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DYNAMIC ANALYSIS OF ASCENDING HORIZONTAL BELT CONVEYOR SYSTEM WITH LUMP MASS METHOD USING LANGRAGE TECHNIQUE

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Abstract

Belt conveyor is a complex electro mechanical system. The belt is the most costly element in the system. Belt failure happens due to excessive stretch occurs during starting. Sudden rise in transient tension, results in belt failure and structural damage. It is difficult to measure these transient stresses. Belt elongation is an evident quantity for these stresses. In this research work, a convex horizontal conveyor system has been considered as series of lumped mass parameter. By Lagrange's approach, equation of motion has been developed. Simulation technique (Simulink®) has been used to evaluate these equations for dynamic quantities. Dynamic analysis of transient stretch occurs in Polyester – Nylon (EP) fabric belt is investigated for fully loaded starting condition. Maximum dynamic stretch developed in transient condition is less than 2% of the total belt length which comprises standard value.

1. Introduction

Belt conveyor has established as the first choice of material handling equipments for the movement and transportation of material in large volume. Typical belt conveyer path can be horizontal, declines, convex or concave

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vertical curves or combination of these. Ascending horizontal belt system is convex vertical type is mostly used system in mines or industries to lift bulk material. Complexity of the system, involvement of mechanical moving accessories, moving bulk material and elastic behavior of the belt itself leads a dynamic analysis of the belt conveyor system. In this paper a dynamic analysis is carried out for ascending horizontal belt conveyor for full load starting condition. A coupled five degree of freedom equation of motion formulated for the system and dynamic characteristics of belt is analyzed. Belt conveyors with change in inclination in profile path shows prominent acceleration shoot up on complete return side of conveyor belt. Velocity curves in shows that transient variation more in tail end of the conveyor and lesser variation to drive end. From displacement curves it is observed that, during initial period of starting belt segments on carrying side have positive displacement whereas; returning side belt segment shows negative displacement i.e. contraction. Elastic stretch means change in belt length that is directly changes with the pull. Belt stretch generally accumulates over a period of time. Gravity take up unit in the system compensate this belt elongation by moving up and down during operation. This way initial tension in the conveyor belt has been maintained irrespective of elongation or contraction in it. Dynamic analysis of belt stretch would predict more realistic value of maximum tension in the belt.

2. Methodology

Mechanical system can be analyzed for dynamics by representing it as a vibratory spring-mass-damper system. Equation of motion is given as follow:

$$M\ddot{x}(t) + C\dot{x}(t) + Kx(t) = F(t) \tag{1}$$

When external force $F(t)$ applied to system of mass M. Damping constant C and spring constant K of the system decides the dynamic behavior of system. Belt is passing over the idlers and running over various pulleys such as drive pulley, - up pulley and tail pulley. Belt carries greater loads on the carrying-side than the return-side. Equivalent linear mass of the belt conveyer system mainly based on summation of belt mass, bulk material mass, and linear inertial mass of idlers for the system. The components of belt conveyor system on carrying and return side contribute their equivalent linear moving masses to the local belt segment. Belt mass load M_b is based on the belt selected for the conveyor. Bulk material mass M_m, Carrying idler mass M_c and return idler mass $M_{r'}$ are calculated by the following formulae (Mulani, 2012).

$$M_m = \frac{\text{capacity of conveying } (Q) kg/\text{sec}}{\text{Velocity ofconveying } (v) m/\text{sec}} \tag{2}$$

$$M_c = \left(\frac{\text{Carrying idler set mass}}{\text{Carrying idler pitch } (S_c)}\right)\frac{L}{L_h}$$

$$+ \frac{\text{impact idler mass} \times \text{No of impact idler}}{L_h} \tag{3}$$

$$M_r = \left(\frac{\text{Return idler set mass}}{\text{Return idler pitch } (S_{r'})}\right)\frac{L}{L_h} \tag{4}$$

Where, L_h : Horizontal distance between head and tail pulley (m). Spring constant $k_i(N/m)$ depends on Young's modulus $k_i(N/m^2)$ of belt material and cross section of belt $A_b(m^2)$ for the belt length $L_i(m)$; whereas damping constant c_i (N-s/m or kg/s) is considered dependent value of equivalent mass and spring constant of the belt unit with loss factor of 0.1 (Genta and Amati 2009; Matsumuro and Kurata, 2017).

$$k_i = \frac{E_b A_b}{L_i} \tag{5}$$

$$c_i = 0.1\sqrt{m_i k_i} \tag{6}$$

Lagrange's approach is an indirect method to determine equation of motion of a system. In this method free body diagram is not required also conservative and non conservative forces are handled separately. Such feature makes it more comfortable than Newton's approach for a complex mechanical system. For the analysis, Polyester –Nylon (EP) fabric conveyor belt is divided in lumped mass units in series. Figure 1 shows belt unit of the conveyor belt.

