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Analysis of load monitoring system in hydraulic mobile cranes

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Abstract: Load moment limiters or safe load control systems or are very important in crane safety. The system detects the moment of lifting load and compares this actual moment with the rated moment. The system uses multiple sensors such as boom angle sensor, boom length sensor for telescopic booms, pressure transducers for measuring the load, anti-two block switch and roller switches. The system works both on rubber and on outriggers. The sensors measure the boom extension, boom angle and load to give as inputs to the central processing, which calculate the safe working load range for that particular configuration of the crane and compare it with the predetermined safe load. If the load exceeds the safe load, actions will be taken which will reduce the load moment, which is boom telescopic retraction and boom lifting. Anti-two block switch is used to prevent the two blocking condition. The system is calibrated and load tested for at most precision.

1. Introduction

A mobile crane is a crane mounted on hydraulic-powered crane or crawlers or with a telescoping boom fixed on truck-type carriers. They are designed to transport to a site and use with various types of load. Mobile crane generally drives a boom from the end of which a hook is suspended by wire sheaves and ropes[3]. A mobile crane consists of an upper carriage, which rotates about 360° angle on the truck chassis (carrier frame) or undercarriage. The carrier also includes the flexible front and rear outrigger assemblies[2].

The word load moment is an engineering word, which states to the product of a moment arm and its force. The moment arm is defined as the shortest distance between the reference point and force vector. The load moment system has aimed to give the operator of crane with the necessary information required to control the machine within its design constraints and limitations. Various crane fucntions and crane capacity are being continuosly monitered by different sensing devices to provide the information to the crane operator. The continuous change in readings,when the crane travelsvia the motions necessary to produce the lift[1].

The load-moment system delivers the information to the operator concerning the working radius, angle of the boom, rated load and the total assessed weight being lifted by the crane. If non-permitted conditions are accosted, the system will notify the operator by giving a warninglight, audible alarm, and locking out those functions that may rise load moment such as lifting the load or extending or lowering the boom. The load moment indicator is a functioning support which cautions a crane operator of imminent excess conditions and of above hoist conditions may causeharm to personnel and

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equipment. The accountability for the harmless crane manoeuvreis still in the hands of the operator who shall ensure that all alarms and directions delivered[2,3].

The system works based on real/bench marked assessment. The experimental value obtained is relatedto the calibration details and reference, kept in the processor storage and calculated.When cut-off points are reached, a cautioning sign for over-burden is created toward those pointer boards. In the same period, those disturbed attack crane movements, for example, such that lift dependent upon What's more blast down, will be ended. Those settled information viewing the crane, such as, limit charts, centres from claiming gravity, measurements What's more blast weights are put away to memory areas in the processor unit (CPU). This information may be the used to assess those working states[2,3,4].

The system consists of[2,3,4]:

I. Indicator panel (operating console) which displays the following:
   A. program number
   B. selected parts of the line
   C. boom radius
   D. boom angle/boom length
   E. load on the hook (actual load)
   F. load moment (permitted load)

II. Central unit (microprocessor and input/output electronics)

III. Angle sensor

IV. Length sensor

V. Pressure sensors

VI. Anti-Two-Block switch

2. Components of load monitoring system

Constantly on data of the crane may be set away inside those vital units of EPROMs. Those national units get the sum genuine information of the crane. This will be transformed against those reference data and the crane status always checked. The central unit has water verification aluminium lodging. It will be mounted on the left, a large portion of the turntable weldment alternately on the stabilizer. Those joins are driven under that focal unit through strain reliefs What's more connected with fast ons. An abrogate switch may be mounted on the lodging on supersede those LMI worth of effort. The skeleton is guaranteed eventually perusing a 2-AMP joint that is mounted on the easier straight side. Inside the national unit, there is particular case table. The principle table that need terminal strips the place control Furthermore different parts would connected with fast ons of the terminal strip. That essential table will be the center of the skeleton. It holds those primary pc and the basic gadgets with get, survey methodology What's more immediate the reliable majority of the data. There are over-burden What's more dangerous should two-piece transfers, which control those BOSCH hand-off for lever lockout, also mounted around this table [2, 4, 7, 8].

