Leading-edge Research Infrastructure Program
Large-scale Cryogenic Gravitational Wave Telescope Project

JGW-T2012128-v2 *KAGRA* 19th of April 2020

LVDT card adjustment and recovery

Fabián Peña Arellano

Distribution of this document:
JGW-DCC

This is an internal working note
of the KAGRA collaboration.

http://gwcenter.icrr.u-tokyo.ac.jp

Table of Contents

Introduction

1.1 Purpose and Scope

The main aim of this document is to describe the procedure to follow when an LVDT card breaks down. The calibration factors of LVDTs depend on the setting of the card, therefore, it is very important to know how to set a new card to the same state as the old one. Understanding the procedure requires to also know how to set up the card ready for calibration. Therefore, this document includes explanations which are also covered in other documents, which are listed as “Related documents” below.

1.2 Version history

10/10/2020: v1 draft.
12/10/2020: We got feedback from Alessandro Bertolini from Nikhef.

1.3 How to edit this document

Download the version written Microsoft Word 2013 and edit it directly.

1.4 Related documents

- Joris's calibration manual: JGW-T1604798.
- Enzo’s calibration manual: JGW-E1707287.
- LVDT card circuit layout: JGW-D1301467.
- LVDT-Actuator Driver Electronics: JGW-T1201255.
- Miyo-kun’s calibration factor list: JGW-T2011597.

Comments from Nikhef

I received comments about the first version of this document from Alessadro Bertolini and he has confirmed the procedure outlined here is correct. He pointed out minor mistakes which have corrected in this version.
A highlight of his comments is that they plan to review the card design for ETpathfinder and that will be our chance to give them feedback. It would be greatly beneficial for both parties to let them know about Tanaka-san's work with the cards, so we could eventually use an improved version out of the box.

Reference signal

All the suspensions use reference signals at 10 kHz but some use different amplitudes:

- BS, SR2, SR3 and SRM use 5 Vpp nominal.
- PR2 uses 6 Vpp nominal.
- PR3 and PRM use 7 Vpp nominal.
- The real values may differ slightly from the nominal value. They should be measured at the output of the signal generator and
- What about Type-A?

Anatomy of an LVDT driver and cards

The description of the relevant elements of an LVDT driver and its cards provides the basis of the procedures of LVDT calibration and card replacement upon failure. In other words, once the role of the relevant elements are clear, the setting up of a card for calibration and its replacement are, in principle, straightforward tasks.

Figure 1 below shows the inside of an LVDT driver chassis. It comprises three cards: a main module at the centre and two LVDT cards at the sides. The main module receives a reference signal from an external generator and it relays the signal to the two LVDT cards. In Type-B suspensions the reference signal is ***nominally*** 5 Vpp at 10 kHz.

Each LVDT card has four channels. Among other components, each channel comprises three adjustable resistors, whose locations are indicated in Figure 2(a):

- One resistor is used to set the gain of the input reference signal,
- A second one is used to set the gain of an amplifier for the signal coming back from the LVDT secondary coil before it is mixed with the reference signal and,
- A third resistor is used to adjust the phase between the reference signal and the signal coming back from the LVDT secondary before they are mixed. The phase is not related to the components on the card but only to the LVDT coils and the cable lengths.

Figure 2(a) indicates the areas where these resistors and probe points are located, and Figure 3 shows each area in more detail. Figure 3(a) shows probe points `P0`, `P1`, `P2`, `P3` and the ground `AGROUND` from which the reference signals for each channel can be sampled. The probe point holes are within turquoise circles. Figure 3(b) shows the adjustable resistors for the gain of the input reference signals. The labels of the resistors are shown on top of each component and they are printed on the board on the right as `D0`, `D1`, `D3` and `D4`. ***Label `D4` should be `D2`***. The adjustment screws are within turquoise circles and one terminal of each resistor is indicated with an arrow. The other terminals are all connected to probe point `P_resisitor`, just above operational amplifier OP211. Thus, for example, resistance `D0` can be measured between its corresponding terminal and probe point `P_resistor`. Figure 3(c) shows the resistors to adjust the gain of the LVDT secondary coil return signal. They are labelled `G0`, `G1`, `G2` and `G3` and the adjusting screws are within circles. The resistance values can be measured between the accessible terminals of each resistor and the 6th pin of the corresponding neighbouring INA103 operational amplifier. Figure 3(d) shows the four resistors used for the adjustment of the phases between the reference signals and the LVDT secondary return signal. Access to the adjusting screws is provided from the font panel. Figure 4 shows the terminals of these resistors underneath the board.

