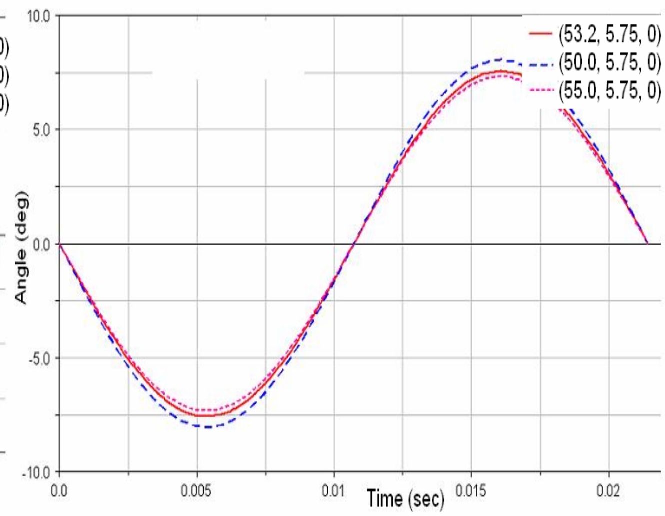


Fig. 10 Angular displacement of fork vs. time

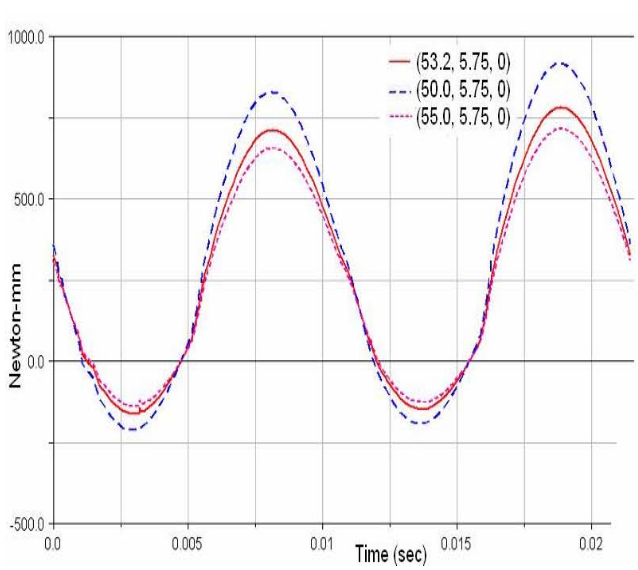


Fig. 11 Input shaft torque vs. time

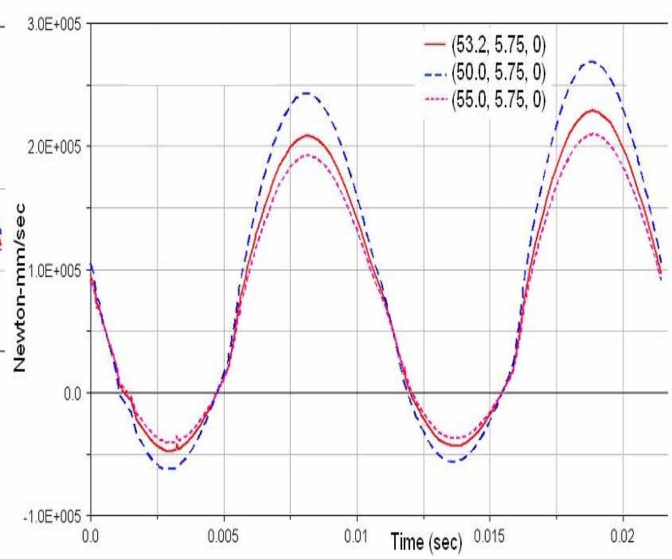


Fig. 12 Input shaft power vs. time

3.2 Result Plots

In this sub-section the plots obtained in ADAMS postprocessor. They are:

1. Z-Displacement of cutter relative to comb vs. rotation of its crankshaft: Figure 9 shows the variation of Z-Displacement of a point on the fork which is sinusoidal. For different locations of hinge point, P7 in Fig. 4, several plots are given in Fig. 9 to show their effects, i.e.,

Solid: P7 = (53.2, 5.75, 0) Existing design (Refer Fig. 4).
Dashed: P7 = (50, 5.75, 0) X-co-ordinate lower then existing, displacement increases accordingly.
Dotted: P7 = (55, 5.75, 0) X-co-ordinate higher then existing, displacement decreases, as it should.

