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Multi-body dynamics simulation of tension on chain link plate under basic conveyor chain system for rubber gloves industry

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Abstract. Conveyor chain is one kind of chain which has been used worldwide to transport or carry an object from one place to anywhere on the production line. In fact, a key factor of conveyor chain design is tension on chain link plate which the traditional static design method has not precise and accurate enough for production line has complex and large size. Multi-body dynamic (MBD) is a new way to analyze system which static analysis method cannot investigate any problem. This paper aims to apply commercial code software to find tension on chain link plate of conveyor chain by using multi-body dynamics (MBD) simulation method which simple model of chain alignment such as vertical, horizontal and incline alignment is fundamental of complex alignment that apply in rubber gloves industry. Finally, the results had obtained from numerical formula and multi-body dynamics (MBD) simulation have an average error less than 7, 5 and 7 percent in horizontal, vertical and incline layout, respectively. Percent error disregards the oscillation effect from increasing the velocity of the conveyor chain while the mathematical formula is not.

1. Introduction

Thailand is the 1 of 3 largest countries who is the latex exporter (nature rubber) in the world. Rubber gloves are the primary product of latex. Thailand is the leader of rubber gloves for a long time [1]. However, the self-know-how of the technology of rubber gloves still has nothing. Many rubber gloves industrial plant in Thailand still hires Malaysia engineering to design and control the plant. One of all design is the chain layout design.

For centuries, Chains have been developed and used to drive machine and move materials on conveyors and up elevators. In the present day, Chains have many kinds of it that developed to properly applications. One type of them that popularly used in the rubber gloves industrial. It is a conveyor chain. The conveyor chain is a key role as to transport products through any process in along a distance of production line that means all of the production lines will stop immediately if the chain has got any problems exist to breakdown. One of all problems have been found from the investigation of reference rubber gloves plant are the fracture in conveyor chain and drive shaft. These problems have been caused by wear and excessive tension force which occur from the dynamic loads. However, this research focus in using commercial code software to investigated tension force instead of using the mathematical formulation that is not enough to investigate the effect of dynamic of heavy loads and long conveyor chain system [2].

One of all challenge for design conveyor chain system is the effect of dynamic behavior during motion that cannot predict by using the static theory that draws a particular attention from many researchers in this area.

The dynamic of a roller chain drive system was studied which simulation model has roller chain drive with two sprockets and two spans by Juntian et al. [3]. It was reported in movement curves such as displacement diagrams, velocity curves, accelerating curves and tension curves. The results show the effect of dynamic cannot be neglected at high speed.

Mulik et al. [4] studied timing chain system of a high speed three cylinders diesel engine by using MBD simulation to investigate dynamic behavior instead of the actual engine to save cost and time. The dynamic analysis shows the result in terms of parameters such as contact force and normal force between different components.

In this paper, The MBD simulation is used to compare with mathematical formulas to investigate tension force and dynamic behavior. Such as the influence of gap between sprocket and rail, the position of rail alignment.

2. Mathematical formulation

For chain design, the chain tension force equations are derived from the basic principles of Newton's equations by using free-body diagram rules. These equations are developed for convenience and compact to calculate chain tension force which basic conveyor chain layouts as shown in Fig. 1. They are the principle of all designs. The formulas for conveyor chain have two modes which mode one is material is carried on the chain, and mode two is material is pushed on a deck [5]. This paper specifies on mode one only. The equations are described in equation (1)-(3) as

Horizontal Conveyors

$$P = Cf_M(2.1M + W) + P_A \tag{1}$$

Vertical Conveyors

$$P = C(M + W) + P_l \tag{2}$$

Inclined Conveyors

$$P = Cf_M \cos\alpha\,(2.1M + W) + (CW \sin\alpha) \tag{3}$$

Where

P = conveyor chain pull (N.)
C = length of the conveyor (m.)
M = weight of the chain, attachments, and carriers (N/m.)
W = weight of the conveyed material (N/m.)
f_M = coefficient of friction for the chain
P_l = take-up tension (N.)
P_A = added chain pull from accumulation (N.)

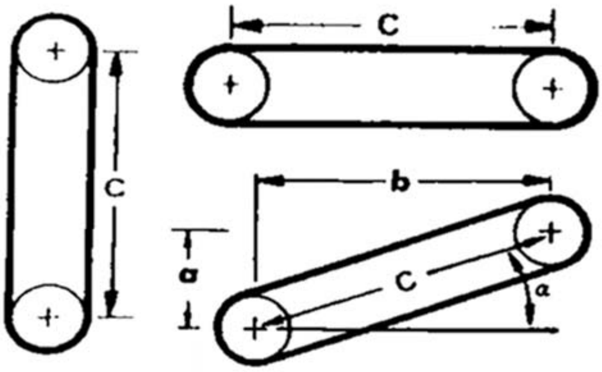

Fig. 1. Basic conveyor chain layouts

All of these equations for chain tension assume in a static condition. The same supports are used for the return span as are used for the conveying span in the term $2.1CMf_M$. If the supports for the return span are different than for the conveying span, the term $2.1CMf_M$ will have to be split into two parts: $1.0CMf_M$ for the conveying span and $1.1CMf_M$ for the return span. In most of the equations, the term $0.1CMf_M$ is included to account for tail shaft or sprocket friction.