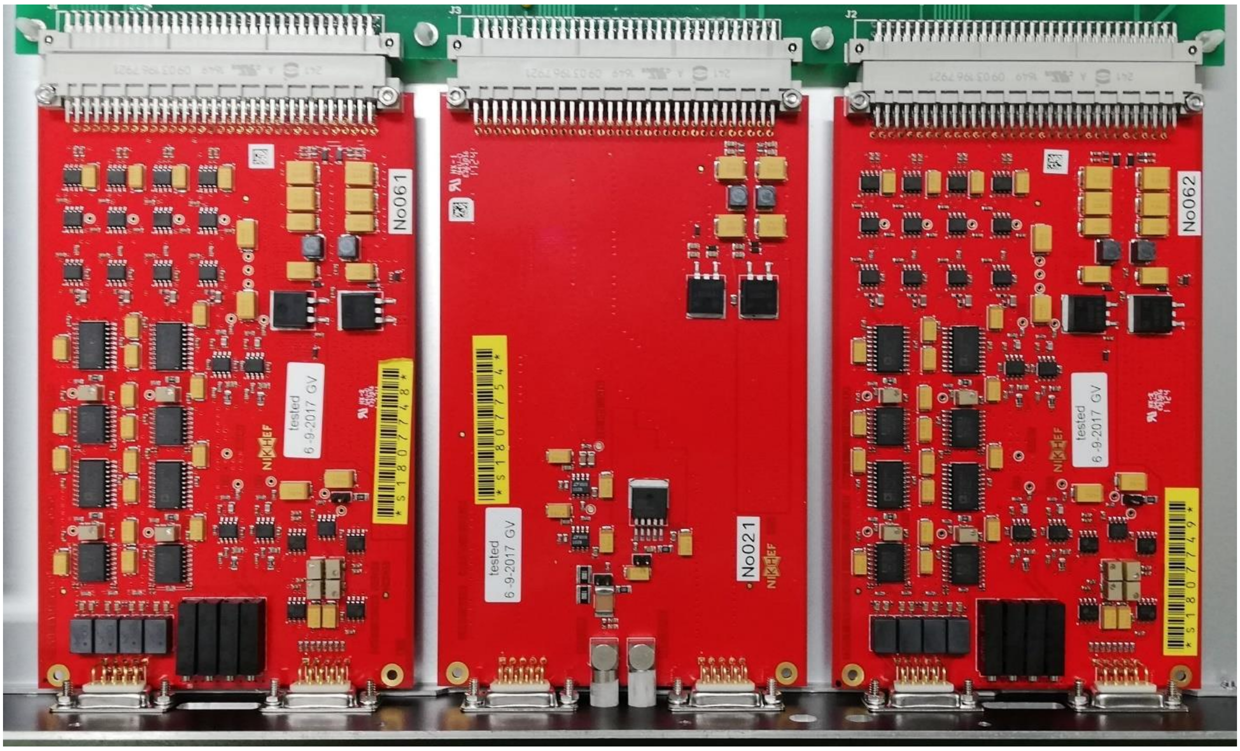

Figure 1. LVDT driver cards

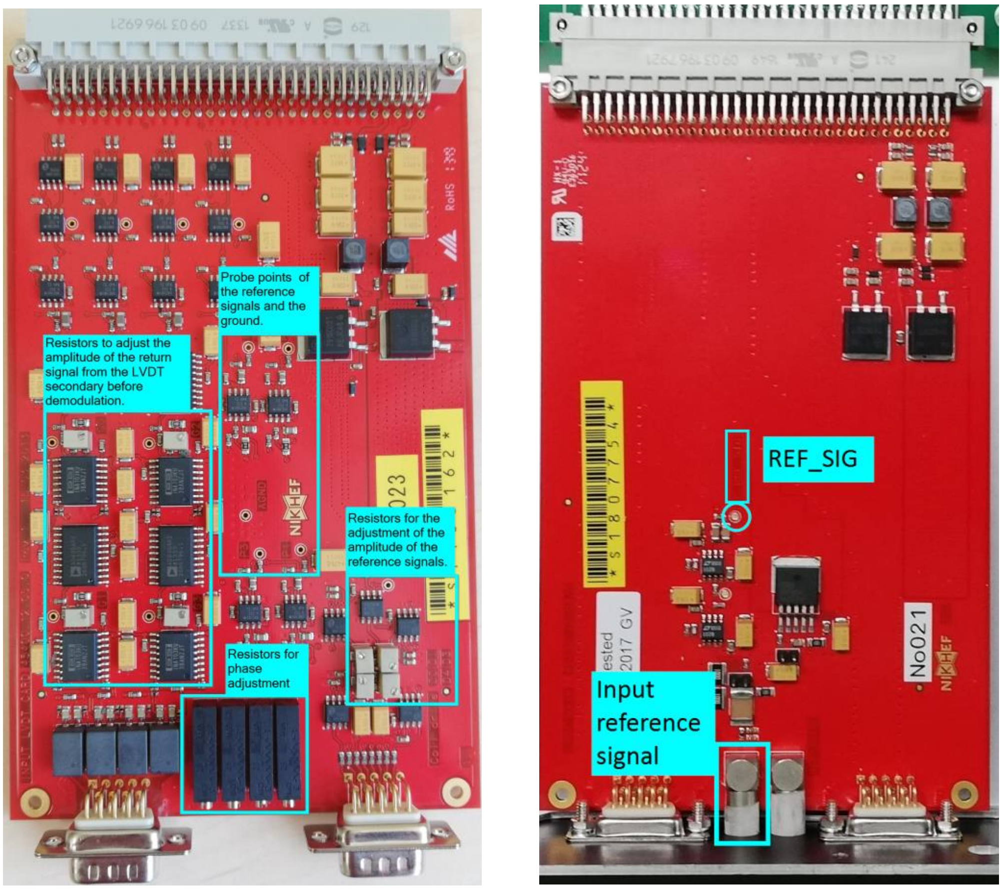

Figure 2. The LVDT card is shown in (a) and the main module in (b). The same relative position they have in the chassis has been kept in the figure for clarity. The main module is shown for reference.

