BENEFITS OF IMPROVED TECHNOLOGY
AND DESIGN ON CONVEYOR BELT SCALES.

Gleed Dean

1 INTRODUCTION.

Conveyor belt scales are by design precision instruments that are both reliable and accurate when tested under controlled conditions. The principle of a mechanical frame transmitting a mass by means of a loadcell to an electronic integrator is widely used in the weighing industry. The challenges in achieving accurate and reliable weighing on a conveyor belt are not in the design of the scale or the implementation of the scale on a conveyor system. They are in the application itself and the ability of the scale to maintain that “just installed” accuracy within the application. Over and above possible “integral failures” that can go undetected there are many “outside influences” that negatively affect the scales ability to weigh accurately and reliably. Conventional scales are unable to either detect, deal with or report an “integral failure” or “outside influence” when they negatively affect accuracy. Even if regular routine maintenance is done, and done properly, the scales “operational accuracy” cannot be guaranteed.

The focus of this paper is on how improved technology has allowed improvements in design to overcome a major deficiency in the conventional conveyor belt scale. Before discussing the design improvements and technological advances we must first understand the complexity of weighing on conveyors and the many “invisible forces” making accurate weighing difficult to achieve.

2. COMPLEXITY OF WEIGHING ON A CONVEYOR.

Unlike other types of scales a belt scale has to measure two components namely mass and speed accurately. To make matters worse the product being weighed is not in separate uniformly filled receptacles with a fixed tare mass such as a truck or box. The “receptacle” in this case the belt is a continuous length of rubber with changing properties that effectively change the tare mass of the receptacle at any time. Further complexities are introduced by the very nature of the application namely the belt itself that holds the product that must be weighed. Belt scales must contend with belt properties such as tension, speed, tare mass, alignment and loading that are constantly varying. In order to weigh accurately there must be a direct and linear relationship between the mass applied to the scale and the mass applied to the load cells. The load cell itself is a completely linear device and provides the integrator with a millivolt output linear to the mass applied to it see Figure 1 below. Any external force working with or against the downward force created by the product mass on the belt will influence the linearity and ultimately the accuracy of the scale.

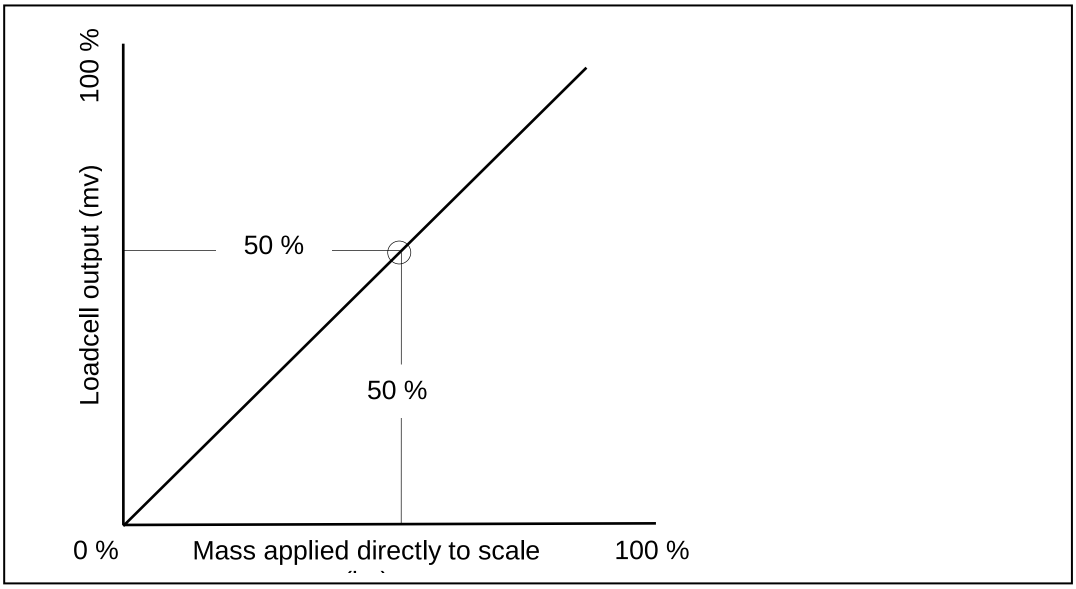


Figure 1. - Shows linear relationship between mass applied to scale and loadcell output

In the case of a belt scale the mass is applied to the belt and not directly to the scale. This can affect linearity of the scale as “outside influences” such as belt position, tension, and properties come into play. Figure 2 below shows how a belt can have an effect on the linearity of the scale, as the loading increases it overcomes the effects of the belt tension through the shear mass on the belt. The overall effect is that on low loadings the scale will under-read and at higher loadings it will become more accurate or can even begin to over-read dependant on where the initial span calibration was done. The results shown below are typical of a scale that is calibrated using an on board test mass or a material test performed at only one point in the scales range.

