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White Paper

How to Lower Gain and Offset Drift of a Load Cell

by using TKGain and TKOffset factors of PSØ8/ PSØ81

February 2010, 1st Revision
Document-No. WP002 V1.1

Preface

In application note 18 we showed that the PSØ8 plays in the premier league in respect of the gain and offset drift behavior. It was proved that a PSØ8 based electronics is good enough to build legal for trade scales with up to 10,000 OIML[1] divisions or even more.

But the gain and offset drift of the electronics is only one part of the gain and offset error of a weigh scale. Another part comes from the load cell itself. Since the last 10 years, the weighing electronic has benefited a lot from the significant progress in high end converter technology. The resolution was improved and in parallel the gain and offset errors were reduced to very low values. As a result, the load cell becomes more and more the dominant part as cause of the gain and offset errors of a scale.

Thus, the overall temperature drift behavior of a weigh scale can not really be improved by only reducing the error of the electronics, e.g. by reducing the offset drift from 10 nV/K to 5 nV/K. The load cell itself still has a 100 nV/K drift.

Nowadays, good converters have a far better behavior in regards of

- Gain drift
- Offset drift
- Nonlinearity
- Hysteresis

than good load cells. Only in regards of the noise behavior even the best high end converters are still 1 to 2 bit below the thermal noise of the strain gage resistors and further improvement in this respect does make sense.

PICOSTRAIN offers new possibilities to lower the gain and offset drift behavior of the load cell by setting 2 parameters in the chip. This leads to an adjustment of the load cell that is more precise than with standard solutions – and simplifies the production (and reduces production cost this way) as a secondary effect. This opens new oppportunities for scale and load cell manufacturers to improve their products while saving costs.

This white paper explains the background and shows how to do the the adjustment in practice.

[1] OIML = Organisation Internationale de Métrologie Légale, is an international organization which gives rules and guidelines for legal metrology. Please see www.oiml.org for more information.

Preface

In August 2008, acam has done load cell adjustments in the manner we describe here. We show and discuss the results of those in the 4th chapter of this white paper. The measurements were done with the PS08 evaluation kit using the high end plug-in module and various load cells.

In February 2010 we added latest information according to insights gained from further practical tests. Information added is about the possiblities to connect R_{span} and its general behavior towards the overall linearity of the load cell over temperature.

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1. Gain and offset drift adjustment of the load cell with A/D converter

At first, we look at the well-known classical A/D converter solutions.

1.1 Setup

Fig. 1 shows a classical schematic of an offset and gain adjusted load cell which can be used with an A/D converter. All compensated load cells for A/D converters are built in this or a similar way.

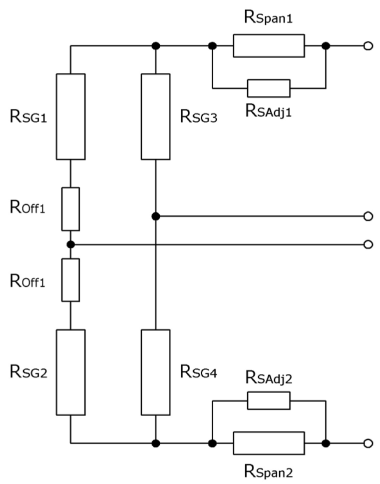


Fig. 1: Schematic of a compensated load cell for A/D converters

In the following we will describe the different components of this load cell.

1.2 Measuring the strain (R_{SG1} to R_{SG4})

R_{SG1} to R_{SG4} are the strain gage resistors themselves. They change their resistance when they are extended mechanically. The typical variation of the resistance is 0.2 % at full load. Strain gages are made of a very temperature stable alloy (e.g. Ni-Cr), but nevertheless they change their resistance slightly over temperature in the range of < 5 ppm/K. The drift varies from strain gage to strain gage and can be seen as one part of the offset drift.

1.3 Gain drift compensation (R_{Span1} and R_{Span2})

The sensitivity of the load cell depends on the temperature. Without changing the load, the differential output voltage of the Wheatstone bridge will change over temperature. This error is called span error or gain drift. The drift is significant and approximately in

1. Gain and offset drift adjustment of the load cell with A/D converter

the range of typically 300 to 600 ppm/K. Without compensation, no precise measurement can be done, especially in weigh scales where the resolution is nowadays in the range of 10 to 20 ppm of full scale (F.S.).

Example:
If an uncompensated load cell of 10,000 g capacity has a gain drift of 500 ppm/K, it will drift 150 g (!) over a temperature range of 30 K. Thereby, the characteristic of the drift is mostly positive, that means with increasing temperature also the sensitivity increases. For a 3,000 divisions weigh scales only 0.05 % gain drift is allowed according to OIML. This is approximately 30 times less than an uncompensated load cell has.

To compensate for this span error, either one or two temperature dependent resistors (R_{Span1}, R_{Span2}) are added to the load cell. The basic working principle is, that the span resistor's value increases with rising temperature. So the effective voltage over the bridge (U_{Br}) is reduced. Consequently, also the differential output voltage (U_{diff}) is reduced. This way, the increasing sensitivity of the strain gage resistors can be compensated by reducing the voltage by means of the R_{Span} resistors. Of course, the values of the Rspan resistors have to be matched to the bridge's drift behavior. The load cell voltage (U_{LC}) itself is stable over temperature.

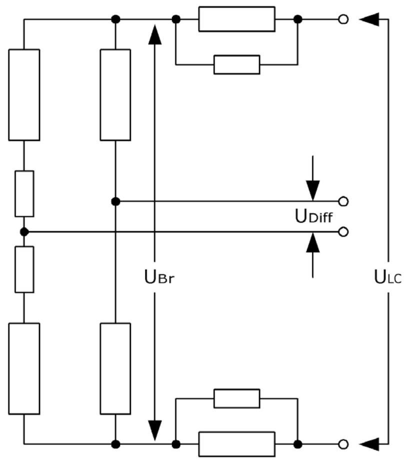


Fig. 2: Voltages of the Wheatstone bridge

As shown in Fig. 2 it is common to use two R_{span} resistors. The reason for that is not the working principle itself (it works with only one Rspan resistor, too), but that former A/D converters had a limited common mode rejection ratio (CMRR). A low CMRR in combi-

1. Gain and offset drift adjustment of the load cell with A/D converter

nation with only one Rspan resistor leads to an unwanted variation in the absolute value of the output voltage. While only a differential voltage variation around the half supply voltage is desired, this leads to an offset drift of the A/D converter. The effect is stronger with a lower CMRR.

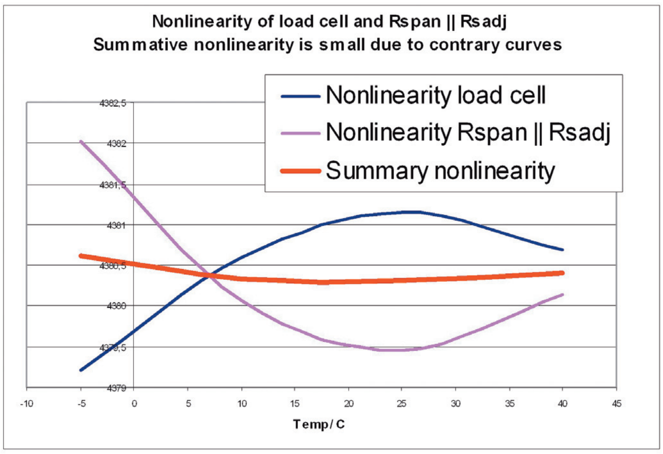
Example:
Coming back to the uncompensated load cell with a gain drift of 500 ppm/K, this means a change in sensitivity of 1.5 % over a 30 K temperature range. In other words, this is the increase of the sensitivity which needs to be compensated by the Rspan resistor. With only one Rspan resistor, this results in a common mode voltage of 37.5 mV at 5 V excitation voltage. With an A/D converter with a CMRR of 80dB this 37.5 mV result in a variation of the output voltage of 3.75 µV or 125 nV/K. This can not be neglected. For an A/D converter with a CMRR of 100dB, the variation is only 375 nV or 12.5 nV/K, which is in an acceptable value.