3. Theory of multi-body dynamic systems

The simplest bodies or element of a multi-body system were solved by Newton equation (free particle) and Euler equation (rigid body). Later, a series of formulas were derived for solving dynamic behavior. The series of geometry are combined as the multi-body dynamic system which composed of multiple bodies is constraints to calculate the motion. The bodies in multi-body dynamic system concern rigid bodies to form equation of motion by the Lagrangian equation [6], [7]. The dynamic equation of each body of the system is given by:

$$\frac{d}{dt}\left(\frac{\partial L}{\partial \dot{x}_k}\right) - \frac{\partial L}{\partial x_k} = F_k; k = 1,2,3,\dots,n \tag{4}$$

Where

$$L = T - U \tag{5}$$

Where x_k is the generalized coordinate of the k-th body, F_k is the generalized force on the k-th body, n is a number of bodies, L is the Lagrangian function, T is kinetic energy, U is potential energy.

The constraint equation relates with bodies is given to assemble bodies by:

$$C_i(x,t) = 0; i = 1,2,3,\dots,m \tag{6}$$

Where m is the number of constraints.

The dynamic equation of system is expressed in the matrix form by:

$$\frac{d}{dt}\left(\frac{\partial T}{\partial \dot{x}_k}\right) + Kx_k = F_k \tag{7}$$

Where K is the rigidity matrix. F_k is the force vector.

The bodies are assembled to a system through constraints. The differential equation of the system is generated by the Lagrange multiplier method which was written in matrix form as:

$$M\ddot{x}_k + Kx_k + J_C^T = F_k \quad (8)$$

Where M is the mass matrix. J_C is the Jacobian matrix of constraints. This dynamic governing equation of the multi-body dynamic system will solve through commercial code.

4. Simulation model of conveyor chain

A virtual prototype of conveyor chain consists the five main parts: conveyor chain, sprocket, actuator, supported rails and frameworks. In simulation, frameworks assume as zero which it is fixed on the ground. The conveyor chain, sprocket and supported rails are simplified as a rigid body. Sprocket use ISO606 standard. The actuator operates as an electrical motor. The contacts were created in between each link of the conveyor chain and supported rails. Which is shown in Fig. 2.

Fig. 2. Simulation model of conveyor chain

5. Results and Discussion

Important parameters for MBD simulation are summarized in Table. 1 – 4 which separates two part: part one in table 1 and table 3 for sprocket which includes numbers of sprocket teeth, sprocket dimension, the distance between sprockets and static/dynamic coefficient of the sprocket. Part two in table 2 and table 4 for conveyor chain which includes total chain length, chain pitch, number of links, conveyor chain dimension, mass of chain and objects and friction coefficient of contact.

Table 1 Specification of the sprockets

Parameter Name	Parameter Value
Drive sprocket teeth	20
Driven sprocket teeth	20
Sprocket diameter	639 mm.
Sprocket width	25 mm.
Distance between sprockets	7000 mm.
Static friction coefficient of sprocket	0 (frictionless)
Dynamic friction coefficient of sprocket	0 (frictionless)

Table 2 Specification of the conveyor chain

Parameter Name	Parameter Value
Total chain length	16000 mm.
Roller diameter	62 mm.
Number of links	160
Chain pitch	100 mm.
Link width	30 mm.
Pitch to back	23 mm.
Mass of chain and objects	50 kg/m.
Friction coefficient of contact	0.7

5.1 Influence of the gap

In rubber gloves plant, conveyor chain must carry heavy loads through production line on the supported rails. The weight of loads has several tons. Therefore, Roller of conveyor chain is necessary part to reduce friction between conveyor chain and supported rails which surface contact together.

In mathematical formulas which were derived for convenience to calculate, they assume surfaces which contact between conveyor chain and supported rails get completely effective of reduced friction through the line. However, it is impossible to get effective of reduced friction through the line because the gap is appeared between sprocket and supported rails. We knew the gap make the loads increase up but do not know how many loads increase up.

To study the influence of the gap. Simulation model set up the gap is 0, 200, 500 and 1000 mm., respectively between sprocket and supported rails both of span and return span, where the major parameters of the conveyor chain system are as shown in table 1 and table 2. The simulation results of the influence of the gap are illustrated in the line graph, as shown in Fig. 3. The results indicate tension force in conveyor chain link increases up as an increment of the gap between sprocket and supported rails.

