UDK621.3:(53+54+621+66), ISSN0352-9045

# A LOW COST FORCE SENSOR FOR AN ELECTRONIC SCALE

Darko Belavič, Stojan Šoba, Marjan Hodnik, Marko Pavlin, Slavko Gramc
HIPOT, Šentjernej, Slovenia
Marko Hrovat
Jožef Stefan Institute, Ljubljana, Slovenia

**Keywords:** kitchen scales, electronic scales, low cost, thick film sensors, thick film technologies, thick film resistors, piezoresistivity, thick film strain gauges, Wheatstone bridges, spring elements, double bending beams, signal processing, microcontrollers, electronic modules, LCD displays

**Abstract:** A low cost electronic scale with a weighing range from 10g to 3kg was developed by taking advantage of a low cost thick film strain gauge on a double bending beam as a spring element. After accelerated tests the characteristics of the low cost thick film load sensor were measured and evaluated. In the light of the results and economic aspects, the materials and construction with optimum characteristics were chosen. An appropriate electronic circuit provides the sensor signal conditioning and converts the measured load into a digital display of the weight. A battery operated electronic circuit with low current consumption, based on a microcontroller, was developed and constructed for an electronic scale module.

# Cenen senzor sile za elektronsko tehtnico

**Ključne besede:** tehtnice gospodinjske, tehtnice elektronske, cene nizke, senzorji debeloplastni, tehnologije debeloplastne, upori debeloplastni, piezoupornost, senzorji sile debeloplastni, Wheatstone mostički, elementi vzmetni, konzole upogibne dvojno, procesiranje signalov, mikrokrmilniki, moduli elektronski, LCD prikazalniki

**Povzetek:** Predstavljamo razvoj gospodinjske elektronske tehtnice z merilnim obsegom od 10g do 3kg. Raziskave na področju senzorjev sile so omogočile izbiro optimalnih materialov in tehnoloških postopkov za izdelavo cenenega senzorskega elementa v debeloplastni tehnologiji. Razviti analogni in digtalni elektronski moduli pa omogočajo obdelavo senzorskega signala od ojačanja, A/D pretvorbe, mikroprocesorske obdelave do krmiljena LCD prikazalnika. Baterijsko napajan elektronski modul z nizko tokovno porabo je realiziran z uporabo mikrokontrolerja in ustrezne elektronske periferije.

## 1. INTRODUCTION

The most important aspects for successful development of an electronic kitchen scale are good-looking design, functionality and low price. Our task was to develop an appropriate sensor element and the electronics.

The required characteristics are: a weight measuring range from 10 g to 3 kg, and an accuracy ±0.2% of the full range. Other requirements are battery operation, self calibration, automatic turn OFF and taring mode function. The weight value must be displayed on a $3^1/_2$ digit LCD display.

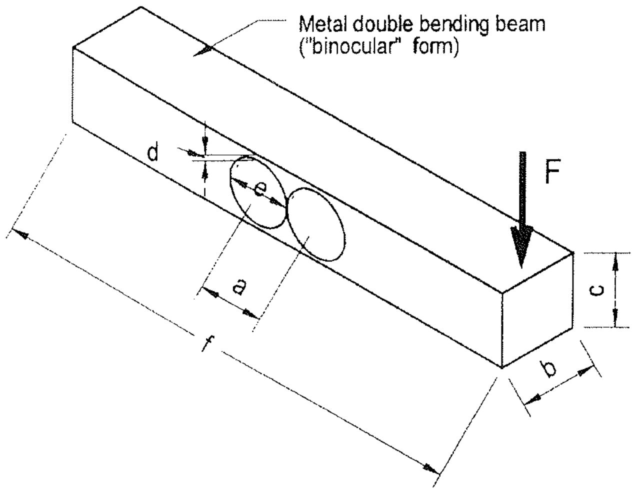
For this application the spring element and strain gauge were designed and analog and digital electronics for signal processing were developed. Cost breakdown analysis shown that a conventional metal foil strain gauge is the most expensive element in an electronic kitchen scale. Therefore, the right choice of strain gauge can effectively reduce the price of the force sensor element. Available and well known thick film technology was used to design a strain gauge based on thick film resistors. A thick film strain gauge offers the advantages of an enhanced sensitivity as compared with a metal foil strain gauge, due to higher gauge factors, and a lower temperature coefficient of resistivity than a silicon strain gauge /1/.

