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SIMULATION FOR MOTION OF PLATFORM DURING TRUCK CHANGING IN TRUCKLIFT SLOPE HOISTING SYSTEM IN OPEN PIT MINES USING ADAMS AND MATLAB/SIMULINK

This paper focused on a study concerned with the motion of platforms at loading stations during truck changing in Trucklift slope hoisting system built in Jaeryong open-pit iron mine, DPR of Korea. The motion of platform in Trucklift slope hoisting system produces undesirable effect on truck changing. To analyze the motion of platform during truck changing, we built the dynamic model in ADAMS environment and control system in MATLAB/Simulink. Simulation results indicate that the normal truck changing can be realized without arresters at loading stations by a reasonable structural design of platforms and loading stations.

Keywords: ADAMS, Matlab/Simulink, Platform, Truck changing, Open-pit mine, Trucklift slope hoisting system

1. Introduction

When mining penetrates increasingly deeper in open pit mines, the mine takes some kind of funnel shape. The deeper the funnel, the greater the expense for transport.

To accelerate and cheapen transport while maintaining flexibility offered by truck transport, there have been developed the Trucklift systems which have also other names [1-3]. In these systems, the advantages are of the transport time being curtailed by the difference in height being

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rapidly overcome and of the reduction of the truck fleet. Various types of Trucklift systems exist according to condition and environment of mines.

This paper covers Trucklift slope hoisting system where trucks are hoisted on platforms by the power of winder [2,4]. These systems are generally similar to structure and operating principle and consist of a slop hoisting plant, platforms, tracks and loading stations. The friction winder and the drum winder are used as hoisting machine and the system can be equipped with single or double track.

In the system with single track, an empty truck drives off the platform and a laden truck drives onto the platform via the lower loading station after the platform reaches at it. The slope hoisting plant is activated to transport the truck out of the mine to the upper loading station. After the platform reaches at the upper loading station, the laden truck drives off and the empty truck drives onto the platform. After truck changing, the platform with an empty truck is transported to the lower loading station. In this way, the slope hoisting plant runs constantly loaded, each time trucks change at the loading stations. The driver stays in his truck during hoisting so that no change of driver is necessary. The platform comprises the frame on which the truck stops and ropes are hitched and the running gears which undertake the carrying and building function on the tracks. The track is a concrete or steel construction, on which the rails for the platform are attached. Rope rollers take over the carrier function for the ropes on the slope section. The winder is appointed in a machine house above the upper loading point, rope sheaves guiding the ropes appropriately.

In the system with double track, there are two platforms and two tracks whereby the platforms move simultaneously but in opposite directions such that one platform counter-balances the other platform. The platform with a laden truck moves up on one track and the platform with an empty truck moves down on the other track. The process of the truck changing on platforms is the same with the system with single track, but truck changings at upper and the lower loading stations are accomplished simultaneously. Trucks may stand on the platform longitudinally, parallel to the transport direction, or transversely, perpendicularly to it. The truck on the platform generally stands longitudinally to be decreased the distance between tracks in the system with double track.

At loading stations without arresters, platforms move on rails on tracks during truck changing by the mechanical interaction between truck and the platform, the weight of truck and the force of rope. When trucks drive onto and off platforms vertically to the transport direction, the platform moves on rails by the weight of truck though the winder has stopped. Then the truck changing is failed because there may be the difference of height between platform and loading station. So platform arrestors are provided at loading stations, which are run out when the platform reaches, ensuring that the platform is held in position when the load changes by truck changing.

When trucks drive onto and off the platform parallel with the transport direction, platforms also move on rails and there appears the varying clearance between the platform and the edge of loading station. Truck changing may be hindered by this clearance. But moving directions of truck and platform are same, so we can avoid the effect of the movement of platforms during truck changing by a reasonable design of the structure of loading stations and platforms without arrestors. For this reason, the moving process of the platform during truck changing must be researched well.

To research the movement of platforms during truck changing, the movement of the truck running on the platform and loading station and the effect of rope hitched to the platform must be considered simultaneously. The motion of the platform is related to various factors as the angle of track, the acceleration of truck and road type, the friction angle between truck tire and surface of the platform, the friction angle between truck tire and surface of loading station and the characteristics of rope hitched to the platform.

Schmid [5] studied the combination of the steady-state Magic Formula approach and the Single Contact Point transient tire model to implement a tire model that can handle transient driving situations into the multibody dynamics engine Chrono::Engine. And it was suggested that to use available tire data specified for the commercial multibody dynamics simulation software MSC ADAMS, it would be appreciated to use ADAMS' *.tir tire data files to input tire data.

Ning et al., [6] made a parametric ADAMS model and then linked it to a Knowledge Based Engineering application in order to reduce development time. Using this simulation analysis system, they analyzed various factors which affect the truck ride comfort.