Those frameworks comprises of a 24/12-volt converter, which proselytes 24 volts on 12 volts on the primary board. An analogue information a major aspect will be included, which receives Furthermore prepares every last one of signs from the transducers for further processing, a analogue/digital converter part, which changes over every last one of transformed simple signs under advanced ones, an advanced part, which holds the fundamental machine and the people of old hardware. The console indicates all geometrical data, for example, length What's more side of the point for essential impact What's more attempting span. It similarly indicates the real load and the best load permitted by stack framework. Besides, it need an caution horn Also An cautioning light for over-burden, Furthermore a pre-cautioning light. The LED's instrument shows a level of the aggravator suitable minute. Those support need pushbuttons on switch those working modes (for decision for crane plans What's more reeving of the block). It similarly need a notice light to overload, dangerous on two-piece states Furthermore an abrogate push-catch to against two-square state. Those length-angle sensor is a blending for two transducers for link reel, fitted toward those base segment of the blast. It comprises about housing, spring-loaded cable with measuring cable, also mounting gear for establishment on the blast. Incorporated in the lodging may be a period sensor, point sensor, slip ring and circuit board. It measures the length and the point of the blast. A winding drum drives An electrical potentiometer, which is those length transducer. Those breadth and number from claiming turns of the link drum designate the uncoiled link length, which chooses that length of the blast. Only the period transducer will be those length link display on the drum, which is a two-conductor (shield what is more core) link. It may be connected of the anti-two-block switch during the blast mind What's more should a slip ring muscle to those capacitive point sensor assesses the plot estimation. Those energy supply voltage for both will be +12/24 v Direct current (DC). Those output from those period transducer may be 4. 00mA dependent upon 20. 00mA. The yield sign to the plot transducer will be 4. 00mA toward 90° should 20. 00mA toward 0°[2,4,5,6,9].

Those anti-two-block switches show the load square and its relationship with the head of the blast. In operational condition, the switch is shut with a resistor from claiming 4.7k-ohm in arrangement. At those snare piece strikes the weight, those out opens, disengaging a transfer yield of the bolt out solenoid valves, the place substantial. The weight toward the anti-two-block switch retains those switch shut until those snare piece strikes it. Anti-Two Block warning systems are employed on cranes to caution or halt the operator of dangerous upward movement of the hook. Without anti-two block safety, operators can pull the load through the crane body, causing safety risks or damaging the crane. Fundamentally, anti-two block systems avoid events initiated by unintentional contact between the boom point hook block (ball), often stated to as two-blocking. One type of two- blocking, frequentlyconsidered as booming down into the block,ensues on mobile cranes because of the location of the hoist drum, which is usuallyattached on the revolving superstructure. Through this preparation, the distance between the boom tip sheaves and hoist drum rises as the boom is lowered, causing the lower block to move nearer to the upper block[5,6,9].

Control and sensing of anti-two block system comprises of a sliding weight, which suspends on a switch. If the crane's hook travels too far upward, it thrusts up the weight and discharges tension on the switch. This change of state issues a warning and stops the upward movement.

The pressure transducer proselytes hydraulic pressure into an analogue signal. Two pressure transducers need aid attached, one of the piston side of the lift barrel Also you quit offering on that one of the Pole side. The pressure transducer is interfaced to the vital unit with a twofold protected cable furthermore four conductors. The supply voltage is +12V dc. Those yield sign will be 4.00mA at 0-bar pressure on 20. 00mA during most extreme pressure (300 bar). Roller switch is used to prevent swing of the winch when the crane is operating on tyres. The switch sends digital signals to the central processor unit to prevent the rotation.During an overload condition or a two-block condition, some movements of the crane needs to be restricted for safety purpose like hoist down, boom up, telescope in. The sensors will transmit a signal to the central processing unit during overload conditions. The Central processing unit will transmit an output signal to a relay, which cuts out the voltage supply to electromagnet. The electromagnets control the valves through which hydraulic fluid flow. Hence, during voltage cut off, the electromagnet gets demagnetised and the valves block the flow of hydraulic fluid in one direction moving the crane linkages to a safer position [[2,3,4,9].
The incoming signals from the transducers, length – angle sensor, anti – two-block switch, roller switch are connected to the terminal board. That indicator of the terminal board is the sign for lever lockout on the transfer. On typical attempting conditions, there would be 12 or 24 volts at this terminal. As there is an over-burden or anti-two-block condition, the sign gets 0 volts. Furthermore, at voltages to the transducers Also support are setting off out by means of the terminal strip[2,3,9].

