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MULTITEXCO - High performance smart multifunctional technical textiles for tensile structures

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Abstract

In recent years, the textile industry developed a new generation of advanced textile materials for the construction sector designed to address the needs of one of the largest markets for textile products. Examples of the advanced textiles developed include fabrics for the rehabilitation of buildings, geotextiles for the consolidation of a wide range of soil structures and the high performance technical textiles for tensile structures. When combine with innovative sensors the fabrics provide an useful tool for the constant monitoring of the structures and can be used to record the mechanical performance or detect anomalies in the expected use of the structures by measuring applied loads, deformations, operating temperatures or other important parameters.
This work highlights recent advances in sensor embedded textiles for structural health monitoring of tensile structures. Attention is paid on ease of application, integration in the textile and the use of established and relatively low cost sensing methodologies. The real innovation lies therefore in transferring these methods to unexplored technological fields for smart textiles such as tensile structures.

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Keywords: Smart textiles, structural health monitoring, tensile structures;

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1. The MULTITEXCO project

The research project MULTITEXCO [1] is an European Research Project founded by the FP7-SME research programme "Capacities: Research for the benefit of SMEs” in order to fully exploit the potentialities of the new generation of advanced technical textiles and smart composites favoring their effective use in the construction sector. The MULTITEXCO project aims at the following main Scientific and technological objectives:

- To develop a knowledge-base able to identify and characterize the performance specifications of existing products and the newly developed knowledge by the RTD performers during extensive scientific characterization laboratory work and tests on the field;
- To develop a collaborative web based knowledge platform to be integrated in the project website and to be provided to the SME Associations as proprietary tool;
- To perform a detailed LCA and LCCA;
- To provide a scientific basis for norms and standards in the construction sector for the new multifunctional textiles in order to favor the standardization process.

MULTITEXCO is focusing on key developments in smart textiles for roadwork and embankments, structure retrofitting and fabrics for tensile structures. This contribution will show examples from the last application area focused on high performance textiles for tensile structures and will provide an overview on multifunctional fabrics that can be used for monitoring tensile structures..

2. High performance textiles for tensile structures

On the basis of the day to day real life experience from the industrial partners of the project, MULTITEXCO identified a series of bottle necks that potentially could decrease the stability and reliability of a given structure.

- Unexpected stresses in the fabric (modelling can become very complex)
- Extreme wind or snow load (difficult to model)
- Friction between support and fabric (small vibrations)
- Misuse (elevated temperatures, chemicals, ..)

The behaviour of the structure can be monitored and investigated through a number of standalone systems available today [2]. However, these require external mounting, additional wiring and/or localized measurements by hand. A new generation of smart textiles with integrated sensors able to identify the various causes of potential failure may increase confidence in tensile structures or signal pending failure. In brief, the development of multifunctional materials integrating pressure, strain, vibration and temperature sensors that can signal design or confection flaws or send out an alarm triggered by a severe environmental impact like snow load or heavy wind. In addition, the materials could signal misuse of the fabrics by using chemical responsive coatings and provide means to avoid warranty dispute. Clearly, the reliability of the sensors introduced in the fabrics needs to match the expected life time of the structure. [3]

In addition to the sensor life time, proper connections between the fabric and the supporting structure are mandatory to ensure the construction is at equilibrium state. In contrast to conventional rigid structures, the tensile structures endure small movements and vibrations. This may cause defects at the fabric-retaining structure interface due to puncture, abrasion and repeated bending.

From the various multifunctional membranes developed, an assessment was done in order to identify the most useful sensor for further testing. This was done in close communication with people in the field of tensile structures. The assessment focuses on applicability, state of development and usefulness (Table 1). From this, the most interesting multifunctional membranes are identified and subjected to further testing.