2. Angular displacement of fork relative to comb vs. crankshaft rotation: Figure 10 shows the angular displacement of the fork which is also sinusoidal.

3. Variation of crankshaft torque vs. rotation of crankshaft: Figure 11 shows the torque variations in which maximum torque is 780Nmm.

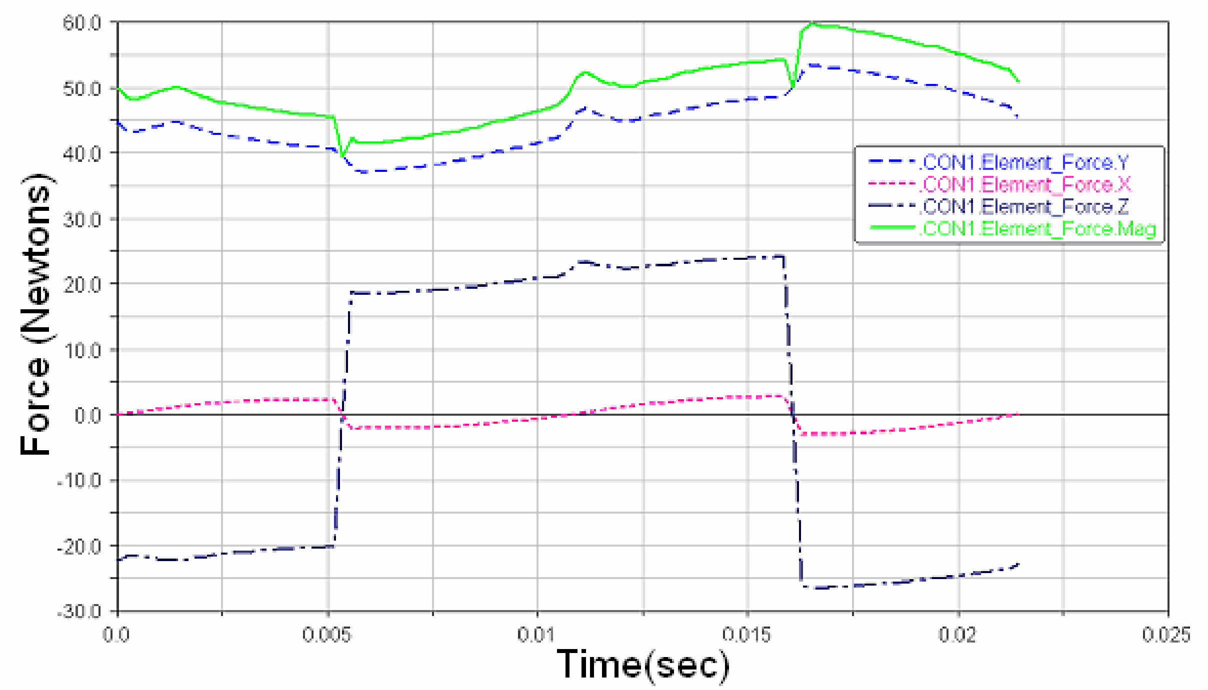
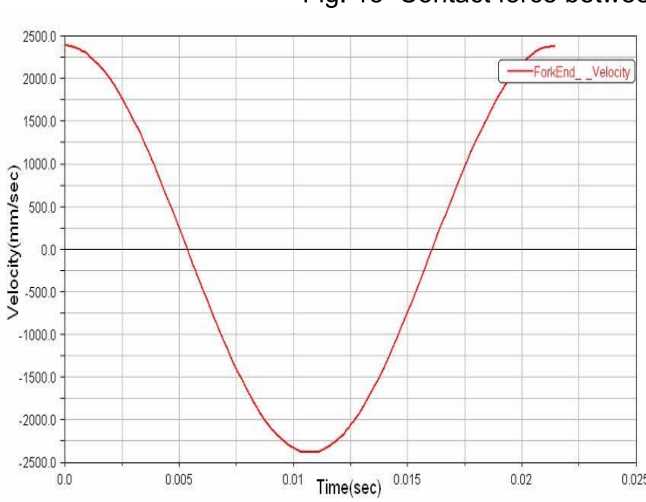


