HYDROSTATIC PRESSURE DEVICE FOR EVALUATION OF CONTACT PRESSURE SENSOR CHARACTERISTICS

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Abstract: In order to gain more insight in the characteristics of Tekscan contact pressure mapping sensors, a hydrostatic pressure cell is designed. The main research topics are load history dependency, inter-pixel output variation and output drift behaviour of the sensors. This leads to a state of the art preconditioning and post processing method which yields a higher accuracy of the measurement data.

Keywords: Tekscan, contact pressure, pressure mapping, preconditioning, post processing

1 INTRODUCTION

Tekscan I-scan sensors are widely used pressure mapping sensors, which are very versatile. In most applications, they are chosen because of their low thickness and the ability to perform continuous and real time measurements [1-3]. The sensors exist of a multiplexed array of conducting material with a layer of piezoresistive material in between. Each overlapping row-column intersection defines a pixel [3, 4]. Tekscan claims that the accuracy of the measurements is generally +/- 10 % over the full scale [5], but they also mention that this accuracy depends on the care taken by the user. To reach this accuracy, Tekscan developed a processing method to deal with the sensor characteristics. Important characteristics are inter-pixel output inequality, drift behaviour and repeatability, caused by the piezoresistive material [6, 7]. In the Tekscan method, first a preconditioning is applied to minimize the drift and increase the repeatability of the sensor. This method consists of applying a cyclic load of 110-120 % of the application load for three cycles of 30 seconds [8]. The other characteristic, inter-pixel output inequality, originates initially from the manufacturing process. A second cause of the unequal sensitivity between the pixels is the difference in load history after repeated use of the sensors [9]. To deal with the pixel inhomogeneity, a uniform pressure can be applied onto the sensor to determine a scale factor (gain) for each pixel. This is achieved by comparing the output of each pixel to the mean output of the sensor pad [9].

Despite the use of the Tekscan processing method, still a wide range of errors is reported in literature. For a quasi-static loading test of two hours, an error of 35 to 50 % is reported by Otto et al [10]. This reveals the inadequacy of the current processing method and the lack in fundamental knowledge of the sensor behaviour, resulting in a wide inaccuracy range.

Furthermore, the Tekscan preconditioning and equilibration is only possible up to 3 MPa with equipment provided by Tekscan [6]. These come both in a pneumatic and hydraulic version [11]. For applications which comprise contact pressures higher than 3 MPa, the advised preconditioning and equilibration can thus not be achieved using these devices.

This paper summarizes the steps taken to do a thorough investigation into the sensor characteristics. The goal is to assess and optimize the accuracy of the measurement processing, and this for loads up to 30 MPa.

2 HYDROSTATIC PRESSURE CELL

To reach higher pressures during the preconditioning and equilibration, a fist test is conducted using two metal plates with sheets of compliant material (buna nitrile rubber) in between. The sensor is placed between these plates in a compression test setup. However, the compliant material is squeezed out of the contact area, resulting in a non-uniform pressure distribution, as shown in Figure 1. Unequal loading leads to a wrong preconditioning of the sensor. The result is that all the pixels show a different and incorrect behaviour after the preconditioning, due to the difference in load history [12].

(a) (b)

