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T0002 - MilliNewton

Errors due to orientation and to lateral forces

Influence of force orientation and lateral forces on the output signal of MilliNewton force sensors.

Thomas Maeder, 21.4.2004

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Summary

The MilliNewton force sensor is sensitive to lateral forces, in the direction of the length of the beam. The degree of sensitivity of such sensors depends essentially on the size of the force centring ball and the length of the cantilever beam.
On the other hand, the sensitivity to lateral forces which are perpendicular to the beam is very small.

1. Introduction

Lateral forces on the force centring ball, due to a misorientation of the force or to friction on the ball, introduce parasitic moments on the measurement beam of force or displacement sensors of the MilliNewton type (fig. 1–1).

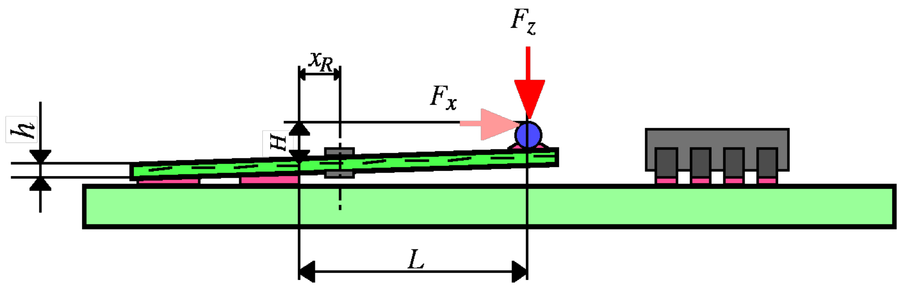

Fig. 1–1. Drawing of a cantilever beam force sensor. A force F_y may also be applied perpendicular to the drawing plane.

The force measurement being made through a bending moment, it is obvious that a lateral force F_x, in the direction of the beam, influences the output signal.
Experimentally, it is easier to modify the inclination angle between force and sensor (fig. 1–2a) than to superpose two forces (fig. 1–2a). These two cases give however slightly different results, due to the shift of the force application point when inclining the force. In this case, one can consider that the force application point remains fixed at the centre of the ball, whereas it remains fixed at its summit in case of superposition of a small lateral force (fig. 1–2b).

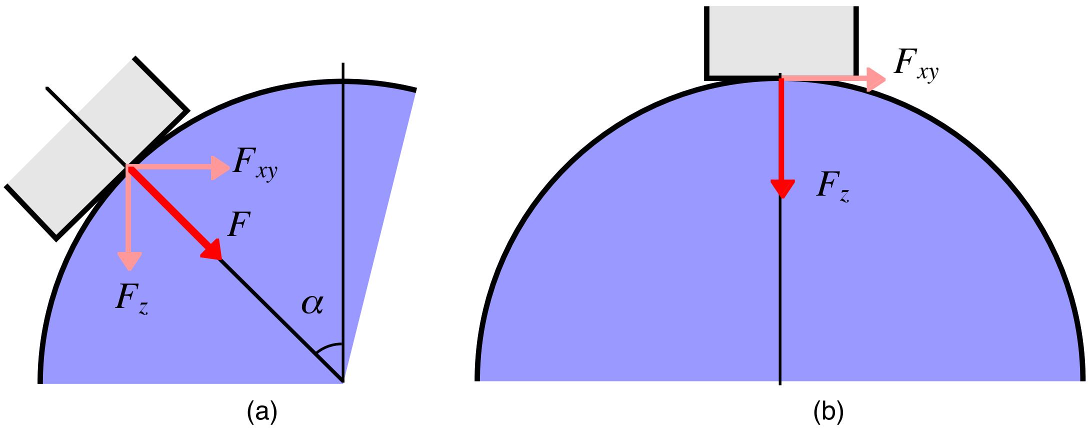

Figure 1–2. Application of a horizontal component F_x ou F_y, by inclination of the applied force (a) or by superposition of a parasitic force, due to friction, for example (b).
In (a), the force application point is shifted, but effectively remains at the centre of the ball.

In what follows, the coordinate axes are defined as follows.

- The x axis is in the plane of the sensor, along the cantilever beam.
- The y axis is in the plane of the sensor, perpendicular to the cantilever beam.
- The z axis is perpendicular to the plane of the sensor, in the nominal direction of force application.