## 2. FORCE SENSOR

The force sensor element is the "heart" of an electronic kitchen scale. The force sensor element consists of the spring (elastic) element and the attached strain gauge. In our case the force (load) is translated into a signal voltage by the resistance change of the thick film strain gauge which is printed and fired on a ceramic ($Al_2O_3$) substrate and bonded with adhesive directly to the aluminium double bending beam of the spring element.

### 2.1. Spring element

The most critical mechanical component in the scale is the spring element for the force sensor. It must direct the applied load (force) into a uniform, calculated strain path for precise measurement by the bonded strain gauge. For our application we designed an aluminium double bending beam ("binocular" form) shown in Figure 1. Due to its high resistance to bending moments and torsion, the double bending beam is less sensitive to disturbance resulting from incorrect application of loads. It exhibits significantly better guidance properties than a simple bending beam. The material ($AlCuMg_2$) for the double bending beam has a Young' modulus of 73,000 $N/mm^2$ with a temperature coefficient of $-580\times10^{-6}/K$ and thermal expansion coefficient of $23\times10^{-6}/K$.




Strain of double bending beam:

$$\varepsilon = \frac{1.5xFxa}{Exbxd^2}$$

E ......... Young's modulus (N/mm$^2$)

F ......... Force (N)

Dimensions of dual bending beam:

a ...... 10.6 mm

b ...... 13.0 mm

c ...... 12.0 mm

d ...... 1.0 mm

e ...... 10.0 mm

f ...... 80.0 mm

*Fig. 1: Aluminum double bending beam*

The working principle of the double bending beam is shown in Figure 2. When a force is applied to the sensing element, the strain is concentrated at two points of the beam. The sensing resistors are located at these two points. The resistors of the attached strain gauge form a Wheatstone bridge (Figure 3 and Figure 4). R1 and R3 are under tensile strain, and the resistors R2 and R4 are under compressive strain.

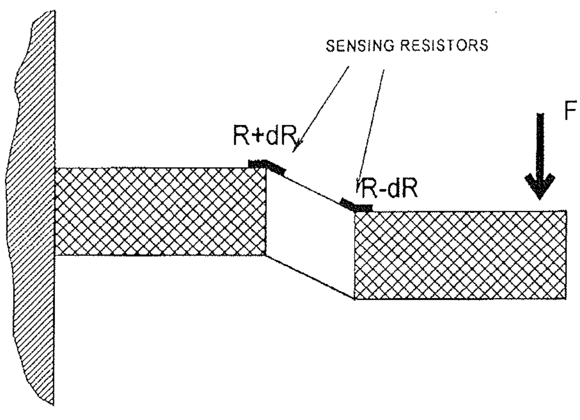



*Fig. 2: Working principle of the double bending beam.*

## 2.2. Thick film strain gauge

A strain gauge is a device capable of translating a deformation (strain) into an electrical signal. The working principle is piezoresistivity which is the property of materials to change resistivity under strain. The sensitivity to strain of a certain material is indicated as a gauge factor (GF). The gauge factor is defined as the ratio between the fractional change in resistance (dR/R) and the strain induced in the resistor by an applied stress.

The thick film strain gauge is designed with four thick film resistors printed and fired on the alumina substrate. The shape and dimensions of the ceramic substrate with the thick film resistors are shown in Figure 3. The four sensing resistors having a size of 2.0 mm × 1.5 mm form a Wheatstone bridge (Figure 4). After previous investigation of the piezoresistivity of thick film resistors /2,3,4,5/, we chose resistor material with a sheet resistivity of 1,000 Ohm/square. Thick film resistor materials have gauge factors up to 20. For the specific demands of our application we chose material with a gauge factor of around 8.

