Modeling and Simulation of a Ball Throwing Machine

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Abstract

This paper deals with computer aided design and simulation of a cricket ball throwing machine. A virtual model of proposed ball throwing machine has been developed in CAD/CAE software package CATIA (Computer Aided Three Dimensional Interactive Application) in order to simulate different mechanical sub-assemblies of the machine using ADAMS (Automatic Dynamic Analysis of Mechanical Systems) software. The interactions of ball ejecting mechanism, ball and wicket, have been carried out by means of contact forces analysis in ADAMS environment. Motion simulation of main sub-assemblies like two-axis tilting mechanism, ball auto feeding mechanism has been done to evaluate the function of mechanical assembly. It is seen that the functional simulation of the machine in virtual environment using CAD/CAE tools at early stage of development will eliminate the flaws and improve quality of product.

Keywords: Simulation, Bowling Machine, CAD/CAE

1 Introduction

In conventional modeling and simulation, an idealized reduced representation of a mechanical system is assumed and then its function is simulated using various concepts of Science and Engineering. But today the new product development process makes use of both virtual and physical prototypes [1]. Virtual Prototyping (VP) enables quick product development and adds quality to the development process, enabling system-based decisions [2]. In this exercise, it is targeted to model the mechanical system such as the 'cricket ball throwing machine' in its true representation to simulate and visualize its 3D – motion behavior under real world operating conditions refining/ optimizing the design through iterative design studies prior to building the first physical prototype. Therefore, convergence of technologies such as simulation, computer aided design (CAD) and Virtual Reality have enabled the development of accessible, low cost, user-friendly VP systems [3]. These VP tools are increasingly being viewed as the next generation of computerized design systems.

The present paper describes the development of the CAD model and subsequently carrying out dynamic simulation of the system in ADAMS [4, 5, 6]. Today cricket is one of the most popular games in India and abroad. So it is felt that modern technology can be utilized to develop a cricket ball throwing machine with variable speed and swing for the benefit of practicing batsman. The cricket bowling machine is to provide accurate and consistent batting practice for players of all standards like professional cricketers, amateur cricketers and club level cricketers.

A 3 D CAD model of the bowling machine was developed in CATIA V5 [7] and various aspects has been simulated namely ball trajectory analysis of seam bowling & spin bowling, autofeeder etc.

2. CAD Model of the Cricket ball throwing Machine

The proposed cricket ball throwing machine (Fig. 1) is an improved version of the earlier machine [8] design and developed at CMERI, Durgapur. The CAD model of the present model was developed in 3D modeling software CATIAV5. The machine consists of the following main units, components or major sub-assemblies like stand (01),controller casing (02), motor (03) and wheel (04) holding cum sliding arrangement, chute (05), quadrapod cum bi-axial precise tilting mechanism containing the pitch axis indexer (06) and yaw axis indexer (07), base plate etc. In the cricket bowling machine of the present work, the main mechanism which has been used is based on pair of counter rotating rubber bonded ball ejecting wheels (04) along with above mentioned subsystems. This machine includes a base member with fork like ends. Each fork carries a wheel and motor holding cum sliding arrangement, which has a slider block (08). Each wheel is supported on slider block through bearing. Each motor is fixed to a slider block by screw. The motor shaft is keyed to the wheel and locked by locking screw from the top, thus preventing the ejection of wheel at high speed of rotation. Each of the wheels preferably includes a rigid central portion of cast aluminium alloy suitably having a flat cylindrical rim and elliptical arm for supporting a body of visco-elastic material. Each visco-elastic body is formed of a peripheral groove, providing a concave cross-section in said body and extending circumferentially around the perimeter of the wheel, for receiving a ball and channeling the trajectory when the wheel rotates.

Quadrapod cum bi-axial precise tilting mechanism is used to hold the base member and to precisely adjust the required position of the delivery point of the ball with respect to two axes system i.e. pitch axis and yaw axis to achieve a certain trajectory of the ball such that the ball pitches at different positions relative to the batsman. The Quadrapod cum bi-axial precise tilting mechanism has two indexers namely; Pitch Axis Indexer (06) and Yaw Axis Indexer (07) integrated with a contoller casing (02).