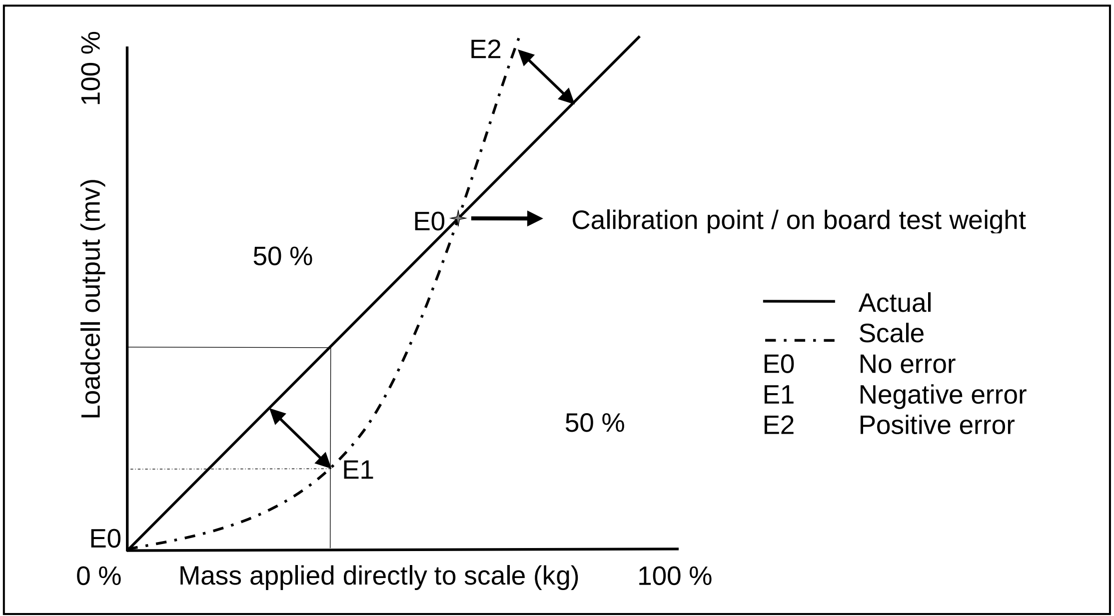


Figure 2. - Shows how belt tension can affect the linearity of the scale.

The effects of belt tension can be seen in figure 3 below and can be proven by testing the scale with static weights positioned on the belt, note the belt tension does change once the belt is running making this method of calibration unreliable.

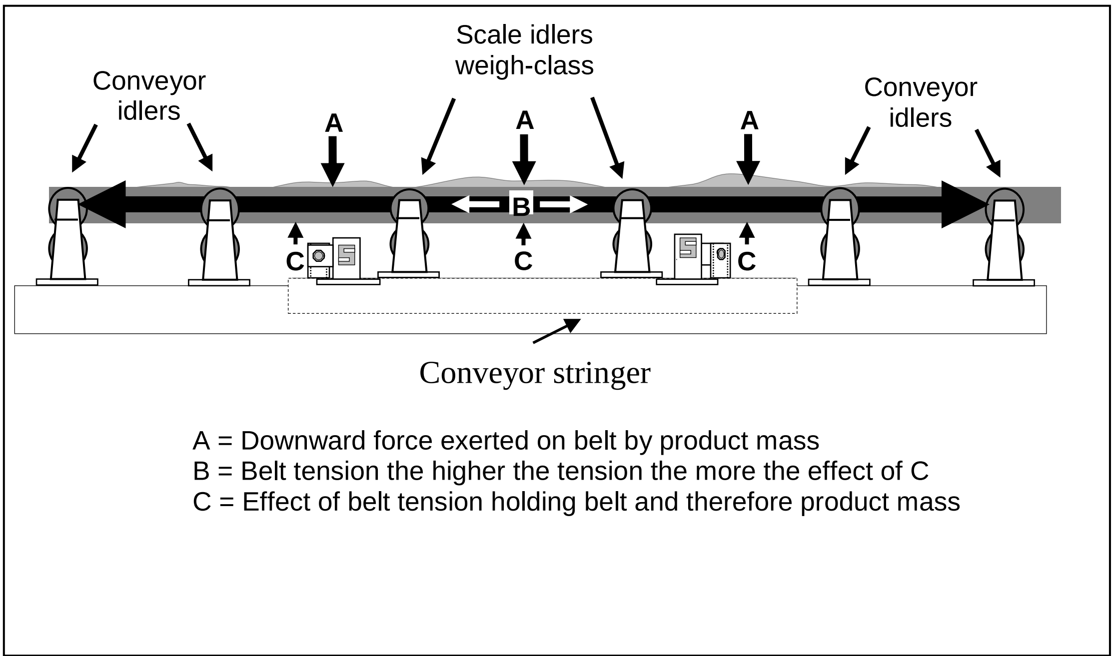


Figure 3. - Effects of belt tension on actual mass of product being transferred to scale.

3. IMPORTANCE OF GOOD MECHANICAL DESIGN

3.1 Stable base.

Any scale requires a stable base in order to weigh accurately. Prove this by weighing yourself on a simple bathroom scale firstly on a tiled floor and secondly on a plush carpet there is a difference in weight. The design of the scale must allow as little deflection as possible (better than 1/900 is acceptable) in order to allow the mass applied to the scale to be transferred to the loadcells in a linear and direct manner without any losses or interference. This is critical on conveyor belt scales, as the correct mass must be transferred in motion and at speed. There is no time for compensation through extending recovery time or reducing speed as on static or other dynamic scales. This design requirement includes the scale frame, idler sets and the conveyor structure on which a scale is to be installed. Deviations will create inaccuracies once commissioned. The structure must be properly designed to limit vibration and movement as far as possible as these affect the scales linearity as shown in Figure 1 above. A poorly designed structure is the worst case scenario for a belt scale.