Because of the fact, that good A/D converter nowadays have a CMRR of at least 100 dB there is practically no need to use the two Rspan resistors anymore. But because it was necessary in former times with older electronics it is still common practice today.

1.3.1 Rspan adjustment resistors (R_{SAdj1} and R_{SAdj2})

The Rspan resistor itself is a special, temperature-dependent resistor which is located very near by the strain gage resistors. It is very difficult to access and adjust these Rspan resistors during production, therfore their value is simply corrected by paralleling standard resistors in the connection field of the load cell. In other words, the value of Rspan is always chosen too high (overcompensation), so that it can be reduced by a paralleling a resistor afterwards.

A second effect of the adjustment resistors is to counteract against the load cell's nonlinearity over temperature. Thereby the paralleling of the resistors introduce a nonlinearity over temperature (simply due to mathematics) which normally goes in the opposite direction of the load cell's nonlinearity so that overall nonlinearity can be reduced. The following graph illustrates the effect:



Remark: If the load cell has a very low nonlinearity over temperature it may not be necessary to balance it by paralleling an Rspan adjustment resistor. However it is common to have an Rspan adjustment in many cases to trim the value of Rspan anyway.

Furthermore please recognize that the described nonlinearity caused by the parallel resistor of Rspan is an effect over temperature and **not** over the load. The normally specified nonlinearity (over the load) is not affected by this resistor.

1.4 Offset drift compensation (R_{Off1} and R_{Off2})

To adjust the offset drift it is necessary to add some resistors. Fig. 1 shows one way how this can be done with R_{Off1} and R_{Off2}.

The total offset drift is a combination of two effects which are independent from each other:

- Offset drift due to the unadjusted zero output voltage of the bridge
- Offset drift due to the different temperature drifts of the four strain gage resistors

1.4.1 Offset drift caused by unadjusted output voltage

In a classical A/D converter circuit it is obligatory to adjust the output voltage of the bridge (Udiff) very close to zero (unloaded case), especially if an Rspan resistor is used. Otherwise, there will be an additional offset drift according to the unadjusted zero voltage.

But what happens, if the zero voltage is not adjusted ?

If there is an unadjusted offset voltage at zero load, it will be affected by the R_{span} resistors. As the R_{span} resistor(s) increases over temperature, this offset voltage will decrease in consequence. This change will be seen as offset drift in the output voltage. Depending on the size of the unadjusted zero voltage the resulting drift can be significant, as the following example shows:

Example:
Excitation Voltage: 5 V
Unadjusted zero offset voltage: 0.4 mV/V
U_{br} variation due to R_{span}: 1.5 % over 30 K

→ Resulting offset drift: 2 mV * 1.5 % = 30 µV over 30 K, that means 1000 nV/K

If we consider that a good C3 load cell has an offset drift of approx. 100 nV/K, it is clear that the offset drift due to R_{span} from the example is 10 times higher and far too much, even though the assumed unadjusted offset voltage of 0.4 mV/V is rather optimistic than pessimistic and hard to reach in reality. So it is quite obvious that classical A/D converter solutions do not achieve good zero offset drift behavior without adjusting the zero offset of the bridge.

1.4.2 Offset drift caused by the temperature drift of the strain gages

Strain gage resistors belong to the resistor types with the lowest temperature drift in industry in general. Nevertheless, their drift is not zero. It is not the drift of each resistor itself that causes an offset drift of the bridge but the mismatching drift of the four resistors.

A short example shows the effect:

Drift mismatch of the 4 strain gage resistors: 0.5 ppm/K

→ Resulting offset drift: 2.5 µV/K at 5V bridge voltage (U_{Br})

Thereby, 2.5 µV/K is 5 times higher than the limit given by the 3,000 division OIML specification. To achieve a matching of 0.5 ppm/K with standard resistors is already hard to reach and does definitely increase production costs. On the contrary, 0.5 ppm/K mismatch in a load cell is very poor and is already reached by standard consumer cells. That means, especially in the field of load cells the problem is widely known and products are available with very small mismatching. A good load cell has approximately 100 nV/K or 0.02 ppm/K mismatch which is an impressive value. But as the example shows, such good values are required for a low offset drift.

It is clear that R_{Off1} and R_{Off2} are obligatory for a good offset drift value. It is common practice not only to use them, but make one of the two resistors temperature dependent in order to make a so called 'active offset drift adjustment'. If this method is used, every single load cell needs to be adjusted in a temperature drift run as the offset drift is not stable over a whole production lot. In other words, every load cell has it's own offset drift behavior.

1.5 Conclusion

In chapter 1 we showed how the gain and offset drift compensation is done in classical A/D converter solutions. It is obvious that **without** doing the compensation, limits given by the OIML specification (or similar) **are exceeded significantly**. So it is obligatory to do this compensation in order to get a reasonable drift behavior. This causes a lot of **efforts and production** costs (trimming of resistors, temperature runs, etc.).

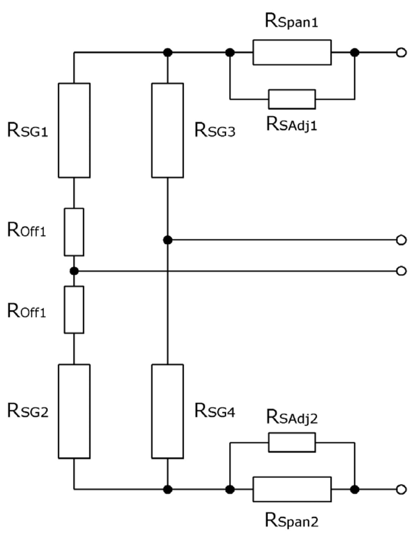
2. Gain and offset drift adjustment of the load cell with PICOSTRAIN

Now we will see how this works with PICOSTRAIN. As mentioned in the preface, PICOSTRAIN offers new possibilities to adjust the gain and offset drift of a load cell – without any mechanical trimming.

2.1 Setup

The next figure shows the schematic of the fully compensated PICOSTRAIN bridge in comparison with the classical solution. It is obvious, that the circuit is much simpler than the classical approach, instead of 6 compensation resistors only one[2] is used. More than that, this one Rspan resistor doesn't need to have the exact value, so no mechanical trimming is required. The fine adjustment of this resistor is entirely done by software.

Fully compensated Wheatstone Bridge for A/D-Converters



Fully compensated PICOSTRAIN bridge

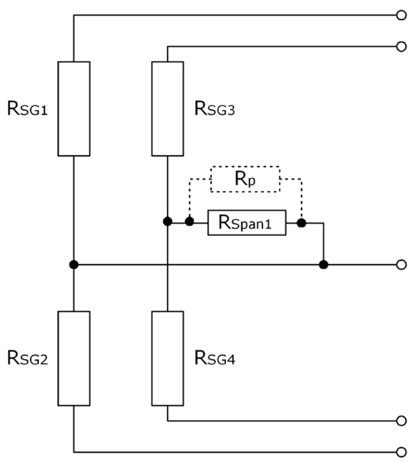


Fig. 3: Classical Wheatstone bridge vs. PICOSTRAIN bridge

A fully compensated PICOSTRAIN bridge has a much lower gain and offset drift than a good compensated classical bridge. Furthermore, the compensation can be done faster in production and lower the cost because no mechanical trimming is required anymore.