Table 1. Overview of smart textiles for tensile structures

Sensing parameter	Technology	Applicability	Status	Positioning *
Crack propagation	Conductive tread	In seams	Need for large scale testing facility	3
Fabric strain	String sensor	Near connection point	Proof of concept	5
Pressure	Piezoresistive	Localized on areas susceptible for ponding/snow load	Lab demonstration	2
Vibration	Piezoelectric	In keders, edges	Testing on demonstrator structure	4
Misuse	Thermochromic	On seams, inside	Lab scale coating, localized coating on seams is preferred	1
	Thermoelectric	Distributed point sensing	Lab demonstration	1
	Biogas sensing	Patch inside structure	Lab scale demonstration	
	Ammonia			6
	H_2S			7

* See Fig. 1 for details

From the various sensors mentioned above, it is clear that correct positioning is crucial for reliable monitoring. Fig. 1 illustrates the most effective position of the various sensors in structural health monitoring of tensile structures.

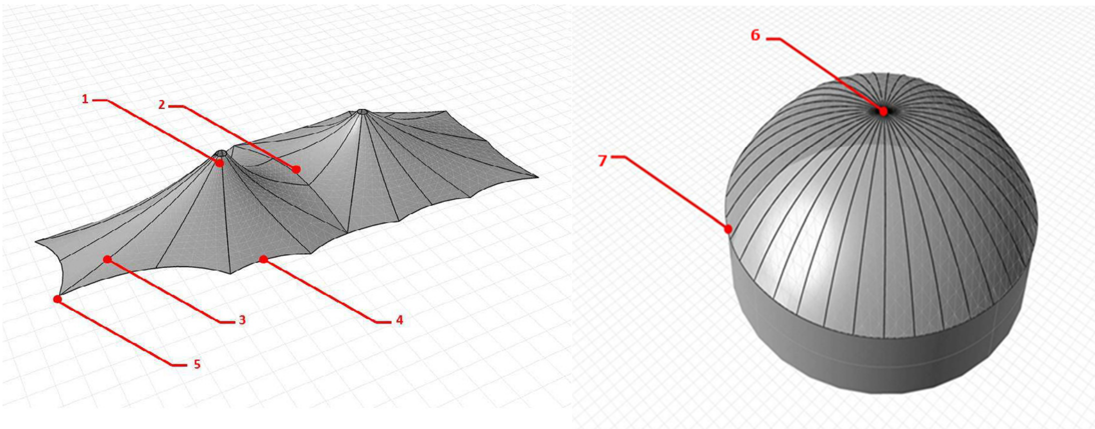

Fig. 1: Proposed positioning of the various sensors for tensile structures, see table 1 for respective sensing parameters left: double curved structure, right biogas dome

3. Thermochromic sensor

Coated fabrics for architectural applications are designed for a temperature range from -30°C to 70°C which includes the most common atmospheric conditions for architectural applications. [4, 5] However, due to the growing markets for industrial applications, such as biogas plants or fabric tanks, the risk that coated fabrics are applied in extreme conditions is increasing considerably. High temperatures can affect the stability of the coating, generally

PCV, and compromise the mechanical performance of the welded connections. [6, 7] According to the EN norm BS EN 15619:2014 “Rubber or plastic coated fabrics. Safety of temporary structures (tents)”. Specification for coated fabrics intended for tents and related structures”, a welded connection exposed at 70°C might lose 60% of the tensile strength at break of the coated fabric with remarkable effects on the safety factors to be adopted in the design of membrane structures.

For this reason, in case of high demanding applications, it is essential to monitor the temperature of the connections and prevent the misuse of the material. The two thermo-responsive sensors identified and developed within the MULTITEXCO project may aid in preventing collapses due to the exposure of the structure to high temperatures.

Thermo responsive coatings allow for a rapid visual inspection of the structure and are recommended in projects where the structure can be easily inspected from underneath. The thermo responsive coating is an acrylate binder with a water soluble reversible thermo chromic pigment with desired threshold temperature in order to be personalized for each specific application and maximum temperature. For the tests carried out for MULTITEXCO, the sensor is designed for a maximum temperature of 65°C, once reached that value the pigment will change from its opaque color to transparent in a reversible way (Fig. 2).

