Design of Permanent Magnet Levitation Roller for Belt Conveyer

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Abstract: Roller is an important component for the belt conveyor. The function of roller is supporting conveyor belt, to ensure the belt conveyor smooth operation. This study aims at the working condition of the roller of long-distance belt conveyor, which suffers from severe wear of mechanical bearing and belt, large rotational resistance, huge power dissipation, large vibration and noise. A new type of maglev roller is designed, which is supported by permanent magnetic bearing (PMB), but the axial force is restrained by mechanical force. The finite element method (FEM) was employed to analyze and design the structure and magnetic circuit of the permanent magnet levitation roller. The structure parameters of magnet levitation roller were optimized. The simulation and test results have proven the proposed bearing feasible and effective.

Keywords: Belt conveyor; Maglev roller; Permanent magnetic bearing; FEM

1. Introduction

The belt conveyor is one of the most important conveying equipment of bulk material, and is widely used in many fields [1]. The roller is effective and important component for supporting conveyer belt especially for smooth operation. However, due to the friction of mechanical bearing, it is difficult to decrease wear, vibration and noise, to improve the transmission capacity and reduce the maintenance cost when belt conveyor is too long [2]. The experiment results show that the roller is about 30% of the total cost, and the energy consumption of about 70% is from the friction between the belt and the roller or the friction of the roller itself. So it is very important to solve the friction energy consumption.

Ohji *et al* [3] proposed a new conveyor system based on a passive magnetic levitation unit, which use repulsive forces between the stator and rotor permanent magnets. They had examined the way of generating vibration and rotation in the conveyance direction by the various excitation methods. Fedorko *et al* [4, 5] had made some investigations about the failure damage of the belt and conveyor belt. Based on the visual control, this conveyor belt cannot be unequivocally determined to be damaged or suitable for operating condition. The paper presents analysis of the sample of the conveyor belt with local anomaly which was formed during the experimental measurements for determination of the dependence among the weight of sharp material falling on the conveyor belt, shatter height and force conditions in the conveyor belt. Another investigation showed the change of physical and mechanical properties of dynamically damaged conveyor belts and analyze their inner structure–conveyor belt carcass by non-destructive method of analysis. Zhang Dongsheng *et al* [6] considered the relationship between belt deflection, the life of roller and idler spacing from the viewpoint of statics, the relationship between cost, rotational resistance and idler spacing from the viewpoint of economics, the relationship between non-resonant design and idler spacing from the viewpoint of dynamics. Due to the roller suffered from complex seal structure, larger rotational resistance in operation, Zhang Yanhua [2] isolated the roller revolute pair with the severe environment and simplified the seal structure of internal bearing. The running resistance was decreased at last. Above all, some optimized idler spacing, the number of roller, the structure of roller, and designed new seal structure to reduce mechanical friction. These methods have achieved some effect, but the overall effect is not obvious.

Magnetic bearings are a typical mechatronic product, which are mainly used for rotating applications but also exist for translational ones [7, 8]. Permanent magnet bearings for rotating shafts are constituted of ring permanent magnets. The values of importance are the magnetic field created by such a ring magnet, the force exerted between two ring magnets and the stiffness associated. Some researchers have discussed the application of the magnetic bearing technology to the belt conveyor [9, 10]. The roller was changed into a permanent magnet block, and the conveying belt is magnetized, then the material was been transported by using the character of permanent magnetic iron. But the magnetic transport belt with high magnet field is hard to manufacture, meanwhile there need complex structure, high cost and hard maintenances.

In this paper, we designed a new type of maglev roller, which was supported by permanent magnetic bearing, the axial force was restrained by mechanical force. The finite element method was employed to analyze and design the parameters of magnet levitation roller. The contact free feature of permanent magnet bearings offers attractive advantages like friction free and lubrication free operation, low maintenance, long life etc. It has a significant sense for improving the speed and precision of equipment operation, adapting to special working environment, and reducing energy consumption.

2. Materials and methods

A combination of theoretical analysis and numerical simulations was used in this study, in which the magnet field of the maglev roller was carefully analyzed, the forces acting on the belt was investigated by a FEM commercial software package ANSYS 12.1.2 (ANSYS Inc., Canonsburg, PA, USA). These approaches aided in selecting the most suitable permanent magnet levitation roller design for the belt conveyer.

