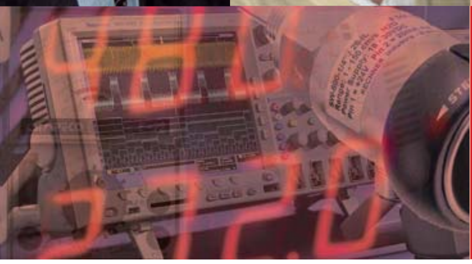

Thick film sensitive strain gauges for structural health monitoring

by Saad Jabir, Synopsys, Germany and Dr. N Gupta, Edinburgh Napier University, UK

For the purpose of improving the safety and reducing the maintenance costs of infrastructures, novel inspection and damage detection techniques need to be developed, tested and implemented on various structures including buildings, bridges, aircraft, and railroads.

One such technique that has gained much attention in the research and industrial communities over the past years is structural health monitoring (SHM). The concept behind structural health monitoring is that every structure has certain properties that change as the structure degrades or becomes damaged. The health of the structure can be monitored by measuring these properties and looking for changes in them over time. An important property of a structure is the stress-strain relationship, which determines many important physical quantities indicating structure health like bending moments, torques, loads, etc. The SHM involves the complete process of obtaining and analysing dynamic response data including implementing an array of sensors/actuators on the structure, periodically obtaining structural response measurements, analysing the measurements and extracting damage sensitive properties, and statistically analysing the extracted properties to describe the current state of the structure (Steven 2008).

The most relevant technique used to assess the structure health is the measurement of the strain caused by loading stresses on the structure and the changing envelope in time of these strains, which could be caused by structure degradation. Strain sensing technology has become one of the most critical areas required for (SHM). This is because strain is one of the key performance parameters that affects the life of mechanical components and civil structures. Stress, fatigue strength, material internal damage and load-history of structure, can be interpreted from strain information (Sun 2006). Measuring stresses of civil structures is adapted by using many techniques and sensor technologies. Among these sensor technologies are metal foil strain gauges, metal wires, fibre optics, and others.

Thick film is a consolidated technology for strain measurement used widely for vessel pressure measurements and is deployed in many industrial sectors among which are automotive, hydraulic-lifts, hydraulic moving machines, power tools etc. This technology has many advantages and can be applied to monitor structural health.

Thick film technology is defined by a particular manufacturing process. This process is screen-printing and firing. The range of materials available, therefore, is determined by their capability of being both printed and fired. Research and development brought all sorts of new materials that reveal sensitivities to various physical and chemical phenomena. Besides the availability of materials, TF fabrication technology allows physical forms to be realised which by constitution and shape facilitates appropriate interaction with the physical world.

Thick-film hybrid technology is also an interconnection technology that allows different electronic components of various degrees of complexity to be assembled to form systems capable of signal elaboration and communication. This process does not require big investment compared, for example, to semiconductor manufacturing. Besides being a mass producible technology, it accommodates different geometrical forms of electronic systems suitable for load relevance according to structure shape.

Thick film hybrid technology responds to the needs of civil and industrial structures of different kinds of sensors, to measure various physical and environmental entities, relevant to building security monitoring like temperature measurement [Ferrari 2002), (Mahayeer 2001), gas (Dae 2002)], and chemical biosensors (Voskerician 2005).

An important topic in SHM is the power supply for the intelligent sensors. The supply is necessary to drive electronics and the networking to monitor a structure during its life, which might last for tens of years.

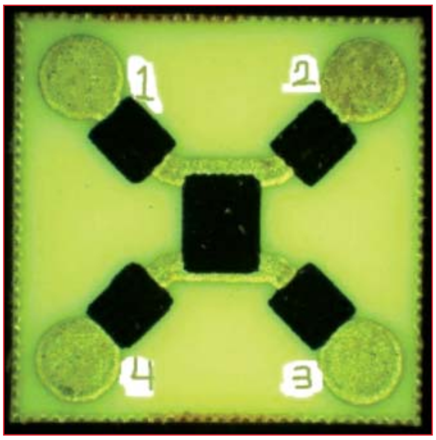

Fig. 1: Piezoresistive thick film strain gauge.

