Textile technological integration of sensor modules in lightweight composite structures and possible applications

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The limited corporation Lightweight Structures Engineering (LSE) develops together with the Competence Center of Lightweight Structures (SLB) and the Chemnitz University of Technology (CUT) sensors for structure integration in polymer materials to increase the functionality and performance density of components in composite design.

The embroidered sensors can detect physical-technical quantities such as strain, capacity and temperature or fill levels in tanks, which can be measured with sensors of known technologies.

The benefits of the embroidery technology are especially the cost efficiency if large areas are fitted with sensors. Due to the embedding of embroidered sensors in complex composite structures components with additional functionality can be created which increases the use-value.

Embroidered sensor structures

Thin metallic wires or conductive coated or rather conductive yarn are used as sensor materials. Stitching techniques are used to attach the sensor material on a non-woven. Figure 1 shows a larger scale image of that. The wire shown in this picture is positioned by Tailored Fiber Placement technologies and fixed with clearly visible purple yarn on a non-woven polymer. In principle the shape and dimension can be designed individually. At the moment the achievable resolution is about 0.8 mm.

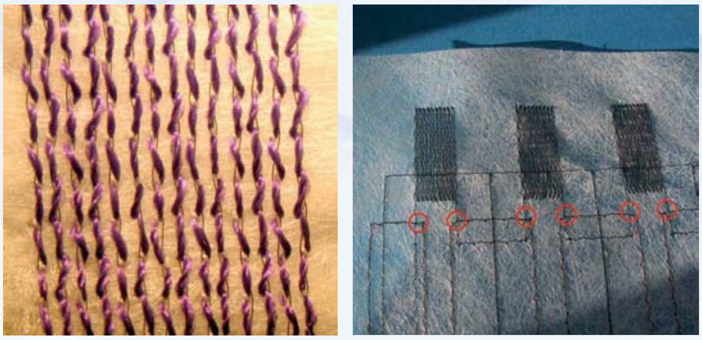

Fig. 1: Embroidered sensor structures

The sensor could operate on capacitive, inductive or resistive working principles. The chosen wire material depends on the purpose of the specific sensor or sensor array. For strain sensors (analogous to strain gauges) resistive wires of constantan are used. Inductive and capacitive sensors are made of copper wire. Conductive yarn or yarn coated with conductive materials can be processed as well. The typical diameter is from 40 μm up to 100 μm. Necessary diameters need to be chosen respective to sensor dimension and the required resistance. The usual use of chemicals to achieve required conductive geometry is not applicable. Sensor wires are soldered to contact pads after stitching. Further processes on other sensors depend on desired application. Signals can be transmitted wireless from inside of the part by integrating radio antennas and radio electronics.

Application as strain sensor

The total resistance is a very important parameter for strain sensors. Its value is key factor for power consumption by sensor system. Besides, typical resistances of 120Ω, 350Ω and 1kΩ per sensor can be designed for any value between and around that. Tolerance for series production is about ±10% at the moment. For small scale and laboratory application a tolerance of ±3% is achievable.

The demonstrated strain sensor has less priority in exact measurement of mechanical strains inside a component like common strain gauges. It is rather used to functionalize fiber reinforced structure

components. For example it is possible to adapt a part with a sensor that gives information about current status (health monitoring). Hence the sensor is embedded it is protected against environmental influence like humidity. By choosing an appropriate geometry and adjusting resistance the sensor can be freely customized and fitted to almost any component.

Through the combination of spring element and sensor to a functionalized structure component, the total amount of single elements in parts (e.g. gas pedal) can be reduced.

A common bridge connection is used to analyze the sensor signal in the same way as for typical strain gauges. If a standard value is chosen for resistance a usual industrial analysis unit can be applied.

A k-value of 1.93 was determined as transmission parameter. If the signal of the embroidered sensor is compared with a signal of a regular strain gauge beam arrangement no significant difference can be determined. (Figure 2 and 3)