1.1. Inclination between force and sensor

In this case, one has a "virtual" fixed application point which resides at the centre of the ball. If the inclination is in the direction of the beam (angle α, fig. 1–3a), the variation of the sensor output Δs is asymmetrical, due to the bending moment exerted by the horizontal component of the force.

$$\Delta s_\alpha = \Delta s_z \cdot (\cos\alpha + k_\alpha \cdot \sin\alpha)$$

$$k_\alpha \cong \frac{\frac{1}{2}h + h_j + \frac{1}{2}D}{L - x_R}$$

Δs_α	response for an inclination along angle α
Δs_z	response for zero inclination (nominal direction)
α	inclination in the sensor along the beam
k_α	sensitivity factor to inclination along the beam
h	beam thickness
h_j	thickness between beam and ball (conductor & solder)
D	Ball effective diameter
L	Beam effective length
x_R	Measurement resistor position (fig. 1–1)

If the inclination of the force lies in the direction perpendicular to the beam (angle β, fig. 1-3b), the horizontal component only exerts on the cantilever a torsion moment, which ideally does not generate a signal (although a residual effect may subsist in practice due to mismatch between the resistors). Ideally, the response is here only generated by the z component of the force, which is the ideal behaviour for such a force sensor.

$$\Delta s_\beta = \Delta s_z \cdot \cos\beta$$

Δs_β	réponse du capteur pour une inclinaison β
β	inclinaison dans la direction transverse à la poutre

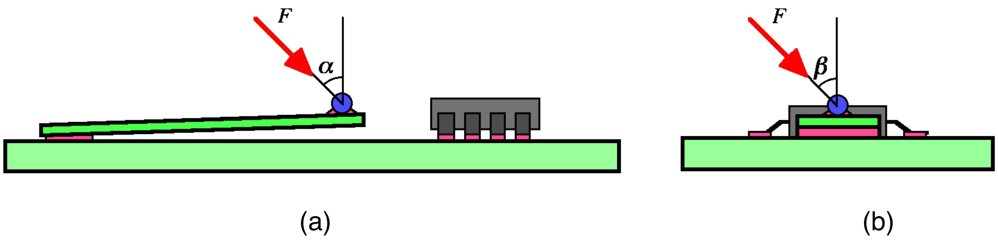

Figure 1–3. Inclination of the force relative to the sensor, along the cantilever beam (a), or perpendicular to it (b).

1.2. Superposition of parasitic horizontal forces

In this case, the force application point normally remains at the summit of the centring ball. This case is often encountered in the application of force sensor, due to friction on the ball. Here, we have, in addition to the applied force F_z, the two parasitic components F_x et F_y. Like in the former case (inclination of the force), only F_x has an important influence on the sensor response.

$$\Delta s_{xy} = \Delta s_z \cdot \left(k_x \cdot \frac{F_x}{F_z} + k_y \cdot \frac{F_y}{F_z} \right)$$

$$k_x \cong \frac{\frac{1}{2}h + h_j + D}{L - x_R} \text{ and } k_y \cong 0$$

Δs_{xy}	response of the sensor to parastic lateral forces
Δs_z	nominal sensor response (to a vertical force)
F_x, F_y	longitudinal and transverse parasitic forces
k_x, k_y	sensitivity factors to parasitic forces
h	thickness of cantilever beam
h_j	joint thickness between ball and beam (solder + conductor)
D	diameter of ball
L	effective length of cantilever
x_R	position of the measurement resistors

The coefficients k_x et k_α differ only by the influence of the ball diameter (*D*/2 ou *D*).

2. Experiments

All verification experiments were of the inclination type, which is much easier to realise than force superposition. Three sensors were studied: a prototype (no 5110) with a 2 mm force centring ball, and two standard sensors (no 6234 and 6237), with a 1 mm ball. Their parameters are given in table 2–I. One expects from no 5110 a much greater sensitivity to parasitic forces, due to the larger ball diameter and to the position of the strain sensing resistors on the beam.

Sensor no		**5110**	**6234** & **6237**
Version		prototype	standard
Cantilever beam thickness	h	0.25 mm	0.25 mm
Estimated thickness between beam and ball	h_j	0.02 mm	0.02 mm
Ball diameter	D	2.00 mm	1.00 mm
Cantilever beam effective length	L	8.0 mm	8.0 mm
Mean position of strain sensing resistors	x_R	3.0 mm	2.0 mm
Sensitivity to parasitic forces (inclination)	k_α	0.23	0.11
Sensitivity to parasitic forces (superposition)	k_x	0.43	0.19

Table 2–I. Parameters of the studied sensors.

The measurements were made by suspending a calibrated 400 mN weight to the sensor arm. The sensor was supplied with 5.0 ± 0.1 V and various inclinations were applied by inserting supports of known thickness under its support.