It is well known that cadmium sulfide can be screen–printed and sintered to form films that display photosensitivity. Photoconductive sensors based on screen printed cadmium sulfide and cadmium selenide thick films printed over standard silver-palladium conductors are feasible. Simple photoconductive arrays and a potentiometric position sensor have been fabricated with thick film technology

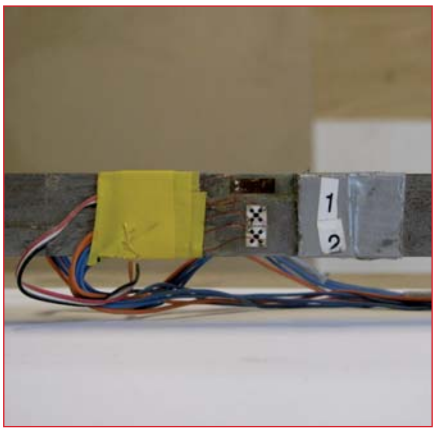

Fig. 2: Thick film and foil strain gauges arranged side to side in 4PBT.

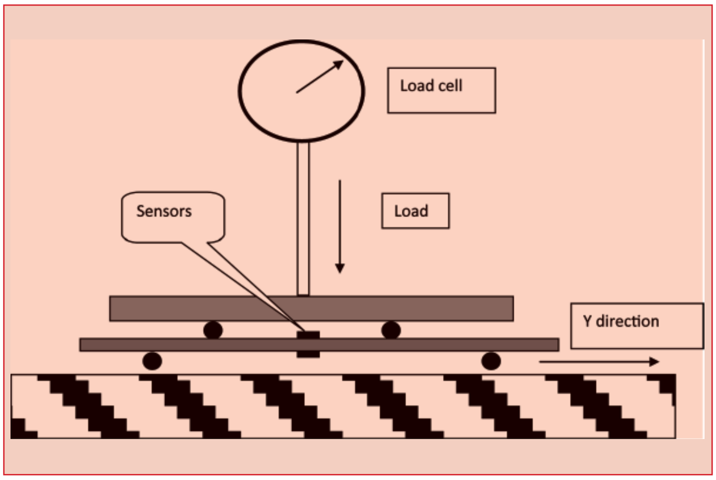

Fig. 3: Four points bending test (FPBT).

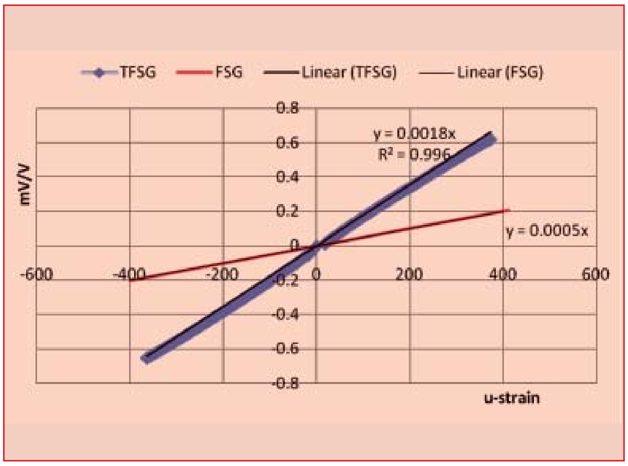

Fig. 4: Thick film strain gauge compared to foil strain gauge.

(Ross1994, Nicoll 1955) and (Vojdani1973).

Substrate made of ceramic material or steel has outstanding mechanical and thermal properties, which make them adequate on one hand to have stable electronic circuits and to withstand harsh environmental conditions on the other.

Thick film strain sensors on beams

A piezoresistive TF strain gauge sensor as shown in Fig. 1 has better response than its counterpart; the well-known foil strain gauge. In fact, when both are put side to side on a steel bar (Fig. 2) in the four points bending test shown in Fig. 3, the TFSG shows higher gauge factor. The measured gauge factor of the TF sensor is about 7,2 compared to the gauge factor of 2 of the FSG as shown in the response graph Fig. 4. The gauge factor is the measure of sensitivity of the sensor to strain and it is by definition in piezoresistive sensors the relative change of resistance with respect to the change in strain. The gauge factor of thick film pastes, ESL #3414-A and ESL #3414-B, is in the 14 to 20 range for sheet resistance in the 1 kΩ/sq to 10 kΩ/sq range and they exhibit low temperature dependence.