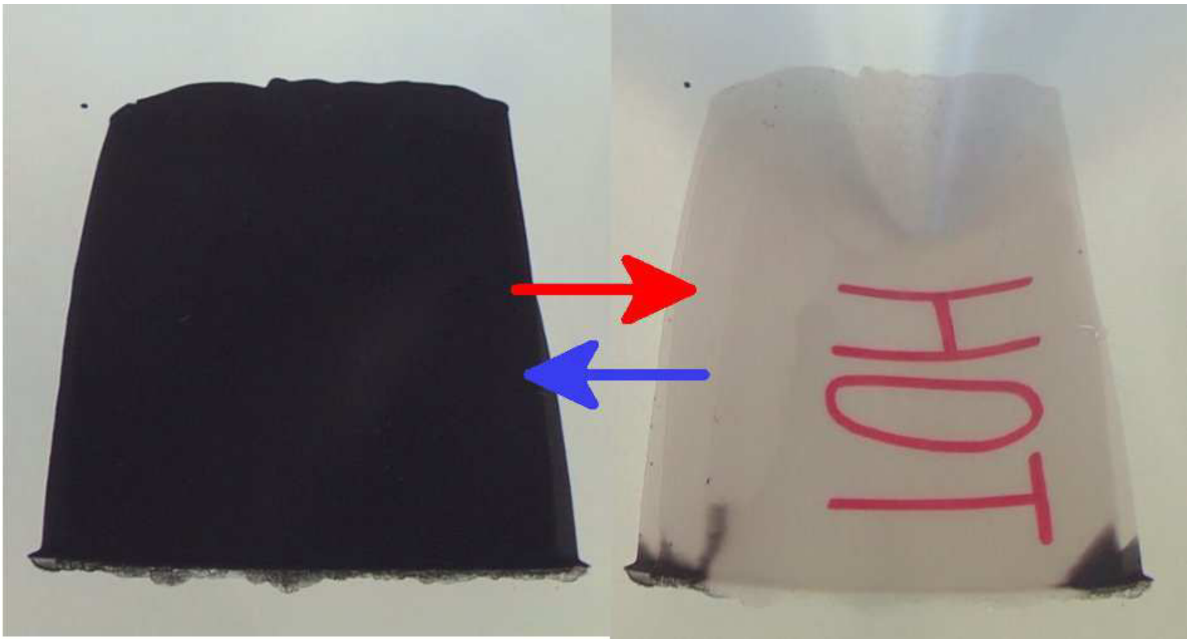

Fig. 2: Textile coating with thermochromic pigments. The coating becomes transparent when submerged in hot water (70°C) (red arrow) and returns black when cooling down (blue arrow).

In contrast to the temperature changing color above, the integrated thermo-electric sensor can be used as an independent alarm unit. The miniature thermo resistive sensor is integrated in the fabric and connected with copper leads that run in the fabric towards the rim. These copper leads have been integrated in the fabric during weaving. The sensor should be placed in a well-considered area during confectioning and the leads should be marked at the fabric rim to ease later installation of the readout. The leads are connected to a standard temperature monitor with PT100 functionality. Due to the very thin and long leads, there may be a temperature bias recorded. It is therefore advised to select a readout unit with bias compensation capabilities (Fig. 3).