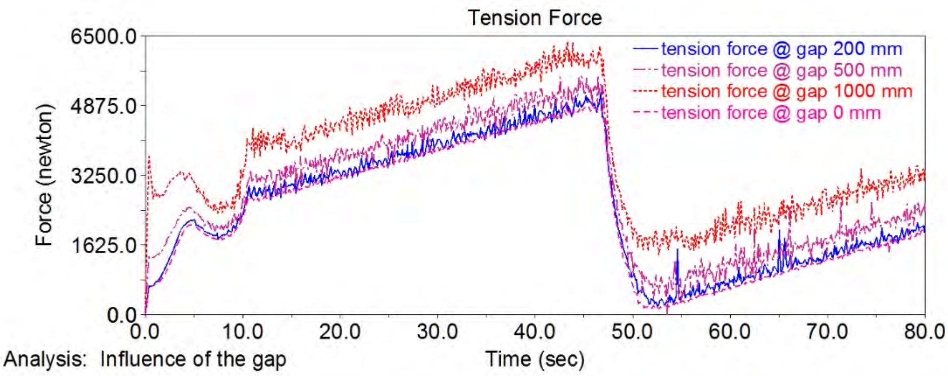

Fig. 3. Influence of the gap at 0.7 friction coefficient of contact and 7 m. of length.

In this reason, the gap should be optimal to avoid the additional loads to the systems.

5.2 Influence of supported rails alignment

Supported rails are a part of the system which supports weight from conveyor chain. In general, supported rails should have the same alignment with a roller. In case supported rails misalignment with a roller. Conveyor chain may have behavior that calls sag. Sag behavior cause loads of conveyor chain increase tremendously which mathematical formulas cannot calculate.

To study the influence of supported rails alignment. Simulation model set up the alignment of supported rails from roller is 0, 10, 50 and 100 mm., respectively with a gap 500 mm. both of span and return span, where the major parameters of the conveyor chain system are as shown in table 1 and table 2. The simulation results of the influence of supported rails alignment are illustrated in the line graph, as shown in Fig. 4. The results indicate tension force in conveyor chain link increase up as an increment of space between supported rails and roller.

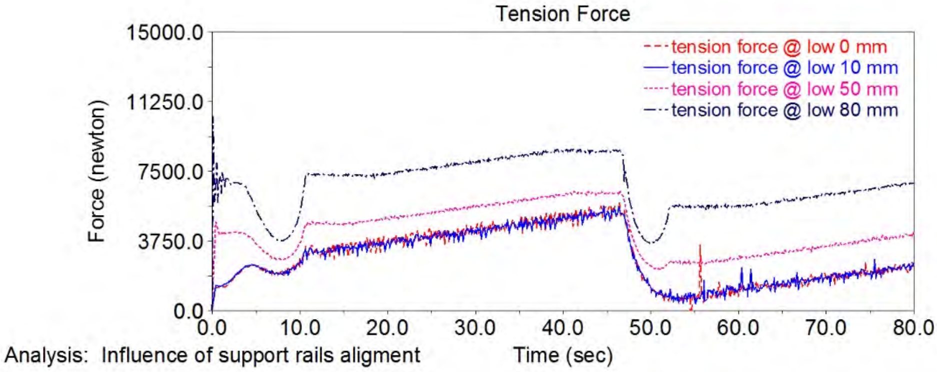

Fig. 4. Influence of supported rails alignment at 0.7 friction coefficient of contact and 7 m. of length with the gap is 500 mm.

5.3 Influence of speed

Speed is behavior which has directly affect to dynamic behavior of the system. The system which operates at high speed will found problems such as vibration, noise signal and energy consumption.

To study the influence of speed. Simulation model set up the angular velocity is 0.1, 0.15, 0.3, 0.6, 1.2 and 1.5 rad/s. which converts to displacement velocity is 0.032, 0.048, 0.096, 0.192, 0.384 and 0.48 m/s., respectively, where the major parameters of the conveyor chain system are as shown in table 1 and table 2. The simulation results of the influence of speed are illustrated in the line graph, as shown in Fig. 5. The results indicate tension force is decreased at a very low speed that is 0.032 and 0.048 m/s. However, high oscillation was found at high speed that is 0.384 and 0.48 m/s.

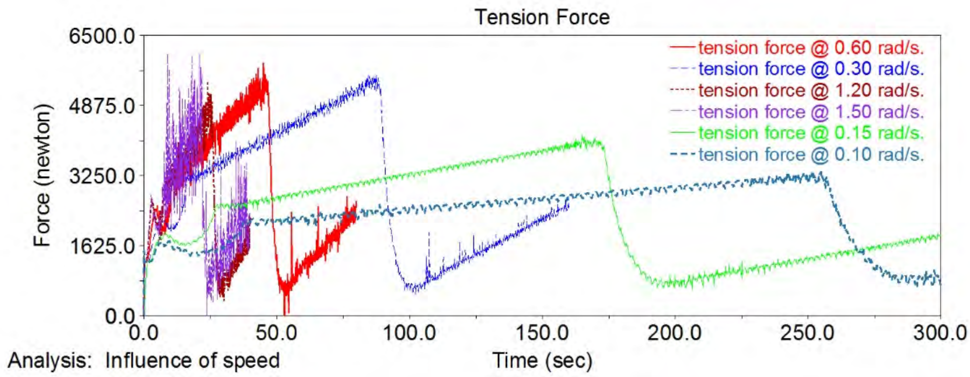

Fig. 5. Influence of speed at 0.7 friction coefficient of contact and 7 m. of length with the gap is 500 mm.

