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CONTINUOUS BELT WEIGHING

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BELTCON 2

BELT CONVEYORS - DESIGN, OPERATION AND OPTIMIZATION

The Institute of Materials Handling — The Institution of Mechanical Engineers — The Materials Handling Research Group (University of the Wit

CONTINUOUS BELT WEIGHING

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SUMMARY

This paper outlines the basic principles embodied in continuous belt weighing and presents an overview of various systems that are employed. These include mechanical type systems which depend on belt and idler deflection, batch weighing and weigh feeding and non-contact type systems such as those employing gamma-ray absorption. Factors affecting the selection of weighing systems are reviewed. The various sources of error that may occur in belt weighing systems are discussed and an indication is given of the magnitude of the errors that may be incurred.

1. INTRODUCTION

Belt conveyors are used internationally to transport bulk solid materials in a variety of forms. In the mining and mineral processing industries in particular enormous tonnages are conveyed almost exclusively by belt conveyor. Keeping account of the vast quantities of materials transported can be quite difficult and may take various forms, the most frequent and obvious of which is the use of the conveyor itself.

Continuous weighing of bulk solids while being transported on conveyor belts has distinct advantages over other discontinuous methods, although it may sacrifice a little accuracy to realise the advantages. The accuracy of continuous belt weighing systems depends on many variables some of which can be controlled and the accuracy thereby improved. The various sources of errors and methods to reduce their magnitude are discussed in some detail.

2. PRINCIPLES OF BELT WEIGHING

Belt weighing is the process of determining the mass-flow rate of bulk material being transported on a belt. It involves the determination of the weight of material on the belt and the linear speed of the belt. These two variables are determined separately and brought together electronically to produce flow rate or total weight as shown in typically block diagram form of Figure 1.

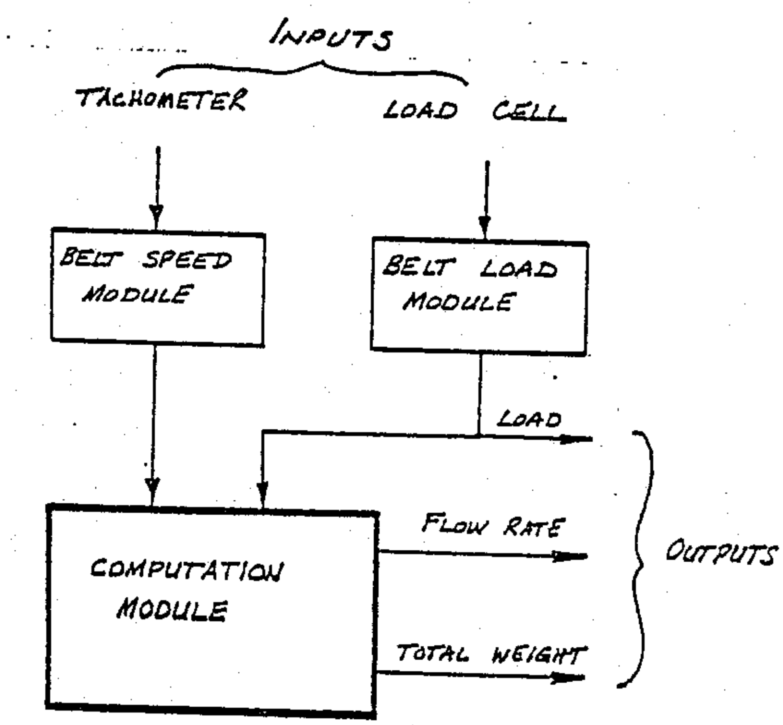

Figure 1 - Block diagram representing typical belt weighing systems

3. CONTINUOUS BELT WEIGHING

Conveyor Belt Weighing methods generally fall into two broad groups.

(i) Continuous Belt Weighing

(ii) Batch Weighing or Weigh Feeding.

Some of the methods are now discussed in more detail.

Continuous Belt Weighing refers to a method of weighing where a short "weigh length" is incorporated into a section of a much larger conveyor installation as shown in Figure 2.

Batch Weighing or Weigh Feeding usually refers to a method of weighing that utilises a special shorter and separate conveyor installed specifically for the purpose of metering and *controlling* mass-flow feeding of bulk material sometimes continuously but usually in batches of lower mass-flow rates.

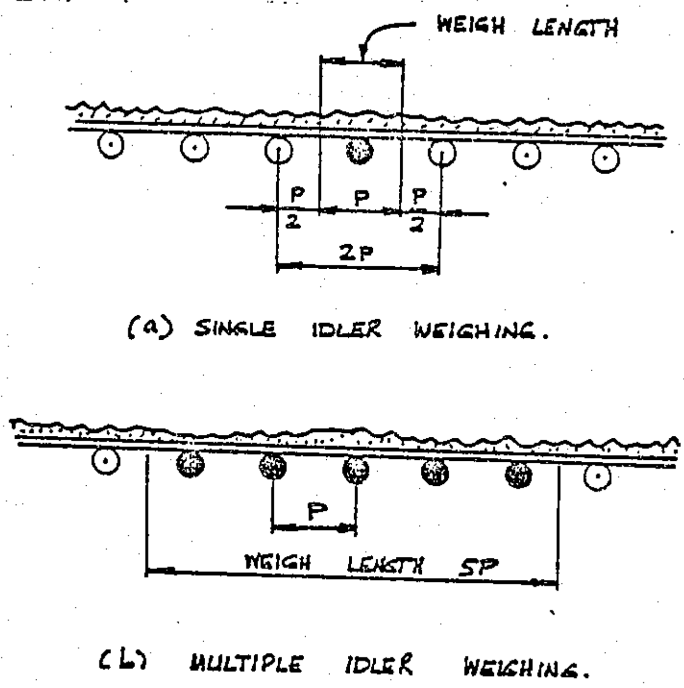

Figure 2 - Configuration of Continuous Belt Weighing

In Continuous Belt Weighing the portion of the conveyor system used in weighing is called the "weigh length" and the idlers called the "weigh idlers". These essentially mechanical systems are either "single idler" systems or "multiple idler" systems as shown diagramatically in Figures 2(a) and 2(b) respectively. An alternative non-contact continuous weighing system, essentially electronic in operation, uses the principles of gamma radiation absorption.

3.1 Single Idler Systems

Single idler systems use one idler set only for the determination of weight of material on the belt. There are various methods by which the weight on the single idler set is measured.

(i) Two compression load cells between the idler frame and main conveyor frame as shown in Figure 3 determine the weight supported by the idler set directly. Some method of flexible constraint is required for most compression load cell installations and accuracy depends to some extent on the design of these constraints.

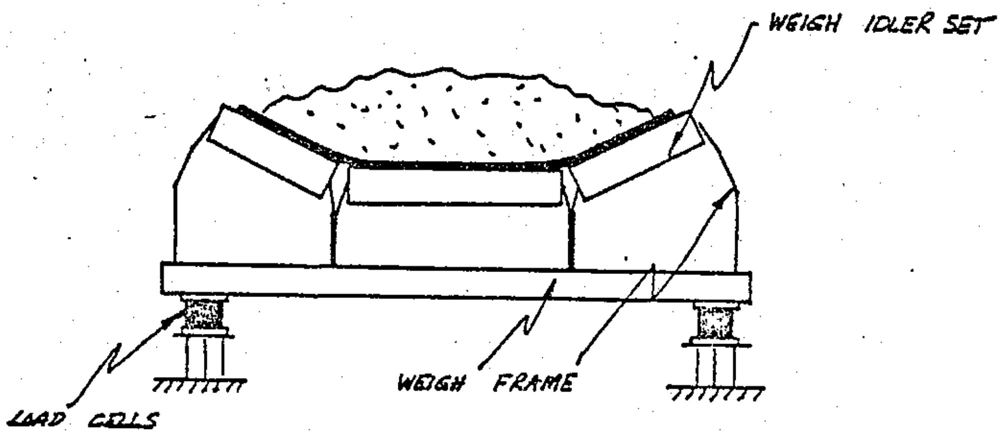

Figure 3 - Single idler double sided compression load cells

(ii) A second and relatively new method uses a strain transducer arrangement to measure flexure in the "weigh idler" frame. This method is reasonably simple and least expensive of all methods to instal but usually does sacrifice some accuracy for these benefits. A simple arrangement of the strain transducer method is shown in Figure 4.

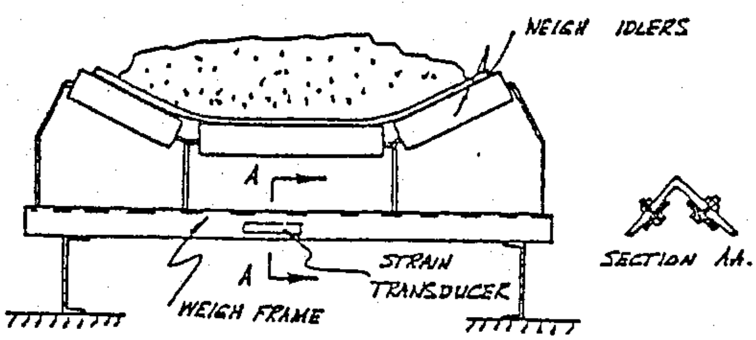

Figure 4 - Single idler strain transducer belt weighing system

(iii) An alternative single idler system using one load cell as the weigh sensor is shown in diagramatic form in Figure 5. The simple weigh frame is pivoted from the main conveyor frame below the belt surface as shown. Either a tension or compression load cell measures the load on the weigh idler which can be mechanically adjusted or zeroed using the counterweight as a balance. A disadvantage of this configuration is the pivot which can sometimes "fret" or sieze in hazardous environments producing an error.