3.2 Keep it simple

It is the author's opinion that the fewer moving parts on the scale frame the better; a full floating frame putting direct load on the load cell is the best system. The improvement in electronics has meant that the resolution that was lost having the weigh-frame using as much as 25% of the load cell capacity is no longer a concern. The benefit in directly applying the mass to the load cells by hanging the scale frame from the load cells and not having moving parts such as bearings, flexures and levers is substantial. Moving parts require maintenance and can seize partially or completely causing inaccuracy. The benefits of the full floating scale will be fully dealt with in section 7 of this paper.

3.3 Idler sets.

On a belt scale the weigh-class idler sets are the interface between the belt and the scale. It is therefore imperative that the idler sets are properly spaced and aligned. Proper spacing and alignment reduce the dynamic load induced by the loaded belt striking the idler set at speed. Any dynamic load will be seen by the scale as mass on the belt causing erroneous readings. In order to achieve proper alignment (+/- 0,5mm is adequate) it is necessary for the idler sets to be accurately manufactured. The frames and rollers must conform to the 1/900 or better deflection specifications of the scale frame and structure. It is also necessary to make sure that the rollers are balanced (better than 6 grams on both horizontal and vertical planes @ 500 RPM) so as to limit vibration being induced into the scale frame. Technological advances have played a part here too. The injection moulded composite plastic rollers available today exceed these requirements off the shelf.

Important design criteria are

- Deflection of better than 1/900
- Limit vibration on the conveyor support structure
- Limit movement on the conveyor support structure
- Prevent dynamic loading by aligning and spacing scale idlers properly

4. TECHNOLOGICAL IMPROVEMENTS IN INSTRUMENTATION.

4.1 Electronics

The advancement in electronic integrator/controllers, especially in the resolution and speed of the A/D converter and computation speed has meant that the belt scale has become less of an averaging device and more of a high-speed sampling device. The speed and accuracy at which modern high-end units sample the weight passing over the scale is notably faster than the more antiquated units. This technology has improved substantially over the last five years and A/D converter rates have increased from 30Hz to 960Hz and internal resolution from 1/250 000 to 1/16 000 000 with processors doing computations every 10 milliseconds compared with every 250 milliseconds. This advancement is allowing scales to be more accurate through improved resolution and speed and more reliable through use of heavier frames and larger capacity load cells (see figure 4 below).

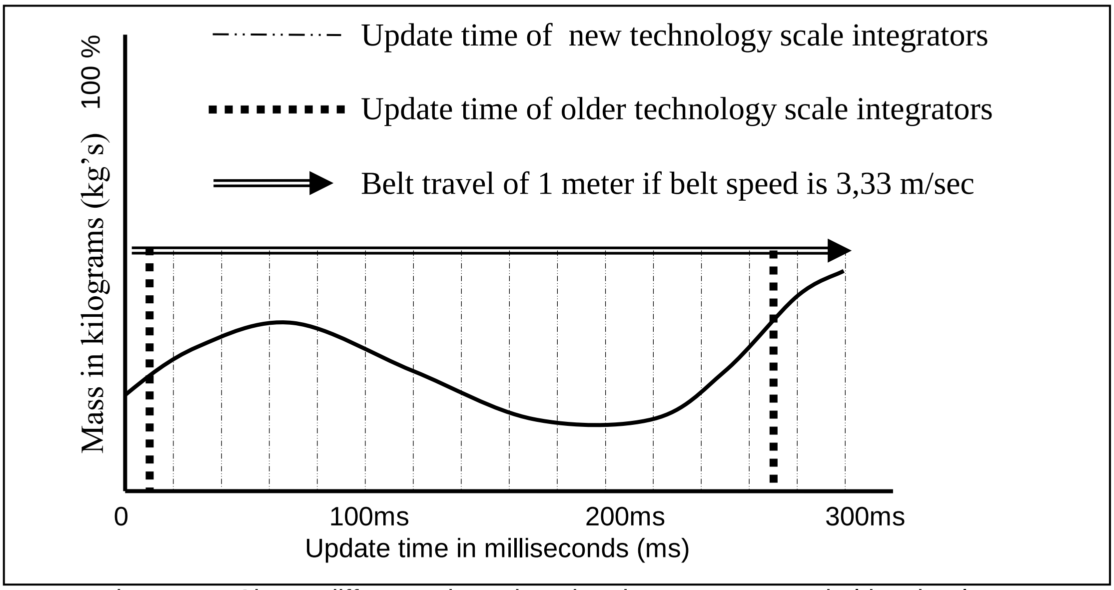


Figure 4. - Shows difference in update time between new and old technology.

4.2 Loadcells

The load cells are the interface between the scale frame and the electronic controller; the electronics being the "brain", the loadcells the "heart" and the scale frame the "body" of the scale. Over and above choosing a reputable quality loadcell, the best accuracy and reliability is achieved by correctly sizing the load cells. Load cells should be sized to allow the scale tare mass (including empty belt) to take up 25% or less of the load cell capacity with the maximum belt loading utilising around 25% of load cell capacity allowing 50% load cell capacity as spare. For reference purposes this method of sizing loadcells will be referred to as the 25/25/50 sizing method. Benefits include allowing for conveyor up-rates, accurately measuring surges, surviving gross overloading and more importantly increasing the lifespan of the load cell.