5.3 Influence of sprocket size

Sprocket is a part of the system to transmit force to drive conveyor chain. Size of sprocket depends on conveyor chain pitch and amount of sprocket teeth. Sprocket has the effect of inertia force that means more diameter of sprocket will take more effect from inertia force. For sprocket, inertia energy is accumulated to serve in term of resistance causes loads increase up. Otherwise, mathematical formulas neglect the effect of sprocket size.

To study the influence of sprocket size as shown in Fig.6. Simulation model compares tension force in conveyor chain link between sprockets have 12, 34 teeth and diameter 450, 1084 mm., respectively which conveyor chain pitch is 100 mm., the friction coefficient of contact is 0.07, the gap is 400 mm., mass per a unit length is 80 kg/m. and the length of conveyor chain is 10 m. under the angular velocity is 0.3 and 0.6 rad/s., respectively. The results indicate tension force in conveyor chain link of the sprocket which has 34 teeth are more than sprocket which has 12 teeth about 300 N. However,these tension force have the results up to 2500 N. in while the tension force is calculated from mathematical formulas just has only 1153 N. As above-mention. The equation $2.1CMf_M$ can separate three part in terms superposition: $1.0CMf_M$ for span, $1.0CMf_M$ for return span and $0.1CMf_M$ for tail shaft and sprocket friction. They can explain the results in each part as follows: 500 N. for span, 500 N for return span and 153 N. for tails shaft and sprocket friction. The results from MBD simulation was considered in terms superposition. Span and return span are the same results as mathematical formulas. Remained tension force which has approximately 1500 N. was affected by sprocket.

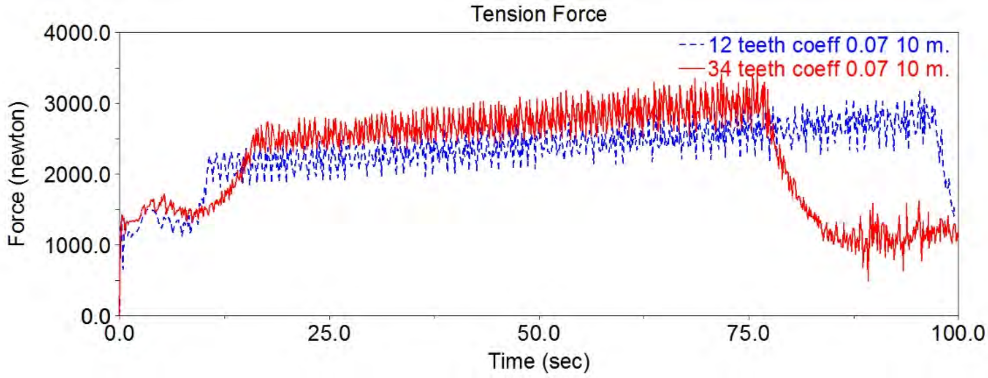

Fig. 6. Influence of sprocket size at 0.07 friction coefficient of contact and 10 m. of length with the gap is 400 mm.

Also, to investigate the effect of sprocket size. Two study case was applied to simulation which case one for high friction coefficient of contact is 0.6 and the same distance is 10 m. Case two for very low friction coefficient of contact is 0.07 and long distance is 50 m. The results indicate the system which has a high friction coefficient of contact is taken the effect of sprocket size less than the system which has a low friction coefficient of contact. The results of simulation are approximate 9900 N. and 10350 N. for sprocket which has 12 teeth and 34 teeth, respectively,. Whereas, the results from mathematical formulas is 9888 N., as shown in Fig.7.

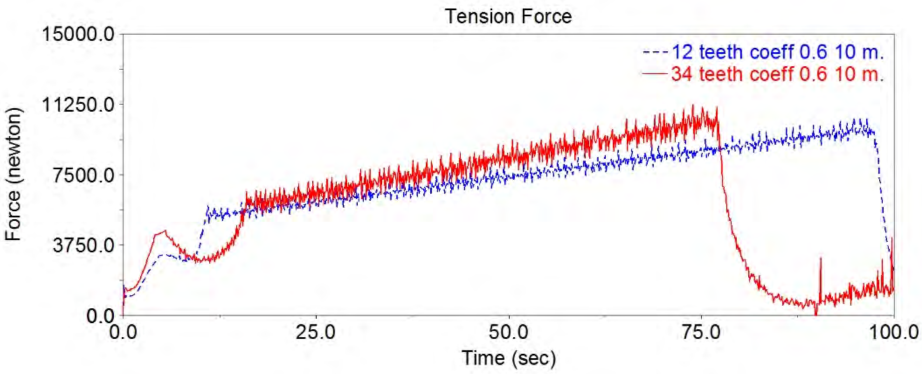

Fig. 7. Influence of sprocket size at 0.6 friction coefficient of contact and 10m. of length.

