ANALYSIS OF BELT CONVEYOR USING FINITE ELEMENT METHOD

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Abstract:

Belt conveyors are the most common material handling conveyor in use today. They are generally the least expensive powered conveyor and are capable of handling a wide array of materials. Depending on the type chosen, belt conveyor can carry everything. Today, belt conveyors are in use in many industries, like mining industry, belt conveyors has an increasing importance and use. They have important part of mining and cement factories, grain manipulation, etc. For a belt conveyor longer than one kilometer, viscoelastic properties of the belt is un-negligible and longer-life with healthy operation for conveyors design require detailed engineering calculation. In this study, a real conveyor project is taken into account. Wave propagation speeds are calculated. Studied belt is divided into finite number of beam elements all of which are represented by mass, spring and a dashpot. Motions of equations are derived by obtaining mass, stiffness and damping matrices. Initial conditions are specified and effecting forces are calculated. Equations of motions formed a linear, second order ordinary differential equation system and it's transformed into state-space equations. By using MATLAB's Control System Toolbox commands, the system is simulated for a step input. Results are separated as velocities and displacements. The conveyor is examined on carry and return sides. Return side and carry side reactions are compared. In the light of obtained data and drawn graphs, belt strength and mill diameters or materials are advised to be revised due to the excessive forces occurred in transient stage. Some additional recommendations are proposed to improve the performance.

Keywords: ANALYSIS, BELT CONVEYOR, FINITE ELEMENT METHOD

1. Introduction

For more than 200 years, belt conveyors are in use in many industries, especially in mining, cement, steel and agricultural industries. Belt conveyors have had an increasing importance and use during the past century. Today, they have the key role in mining, cement factories, grain manipulation, etc. By time, applications of transporting materials from one point to another extended its boundaries; by requiring longer transfer distances, much faster speeds and much higher capacities. While expectations from belt conveyors are growing bigger, problems to be solved grew in parallel. For a belt conveyor longer than one kilometer, viscoelastic properties of the belt is un-negligible and longer-life with healthy operation for conveyors' design require extensive engineering work and more complex calculations.

The dynamic behavior of conveyors have not been an issue of interest until a few decades ago. However, as a general issue, dynamic behavior of axially moving continua is first examined in late 19th century. This subject hasn't met a general interest until 1960s. Scientists and engineers accelerated their research on analytical solutions for axially moving strings as they are the simplest form. From 1960s to 1970s, the solution techniques, scenarios and models have been improved. From 1970s, various beam models have been introduced. In parallel to emerging capabilities of computers, in 1984 first FE (finite element) model of a belt conveyor is applied. The use of FE models expanded the research of belt conveyor dynamic behavior research. As an advantage of FEM (finite element methods) planar and web methods have been introduced lately [1-9].

2. Parameters of Belt Conveyors

Belt conveyors typically consist of a series of sections that makeup an entire conveyor. Shorter units can be single self-contained conveyors. All conveyors consist of sections: intermediate beds, drive, take-up, end pulleys (end brackets).

Several calculation methods for conveyors are mentioned and described. Those methods are identified and common figures and differences are mentioned and compared. Furthermore, the most frequently used two methods; DIN 22101[9] and CEMA[10] (Conveyor Equipment Manufacturers Association) Universal Method are introduced in detail, formulas and tables are included. German standards have much wider scope and specify the full conveyor design process. The CEMA approach is based on identifying the tension and power contributions from several friction mechanisms and components.

In this study a real conveyor project is taken into account. The studied overland belt conveyor is planned and designed to be operative in ERDEMIR which is the largest flat steel manufacturer of Turkey [12]. This conveyor is a troughed belt conveyor with 35° trough angle on carrying side. Return side is flat. The conveyor is the longest part of a conveyor system which is over 3 kilometers in total to transport 1500 tons of iron ore per hour from New Ore Stock Area to existing ore manipulation system in the factory.

The belt conveyor is designed to carry iron ore pellets with lump size less than 20 mm. The desired capacity to be conveyed is 1500 tones and a safety factor; 1.25 is used in order to compensate the irregularities during reclaim. The conveyor speed is chosen to be 2.6 m/s; the same speed value as the existing ore manipulation system. Studied conveyor is the longest belt conveyor in the system and is 1000 meters long. It has a straight profile without any vertical or horizontal curves. ERDEMIR Plant Standards are also followed in the design, like idler distance is taken as 1 meter.

Before the calculations, some simplifications are considered. All the secondary resistances according to DIN 22101 are ignored. Gravity take-up is assumed to be connected to the head / drive pulley. Pulley resistances are ignored.