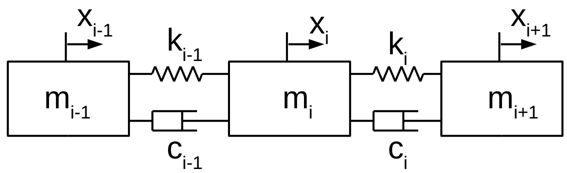

Figure 1. Lumped parameter model for belt unit.

Kinetic energy K_E, potential energy V_E and dissipation energy D_E of i-th unit are written in the terms its mass, stiffness and damping coefficient which are represented by m_i, k_i respectively. For small linear vibrations for i-th unit, practical Lagrange equation is used (Jazar, 2013).

$$\frac{d}{dt}\left(\frac{\partial K_E}{\partial \dot{q}_i}\right) - \frac{\partial K_E}{\partial q_i} + \frac{\partial V_E}{\partial q_i} + \frac{\partial D_E}{\partial \dot{q}_i} = Q_i \tag{7}$$

Q_i is applied force on i-th unit comprising of external drive force applied on i-th unit and its friction resistance to the motion, both are opposite in nature. In case of single drive conveyor belt, external drive force applied at belt unit near the drive pulley on carrying side. Frictional resistance at various station of belt conveyor is represented by W_i and it is assumed that the magnitude and the direction of the resistance force depend on the belt conveying speed (Song et al., 2006). Thus resistance has been treated as additional damping for the belt segment and substituting its value as $w_i = W_i/v$, a modified equation of motion obtained is written as

$$m_i\ddot{x}_i + (c_i + c_{i-1} + w_i)\dot{x}_i - c_i\dot{x}_{i+1} - c_{i-1}\dot{x}_{i-1} + (k_i + k_{i-1})x_i$$
$$-k_i x_{i+1} - k_{i-1}x_{i-1} = F_i(t) \tag{8}$$

System of belt conveyor is considered as vibratory system of five degree of freedom (Sakharwade, S. G., and Nagpal, S. [2]). Two lump mass units on carrying side. Three on return side as shown in Figure 2. Length of units is considered on the basis of geometrical profile of belt conveyor system. Equivalent mass, frictional and inertial resistance for each unit is calculated independently based on devices and system part allied with it.

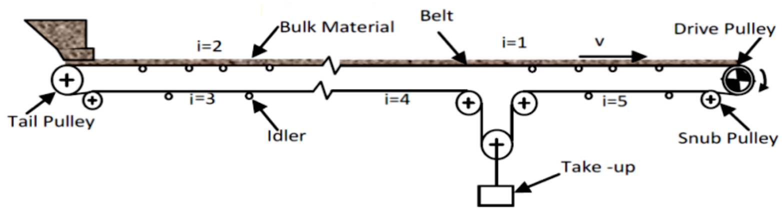

Figure 2. Five segments of conveyor belt system.

Power for transporting material on belt needs to overcome friction resistance and to raise potential energy of material. Conveying resistance (all frictional and non frictional) occurred at the belt segment is calculated by using following generalized formula. Suffered resistance is considered when bulk material was fully stacked on the conveying belt.

$$w_i = [CfgL_h(M_c + M_r + M_m + 2M_b) + M_m H_m g]_{i=1, 2, \ldots, 5} \tag{9}$$

Force requires for steady state running of fully loaded belt conveyor thus calculated as follows. Practical value of tractive pull at starting is considered 1.45 times more than calculated value to overcome system inertia. Calculation of starting time t_s is dependent on conveying velocity and starting acceleration is shown following equation (Mulani, [3]).

$$t_s = \frac{v}{\left(\frac{P_s - P}{M'}\right)} \tag{10}$$

Belt conveyor is as fully stacked on carrying side with bulk material and at rest condition. Initial conditions for the differential equation are at, $0, \dot{x}_i = 0$. There are differences in between the variation of displacement curves of each belt segment at starting of belt which causes elongation and contraction between conjugative belt segments. Greatest stretch at the belt found before head pulley on carrying side. Return side is slack side of belt. Accumulation of belt occurs between drive pulley and take-up. This contraction of belt lowers down overall stretch in conveyor belt for a period of steady state cyclic running time. This contraction has been neglected for short period of transient condition. Total stretch in the belt is formulated as follows.

$$Y(t) = \sum_{i=1}^{n-1} [x_i(t) - x_{i+1}(t)] \quad (11)$$

Figure 3 shows ascending-horizontal profile belt conveyor for transporting dry sand run for a conveying distance of 182.88 m with 11 m of lift. EP630/3, 0.915 wide fabric belt is used for transportation. Carrying idlers: 3 roll type tough idlers at 1.372 m spacing. Return idlers: Single horizontal roll type idlers at 3.05 m spacing

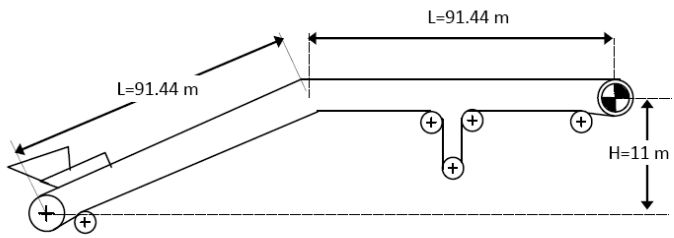

Figure 3. Ascending Horizontal belt conveyor.