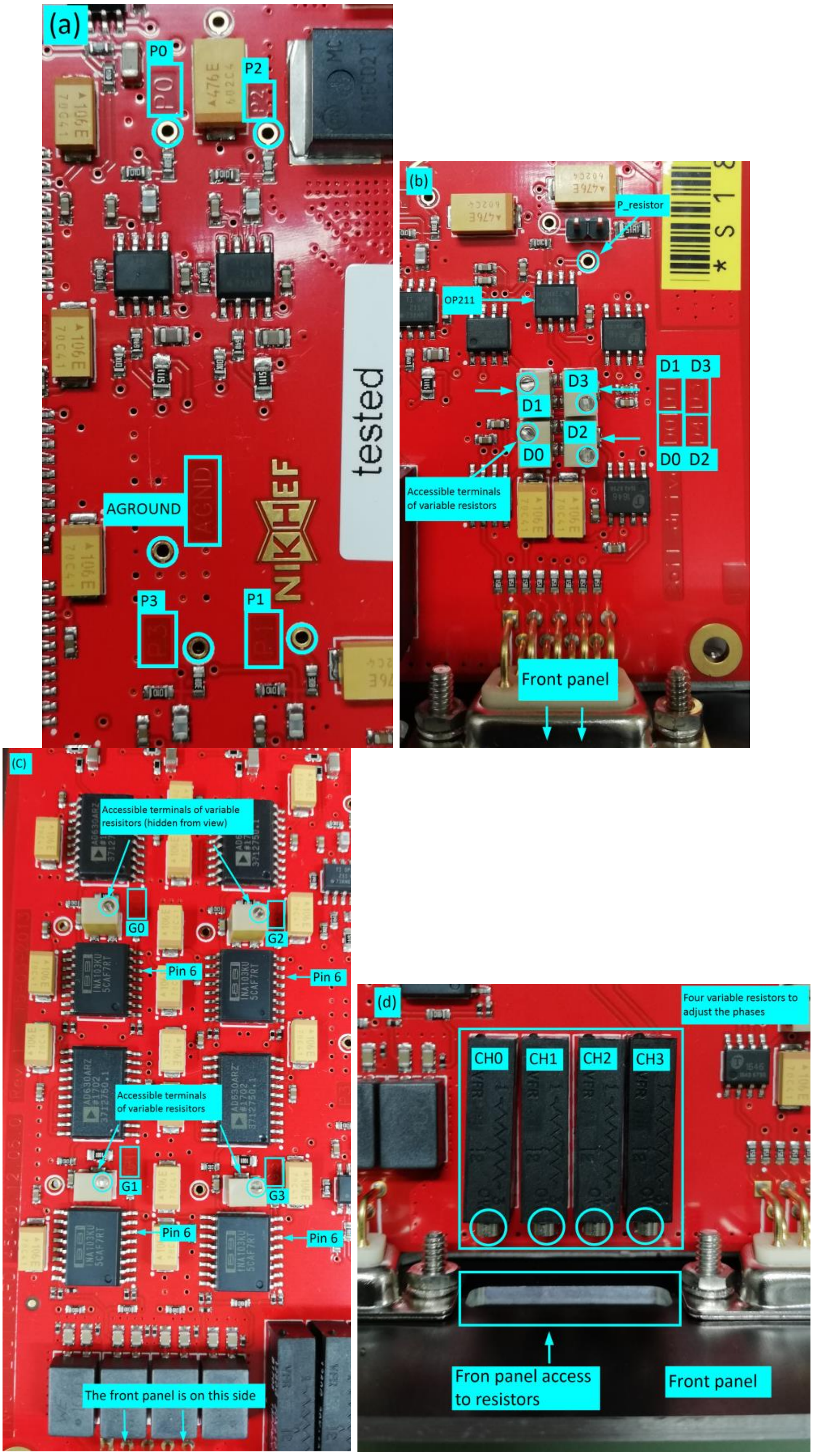

Figure 3. The important components to pay attention to are in four different sections of the board.

Figure 4. The pins of the potentiometers that determine the phase between the return signal from the LVDT secondary coil and the reference signal are accessible from underneath the board.

Setting up the LVDT card ready for calibration

In the present context, calibration refers to the process of measuring the mathematical relationship between the real displacement of a GAS Filter keystone or IP table, in units of µm, and the signal acquired by the digital system in units of counts. This procedure is achieved by moving the keystone in steps of a certain size and by measuring its displacement with respect to a reference object with a calliper with a Vernier scale. Such a process can only happen after the LVDT card has been properly prepared. Conceptually, various elements need to be considered:

- Passive vibration isolation devices are very soft, tend to move with large amplitudes and we want to track their positions at all times, therefore we require large measuring ranges.
- We should aim to use almost all the capacity of the ADC with a safety margin.
- The process of demodulation should yield an optimum output signal.

For each of the four channels in an LVDT card the procedure to follow is:

1. Set to zero the relative phase between the input reference signal and the return signal from the LVDT secondary coil. This should optimize the demodulation process.
    a. Sample the reference signal using the probe points `P0`, `P1`, `P2` or `P3` and `AGROUND` in the LVDT card. See Figure 3(a).
    b. Sample the signal coming back from the LVDT secondary coil from probe points `G0`, `G1`, `G2` or `G3` and `AGROUND`. See Figure 3(c).
    c. Use an oscilloscope to measure the relative phase in units of µs. For a 10 kHz signal, 2π radians correspond to 100 µs. Figure 5 shows an example. The reference signal is shown in yellow (channel 1 in the oscilloscope) and the modulated signal from a probe point in green (channel 2 in the oscilloscope). The vertical lines are cursors placed at the peaks of the signals and the oscilloscope calculates the phase difference between the cursors. In the case of the figure such a difference is 10 µs.