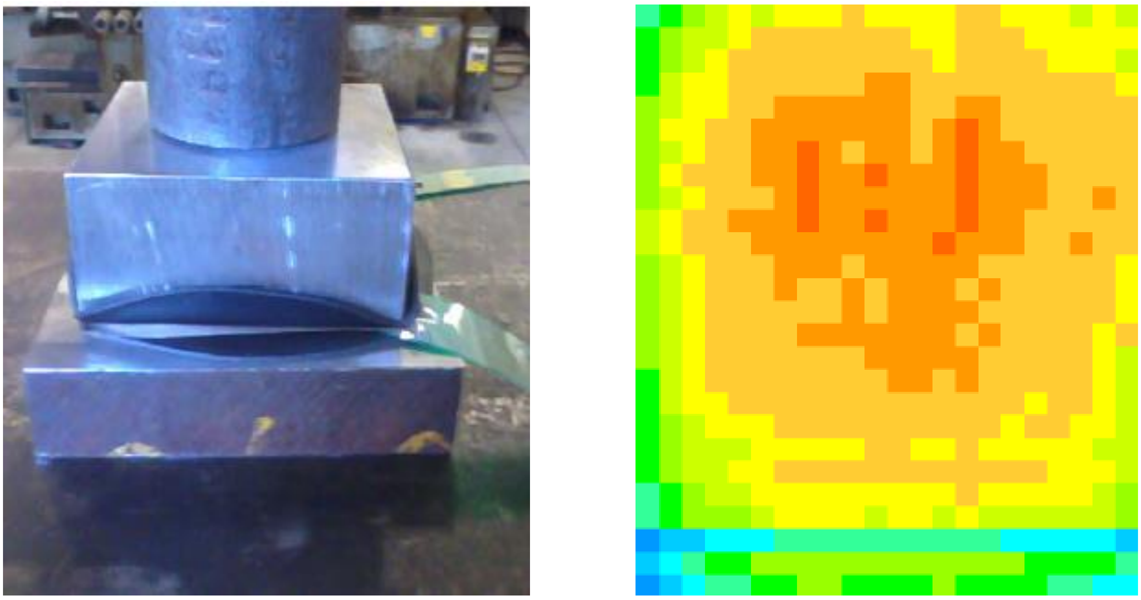
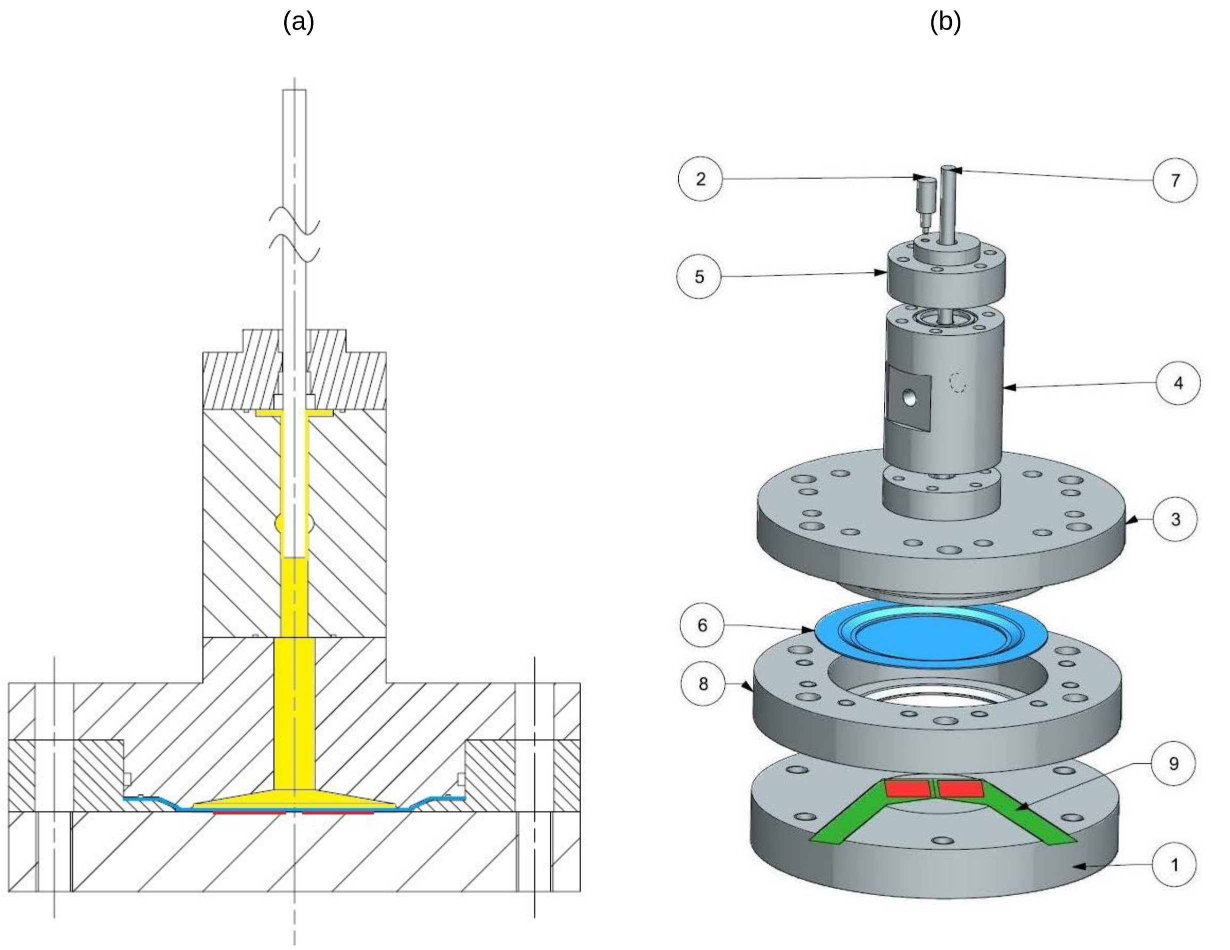