Ascending horizontal belt conveyer has been divided in five units and calculations are done for equivalent linear moving mass and conveying resistance for each unit. Second order constant coefficient differential equations can solve using a pair of integrators. (Herman, 2017). A simulink model is prepared for the above five equations. All above equations are 2nd order differential equations represents dynamics of each belt segment. In these five coupled simultaneous equations, unknowns are acceleration, velocity and displacement of each belt segment. Velocity and displacement of each segment equation also act as excitation for other belt segment equation, which increases the complexity of simulink model.

3. Conclusion

Acceleration curves in Figure 4, shows starting acceleration increases rapidly. Sudden rise in acceleration on carrying side segment increases belt stress whereas on return side (empty side) it creates instability of system. Acceleration variation in transient period progressively gets stable to steady state condition in due time. Acceleration curves of 5th belt segment (on return side near the drive pulley) has prominent shoot up during transient period, requires more stable return idlers in that region.

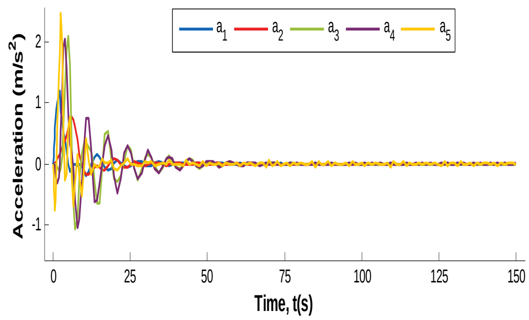

Figure 4. Acceleration curve.

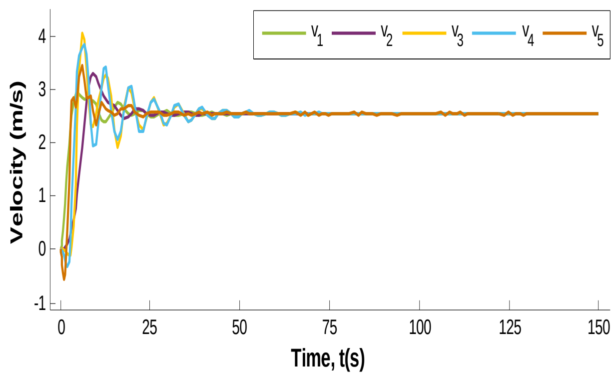

Figure 5. Velocity curve.

Time lag between velocity curves Figure 5 shows that a nonlinear stress wave progressively spread from drive end towards tail end. Transient acceleration and velocity curves indicate that there is more vibration on the return side of belt than carrying side. Variation from settling time to a steady state condition is different for each belt segment shows viscoelastic behavior of conveyor belt.

At any time instance, each belt segments are having different displacement value Figure 6. This difference causes elongation and contraction between belt units. More deviation in these differences has been observed during transient period. Thereafter theses differences remain constant for the period of steady state running. Two belt segments on carrying side have maximum positive difference in the displacement values, indicate maximum belt stretch near drive pulley in the carrying side. Algebraic summation of these differences in the displacements value gives rise stretch at particular time instance in the belt Figure 7. Its transient variation is remarkable in starting stage and settled at steady state condition.

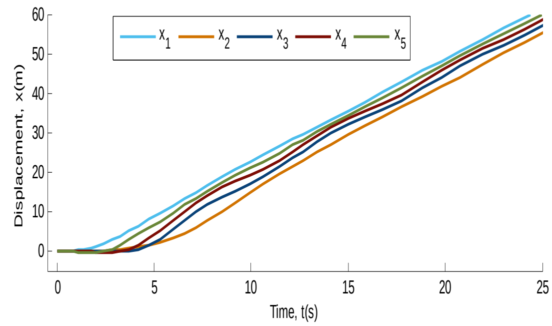

Figure 6. Transient displacement curve.

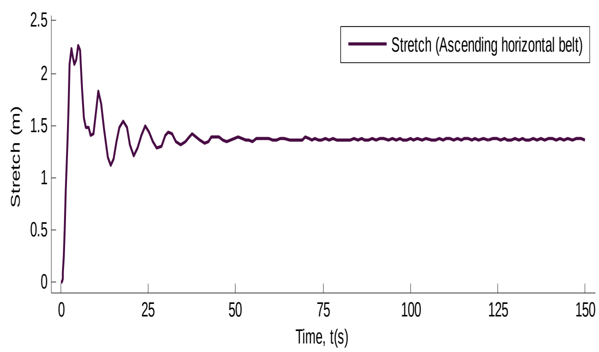

Figure 7. Belt stretch curve.

Figure 7 shows variation of belt stretch for belt conveyors. Belt stretch value for the ascending horizontal belt conveyor is found as 0.6% of the total length. Conveyor manual and belt manufactures recommended the stroke length of take-up which is able to adjust maximum 2.0% elongation of fabric belt length.

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