Zhang et al., [7] built the multi-body truck dynamic model is in ADAMS/Car and considered the non-linear characteristics of tire, bushing, spring and damper, so they could accurately express the dynamics performance of the truck. Besides, logic threshold control model of ABS based on wheel deceleration and slip rate was designed under Matlab/Simulink environment, and the two models were integrated and co-simulation by the interface of ADAMS/Control.

Adamczyk et al., [8] presented techniques that can be used to perform virtual prototyping and virtual dynamic testing of unmanned ground trucks in off-road settings. They built the dynamic model in ADAMS/Car and the control system in MATLAB/Simulink and also addressed effective linking of ADAMS/Car and MATLAB for complete control system development.

As mentioned above, using ADAMS/Car, some researchers could quickly create assemblies of suspensions and full trucks, and then analyzed them to understand their performance and behavior. And linking ADAMS/Car and MATLAB, they resolved the dynamics and control problems. However, seldom have we read the similar research data to simulate the motion of the platform hitched by the rope with elasticity, on which truck moves during the truck changing in the Trucklift slop hoisting system in open pit mines. In this paper presents a method of simulating the truck changing process in the Trucklift slop hoisting system where trucks stand parallel to the transport direction on the platform, using ADAMS and MATLAB/Simulink. Then the movement of platform and the force of rope are analyzed and proposed the important data for design of platform, loading station and arrestor.

2. Motion simulation of truck changing process in the Trucklift slop hoisting system

2.1. The Trucklift slop hoisting system simulated

Fig. 1 shows the Trucklift slop hoisting system built in Jaeryong open-pit ore mine, and it is used for simulating the motion of platform caused by the truck movements on the platform.

Each end of 2 ropes, wound on two drums of the double drum winder, is hitched to the platform. There are two platforms and two tracks whereby the platforms move simultaneously but in opposite directions such that one platform counter-balances the other platform. Simultaneously, two platforms reach upper and the lower loading stations respectively.

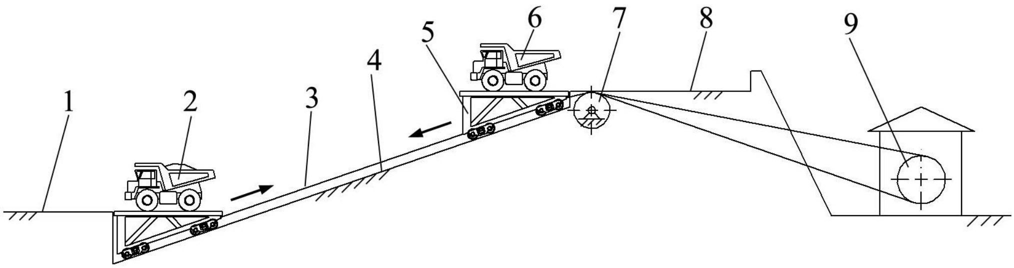


Fig. 1. Schematic diagram of the Trucklift slop hoisting system. 1 – lower loading station, 2 – laden truck, 3 – rope, 4 – track, 5 – platform, 6 – empty truck, 7 – guide pulley, 8 – upper loading station, 9 – double drum winder

The external forces acting on platforms are varied due to the movement of empty and laden trucks on the platform during truck changing. Thus, the force acting on the platform hitched by rope varies. The rope has elasticity, so platforms move on rails. Here are used dump trucks for mine with a payload of 27 t.

2.2. Modeling using ADAMS and MATLAB/Simulink

The moving displacement of the platform at the lower loading station during truck changing is longer than one at the upper loading station because the rope length from winder to the lower loading station is longer than to upper. Therefore, we consider the process of truck changing at the lower loading station.

After the platform with empty truck stops at the lower loading station, the empty truck on the platform begins to accelerate and moves straightly to the loading station. While the truck moves, at first, two axles of truck are placed on the platform, and then the front axle is placed on the loading station and the rear axle is placed on the platform. Finally, two axles are placed on the loading station. After the empty truck driving off, the laden truck drives onto the platform with a constant low velocity. At first, two axles of truck are placed on the loading station, and then the rear axle is placed on the platform and the front axle is placed on the loading station. Finally, the truck decelerates and stops, then two axles are placed on the platform. When truck moves on the platform and loading station during truck charging, the force reverse to the moving direction of truck acts on the platform.

Thus, when a truck moves, the position of gravity centre and wheels of truck varies continuously. And there exist acceleration, constant velocity and deceleration intervals. The varying force during truck charging by the elasticity of rope hitched to the platform acts on the platform and the rolling resistance acts on wheels of the platform. It is difficult to consider the motion of the platform under the force of rope during driving on and off, so we solve this problem using ADAMS and MATLAB/Simulink.

2.2.1. Building a model in ADAMS/View

When the empty truck drives off at the lower loading station, external forces in system are shown in Fig. 2.