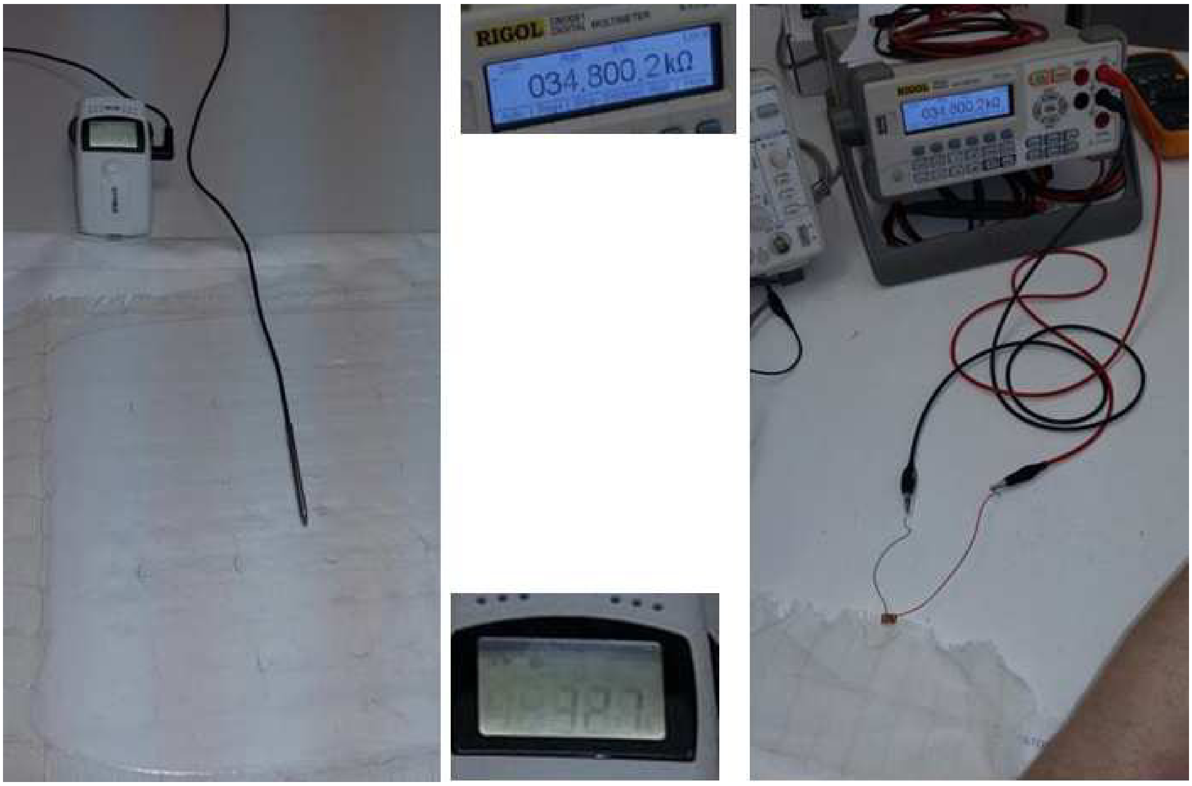

Fig. 3: Electronic sensor integrated in PVC coated polyester fabric for the monitoring of the operating temperature.

4. Chemicals sensor

The use of chemical sensors in tensile structures may seem farfetched at first glance. However, fabrics for tensile structures are sometimes used in situation they are not really designed for. One may think about for example biogas domes. [8] In such fermenters, high levels of hydrogen sulfide and ammonia may accumulate and attack the fabrics [9]. If the fabrics used in such construction are not designed for these harsh conditions, the corrosive gases will deteriorate the materials leading to hazardous situations. [10] Is such event, the fabric manufacturer may find himself in aggravating warranty dispute. The use of irreversible chemical sensors may therefore be very useful in identifying exposure events to reactive biogases. If the sensor signals gas exposure on fabrics not developed for such applications, warranty can be waived more easily. Two sensors have been developed within the MULTITEXCO project: one for the detection of ammonia, and one for the detection of hydrogen sulphide. Both show an irreversible colour change upon exposure (Fig. 4).

Although the sensors are stable, it has proven difficult to set a precise detection limit. The accuracy of the chemical sensors is reported to be around 0.1-4% for H_2S and 0.5-30% for ammonia [11]. As a result, we do not suggest using both sensors for analytical purposes and only the presence of potentially dangerous levels of toxic gases can be detected. However, the current sensitivity is high enough to signal misuse of fabrics not suited for biogas fermenters.

