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Original Research Paper

# Optimization and experimental study of transport section lateral pressure of pipe belt conveyor

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ABSTRACT

Due to the squeezing action of bulk materials, conveyor belt was expanded and deformed outwards when the pipe belt conveyor was used to transport the materials; lateral pressure borne by this belt also varied in a complex way. In this paper, the condition of lateral pressure borne by conveyor belt of pipe belt conveyor was studied to establish a coupling model for such a lateral pressure. Furthermore, considering the actual sophisticated forces of the conveyor belt, a calculation formula was further derived for relations among lateral pressure of the pipe conveyor belt, material diameter and filling rate. In addition, the discrete element method was also adopted to simulate its lateral pressure and a prototype was developed for the conveyor belt of a pipe belt conveyor to perform experimental verifications. It was found that simulation analysis approximately agreed with test results. Under a circumstance of definite design conditions, the optimization of material diameter and filling rate was beneficial to improvement of forces taken by the conveyor belt of the pipe belt conveyor as well as its service life and reliability.


## 1. Introduction

Pipe belt conveyor is a kind of special belt conveyor developed based on the ordinary trough belt conveyor. As it is equipped with an exclusive rounding roller set, flat friction tape navigation can take a shape of round piping through external force constraints so as to realize material custody transfer. In addition to features of large transport capacity, long transport distance, strong adaptability and transport continuity, etc. Which are possessed by ordinary belt conveyors, the pipe belt conveyor is also provided with multiple advantages such as less environmental contamination thanks to the custody transfer, space saving, small radius of turning circle, achievable inclination conveying and space turning, little maintenance and low use cost. As shown in Fig. 1, it is a green, efficient and environmental continuous conveyor device with great development potential in the new age.

In contrast to the ordinary belt conveyor, the pipe one has a more favorable character of service, such as small installation space, being airtight and environmental, and space turning and large inclination transport. [1,2]. Without any doubt, the pipe belt conveyor which is equipped with multiple merits is an important choice for bulk material transportation. At the time of transporting such materials, the conveyor belt of this conveyor is under actions of several forces including the gravity, the friction force, the lateral pressure from materials and tension, etc. [3]; especially the outward expansion of belt caused by lateral pressure from materials, it makes stress states of a pipe belt conveyor become more sophisticated than belts of ordinary belt conveyors so that both the reliability and the service life of them are substantially reduced and shortened respectively [4]. For the calculation formula that can be used to compute the lateral pressure taken by belts, it has not been generally accepted by the academic circle and thus becomes a research content for many scholars both at home and abroad [5]. According to Professor Vieroslav, a computational formula was acquired for the layout space between the lateral pressure of conveyor belt and the roller by utilizing a comprehensive test experiment platform for the transition segment of a pipe belt conveyor through data regression analysis [6]. For Professor Zamiralova and Gabriel, they jointly designed a special test device for pipe belt conveyor to carry out real-time tests for static and kinetic stress characteristics of pipe conveyor belt [7]. A scholar from the Netherlands established a finite element model for the pipe conveyor belt and also performed simulations to comparatively analyze the simulation and the measured results so as to obtain the static properties of such a belt [8]. Besides, specialists and scholars from Australia [9], Poland [10], Spain [11] and Malaysia [12], etc. all con-

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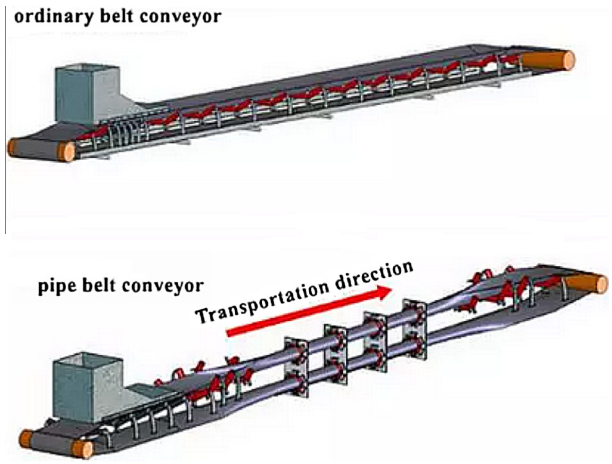


**Fig. 1.** Principle comparison chart between ordinary belt conveyor and pipe belt conveyor.

ducted in-depth researches on the pipe belt conveyor. Concerning writer of this paper, he studied the design for tension transition segment of a pipe rubber belt conveyor [13] in the 1990s. Other domestic scholars such as Sun Kewen [14] and Yang Houhua [15] also performed researches on the tension of a pipe belt conveyor's conveyor belt. Under the joint efforts of researchers at home and abroad, design philosophy of the pipe belt conveyor with a more and more extensive application scope becomes increasingly perfect. However, due to the unique pipe structure of the conveyor belt, its application in the main transportation area of raw coal in a coal mine shaft has been limited and there are no its successful application cases yet publicly covered by literatures for now.