As can be seen from Fig. 4, TFSG maintains a very good linearity and repeatability; it is also good and is a function of glue and gluing techniques.

SMD-mounted thick film sensors embedded in structures

This same sensor can be mounted in surface mounting technology on PCB to be inserted in the material to measure the load applied directly on the structure as shown in Fig. 5.

Experiments have shown that TF piezoresistance is not affected by humidity to which it might be subjected during e.g. concrete or plaster cure period in civil engineering applications. Also, for already erected civil structures a small hole can be made in the structure to accommodate the surface mounted sensor and the remaining empty space in the hole can be then filled with a two-component epoxy which would enable the sensor to work in compression and tension. It is particularly useful to monitor structures' stability in time and under different loading conditions. Fig. 6 shows the application of TF strain gauges to monitor the stability of a plaster column. Sensors are shown to be glued on the surface and embedded in the column structure. The response of the embedded TF sensors to the movement of load away from the column centre is shown in Fig. 7 where the x-axis is the distance from the column centre in millimetres.

Direct load application on thick film sensor substrate

This technology offers also a different and very significant method of application by loading the sensor substrate directly. Fig. 8 shows four TF ceramic sensors glued on the angles of a steel cube which is loaded by a load cell and the response of each sensor is shown in Fig. 9.

This application may be used to monitor stability when one side of the sensors is differentiated with the response of the sensors on the other side. In the case that the total load is the only interesting measure, the sum of the sensor response will give a direct measure of load even if the load is not centred.

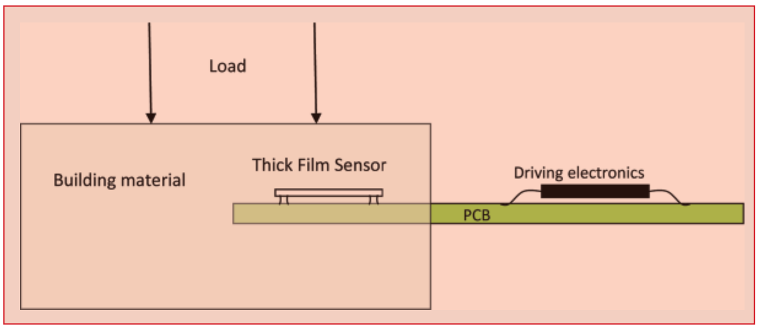

Fig. 5: Thick film strain gauge on PCB embedded in the material.

Fig. 6: Thick film sensors embedded in plaster column to measure stability.

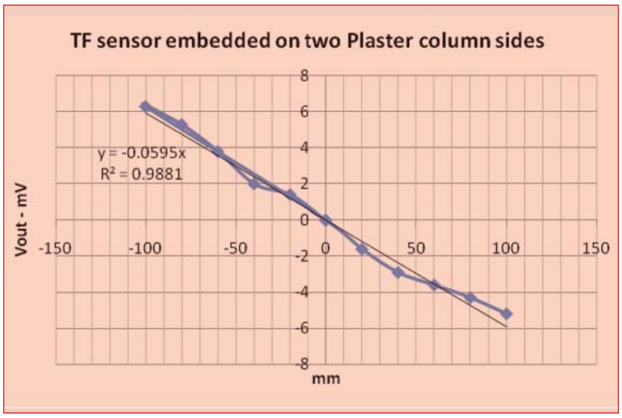

Fig. 7: Response of the embedded TF sensors to decentralised load.

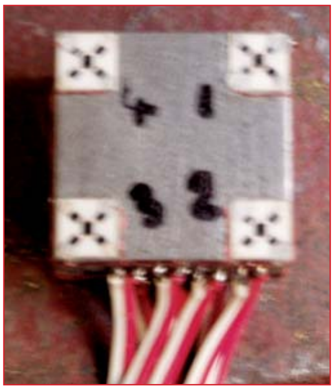

Fig. 8a: A steel cube with four thick film sensors on the angles.

