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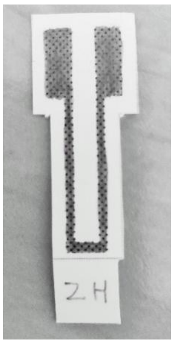
BOUF Incorporated

Pencil Drawn Strain Gauges



General Features

- Low power consumption
- Easy-to-use
- Small size
- Low cost
- Short response time
- Detection of inward deflection
- Detection of outward deflection

Description

Usually used as strain gauges, these pencil drawn sensors are based on electron conduction through the pencil traces. After all, the pencil leads, composed of fine graphite particles bound together by clay binders, form a network of conductive film of graphite particles on paper.

All pencils are categorised based on the percentage of graphite particles inside their leads, ranging from 9H to 9B (hard to soft, respectively). More concretely, the higher the carbon content of a pencil, the softer the lead and darker the traces.

Using a certain pencil, the sensors are drawn in a U-shaped pattern, linked to two rectangles (which serve as the electrodes of the device) on a piece of hard paper. Variations of electrical resistance along the U-shaped trace can be monitored using a transimpedance amplifier connected to the electrodes by toothless alligator clips[1].

Applying a deflection on this sensor may cause additional or fewer connections between graphite particles, depending on the orientation of the deflection (see *Figure 1* for an illustration of this principle). Additional links cause fewer resistance while higher links cause lower resistance. Therefore, computing the relative variation in resistance for some pencils can be used to determine which deflections has been applied to the sensor.

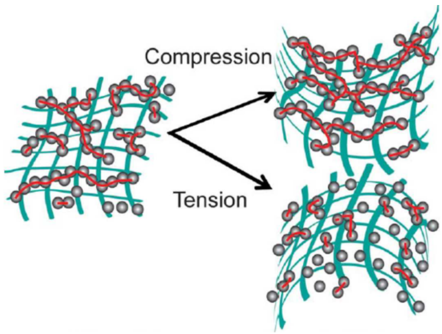


Figure 1: Illustration of how deflections can cause additional or fewer graphite links

[1] Toothless alligator clips's impedance is smaller than the impedance of the sensor : $Z_{sensor} >> Z_{toothless\ alligator\ clips}$

Specifications

Type	Graphite nanoparticle based sensor
Materials	● Graphite particles ● Clay (mainly composed of O, Mg, Al and S)
Sensor Type	Passive
Deflection measurement	Resistance measurement
Dimensions (cm)	3.35 x 1.25
Mounting	Toothless alligator clips

Standard Usage Conditions

	Unit	Typical value
Temperature	°C	20 ± 5
Deflection	mm	[14 ; 43]

Electrical Characteristics

	Unit	Value		
		Min	Typical	Max
H	MΩ	10,859	20,684	39,000
HB	MΩ	7,407	12,927	29,845
B	MΩ	434	1,044	1,495
2B	MΩ	30.8	45.57	79.9
4B	MΩ	14.28	18.02	21.07

Measurement Procedure

The pencil drawn strain gauge characteristic has been determined by measuring the voltage evolution with multiple different deflections. These measurements can then be converted into the corresponding resistances. The figures below (*Figure 1 and 2*) represent the evolution of normalized resistance in function of predetermined deflections, where R_0 the electrical resistance of the gauge when there is no deflection applied is.

The measurement changes the experimental setup, such that the quantity being measured may differ from the measurand. In this case, adequate cohesion with other measurements is necessary. This is the reason why the following graphs are representing the relative variation of the sensor's resistivity.

In the experiments used to determine the curves found in *Figures 2 and 3*, a 3D printed model was used, in order to have deflections with constant and known angles. Nevertheless, this and other attempts to improve the repeatability (like adding resistors in parallel in order to reduce the fluctuations or putting a isolant material under the paper under the alligator's clips) do still not guarantee an increase of reproducibility of these experiments.

Warning: It is quite difficult to have a repeatable experiment with these sensors. Quite often, more graphite has to be added to the sensor by redrawing them, due to a significant loss of graphite over time because of the alligator clips friction with the paper.

In addition, touching it can remove particles of graphite or add some organic materials to the sensor which will lead to a malfunction. Finally, exceeding the deflection limits for an extended amount of time may lead to irreparable damage to the sensor.