Figure 1: (a) Compression test between two viscoelastic solids at 20 MPa, (b) raw sensor output [12]

For a second test setup, a custom made solution is designed and manufactured in the form of a hydrostatic pressure cell. The use of hydrostatic pressure to investigate the Tekscan sensor characteristic is already successfully used by Otto et al. [10], Shaw et al. [13] and Ferguson et al. [14]. To discuss the design concept of the pressure cell, Figure 2 shows a cross sectional view (a) and an exploded view (b). In the exploded view, the Tekscan sensor (9) is visible and is located on the base plate (1). To prevent pinching of the sensor flat cables, dedicated grooves are milled in the base plate. The pressure that is transferred to the sensor is generated by a hydraulic fluid inside the cavity. This pressure is built up by compressing the hydraulic fluid with a plunger (7). This decreases the volume in the cavity and hence induces a pressure in the hydraulic fluid, as a result of its low compressibility. The pressure is transferred homogeneously to the sensor through a Urethane membrane (6) of a compliant material, clamped to the top block (3) by a ring (8). On top of the body, a cylinder (4) is placed, to enlarge the stroke of the plunger. The dynamic rod sealing of the plunger is located at the cylinder head (5). The latter is also equipped with a bleeding valve (2).



1. Base plate	2. Bleeding valve	3. Top block	4. Cylinder	5. Cylinder head
6. Membrane	7. Plunger	8. Ring	9. Tekscan sensor	

Figure 2: Cross sectional view of pressure cell (a) and Exploded view of pressure cell (b)

3 RESULTS

A series of experiments is performed, using the pressure cell, to investigate the preconditioning and equilibration of the Tekscan sensors.

3.1 Preconditioning

Tekscan advises to load the sensor prior to the actual measurements, so the initial change of sensitivity occurs before the measurement begins. It is preferable to use a load greater than the test load. Preconditioning the sensor pad minimizes drift and improves repeatability during the experiment. In different literature from Tekscan, both a cyclic and a static precondition are advised for the I-scan system:

Cyclic [9]:
- Mimic the interface profile if feasible (i.e. flat / roller).
- Impart pressure at ~ 115 % / ~ 120 % higher than the application pressure.
- Apply the pressure for three cycles at ~ 30 seconds per cycle.

Static [8]:
- Apply (within ± 30 %) the maximum load you expect to see during test.
- Fully load the area which will be loaded during test.
- Leave this load applied for a full 5 minutes (or a similarly long test time), then release.

Both methods are tested on two new sensors. The influence of this preconditioning on the output level (sensitivity), drift and inter-pixel output inequality is investigated.

3.1.1 Cyclic preloading

A new sensor is subjected to a repeated cyclic load of 15 MPa during cycles of 15 minutes. Figure 3 shows the raw output of the sensor, averaged over all the pixels. After every cycle, the raw output is compared to the first cycle, to investigate settlement. It is observed that after applying the same load for 12 cycles, the raw data output is increased with around 20 %. This increase starts approximately linearly during the four first cycles, after which stagnation starts to manifest around the eighth cycle. Once the sensor is in this stagnation zone, the variation between the consecutive cycles lies within +/- 1 percent.