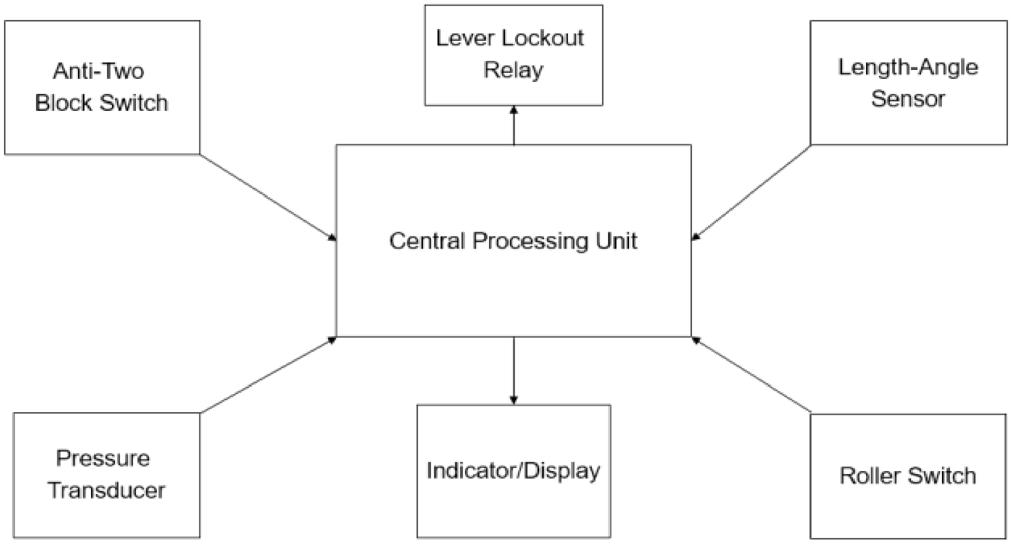

Figure 1. System Layout

3. Load and force calculations

Consider a crane carrying a load ‘W’ on its boom at a distance of CD (y units) from the boom lift pivot. Let AC (x units) be the distance between the boom lift pivot and the boom-body pivot. The force required by the cylinder to lift the load is ‘F’. The boom angle is ‘α’ and the angle between the cylinder and the ground is ‘α’. Figure 2 shows a schematic diagram of the load lifting.

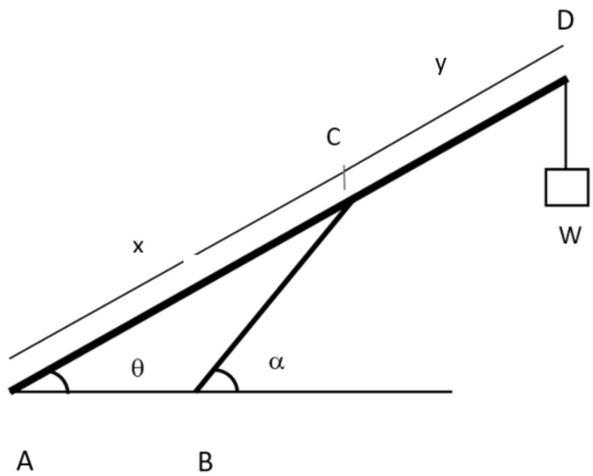

Figure 2. Line Diagram of load lifting

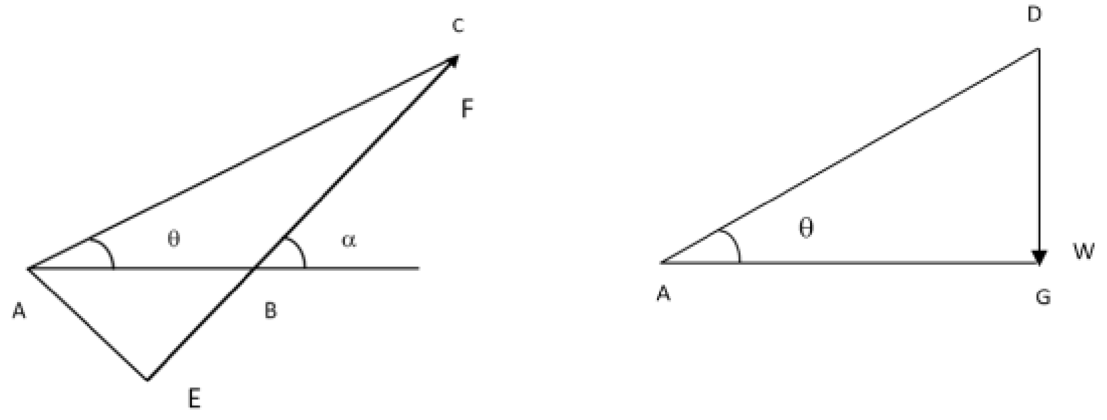

Figure 3. Free body diagrams

From the free body diagrams; Figure 3 shows a schematic diagrams of the free body diagrams.