According to the above problem, an optimized design scheme is presented in this paper for the lateral pressure of a pipe belt conveyor's transport segment with an aim to reduce the lateral pressure borne by its conveyor belt and improve both reliability and service life of the belt.

## 2. Mathematical model for lateral pressure borne by pipe conveyor belt

Pipe belt conveyor for underground filling materials was developed by writer of this paper together with Triumph Heavy Industry Co., Ltd. in 2012 through co-operation and this is the first conveyor of this kind in China. In addition to the obtainment of an MA certificate which was also the first one within the industry, the conveyor was successfully applied to the working face of gob-side entry retaining operation in Xieqiao Coal Mine of Huai'nan Mining Industry, which lays a solid foundation for theoretical researches and practical applications of the pipe belt conveyor in the future.

### *2.1. Simplification model*

Based on the domestically first underground pipe belt conveyor developed by the Triumph Heavy Industry Co., Ltd., as given in Fig. 2, a modified 3-D simplification model is put forward to study the side pressure (between every two sets of hexagonal roller groups) of pipe conveyor belt, as shown in Fig. 3. The inclination between the transport direction of a pipe belt conveyor and the horizontal coordinate is $\theta$; and the pipe belt conveyor moves in low speed along this direction. Assumptions made for this model as follows. Coal and ores which are both scattering particle media are applicable to continuum hypothesis; that is, materials can be seen as numerous continuums which are distributed continuously and formed by isotropic particles.

**Fig. 2.** Chinese first coal mine underground pipe belt conveyor.

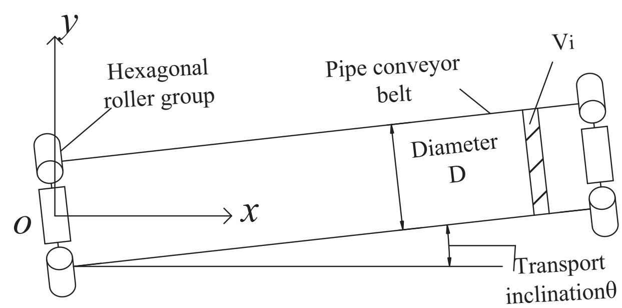


**Fig. 3.** Simplified model of pipe belt conveyor.

### *2.2. Construction of mathematical model*

Fractal dimension which is an important principle for fractal can be defined as follows. If $R(x)$ is a non-void subset of $(X,d)$ in d-Euclid space, for a set of $A \in R(x)$ which can be covered by the closed set with a finite number of $N(A,r)$ and a radius of $r$ no less than 0, make

$$Q = \lim_{r\to 0}\{\ln[N(A,R)]/\ln(1/r)\}$$

Then, $Q$ is the fractal dimension of Set $A$.

Fractal model for raw coal materials can be described as follows. In Fig. 4, while the box represents solids of raw coal particles, the white part refers to crack distribution of particles; then, cube particles of a unit size are taken and assumed to be broken into particles whose sizes are half of the original ones. If the broken particles are 3-D Euclidean BULKS, 8 post-breaking granules with the proximate grade can be formed. However, considering that material particles are small fractal blocks where crack defects exist, it is impossible for such 8 post-breaking granules to take shape while the sum of the number of cracks and the number of small material granules with the proximate grade remains unchanged. For small fractal blocks with half size of raw coal particles are crushed in line with the above rules.

Regarding the fractal distribution, granule number $N$ and particle diameter $d$ satisfy a such a relation [11],

$$N(d) = d^{-Q}$$

where $Q$ refers to the fractal dimension of post-breaking raw coal particles and it ranges from 2.0 to 3.0 [16]. In common cases, it is assumed that the original diameter of raw coal particles is $d_1$, while $d_1/b$ for post-breaking granules with the proximate grade the number of which is $b_w$, $w$ refers to the conventional Euclidean dimension. For granules of the proximate grade which are crushed according to the rule above, after they are crushed for $i$ time(s)