2.1 Maglev belt conveyer

In our laboratory, a model of maglev belt conveyer, consisting of some of permanent magnet levitation roller was designed, as shown in Fig. 1. Since the transport belt in this belt conveyer is magnetically levitated, there is no mechanical contact between the rotating and stationary parts in radial direction, which will lead to increasing of durability and improving the transport capacity of the conveyor.

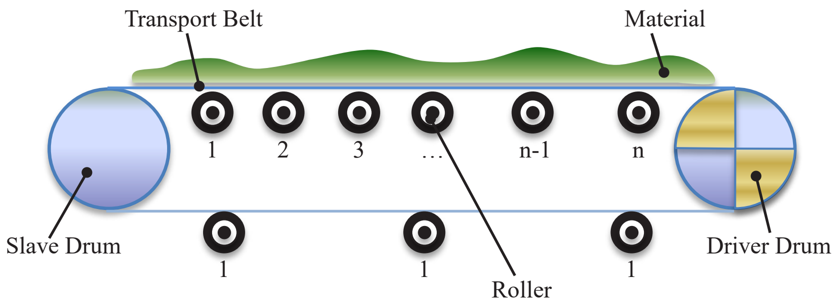
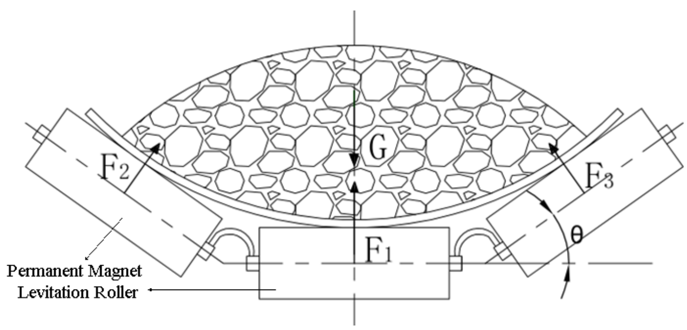


Fig 1. Permanent magnet levitation belt conveyor

Assuming that the transmission line is set on the n section of the supporting area, the supporting spacing as the traditional supporting roller bearing is the same, but the supporting structure is changed. The transport belt, the material and the roller of each interval are set to the gravity G, and the mechanical model is shown in Fig. 2.



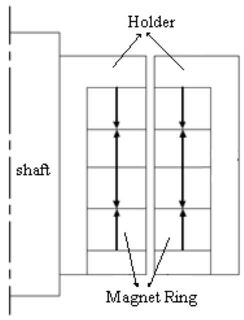


Fig. 2. Mechanical model Fig. 3. Permanent magnetic bearing

The magnetic force generated by the permanent magnet levitation roller is *F*:

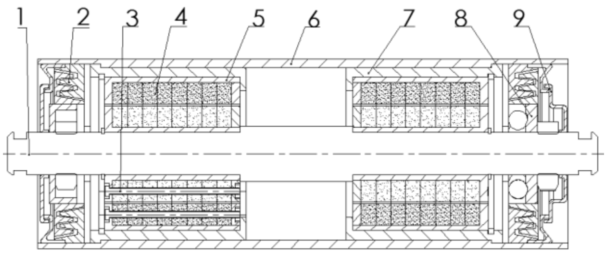
$$F \approx G = (q_B + q_G)a_0 g + q_{GR} \tag{1}$$

where q_B is the mass of unit length conveyer belt (kg/m), and q_G is mass of unit length material (kg/m), q_{GR} is the rotating part mass of roller (kg/m); g denotes the acceleration of gravity; a_0 represents the spacing of bearing roller (m).

According to our design object, a_0=500mm, q_B=8.8kg/m, q_G=44.2kg/m, q_{GR}=5.45kg/m. So, the magnetic force must bigger than 120N.

2.2 Permanent magnet levitation roller

To realize the maglev supporting of roller, axial magnetized ring was choose, the structure as shown in Fig. 3. The structure schematic diagram of permanent magnet levitation roller was proposed, as shown in Fig. 4, including shaft (1), sealing device (2), holder (3), permanent magnetic bearing (4), cylinder (5), fixed bolt (6), bearing block (7), and ball bearing (8).