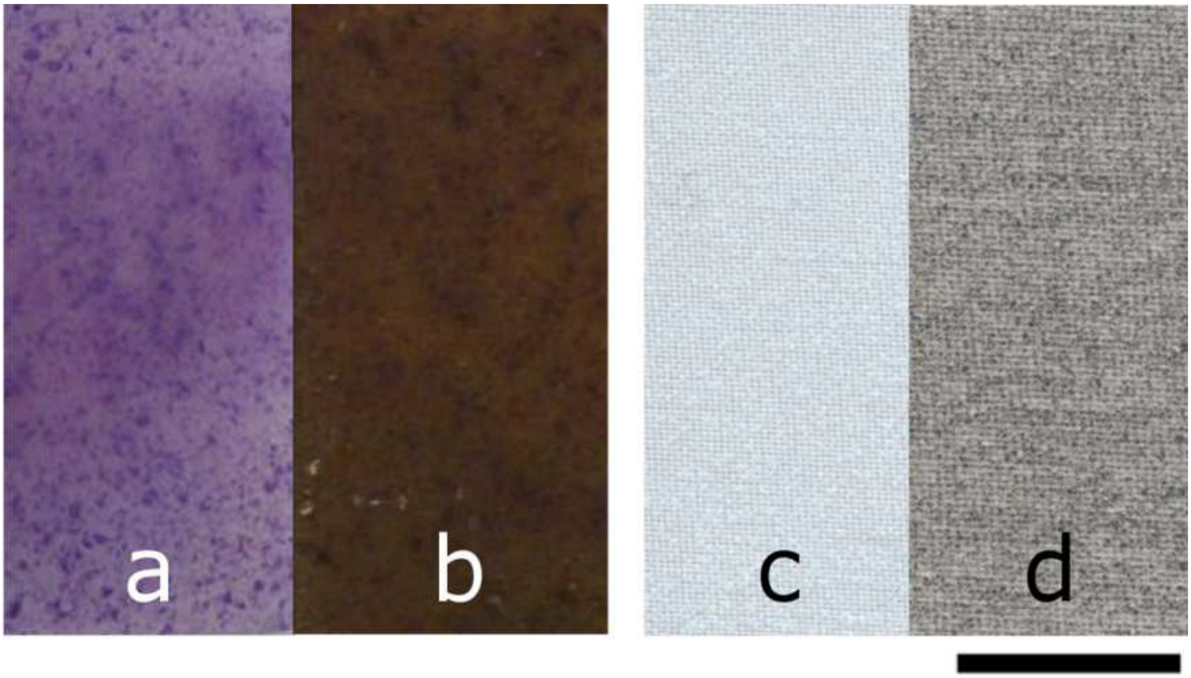

Fig. 4: Chemical responsive coatings with irreversible colour change: left ammonia, right hydrogen sulphide, a and c are before exposure, b and d after exposure. Scale bar is 1 cm.

5. Pressure sensor

The flexibility and elasticity of textiles permit designers to create very attractive forms and organic shapes for tensile structures. [5] These unique properties of textiles as a building material are also responsible for a very complicated and iterative modeling process. Because both form and shape of the structure change when forces are applied, modeling tools based on rigid structures are no longer valid. Every change in applied force on the structure therefore requires a new loop of form finding and a new loop of calculations in order to obtain strain and tension distributions. [12] Especially for smaller structures with a limited modeling budget, it can be troublesome to avoid snow pile-up or water ponding. The pressure sensors integrated in the fabric developed within the MULTITEXCO project allows monitoring of critical areas of the structures susceptible of overloading (snow, water ponding, etc). The sensors are integrated in the fabric and can be used for triggering an alarm in case of an emergency, or help to improve structure design in the development phase. The sensor is a piezo resistive film with control leads are soldered to thin copper wires. Similar to the electronic temperature sensor mentioned above, the copper wires were previously integrated in a polyester fabric during weaving to fit the pin-out configuration of the pressure sensor. The fabric with pressure sensor is subsequently laminated on the fabric used for tensile structures and embedded in a PVC layer. In this way the sensor is well protected from the surroundings and the connector leads reach the fabric rim making both the sensor and the leads almost invisible (Fig. 5).