As most loadcells can be loaded to 150% of capacity without being damaged the 25/25/50 method ensures that the loadcells can never be damaged by overloading under normal running conditions. This 25/25/50 sizing method allows the measurement of the product conveyed to be done utilising the most repeatable and accurate range of the load cell (10-90%). The old school of trying to achieve maximum resolution by utilising as much of the loadcell capacity in order to weigh the product on the belt is no longer valid. This method requires lightweight and or counterbalance type frames that are not ideal for achieving accuracy or reliability over the long term. With the advance of electronics described in 3.3 above, the 25/25/50 method of load cell selection has several advantages.

- Larger capacity loadcells mean
    - Longer loadcell lifespan
    - Scale is able to weigh surges accurately
- Heavier frames can be used allowing
    - Lower deflections therefore better accuracy
    - Increased lifespan and lower maintenance on scales
- Standardisation of scale components and loadcells
- More robust installations less susceptible to damage.

5. CORRECT APPLICATION OF THE TECHNOLOGY.

Technology cannot overcome the laws of physics and a scale must be applied to a conveyor using proven basic application principals. The physical properties of each application need to be evaluated prior to choosing the correct scale and selecting the location for the installation on the conveyor. Each installation needs to be evaluated separately as the properties of each application/conveyor are unique. The following physical properties must be evaluated in order to correctly apply a scale to a conveyor application.

Conveyor

- Belt properties (width, type, mass/m, flexibility)
- Conveyor properties (tension, profile, speed, troughing angle)
- Material properties (Bulk density, lump size, moisture content)
- Flow properties (Throughput min, max and average)
- Loading characteristics (consistency, variation, surges)
- Mechanical properties of conveyor structure (rigidity, stability, integrity)

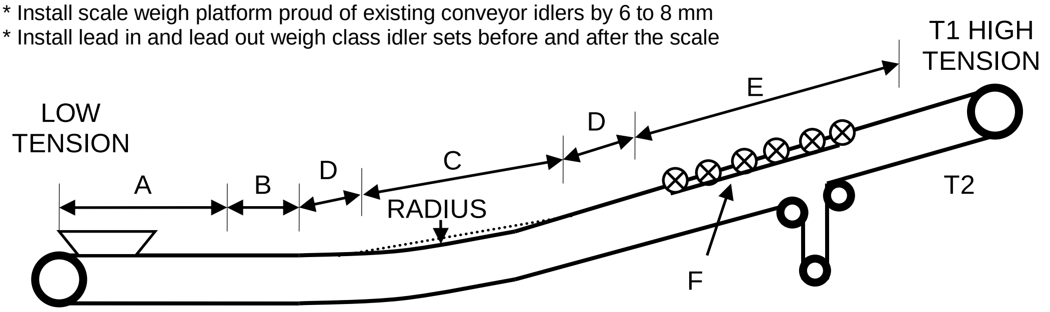
Scale

- Design (deflection in frame, rollers)
- Type (full floating, counterbalance, special)
- Size (1, 2, 3, 4 or 6 idler weigh-frame)

The type of scale that is to be used is dictated by firstly the accuracy required by the end user and secondly, but more importantly, by the evaluation of the unique properties of the application itself. The practice of choosing a scale off a catalogue that typically shows a six idler scale being accurate to within +/- 0.25% and a single idler to be accurate to within +/- 2,0% is uninformed. This practice leads to incorrect scale choice for specific applications, as it is the unique properties of the application that dictate scale requirements. A six idler scale will deliver exactly the same results as a one or two idler scale if the application allows for it, if not however even a six idler scale may not achieve 1% accuracy. In some cases no conventional scale will be able to achieve the desired results and a special scale would have to be built or the weighing abandoned altogether.

The conveyor shown below in figure 5 below is a typical example of how choosing a scale from a catalogue using quoted accuracies is not the correct way to select a scale. For this application requiring only +/- 1,0% accuracy most manufacturer's catalogues will advocate a two-idler scale. The ideal place to install a scale is in the low-tension flat area of the conveyor near the tail pulley. In this case there is insufficient space between the feed point and the start of the radius to effectively install a scale. If we look further down the conveyor it is not possible to weigh accurately in the radius due to belt lift under tension. Further along we have an incline that is straight and long enough for the scale to be installed far enough away from the radius not to be influenced by it. Whereas a two idler scale would be ideal if installed in the low-tension flat section of the conveyor the incline and the increased tension near the head end means that a six idler unit would be advisable if an accuracy of 1,0% were to be achieved.

Installation rules
* Do not install in radius of conveyor
* Install in low tension area
* Allow material to settle before passing over scale
* Do not allow installation of training idlers within 12 idler sets of scale weigh platform
* Install scale weigh platform proud of existing conveyor idlers by 6 to 8 mm
* Install lead in and lead out weigh class idler sets before and after the scale



A = Feed settling area cannot install
B = Insufficient space between A & C for installation
C = Radius in conveyor cannot install
D = Safety zone before and after radius cannot install
E = Available installation area although not ideal due to steep incline and higher belt tension in this area.
F = **6 idler scale installed** due to effects of E even though most scale brochures indicate a two idler will easily achieve +/- 1,0

Accuracy required = +/- 1,0 %
Scale specified for 1,0% = 2 idler

Figure 5. – Choosing a scale for an application.

6. POSITIONING THE SCALE ON A CONVEYOR.

If a scale is installed using proven basic application principals it will perform to the required specifications providing the application properties remain constant, no integral failures occur and it is properly calibrated and maintained.

In order for any scale to operate properly the following is required.

1) A stable base
2) No interference from external sources
3) The product must be stable when weighed.

Belt scales should be installed where the structure is the most stable. Between two support structures near the tail end is usually the best position as the foundation is more substantial at the head and tail end. The tail section is usually better protected from the elements as well.