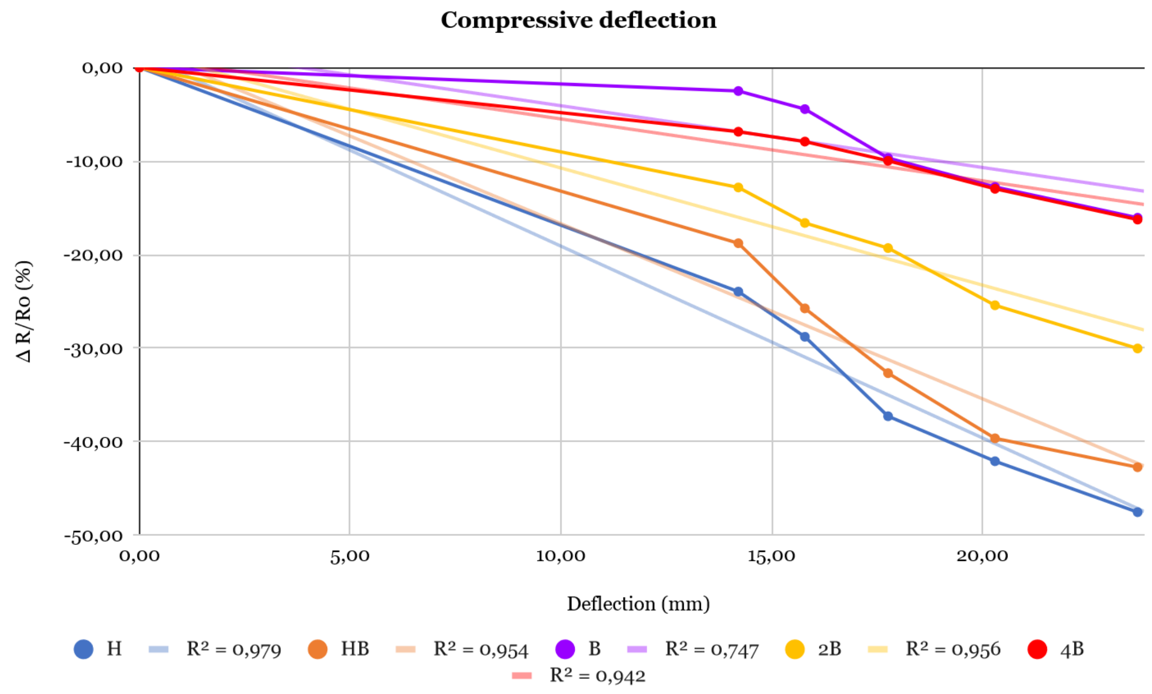


Figure 2: *Variation of normalized resistance versus deflections for devices drawn with five different types of pencils during compressive mode of deflections.*

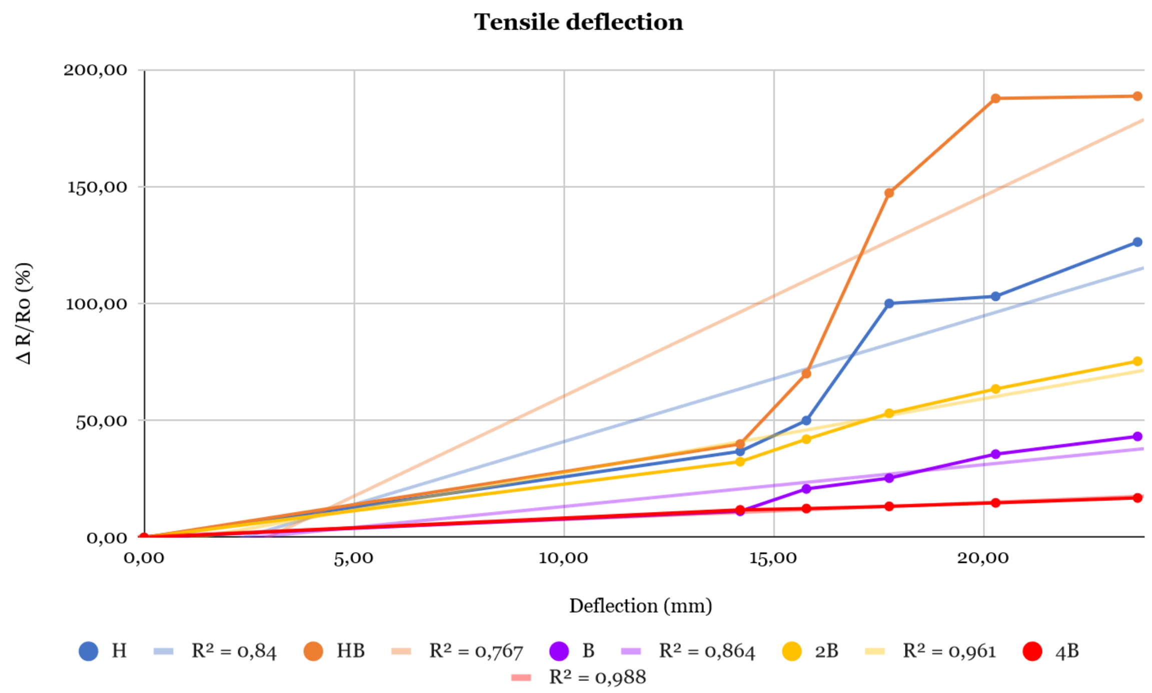


Figure 3: *Variation of normalized resistance versus deflections for devices drawn with five different types of pencils during tensile mode of deflections.*

Dimensions

Sensors are drawn on U-shaped patterns.