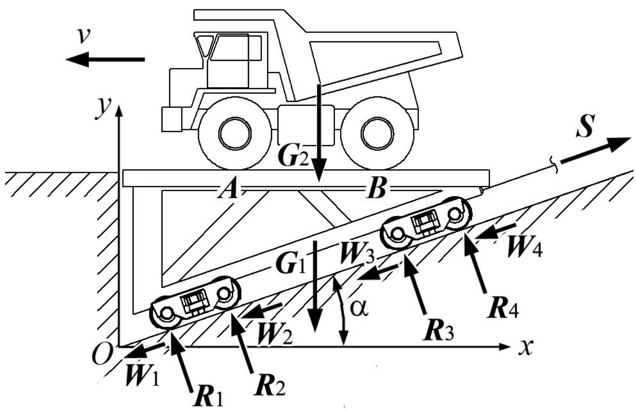


Fig. 2. External forces in system when the empty truck drives off the platform at the lower loading station

As shown in Fig. 2, external forces in system are as follows: G_1 is the force derived from the weight of the platform and G_2 is derived from the weight of truck; R_1, R_2, R_3 and R_4 are normal forces on the wheels of the platform; W_1, W_2, W_3 and W_4 are rolling resistances at the wheels of the platform; S is the force of rope. The longitudinal tire force and rolling resistances interact between tires and the surfaces of the platform and loading station.

ADAMS software is used for simulation of kinetic process of the truck and the platform. It is the world's most widely used multibody dynamics simulation software. ADAMS/View is the general purpose rigid body dynamics package and it can work with the ADAMS/Controls module for interfacing with MATLAB.

Fig. 3 shows the geometry for simulation which consists of a truck, a platform and a lower loading station. The ground consists of a loading station and a track with an angle of slop. Rails are attached on the track. The truck consists of a body and tires. Surfaces of platform and loading station are horizontal plane and trucks move with low velocity.

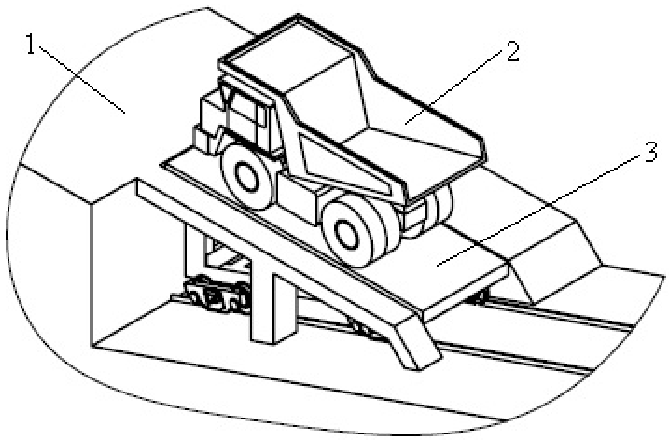


Fig. 3. Geometry to simulate the truck changing. 1 – ground, 2 – truck, 3 – platform

To analyze the influence of slope of track, geometries were built with angles of slope of 19°, 25° and 30°, respectively. As shown in Fig. 4, six geometries were built, considering the processes of driving off and onto the platform, respectively. The process of truck driving off was simulated by geometries in Fig. 4. (a), (c), (e), and the process of truck driving onto was simulated by geometries in Fig. 4. (b), (d), (f).