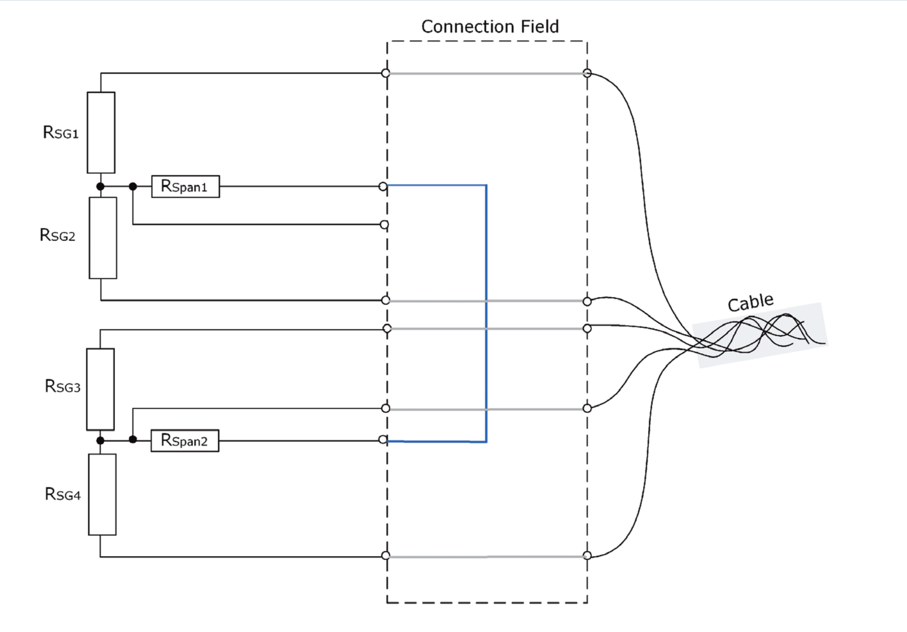
[2] The R_{span1} resistor is good to compensate for temperature drift. It may be necessary to put another fixed resistor in parallel (R_p) to reduce the nonlinearity of the load cell over temperature. This resistor R_p is NOT the same as an adjustment resistor, it is not necessary to make an adjustment as R_{span1} is not adjusted by R_p. Please see 1.3.1 and 2.3.1 for more details.

2. Gain and offset drift adjustment of the load cell with PICOSTRAIN

Please note:

PICOSTRAIN needs only one Rspan resistor. As the CMRR of the PICOSTRAIN products is nearly infinite (up to 135 dB !), there is no need to use two Rspan resistors. Indeed, PICOSTRAIN can not handle bridges with two Rspan resistors. If more than one Rspan is used then the methods described here can not be used!

However even if there are natively 2 R_{span} resistors on the load cell there are ways to change it to have only 1 R_{span}. One possibility is to short-cut 1 of the R_{span} resistors, the other possibility is to wire them differently, as far as the wires are available in the connection field as shown in the following picture:



The PICOSTRAIN bridge has a different wiring compared to the classical Wheatstone bridge. There are load cells available which have the PICOSTRAIN wiring already, but also ordinary load cells can be modified from Wheatstone wiring to PICOSTRAIN wiring easily as this is only done in the patch-field of the load cell. The sensors themselves are not touched or modified in any way.

Once you have the PICOSTRAIN wiring, there is no further need to mechanically trim or touch the load cell. This means that you can fully produce the load cell and do the compensation afterwards! This way, the compensation is no longer part of the production process itself.

2. Gain and offset drift adjustment of the load cell with PICOSTRAIN

You may ask how we can do a compensation fully by software? The simple answer is that we can gain more information from the bridge as usual A/D converters. While an A/D converter has only the information of a varying bridge output voltage, we can collect data from every resistor thanks to the different measurement principle. In this way we can correct mathematically the single resistor values respectively the ratios of the resistors. Learn in the next section about the basic working principle of PICOSTRAIN and how we do the measurement of the strain.

2.2 PICOSTRAIN measurement principle

In this section we want to give a short introduction into the PICOSTRAIN measurement principle. A detailed explanation can be found in the data sheet of the PICOSTRAIN products, available on the acam website[2)].

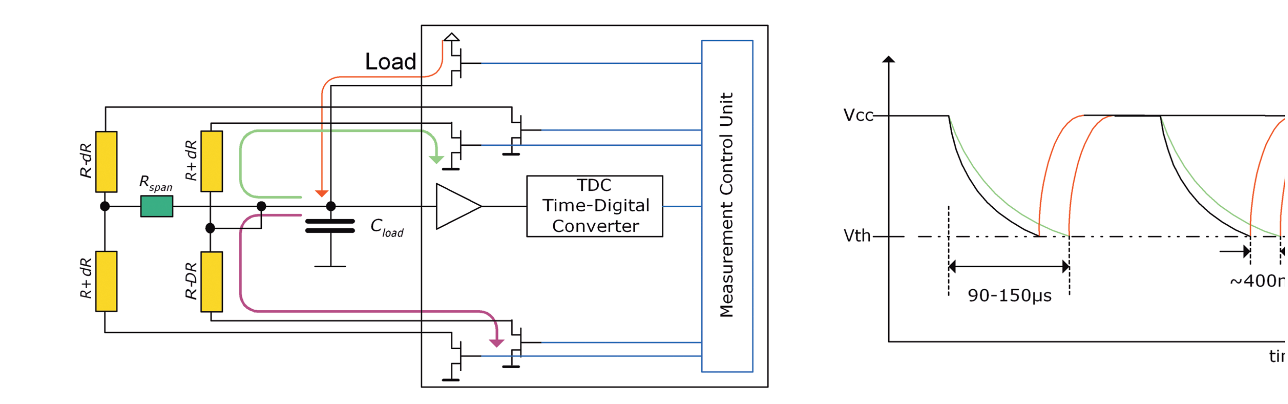


Fig. 4: PICOSTRAIN bridge

The capacitor Cload is charged up to supply voltage through the load pin of the chip. Then, in a second step, Cload is discharged over one of the resistors R_{SG1} to R_{SG4} sequentially by switching one of the ports P1 to P4 to ground (chip intern). The discharge time of Cload down to a given threshold is measured with a so called time-to-digital converter (TDC) with a resolution in the lower picosecond range (15ps). Thereby, R_{SG1} and R_{SG2} are measured direcly while R_{SG3} and R_{SG4} are measured in combination with R_{Span1}.
This way R_{Span1} is the only resistor needed to get the temperature information. Furthermore, this resistor is at the best place (directly on the load cell) to sense the temperature and give the information to the chip. So the efforts are minimized but the method is very efficient.

(The methods described here are patented by acam with European and US patents)

[2)] acam website: http://www.acam.de/products/picostrain

2. Gain and offset drift adjustment of the load cell with PICOSTRAIN

2.3 Gain drift compensation (TKGain)

Meanwhile a classical A/D converter solution has only one information, the differential voltage, we can gain a lot more information with PICOSTRAIN. With some chip-internal mathematics it is possible to get every resistor ratio of the bridge. We can even build the ratio of R_{span} to the sum of the strain gage resistors (R_{SG1} to R_{SG4}).

It's easy to imagine that we can multiply any ratio by a factor given through a register. In particular, we are multiplying the ratio R_{span} / R_{SG} by a factor called "TKGain", a temperature correction factor. Doing this corresponds to a mulitplication of R_{span} by TKGain. The final output result of the bridge is then multiplied by this 'corrected R_{span}', so that the behavior equals a bridge with a (software) trimmed R_{span}.

Example:
We take a 350 Ω load cell with a 40 Ω R_{span} resistor.

If we set TKGain to 0.9, the behavior of the load cell is now like the one with a 36 Ω Rspan resistor. Thereby, other properties of the Rspan such as the temperature dependency are not touched in any way. This means that an original 40 Ω Span resistor with 6,000 ppm/K will also have this temperature dependent behavior after the multiplication.

By the help of the TKGain factor, the gain drift of the load cell can be adjusted much more precisely than it ever could be done by soldering resistors in parallel. In theory, the gain drift can be reduced to zero. Practically, the gain drift can be reduced to < 2 ppm/K, depending on how accurate the adjustment measurements are done.