$AG=AD\times\cos\theta$ (1)

$AG=(x+y)\times\cos\theta$ (2)

$AE=AC\times\sin(\alpha-\theta)$ (3)

$AE=x\times\sin(\alpha-\theta)$ (4)

$W\times AG=F\times AE$ (5)

$F=W\times AGAE$ (6)

$F=(W\times(x+y)\times\cos\theta)(x\times\sin(\alpha-\theta))$ (7)

Tipping load of a crane is the load above, which the crane, which the outrigger will lift off from the surface and crane, tends to topple. Consider a crane carrying a load ‘W’ on its outriggers. The reaction forces on the outriggers are ‘Fa’ and ‘Fb’. Let ‘x’ be the distance between the centre of gravity of the crane and the outrigger. Let ‘y’ be the distance between the outrigger and the line of action of the load (load radius). Let the weight of the crane be Wc.

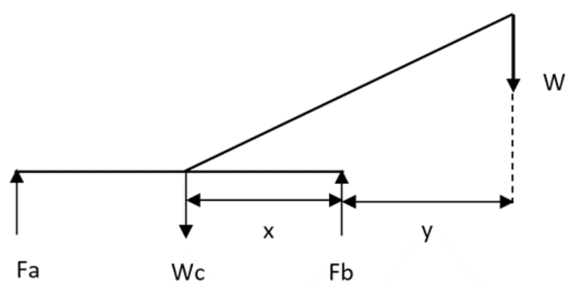

Figure 4. Free body diagram to measure tipping load

The tipping action (Figure 4) happens when the reaction force on the outrigger becomes zero (Fa=0). Equating moment around point B,

$$x\times Wc=y\times W(1) \qquad (8)$$

$$W=x\times Wcy\times W(2) \qquad (9)$$

Where, W is the maximum load the crane can carry without tipping.

4. Modelling and simulation

A model of the crane is designed and modelled in SolidWorks software to analyse the load monitoring system in cranes. The model is constrained such that lifting and extending of the boom is possible by applying force to the cylinders attached to it. The telescopic of the boom is of two stages. This CAD model is exported to MATLAB SIMULINK. Figure 5 shows a schematic diagram of the CAD model.

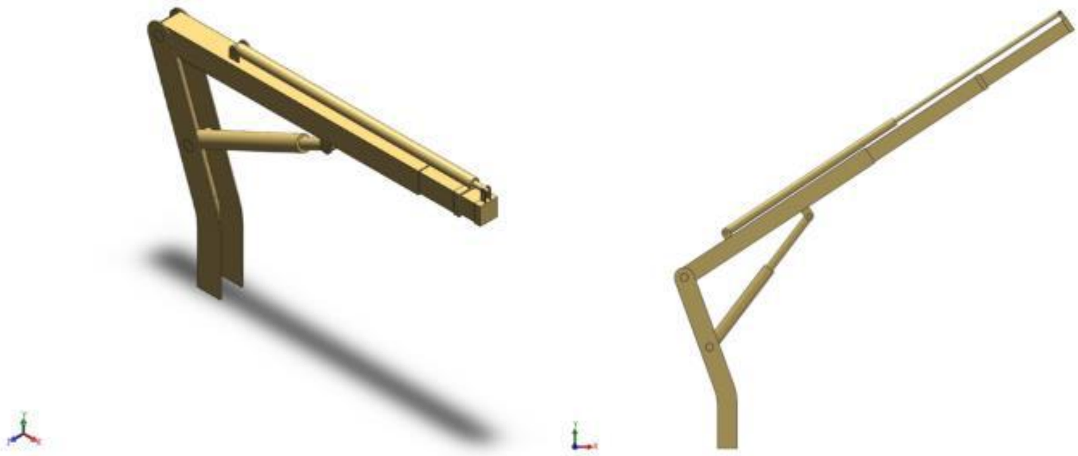

Figure.5 CAD Model

The SolidWorks model of the crane is imported into MATLAB Simulink environment. Joints are provided between the parts based on the required motion. Revolute joints are provided between the cylinder for lifting the boom and the crane body. A cylindrical joint is provided for the cylinder motion. Prismatic joints are provided for obtaining telescopic motion for the boom. The joints are actuated by using joint actuators. The telescopic boom is extended with the help of a cylinder, which is given motion, by the help of an actuator. Similarly, boom is lifted by applying force on the cylinder between the crane body and the boom with the help of a joint actuator.