A belt scale is different from most other scales as the mass is applied through the belt and not directly to the scale. For this reason the scale must be located in an area where the belt is least likely to interfere in the direct transfer of the mass onto the scale.

The scale must be installed in a location and manner that makes certain that the product being weighed is lying in a stable fashion on the belt when presented to the scale.

7. CALIBRATION

Incorrect calibration is the single biggest reason for an inaccurate scale; the nature of the task of calibrating a scale lends itself to errors. Calibrating a conventional scale is a methodical task and if any of the steps are not followed, can induce errors that are difficult to find. A poorly calibrated scale can appear to be correctly calibrated using the zero and on-board test weight span calibration that is commonly used. The following examples show us what can happen.
Often production pressures or lack of facilities cause a technician to only partially calibrate or check the calibration integrity of a scale. Often it is found that the weight calibration takes preference over the speed calibration, linearity checks on the mass calibration are seldom done due to the logistics involved. Doing only a zero mass calibration without checking the speed or mass span calibration can induce errors into the scale. The graph below shows how this can happen.

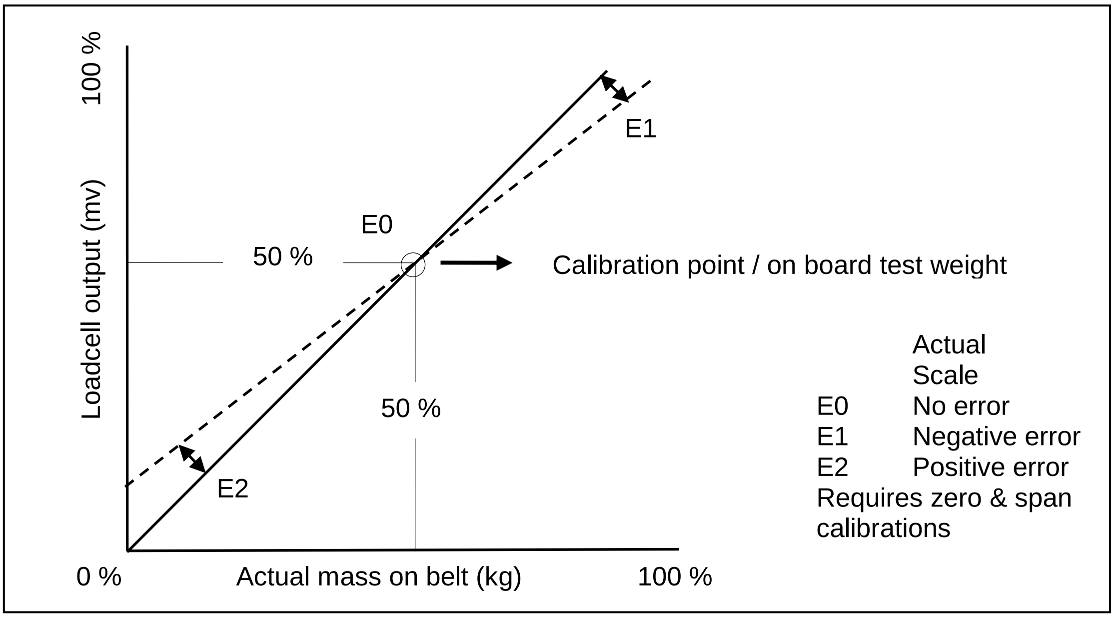


Figure 6. – Shows a scale with both zero and span errors.

A scale can be accurate at its zero or no load point and at its span or calibrated load point and yet both the speed and weight calibration of the scale can be out. This will cause the scale to be accurate at only two points on the calibration curve and anywhere else on the curve will give erroneous readings. The scale can be routinely checked using the dynamic zero checks and on board test weight checks and pass the tests and still be inaccurate. This is the worst case scenario.

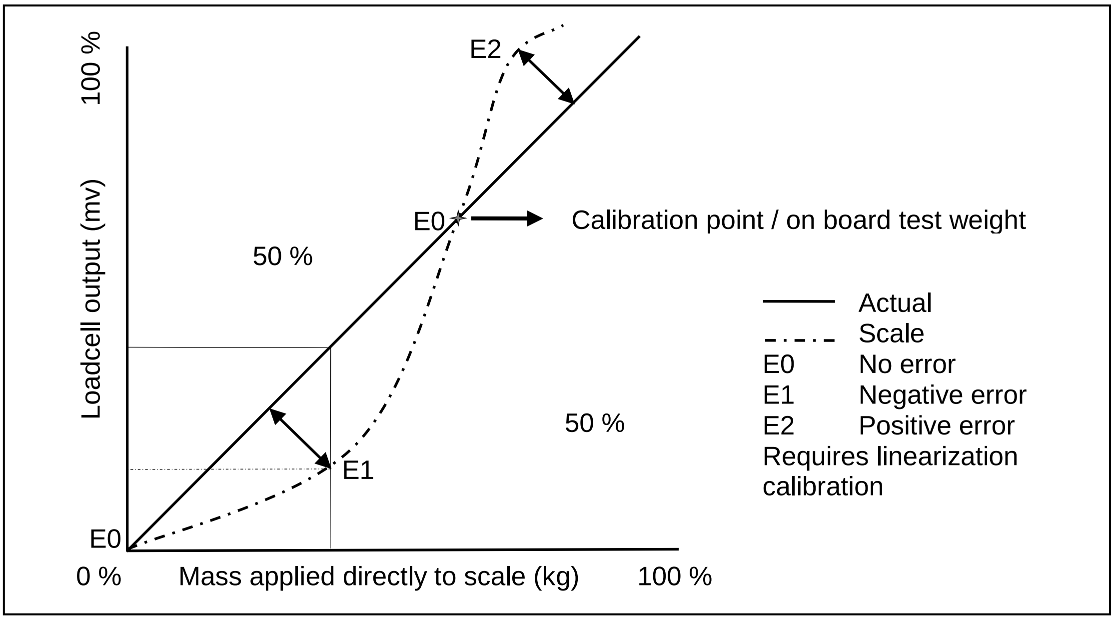


Figure 7. – Shows a scale with linearity problems.