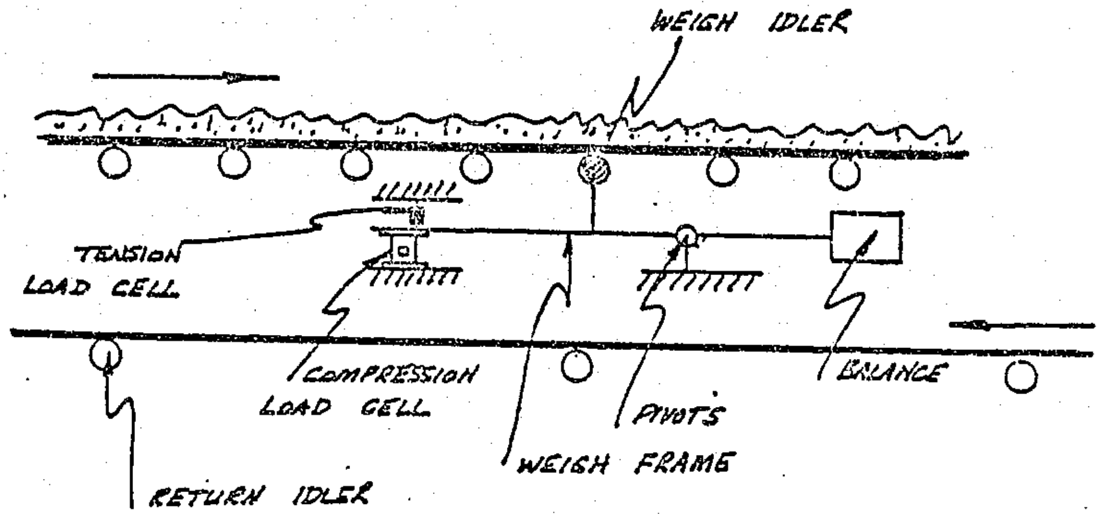

Figure 5 - Single idler load cell and pivot system

(iv) To overcome this problem a rigid cantilever idler support has been used. A typical configuration of this method is shown in Figure 6 where the deflection of the cantilever is measured with a displacement transducer. Although this method eliminates the problems that can result from a badly worn or siezed pivot another source of error may be introduced. A displacement transducer requires as much displacement as possible to operate accurately within the limits of resolution of displacement transducers. Too much deflection however causes misalignment of the weigh idler and another error is introduced.

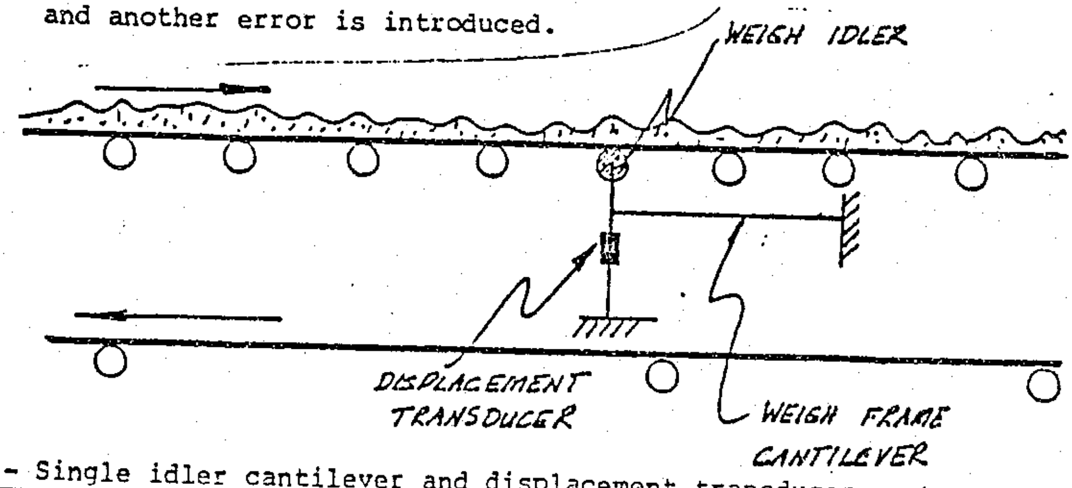

Figure 6 - Single idler cantilever and displacement transducer system

To overcome some of the problems normally encountered with the single idler systems described, a compromise system is currently under study at The University of Newcastle. This system will have no pivots to wear or sieze and no load cells which need flexible constraints. The need for a displacement transducer is eliminated by using a specially designed instrumented cantilever support. Deflection is reduced to an absolute minimum by using a cantilever of rigid design producing relatively high bending stresses. The proposed system will have limited accuracy of ± 1% similar to single idler systems but will have the advantage of increased reliability and lower cost.

Single idler systems generally are a cost effective way of determining flow rate with an accuracy of ± 1% to ± 2% which is usually sufficient for process flow control purposes and inventory management but not for totalising.

3.2 Multi-Idler Systems

Multi-Idler systems, as the name suggests, measure the weight supported by more than one idler set. This method is generally more accurate and is used where totalising weighers are required. Multi-idler systems have gained acceptance by the relevant bodies governing Weights and Measures and usually have accuracies of ± 0.5% or better if installed correctly. The length of weigh frame depends on a number of factors which need careful consideration.

- Belt width
- Capacity
- Configuration of installation and constraints
- Accuracy required
- Budget.

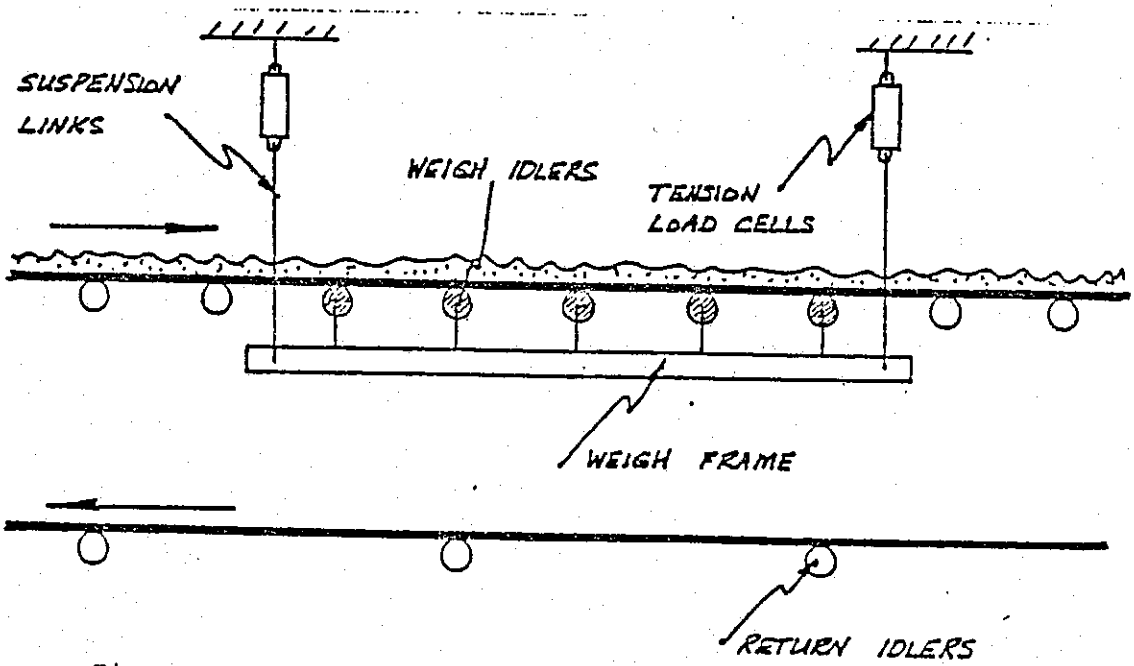

Figure 7 - Multi-idler tension load cell system

Two of the more common configurations in multi-idler systems are briefly discussed.

(i) Tension or compression load cells can be used to support a separate weigh frame consisting of a number of idler pairs as shown in Figure 7.

The use of tension load cells is limited generally by availability of overhead space required to mount hangers and load cells. Both tension and compression load cell arrangements require good flexible restraints to reduce side loading and excessive side movement of the weigh frame which can usually be a cause of weighing errors.

(ii) A typical arrangement using a mechanical lever and pivot system is shown diagramatically in Figure 8. This method is the oldest and generally very reliable method provided the system is adequately maintained. In dusty environments the pivots can suffer from excessive friction which is a cause of weighing errors. Vibration will also cause premature wear on the pivot surfaces and ultimately result in weighing errors. These problems can be overcome through regular maintenance which can however be very costly.

