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An Investigation into the Performance Failure of Conveyor Belt Ploughs

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Summary

This article deals with and investigates the performance failure of a common conveyor belt plough. The type of plough referred to is widely used in the bulk materials handling industry, especially in the fields of coal and mineral ore mining.

The investigation also uncovers and analyzes the plough's failure to clean a conveyor belt return strand of incidental material fines and proposes means to overcome and rectify this shortcoming in a practical and economic way.

1. Introduction

A conveyor belt plough arrangement, as shown in Fig. 1, is extensively used in materials handling industries. It protects conveyor belts against damage caused by spillage material. Material, falling on to the empty return belt, is removed by its vee shape, before it can get caught between pulley and belt.

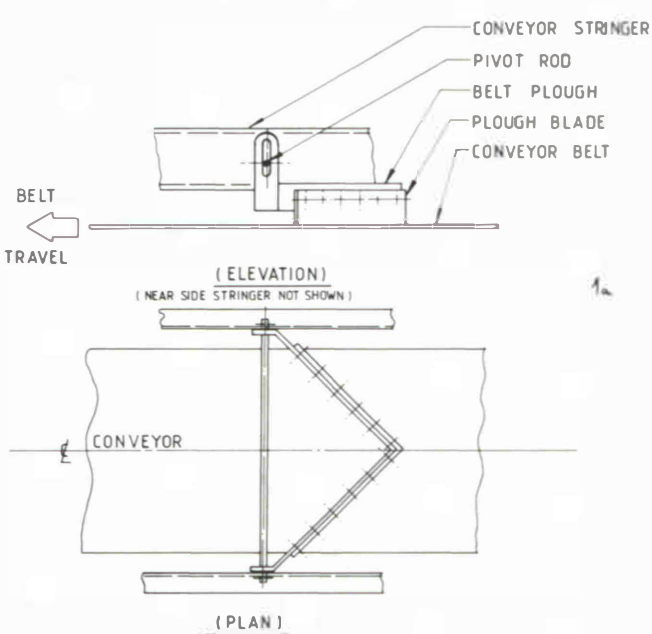

Fig. 1: Common conveyor belt plough arrangement

To be effective, it is installed either near the conveyor tail end to protect its pulley or it is situated ahead of the automatic belt tensioning arrangement, where it prevents spillage from falling on to the take-up pulley.

When a device of this kind is considered adequate for its purpose, the simplicity of its design and the economic appeal of both manufacture and installation, make it a favourable competitor against other similar devices.

Failure to perform as expected during operation is likely to be attributed to faulty installation or negligent maintenance. The nature of its failure to perform adequately can be detected by the fact that material finds its way past the plough's scraping blade. Under certain conditions, this material adheres to the pulley face and builds-up on it to such proportions that it will ultimately damage the belt.

In order to perform satisfactorily, the scraping blade of the plough must be in continuous contact with the belt across its full width; the contact pressure being as uniform as practical. It can be proven that this condition cannot be achieved under operating conditions with an arrangement as shown in Fig. 1. The aim of the following investigation is to find its shortcomings. Simple modifications will be suggested, resulting in the improvement of the plough's efficiency, without having to employ a more complex belt cleaning system.

2. Pre-Start Condition

The belt plough is an item to be fitted to the conveyor assembly after its belt has been installed. This takes place when the system is at rest. It is assumed here that the belt plough has been correctly installed, i. e. position, alignment, contact between belt and blade are all according to its design criteria. (See Fig. 2)

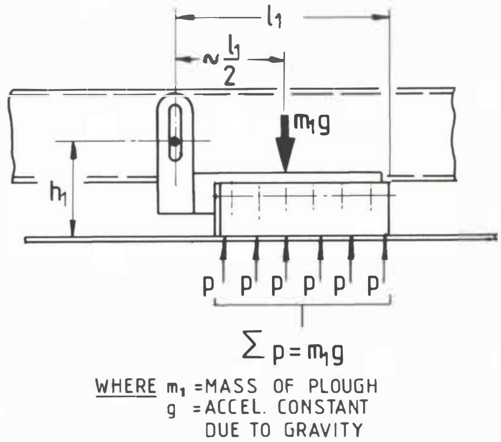

Fig. 2: Balance of forces on plough at rest (pre-start condition)

3. Operating Condition

Fig. 3 shows the forces acting, as assumed, on the belt plough to be in equilibrium under operating conditions.