Fig. 13 Contact force between the cutter and comb



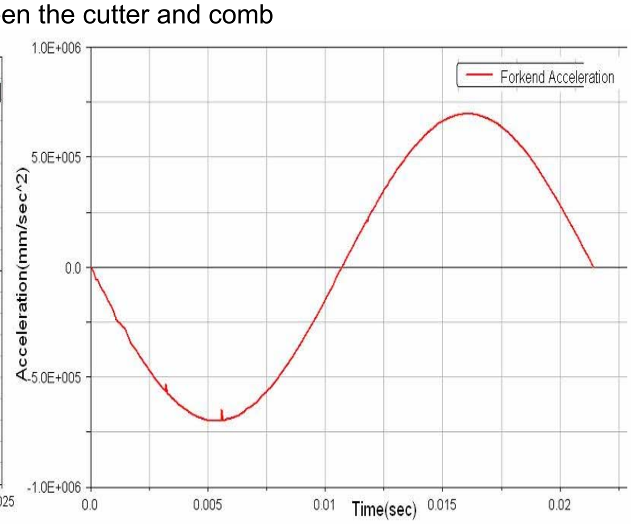


Fig. 14 Fork end Z-velocity vs. time

Fig. 15 Fork end Z-acceleration vs. time

4. Variation of power with crankshaft rotation: Figure 12 plots the power variations in which the maximum power is 230W, while the input crank speed is 2800rpm.This is close to the power of actual motor, which is 250W. If P7 is moved to 50mm (dotted line), the power requirement decreases simultaneously and vice versa for P7 moved to 55mm (dashed line).

5. Contact force between the cutter and the comb: Figure 13 shows the plot. Force of 50N is applied to the pressure pin to simulate pressure in actual machine. The normal reaction along Y, which is between the cutter and the comb is approximately 48N. Since the friction force along Z is equal to Y-component*0.5 (coefficient of friction), it is approximately 24N. Accordingly plots are obtained.

6. Variation of fork end velocity vs. crankshaft rotation: Figure 14 shows the Z component of fork end velocity. Velocity is maximum at the mean position, when displacement is zero. Maximum velocity is 2.34m/sec and the variation is sinusoidal

7. Variation of fork end acceleration vs. crankshaft rotation: Figure 15 shows the Z component of fork end acceleration whose maximum value is 700m/s^2 and minimum one is zero at mean position.