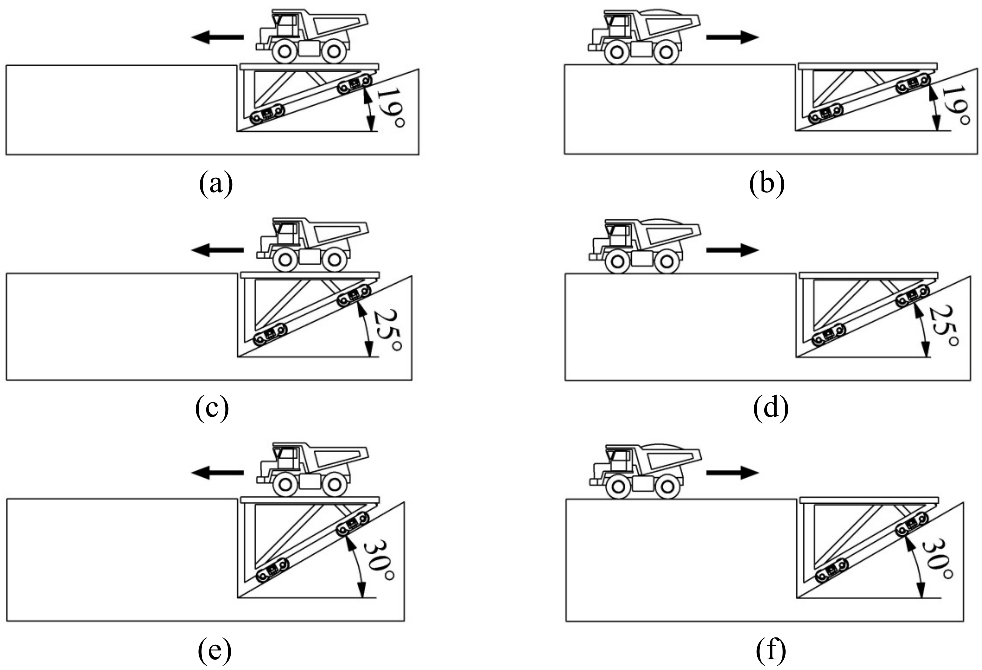


Fig. 4. Geometries to simulate the truck changing according to angles of slop of track. (a) Geometry for truck driving off when angle of track is 19°; (b) Geometry for truck driving onto when angle of track is 19°; (c) Geometry for truck driving off when angle of track is 25°; (d) Geometry for truck driving onto when angle of track is 25°; (e) Geometry for truck driving off when angle of track is 30°; (f) Geometry for truck driving onto when angle of track is 30°

Table 1 shows the parameters of truck, platform and track. Geometries are built by using SOLIDWORKS and imported to ADAMS/View. In ADAMS/View model, there are several elements such as a translational constraint, four rotational constrains and eight contacts, a rotational motion, a force and gravity.

TABLE 1

Parameters of truck, platform and track

Length of track	640 m
Mass of truck	21 t
Payload of truck	27 t
Mass of platform	19 t

Translational constraint is defined between ground and platform. It enables to move the platform on rails and the frictional coefficient between wheels of the platform and rails is added to it. Four rotational constraints are defined between tires and body of truck. These enable to rotate tires around their axes during movement of truck. Contacts are defined between tires and the platform, tires and ground. Rotational motion is defined to rotational constraint on rear tires of truck. The force acting on the platform is equal to the force of rope. Its direction is parallel to rails and tends upward as shown in Fig. 2. And value of the force depends on the displacement of the platform.

ADAMS/View model has 7 variables defined to co-simulation with MATLAB/Simulink, they are rope force, rotational velocity of rear tire, displacement of the platform, speed of truck relative to the platform, speed of truck relative to ground, position of truck relative to the platform and position of truck relative to ground. By using ADAMS/Controls, force of rope and rotational velocity of rear tires are defined as input variables and other variables are defined as output variables. Adams/ Controls, part of the Adams suite of software, is a plugin to MSC Software's Adams/Car, Adams/Chassis, Adams/View, or Adams/Solver that helps users add sophisticated controls to Adams model. Adams/Controls lets them connect their Adams model to block diagrams that they have developed with control applications such as Easy 5 or MATLAB. Adams/Controls saves the input and output information in an *.m (for MATLAB). It also generates a view command file (*.cmd) and a solver dataset file file (*.adm) which are used during the simulation process in Adams.

2.2.2. Building a MATLAB/Simulink Controller

MATLAB, the mathematical library made in MathWork contains various kinds of math tools. Combined with other applications, this software performs mathematical analysis and control and generates a graphical visualization of the results. MATLAB/Simulink is a software package that enables users to model, simulate, and analyze systems whose outputs change with time. In MATLAB/Simulink, the m file written by ADAMS/Controls is run as a script, initializing variables and adding paths to make the interface function correctly. The MATLAB command "adams_sys" creates Simulink blocks providing access to the ADAMS/View model's inputs and outputs. The controller is built around the block named "adams_sub", this block represents all dynamics of the model in ADAMS, and takes the place of state equations and integrations that would be included a self-contained Simulink dynamics model (Fig. 5). The inputs and outputs defined for the model appear in the adams_sub block. The input and output names automatically match up with the information read in from the *.m file.

In MATLAB/Simulink, the control block diagram is constructed by using adams_sub block and some blocks in the library. Fig. 6 shows control block diagram in MATLAB/Simulink.

Velocity of truck is specified by using Signal Builder block as shown in Fig. 7. Signal Builder creates interchangeable groups of signals whose waveforms are piecewise linear. Velocity of truck during truck changing is specified to 5 km/h with acceleration 0.25, 0.5, 0.75, 1 m/s^2, respectively. Running distances are same. Once simulation begins, the platform moves by the elasticity of rope and then stops. It takes 4s for the platform to stop sufficiently, so truck begins to move after 4s.

Input variables of adams_sub block are specified by using MATLAB Fcn block. The MATLAB Fcn block applies the specified MATLAB function or expression to the input. Input variables of MATLAB Fcn block are displacement of the platform and velocity of truck. Output variables of MATLAB Fcn are force of rope and rotational velocity of rear tire of truck, and they are determined based on parameters of rope and tire. Table 2 shows the parameters of rope.