This value is quite impressive as for a 10,000 OIML divisions scale the maximum gain drift is specified to < 5 ppm/K. But not only high end scales can be improved easily and brought into the specification limits this way. The method also offers manifold possibilities for standard scales which can be improved in quality and reduced in production costs.

2. Gain and offset drift adjustment of the load cell with PICOSTRAIN

TKGain can be set in a range from –8.0 over 0.0 to 7.99999. With the TKGain value of 1.0, the original value of the implemented R_{span} is used so that the gain drift behavior is not touched in any way. Generally, there is a wide range to set TKGain. Even negative values can be set. This is possible due to the fact that pure mathematics is used inside the chip. With a negative TKGain the effect of the R_{span} is inversed. This may be used if an R_{span} with the 'wrong direction' regarding it's temperature drift behavior is taken, but it doesn't make too much sense, of course.

In case you have a load cell which has already a good gain compensation (correct R_{span}), then TKGain = 1.0 is the right value to set.

Please note:
If a load cell with an R_{span} resistor is used, you need to enable the ‚modification possibilities' by setting mod_rspan = 1. Even if the load cell's original R_{span} shall be used without any further adjustment, mod_rspan needs to be set to 1 (with TKGain = 1.0 and TK-Off = 0). Setting mod_rspan = 0 is only an option for uncompensated load cells that have no R_{span} resistor at all

The absolute correct value for TKGain can be determined by doing an accurate temperature run. But even without doing the temperature run or doing it not absolutely accurately, you can achieve the following:

- Correcting a complete lot of load cells which would have been wasted because their gain drift is too high. This requires the determination of the proper TKGain value once as well as a the determination if the drift behavior of the whole lot is similar.

- Correcting the R_{span} resistor into the correct range. For standard scales it may not be necessary to adapt the R_{span} resistor very accurately, but it will be necessary to adapt it to a reasonable behavior. With the software correction, the load cell production is simplified.

2. Gain and offset drift adjustment of the load cell with PICOSTRAIN

2.3.1 Nonlinearity of gain over temperature

Independently of the PICOSTRAIN gain drift compensation we have always a nonlinearity of the load cell over temperature. This nonlinearity generally has two causes, the nonlinearity of the load cell itself (material, glue, wiring, etc.) and a nonlinearity coming from the paralleling of the R_{span} resistor with its adjustment resistor (R_{sadj}). Normally these two effects are in opposite direction, so that overall nonlinearity can be reduced. In other words, the nonlinearity introduced by the paralleling of the resistors is compensating to some degree the nonlinearity coming from the load cell itself.

However there is a change in behavior if the adjustment resistor (R_{sadj}) is missing at all, as there is no compensating effect of nonlinearity any longer. In the basic set-up of a PICOSTRAIN bridge with 1 R_{span} there is no further adjustment resistor needed and therefore missing. This is not a problem if the load cell's nonlinearity itself is very low. But if it has a nonlinearity not neglectable, it may be required to add a parallel resistor to compensate for the nonlinearity. Please note, that this parallel resistor (R_p) does not have the purpose of correcting R_{span} in its resistor's value, but only for nonlinear compensation of the load cell itself.

In order to decide whether a parallel resistor is necessary or not, please check for matching one or more of the following criteria:

- The load cell normally has an adjustment resistor and R_{sadj} < 10 x R_{span} is true
- In the first run of determining TK-Gain you get a value < 0.8
- A temperature run with TK-Gain = 1 shows a gain drift > 100 ppm/K

Examples:

Your load cell has an Rspan of 40 Ω with an adjustment resistor R_{sadj} in parallel of 350 Ω. In this case R_{sadj} is smaller than 10-times Rspan and so it's recommended to keep the resistor. You also could choose standard values like 330 Ω or 390 Ω (over complete production).

Let's assume you only have 1 R_{span} and no adjustment resistor in parallel and you are determining TK-Gain for the first time. If TK-Gain is smaller than 0.8, i.e. 0.73 it's recommended to switch a resistor in parallel (R_p).

2. Gain and offset drift adjustment of the load cell with PICOSTRAIN

Please note, that the parallel resistor (Rp) can be an ordinary fixed resistor and does NOT have to be a special kind of adjustment resistor. Of course if you have already one in parallel which fulfills the requirements you can keep it.

The size of Rp is calculated by our TK-Gain / TK-Off calculation sheet TKGain_TKOffs_Calculation.xls available from our website at: http://www.acam.de/fileadmin/Download/_software/TKGain_TKOffs_Calculation.xls. It is thereby not necessary to choose it exactly to the value proposed, but roughly. For example if the calculation sheet suggests an R_p of 462.5 Ω you can simply pick the next value from the E12 row which would be 470 Ω, even the following, 510 Ω would be possible.

2.4 Offset drift compensation (TK-Off)

The mathematics of the chips is really powerful. When the bridge is recombined mathematically in the CPU of the PICOSTRAIN chips. Even resistors can be virtually added that do not exist in reality. Exactly this is done when it comes to the offset adjustment:
A resistor is added virtually and can be configured by the TKOff register. The properties of this 'virtual offset resistor' are:

- absolutely precise
- set in ppm, relatively to the strain gage resistors
- can be positive or negative
- can be chosen in a very wide range (24 bit value with 0.01ppm steps)

This is indeed the most ideal resistor which can be built.

Just to make clear the dimension of this ideal resistor: if we take for example a 350 Ω strain gage resistor then the minimum step size would be 3.5 µΩ. Doing such a resistor trimming in reality will be pretty challenging!

2. Gain and offset drift adjustment of the load cell with PICOSTRAIN

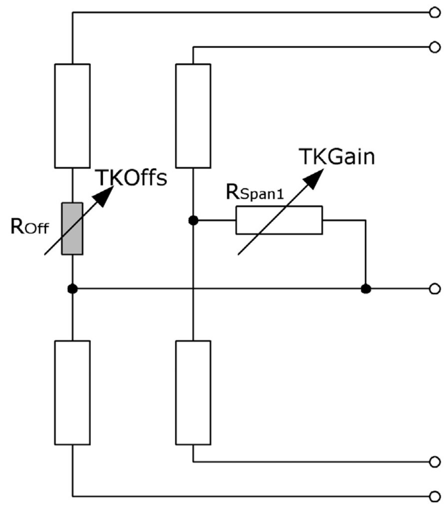


Fig. 5: Adding an offset adjustment resistor virtually

→ **This virtually added resistor can adjust the offset drift of the load cell and can compensate both parts of the drift. This is indeed an ideal offset adjustment!**

2.4.1 Offset drift compensation without temperature run (partly compensated)

By means of this virtually added resistor the bridge's zero offset can be adjusted exactly to zero. Unlike in classical solutions, there is no need to add an offset adjustment resistor mechanically on the load cell The adjustment is entirely done by software (register setting). By adjusting the bridge to zero, at least one of the two possible causes of the offset drift can be eliminated (see section 1.4 Offset drift compensation). The adjustment of the bridge's zero offset does not require a temperature run.

How can the adjustment be done ? - Two simple steps are required:

1. Unload the load cell entirely (here the 'real zero load' is needed, because even a slight weight like the weighing plate will have effects on the gain drift). The best moment to do that is during the load cell production.

2. Adjust the value for TKOff in such a way that the displayed measurement result (it's called HBO at PS08/PS081) is showing zero. The checkbox 'zero-offset' in the evaluation software needs to be unchecked before, of course. If necessary, choose negative values for TKOff in order to adjust the value to zero.

2. Gain and offset drift adjustment of the load cell with PICOSTRAIN

After doing this, the bridge is perfectly zero-offset adjusted. The Rspan resistor will not cause any offset drift from now on. This method is simple and cost effective because no temperature run is needed.