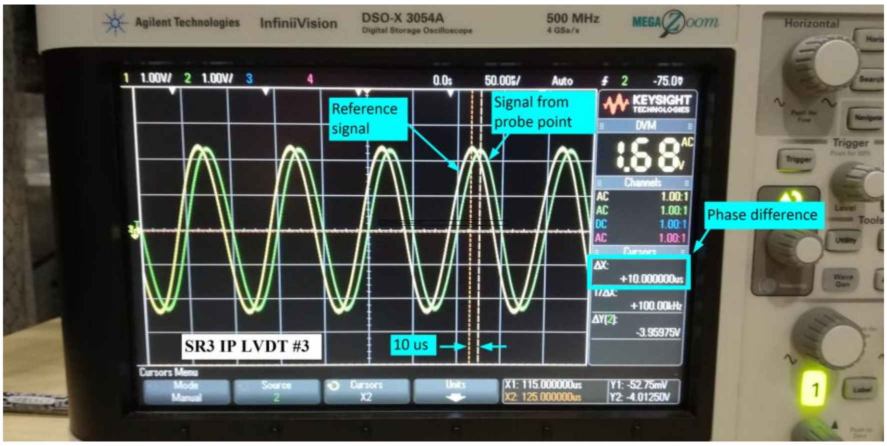

Figure 5. The phase can be measured with an oscilloscope.

   d. Using the screws accessible from the front panel, adjust the values of the resistor so the phase difference becomes **zero**. See Figure 3(d). In many cases in Type-B systems, the phases were not inspected while setting up the card. They only inspected the final output and somehow decided the setting was convenient, but they did not adjust the phase to zero. Later on I measured the phase and reported their values as in klog entry 9025. ***Note that the values reported in the klog for Type-B suspensions must be updated because of an error in the original characterization procedure***.

2. Adjust the input gain. In Type-B suspensions this quantity was never adjusted. We just used whatever values the resistors had. Later on, we realized we don't know how to experimentally check that changing the values of these resistors changes the amplitude of the signals. See klog entry 9658. What we did instead was just to measure the values of the resistances for the record.
   a. Use the same probe points as in step 1a.
   b. Using convenient criteria, adjust the variable resistors `D0`, `D1`, `D2` and `D3`. If we still do not have the criteria, just use the current resistance values, which must be measured with the driver off.
3. Adjust the gain of the LVDT secondary coil return signal. Use the signals acquired by the digital system in units of counts.
   a. In a GAS Filter move the keystone all the way up to its upper physical stop and leave it there. In the case of an IP rotate it in positive yaw.
   b. Adjust the value of the variable resistor until the LVDT output is lower than the maximum of the ADC with a safety margin.
   c. In a GAS Filter move the keystone all the way down to its lower physical stop and leave it there. In an IP rotate it in negative yaw.
   d. In case the LVDT output is within limits of the ADC capacity, including a safety factor, do not adjust the resistor again.
   e. In case the LVDT output goes beyond the ADC capacity and saturates it, change the value of the resistor again.
   f. Turn off the driver and measure the value of the resistor using either probe point `G0`, `G1`, `G2` or `G3` and the 6th pin of the corresponding INA103 op amp. See Figure 3c.

Now the card is ready for LVDT calibration.

Recording the state of the card

Once the LVDT has been successfully calibrated, we need to report properly the state of the card. For each channel record the values of the input and output gain resistors and the phase, which would typically be zero. An example that corresponds to SR3 suspension is:

LVDT	Input gain resistance (kΩ)	LVDT 2ry coil gain resistance (Ω)	Phase (μs)	Board and probe point
BF	1.363	62.5	16, signal at probe point ahead. (Update required.)	Left board, P0 and G0.
SF	3.750	60.6	10, signal at probe point ahead. (Update required.)	Left, P1 and G1.
F0	5.187	60.8	17, signal at probe point ahead. (Update required.)	Left, P2 and G2.
IP #1	5.619	50.6	10, signal at probe point ahead. (Update required.)	Right, P0 and G0.
IP #2	5.408	50.4	8, signal at probe point ahead. (Update required.)	Right, P1 and G1.
IP #3	5.498	50.2	10, signal at probe point ahead. (Update required.)	Right, P2 and G2.