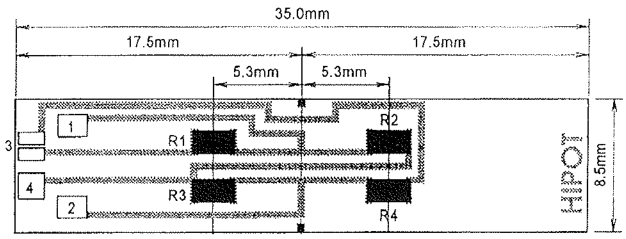



*Fig. 3: Ceramic substrate with thick film resistors connected in Wheatstone bridge.*

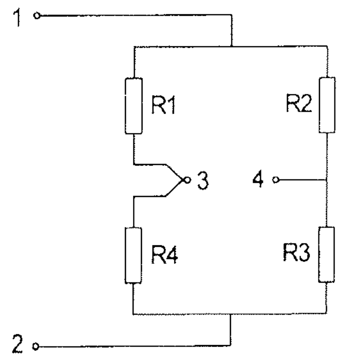



*Fig. 4: Wheatstone bridge*

## 2.3. Assembly

An important factor in optimising the force sensor characteristics is the assembly technology /6/. The force must be transferred to the sensing element without distortion. This problem was solved by the mechanical construction. Special attention was paid to mounting the ceramic substrate on an aluminium beam (Figure 5), because this process has a great influence on the linearity, repeatability, stability and creep of the force sensing element. For better linearity, repeatability and stability, it is vital that the bonding material has a high adhesion between ceramic and metal, and a high resistance to plastic deformation.

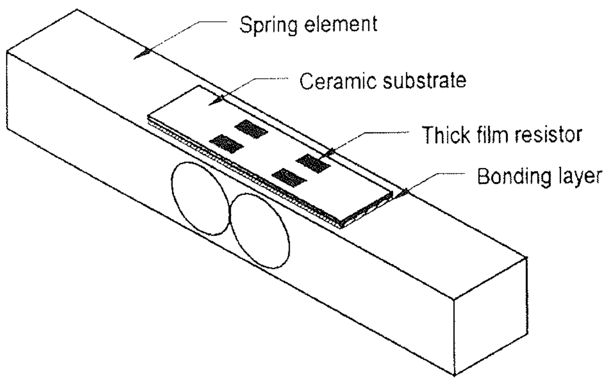



*Fig.5:* *Spring element with thick film strain gauge attached*

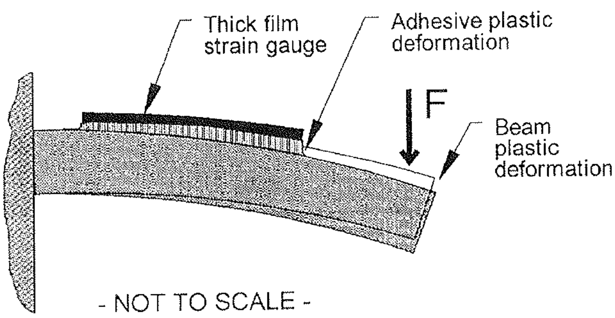



*Fig. 6:* *Principle of compensation of adhesive plastic deformation with beam plastic deformation*

If the force sensor is subjected to a static strain, its resistance changes with time, despite the constant strain in the sensor element. These changes in the measured signal take place very slowly and the sensor output is said to be subject to "creep". The cause lies in the characteristics of the bonding layer between the ceramic substrate and the aluminium beam, and also in the beam itself, which transfers the strain. The creep of the bonding layer depends on the bonding material and the thickness of the layer. The creep of the beam depends on its material and construction. Plastic deformation of the bonding material leads to a decrease of signal, and plastic deformation of the beam material leads to an increase of signal. Therefore it is possible to compensate one creep by the other with the right combination of dimensions and materials in the bonding layer and beam. The principle of creep compensation is shown in Figure 6.

## 2.4. Testing

For a low cost force sensor we investigated the bonding of the thick film strain gauge on the spring element using different bonding materials. All the tested materials were polymeric adhesives used for ceramic-metal bonding. To evaluate the results we compared them with reference samples made with metal foil strain gauges. These force sensors were made under supervision of a metal foil strain gauge producer. The sensor elements were prepared with different bonding materials and tested for sensitivity, temperature coefficient of sensitivity, offset, creep, stability, linearity and repeatability.