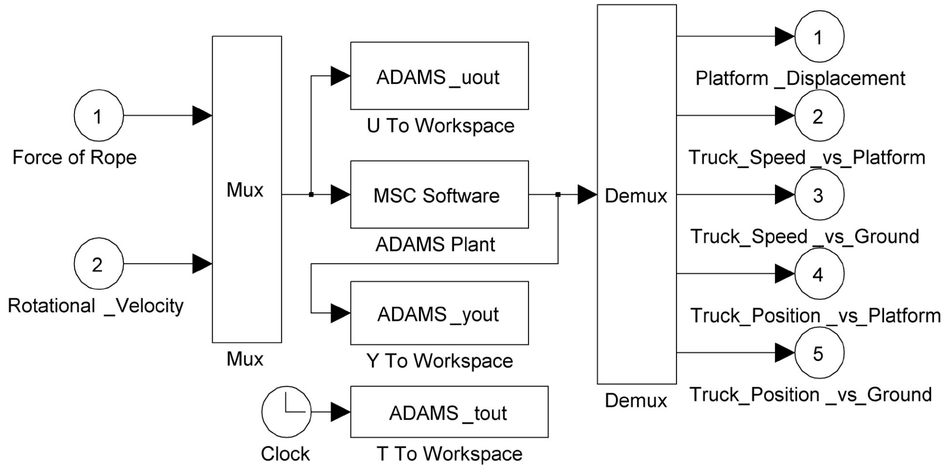


Fig. 5. adams_sub block

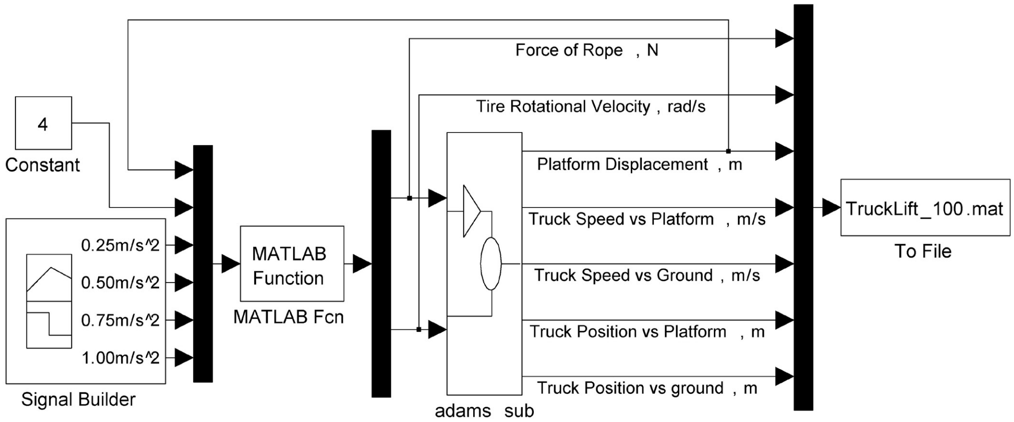


Fig. 6. Control block diagram in MATLAB/Simulink

TABLE 2

Parameters of rope

Diameter of rope	56 mm
Length of rope	820 m
Elasticity modulus of rope	1.0×10^{11} Pa
Breaking force of rope	2190 kN

MATLAB Fcn outputs zero for force of rope if it is less than zero. To calculate the rotational velocity of rear tire of truck, MATLAB Fcn uses a velocity profile in 4 signals generated from Signal Builder by using value specified to Constant block. The Constant block generates

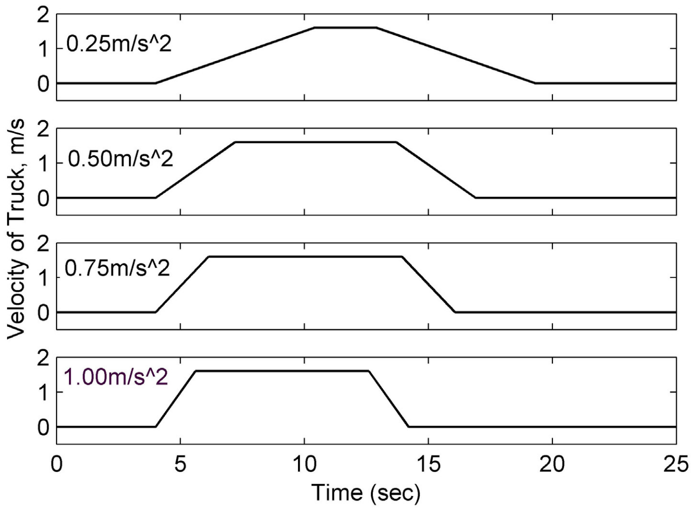


Fig. 7. Velocity of truck defined in Signal Builder block

a real or complex constant value. MATLAB Fcn selects the velocity profile with acceleration 0.25 m/s^2 if value of Constant block is 1, the velocity profile with acceleration 0.5 m/s^2 if value of Constant block is 2, the velocity profile with acceleration 0.75 m/s^2 if value of Constant block is 3, the velocity profile with acceleration 1 m/s^2 if value of Constant block is 4. Calculated input and output variables of adams_sub block are saved to mat file.