The conveyor power is calculated with DIN 22101-1982 method. General friction coefficient, f is taken as 0.022. Required, steady-state drive torque is obtained. Then a reducer and hydraulic coupling is chosen. Considering the total efficiency motor power requirement is also calculated.

Reducer is chosen according to the motor speed, in this case 1500 rpm, and desired conveying speed. Hydraulic coupling is preferred to limit the excessive start-up torque of the motor.

After selection of drive equipments, belt tensions are calculated. Eytelwein Equation is used to determine the steady state tension values on carry side and return sides of the drive pulley. Belt safety is checked with the highest belt tension. Steady-state tension on carry side is wanted to be over a certain value that the sag between
two carrying idlers is not less than 1.5% of the distance. Weight of the gravity take-up is calculated according to the steady state tensions.

![Fig. 1 Dynamic Model of Belt Conveyors](image1)

In this study, the startup of the conveyor after an emergency stop is examined. Early seconds of transient behavior of the conveyor belt is studied. The conveyor is supposed to start while carried material is fully laid on the carry side of the belt. The belt is initially tensioned with gravity take up.

3. **Finite Element Method Approaches**

The finite element method has been most extensively used in the field of solid and structural mechanics. The various types of problems solved by the finite element method in this field include the elastic, elastoplastic and viscoelastic analysis of trusses, frames, plates, shells, and solid bodies. In dynamic problems the displacements, velocities, strains, stresses, and loads are all time dependent.

![Fig. 2 The variation of velocity on the carry side of the conveyor.](image2)

A model of viscoelastic beams lined one after another can be represented as a multi-degree of freedom mass-spring-damper system. Motor torque output through the hydraulic coupling and reducer is introduced to the first element as the drive force. Resistance, inertial and viscoelastic forces that applies on each element is assigned.

To obtain the equations of motion; mass, stiffness and damping matrices are determined. Mass matrix is a diagonal matrix and elements representing the carry side and return side have significantly different values. In stiffness matrix, the connection pattern is not changed for the entire conveyor. Damping coefficient varies on carry side and return side. Thus, damping matrix element values are significantly different for representing carry and return sides. Force vector is formed as the only external force is applied at the drive pulley.

![Fig. 3 The variation of velocity on the return side of the conveyor.](image3)

Equations of motions formed as linear, second order ordinary differential equation system and its transformed into state-space equations. By using MATLAB's Control System Toolbox commands, the system is simulated for a step input. Results are separated as velocities (Fig. 2, Fig.3) and displacements (Fig.5) and variation of tensions on the carry side of the conveyor belt (Fig.4).

![Fig. 4 The variation of tensions on the carry side of the conveyor belt.](image4)

4. **Discussion and Results**
CEMA and DIN 22101 standards use static analysis. It is used as all masses are accelerated at same rate and time and the belt like a rigid body. The belt on drive pulley with drive torque creates a stress wave. The stress wave propagates along the belt when the belt starts moving. There are stress variations along the belt. These stress variations are cause longitudinal waves. Longitudinal waves are dampened by resistances to motion. Therefore belt elasticity is taken into consideration in the mathematical model of the conveyor belt.

Wave propagation speeds are calculated for carrying side and return side of the conveyor. It's observed that there is no single wave propagations speed that is unique all around the belt but two different speeds due to element masses in carry side and return side. Due to load in the carry side, wave propagation speed of the return side is almost bigger than on the carry side.

The transient behavior of the conveyor for early stages of start-up is examined on carry and return sides. Three locations are viewed through simulations; head, intermediate and tail. Speed and displacements of the chosen nodes and speed and displacement of carry and return sides are plotted together and compared. Return side and carry side reactions are calculated. Tension changes are plotted. Wave propagation speed differences and its effects are given at various plots.

The variation of velocity on the carry side of the conveyor belt is displayed in Fig. 2. The velocity values at head, intermediate and return ends of the belt conveyor can be investigated.

The variation of velocity on the return side of the belt conveyor is displayed in Fig. 3. The values of velocity on head, intermediate and return ends of the belt conveyor can be investigated.

![Fig. 5 The variation of displacements on the carry side of the conveyor belt.](image)

5. Conclusions

The higher tension means the higher forces acting on the shaft of the pulley. Therefore, the diameter of the pulley shaft should be increased.

It has been observed that the wave propagation progress to the other side of the belt. It caused the excessive stretch of the belt. Therefore, initial choice of belt can be made carefully.

References

[9] DIN 22101 “Continuous conveyors – Belt conveyors for loose bulk materials- Basic for calculation and dimensioning”.