Pitch Axis Indexer (06) is used to control the length of the bowling. Pitching is the rotation of the top platform, over which the base member is fixed, about the pitch axis. Yaw Axis Indexer is used to control the line of the bowling. A worm wheel for yaw meshes with a worm with knob for yaw rotation, inside the quadrupod casing.

The rack is fixed to the slider block with the help of screw. The pinion, which rotates inside a bush fitted in a casing and screwed to the base member in such a way that it, meshes with the rack. The rack and pinion mechanism is used to control the gap between the two wheels for bowling balls of different diameters.

The ball is guided on a ball delivery chute (05) attached to the base member until it touches the curved surfaces of the wheels rotated in opposite direction. The ball passes through the gap that is less than the ball diameter and thereafter ejected tangentially forward. As the ball passes through the gap between the two wheels, the rubber material gets compressed. The concave surface provides a better contact and fillet edges provide a finger like grip on either side of its surface. The finger like gripping action of the fillet edges helps in controlling the trajectory of the ball. By controlling the relative speeds of the two counter rotating wheels as well as amount of rolling, a spin can be imparted to the ejected ball. The spin imparted to the ejected ball can cause it not only to drop but also to take curve path to the left or right as well.

3. Mathematical Modeling of the Ball Trajectory

The trajectory of the ball simulated in ADAMS is based on the mathematical modeling of the projectile motion. In still air, suppose the resistance/air drag force F_d is

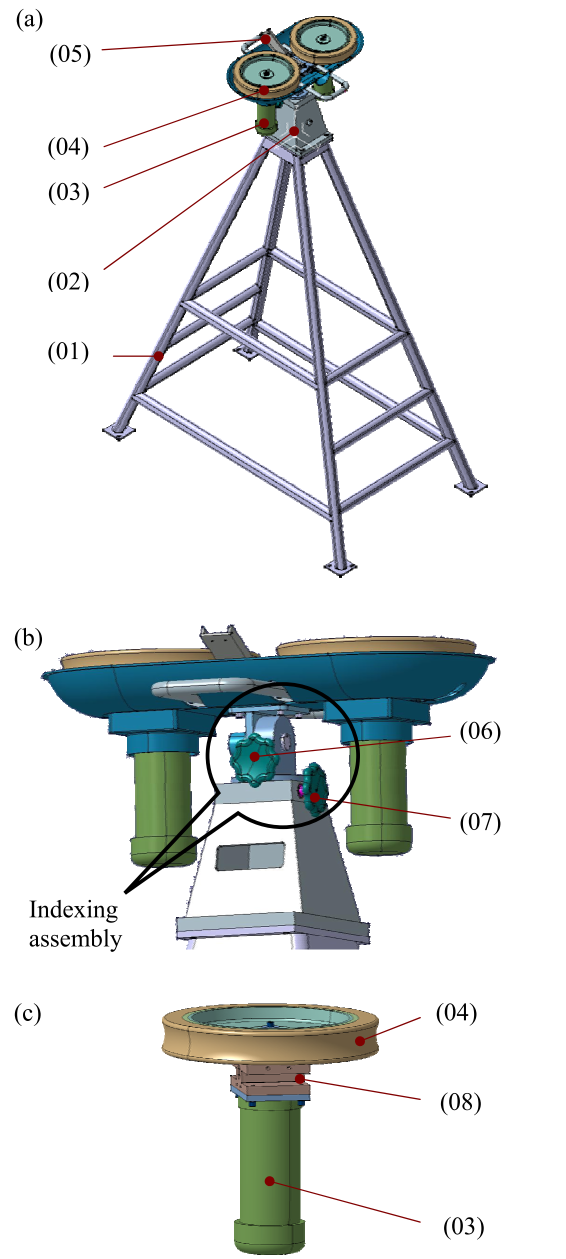

Fig.1: 3D CAD Model (a) Full Assembly, (b) Indexing Assembly (c) Wheel –motor Assembly

proportional to some power of the speed i.e.

$$F_d = KV^n$$

or $\mathbf{F}_d = KV^{n-1}.\mathbf{V}$ where K is a constant and V is the velocity of center of mass of the projectile.