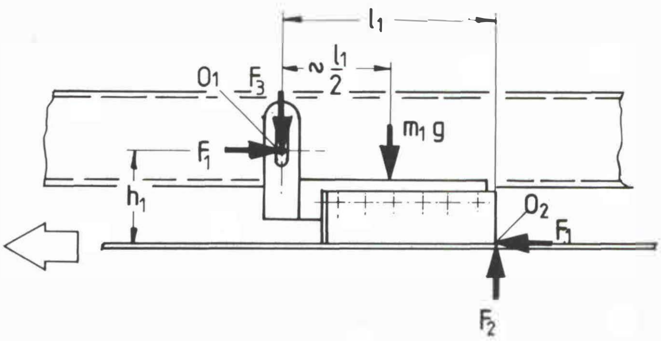

Fig. 3: Balance of forces under operating conditions (assumed)

At start-up, the belt carries the plough with it, until the slack in the hinge is taken up and the pivot rod is jammed between the holes of the pivot lugs of the plough and holes in the conveyor stringer. Fig. 4 shows this instant. Thereafter, the plough begins its function as the belt slides beneath its blade.

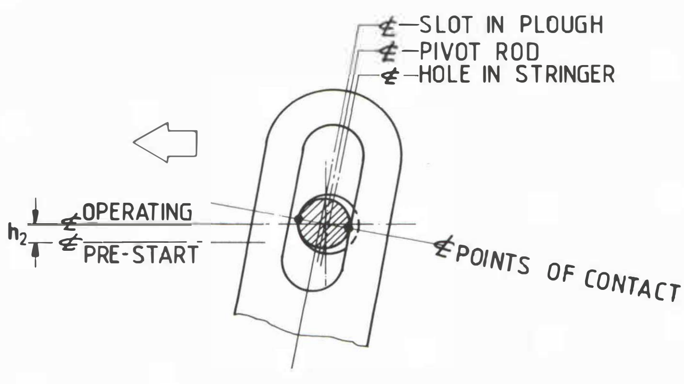

Fig. 4: Pivot rod after start-up

The frictional resistance, F_1, of the plough to the movement of the belt, can be expressed as follows:

$$F_1 = \mu_1 m_1 g$$

where μ_1 = coefficient of friction between belt and blade

Since F_1 acts at a distance h_1 from O_1, the resulting moment, $F_1 h_1$ tends to rotate the plough about O_1 in a clockwise direction. O_2 being the point on the plough furthest away from O_1 prevents this rotation by being pressed against the conveyor belt with force, F_2.

The shortcoming of this system is highlighted when it is assumed that belt and blade are made of inelastic materials. Thus, the reactive force F_2 at O_2 acting over the distance l_1 constitutes the opposing moment to establish equilibrium. Therefore:

$$F_2\, l_1 = F_1\, h_1$$

Examining the equilibrium condition, by employing moment equations around points O_1 and O_2, it can be shown that:

$$F_2 = \frac{m_1 g \left(\mu_1 h_1 + \frac{l_1}{2}\right)}{l_1}$$

and that:

$$F_3 = \frac{m_1 g \left(\mu_1 h_1 - \frac{l_1}{2}\right)}{l_1}$$

(clockwise moments +ve)

In practice $\frac{l_1}{2} > \mu_1 h_1$ renders F_3 negative. This indicates that F_3 acts in the opposite direction as assumed and consequently lifts the plough at O_1 by an amount h_2. (See Fig. 5)