Unfortunately, this method is not sufficient when it comes to the second cause of the offset drift: the mismatching drift of the four strain gage resistors (summary drift). So if this part is the major cause of the offset drift, the simple adjustment described above is not sufficient. In this case, an adjustment with a temperature run is required like described in the next section.

2.4.2 Offset drift compensation with temperature drift run (fully compensated)

Doing a temperature run offers the possibility to compensate both causes of the offset drift – the unadjusted zero-offset of the bridge and also the mismatching drift of the strain gage resistors.

You know already, that by means of the virtually added resistor the zero-offset of the bridge can be adjusted to zero and so the influence of the R_{span} in regards of the offset drift can be minimized. But this virtual offset resistor can do more: it's able to compensate also the mismatching drift of the 4 strain gage resistors, if the TKOff value is set correctly – in both, the value and direction (positive or negative).

In other words, the value of TKOff does combine the compensation of both drift sources. So once the offset of the bridge is adjusted to zero, the Rspan helps indiretly to determine the offset drift caused by the mismatch of the strain gage resistors. With this pair of information the TKOff can be set to counteract against both drift sources and reach a low summary drift, as principally shown in Fig. 6.

2. Gain and offset drift adjustment of the load cell with PICOSTRAIN

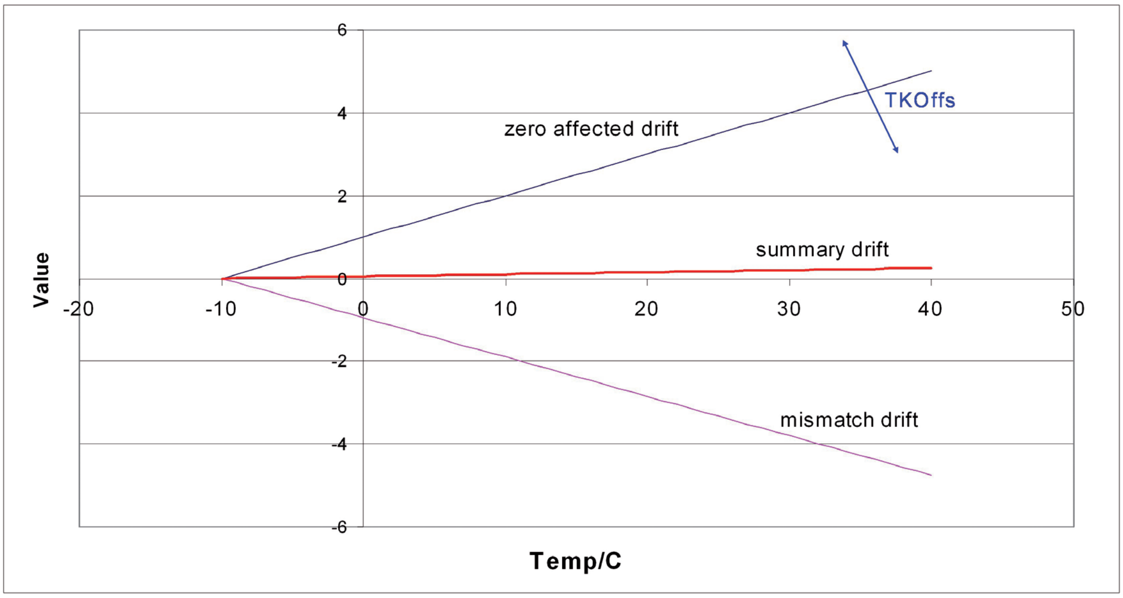


Fig. 6: Adjust the summary offset drift to a minimum by using TK-Off

The full offset compensation requires a temperature run with 2 different temperatures. With the results of the measurement, the proper factor for TK-Off can be calculated. Because the offset drift varies from load cell to load cell (even within a production lot), the proper value needs to be determined with every single load cell (in classical A/D converter applications this is done anyway, if a low offset drift behavior is required).

3. How to do the gain and offset adjustment with PICOSTRAIN

3.1 Adjustment without temperature drift run (partly compensated)

As described, the corrections can be done without a temperature drift run but will compensate the gain and offset drift only in parts.

Gain drift:
Assuming the mismatch of the Rspan is known, the resistor can be corrected by setting the TKGain value. This can be done for a whole lot, so maybe lots out of the limits can be saved this way.

Example: due to the measurement of some sample load cells out of a production lot in the temperature chamber it is known that the Rspan resistors in that lot is 10 % lower than required. But as it is a commercial scale lot, a mechanical trimming would be too expensive and with a deviation of 10 % almost not feasible. In this case, TKGain simply needs to be set to 1.1, so the Rspan resistor is corrected to the value needed without any further efforts.

Offset drift:
As described in the previous section, you can eliminate the offset drift caused by the non-adjusted zero-offset of the bridge. This can be done best during the load cell production when no load is on the load cell at all. Then the TKOff value is modified until the bridge's result shows zero. This way, at least one part of the offset drift can be eleminated in a simple manner.

Both results, the TKGain and TKOff value could be written on a small label on the load cell itself, so that this value can be set in the registers when a PICOSTRAIN converter is used.

3.2 Adjustment with temperature drift run (fully compensated)

A much more precise compensation can be achieved by determination of the correct values for TKGain and TK-Off during a temperature run. Basically there is the possibility to adjust the offset drift only or to adjust both, the gain and offset drift with one run.

3. How to do the gain and offset adjustment with PICOSTRAIN

Only offset drift adjustment

In production it is usually easier to get a good adjusted gain drift than a good adjusted offset drift. Because of this it can make sense only to adjust the offset drift more accurately with TKOff.

Another case are high capacity load cells, because you hardly can run a temperature drift test with a 1000 kg maximum load in a temperature drift chamber. Our offset drift adjustment can be done anyway in this case.

Full adjustment

With a full adjustment the gain and offset drift is minimized all at once in one temperature run. This is the best possible compensation with PICOSTRAIN.

The temperature run requires to set two different temperatures and to let them get settled long enough (approx. 1.5 h minimum). At each temperature some measurements are done and the results written into an Excel-Sheet (provided by acam, available at: http://www.acam.de/fileadmin/Download/_software/TKGain_TKOffs_Calculation.xls). Based on these measurement results, the sheet calculates the proper TKGain and TKOff values. The detailed steps are explained in the following two chapters:

3.2.1 Doing only offset drift compensation (TKOff)

To do the TKOff adjustment, it is important to fulfill one precondition:
Either the TKGain value is already correct (e.g. you know the R_{span} is 10 % too small over the whole charge, so it can be set to 1.1) or you set TKGain to 1.0 but do not load the cell at all (this means, even small weights like the weighing plate needs to be removed). If this precondition is not fulfilled, the influence of the gain drift will make it impossible to adjust the offset drift to a minimum value.

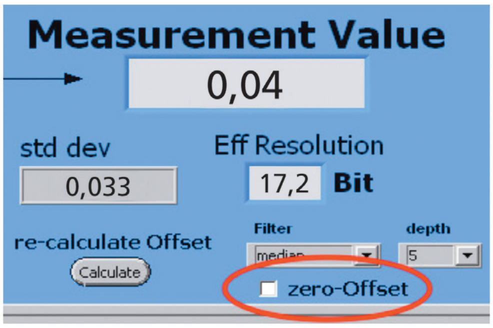
The two temperatures should be apart far enough, with at least 30 K difference is between them, e.g. +10 °C and +40 °C.