In relation to a variable of distance, the results of the simulation are approximate 6200 N. and 7200 N. for sprocket which has 12 teeth and 34 teeth, respectively,. Whereas, the results from mathematical formulas is 5768 N. which the results between MBD simulation and mathematical formulas of 50 m. of distance are closer than the results of 10 m. of distance. The results indicate the effect of sprocket size has a decrement in the system when the system has an increment in the distance. However, this effect still affects in the system which has large sprocket size, as shown in Fig.8.

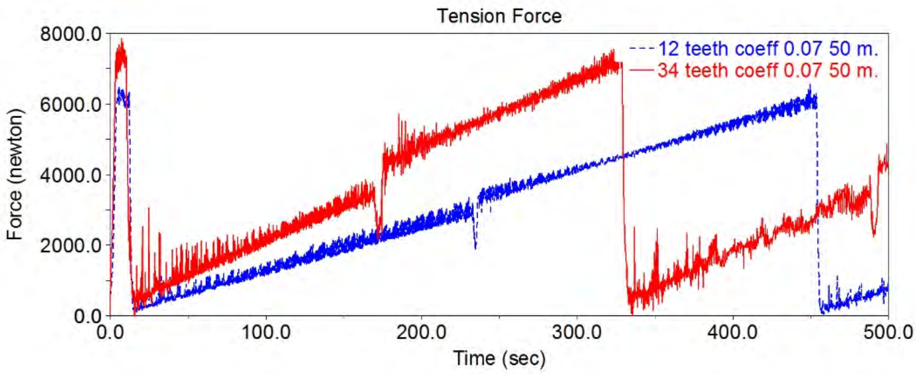

Fig. 8. Influence of sprocket size at 0.07 friction coefficient of contact and 50 m. of length with the gap is 400 mm.

One of dynamic behavior was founded in MBD simulation is a sprocket size. The behavior can be noticed obviously in systems which have very low friction coefficient. Whereas, this behavior can be neglected at low to high friction coefficient.

5.4 Tension force

In general, mathematical formulas are used in kinematical and static analysis as above-mentioned. However, these formulas cannot predict the dynamic behavior of the system, and it is difficult to calculate the system which complicates. Draw a comparison between using the commercial code and mathematical formulas to solve the solutions under basic conveyor chain layout.

Table 3 Specification of the sprockets

Parameter Name	Parameter Value
Drive sprocket teeth	34
Driven sprocket teeth	34
Sprocket diameter	1084 mm.
Sprocket width	25 mm.
Distance between sprockets	10000 mm.
Static friction coefficient of sprocket	0 (frictionless)
Dynamic friction coefficient of sprocket	0 (frictionless)

Table 4 Specification of the conveyor chain

Parameter Name	Parameter Value
Total chain length	23400 mm.
Roller diameter	62 mm.
Number of links	234
Chain pitch	100 mm.
Link width	30 mm.
Pitch to back	23 mm.
Mass of chain and objects	80 kg/m.

A basic layout is the principle model that including horizontal, vertical and incline, where the major parameters of the conveyor chain system are as shown in table 3 and table 4. Supported rail alignment and the gap are optimized to avoid the additional loads to the system. The gap is 400 mm. and supported rail alignment is 0 mm both span and return span. The relation of tension force and time of conveyor chain loop in the horizontal layout is shown in Fig. 9., when the start-up period is 10 seconds.

In term of motion, HAVSIN(time , 0 , 0 , 10 , 0.3) function was applied as an initial condition. The angular velocity of the drive sprocket is 0 rad/s. at time is 0 s. Then the speed of angular velocity increases gradually until angular velocity is 0.3 rad/s at time is 10 s. This function has a performance better than immediately step function or constant as out of speed control, as shown in Fig. 10. Comparison of functions of motion during start-up indicates the tension force in the system which out of speed control immediately increases up higher than tension force from loads that should be. Whereas, the tension force gradually increase up approximate tension force from loads in the system which controls increment of speed.

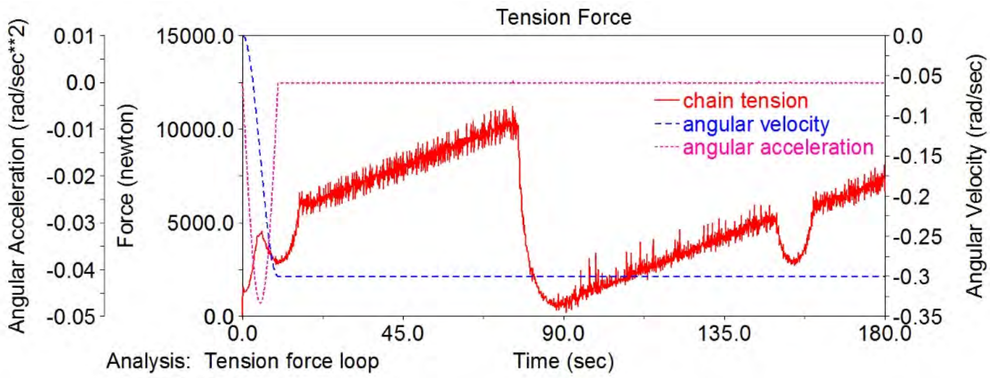

Fig. 9. Tension force loop at 0.6 friction coefficient of contact and 10 m. of length with the gap is 400 mm.