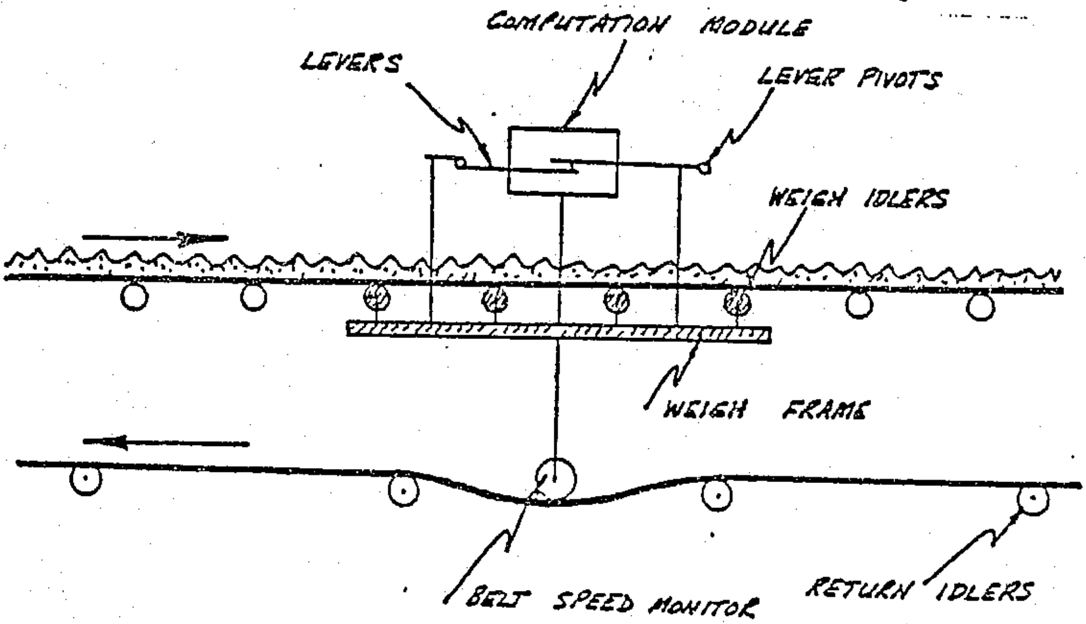

Figure 8 - Multi-idler mechanical lever system

Higher performance can generally be expected from multi-idler systems for reasonable cost and relatively easy installation into existing belt weighers.

Both single-idler and multi-idler weighing system performance depends on the weighing application. The obvious question of how many weigh idlers is a common one and depends on a number of factors.

A wide variation in mass/unit length of bulk material on the belt suggests that a quick response in weighing is required. A single-idler system would be best suited for this purpose. A longer weigh length will tend to average the variation in load which may cause errors. The magnitude of the error depends on the actual fluctuation in belt load and the duration of measurement.

Belt tension and stiffness effects can best be minimised by increasing the weigh length to a multi-idler system.

3.3 Nucleonic Continuous Belt Weighers

Nucleonic continuous belt weighers operate on the principle of Gamma-ray absorption [1]. The relationship of radiation absorption by material is given by

$$I = I_o e^{-\mu m} \qquad (1)$$

where I = the unabsorbed primary radiation detected through the material of mass-unit area 'm'.

I_o = the radiation detected with no material on the belt.

μ = absorption coefficient for the radiation - bulk material characteristics.

The use of nuclear radiation eliminates the problem arising from mechanical systems but does however suffer from other problems. The main cause of error stems from the variation in surface profile of the material on the belt and also from the variation in particle size of the material transported (variation in absorptivity) since mass/unit cross sectional area is measured.

These errors can be minimised by choosing μ, the coefficient of absorption, to be relatively high so that it becomes less dependent on material composition. The principle of operation is shown diagramatically in Figure 9. In its simplest form the system consists of a radiation source (usually Cs-137) and a detector with the belt and material passing between them. For this type of arrangement the quality of the primary radiation signal reaching the detector depends on the source signal, the type of material conveyed and the degree of variation in mass/unit area, the distance of separation between source and detector and the efficiency of the detector.

Figure 10 shows the variation in path length ℓ_1 and ℓ_2 travelled by gamma-radiation from a point source. For wider belts this can be a problem where the projected path of gamma-radiation is larger towards the edges of the belt particularly when trying to minimise the distance from the belt (the angle θ becomes larger).

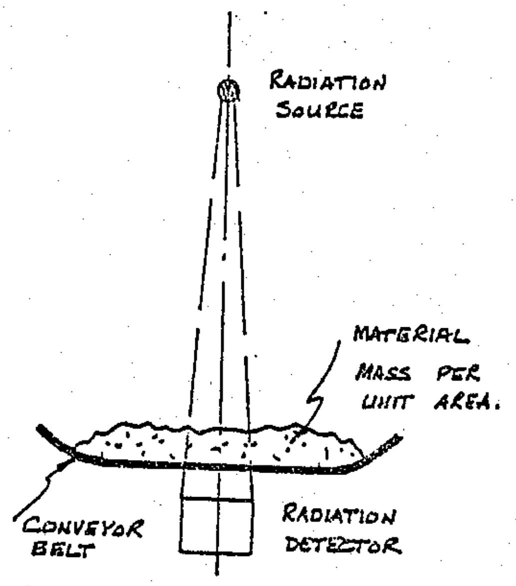

Figure 9 - Operating principle of gamma-radiation absorption in conveyor belt weighing

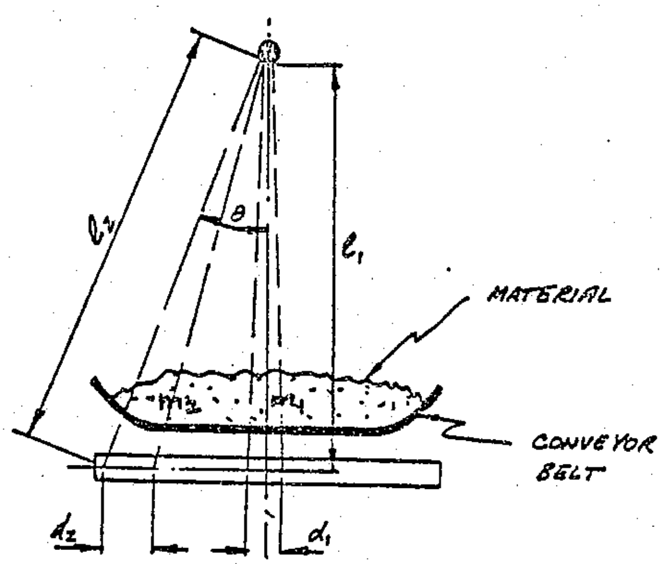

Figure 10 - Variation of signal across belt

Two basic practical solutions for nuclear weighers are shown in Figures 11 and 12. A "point" source - "line" detector system is shown in Figure 11 while a "line" source - "line" detector system is illustrated in Figure 12. Both systems have merit. For a given separation distance the "line" source - "line" detector system of Figure 12 gives best results. In this configuration the radiation path is constant for the entire belt width compared to the varying radiation path length for a point source. By moving the point source further away i.e. increasing separation of source and detector, the angle θ becomes smaller and accuracy is improved. Another method is to use a "point" source and a curved "line" detector to make the radiation path length constant. The belt speed is measured using a tachometer or tachogenerators as for idler weighing systems. The flow rate is simply the product of the belt speed and the mass/unit area signal linearised and integrated for total weight conveyed.

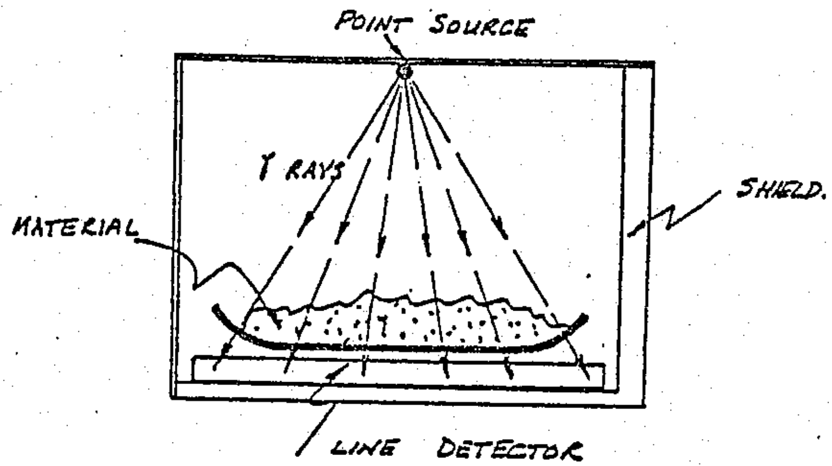

Figure 11 - "Point" Source - "Line" Detector System

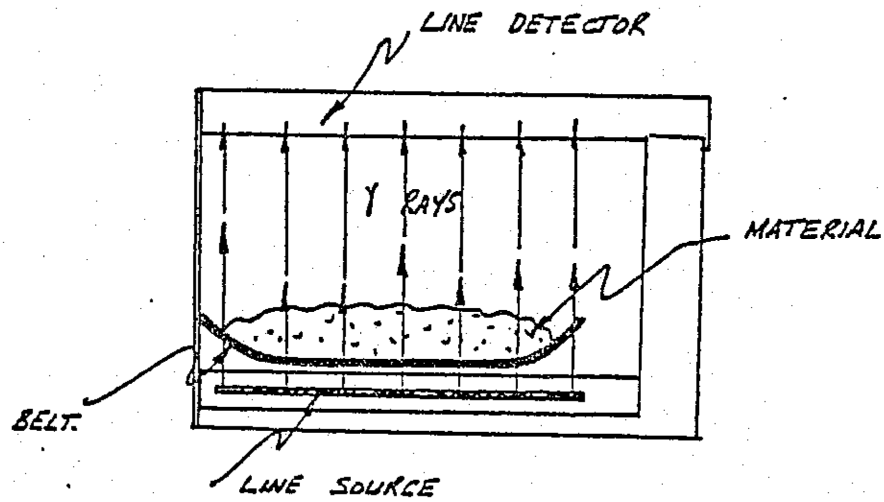

Figure 12 - "Line" Source - "Line" Detector System

Calibration of nucleonic belt weighing systems is essential with the material being conveyed and for a range of expected flow rates. Typical response curves are shown in Figure 13 for coal and for iron ore.