3. How to do the gain and offset adjustment with PICOSTRAIN

How the measurements are done…

a) Set the temperature chamber to the lower temperature, e.g. 10 °C and wait for some time, at least 1.5 hours (settling time). Set TKGain as advised formerly and do not load the cell.

b) Start the evaluation software and uncheck the automatic zero offset checkbox, e.g. as shown in the picture of the PSØ8/PSØ81 evaluation software:



c) Set TKOff to 0 and start the measurement. Write the result of the measurement to the field: 'low Load with TKOffs1' (see picture) in the Excel sheet: TKGain-TKOffs_Calculation.xls, page 'Only TKOffs'.

d) Stop the measurement, set TKOff to a value unequal 0, e.g. 10,000 and start the measurement again. Write the result to: 'low Load with TKOffs2'

Measurement results at lower temperature

Condition	Result
low Load with TKOffs1	-334.45
low Load with TKOffs2	-4,802.30

3. How to do the gain and offset adjustment with PICOSTRAIN

e) Do the same at the 2nd temperature (after waiting the settling time of 1.5h) and write the results to the table indicated with 'Measurement results at higher temperature'.

Measurement results at higher temperature

Condition	Result
low Load with TKOffs1	-382.64
low Load with TKOffs2	-4,769.99

f) After filling in the four values, the correct value for TKOff is shown in the cells below:

Calculated TKOffs Value for Loadcell

PSØ8	**TKOffs:**	**5,986.3**
PSØ21	**TKOffs:**	**59.9**

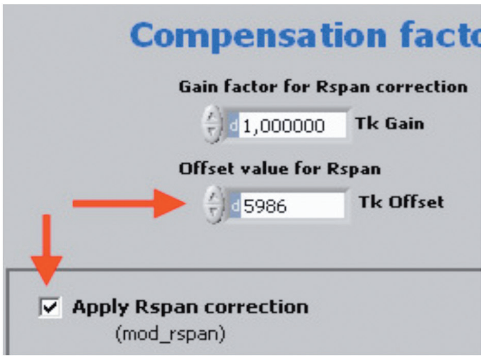
Write now the integer part of the value – in this example 5,986 for PSØ8/PSØ81 respectively 60 for PSØ21 – to the corresponding registers in the PICOSTRAIN chip. Depending on which chip you use, the registers and the format is different:

PSØ8/PSØ81:
In PSØ8/PSØ81 the value for TKOff is stored in register 9 as a two's complement number, 24-bit wide. One step in this number equals 0.01 ppm of the strain gage resistors. This means, the above number corresponds to a correction of approx. 59.8 ppm and is written in hexadecimal format to the register: 0x001762. Also negative numbers can be set. Please note the notation in two's complement writing, e.g. – 5,986 would correspond to 0xFFE89E.

PSØ21:
In PSØ21 the TK-Off value is stored in register 12 as a 24-bit value. But here the notation is different. It's also written in the two's complement but with 16-bit integer and 8-bit fraction. One step in the integer part corresponds to 1 ppm of the strain gage resistors. The upper example would mean to write 0x003C00 for 60 to register 12. Of course, you can also use the exact value which is 59.86 and corresonds to 0x003BDC. Normally it is enough to fill in the integer part only. The corresponding value for –59.86 would be 0xFFC424 then.

3. How to do the gain and offset adjustment with PICOSTRAIN

Either way, you determined the proper TKOff value now and can write it into the corresponding register. From now on, the offset compensation is active. Please note, that 'mod_rspan' always needs to be activated to enable the compensation.



Annotations:

By setting the correct TK-Off value and activating mod_rspan, the offset compensation is active. Of course you can run another temperature drift test at 2 temperatures and see how the offset drifts over temperature in order to see how the improvement is.

In step d) the TKOff value is set to 10,000. How to set this value depends on how strong the offset drift of the load cell is. That means, with a strong drifting load cell, you can choose this value higher, e.g. 20,000 or even 100,000. If the TKOff value which is calculated by the Excel-sheet has indeed such a high value like 100,000, this value can only be set in PSØ8/PSØ81. In PSØ21 the maximum is 65,535 (16-bit).

3.2.2 Doing gain and offst drift compensation (TKGain and TK-Off)

To do the full compensation, a temperature drift run with measuring several values at the two temperatures is needed. The main difference to the 'only offset drift compensation' measurements is that some measurements need a load. So you have to charge the load cell by a weight. Although it doesn't matter what size the load basically has, it is recommended to choose a load > 0.5 maximum capacity in order to keep the quantization error at a minimum (e.g. use a weight > 2.5 kg with a 5 kg load cell).

3. How to do the gain and offset adjustment with PICOSTRAIN

Again, the two temperatures should be enough apart so that at least 30 K difference is between them (e.g. +10 °C and +40 °C). Before doing the measurements at each temperature, let the temperature get settled at least 1.5 hours. At each temperature, 5 measurements are done and the results written to the Excel sheet 'TKGain-TKOffs_Calculation.xls', page 'TKOffs and TKGain', available at
http://www.acam.de/fileadmin/Download/_software/TKGain_TKOffs_Calculation.xls

Preliminary considerations

Before you start with the measurements, you need to pre-select a value for TKGain and TKOff. They should be chosen in a reasonable range in order to avoid quantization errors.

But what does this mean, 'reasonable range' ? – Let's give you an example:

If you have a load cell where the R_{span} is already matched, then a TKGain value of 1.0 would be the right choice. If you know that it is approx. 10% too small, then you can set TKGain to 1.1. The TKOff is chosen according to the expected offset drift. This is normally within the range of ±1mV/V (= 1,000ppm), so the right pre-setting in PSØ8/PSØ81 would be TKOff = 100,000 or 1,000 in PSØ21.

Let's turn attention to the charging of the load cells: some measurements require the load cell to be charged, at least with the half weight of full scale, e.g. >2.5 kg at a 5 kg load cell. So when we are talking about load = 'low' in the Excel sheet we mean the unloaded scale, only with the weighing plate but nothing more on it. In the fields marked with load = 'high' you apply the load to the scale.

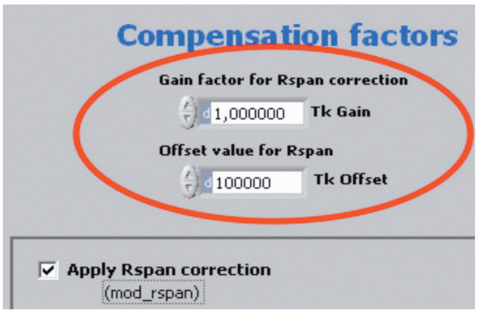
So in our example, we use PSØ8/PSØ81 and set the values in the Excel sheet accordingly:

Choosen TKGain	1.0000
Choosen TKOffs	100,000

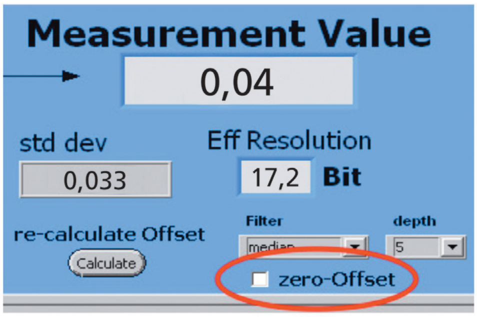
3. How to do the gain and offset adjustment with PICOSTRAIN

Now we can start with the measurements…

a) Set the temperature chamber to the lower temperature, e.g. +10 °C and wait for some time, at least 1.5 hours (settling time). Set TKGain and TKOff on the ALU page according to your preliminary considerations, e.g.:



b) Start the evaluation software and uncheck the automatic zero offset checkbox, e.g. as shown in the picture of the PS08/PS081 evaluation software:



c) Start the measurement and write the results to the Excel sheet. Load = 'low' means no weight on the scale, load = 'high' means weight on it. Please pay attention to the TKGain and TKOff values which are given by the Excel sheet. You need to set them accordingly before doing the measurement. Doing all this, a possible result may look like this:

Measurement result at lower Temperature

	Conditions		
Load	**TKGain**	**TKOffs**	**Result/Div.**
low	0	0	360.76
low	1.0000	0	302.26
low	0	100,000	-139.12
high	0	0	6,179.60
high	1.0000	0	5,184.70

3. How to do the gain and offset adjustment with PICOSTRAIN

d) Heat up the temperature chamber and do the same measurements at the 2nd temperature again (after waiting the settling time of 1.5h) and write the results to the table indicated with 'Measurement results at higher temperature'.