For a projectile moving in still air under gravity equation of motion,

$$m\frac{d\mathbf{V}}{dt} = -mg\hat{\mathbf{k}} - KV^{n-1}.\mathbf{V}$$

It is usually found that the resistance varies as the speed for low speeds and as the square of the speed for high speeds. In still air the resistance or air drag force of the motion acts in a direction opposite to that of the velocity. So we must include the air drag force on the projectile. Therefore, the motion of a projectile of mass 'm' influenced by gravity 'g' and air drag force is described by,

$$F_d = KV^2 \text{ where } K = \tfrac{1}{2}\rho C_d A$$

$$V = \sqrt{\left(V_x^2 + V_y^2 + V_z^2\right)}$$

The drag force F_d acting on the projectile depends on the density 'ρ' of the air, the silhouette area 'A' of the body (its area as seen from the front) and drag coefficient C_d that depends on the shape of the body. Typical values of C_d for Cricket balls are in the range from 0.2 to 1.0.For our model we have taken the following inputs:

$\rho = 1.2\,Kg/m^3$ (appropriate for a ball at sea level)

d = diameter of the ball=0.072m

C_d =0.5 (appropriate for batted ball or pitched fast ball)

$$A = \frac{\pi d^2}{4} = 0.00407 \text{ m}^2$$

Therefore,

$$K = \tfrac{1}{2}\rho C_d A = 0.001222$$

$$F_d = KV^2 = 0.001222V^2$$

The equation of motion can be written as,

$$\frac{d\mathbf{V}}{dt} = -9.81\hat{\mathbf{k}} - 0.007433V.\mathbf{V}$$

The value of drag force F_d is substituted in ADAMS as a function of the square of velocity of the centre of mass of the ball as shown in Fig. 2

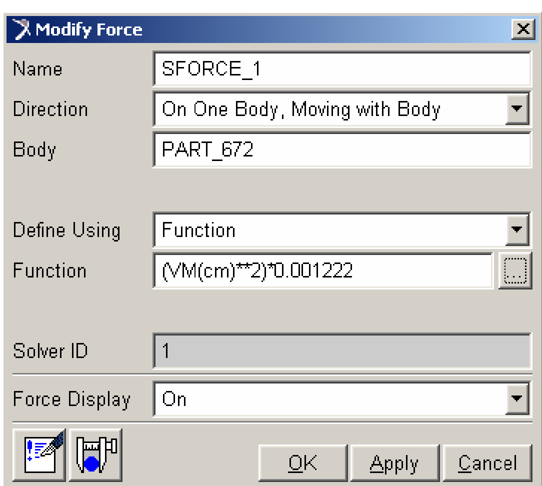

Fig. 2. Drag force input to ADAMS

4. Results and Discussion

4.1 Assembly Simulation of the cricket bowling machine

In CATIA V5 Fitting Simulation workbench the assembly /disassembly has been simulated for the cricket ball throwing machine made up of multiple parts. It has enabled us to define the trajectory of parts of the cricket ball throwing machine (Fig. 3) to be assembled or disassembled. Replay of the trajectories has helped us to validate the impact of design changes. Using fitting simulation, the system identified and visualized collisions and minimum clearance violations in the prototype. The simulation has enabled us to visually analyze assembly motion from any point of view.

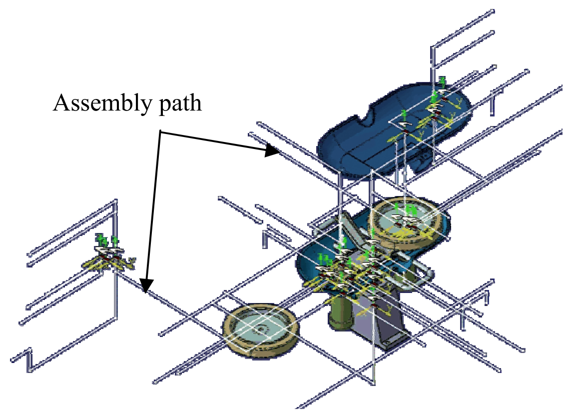

Fig. 3: Fitting simulation of the system

4.2 Simulation and synchronization of auto feeder of Cricket Bowling Machine

An autofeeder was designed for the cricket ball throwing machine developed in CMERI. The autofeeder is an accessory fitted to the ball throwing machine for releasing balls after a certain time interval. Before manufacturing the same, synchronization between the balls and plunger of the solenoid valve was required to obtain the dimensions as well as the specification of the solenoid as shown in Fig. 4.