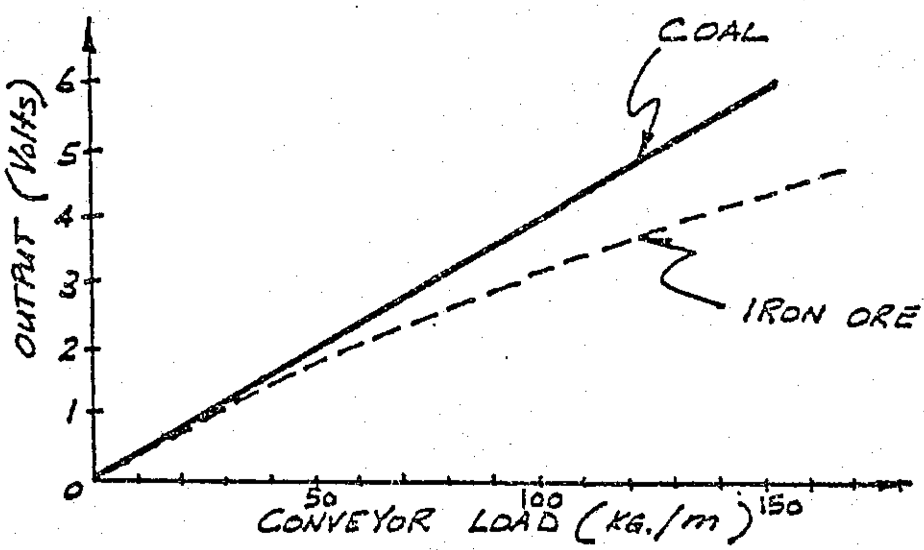

Figure 13 - Typical response curves of nuclear weighing system for a coal and iron ore

4. BATCH WEIGHING AND WEIGH FEEDING

Batch Weighing and Weigh Feeding are generally used for flow control purposes. The systems are generally designed for a smaller throughput than continuous weighers and are usually installed as a separate unit for feeding and weighing from a storage bin. Basically there are three configurations:

4.1 Idler Weighing or Weigh Platform

Idler weighing or weigh *platforms* where a portion of total conveyor is used to measure the material on the belt as illustrated in Figure 14. The various methods of determining weigh are similar to those already discussed for Continuous Belt Weighing methods. The systems used in batch weighing however are generally much more accurate due largely to the sophisticated belt tensioning devices employed and to the improved alignment of idlers usually easier to achieve for the smaller belt.

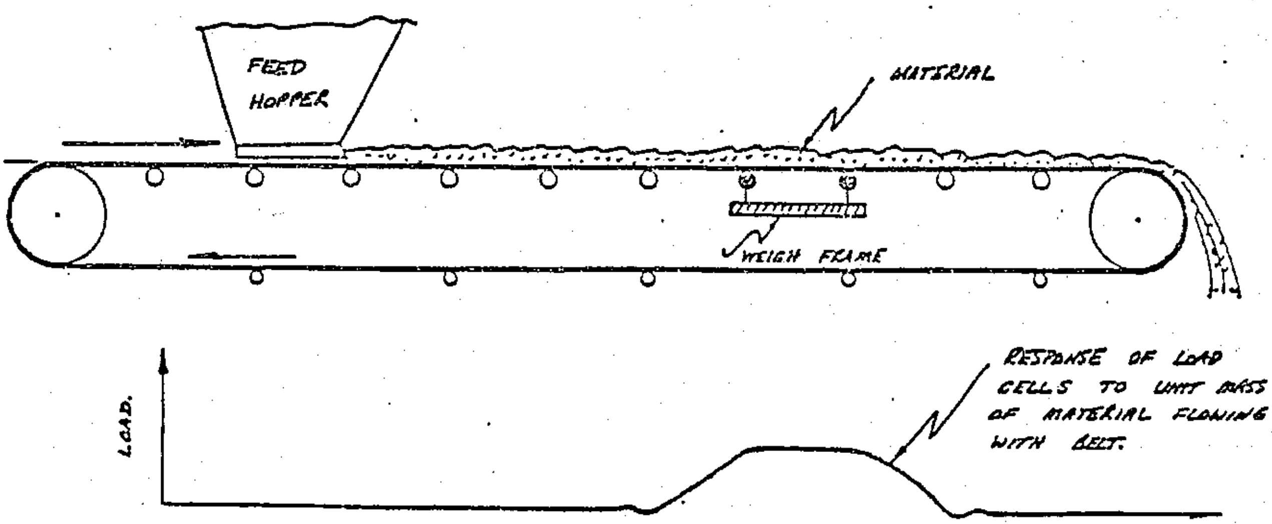

Figure 14 - Single or multi-idler systems

Accuracy is also improved by using a much thinner flexible belt of negligible stiffness. Lever and fulcrum systems of weighing are still relatively popular in batch weighing machines since it is fairly easy to isolate the mechanism from harsh environmental effects.

4.2 Totally Supported Conveyor

By simply supporting the whole conveyor on load cells or some other weighing device all of the material on the belt at any instant of time can easily be determined. With this method unfortunately all of the feeder loads are also measured and, depending on the type of feeder and storage bin arrangement, unusually high and varying loads can sometimes be present and may be a serious source of error. The other restriction is the overall length of conveyor with this method becoming increasingly less accurate with increase in overall length. A typical arrangement is shown in Figure 15 where the whole conveyor is supported on compression load cells. Tension load cells and mechanical level systems are also used in this basic configuration of batch weighing.

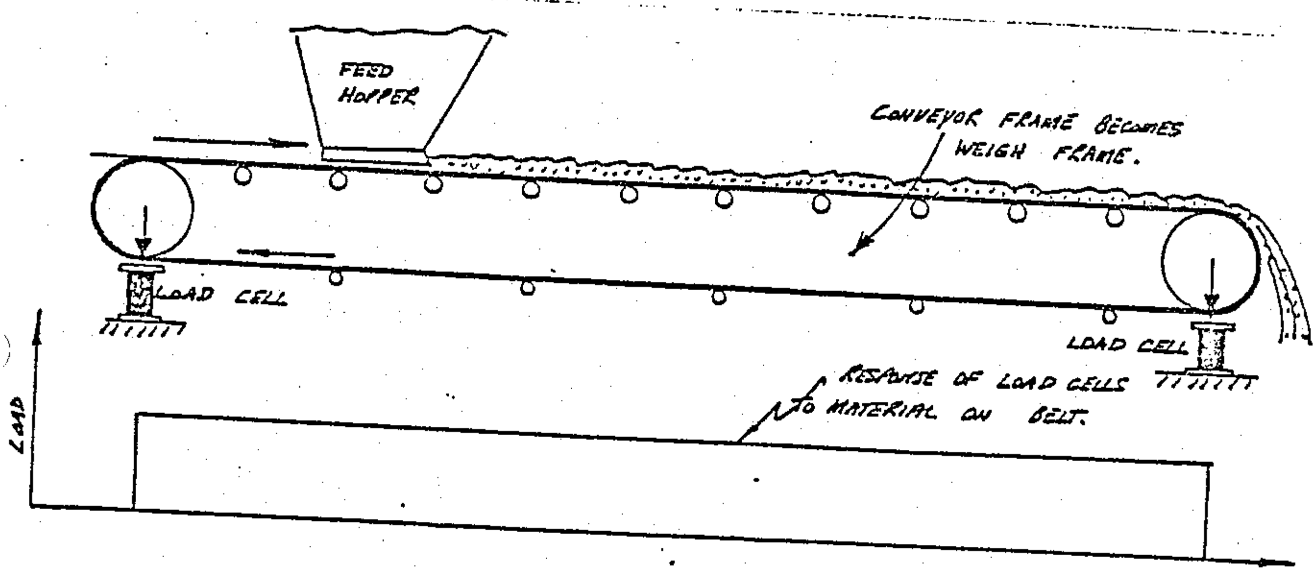

Figure 15 - Totally supported conveyor structure becomes weigher

4.3 Pivotting Conveyor

The pivotting conveyor arrangement of Figure 16 overcomes to some degree the problems of feeder load errors by weighing only one end of the conveyor and picotting the end usually nearer the feeder. The added advantage of this configuration is that the section of the conveyor which has most influence on the weighing device is right at the discharge end of the conveyor. This gives more precision in feed control because there is less time lag between weighing of material and actual discharge into the process.