3. Results and discussion

3.1. Simulation and Result

The duration for simulation was set as 25s for truck driving off, and also 25s for truck driving onto. For 4 seconds from the beginning of simulation, a truck stays on the platform or the loading station and the platform stops. Force in rope reaches to the corresponding initial value, too. After 4 seconds, a truck begins to drive onto the platform or off the platform with a constant acceleration. In this time, the force of rope changes by the interaction between truck and the platform due to moving of the platform. For some seconds after stopping of truck, the platform still oscillates and then stops its movement. When an empty truck drives off the platform with acceleration of 1 m/s^2, front tires contact on loading station at 6.6s and rear tires at 8.8s. Fig. 8 illustrates the variation of force of rope during driving off the platform with acceleration of 1 m/s^2.

From 4s (point A) to 6.6s (point C), the force of rope changes by the movement of empty truck on the platform and suddenly decrease to 8.8s (point D), because front tires of truck lay on the platform. Then the force of rope changes with reduced amplitude due to the rolling resistances at the wheels of the platform. After 12.2s (point E), the force of rope has a constant value. Fig. 9 illustrates the minimum force of rope when an empty truck drives off the platform.

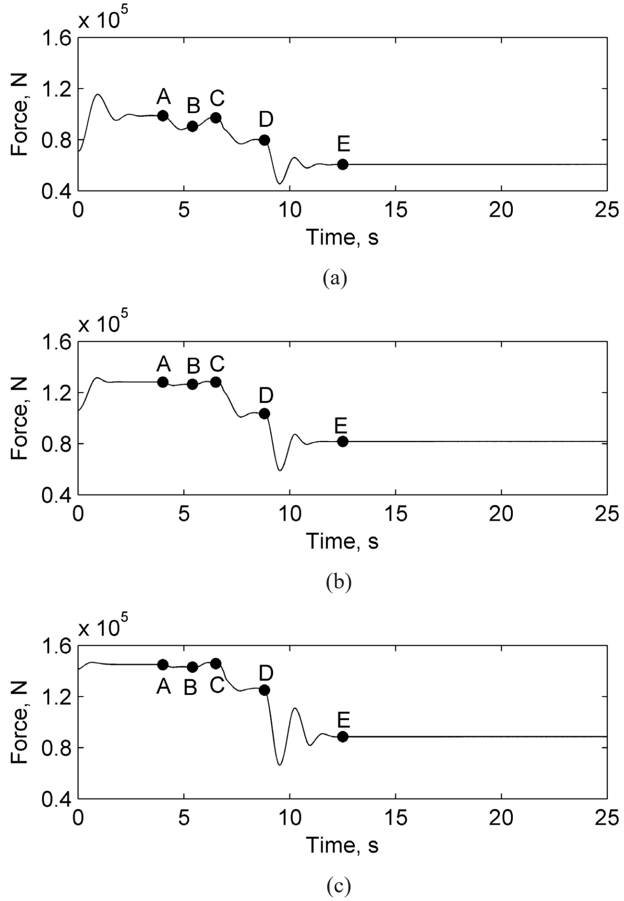


Fig. 8. Force in rope during driving off the platform with acceleration of truck a = 1 m/s^2.
(a) When slope of track is 19°; (b) When slope of track is 25°; (c) When slope of track is 19°

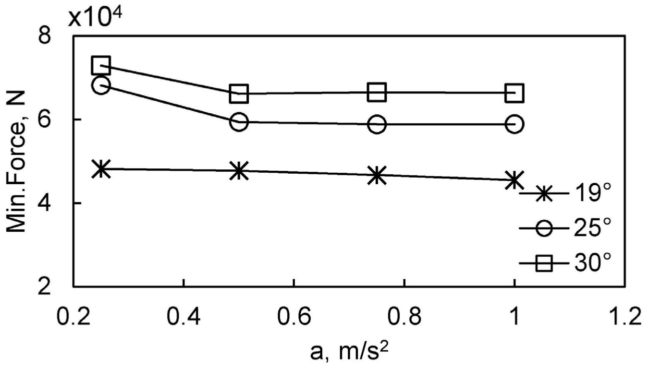


Fig. 9. The minimum force in rope during driving off the platform

When an empty truck drives off the platform, the greater acceleration and smaller slope of rail, the smaller the minimum force of rope. When a laden truck drives onto the platform with acceleration of 1 m/s^2, rear tires contact on the platform at 9.9s and front tires at 12.2s. And then the laden truck stops movement on the platform at 14.2s. Fig. 10 illustrates the force of rope during driving onto the platform with acceleration of 1 m/s^2.