Apart from the output level, also the drift behaviour starts to settle during the preconditioning. It is most pronounced during the first cycle, the second cycle is already eight percent less. Further on, the decrease is always lower than one percent until a settlement is reached at a drift value around three percent increase over 15 minutes. Finally also effect on preconditioning on the inter-pixel output inequality is assessed, but this remains unaffected over all the cycles.

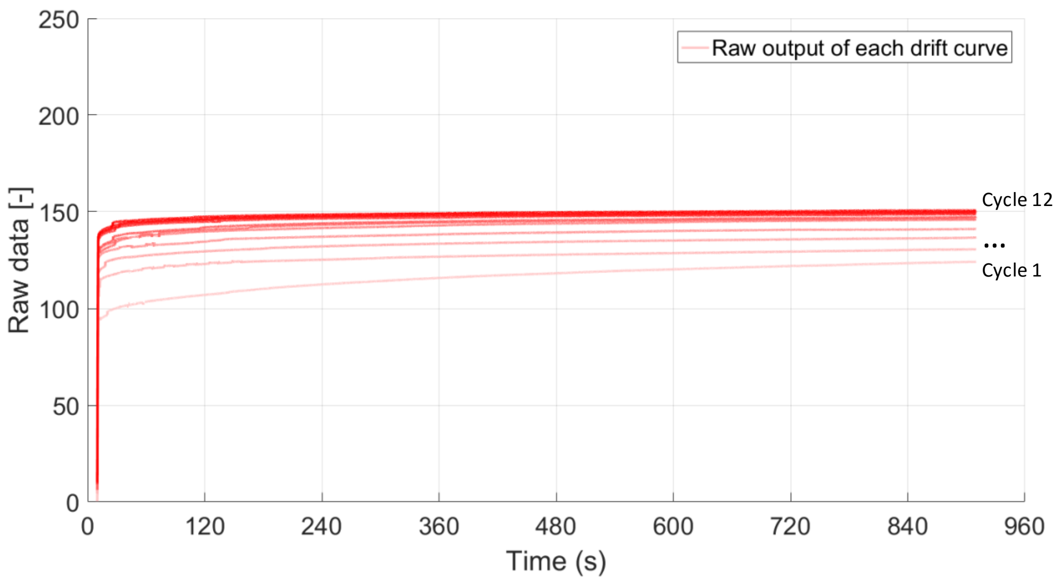


Figure 3: Sensor output for pressure cycles of 15 minutes

The effect of this preconditioning slightly diminishes over time. Hence, before every new set of measurements, a re-preconditioning is advised. By doing this, the sensitivity rises and drift decreases rapidly to the stabilized condition of the sensor.

3.1.2 Static preloading

A second sensor is preconditioned by subjecting it to a static load of 15 MPa for a duration of three hours, without interruption. To identify the influence of this static load before and after the preconditioning, a reference cycle of 200 seconds at 15 MPa is recorded to characterize the sensor behaviour. From these reference cycles, an increased sensitivity of 15% is observed after the 3 hour loading period. For the change in drift behaviour no significant influence is found with the static preconditioning. Also no influence on the change in homogeneity of the output of the sensor could be observed after static loading. It can be concluded that static loading is only beneficial for stabilizing the sensitivity, but not for drift. To verify that only cyclic loading results in a decreased drift behaviour, a cyclic load is also applied on this sensor. This results in a decreased drift behaviour and even further increased sensitivity.

3.2 Equilibration

The pressure cell is also usable for the equilibration of the sensor, similar to the Tekscan pressure applicators but at ten times higher pressure. Equilibration is investigated at different pressure levels, to determine the load dependency of the gain factors. A comparison is made between the gain factor of every pixel of a sensor pad at 5, 10 and 15 MPa. The gain factors are visualized in Figure 4.