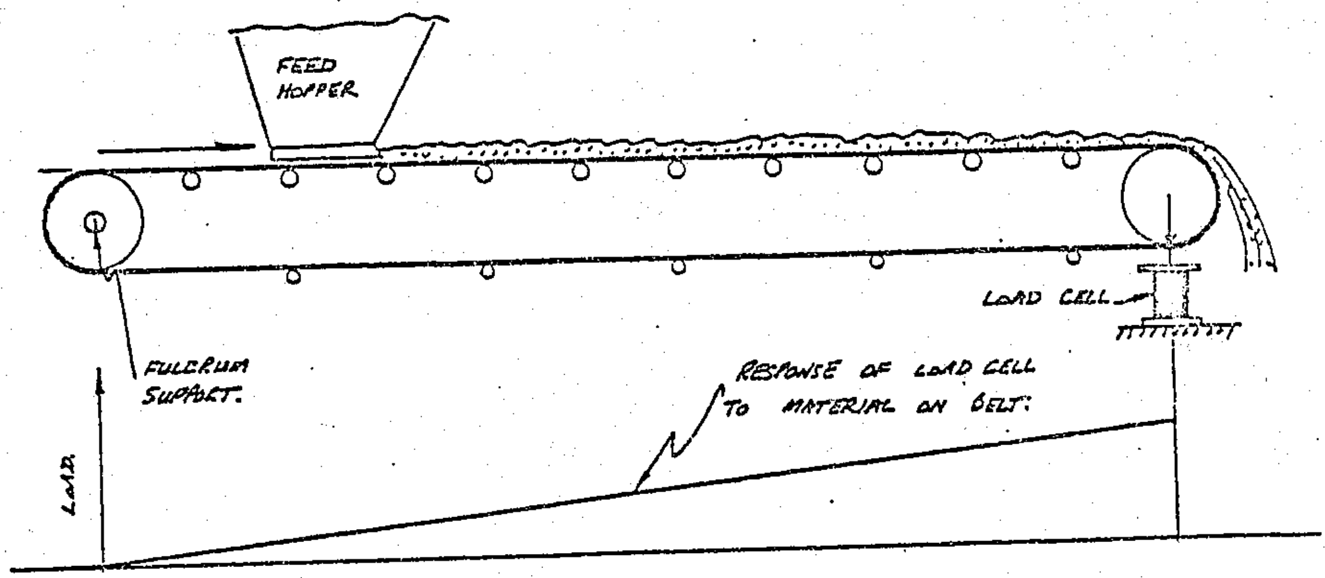

Figure 16 - Pivotting conveyor as weighing system

For all three weigh feeders discussed the feed rate may be maintained by adjusting the belt speed in a closed loop control system with the weighing module. Both A.C. and D.C. conveyor drive motors are used with both direct speed control or gearbox speed control [2]. D.C. drives are not influences by fluctuations in mains supply frequency and do not suffer from motor slippage for high feeder load variations. Higher accuracy feed control is obtainable using D.C. drive systems and is usually of the order of 0.5% or better depending on the weight sensor used and the particular installation.

5. SELECTION OF BELT WEIGHING EQUIPMENT

The overall performance of a belt weighing system depends on a number of factors which should all be carefully considered when selecting a weighing system for a particular installation. A number of these factors are discussed in some detail with a view to maximising performance from weighing equipment.

5.1 Function

One of the most important factors affecting the choice of a belt weighing system is the function it is expected to perform. This can generally be one or a combination of the following:

(i) Sales Function - where the material conveyed is weighed out for sale. This function demands the highest possible accuracy to protect the purchaser and obviously also to maximise the users profitability. The relevant statutory and regulatory bodies governing Weights and Measures have legal requirements that must be satisfied by the weighing system. Both Continuous Belt

Weighing and Batch Weighing systems are used for this purpose with accuracies of 0.5% to 0.1% as a requirement.

(ii) Process Control - where close tolerances for blending and batching processes are required to produce consistent product blends. Both continuous belt weighing and batch weighing systems are used with accuracies generally of 1% - 2% considered acceptable for most blending processes.

(iii) Inventory Management - where records of stocks and production are required for management and planning purposes. Some continuous belt weighers mounted underground for example have been used to determine mine productions on which production incentive payments have been made.

Accuracies of 1% - 2% have generally been acceptable for the purpose of making production incentive payments and inventory management.

5.2 Physical Limitations

The physical constraints in existing materials handling plants and those sometimes imposed for new installations can have a significant influence on the choice of a weighing method for that installation. Underground conveyors in the mining industries for example have limited head room and would preclude the belt weighing devices requiring considerable head room. Another common constraint is limited conveyor length between two transfer points. In this situation simply supported or pivotted batch weigher systems would have an advantage.

5.3 Accuracy Requirements

Accuracy requirements for a belt weighing installation can often decide the type of system installed. Experience has shown that, in general, accuracies are overstated by decision makers without due consideration being given to the functions of belt weighing systems as discussed previously in Section 5.1. Careful consideration given to the function can often result in considerable savings in initial capital cost and also in unnecessary periodic calibration where it is not essential. For example in a process control function the "presence" of material on a belt can sometimes be the information required rather than "how much" material. In this case a high accuracy belt weighing device is not warranted. On the other hand weighing for commodity sale is governed by relevant authorities and belt weighing equipment has to meet the accuracy requirements of that authority.

5.4 Fluctuations in Belt Load

Fluctuations in conveyor belt load can influence the weighing accuracy of a belt weighing system and should be carefully considered when making a decision to instal weighing equipment. For higher accuracy systems in Batch Weighing the type of feeding system used should be chosen to ensure a reasonably consistent feed onto the belt. It has been shown [3] that gravity discharge from mass-flow hoppers is more accurate than other means of drawing material from storage hoppers as shown in Figure 17. The other equally important consideration is the dependence of weighing accuracy on system rated capacity. As illustrated in Figure 18 a simplified relationship of percentage error expected from typical Batch Weighing installations as a function of rated capacity (percent full scale) shows that weighing errors can increase by 1% from a nominal 0.3% at full scale to 1.3% at only 50% full scale. When choosing a Batch Weighing system or Continuous Weigher the design capacity of the weighing device should be matched to the conveyor system as closely as possible to reduce this source of error if weighing accuracy is a prime consideration.

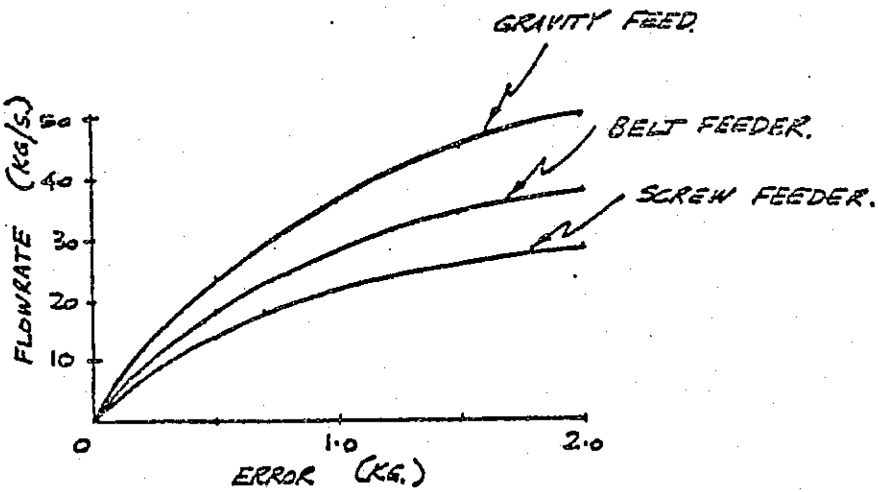

Figure 17 - Typical weighing accuracy compared with type of feeder

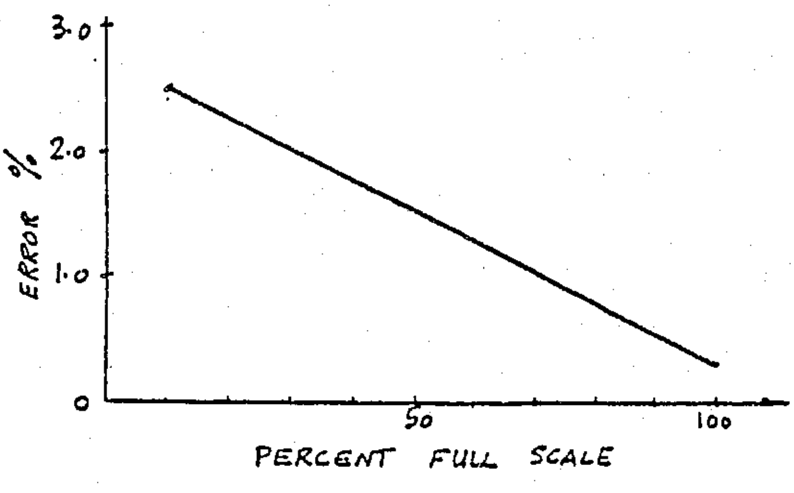

Figure 18 - Batch weighing accuracy as a function of full scale

As detailed in Ref. [8] the loads acting on feeders can vary significantly and thus must be taken into account when designing a weigh feeder.

5.5 Material Conveyed

The material conveyed will influence the choice of belt weighing device and should be considered closely with the type of feeding device discussed in 5.4.

For fine powders with low permeability careful consideration needs to be given to their flow properties [4] and a suitable hopper and feeder installed to feed onto the belt weigher. If the material flows under the influence of gravity alone a carefully designed hopper outlet is better and more cost effective than using flow promotion aids such as bin activators and vibratory feeders. If, however, flow promotion is necessary there are a range of devices available [5] for this purpose to suit most bulk solids.

The variation in average bulk density of the bulk solids will vary with particle size and will affect the accuracy of nuclear belt weighing systems. Minimising fluctuations in average bulk density as well as fluctuations in feed rate for belt weighing using nuclear devices is essential to obtain reliable results.