Measurement result at higher Temperature

	Conditions		
Load	**TKGain**	**TKOffs**	**Result/Div.**
low	0	0	360.66
low	1.0000	0	297.11
low	0	100,000	-139.00
high	0	0	6,280.30
high	1.0000	0	5,176.58

f) After filling in all values to the corresponding columns, the values for TKGain and TKOffset are calculated and shown as follows:

Calculated Adjust Values for Loadcell

PSØ21	TKGain: 0.95914	TKOffs: 733.40
PSØ8	TKGain: 0.95914	TKOffs: 73,340

Now you have the proper values for TKGain and TKOffset and can write them to the corresponding registers, which is 0x0F58A3 in register 8 (TKGain) and 0x011E7C in register 9 (TK-Off) of PSØ8/PSØ81.

For the differences of TKGain and TKOffset registers between PSØ8/PSØ81 and PSØ21 please see section 3.2.1. There it is also explained how negative values can be set properly.

3.2.3. Discussion of results

For TKGain we got the value 0.95914. This means, that the original Rspan on the load cell is a little bit too high. The load cell is overcompensated. By setting this value for TKGain, the Rspan is adjusted from:

Original R_{span} value of 40 Ω to the corrected R_{span} of 38.36 Ω

The load cell's behavior is now as it would have an R_{span} of 38.36 Ω.

3. How to do the gain and offset adjustment with PICOSTRAIN

As the value for TKOff is unequal zero, a resistor is added virtually. The value of the resistor corresponds to an offset shift of 733.4 ppm or in other words 0.7334 mV/V. With this TKOff value the scale is offset adjusted from now on.

3.3 Conclusion

PICOSTRAIN offers a **new and comfortable method** to adjust the gain and offset drift of a load **cell only by software**. This offers **manifold possibilities** compared with existing A/D converter solutions because a mechanical trim is no longer needed.

We showed in chapter 3 that both, gain and offset drift, can be adjusted accurately. The adjustment of the gain drift can always be done over the whole lot by measuring only some sample load cells and then applying the TKGain value to all the load cells of the same charge. To adjust the load cell's offset drift, it is required to find the proper correction factor for each load cell which is common practice nowadys anyway (as it is normally applied at high quality load cells or to those with a very high offset drift). The advantage of the PICOSTRAIN method is the **easy way of how the adjustment is done** and that the load cells can be partly or fully adjusted – **without touching them mechanically**.

We see the following advantages for the load cell manufacturers / quality of the load cell:

- Achieve a good gain and offset drift behavior
- Adjust the load cells more accurate than it can't be done today
- No mechanical trim is needed anymore
- Because of the simplified method you save time and costs in production
- The load cell itself gets simplified (lower complexity due to less resistors)

These advantages offer new possibilities in the production:

- As the adjustment is easier it can be done at any place (e.g. different branches)
- It generally increases the quality in production
- Costs are lowered due to less efforts and lower number of compensation resistors
- Aged or misadjusted load cells can be 're-adjusted'

We at acam believe that this new method of temperature compensation just by software brings many benefits to the manufacturers. In short words, **the quality is increased by less efforts and money**. The method is really valuable for load cell and scale manufacturers.

4. Load cell adjustment in practice

In this last chapter we want to describe the results which we gained from doing the temperature compensation following the discussed method. Therefore, we adjusted 4 load cells here at acam in August 2008. The results are given here and are discussed shortly in the conclusion.

All measurements have been done with the PS08 evalution kit and the high resolution plug-in module. We applied the compensation on 1 HBM load cell and on 3 CZL load cells, which are simply standard C3 load cells with PICOSTRAIN wiring as we deliver them with the evaluation kit.

4.1 Applied on an HBM-SP4C3 load cell

Setup

An ordinary HBM load cell (type: SP4C3) was taken and modified to PICOSTRAIN wiring. To get the PICOSTRAIN wiring the connections were changed in the connection field of the load cell. Except one R_{span} resistor and its corresponding adjustment resistor R_{sadj1} all the other compensation resistors were removed. The original load cell had 2 R_{span} resistors each paralleled by an adjustment resistor. One pair (R_{span2} and R_{sadj2}) were shortcut so that only the pair of R_{span1} and R_{sadj1} remained. As explained in chapter 2, the temperature drift compensation of PICOSTRAIN works with only one Rspan resistor.

Shortcutting one R_{span} resistor meant to change the gain drift behavior significantly, because the total R_{span} value was halfed. Nevertheless, we can set the TKGain value accordingly in order to make the correct compensation.

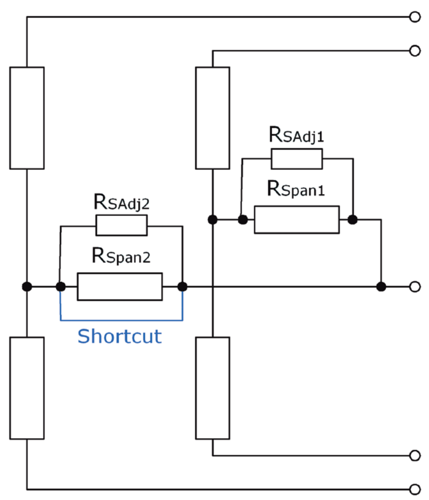


Fig. 7: Modified circuit of the HBM-SP4C3 (only one active Rspan resistor)

4. Load cell adjustment in practice

Preliminary considerations

Due to the shortcut of the second Rspan resistor (R_{span2}), a preliminary value of 2.0 for TKGain was assumed. In other words, we need to double the value of the existing Rspan resistor to get approx. the total, former Rspan value. The offset drift was assumed to be low so only ±0.1mV (respectively 10,000 for TK-Off) were chosen.

To charge the load cell a weight of 5kg was used (F.S. is 15kg).

So in the Excel sheet the following values were set accordingly:

Choosen TKGain	2.0000
Choosen TKOffs	10,000

Measurements

As described in the previous chapters, 6 measurements were made at each temperature (lower temperature = 10 °C and higher temperature = 40 °C). The load was 5 kg (high).

Measurement result at lower Temperature

	Conditions		
Load	**TKGain**	**TKOffs**	**Result/Div.**
low	0	0	360.76
low	2.0000	0	302.26
low	0	10,000	-139.12
high	0	0	6,179.60
high	2.0000	0	5,184.70

Measurement result at higher Temperature

	Conditions		
Load	**TKGain**	**TKOffs**	**Result/Div.**
low	0	0	360.66
low	2.0000	0	297.11
low	0	10,000	-139.00
high	0	0	6,280.30
high	2.0000	0	5,176.60

4. Load cell adjustment in practice

Results

Calculated Adjust Values for Load cell

PSØ21	TKGain: 1.91881	TKOffs: 73.34
PSØ8	TKGain: 1.91881	TKOffs: 7,334

The value of TKGain is with 1.91881 in the expected range and the value of TK-Off with 7,334 (73.34 ppm) is quite low and shows that the load cell was already good adjusted previously.