The accelerated tests consisted of:

- long term ageing at 100°C
- temperature cycling (1 cycle: 15 min/-25°C, 5min/25°C, 15min/125°C, and 5min/25°C)
- constant loading (30 N),
- overloading (100 N)
- periodical loading (30N with 2.5 seconds period)

After each test the samples were inspected. The output signal of the Wheatstone bridge with a stabilised bridge voltage of 5V was measured as a function of increasing and decreasing applied force with several repeats. For creep measurments the force sensors were loaded for 10 minutes with 30N and then unloaded for 10 minutes. During this test the output signal of the Wheatstone bridge was measured automatically.

## 2.5. Results

Figure 7 shows the measured output signals of the force sensors with thick film and metal foil strain gauges, and Figure 8 shows the creep of the same samples.

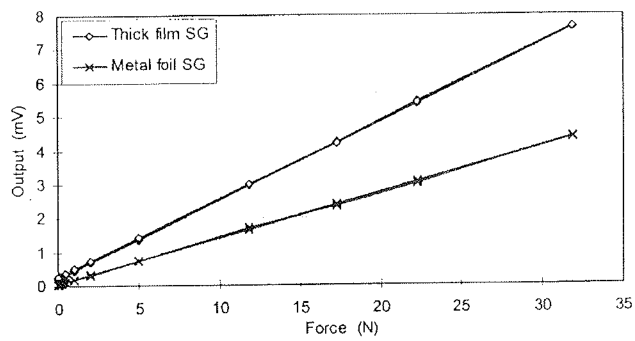



*Fig. 7:* *Output characteristics of the force sensor with thick film and metal foil strain gauges (SG)*

Other characteristics of the thick film force sensors such as sensitivity, temperature coefficient of sensitivity, offset, creep, linearity and repeatability are shown in Table 1 and Table 2. Linearity and repeatability are presented as the R-squared value. R-squared values near 1 indicate a good fit to linearity and repeatability.

After the experimental investigation of the low cost force sensors with a thick film strain gauge and different polymer adhesives, compared with metal foil strain gauge and analysis of the results, we chose the polymer material with optimal characteristics. In comparison with a metal foil strain gauge, sensors made with a thick film strain gauge have higher sensitivity, a lower tempera-

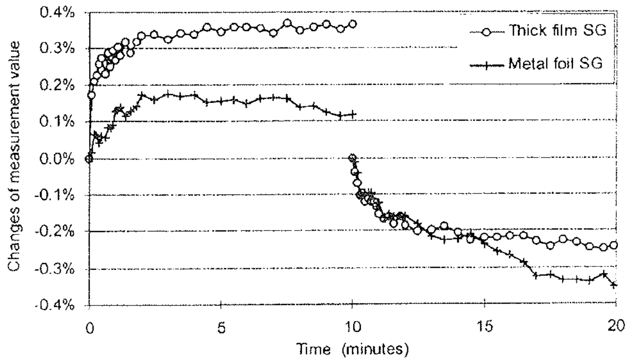



*Fig. 8:* *Creep dependence of the force sensor with thick film and metal foil strain gauges (left-loaded, right-unloaded).*

ture coefficient of sensitivity, a relatively high offset, higher uncompensated creep and better long time stability. The offset is adjusted later with an electronic circuit. Creep can be reduced by optimising the thickness of the bonding layer.