3. Results

The relative responses (divided by the nominal values without inclination) are given, as a function of the two inclination angles α and β, in figures 3–1 to 3–3, where they are compared to the values calculates from the parameters in table 2–I.

A very good agreement between calculated and measured responses is obtained, which lends support to the model described in the introduction.

These results also clearly demonstrate the need to reduce the height of the force centring element, which correspondingly reduces the lever arm for the parasitic bending moment.

Finally, the results also confirm the hypothesis that the lateral forces perpendicular to the cantilever beam only generate very little response.

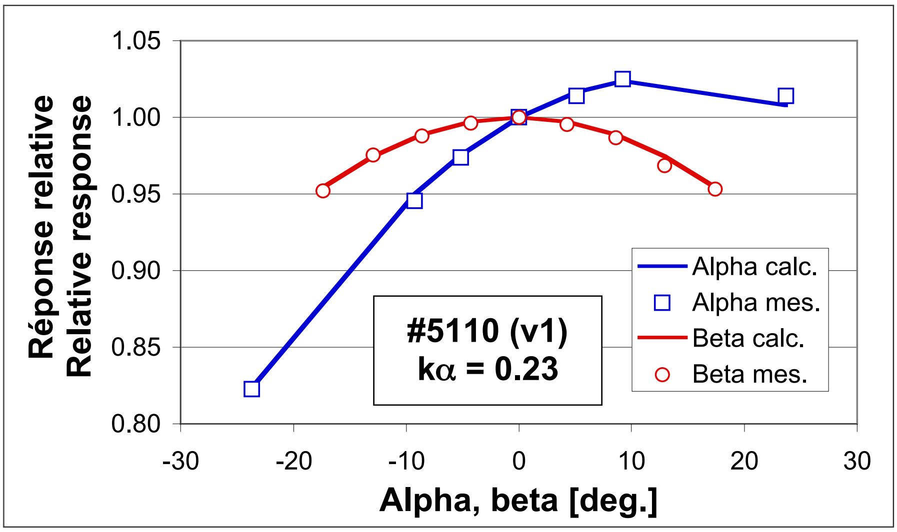

Figure 3–1. Relative response of sensor no 5110 vs. inclination, measured and calculated.

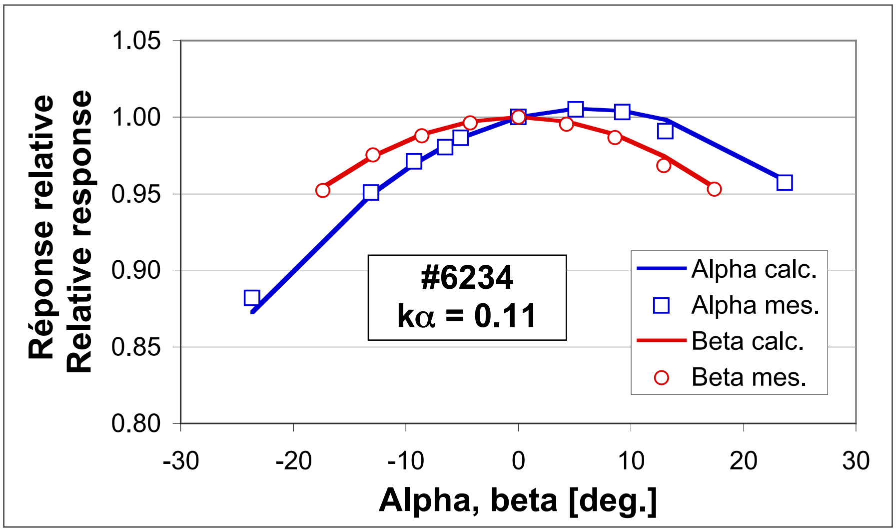

Figure 3–2. Relative response of sensor no 6234 vs. inclination, measured and calculated.