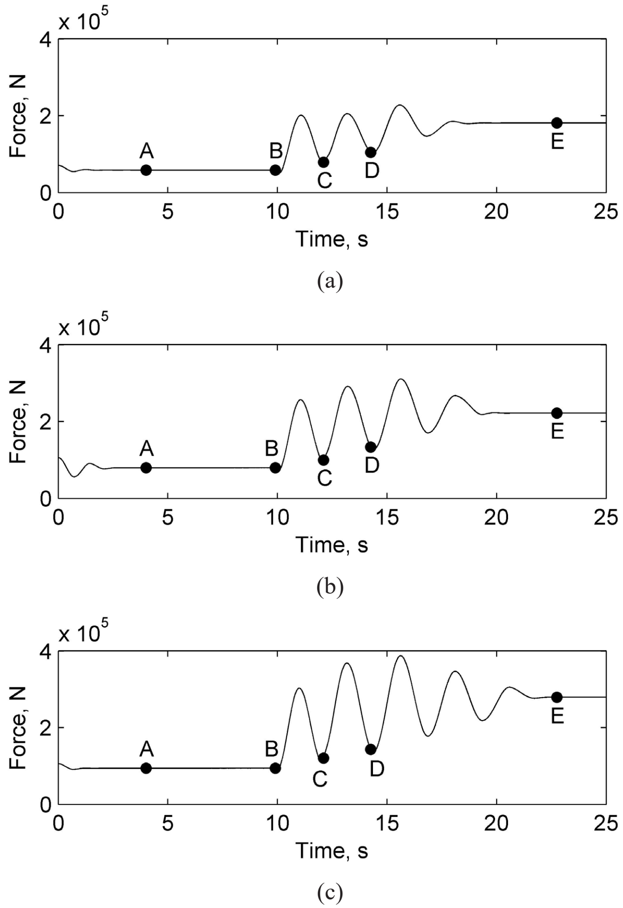


Fig. 10. Force in rope during driving onto the platform with acceleration of truck a = 1 m/s^2.
(a) When slope of rail is 19°; (b) When slope of rail is 25°; (c) When slope of rail is 19°

From 4s (point A) to 9.9s (point B), the force of rope has a constant value because a laden truck moves on loading station. At 9.9s, it reduces lightly due to the contact between rear tires and the platform, and then rapidly increases. To 14.2s (point D), the force of rope oscillates with large amplitude by the interaction between laden truck and the platform. After 14.2s, force of rope changes with reduced amplitude due to the rolling resistances at the wheels of the platform. After 18.8s (point E), the force of rope has a constant value. Fig. 11 illustrates the maximum force of rope when a laden truck drives onto the platform.

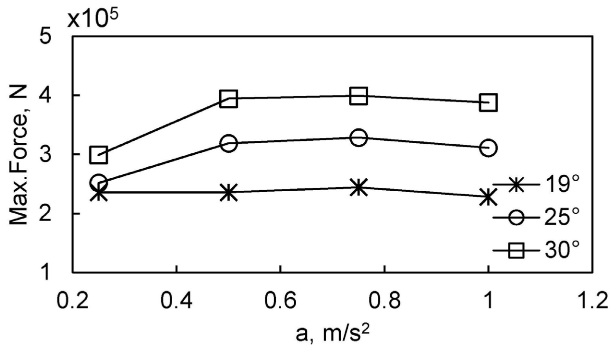
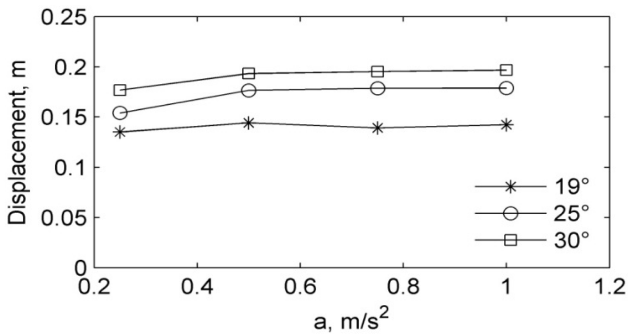
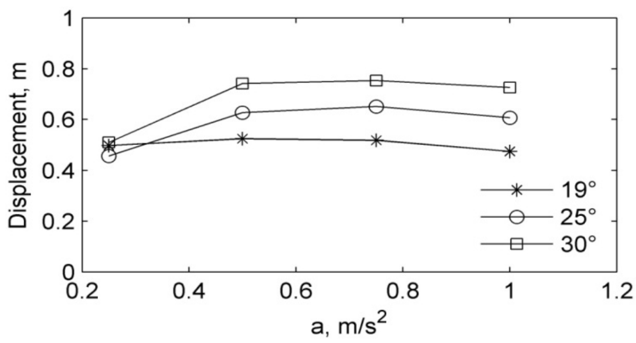


Fig. 11. The maximum force in rope when a laden truck drives onto the platform

The greater the acceleration of truck and the larger the slope of rail, the greater the maximum force of rope when a laden truck drives onto the platform. The force in rope is in proportion to the displacement of the platform. Fig. 12 illustrates the maximum horizontal displacement of the platform during truck changing.