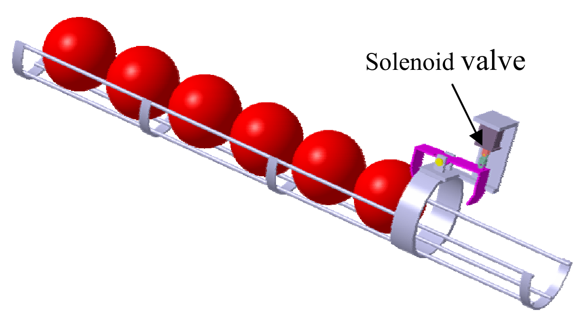

Fig. 4: Autofeeder with balls

We created a model for describing the complex synchronization mechanism and predicted the movement and contact force of the synchronization components for a short time phenomenon. The simulation gives us the knowledge of the force and stroke required to operate the plunger of the solenoid (Fig. 4). Motions for each of the revolute joints are defined through STEP Math Function. The actuator motion expression is as written below:

$$\text{STEP}\left(\text{SIN}\left(2\pi * \text{FREQ} * \text{TIME}\right), \text{TRAN\_VAL\_LOW}, \text{LOWER}, \text{TRAN\_VAL\_UP}, \text{UPPER}\right)$$

A number of iterations were carried out to synchronize the motion between the balls being delivered and stroke of the solenoid. It is found out that the stroke length of the solenoid required for the designed autofeeder is 18mm. Some of the important parameters of the ball feeder are as noted in Table-1 below. Fig. 5 shows an expression of the actuator motion of the solenoid. The simulation helped in the selection of a solenoid for the autofeeder unit of the bowling machine. Fig. 6 shows the simulated results of the autofeeder.

Table-1: Ball Feeder –Important Parameters

Ball Mass	: 0.166 kg
Rigid Body Contacts	: 32
Plunger Time Derivative	: displacement
Expression: $\text{STEP}\left(\text{SIN}\left(2\pi*0.5*\text{TIME}\right),-1.0,-4.0,1.0,14.0\right)$	
Plunger Downward velocity	: 4000 mm/s
Stiffness	: 1.0E+005 N/mm
Damping	: 10.0 N-s/mm
Exponent	: 2.2
Dmax	: 0.1 mm
Coulomb Friction	: ON
Mu Static	: 0.3
Mu Dynamic	: 0.1
Stiction Transition Velocity	: 0.1 mm/sec
Friction Transition Velocity	: 1.0 mm/sec.