The motion of the boom is sensed by using joint sensors and body sensors. The horizontal boom extension (load radius) from the centre of gravity of the crane is measured by measuring the X co-ordinate of the tip of the boom by using a body sensor connected to the co-ordinate system (CS) of the tip of the boom. The angle of the boom, which is the angle between the boom and the ground, is measured using a joint sensor connected to the revolute joint between the boom-lifting cylinder and the crane body.

The length of the boom and the angle of the boom are continuously measured by the joint sensors and are fed back to the controller to provide further actuation based on the load limit for the current load radius. The boom length and boom angle are displayed using the display blocks. Figure 6 shows a schematic diagram of the MATLAB model.

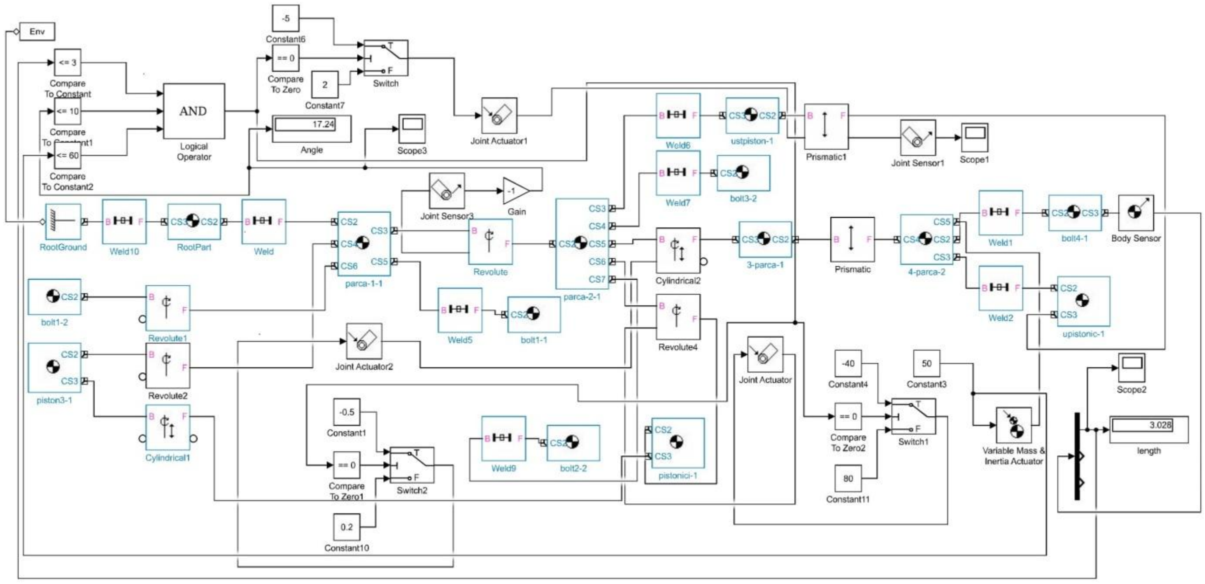

Figure 6. MATLAB Model

The controller subsystem of the model consists of logical operators and switches to select the required value of force to be given to the actuator based on the load radius and the load being lifted. The input to the controller is length of the boom and the load being lifted. The inputs are given to an 'if else-if' subsystem to compare its value with the safe working range. The output of the subsystem is joint actuator inputs. The subsystem compares the safe load that the boom can lift for that current length of the boom and the load, which is being carried. Based on the decision by the subsystem, the signals are sent to 'if', 'else-if' or the 'else' subsystems for selecting the particular value of force to be given to the actuator so that the crane works in safe range. The 'if' and 'else-if' subsystems provides positive movements to the boom according to the requirement of the crane operator. The 'else' subsystem gives an output such that movements are limited such as boom extension and boom down operations will not carried out. The boom will go up and the boom telescopic will move inside so that the load radius decreases so that the crane will not move into the unsafe working range.The model is simulated to analyse the load monitoring system of the crane. The model is simulated with and without the controller to obtain separate results. Figure 7 shows a schematic diagram of the MATLAB Simulation.