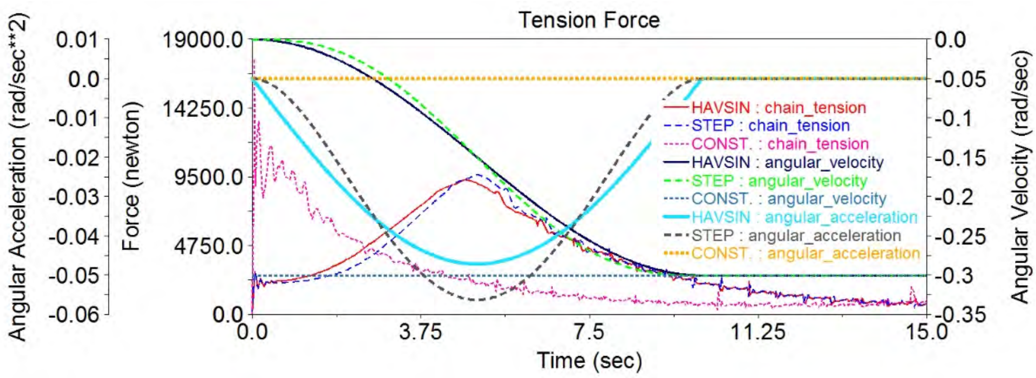

Fig. 10. Compared functions of motion between HAVSIN(time, 0, 0, 10, 0.3), STEP(time, 0, 0, 10, 0.3) and CONSTANT(0.3) as out of speed control.

Furthermore, tension force can be plotted in the form of tension profile is illustrated in the line graph, as shown in Fig. 10 - 12. Tension profile is a relation of tension force vs. displacement which tension force is a magnitude of force including X-magnitude, Y-magnitude and XY-magnitude.

The tension force raises up through span and reaches a maximum at the point that contacts the first tooth of driver sprocket. Tension force immediately decreases down through the driver sprocket and reaches a minimum at the point that contacts a final tooth of driver sprocket. However, the tension force is not reached to zero. The tension force is accumulated through return span until contact driven sprocket then become to span position.