*Table 1:* *Characteristics of the force sensor*

| | Metal foil strain gauge | Thick film strain gauge |
|---|---|---|
| Sensitivity (μV/V/N) | 30 | 45 |
| TC of Sensitivity ($10^{-6}$/K) | -1.000 | ±150 |
| Offset (mV) | / | ±4 |
| Linearity - R Squared (number of nines) | 5 | 5-6 |
| Error because of uncompensated creep after 1 hour constant loading at 30 N | 0.2% | 0.4% |

*Table 2:* *Linearity and Repeatability of thick film force sensors (R Squared)*

| | Metal foil strain gauge | Thick film strain gauge |
|---|---|---|
| Initial value | 0.999997 | 0.999999 |
| After 100 temperature cycles | 0.999954 | 0.99996 |
| After ageing 1.000h/100°C | 0.999928 | 0.999998 |
| After 11.000 load cycles | 0.999992 | 0.999999 |

The final form of two low cost force sensors with thick film strain gauges are shown in Figure 9. Both sensors are intended for use in an electronic kitchen scale with a weighing range from 10 g to 3 kg, and an accuracy of ±0.2% of the full range. One sensor element is constructed with an aluminium double bending spring element, and other with a steel simple bending beam.

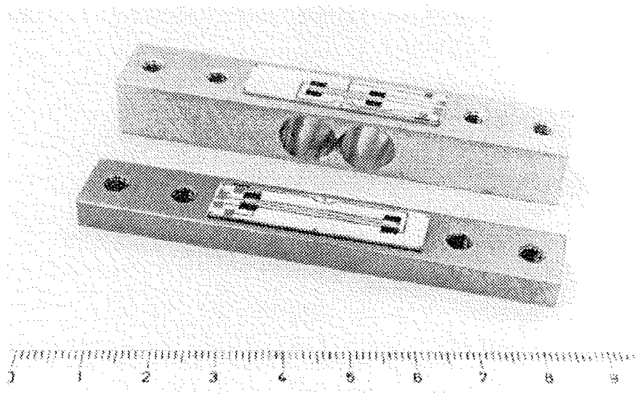


*Fig. 9:* *Low cost force sensors for use in an electronic kitchen scale. The thick film strain gauge is mounted on a double bending spring element (above) or on a simple bending beam (below)*

## 3. SIGNAL PROCESSING

The electronic circuit for signal processing was developed with the objectives of function requirements, battery operation and request for a low cost. The block diagram of the electronic circuit is shown in Figure 10 and consists of voltage regulator, temperature sensor, signal amplifier, microcontroller, EEPROM, LCD display and two keypads.

The electronic circuit is supplied by one 9V battery. A low consumption voltage regulator stabilises the supply voltage at 5V. The circuit was designed for a current consumption of 2mA during weghing and only 10 μA in the power down mode. Measuring units are "g" and "kg" or "oz" and "lb". A tare function can be achieved by pushing the Tare key. The ON/OFF key activates the scale or puts it into the power down mode. By switching the scale ON, automatic tare and autozero are activated. When the scale is not in use for 3 minutes, it goes into auto power down mode. Calibration of the scale is done after assembly and and can be repeated any time. The calibration procedure simply requires loading the scale with two different known loads and conforming them by

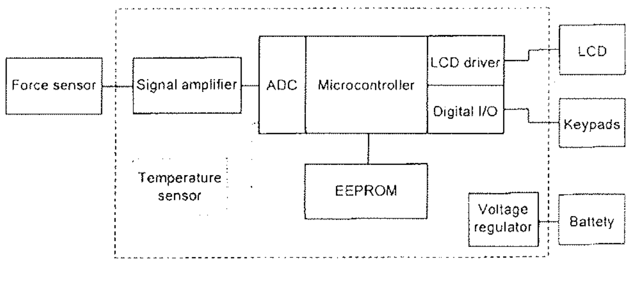



*Fig. 10:* *Block diagram of electronic scale module*

pushing the key. After this procedure the characteristic of the sensor element is saved in EEPROM. The electronic scale module has the possibility of including a temperature sensor for tempereture compensation. The outline and dimensions of the electronic scale module are shown in Figure 11.