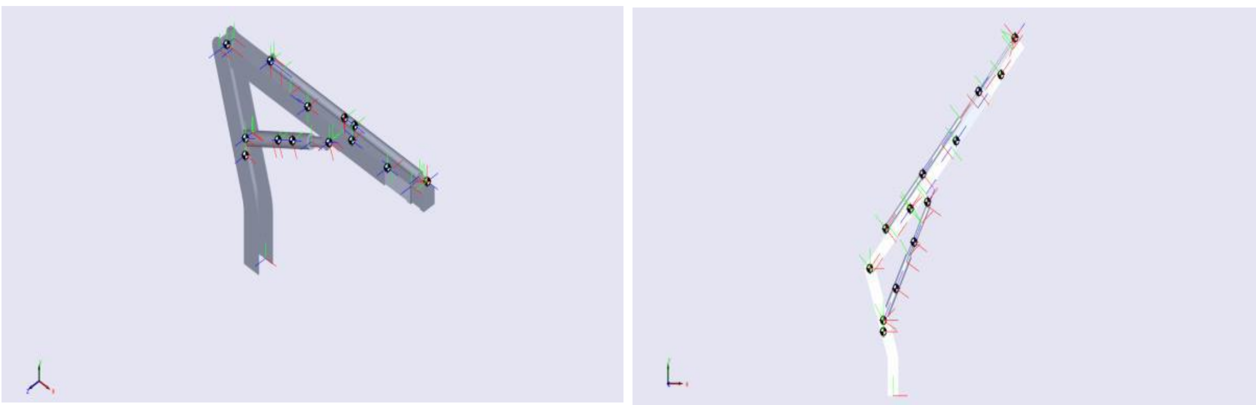

Figure 7. MATLAB Simulation

5. Results and discussion

The model is simulated and the plots are taken to obtain the relation between the boom extension and boom angle with respect to time. The results are obtainedwith (Table 1) and without (Table 2) using the controller subsystem to find the difference in boom actuation when the crane works in the unsafe working range assuming the crane works on outriggers. Figures 9-11 shows graphical representation of the results with and without controller

Tipping load calculated for the designed model for each value of load radius (‘y’ m) assuming the weight of the crane Wc = 400kg and the distance between the centre of gravity of the crane and the outrigger, x=1m.

Table 1. Calculated load range; Results obtained without using the controller

Load Radius (m)	Maximum Load (kg)
2.50	160
2.75	145
3.00	133
3.25	123
3.50	114
3.75	106
4.00	100

Table 2. Simulation results (without controller); For, Load = 130 kg

Parameter	Initial	Final
Boom Length (m)	2.40	3.73
Boom Angle (drg)	0	29

Boom Length vs Time:

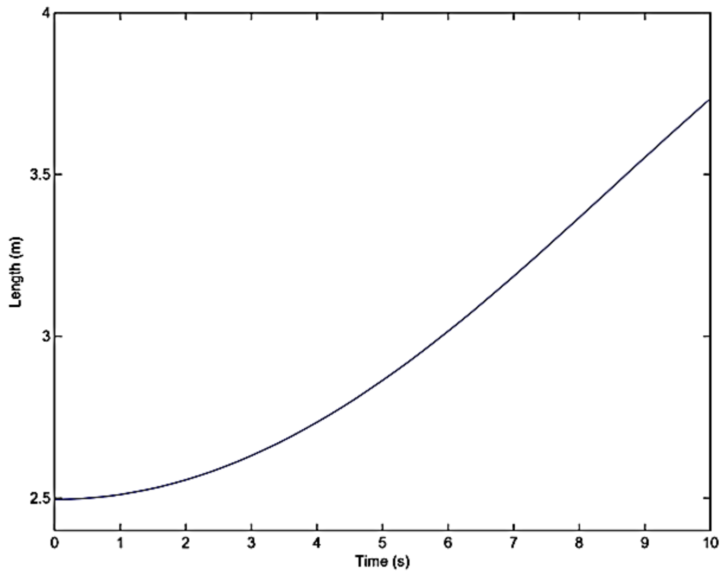

Figure 8. Boom length vs Time (without controller)

Boom Angle vs Time:

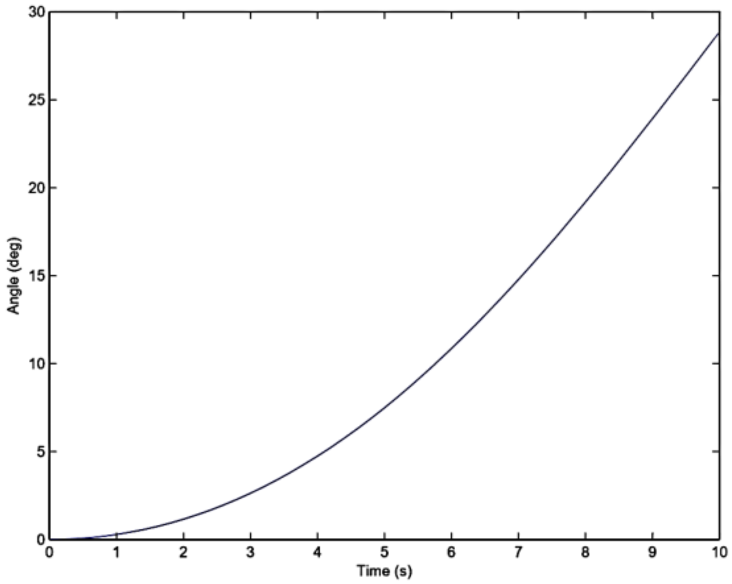

Figure 9. Boom angle vs Time (without controller)

Results obtained using the controller/load moment indicator system,
For, Load = 130kg

Table 3. Simulation Results (with controller)

Parameters	Initial	Final
Boom Length(m)	2.40	3.08
Boom Angle(deg)	0	34

Boom Length vs Time

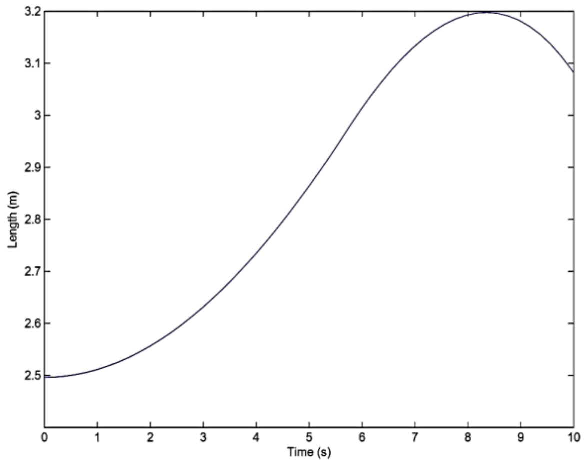

Figure 10. Boom Length vs Time (with controller)

BoomAngle vs Time

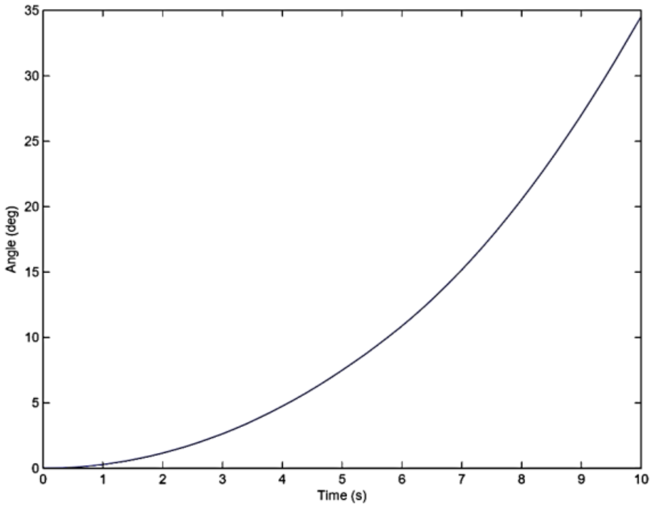

Figure 11. Boom angle vs Time (with controller)

The load moment indicator system, which consists of boom angle, sensor, telescopic boom length sensor, pressure transducer, anti-two block switch, roller switch and an indicator, is installed on the mobile crane. The system is tested for accuracy.

6. Conclusion:

A model of the system is designed and modelled in CAD software and then simulated and analysed in MATLAB Simulink environment. Plots are taken from the model after simulation. From the plots and results taken, it is observed that when the load being lifted exceeds the maximum permissible load it can carry, the boom retracts and boom angle increases to lift the boom so that the load radius decreases and in turn, the load moment decreases. This prevents the crane from tipping. When the load being lifted falls in the permissible load range, the boom extends and the boom angle decreases or increases as per the input requirements.

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