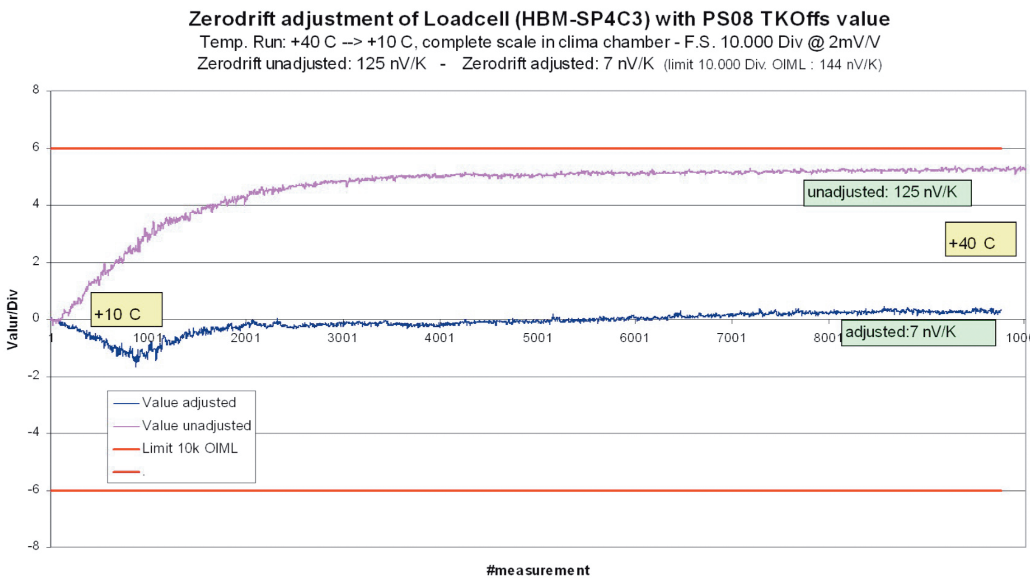
Validation runs

In order to validate the results and see the compensation effect of the TK values, we did a validation run. That means, two temperature drift curves of the offset drift (no load) were taken with the following values:

a) first run with the preliminary values, that means without the calibration:
TKGain = 2.0 and TK-Off = 0

b) second run with the obtained proper TK-values:
TKGain = 1.91881 and TK-Off = 7,334

See the following diagram for the results:



4. Load cell adjustment in practice

It can be seen that the result with the adjusted values is much better than unadjusted. The red lines are indicating the limits for 10,000 OIML divisions (we took the limit values for the whole scale, because load cell **and** electronics were in the temperature chamber).

The limit for the offset drift for 10,000 OIML divisions is 144 nV/K. Even if the compensation is not applied, the curve is within the 10,000 OIML divisions limit (pink curve, 125 nV/K) which shows, that the load cell itself has already a good offset drift behavior. Using the proper correction factors – that means the compensation of PICOSTRAIN is on – the drift is extremely low with approx. 7 nV/K. This is much, much better than any known existing specification and practically zero!

The limit for the gain drift for 10,000 OIML divisions is 5 ppm/K - again for the whole scale. The measured gain drift of the load cell before compensation with TKGain = 2.0 was 52.2 ppm/K which is far beyond that value. But this significant overcompensation effect is a result of the missing adjustment resistor for R_{span}, which we removed in the beginning. It is a normal procedure for load cell manufacturers to chose a R_{span} with overcompensation which is reduced then by the adjustment resistor to the proper value.

Using the correct TKGain value of 1.91828, the gain drift is reduced to –3.39 ppm/K. This value is not so close to zero as it was the offset drift, but it is still good within the limits of 10,000 OIML divisions.

So it can be shown, that both – the gain and the offset drift – could be improved significantly by the use of the TK correction factors and generally speaking by the compensation method of PSØ8/PSØ81. It was possible to prove, that this load cell in combination with PSØ8/PSØ81 electronics is able to reach the 10,000 OIML division limits.

4.2 Applied on CZL-601 load cells

Setup

After testing the HBM load cell, we tested another 3 load cells of the type CZL-601. This kind of load cell is delivered by acam with the PSØ8/PSØ81 evaluation kit. The load cell comes already PICOSTRAIN-wired from the load cell manufacturer.

At the CZL-601-1 load cell we shortcutted the offset resistor to see the effect of this compensation resistor. The other two load cells were not touched.

4. Load cell adjustment in practice

Preliminary considerations

As the R_{span} resistor is already roughly matched to the compensate the bridge, we chosed TKGain as preliminary setting to 1.0. The offset drift was assumed in the range of ±0.5 mV/V and therefore set to 50,000.

Choosen TKGain	1.0000
Choosen TKOffs	50,000

With this values the 6 measurements at each temperature (again 10 °C and 40 °C) were done and written to the Excel sheet. We gained the following results from the measurements:

Results

	TKGain	TK-Off
CZL-601-1	1.0143	61.978
CZL-601-2	1.0479	72.291
CZL-601-3	1.0215	5.884

So it can be seen, that the TKGain value is in all 3 cases approx. 1 and was chosen in the correct range. The offset value is in 2 load cells higher than assumed, in one case lower. With this values for TKGain and TK-Off we did the validation runs as previously with the HBM cell. See the following results:

Validation runs

Again we did two temperature runs for each load cell, one with the unadjusted values (TKGain = 1.0 and TK-Off = 0) and then afterwards with the calculated values shown in the upper table. The results are as follows, first the values of the run without TK compensation:

	Before TKGain/TKOffs adjustment	
	Gaindrift ppm/K	**Offsetdrift nV/K**
CZL-601-1	4.4	1,171.4
CZL-601-2	25.2	1,434.5
CZL-601-3	11.2	107.8

OIML 10,000 div. Limits (whole scale)
Offset drift: 144 nV/K
Gain drift: 5 ppm/K

4. Load cell adjustment in practice

CZL-601-1:
As we shortcutted the offset compensation resistor at this load cell, the offset drift was quite high with 1,171 nV/K and far out of the OIML specificatiton. The gain drift was very good with 4.4 ppm/K.

CZL-601-2:
This load cell wasn't modified by acam. It showed very bad temperature drift behavior in both, the gain and offset drift and far beyond the OIML limits. It seems, that no compensation was done at all from the load cell manufacturer.

CZL-601-3:
This load cell wasn't modified by acam. It showed quite good behavior in both, the gain and offset drift. The values are within the 10,000 OIML divisions specification.

The following table shows the values with the proper TKGain and TK-off values set (active compensation):

	After TKGain/TKOffs adjustment	
	Gaindrift ppm/K	**Offsetdrift nV/K**
CZL-601-1	0.7	34.8
CZL-601-2	2.2	-33.4
CZL-601-3	-1.2	36.0

With active PICOSTRAIN compensation ALL load cells meet the 10,000 OIML divisions specification!

The offset drift of all load cells are between 30 and 40 nV/K. This is a value which is normally only reached with today's best C6 load cells. With the PICOSTRAIN compensation method it was possible to bring ordinary C3 load cells in this range – and this although we had 2 load cells with very bad offset drift behavior before (in one we shortcutted the offset resistor, the other one was obviously not adjusted by the manufacturer at all).

The gain drift was less than 3 ppm/K at all load cell after the adjustment. We here at acam do not know any load cell which is specified with such low values.

4. Load cell adjustment in practice

4.3 Conclusion

The performed tests prove the theoretical explanations in this sheet. We showed, that the temperature compensation of PICOSTRAIN for load cells works as expected and that the **results are really impressive**.

The quality load cell from HBM was before the compensation already in a good range regarding the offset drift, the gain drift was not representative as we removed the R_{span} adjustment resistor. With the PICOSTRAIN compensation we got impressive results regarding the offset drift (7nV/K, which is practically zero) and brought the gain drift into the 10,000 OIML divisions specification. This corresponds to an improvement of almost **18 times**!

The tests with the three ordinary C3 load cells were even more impressive. In spite of a bad starting position (no compensation at all and removed offset resistor) we brought them with PICOSTRAIN compensation to an offset drift behavior which only very good C6 load cells have (the worst load cell was improved by factor 44!) and in regards of the gain drift to absolute fantastic values (<3 ppm/K), which is an improvement by factor 6 to 11, depending on which load cell we are looking. With active compensation **all 3 load cells** are **deeply within** the 10,000 OIML divisions specification!

As demonstrated the PICOSTRAIN compensation works very well and offers possibilities not known nowadays. We can imagine that this method will lead to increased quality in the area of load cell production. The acam team will be glad to assist you in load cell adjusting with PICOSTRAIN.

acam headquarters, Stutensee, October 2008 and February 2010