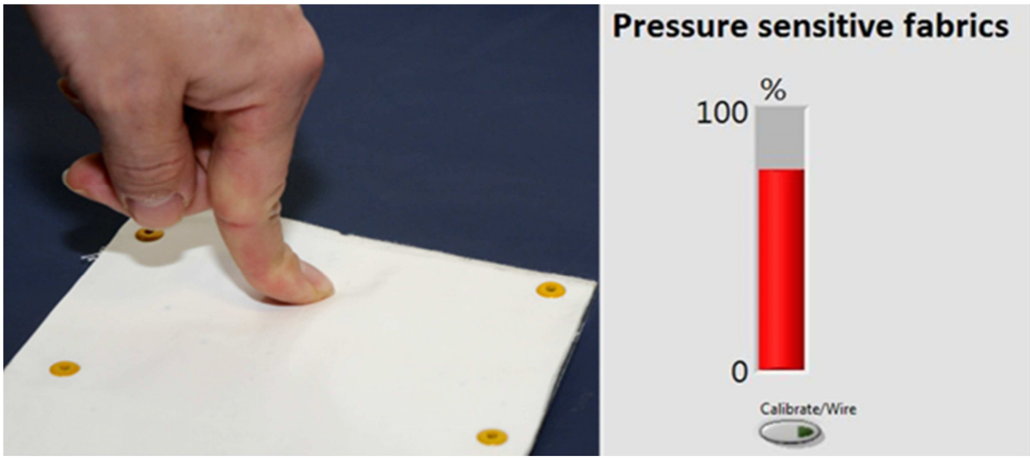

Fig. 5: Pressure responsive sensor integrated in PVC coated polyester fabric (left), response on acquisition software (right)

The calibration of the sensors allows for calculating the load exerted on the fabric by measuring the sensors resistivity. For architectural applications the sensor can measure applied loads form 0 to 500mbar for low pressure sensors. However, the sensors are very sensitive in the lower third of the detection window, which makes them useful for snow load (± 1800 Pa) and water ponding (± 3000 Pa) (Fig. 6).

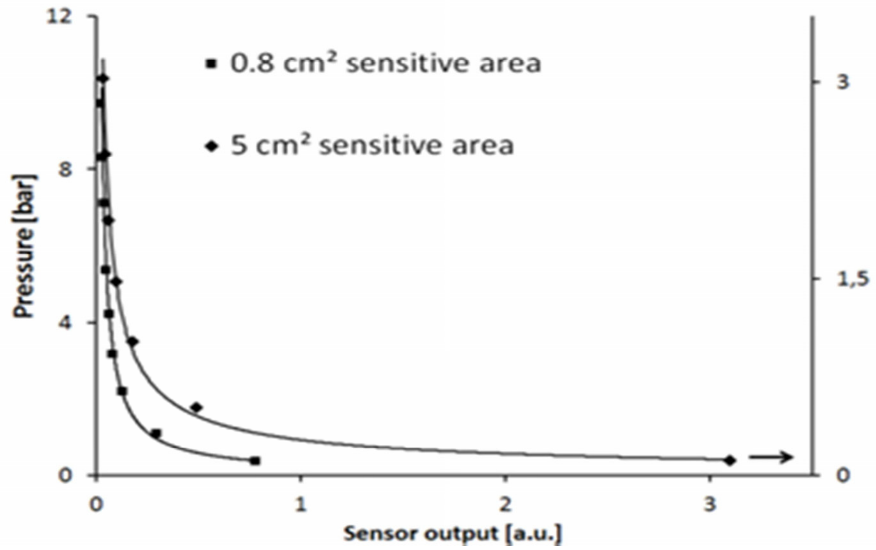

Fig. 6: Calibration curves of small and large area sensors.

6. Vibration sensors

In addition to the flexibility and elasticity of fabrics, yet another asset of fabric structures is their light weight and high strength. The light weight of fabric structures makes them prone to wind load which may result in fluttering. In extreme circumstances, this fluttering may induce unexpectedly high tension forces in the fabric and connection points. [5] MULTITEXCO proposed the use of piezo electric materials to check if fluttering may become an issue in a given tensile structure. The vibration sensor allows the detection of vibrations in crucial areas of the structure such as flexible edges or areas prone the wind suction. The monitoring can detect the frequency of the vibration and trigger an alarm in case the values exceed the safe range. A piezo electric sensor is often used for vibration monitoring. [13] In this case a polarized PVDF film in between a conductive core and braided shell was used. The piezo fiber is embedded in a protective gauge. Movement of the piezo cable will induce a polarization change in the cable that can be recorded by a voltage measurement. The sensor allows detecting and recording of movements in the structure with frequencies above 1Hz.

