2.1.2 Sensory washer

As a universal measurement system washer based sensors can be applied retroactively in a multitude of standard screwed joints to determine long time stable static preload forces or dynamic load changes. In mobile or rotating machinery wired measurement units can be an obstacle. For this purpose, an active smart sensor system with wireless data transmission based on Bluetooth Low Energy was developed. A steel substrate with washer geometry is used for the piezoresistive thin film system with a balcony-like bulge added. The thin film system is shown in Fig.1. With an angle of 120° three load sensitive areas (F1, F2, F3) were applied to determine preload forces as well as uneven loads in the screwed joint. For temperature compensation another two sensor areas (T1, T2) are placed in the unloaded region of the DiaForce® thin film. Also a meander structure as temperature sensor is integrated in the thin film sensor system, as shown in Fig. 14.

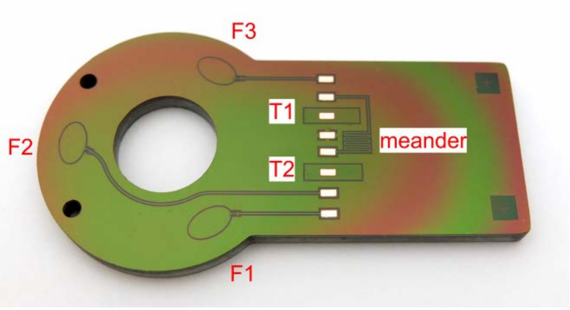

Figure 14: Sensory washer with three load sensor structure, two structures for temperature compensation and one meander structure for temperature measurement.

A loaded (F) and an unloaded (T) sensor are connected in series to construct a voltage divider as a branch of a Wheatstone half-bridge. The single load sensors are driven sequentially by a multiplexer to be measured by only one acquisition unit. The measurement and data transmission circuit is reduced to a size of a 4 cm² both sided board which includes the processing of the analog signal, the digitalization with a 16-bit ADC and the data handling in an internal ATMEL ATmega328P microcontroller. The data transmission is provided by a Bluetooth Low Energy module on the backside of the circuit board. This board is shown in Fig. 15. On the bulge of the base body the measurement unit is stacked with a 240 mAh accumulator which is needed to provide the transmission energy under a capsular housing, shown in figure 16.

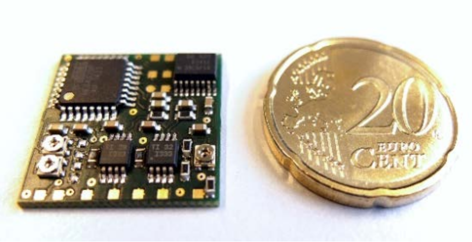

Figure 15: The just 4 cm² circuit board of the sensory washer.

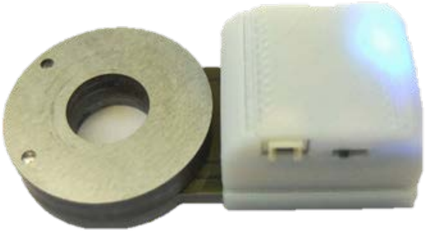

Figure 16: Sensory washer system with connected wireless Bluetooth Low Energy data transmission system.

The fully integrated system reaches an accuracy up to 1% FS (full scale) with a transmission range up to 40 m. In this case a standard tablet is used to receive and visualize the sensor data due to the Bluetooth 4.0 interface, as shown in Fig.17. Therefor an Android application was written to calculate out of the sensor signals the responding forces applied on the washer system.

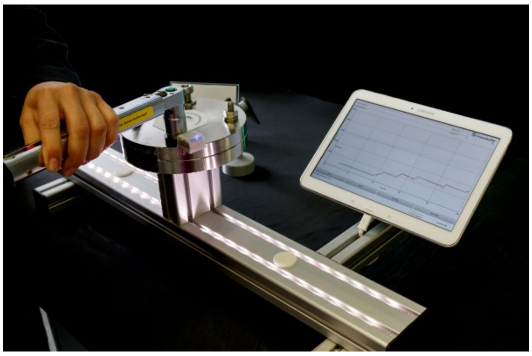

Figure 17: Test arrangement of a screw joint with integrated sensory washer system. Tighten of the screw can be directly observed on the tablet.

4 Conclusion

The integration of sensor systems in machinery for getting real time data about the load and temperature distribution is a very important theme for an optimized, flexible and costumer oriented production. Therefor multifunctional thin film systems directly coated on the tool surface can be one solution. Just 10 µm thin layer systems with integrated load sensor structures as well as temperature sensors even on complex shaped tools can be fabricated as shown on blank holder tools for deep drawing processes. The load sensor systems are based upon the piezoresistive hydrogenated carbon layer called DiaForce®. This coating has a negative temperature coefficient due to the fact that the electrical resistance is decreasing with increasing temperature. This effect is also mentioned in the introduction for the carbon nanotube layer used as new temperature sensitive film. Also meander structures out of Cr are integrated in the thin film system for the local temperature measurement. These sensor systems show a positive temperature coefficient like it is well known from metallic layer.

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