See klog entry 9658, where C→D0, B→D1, D→D2 and A→D3. ***The phase values in this table require updating. The reported values were measured using the wrong terminals***.

The channel assignment for Type-B suspensions is clear from the **"LVDT"** and **"Board and probe point"** columns in the Table. In terms of the position of the card, as seen from the front panel, the channels are assigned as follows:

- Left 0: BF,
- Left 1: F1,
- Left 2: F0,
- Left 3: Not used,
- Right 0: IP #1,
- Right 1: IP #2,
- Right 2: IP #3,
- Right 3: Not used.

Also notice that the relative position of the signals is reported when the phase is not set to zero. The signal measured at the probe points `G_{i}` are ahead of the reference signal as show in Figure 5.

Replacing the card after failure

In the case in which the information referred to above was recorded by the original operator, use Method 1. In case the values of the two resistances and the phase were not recorded, use Method 2.

Method 1

1. **Do not change the values of any of the resistors in the old card. We might need to measure them again.**
2. In the klog look for the settings of the card that requires replacement. If no report was filed by the original operator go to Method 2.
3. Using a multimeter set the input and output gain resistances to the appropriate values. Make sure the driver is off.
4. Connect the LVDT driver and use the oscilloscope to set the phases to their respective appropriate values. They should be typically zero, but many of them were not set to zero.
5. Measure transfer functions and make sure they coincide with what we had before.
6. If the transfer functions do not coincide measure the vales of the resistances in the broken board and use them to set the new card. Use the values of the phases reported in the klog.
7. Measure transfer functions again.

This method has been successfully used in SR3 (klog entry 9658). After the replacement, the transfer functions of the whole system were the same as the ones before the failure.

It is worth mentioning that for Type-A and Type-Bp suspensions, their respective groups did follow a procedure to recover the same transfer function after the replacement, but they did not aim to recover the calibration factor. This means that, in those cases, we do not know the location of the moving objects with the same accuracy as before.

Method 2

1. Measure the resistance values of `D0`, `D1`, `D2` and `D3` resistors.
2. Measure the resistances associated with probe points `G0`, `G1`, `G2` and `G3`.
3. Remove the LVDT card from the chassis.
4. Measure the resistances the across the pins shown in Figure 4.
5. Set the corresponding resistance values in the new board to the same values.

Difficulties in using the cards.

There are several features of the cards and their setup within the chassis that make working with them difficult. Very simple tasks take a lot effort and time and require two people. For the sake of efficiency, there should be an effort in changing this situation. A solution necessarily requires participation of Nikhef, who is the manufacturer, and AEL group in KAGRA, who is the one mounting them in the chassis.

- The probe points do not have appropriate pins to attach probes onto it. They are holes closed with solder or, in the best case, the holes are open and take pins of a suitable size. When the hole is closed, a person has to press a probe onto the probe point at all times during a measurement. When a pin is used, the pin is often pulled out from the hole by the tension in the probe cables. This is definitely one of the main annoyances of working with these cards.
- Access to probe points from the front panel should be arranged. For instance, see Fig. 1 in document JGW-T1201255. The original Nikhef chassis has cables routing probe points `P` and the ground to the front panel.
- There are no probe points to measure the gain resistance values for the LVDT secondary signal. The 6^{th} pin in the INA103 and the back terminals of the resistors have to be used instead. They both are difficult to access. The measurement is not an impossible task but it is currently unnecessarily difficult.

Issues to keep vigilant about

From measurements in SRM LVDT driver I had the impression the values of the resistors may be subject to drift, and I was speculating this was related with temperature drifts in the mine and the effect of the thermal cycle on the adjusting moving screws in the resistors. (This issue has not been reported properly in the klog yet, but only on page 185 of my notebook.) However, Alessandro says such an effect would be too small to be noticeable.