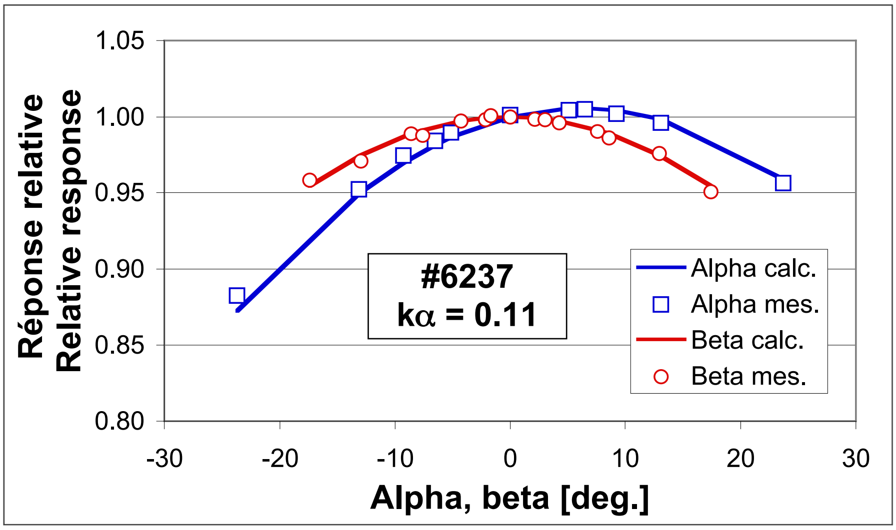

Figure 3–3. Relative response of sensor no 6237 vs. inclination, measured and calculated.

4. Conclusions and suggestions

Simple cantilever beam force sensors are sensitive to lateral forces. However, a good understanding of this sensitivity and adequate design principles allow to minimise the corresponding errors.

4.1. Reducing the lateral forces due to friction

An improvement in precision can be achieved through lowering parasitic lateral forces. Such forces can easily appear by simple friction if measures are not taken. Fig. 4–1 shows such a basic design which can generate high parasitic friction forces.

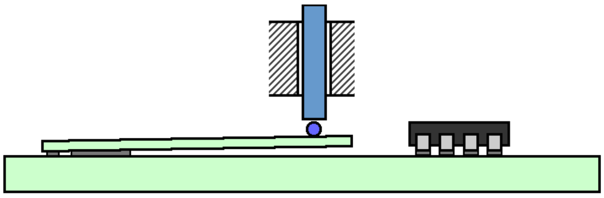

Figure 4–1. Conception entraînant une force de frottement latérale.

The maximum effect due to friction occurs when the friction force lies parallel to the cantilever beam. Its is given by the following expression.

$$\left|\Delta s_f\right| \leq \mu \cdot k_x \cdot \Delta s_z$$

Δs_f	error due to friction
Δs_z	sensor response (without friction)
k_x	sensitivity factor to forces parallel to the beam
μ	friction coefficient

For a reasonable value of the friction coefficient $\mu = 0.2$ and for the sensitivity $k_x = 0.19$ to lateral forces along the beam of MilliNewton A, the maximal induced error ist ca. ±4% of the measured force: reproducibility is strongly affected. One must therefore try to reduce this value, by reducing the friction coefficient and/or the lateral rigidity of the part in contact with the sensor. Fig. 4–2 shows such a design, which markedly improves on the basic version shown in fig. 4–1.

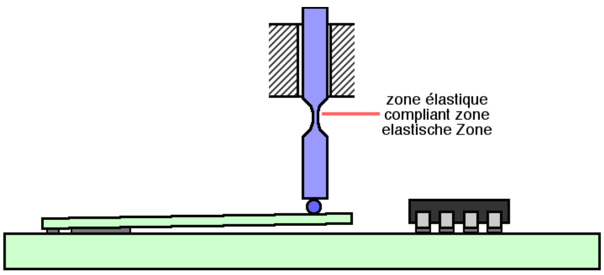

Figure 4–2. An improved concept to lower parasitic forces.

4.2. Reducing the sensitivity to lateral forces

As seen from the results, the sensitivity to lateral forces is very dependent on whether this force is perpendicular (fig. 4–3, left) or parallel (fig. 4–3, right) to the cantilever beam. If the direction of the lateral forces is known, the sensor must be oriented so that these forces and the cantilever beam are perpendicular.

Important note

In all cases, lateral forces should be kept below 0.5 N, in order to avoid shearing off the force centring ball.

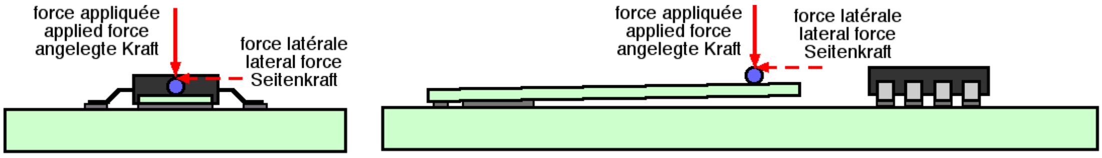

Figure 4–3. Orientation of sensor relative to lateral forces.
Left: advantageous; right: disadvantageous.