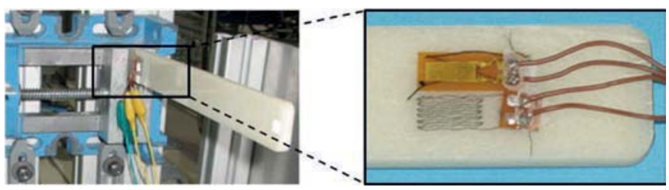

Fig. 2: Beam arrangement to compare embroidered sensor with regular strain gauge

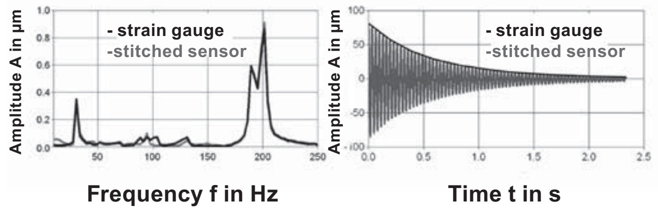

Fig. 3: Comparison of stitched sensor signal with strain gauge signal

Application as fill level sensor

Capacitive sensors are applied to measure fill levels in tanks. Working principles and measuring methods of that kind of sensors are well known. One possible method is detecting changes in the electric field. Hence, the medium to be measured must be at least weakly conductive. With that method limits can be detected or fill levels can be measured continuously. Two electrodes are required and needed to be placed as close as possible to the liquid. For thick walled containers this can be a real challenge. To get a stronger signal it is better to place it as close to the medium (liquid) as possible. Using those sensors, it is possible to position them anywhere within the wall thickness. The total thickness of the wall is nearly unimportant (compare Figure 4). Due to the sensors thickness of about 200µm they are very suitable for thin walls as well. The non-woven with sensor geometry embroidered is incorporated in thermosetting resin. Therefore the sensor becomes part of the support structure of the polymer matrix. So it is not creating a separate layer which is leading to structural weakness. The same applies to embedding into thermoplastic materials.

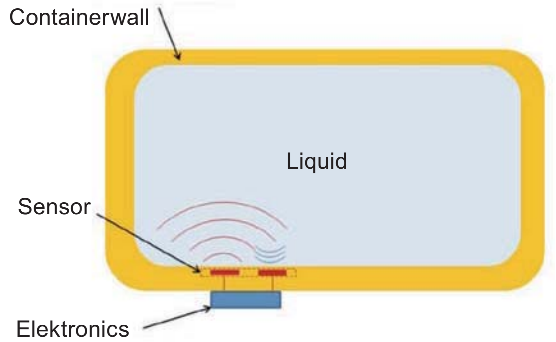

Fig. 4: Functional principle of a capacitive fill level measurement system

Other authors of different publications name some possibilities to integrate sensors into container wall, but this has never been realized in a real application. Apparently suitable production technologies or integration methods and proper sensors are missing.

Because of small installation height the embroidered sensor is quasi-two-dimensional shaped. Therefore they can be integrated into tank wall or applied outside. Due to embroider technology shape and size of these sensors can be designed freely. Hence small and larger series can be produced economically. Because of embedding the sensor inside polymer matrix the medium (liquid) cannot touch sensible wire construction. At the same time the sensor is protected against mechanical damage, corrosion and dirt during whole product life cycle. Additionally the sensor cannot be damaged while cleaning the container. The wall itself is sensor case. The tank remains form-fitted and still has the same structural stability as without sensor.

The sensor can be fitted to arced or buckled surfaces. The used thermosetting or thermo plastics must not be conductive. Improved productions methods for structure integration into polymers are a real innovation. Novel sensitized tanks with new functions can be created. Additional mounting and adjustment processes are no longer necessary.

The basic capacity is about 100 pF. For water as liquid medium change in capacity could be about 30% to 50%. The water level can be measured analogue and gapless.

Application as humidity sensor

Capacitive and resistive measurement setups are known techniques to measure humidity inside materials. For the first time economic measurements of humidity directly inside a material are possible using the embroidered and structure integrated sensor system developed by Competence Centre for Lightweight Structures.

Through the embedding of stitched sensor systems in mineral construction materials (e.g. masonry, concrete, plaster, etc.) as lost sensors permanent measurements can be taken in defined periods of time. That cannot be realized with any other existing measurement technique. Stable Measurements can be taken any time, even after many years. In case of renovation works leak detection or wet areas can be localized easily. Therefore actions of quality control and quality assurance can be significantly improved.

Based on own research activities it can be shown that capacitive measurement methods give better result in mineral construction materials. Thereby the measurement principle is similar to DNS method in building industry with the advantage of performing measurements directly inside the structure. Comparisons between stitched structure integrated humidity sensors and general accepted laboratory methods according to Darr-principle show sufficient matches.

Application as Temperature Sensor

Temperature sensors can be made in two working principles. First the sensor can be designed like a thermocouple. Therefore two different wire materials are an embroidered on a web. On a junction between two wires the different metals produces a voltage related to a temperature difference. An electronic circuit can covert the voltage change into a temperature signal. This method is ideal for measuring single spots. An application could be to measure the core temperature of a heated composite mould.

On the other hand the sensors can be designed in the same way as strain sensors. Due to a high temperature coefficient nickel is chosen as an appropriate wire material. The change in resistance is related to the change in temperature. An electronic circuit is used to convert the changes into a voltage or current. The sensor can be designed to cover large or small measurement areas.

We are using a nickel wire to measure the temperature. The wire is place in the meander pattern on a fibrous web. The size of the sensor depends on the desired resistance at room ambient temperature. And the resistance is based on the diameter and the length of the wire. A higher resistance leads to a higher sensibility and better accuracy and to larger temperature ranges as well.