A set of preliminary tests carried out by MacoTechnolgy on a 1:1 scale mock-up allowed to investigate the main factors which can affect the reliability and the accuracy of the data recorded by the piezo electric sensors. The results indicate that a piezo sensor that is moving up and down will not provide a signal, for this reason it is very important to choose an appropriate location of the sensors (Fig. 7; Fig. 8). For this reason it is proposed to integrate a piezo coaxial wire in the keder of a tensile structure. In this way, the wire ends is fixed and fluttering will induce bending of the piezo wire. This will result in a clear electric signal which can be correlated to the vibration frequencies of the structure.

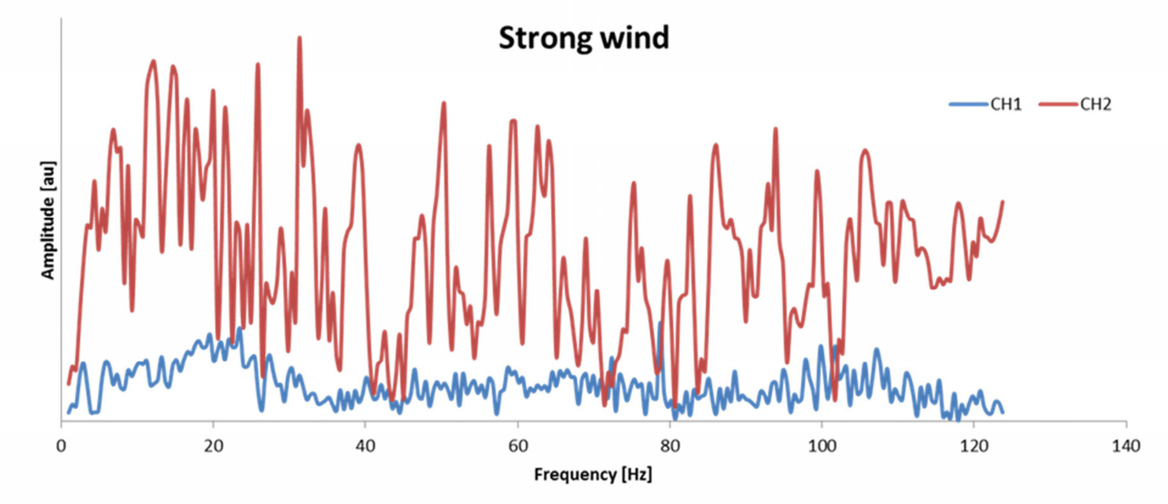

Fig. 7: FFT output of piezosensors on a tensile structure during strong wind load. Ch1: sensor positioned on a plain area, Ch2: sensors positioned at the fabric edge.

Fig. 8: Detail of the demonstrator for the calibration of the vibration sensors .

7. Conclusions

Fabrics for tensile structures are exposed to harsh conditions and because the fabric itself is responsible for the equilibrium state, any failure will result in a hazardous situation. Computational modeling of flexible and elastic materials such as fabrics for tensile structures is laborious and therefore expensive. In addition, variations in the fabrics specifications such as tensile strength and elongation add uncertainty to the final construction. Moreover, assembly flaws and construction errors are impossible to predict and may put even the best modeling effort on the hill. In this work, a number of textile integrated sensors are introduced to aid design and modeling of tensile structures, signal pending failures or help in warranty issues. Although the sensors used are state of the art and of general low cost compared to other techniques such as optical fibers or videogrammetric monitoring [14]; integration of electronic components in an industrial manner directly in textile production mills needs further attention. Tools to integrate conductive tracks in or on fabrics are available, but integrating the miniature electronic sensors at the correct position is still a worrisome undertaken done by hand. The integration of pick-and-place machinery to weaving looms may be the next step towards large scale production of smart textiles at affordable cost levels. [15, 16]

Acknowledgements

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