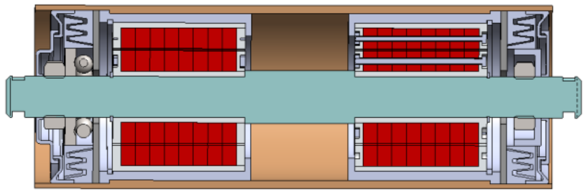


Fig. 4. Permanent magnet levitation roller

3. Results and discussion

According to the research[11], when the radial width of inner ring l and outer ring L is close or equal, and the cross-section of magnetic ring is square or rectangular, the radial bearing stiffness will be optimal.

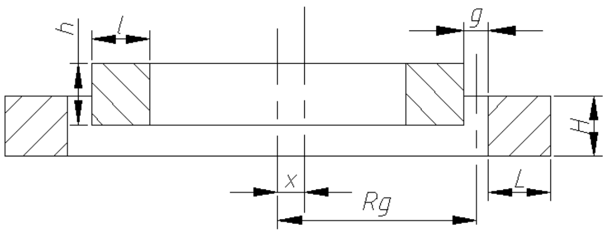


Fig. 5. Parameters of radial permanent magnetic bearing

The parameters of radial permanent magnetic bearing is shown in fig. 5. The axial length of inner ring is h. The axial length of outer ring is H. The radial width of inner ring is l. The radial width of outer ring is L. The air gap is g. The radius of air gap is R_g. The radial displacement is x.

Based on the traditional structure of roller improvement, shaft diameter, shell diameter, roller length should be observed the industry standards as far as possible. The parameters of radial permanent magnetic bearing is shown in Table 1.

Table 1　Parameters of radial permanent magnetic bearing

Parameters	Value
Diameter of shaft /mm	20
Diameter of shell/mm	89
Radial levitation force /N	>120
Inner radius of inner ring/mm	25
Outer radius of inner ring /mm	45
Inner radius of outer ring /mm	47
Outer radius of outer ring /mm	67
Axial length/mm	8
Air gap/mm	1
Number of ring	6

3.1 The axial length of magnetic ring

Due to the constraint in size, the radial width of magnetic ring was set as 10 mm. In order to analyze the influence of the axial length of magnetic ring reasonably, the axial length of magnetic ring from 4 to 12 mm was analyzed. When the axial length of inner ring h and outer ring H is close or equal, the radial bearing stiffness will be optimal. The outer ring H is equal to the inner ring h and the axial displacement was 0 mm. With the increase of the outer ring H, the radial force of one pair magnetic rings increased at the same radial displacement x. With the increase of the radial displacement x, the radial force of one pair magnetic rings increased at the same axial length H, as shown in fig. 6. When H<8 mm, the increase trend that the radial force of one pair magnetic ring was large. With the increase of the outer ring *H*, the increase trend became slowly. Besides the magnetic rings not only satisfy the levitation force, but also consider the strength. Because the magnetic force is large, it's easy to break up if the thickness of ring is too thin. Therefore, when *H*=8 mm, the radial force of one pair magnetic ring was the optimal.