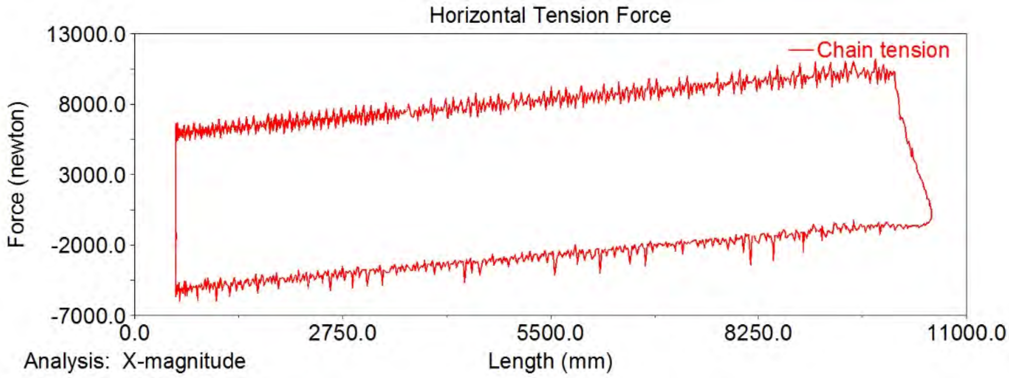

Fig. 10. X-magnitude of tension profile vs. displacement

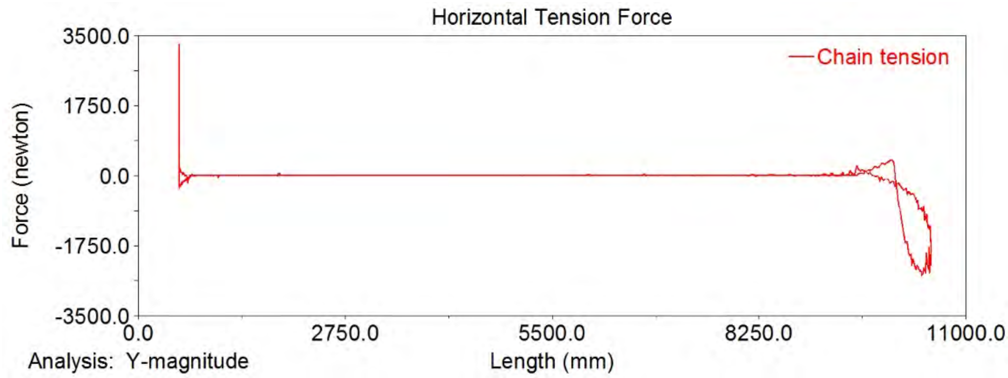

Fig. 11. Y-magnitude of tension profile vs. displacement

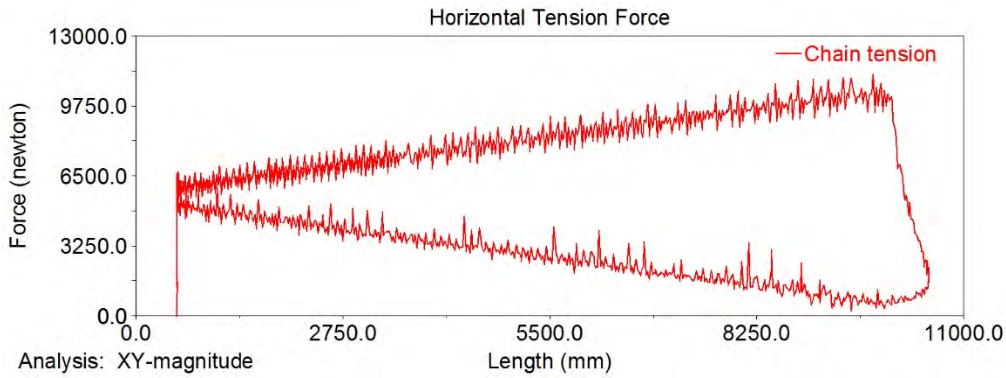

Fig. 12. XY-magnitude of tension profile vs. displacement

Fig. 13. presents a horizontal layout which varies in roller friction coefficient. Simulation model set up the roller friction coefficient is 0.03, 0.07, 0.1, 0.3 and 0.6, respectively. Comparison of tension force shown the results obtained an average error less than 7%

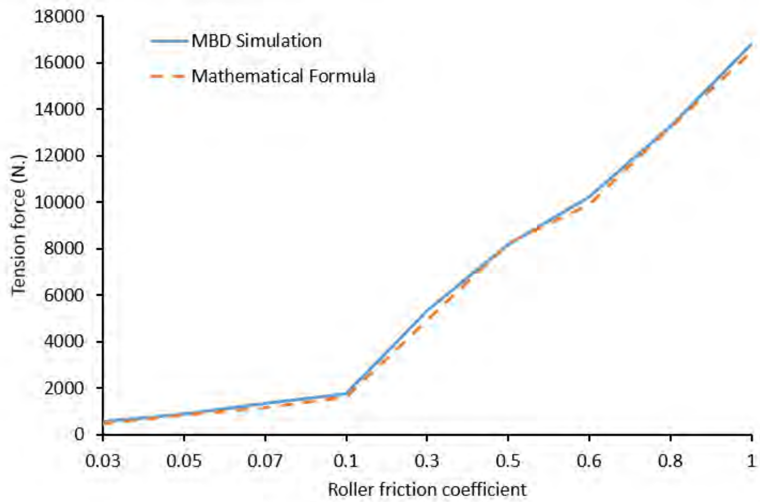

Fig. 13. Horizontal layout

Fig. 14. presents a vertical layout which varies in chain length. Simulation model set up the roller friction coefficient is 2, 4, 6, 8 and 10m., respectively. Comparison of tension force shown the results obtained an average error less than 5%

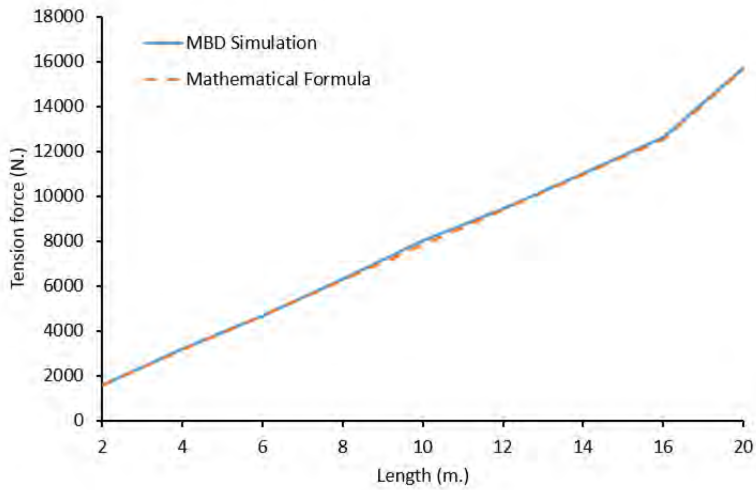

Fig. 14. Vertical layout

Fig. 15 – 17. presents an incline layout has angle 30, 45, 60 degrees, respectively which varies in roller friction coefficient per one angle position. Simulation model set up the roller friction coefficient is 0.03, 0.07, 0.1, 0.3 and 0.6, respectively. Comparison of tension force shown the results obtained an average error less than 7%