5.6 Location of Weighing Equipment

The belt weighing device should ideally be mounted in a horizontal section of the conveyor and away from the influence of transition points. A short inclined conveyor belt is generally unsuited for installation of a continuous belt weigher.

6. GENERAL COMMENTS ON INSTALLATION

Batch Weighers and Weigh Feeders are generally designed and installed as a separate piece of equipment purchased for a particular function. Because of this feature Batch Weighing machines and Weigh Feeders usually perform to expectations provided the machine has been chosen carefully.

Continuous Belt Weighers however are not entirely a separate piece of equipment but become part of an existing system. The performance of Continuous Belt Weighers depends therefore on a number of factors.

(i) Location. Location of the belt weigher in the existing system is critical (refer to previous section).

(ii) Belt Tension. Variation in belt tension can have a detrimental effect on weighing accuracy. Gravity take-up devices for conveyors should be used if good accuracy is required. Screw take-up systems are generally not acceptable if weighing accuracy is important.

(iii) Belt Stiffness. Consideration should be given to belt stiffness with continuous belt weighing systems. The belt troughing angle and idler spacing both effect belt stiffness as does the obvious variable of belt composition. Ideally continuous weighing should be carried out on a flat portion of conveyor i.e. no troughing angle. This is not desirable in practice although it is practicable in most cases to limit troughing angles to 20°. Variations in belt temperature have quite a significant influence on belt stiffness, particularly where troughing angles are in excess of 20°.

(iv) Alignment. Good idler alignment, in both horizontal and vertical planes, is essential to achieve accurate weighing with continuous belt weighers. The weigh idlers in multiple idler systems must be accurately aligned with each other but of equal importance with existing conveyor idlers, particularly those immediately adjacent to the weigh idlers.

(v) Belt Tracking. Provision must be made in the conveyor system for adequate belt tracking to avoid any unwanted forces on the weigh idlers.

(vi) Belt Splicing. Vulcanised splicing should be used and wherever possible metal belt slip type fasteners avoided. One uniform type of belt is also essential for accurate belt weighing.

(vii) Consistent Load. Allowance should be made in the design for feeders to provide consistent feed rate to the belt weigher if accurate weighing is required. For continuous belt weighers the variations in belt tension and stiffness due to temperature effects will have a more significant influence on errors when the conveyor is loaded outside the normally recommended range of 50% - 100% of rated capacity as shown in Figure 19.

7. ERRORS IN BELT WEIGHING

Some of the sources of errors in belt weighing have already been mentioned. Further detailed discussion is necessary since an understanding of the error sources can sometimes lead to their elimination and eventually an improvement in weighing accuracy.

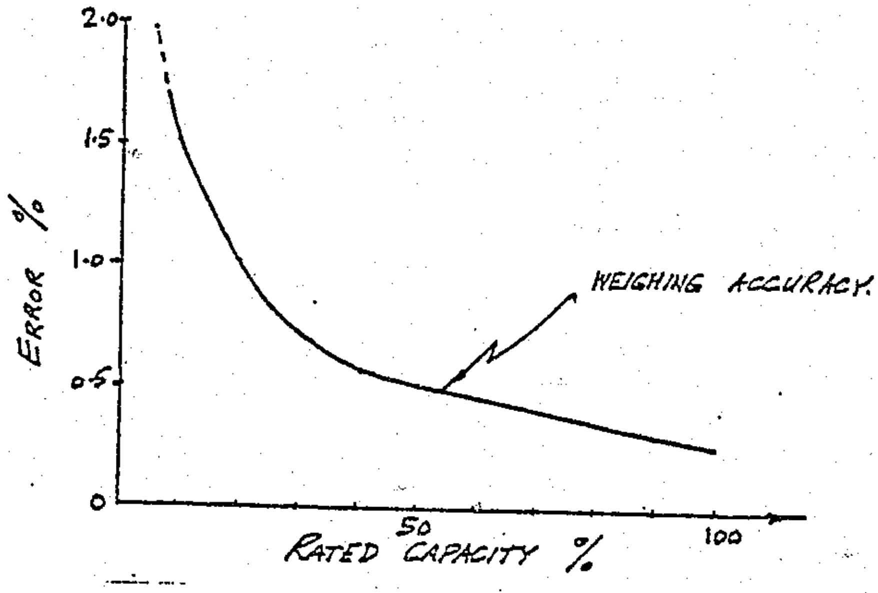

Figure 19 - Typical errors due to variation in flow rate

Errors in the weighing system generally originate from either the

(i) Belt weight sensor

(ii) Belt speed sensor or

(iii) System electronics.

These three system modules, as illustrated in Figure 1, have their own characteristic error band. The magnitude of these errors is generally not significant when compared with errors generated by other factors such as belt tension and belt stiffness which become significant with idler misalignment. The end user can do very little to reduce the drift problems in an electronic circuit for example, but can do much to reduce the larger errors resulting from idler misalignment. The magnitudes of errors in electronics and strain gauge load cells is generally much less than 0.1% of full scale and are not further discussed in this overview.

7.1 Idler Alignment

For perfectly aligned idlers and assuming a flexible belt, that is, neglecting belt stiffness the force R on the idler is given by

$$R = Mg\,P \qquad (2)$$

where M = full scale belt load (kg/m assumed constant)

P = idler pitch (m)

g = gravitational acceleration (m/s^2)

When a small misalignment occurs in the vertical plane such that the weigh-idler is displaced by a distance y from adjacent idlers an additional force is introduced of magnitude

$$R_o = \frac{2Ty}{P} \qquad (3)$$

Figure 20 shows a simplified analysis after Hidden [6] for static conditions.

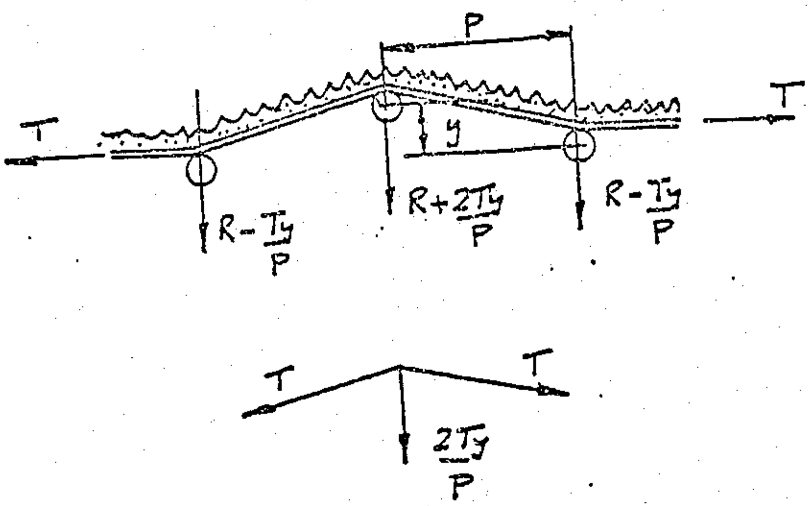

Figure 20 - Simplified analysis of force due to vertical misalignment of Weigh Idler

Expressing this error force as a fraction of the true force without misalignment gives

$$\frac{R_o}{R} = \frac{2T}{Mg\ P^2 y} \qquad (4)$$

and shows the effect of idler pitch P and belt tension T. The relationship shows that to minimise errors the belt tension T ideally should be low and the idler pitch P should be large.

In practice there is a limit to allowable belt sag, a function of belt tension, and for convenience is expressed as a function of idler pitch as shown in Figure 21. For a constant belt tension T and small values of s

$$\frac{R_o}{R} = \frac{y}{4s\ P} \qquad (5)$$

where $T \approx \frac{Mg\ P}{8s}$ from Figure 21.

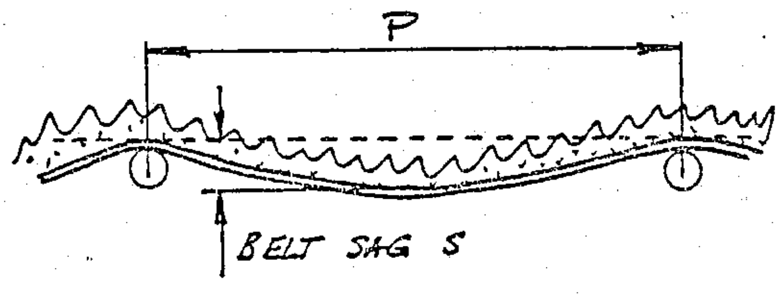

Figure 21 - Definition of belt sag s

This analysis holds true for single idler. For a recommended maximum sag of 2% [7] the error expressed as a fraction of full scale load is

$$\frac{R_o}{R} = \frac{y}{0.08\ P} \qquad (6)$$

Errors are plotted in Figure 22 for values of y and P. Variations in conveyor belt tension can be a problem, particularly during start-up and run-down and with fluctuations in flow rate, particularly on inclined conveyors. Belt tension can be maintained at a constant level only on short horizontal conveyors using gravity take-up systems. There is a lower limit to practical belt tension for a given installation. If the tension is allowed to go below this limit excessive flexing of the belt may reduce belt life and will increase conveyor power.