A more common error is zero drift where the scale's zero calibration has been affected by a change in belt properties such as tension, or as a result of a partial integral failure of the loadcells or scale frame. This will shift the zero point as indicated by the scale away from the true zero point shown on the actual weight curve on figure 8 below. In such a case a zero calibration will correct all errors.

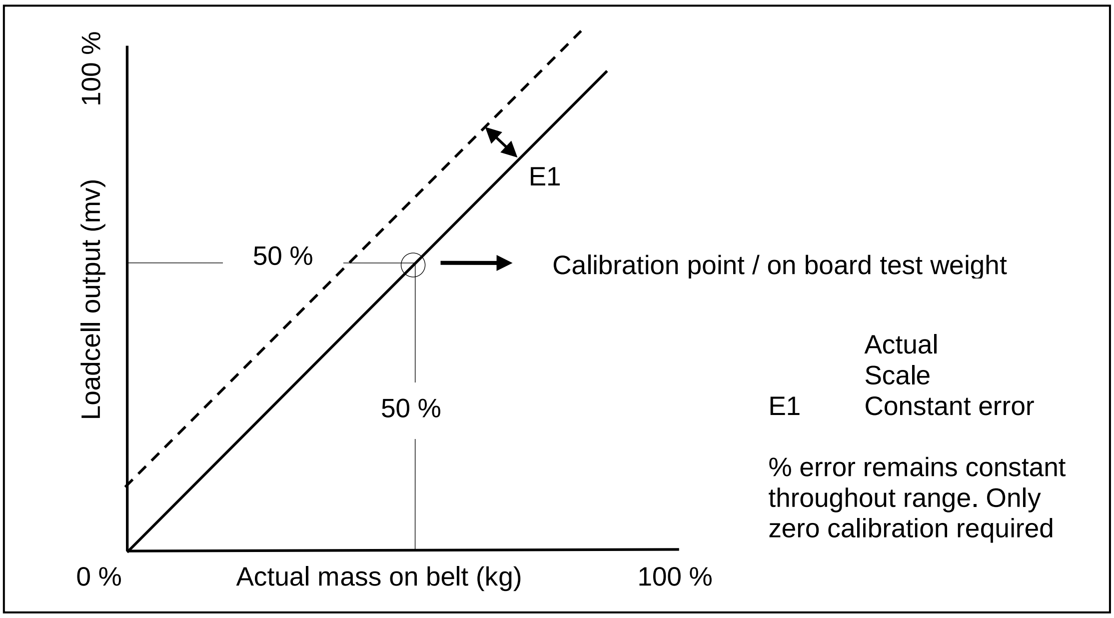


Figure 8. - Shows a scale with a constant linear zero error

Span errors usually occur when a scale is calibrated at the span point without first checking the zero calibration. When the scale is checked again and the zero error is corrected the span calibration point indicated by the scale shifts from the actual mass leaving the scale with a span error and only being accurate at the zero point. See figure 9 below.