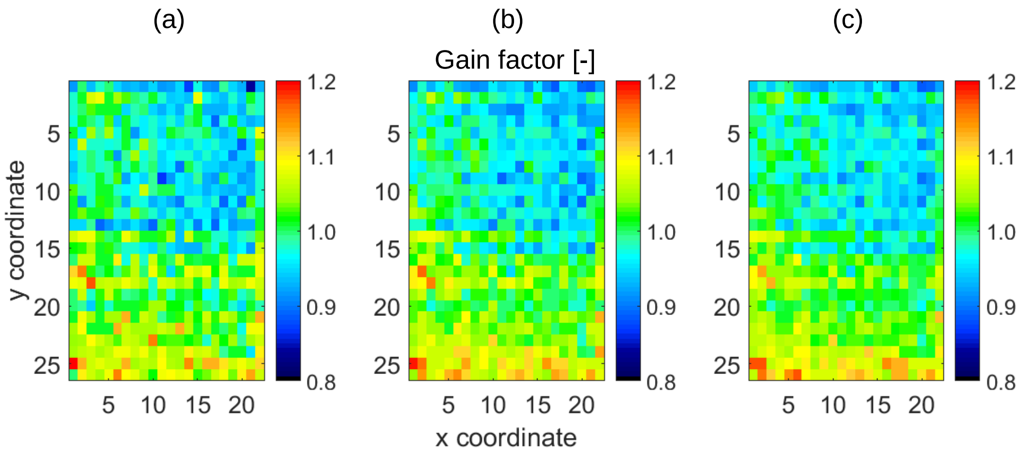


Figure 4: Gain map for 5 MPa (a), gain map for 10 MPa (b) and gain map for 15 MPa (c)

The mean deviation of the gain factors between adjacent pressure levels is 1,5 %, with a standard deviation (SD) of 7,0 %. This means that for some pixels the difference in gain factor can be particularly high. Such a high variation in gain factor can have a huge influence for actual measurements. Certainly for measurements with a small contact area, involving only a few loaded pixels. In this case the output of one pixel can make a huge difference on the entire measurement.

The necessity for this equilibration procedure is more pronounced for a used sensor (Figure 5), where the output inequality is greater due to the different load history between pixels. Even for an inhomogeneous output with a standard deviation of 15,7 % it is possible to process the output to a standard deviation of only 0,3 %. The high output variation is quantified in the histogram of Figure 6. Therefore it is highly recommended to re-equilibrate the sensor prior to every new set of measurements.