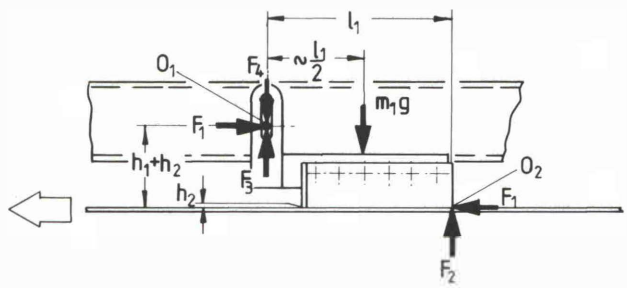

Fig. 5: Actual situation under operating conditions

The frictional resistance, F_4, offered by the rod against the upward movement of the plough, can be expressed in terms of F_1 and μ_2, where μ_2 is the coefficient of friction between the materials at their point of contact (steel/steel). Therefore:

$$F_4 = F_1 \mu_2$$

For the vertical equilibrium condition, where forces acting upwards are considered +ve,

$$F_2 + F_3 - F_4 - m_1 g = 0 \text{ (See Fig. 5)}$$

Therefore:

$$F_3 = \frac{m_1 g}{l_1}\left[l_1(\mu_1\mu_2 + 1) - (\mu_1 h_1 + \frac{l_1}{2})\right]$$

To determine the direction of this force, realistic values are ascribed to the terms enclosed in the bracket:

$\mu_1 \sim$ 0.5 (rubber/rubber)
$\mu_2 \sim$ 0.15 (steel/steel)
$l_1 = l_1$
$h_1 \sim 0.3\, l_1$
$\therefore [l_1 (0.15 \times 0.5 + 1) - (0.15 \times 0.3\, l_1 + 0.5\, l_1)]$
$\therefore [1.075\, l_1 - 0.95\, l_1] = 0.8\, l_1$ (+ve)

Therefore the direction of the F_3 remains as assumed — upwards. In consequence, there is a lift-off of the plough from the belt permitting fines to find their way past the plough's blade and so providing the possibility of material build-up on the pulley faces, eventually causing damage to the conveyor belt.

Removing the assumption of the inelasticity of the belt and blade materials does not remove the tendency of behaviour of the plough. The exact position of F_2, the actual amount of contact area, the local deflection of the belt due to F_2, etc. do not form part of this investigation. Their influence on the problem effects only the magnitude of h_2.

Since h_2 is a maximum at O_1, the major material build-up on the conveyor pulleys can be expected increasingly towards the edges of the belt.

4. Correction

It was shown in the foregoing discussion, that under operating conditions a force, F_3, acts upwards at O_1. Applying an equal and opposite force at this point will bring the plough back into its original position, the one it occupied at pre-start condition.

Introducing a set of links of mass, $m_2 g$, as shown diagrammatically in Fig. 6, will have a reacting force, F_5, of magnitude $^1/_2\, m_2 g$, acting vertically at O_1.

Therefore: $$F_5 = \frac{m_2 g}{2}$$

Fig. 6 shows the forces acting at O_1 under operating conditions.

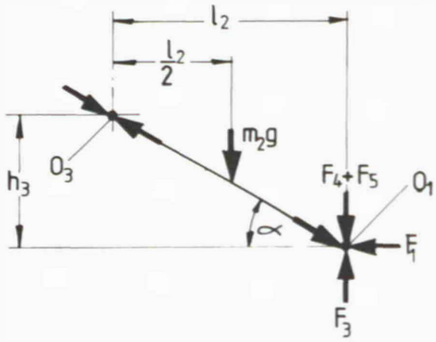

Fig. 6: Forces acting at O_1 under operating conditions

For the moment equilibrium around point, O_3

$$\Sigma MO_3 = 0 \text{ (clockwise moments + ve)}$$

$$(F_4 + F_5)\, l_2 + F_1 h_3 - F_3 l_2 = 0$$

dividing by l_2

$$F_4 + F_5 - F_3 + F_1 \frac{h_3}{l_2} = 0$$

from which

$$\frac{h_3}{l_2} = \frac{F_3 - F_4 - F_5}{F_1}$$

but l_2 is a function of F_5, which leaves h_3 to be the only unknown quantity.

To prevent the plough from jamming between belt and hinge point, O_3, the angle, α, being the inclination of the link to the horizontal, should be kept at around 20°, or

$$\tan \alpha = 0.4$$

$$\therefore \frac{h_3}{l_2} = 0.4$$

from which $$h_3 = 0.4\, l_2$$

and $$\frac{F_3 - F_4 - F_5}{F_1} = 0.4$$

Depending on the masses $m_1 g$ and $m_2 g$ of the belt plough and the linkage, the above stated relationship of forces might not hold true. Therefore, means have to be introduced, in order to obtain this relationship.