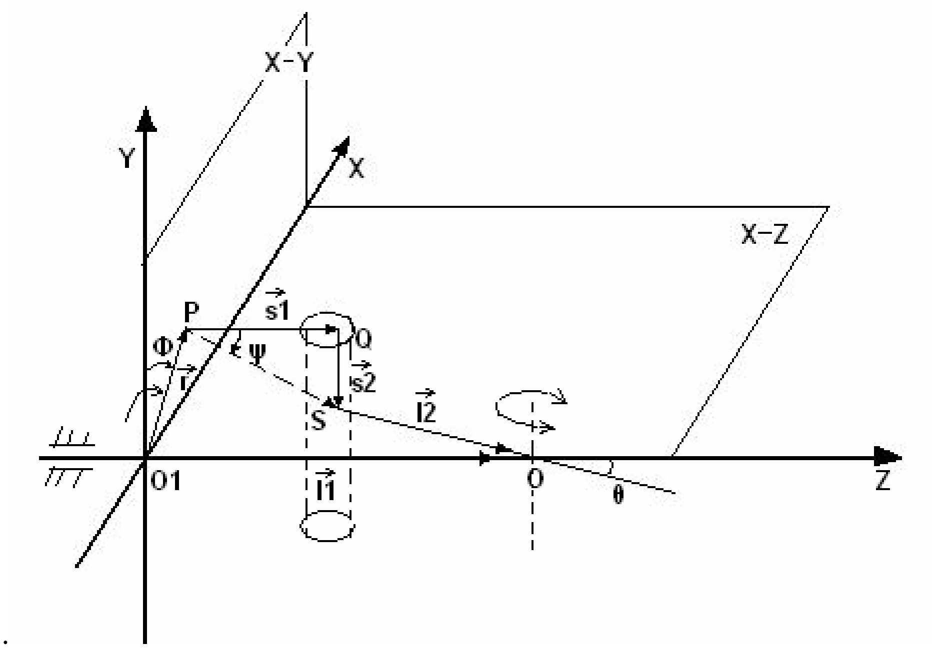


Fig. 16 Line diagram for the system and vectorial representation of links

7. ANALYTICAL MODEL

In this section, analytical expressions are obtained from the kinematic constraints between the crank and fork. Following the vector method (Ghosh and Mallik, 1998), a set of expressions in position level are obtained. Those expressions are used for position analysis using MATLAB programming. The output of MATLAB program is used to validate the results of ADAMS kinematic results, as in section 3. Referring to Fig. 16, the following definitions are introduced:

O_1P = **r** = Vector representing crank length with orientation ϕ from the vertical Y-axis.

PQ = $\mathbf{s_1}$ = Vector representing the change in length of crank-ball-fork joint. It is always directed parallel to the Z-axis.

QS = $\mathbf{s_2}$ = Vector representing the change in elevation of crank-ball contact point Q over the plane of oscillation of fork, i.e., horizontal XZ plane. The point, S, lies in this plane always.

PS = **s** = $\mathbf{s_1} + \mathbf{s_2}$

SO = $\mathbf{l_2}$ = Angular displacement vector of constant magnitude representing orientation of fork in its plane

O_1O = $\mathbf{l_1}$ = Vector representing the fixed link (crank bush to fork pivot)

From the closed loop of the mechanism

$$\mathbf{r + s + l_2 = l_1} \qquad \text{..... (1)}$$

Expressing eq. (1) in terms of its three coordinates yields

$$\begin{Bmatrix} r\sin\phi \\ r\cos\phi \\ 0 \end{Bmatrix} + \begin{Bmatrix} s_x \\ s_y \\ s_z \end{Bmatrix} + \begin{Bmatrix} l_2\sin\theta \\ 0 \\ l_2\cos\theta \end{Bmatrix} = \begin{Bmatrix} 0 \\ 0 \\ l_1 \end{Bmatrix} \qquad \text{..... (2)}$$

Note from Fig. 16 that $\mathbf{s = s_1 + s_2}$, which always lie in the plane parallel to the YZ plane due to the constraints on its end points, viz., the crank pin on its tail and slotted lever axis on its head. Thus,

$$s_x = 0;\ s_y = s\cos\psi;\ s_z = s\sin\psi \qquad \text{..... (3a-c)}$$

where ψ is measured counterclockwise looking from the positive X-direction. Then, from the set of equations namely, eq. (2), one obtains

$$l_2\sin\theta = -r\sin\phi;\ s_y = s\sin\psi = -r\cos\phi;\ s_z = s\cos\psi = l_1 - l_2\cos\theta = l_1(1-\cos\theta) \qquad \text{..... (4a-c)}$$