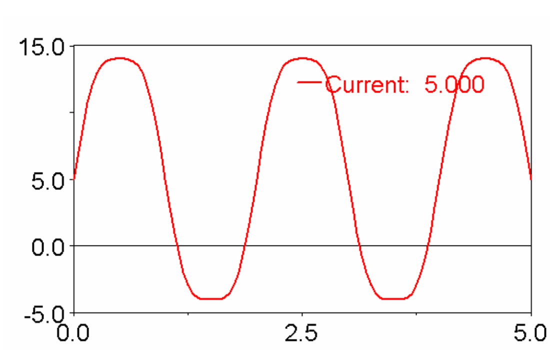

Fig. 5: STEP Math Function

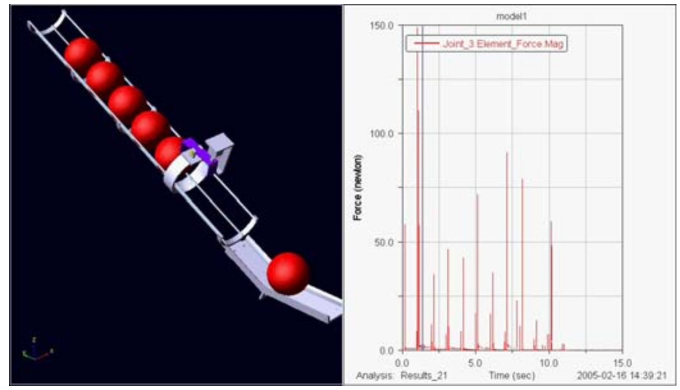

Fig.6: Simulation and synchronization of auto feeder

4.3 Simulating of the ball trajectory

The CAD model of the bowling machine is exported into ADAMS workbench through CATIA SimDesigner Software. Impact based contact parameters have been defined between the ball and pitch, ball and wickets etc. to make the simulation more realistic.

The simulation is evaluated for 60 time steps. In the simulation, each time step represents an integration step in which the new positions, orientations, velocities and accelerations of the ball w.r.t to the global reference frame are computed based on the drag force F_d acting in a direction opposite to that of the velocity of the delivered ball . Drag force F_d (i.e. resistance/air drag force) is substituted in ADAMS as shown in Fig. 2. Simulation of the ball trajectory for both seam bowling and spin bowling are simulated in ADAMS. For evaluating different kinds of ball trajectories a number of iterations are carried out by changing the initial velocity at the time of delivery and the impact parameters i.e. ball hitting the deck.

Fig. 7 (a) shows the simulation results for seam bowling with initial velocity V_x= -0.1 m/sec, V_y = -0.5 m/sec and V_z = -30.0 m/sec. Also the pitching angle is varied by varying the Pitch Axis Indexer and output is plotted as shown in Fig. 7 (b).

Fig. 8 (a) shows the simulation results for seam bowling with initial velocity V_x = 0.8 m/sec, V_y = 1.5 m/sec, V_z= -20.0 m/se, ω_y = 4.0E+002 deg/sec, ω_z = 3.0E+002 deg/sec. Yaw angle is also varied by varying the Yaw Axis Indexer (07) and output is plotted as shown in Fig. 8 (b).

The obtained simulation results gives us the knowledge about the mechanics behind ball seam and spin bowling such as deviation of the ball with topspin, axis of rotation of the ball for maximum turn after hitting the deck, angle and velocity of ball delivery for pitching at the good length area, maximum bounce etc.

(a)

(b)