(a)



(b)

Fig. 12. The maximum horizontal displacement of the platform during truck changing.
(a) When an empty truck drives off the platform, (b) When a laden truck drives onto the platform

The maximum horizontal displacement of during driving onto the platform has larger value than driving off.

3.2. Discussion

As known from the above simulation results, the platform moves on rails during truck changing without arresters. The displacement of the platform can be shortened by reducing the acceleration of truck and the angle of slop of track part at loading station.

The maximum horizontal moving displacement from above simulation result is about 0.78 m.This means that there appears the clearance between the edge of loading station and the edge of the platform during truck changing, so tires of truck can be fallen into it. The structure of the platform and loading station, maintaining the normal truck changing, can be designed after determining the moving displacement of the platform in the Trucklift slop hoisting system. In the case of slop angle of track of 19°, the maximum moving displacement of the platform is 0.5 m from simulation result, so two guide floors with length of 0.9 m were attached to the edge of loading station to maintain the normal truck changing (Fig. 13). As seen from the force diagram of rope, the value of the minimum force is decreased suddenly. Thus, when the platform moves during truck changing in the Trucklift slop hoisting system with friction winder, sometimes the force in ropes is decreased and the slipping of ropes in drum groove can be occurred, so the arrangement of arresters in this system must be examined from simulation results. In the case of the slop angle of track of 19 and the breaking force of rope of 2190 kN, the maximum force in the rope is 244.2 kN and then the safety factor is 8.97.

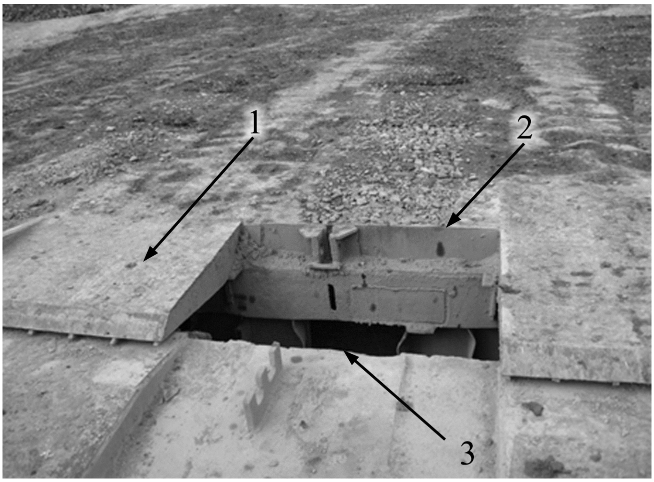


Fig. 13. Platform and guide floor at loading station.
(1 – guide floor, 2 – edge of loading station, 3 – edge of platform)

The force in rope acting on the platform becomes the main design data of arresters when arresters are provided at loading stations. It seems that above simulation results agree with the mechanical principle and the actual results. Our study provides additional support for the design, predicting the motion displacement of the platform and the force acting on the platform without arrestors. The more correct result can be given if interaction between tires of truck and the platforms is considered in ADAMS/Tire and the effect of rope is considered in more detail.

4. Conclusions

This paper simulated the motion process of the platform by the motion of truck on the platform and the effect of rope hitched to the platform, using ADAMS and MATLAB/Simulink. Thus, the effect of various factors on the movement of the platform and the force in rope could be considered quantitatively.

The maximum displacement of the platform at the lower loading station during truck driving onto is longer than during driving off. The maximum displacement at the lower loading station is longer than at the upper loading station. The greater the angle of slop of track, the greater the maximum displacement. The maximum displacement of the truck on the platform grows to the extent of the acceleration of about $0.5m/s^2$ and then decreases gradually.

After determining the moving displacement of the platform in the Trucklift slop hoisting system with drum winder, the normal truck changing can be realized by a reasonable designing of the platform and loading station in the Trucklift slop hoisting system where trucks stand on the platform longitudinally.

In the Trucklift slop hoisting system with friction winder, the arrangement of arresters at loading station must be examined from simulation results not to occur slipping of ropes in drum groove due to the movement of the platform during truck changing. If arresters are provided at loading stations, the force acting on the platform from simulation result can be used as the reference data for design of arresters. The results given from the considered simulation method are the significant data for the design of loading stations, platforms and arresters in the Trucklift slop hoisting system where trucks stand on the platform longitudinally.

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