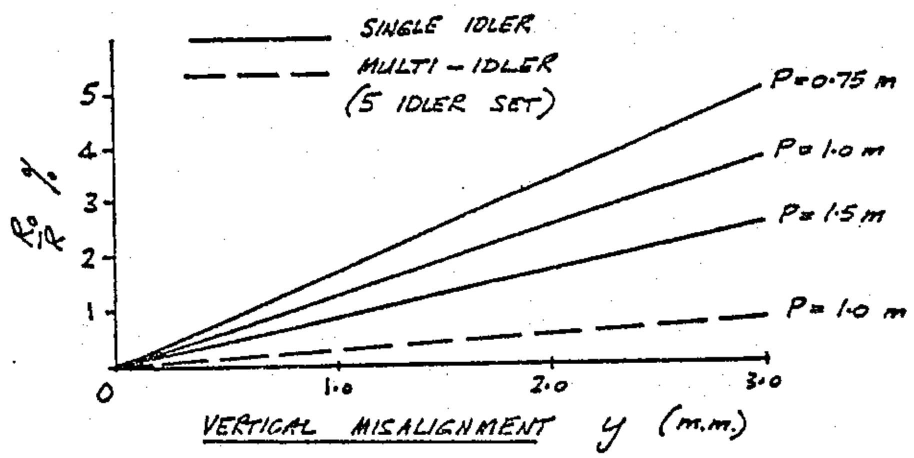

Figure 22 - Errors due to misalignment of weigh idlers for values of idler pitch P

The errors caused by idler misalignment can be reduced to some extent by using a multi-idler weighing system or in Batch Weighing applications, by weighing the whole conveyor as previously discussed. Misalignment between end and adjacent idlers generally only contribute toward misalignment errors. The weighing error is inversely proportional to the number of weigh idlers used assuming the same misalignment as shown by the simplified analysis of Figure 23. For comparison purposes the error is plotted on Figure 22 as a function of misalignment for an idler pitch of 1.0 m.

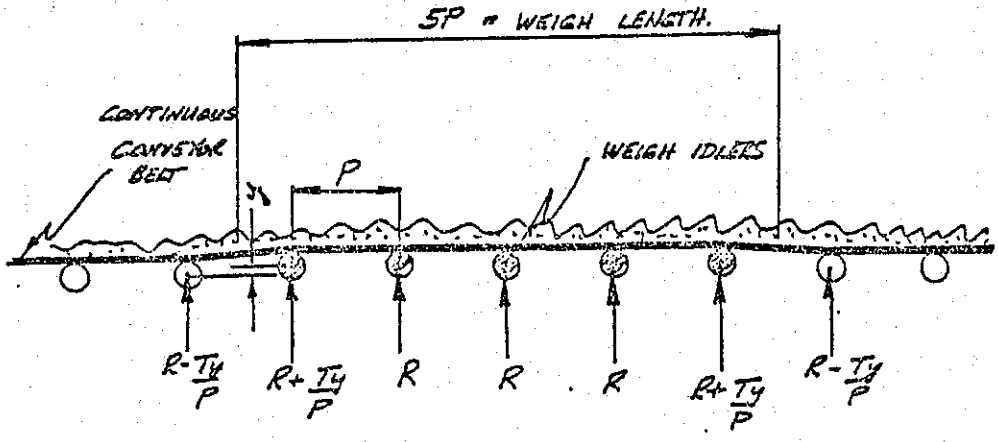

Figure 23 - Simplified analysis for misalignment of multi-idler weighing system

7.2 Belt Stiffness

It has been assumed to this point that the belt is perfectly flexible and without stiffness. Clearly conveyor belts have varying degrees of stiffness and will cause additional error forces on weigh idlers.

Colijn [8] expressed a belt stiffness factor K_C as a function of belt tension T, belt section stiffness EI and idler pitch P so that

$$K_C = \frac{2Ty}{P} \left[1 - \frac{2}{P}\sqrt{\frac{EI}{T}} \tan h \left(\frac{P}{2}\sqrt{\frac{T}{EI}}\right)\right]^{-1} \qquad (7)$$

Another expression for belt stiffness factor K_T has been given by Cutler-Hamer Inc. Thayer Scale Division as

$$K_T = 1 + 12 \left[\frac{1}{P}\sqrt{\frac{EI}{T}}\right]^2 \qquad (8)$$

Hidden [6] assumes the belt to be of infinite length and free to rotate at each idler support point allowing for propagation of deflections along the belt as shown in Figure 24(c). Figure 24(b) shows the analysis of Colijn and Thayer where the belt is considered horizontal at the idlers adjacent to the weigh idler. The stiffness factor K_H proposed by Hidden is given as

$$K_H = K_C(1 + \varepsilon\beta) \qquad (9)$$

where $$\varepsilon = \frac{\left(\cosh\left(\frac{PT}{EI}\right) - 1\right)^2}{\sinh\left(\frac{PT}{EI}\right)\left(\sinh\left(\frac{PT}{EI}\right) - \frac{PT}{EI}\right)}$$

and

$$-\beta = \frac{\frac{PT}{EI}\cosh(\frac{PT}{EI}) - \sinh(\frac{PT}{EI}) - (\frac{\frac{PT}{EI}\sinh(\frac{PT}{EI})}{K_c})}{(\sinh(\frac{PT}{EI}) - \frac{PT}{EI}))}$$

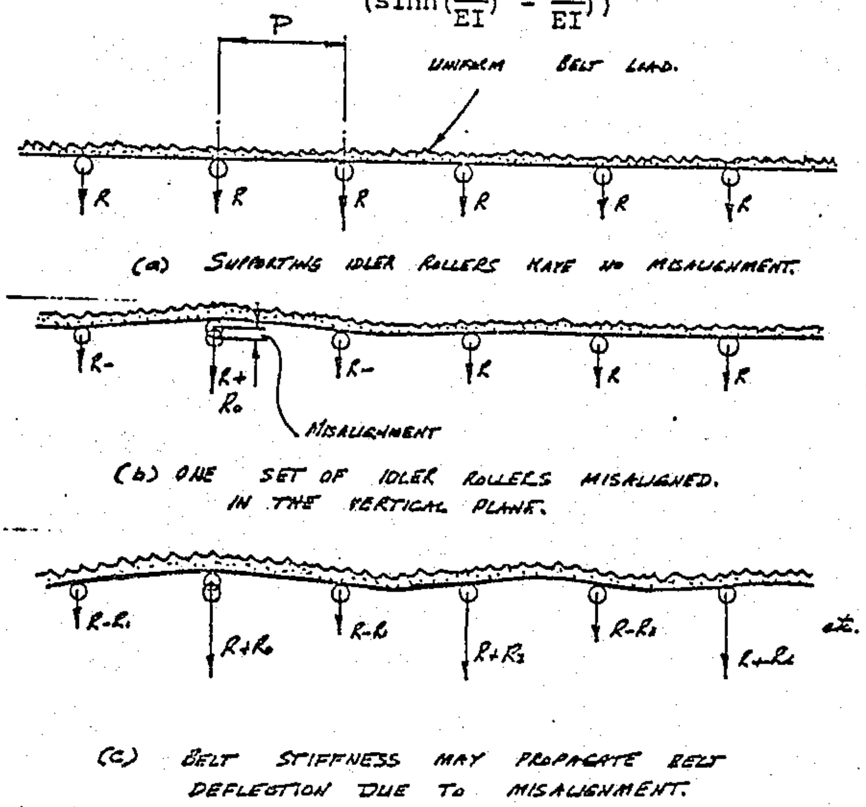

Figure 24 - Comparison of analyses of the effects of belt stiffness and idler misalignment

The results of the three approaches are shown in Figure 25. The analyses of Colijn and Thayer agree very well for reactions at both the misaligned idler R_o and at adjacent idlers R_1. Hidden is in good agreement with Colijn and Thayer for adjacent idler reaction R_1 but is more optimistic of errors at the misaligned idler R_o. Hidden also has an expression for the reaction at idlers a distance of 2P from the misaligned idler. This suggests that good alignment of idlers must extend beyond the weighing idlers if high accuracy weighing is to be achieved.

The practical use of these derivations is limited to knowledge of belt stiffness EI which will no doubt vary eith troughing angle and service temperature.

One other very important factor not yet considered is the addition to belt stiffness by the material being conveyed. It is true that most materials handled by conveyor exhibit some cohesive strength and may have adhesive characteristics. It is also true that these strength and adhesion characteristics will change with nominal bulk moisture content and average particle size resulting in changes in belt stiffness not only with varying conditions for the bulk solid but also with varying flow rates.

A stiffer belt will generally produce less weighing error than a flexible belt for the same conditions of misalignment, idler pitch and belt sag. This is due simply to the fact that the stiffer belt will require less tension for the same sag. The benefit of less tension is expressed in equation (4).