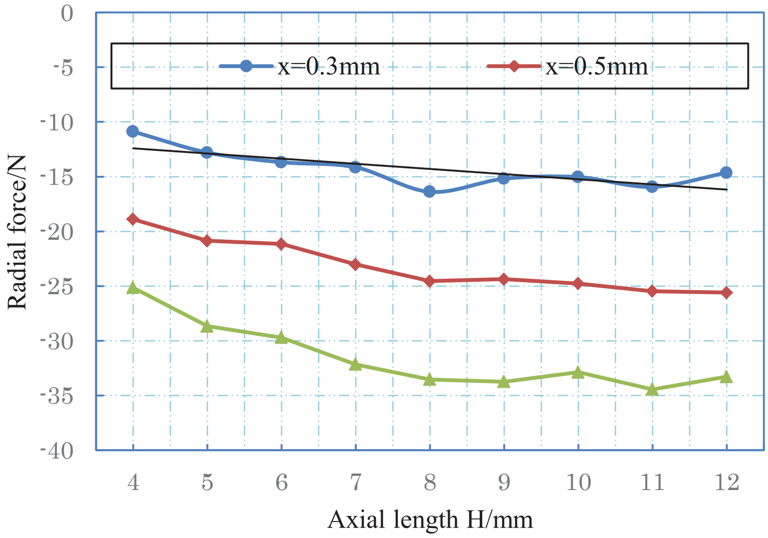


Fig. 6. Influence of axial length on the radial force

3.2 The air gap of magnetic ring

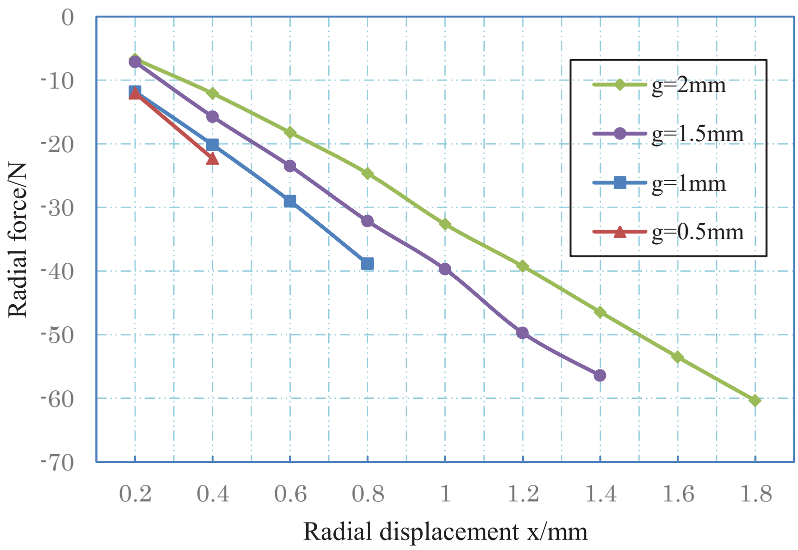


Fig. 7. Influence of radial displacement on the radial force

When the radius of air gap *Rg* is constant, the radial magnetic force of permanent magnetic bearing was obtained at the different air gap from 0.5 mm to 2.0 mm, as shown in fig. 7. With the decrease of air gap, the rise trend of radial force became large, as shown in fig. 7. But the smaller air gap was relevant to the smaller the largest radial force. Because of the influence of the structure and working condition, to obtain large radial force and stiffness, the air gap was set as 1 mm.

3.3 The number of magnetic ring

For radial permanent magnetic bearing, the capacity of one pair magnetic ring was limited. To be able to support the weight of the materials, usually muti-pair magnetic rings were used to improve the capacity. Because radial superimposed permanent magnetic ring will occupy a larger space, the process and assembly requirements are difficult, so the axial superimposed manner is adopted. The influence of the different number of magnetic ring on the radial force and stiffness was analyzed. With the increase of the number of magnetic ring, the radial force of permanent magnetic bearing increased at the same displacement *x*. With the increase of the displacement *x*, the radial force of permanent magnetic bearing increased at the same number of magnetic ring, as shown in fig. 8.