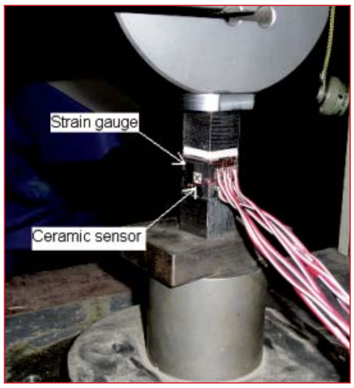

Fig. 8b: Experiment to homogeneously load the steel cube.

If both stability and total load are of interest, the block diagram in Fig. 10 can be deployed to have an indication of stability in the X-Y plane and a total load measurement at the same time.

Conclusion

The combination of relatively high gauge factor and temperature stability in addition to mass production capability and low cost are the major factors justifying implementing TF technology for building reliable force sensors to monitor structure stability. Thick film piezoresistive sensors can be deployed in various methods; a) glued on the material b) embedded into structures and c) with direct application of load on sensor substrate. TF sensors can be combined in arrays in SM technology with the integration of driving electronics in one hybrid package. The technology offers many advantages which make it the best candidate for SHM strain measurement of large civil structures.

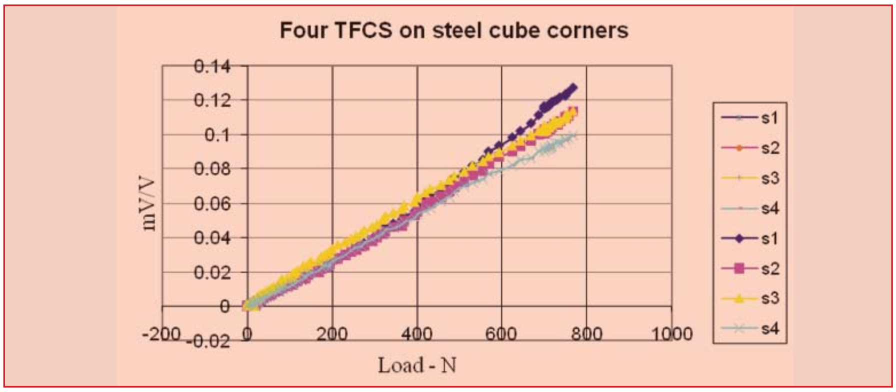

Fig. 9: Four sensors response in direct load application on steel cube.

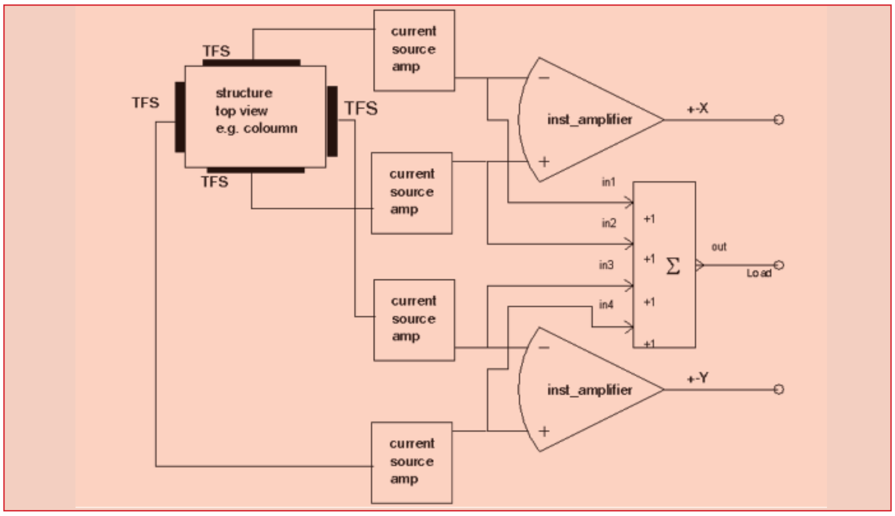

Fig. 10: Block diagram of load and stability measuring system.

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