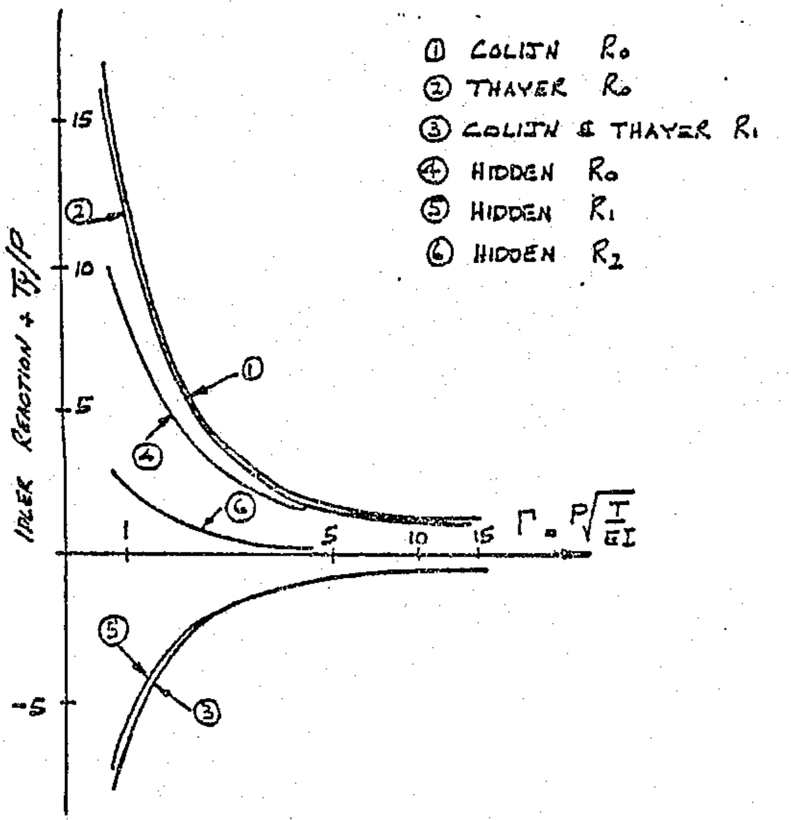

Figure 25 - The effect of belt stiffness on weigh idler reaction

It must also be remembered that belt stiffness is an added source of error *only if* misalignment of a weigh idler or adjacent idler has occurred.

Causes of Misalignment

The most common causes of idler misalignment are -

(i) Deflection of weigh idler under the weight of material. This is generally the result of poor design. Deflection should be kept negligible in the weigh idlers.

(ii) Misalignment of weigh idlers when installed.

(iii) Deflection of conveyor gantry frame due to thermal loads or other sources of loading.

(iv) Eccentricity of idlers can give the same effect as misalignment on a weighing system.

(v) Build-up of material on weighing or adjacent idlers.

Misalignment of idlers on Batch Weighers and Weigh Feeders has not generally presented problems. These weighing machines are usually made to tight tolerance specifications as an integral unit and are generally installed in one piece as manufactured. The devices also use thin flexible belts, usually arranged flat rather than troughed. Most of the errors and their sources discussed in this section only apply to continuous belt weighing systems.

7.3 Skirt Plates

Skirt plates should be avoided wherever possible in belt weighing applications. The frictional characteristics of the bulk solid material against the skirt plate material will cause weighing errors that will vary with belt speed, the amount of material on the belt and the composition of material on the belt. The error caused by skirt plates is not generally systematic and is therefore difficult to correct.

A simplified analysis is presented in Figure 26 which shows that the vertical force exerted by the material W on the weigh idlers is reduced by the forces F the frictional forces on the skirt plates.

By this simplified analysis the correct weight W per unit length is given by

$$W = bh\,\gamma \qquad (10)$$

where γ = specific weight of material tons/m^3.

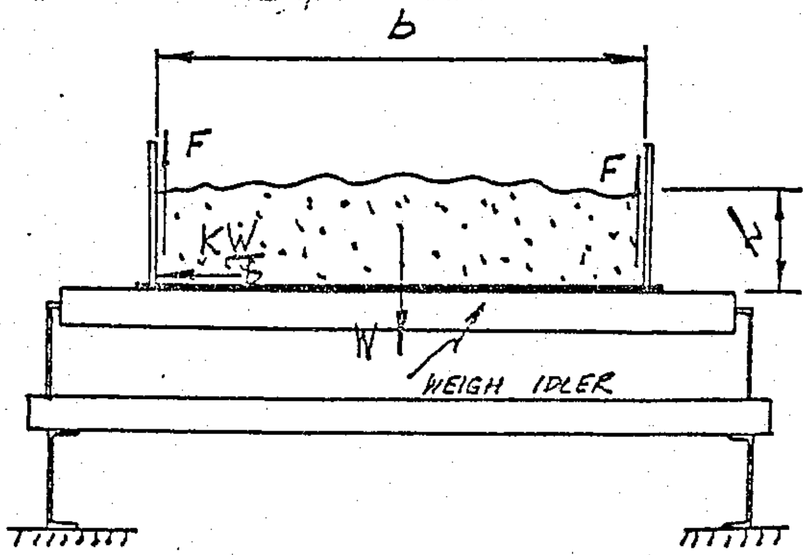

Figure 26 - Simplified analysis of the effect of skirt plates on belt weighing accuracy

The forces perpendicular to the skirt plates are assumed hydrostatic for simplicity and considering the bed depth h is shallow and the material is moving along the wall, this simple approach appears to be quite acceptable.

The frictional force F is therefore approximated by

$$F = \mu K \frac{W}{b} h \qquad (11)$$

where $\mu = \tan \phi_w$ the wall friction angle

and $K = \frac{1 - \sin\delta}{1 + \sin\delta}$

for δ = effective angle of internal friction.

Expressing the effect of skirt plates as a percentage error gives

$$\frac{F}{W} = \frac{\mu K h}{b} \qquad (12)$$

It should be noted that the value of K can vary significantly as discussed in Refs. [8] and [9].

The true values of skirt friction will obviously vary with many factors peculiar to the particular installation. This approach is an oversimplified one which does give some feel for skirt plate errors as shown in Figure 27.

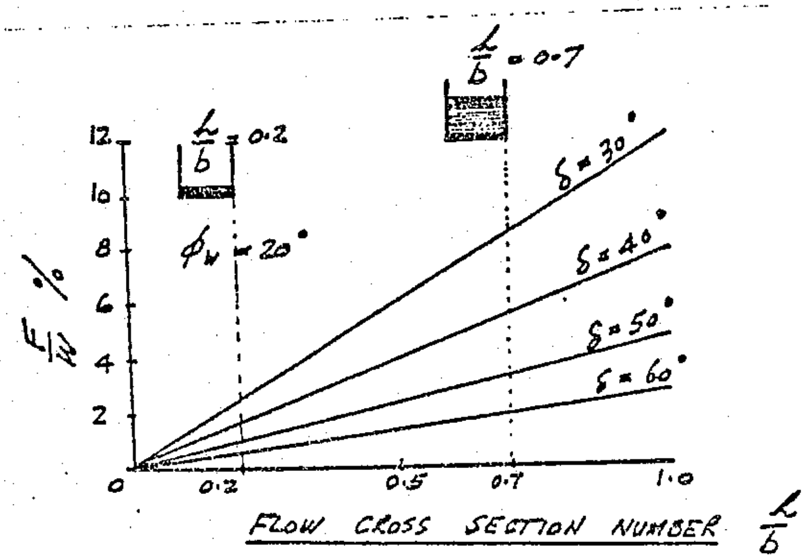

Figure 27 - Skirt plate errors as a function of $\frac{h}{b}$ for values of δ

8. CALIBRATION

For batch weighing and weighing for the purpose of commodity sale absolute calibration on a periodic basis is essential and is a requirement of the governing Weights and Measures body. There are basically three methods for obtaining calibration.

(i) Material Calibration. This method is by far the most accurate method but is generally the most difficult to achieve. The material passed over the belt weigher must be weighed before or after calibration on an approved scale of known accuracy. This method is the most accurate and takes into account -

- Material stiffness effects
- Normal extent of operating ranges.

(ii) Chain Calibration. Chain calibration is a method which uses a roller chain of known mass/length and is passed across the weigher as for normal operation. Calibration is usually conducted at one loading level rather than at various loading levels to cover the expected range of operation. This reduces the accuracy of the calibration method. Stiffness of the material is not accounted for using this method of calibration. Chain calibration can be convenient particularly for lower capacity Belt Weighing Systems.

(iii) Dead Weight Calibration. This method is by far the most convenient but least accurate and should only be used as a quick check rather than absolute calibration. Belt speed needs to be calibrated separately if dead weight is used for the weigh sensor.

Both *Chain Calibration* and *Dead Weight Calibration* methods are used generally only as a preliminary course calibration prior to accurate material calibration or as calibration methods for belt weighers where accuracies of 1% to 2% are adequate.

9. CONCLUDING REMARKS

Batch Weighers and Weigh Feeders generally provide accuracies in the range 1.0% to 0.1% and are accepted weighing devices by statutory authorities in many countries. Through their construction, misalignment of idlers is negligible and belt speed control precise and responsive.

The use of continuous belt weighers in larger conveyor systems continues to grow with improvements in weighing accuracy ever advancing. Accuracies of 0.5% F.S. are not uncommon for correctly matched and installed systems. There is a growing acceptance of these weighing systems by the governing Weights and Measures authorities as systems accuracy improves further.

Some recently developed systems use the microcomputer to *auto-zero* the system thus allowing for build-up on idlers and variations in belt tension and speed.

The weigh length and idler misalignment are clearly the major influences affecting weigher accuracy. Belt tension and belt stiffness have little or no influence on weighing accuracy without any misalignment problems present. Accuracy can generally be improved by increasing the number of weigh idlers. This has the effect of reducing rapid response to load fluctuations because the larger weigh length has averaging effects of load fluctuations.

The belt speed sensing wheel should be as large and light as possible and located as closely as practicable to the weigh length and held against the belt with a constant force.

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