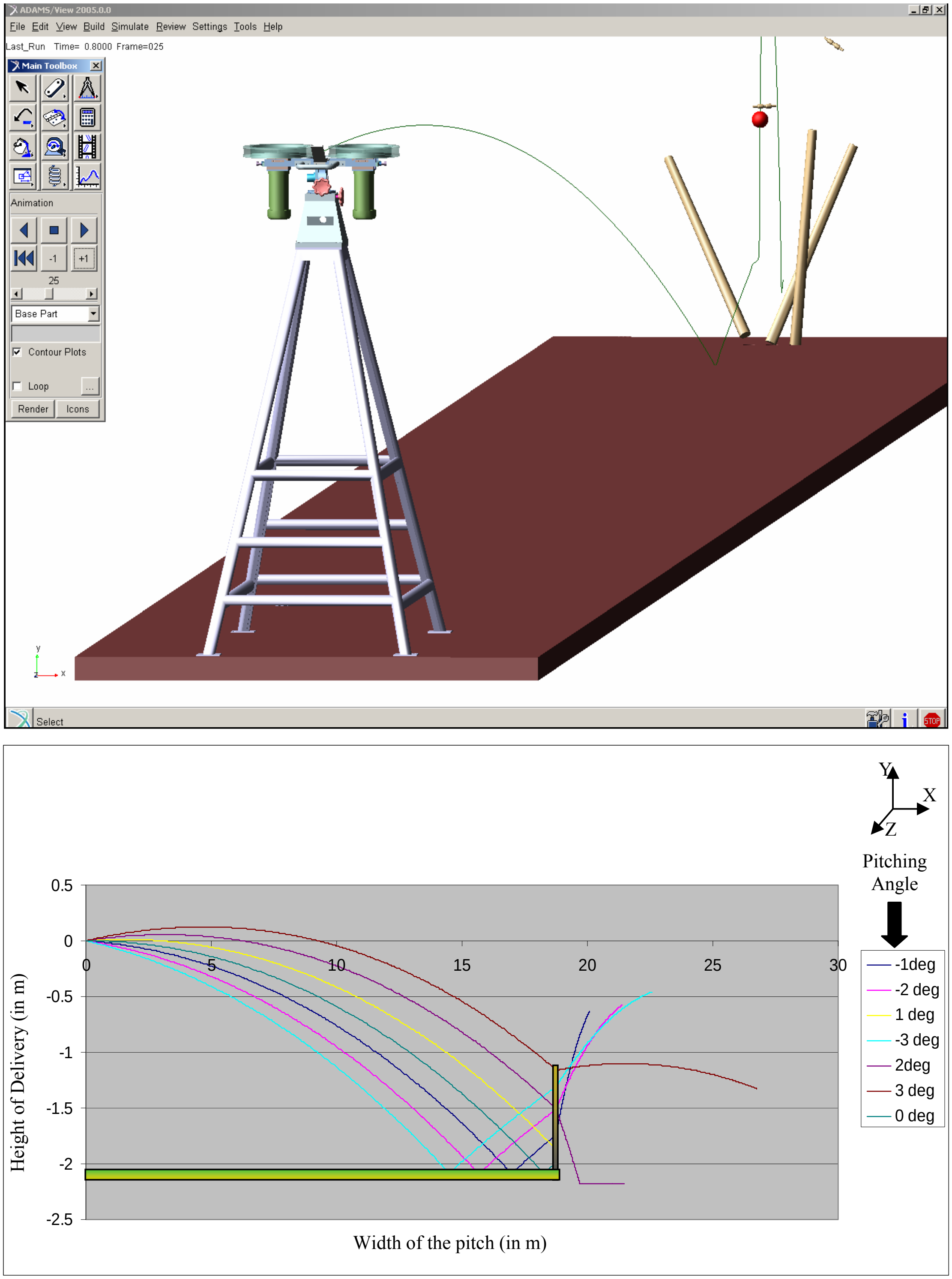

Fig 7 : Seam Bowling (a) Simulation in ADAMS (b) Ball Trajectory w.r.t. tilting of the pitching axis of the bowling machine