That kind of embroidered temperature sensor is a distributed sensor. The measured temperature is the average temperature in the sensors area. Currently the smallest sensor is about 35 x 35 mm. A smaller sensor could be developed if necessary. However, sometimes it is better to measure the average temperature of a small area instead measure a single spot. Lager areas can be covert easily by increasing the distance between the wires of the meander structure.

Conclusion

Embroidered sensor systems have huge potential of innovation. The high degree of design freedom with conductive wires allows individual solutions where standard sensors cannot be applied. Size, shape and output signal of sensors can be adjusted as desired. If sensor geometry is placed in pattern, a high flexible functional sensor system can be created. Depending on sensor applications and required properties different conductive materials and diameters can be used. Due to their small thickness of about 200µm and limp base material embroidered sensors can be embedded into fibre reinforced plastics. This sensor becomes just another layer and does not affect the structures stability at all. The embedding protects the sensor against environmental influence of any kind because the component is casing the sensor at the same time. This technology can be applied to thermo or thermosetting polymers and others like mineral building materials. Components can be functionalized with positive affects to the value chain. Additional mounting and adjusting steps of those sensors can be omitted. The sensors can be applied in different ways. They can detect intern status of structures like stress or health monitoring or they can measure external properties like temperature or fill levels. Stitching is a very customizable technology which allows a wide range from small to large scale production.

All these facts show the potential of this technology. Though, more research needs to be done. Not all side effects are understood yet. There are no design rules or standards for embroidered sensors. Any sensor needs to be designed individually. There is no out-of-box solution for standard applications yet. For industrial applications reliability and production methods needs to be improved as well.

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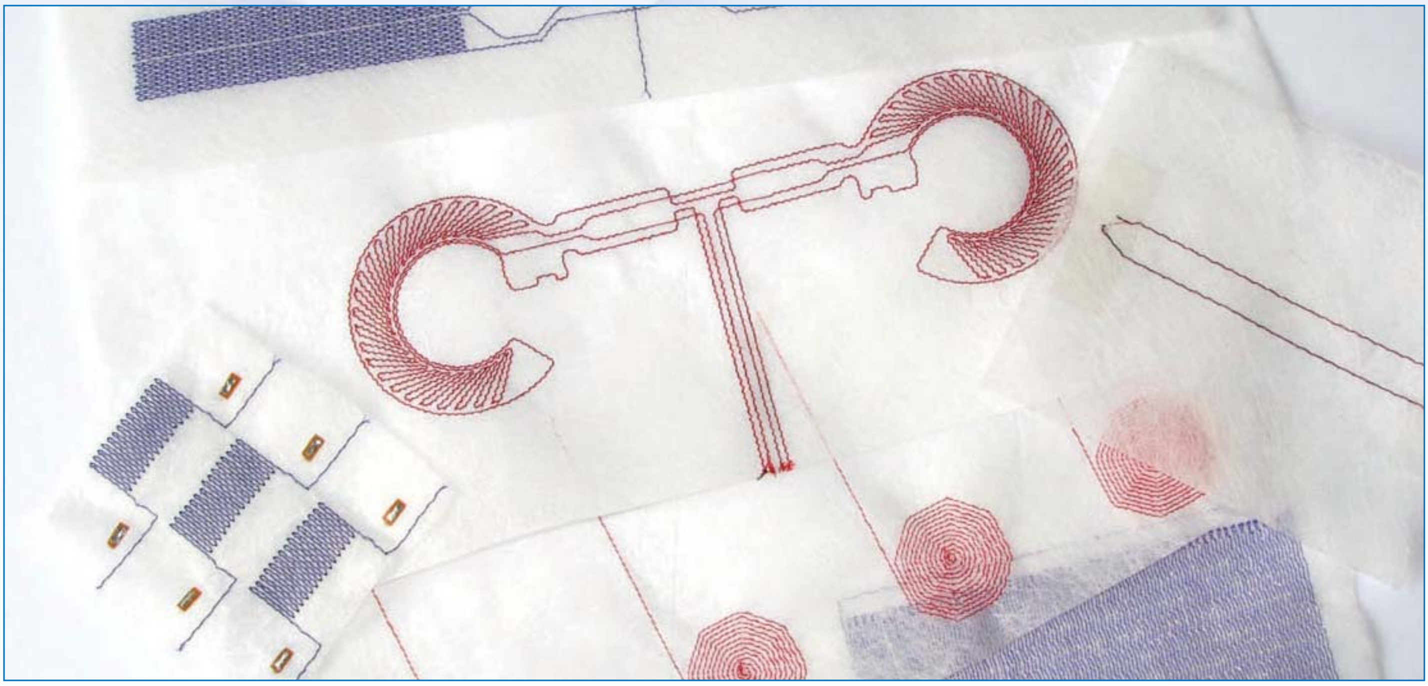

Fig. 5: Several embroidery designs