There are two possibilities besides the statement being an equality;

a) $$\frac{F_3 - F_4 - F_5}{F_1} < 0.4$$

and

b) $$\frac{F_3 - F_4 - F_5}{F_1} > 0.4$$

To make case (a) an equal statement, F_3 has to be increased accordingly. F_1, F_3, F_4, and F_5 can be established physically; then let F_{xa} be the quantity necessary to make the statement equal:

$$\frac{F_3 + F_{xa} - F_4 - F_5}{F_1} = 0.4$$

$$F_{xa} = 0.4\, F_1 + F_4 + F_5 - F_3$$

Fig. 7 shows an arrangement where the additional mass, $m_3 g$, is placed centrally at a distance l_3 from O_3.
From the moment equation:

$$F_{xa}\, l_2 = m_3 g\, l_3$$

$$m_3 g = F_{xa} \frac{l_2}{l_3}$$

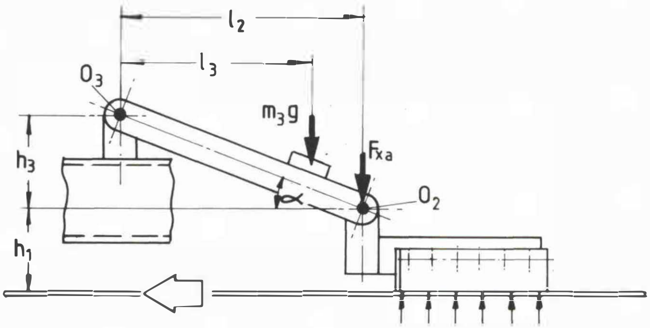

Fig. 7: Additional mass for case (a)

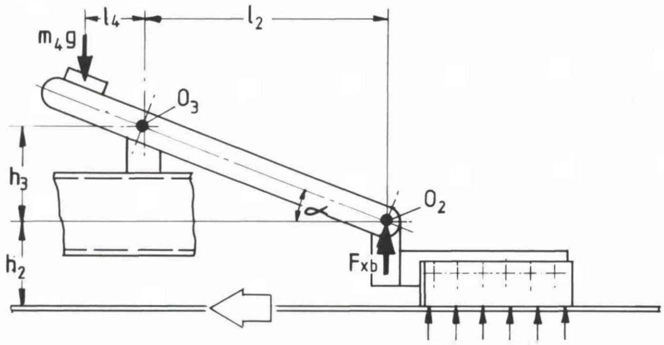

Fig. 8: Additional mass for case (b)

Similarly to make case (b) an equality, the effect of F_3 has to be reduced by an amount F_{xb}.

Fig. 8 shows an arrangement, where this is possible. By extending the links as shown and placing a mass, m_4g, centrally at a distance l_4, from point O_3, the equality can be realized thus:

$$\frac{F_3 - F_{xb} - F_4 - F_5}{F_1} = 0.4$$

$$F_{xb} = F_3 - F_4 - F_5 - 0.4\,F_1$$

From the moment equation:

$$F_{xb}\, l_2 = m_4 g\, l_4$$

$$m_4 g = F_{xb}\,\frac{l_2}{l_4}$$

where l_4 is an assumed practical dimension. It must be borne in mind that the mass of the additional length of the link, depending on the magnitude of F_{xb}, is of more or less significance and it is left to the Designer's discretion to ignore it or not in his value of m_4g.

5. Conclusion

A belt plough of the design considered here is a relatively small item in a conveyor assembly. It is not meant to be a belt cleaner as used on the working face at the discharge end of the conveyor. Its function is to protect the belt having holes punched through its carcass by lump size material after getting trapped between pulley and belt. However, fines do find their way on to the return strand of the belt, which could cause trouble, if not removed from the belt.

Their removal means an improvement in the function and efficiency of the plough and less down-time and maintenance.

Furthermore, in the region of contact between belt and plough, the belt must be flat. It is advisable to locate a flat return idler immediately before and after the plough.

The original slotted holes in the plough's hinges, allowing for blade wear, are no longer required. However provision should be made to avoid the metal part of the plough touching the belt and so prevent possible damage to the belt.

Acknowledgements

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