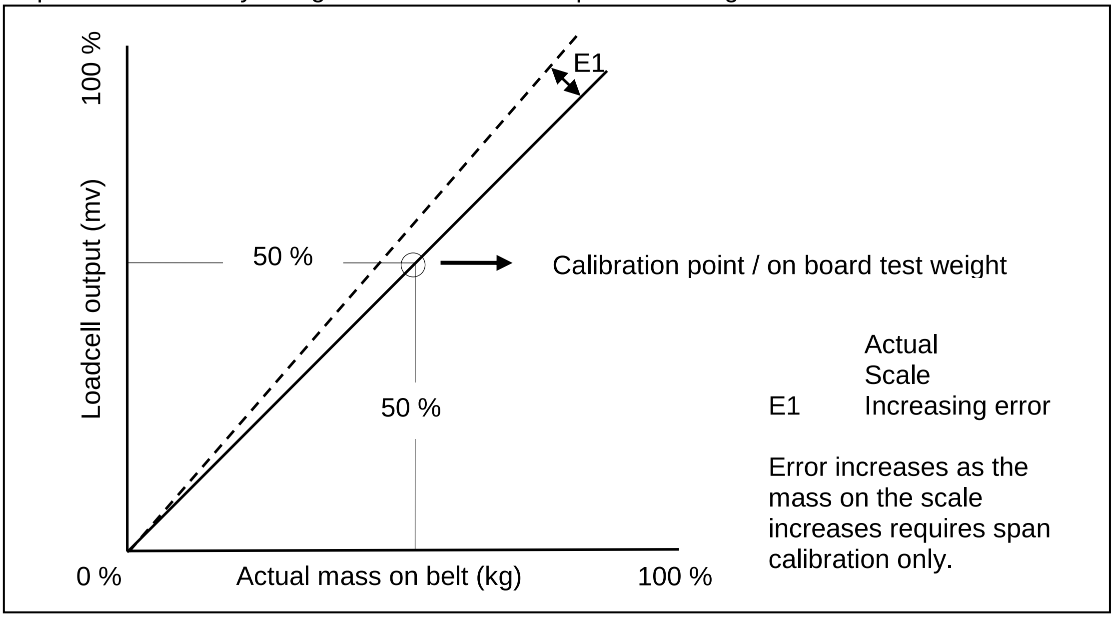


Figure 9. – Shows a scale with a constant linear

8. DEFICENCIES IN THE CONVENTIONAL CONVEYOR BELT SCALE DESIGN.

The conventional conveyor belt scale is not able to detect and deal with integral failures or outside influences that negatively affect accuracy and reliability. The following hazards remain undetected to the conventional design during normal operation.

Integral hazards.

- Electronic failure (specifically partial failure of loadcells, integrators, speed detection devices).
- Mechanical failures (specifically partial mechanical failures, loadcell mounting failures and scale misalignment)

External hazards

- Incorrect installation (misalignment, balance out, incorrect calibration)
- Changing belt conditions (belt slip, belt tracking, belt loading)
- Foreign objects on scale (spillage, tools, foreign objects)
- Human interference (deliberate intervention, incorrect calibration)

As depicted in figure 10 below the load cells on conventional belt scales are electrically joined by connecting the four loadcells electrical supply and signal wires in parallel effectively changing the loadcell's input to the controller into a single input with each loadcell contributing 25% to the overall signal.

The deficiency in this system is that in the case of a load cell failure the signal to the controller would change and would go unnoticed until a zero check is performed. Once the fault is found two things could be done by the technician

1) Find the fault, take the conveyor and interlocked conveyors out of service, disconnect the load cells one by one and test them by means of a digital multimeter. The load cell would then have to be replaced and the scale recalibrated completely.
2) Take the conveyor out of service, run a zero calibration in order to get rid of the error leaving the scale compromised, and in operation with a faulty load cell.

In both cases above the scales could have more than one loadcell that is not healthy. Without linearity checks being done on each individual loadcell the technician can put a scale back into service that is not working properly. The same process is required to find all integral faults on conventional belt scale designs, including a single loadcell counterbalance system. The conventional system shown below cannot detect, report or compensate for such integral failures to loadcells or speed input devices nor can it detect belt slip, misalignment, foreign objects, uneven material loading etc. All of these affect the accuracy of a scale and hence the deficiency in conventional design.

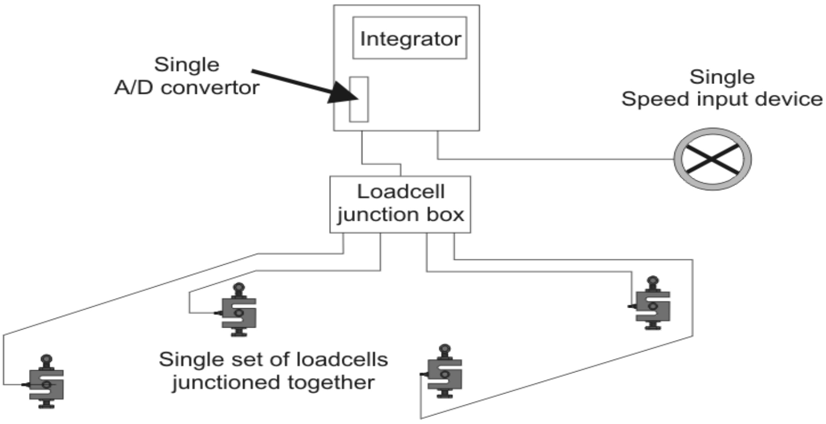


Figure 10.
Conventional scale

In order to attempt to overcome these deficiencies, various systems have been tried in the past. These range from automatic zero checks to intensive maintenance plans and even installing two scales in tandem on the same belt. Although such systems do help police drift in calibration of the scales, the reasons for the drift still have to be diagnosed following the process shown above. The scales still suffer from the same deficiencies and calibration errors. If drift is detected a choice must be made between downtime and inaccuracy. In most cases production takes preference to the accuracy of the scale leaving the accounting system compromised to be adjusted by estimation later on.

In order to make the belt scale a reliable weighing instrument intelligence and redundancy is required. A smarter system could detect integral failures and external hazards under normal running conditions not only diagnosing them but also overriding and reporting the fault. Redundancy can then allow the scale to carry on weighing accurately until the technician on site can replace the already isolated, faulty component during normal scheduled maintenance without taking the belt out of service.

9. DESIGN IMPROVEMENTS.

The shortfalls of conventional conveyor belt scales are the cause of the continual battle between mining, production; engineering and accounting over production rates and throughputs that are so common on mines and plants. The fact remains that the as installed accuracy of conventional scales can be affected by component failure or changes in belt conditions at any time. Such deviations in accuracy will go undetected until routine maintenance checks are performed even then as shown above regular calibration checks cannot ensure that the scales will provide accurate and reliable weighing results.

The solution is a scale that not only detects a problem but that also diagnoses it to a specific component or problem and then is able to isolate the failure and continue weighing accurately without stopping the process. The smart scale principal is a simple idea that effectively provides this solution. The scale has built in redundancy on load cells, speed detection devices and electronic components that not only allow detection of problems that negatively influence accuracy but also allow the scale to isolate and report the fault and continue weighing accurately.