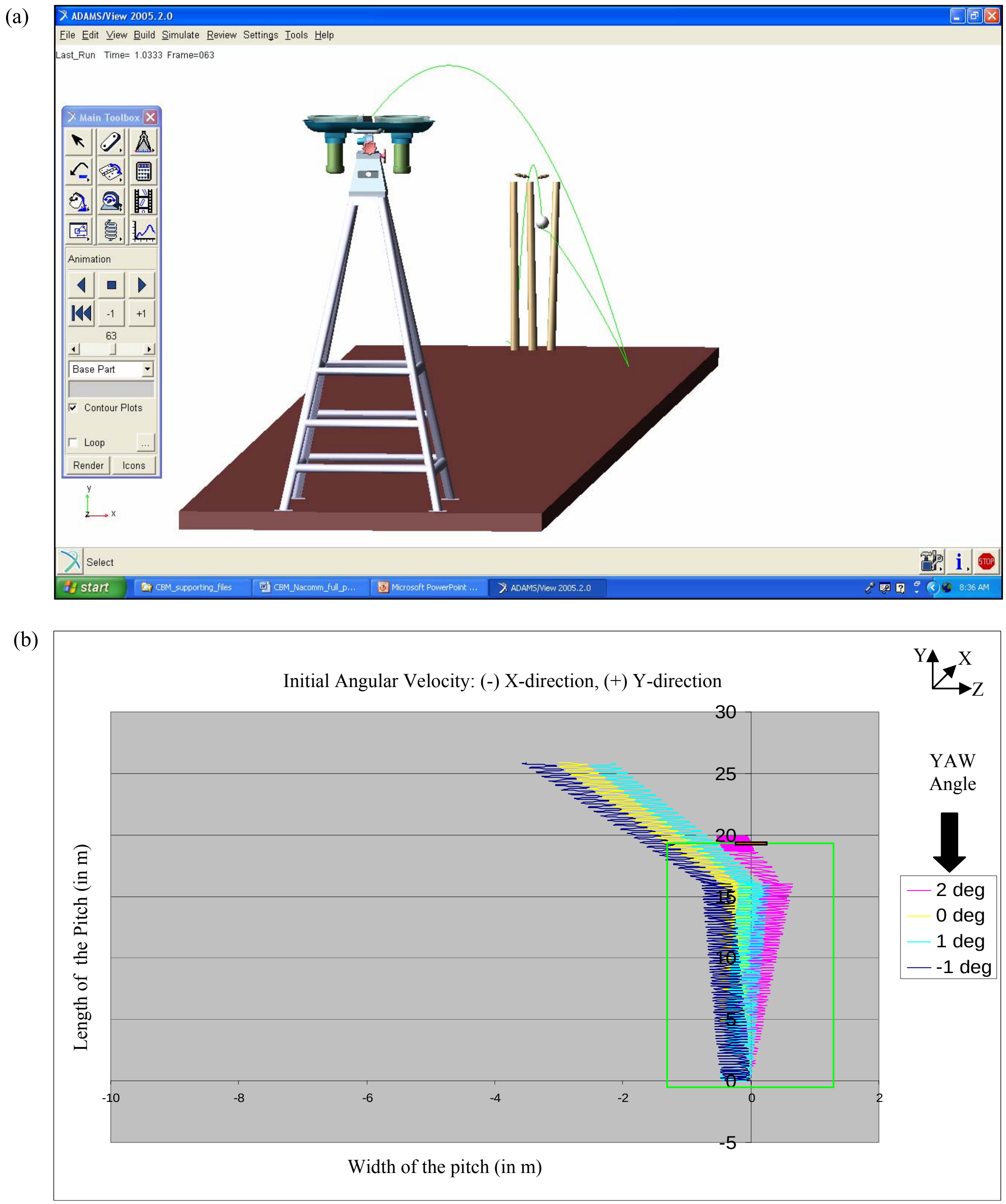

Fig 8 : Spin Bowling (a) Simulation in ADAMS (b) Ball Trajectory w.r.t. tilting of the yaw axis of the bowling machine

4.4. Physical Demonstration

An experimental prototype of the cricket bowling machine has been developed. This was tested in the laboratory for measuring its bowling speed as well as the swing and spin characteristics (Fig. 9). In the normal functioning of the machine, the ball comes out of the chute and reaches space between the two wheels and is thrown straight towards the practicing batsman. To control the length of the bowling, the tilting platform is inclined with respect to pitch axis by means of pitch axis indexer. By using yaw axis indexer the line of the ball is controlled. Inward or outward sliding of the two wheels with the help of slider block and rack-pinion mechanism will enable the bowling machine to accommodate balls of different diameters. In case of swing of the ball, a differential speed is maintained of the two wheels. To generate spin ball of different kind, a differential speed is maintained between two wheels and at the same time tilting platform is either inclined towards the left or towards the right by means of roll axis indexer, according to the kind of the spin. In the present experiment, Sports Radar 3500 measures the speed of the ball. Maximum speed of the ball obtained during experiment was 152 Km/hr.

Fig.9: Trial Run with the experimental prototype of cricket ball throwing machine

5 Conclusions

By controlling pitching angle, the length of the bowling can be varied from bouncer to Yorker, according to the will of the batsman. Using simulation with correct input conditions one can get the precision and reproducibility of ball pitching distance that is required for effective batting practice. Simulation will help in setting precisely the rotation of worm with knob and worm wheel for pitch which is attached with top platform of the Pitch Axis Indexer. In future scope of work, complex interactions involved between the ball and rubber wheel interface can be studied using non-linear transient dynamic solver like LS DYNA.

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