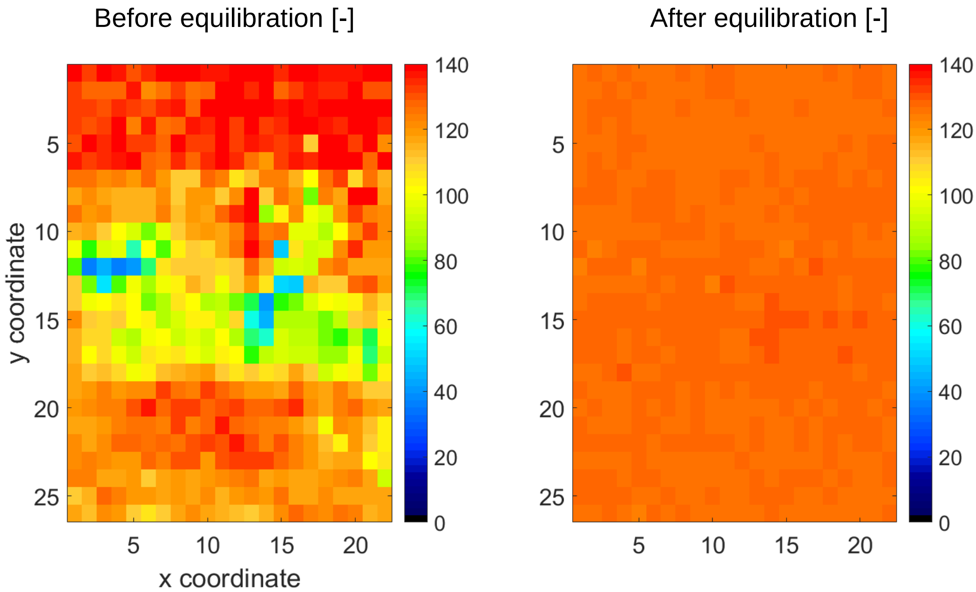


Figure 5: Sensor output before and after equilibration

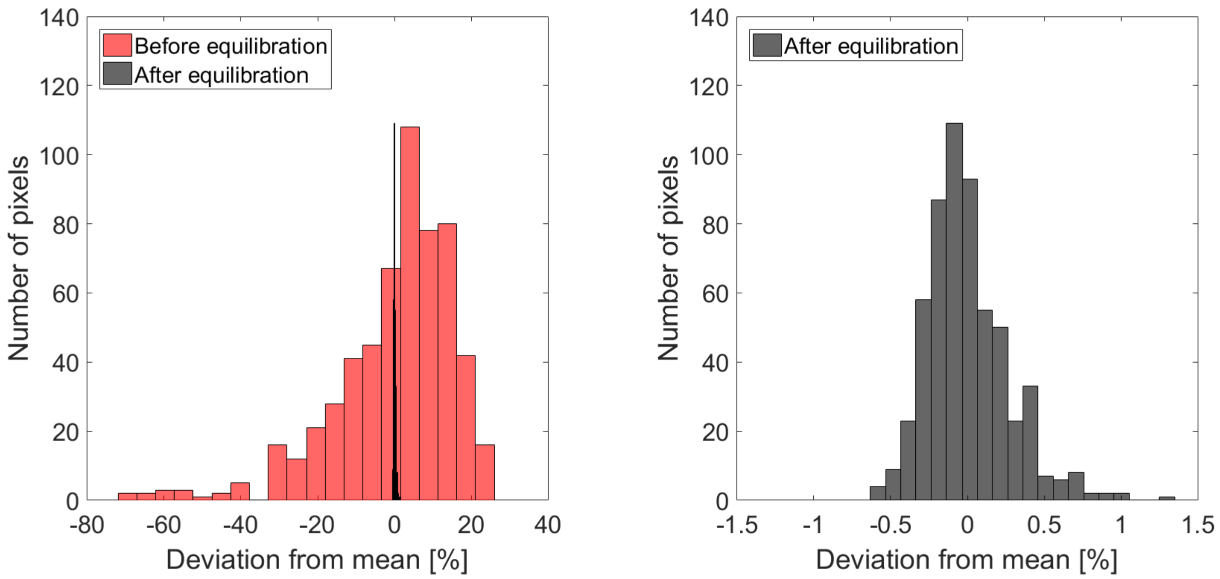


Figure 6: Histogram of the sensor output before and after equilibration

Another advantage of calculating the gain factors at different load levels is the inherent ability to check the sensitivity between different levels. The difference in gain factor between different loads can be used to validate if pixels are broken. If the gain factor of a pixel increases excessively with increased load, this indicates that the pixel is no longer adequately responding to the increase in load.

4 CONCLUSION

Using a newly developed hydrostatic pressure cell, an evaluation of the preconditioning and equilibration is conducted. For a new sensor, it is concluded that the optimal preconditioning method is cyclic loading of the sensor over a period of minimum three hours, at a load which is representative for the application. This leads to a stabilization of the sensitivity and drift behaviour, thus increasing the repeatability. For optimal reproducibility, a few re-precondition cycles can be applied prior to every set of measurements. This is necessary because the effect of preconditioning diminishes partly over time while the sensor is unused. For equilibration, tests pointed out that the gain factors are load dependent. Due to unfavourable application conditions, the equilibration of the output can be disturbed during the lifetime of the sensor. Frequent re-equilibration is useful in this respect. By tracking the evolution of the gain factors, the well-functioning of the sensor can be evaluated. By tracking the pixel output at different load levels, the sensitivity of each pixel can be evaluated.
From these observations, the utility of the hydrostatic pressure cell is proven for applications involving contact pressures up to 30 MPa, where Tekscan only provides devices up to 3 MPa.

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