Features of the scale:

- Weighting capacity: 10g ÷ 3kg
- Units; g, kg, (optionally oz, lb)
- Resolution:
  - d = 1g (10g ÷ 1000g)
  - d = 1.5g (1000g ÷ 3000g)
- 3½ digit LCD display
- Tare function
- Autozero function
- Calibration function
- Auto power down mode
- Battery operation (1 battery - IEC R6 PF 22 9V)
- Current consumption:
  - 2 mA in use
  - 10 μA in power down mode
- Operating temperature: +5°C ÷ +40°C
- Storage temperature: +0°C ÷ +84°C

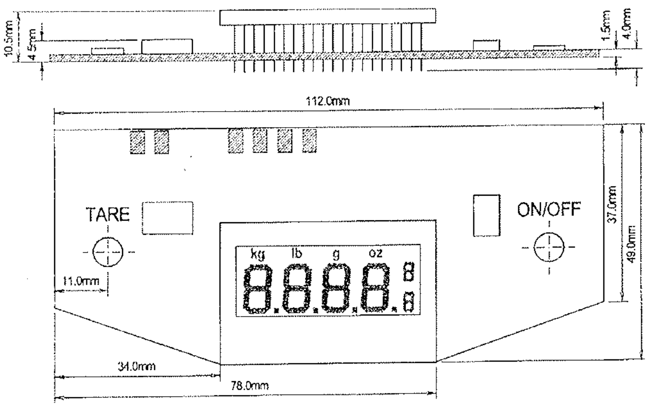



*Fig.11: Electronic scale module*

## 4. CONCLUSIONS

A low cost force sensor was developed by taking advantage of the piezoresistive effect in thick film resistors printed and fired on a ceramic substrate. The substrate was bonded on a metal double bending beam. With the chosen materials and procedures the following results were obtained; a sensitivity of the load cell of 40÷50 μV/V/N, a sensitivity stability of ±0.5%, a temperature coefficient of stability lower than $\pm 100 \times 10^{-6}$/K, a maximum offset of ±4mV, an offset stability of ±0.5mV, and the drift of the output signal due to creep of less than 0.2%. For this force sensor an electronic scale module was developed. An electronic circuit with low current consumption based on a microcontroller ensures that it satisfies all purpose requirements.

## 5. REFERENCES

/1/ M. Prudenziati, B. Morten, "Piezoresistive properties of thick film resistors - an overview", Hybrid Circuits, 10, May 1986, 20-23

/2/ M. Hrovat, D. Belavič, J. Holc, S. Šoba, "An evaluation of some commercial thick film resistors for strain gauges", J. Mater. Sci. Lett., 13, (1994), 992-995

/3/ M. Hrovat, G. Dražič, J. Holc, D. Belavič, "Microstructural investigation of thick film resistors for strain sensor applications by TEM", Proc. 22st Int. Conf. Microelectronics MIEL-94 / 30th Symp. on Devices and Materials SD-94, Terme Zreče-Rogla, 1994, 207-212

/4/ M. Hrovat, J. Holc, D. Belavič, S. Šoba, "A possible way to increase the gauge factors of thick film resistors", J. Mater. Sci. Lett., 14, (8), (1995), 584-586

/5/ M. Hrovat, G. Dražič, J. Holc, D. Belavič, "Correlation between microstructure and gauge factors of thick film resistors", J. Mater. Sci. Lett., 14, (15), (1995), 1048-1051

/6/ D. Belavič, S. Šoba, M. Pavlin, S. Gramc, D. Ročak, "Packaging technologies for thick film sensors", IMAPS/NATO Advanced Research Workshop on Electronic packaging for high reliability, low cost electronics, May 10-13, 1997, Bled

*Darko Belavič, dipl.ing.*
*HIPOT, d.o.o.*
*c/o Jožef Stefan Institute*
*Jamova 39, 1001 Ljubljana, Slovenia*
*Tel.: +386 61 1773 479*
*Fax: +386 61 1263 126*
*E-mail: darko.belavic@ijs.si*

*Stojan Šoba, dipl.ing.*
*Marjan Hodnik, dipl.ing.*
*Marko Pavlin, dipl.ing.*
*Slavko Gramc, dipl.ing.*
*HIPOT, d.o.o.*
*Trubarjeva 7, 8310 Šentjernej, Slovenia*

*dr. Marko Hrovat, dipl.ing.*
*Jožef Stefan Institute*
*Jamova 39, 1001 Ljubljana, Slovenia*

*Prispelo (Arrived): 09.09.1997 Sprejeto (Accepted): 16.09.1997*