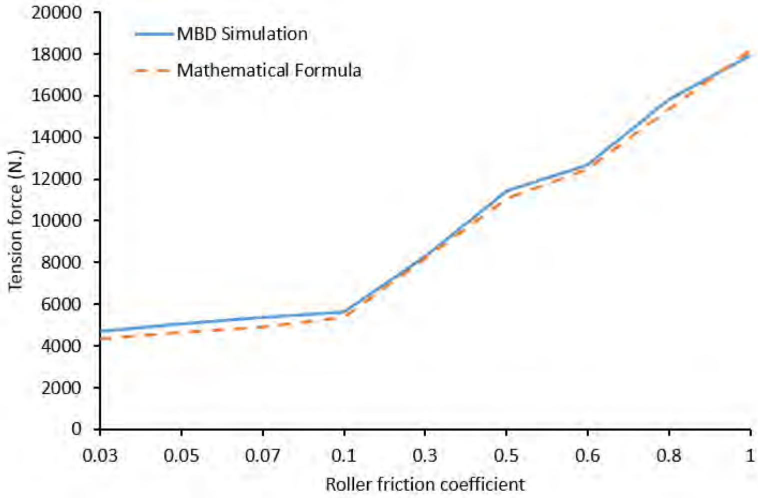

Fig. 15. Incline 30 degrees layout

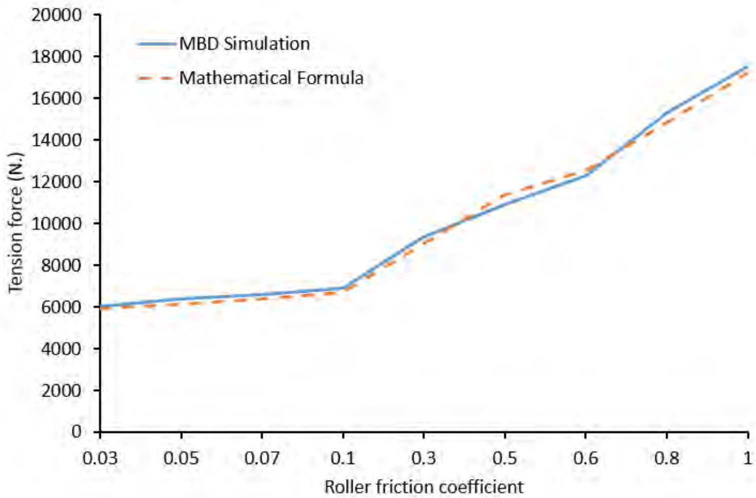

Fig. 16. Incline 45 degrees layout

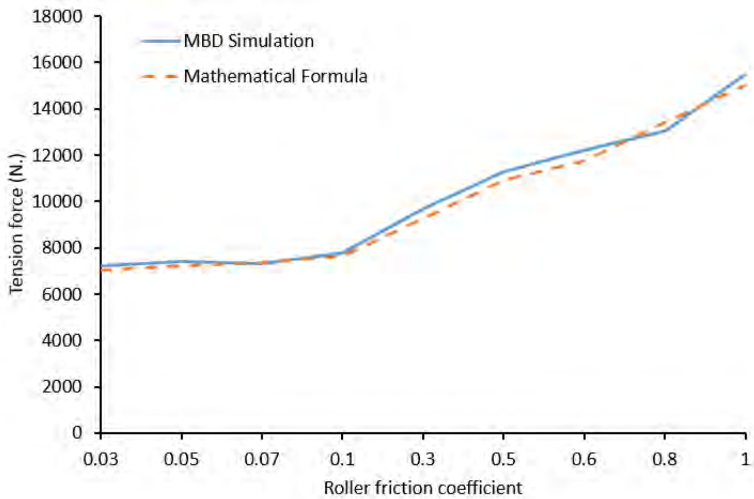

Fig. 17. Incline 60 degrees layout

7. Conclusion

The conclusion can be drawn from the study on the multi-body dynamic simulation using the commercial code as follows:

1) The results of tension force in conveyor chain by using multi-body dynamic simulation through commercial code were in good agreement in precision and obtained average error less than 7, 5 and 7% in horizontal, vertical and incline layout, respectively. The results that compared with mathematical formulas neglected the effect of dynamic behavior. Such as the effect of the gap, sprocket size, supported rails alignment and speed.

2) The general software is used to design conveyor chain system was developed from a general mathematic model which mathematical formulas such as American chain association or other chain companies in America, Europe or Asian were derived for compact and convenience for calculation. They cannot predict the dynamic behavior of a part of the component or the whole part of the system such as rubber gloves plants which have a very long production line.

3) Alignment of the component in the system has direct influence to dynamic loads and dynamic behavior as a study case that shown in this paper. Therefore, the alignment should not be disregarded. The good alignment design can reduce loads and protect excessive loads or unexpected loads in the system from dynamic effect.

4) The multi-body dynamic simulation would be useful and advance to design and calculate the complicated layout, strength in flexible-body and the dynamic loads of the conveyor chain system to save time and cost for the production line of rubber gloves plant in further work.

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