Now, since $|\ \mathbf{l_1}\ | = |\ \mathbf{l_2}\ |$, from eq. (4a)

$$\theta = \sin^{-1}\left(\frac{-r\sin\phi}{l_2}\right) \qquad \text{..... (5)}$$

Next, squaring and adding eqs. (4b-c), the following is obtained:

$$s^2 = r^2\cos^2\phi + l_1^2(1-\cos\theta)^2 \qquad \text{..... (6)}$$

and dividing eq. (4b) by eq. (4c), one gets

$$\tan\psi = \frac{-r\cos\phi}{l_1(1-\cos\theta)} \qquad \text{..... (7)}$$

Hence, s, ψ and θ are obtained for input angle ϕ.

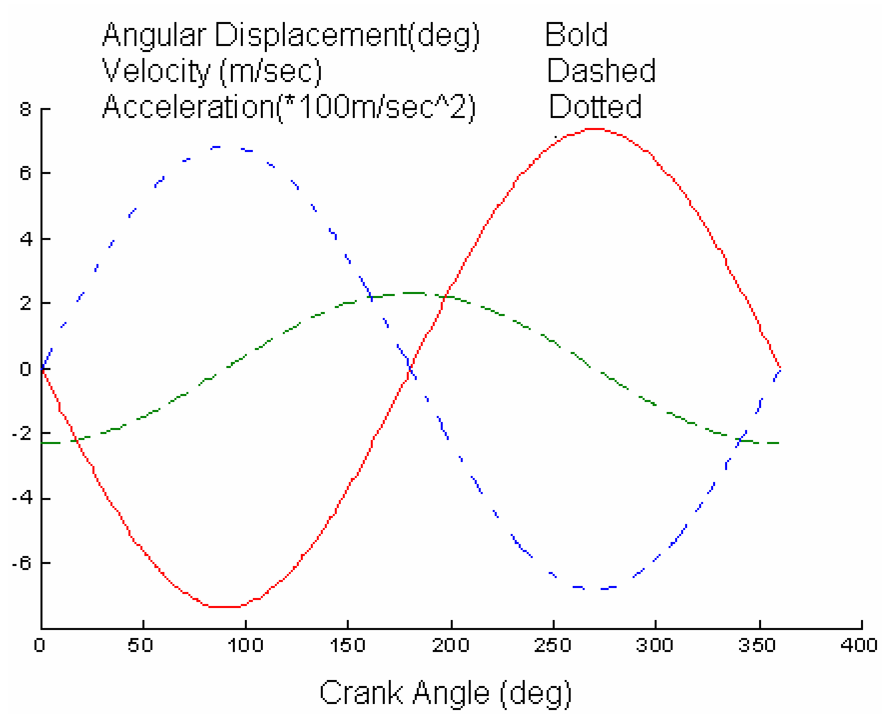


Fig. 17 Fork displacement (deg), velocity (m/s), acceleration (m/s^2)

Figure 17 shows the angular displacement, θ vs ϕ, while the linear velocity and acceleration are also obtained and reported for verification purposes. Note that the nature of variation is sinusoidal and the results match with the results obtained from ADAMS model. This kinematical analysis forms the basis of the analytical model of the sheep shearing machine, which will be reported in future.

5. CONCLUSIONS

Based on the work reported in this paper, the following conclusions are drawn:

1. Using computer simulation tools and software one can carry out complex iterative changes within short time.
2. Based on the simulation results, one can perform design changes for improved performances.
3. Analytical formulations using the vector method and MATLAB programming helped to check the results obtained using ADAMS model.
4. It should be kept in mind that every computer model is built with a number of simplifying idealizations like every link is rigid, joints are clearance free, ideal frictional and contact force characteristics, etc. Hence it is difficult to depict the real behavior exactly. This can be seen from the differences in the measured parameters from the models and their actual values, as in Table 1, and elsewhere. In fact, based on the analysis results of a software or analytical model one must develop a real prototype to test the above aspects before the system goes for actual production.

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