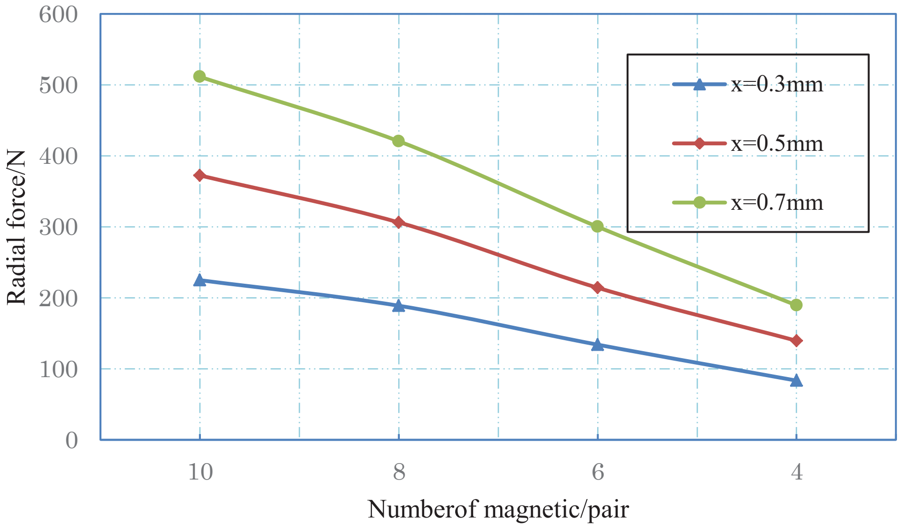


Fig. 8. Influence of number of magnetic ring on the radial force

The magnetic force must bigger than 120N. As the materials distribute unevenly on the belt, the magnetic force need to be smaller or bigger. Therefore, considering to support the maglev roller and obtain a large stiffness, the number of magnetic ring was adopted 6 pairs.

3.4 Rotational resistance test

The rotational resistance of roller was measured by lifting the weights. When the roller started to rotate, the mass of the weight was write down. If not spinning, then continue to add the weight. The results are showed in Table 2.

The rotational resistance of the maglev roller compared with ordinary roller decreased by about 25%, as shown in Table 2. Because of the large number of belt conveyor rollers were used, thus reducing the rotational resistance effect was quite obvious. The maglev roller was shown in fig. 9.


Fig. 9. Maglev roller

Table 2 Rotational resistance

Maglev roller			Mechanical roller		
Shell Diameter (mm)	weight (g)	Rotational resistance (Nmm)	Shell Diameter (mm)	weight (g)	Rotational resistance (Nmm)
54	140	74.088	54	190	100.548
	160	84.672		200	105.84
	140	74.088		210	111.132
	150	79.38		200	105.84
	160	84.672		200	105.84
Mean		79.38	Mean		105.84

4. Conclusion

Aiming at the problem of severe wear and large rotational resistance, we designed a new type of maglev roller. The advantages of permanent magnetic bearing no friction, low power consumption were used.

The parameters of radial permanent bearings are optimized by finite element method. And ultimately the magnetic circuit and the structure are designed, a small range of air gap could obtain a great radial stiffness to meet the design requirements.

The experiment showed that the rotating resistance of maglev roller was less then mechanical roller obviously. Next, we will optimize the roller structure, and further accomplish the experiment of the whole belt conveyor.

Acknowledgements

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References

[1] SONG Weigang, ZHANG Zunjing, Wang Ying. The progress of the belt conveyor systems[J]. Hoisting and Conveying Machinery, 2004(2):1-4.

[2] ZHANG Yanhua, Optimization design on roller structure of long-distance belt conveyor[J]. Coal Mine Machinery, 2014,11:173-174.

[3] Ohji T, Ichiyama S, Amei K, et al. A new conveyor system based on a passive magnetic levitation unit having repulsive-type magnetic bearings[J]. Journal of Magnetism & Magnetic Materials, 2004, 272(272):1731-E1733.

[4] Fedorko G, Molnar V, Marasova D, et al. Failure analysis of belt conveyor damage caused by the falling material. Part II: Application of computer metrotomography[J]. Engineering Failure Analysis, 2013, 34(8):431-442.

[5] Fedorko G, Molnár V, Živčák J. Failure analysis of textile rubber conveyor belt damaged by dynamic wear[J]. Engineering Failure Analysis, 2013, 28(3):103-114.

[6] ZHANG Dongsheng,ZHANG Licai,MAO Li. Optimum design of belt conveyor idler spacing[J].,2008,12:32-34.

[7] Schweitzer G, Maslen E H. Magnetic bearings: theory, design, and application to rotating machinery[M]. Springer, 2009.

[8] HU Yefa, JIANG Zhengfeng, Zhou Zude. Basic theory and application of magnetic bearings[M]. Machinery Industry Press, 2006.

[9] CHENG Gang. Research on magnetic cushion belt conveyor[D]. AnHui University of Science and Technology, 2012.

[10]HU Kun, WANG Shuang, LI Deyong et al. Research on air gap characteristics of permanent magnetic cushion belt conveyor[J]. Journal of China Coal Society, 2015(3):701-706.

[11]JIA Dongfang, LI Wenpeng, WANG Xiping et al. Study and design of a radial permanent magnet bearing[J]. Machine Design and Research,2010,02:38-42.