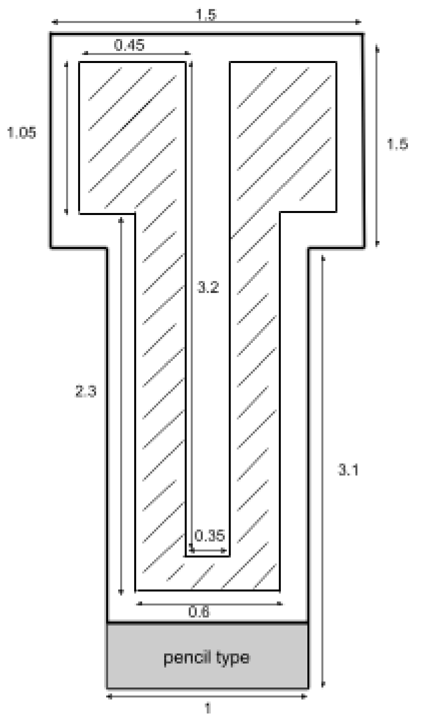


Figure 4: sensor's dimensions (cm)

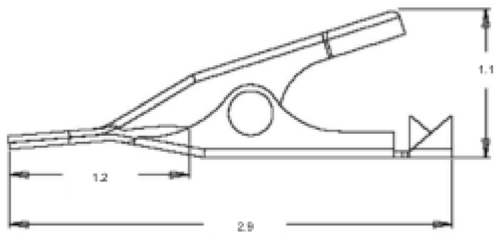


Figure 5: toothless alligator clips's dimensions (cm)

Typical Application

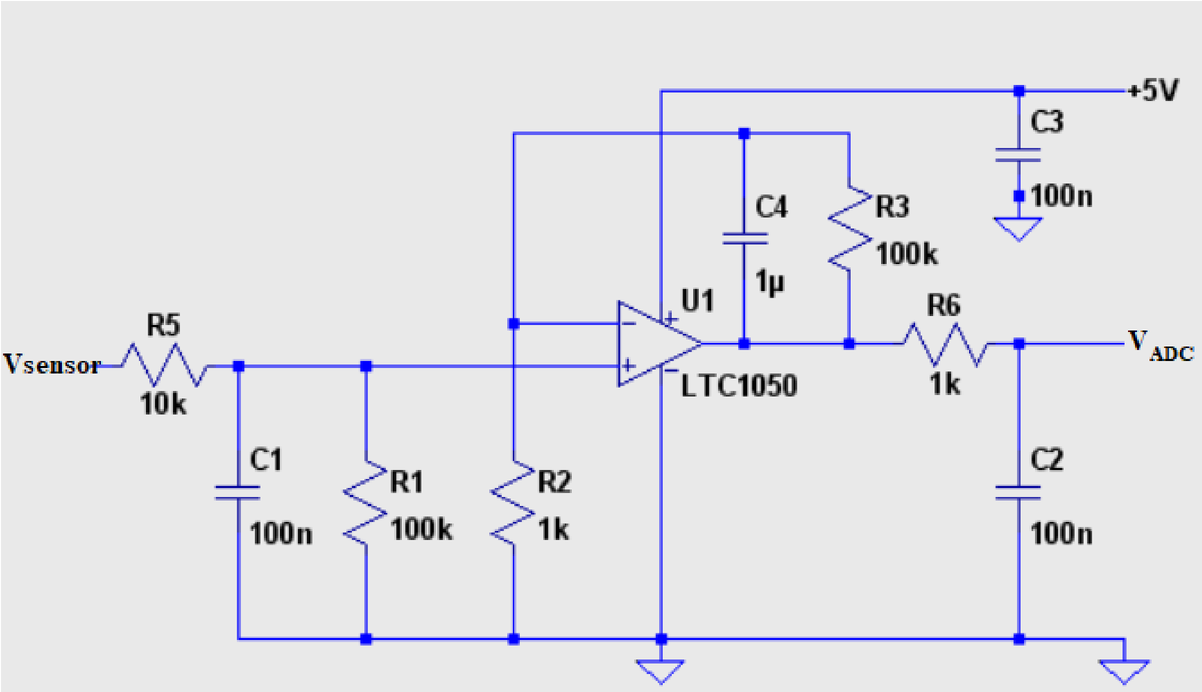


Figure 6: Electrical scheme of the sensor connections.

In the Figure above a typical application of the sensor in an analogue circuit can be found. The sensor is connected in series with two resistors in a dividing bridge configuration. The resulting tension is then amplified by a LTC-1050 operational amplifier, before being filtered by a RC filter (low pass). The tension from the ADC sensor can be connected to a 5V ADC (an Arduino Uno's[2] for instance).

[2] Arduino's input impedance is smaller than the output impedance of the sensor : $\underline{Z}_{sensor} >> \underline{Z}_{Arduino}$