The system consists of a full floating scale frame with two sets of four loadcells each, two speed input devices and separate Analogue to digital converter card for each load cell and speed input device. This allows the scale to compare individual loadcells and speed input devices with each other and at the same time compare two complete scales with each other while the belt is running. The comparisons allow the electronic integrator/controller to determine even the smallest failure on a loadcell or speed input device, isolate, override and report the fault and replace the faulty component with the closest working unit (neighbour) thereby maintaining an accurate scale. The system effectively addresses all potential integral failures and partial failures on the run making the scale intelligent and reliable.

A further advantage of this system is that it can also detect and alarm external hazards that affect the scales accuracy. The comparison of load cells can detect belt misalignment, uneven material loading, and foreign object on the frame as well as belt slip through the comparison of the dual speed input devices between each other and the reference speed stored in the controller.

By comparing individual loadcells and speed input devices between themselves and reference data stored in the scale during initial commissioning the improved design can diagnose the faults and hazards that are invisible to conventional design. The same multiple loadcell design has the required redundancy to allow the scale to override the faulty component and continue weighing accurately. Further intelligence is built into the software that stores any failures or events on an internal database giving a historical overview of the scale. An onboard diagnostics screen allows the technician to perform diagnostics down to component level instantly without the use of measuring instruments.

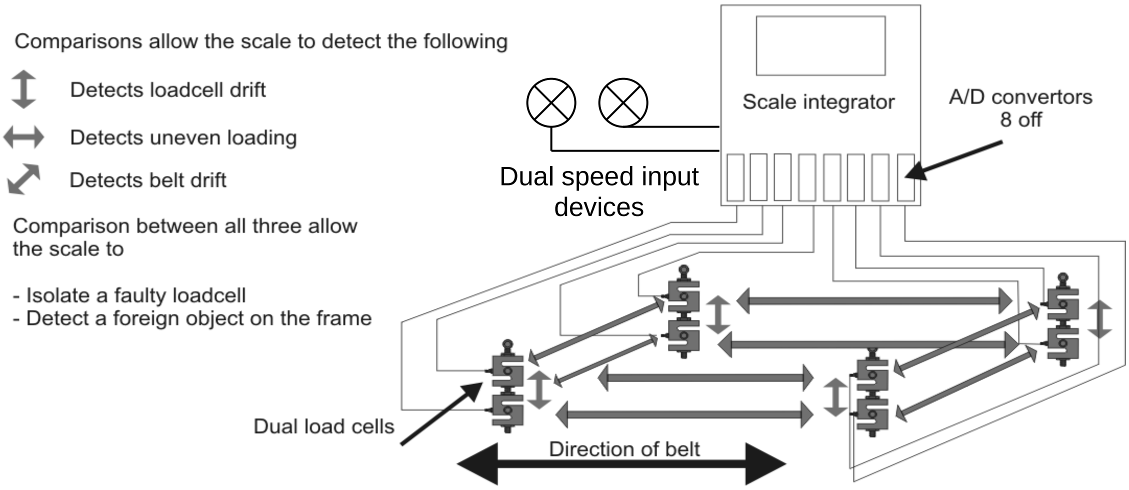


Figure 11

The above system has the capability of detecting and overriding the following failures, reporting the following hazards as well as assisting in the initial calibration and alignment of the scale, the system monitors and records calibration changes and reports suspect calibrations

Integral failures

Load cell failure
- Catastrophic
- Partial

- Load cell mounting failure
  - Catastrophic
  - Partial
- Speed input device failure
  - Catastrophic
  - Partial
- Component failure
  - Electronic
  - Mechanical

External hazards
- Belt slip, tracking, and uneven loading
- Foreign objects on frame

Calibration errors
- Zero error checks on the run every time the belt runs empty
- Calibration errors mass and speed.

Initial calibration

- Mass and speed calibration to within 0,25%
- Alignment of the scale using load cell comparisons
- Does not require on board test mass as scale monitors loadcell condition.

On board data base

- Full historical overview
    - Calibration changes
    - Process alarms (speed faults, belt slip, overloading etc.)
    - Totalizer readings (old values, time date stamp for resets)

On board diagnostics screen

- Diagnostics of all failures to component level

10. TECHNOLOGICAL ADVANCES

The weighing industry is notoriously slow to implement, and is a follower and not a leader as far as technological advances go. Recent advances in technology in the weighing industry have allowed the implementation of a new type of scale that overcomes the deficiencies of the conventional conveyor belt scale. In the past weighing electronics did not have the speed, flexibility or programmability to allow the new generation scale to make it into production. In 2002 technology became available that could be utilised in making the new generation scale a reality. A dedicated weighing device that met the requirements for the comparison of multiple load cells and speed measuring devices while retaining speed and resolution became available. Substantial work was still required at hardware, firmware and software level to get the device to perform the required functionality. A prototype new generation intelligent scale was developed and installed in one of the biggest coal terminals in the world for testing and further development.

11. CONCLUSIONS

The development of the smart scale has finally overcome the deficiencies of the conventional type conveyor belt scale that have for decades questioned the integrity of the “operational accuracy” of the belt scale.

12. AUTHOR INFORMATION

G. R. Dean has been in the conveyor belt scale industry since 1990 and started as a field technician in the industry. Mr Dean started manufacturing and designing his own scales in 1995 and holds the patent on the smart belt scale described in this document. Mr Dean now heads Lorbrand’s scales department.

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