

INFN-17-04/LNF
6th March 2017

Feasibility of Stresses Release Monitoring of GEM Foils

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Abstract

A brief note concerning the evaluation of the strains to be measured on a typical GEM foil in order to monitor the possible release of stresses during long time operation in a severe environment.

Publicato da SIDS–Pubblicazioni
Laboratori Nazionali di Frascati

1 Introduction

The monitoring of the release of stresses of the GEM foils during long time operations in a severe environment is a debate question. The fundamental consideration is that the GEM arrays are placed in a vertical position inside the CMS detector and then there is no lateral load q (as the own weight $1.21 \cdot 10^{-6} N/mm^2$) to “perturb” the flatness of the foils (the electrostatic loads, which are of the same order of magnitude of the weight ones, also vanish during continuous working operations because each foil is attracted on both sides by more or less the same electric field, say $5 kV/cm$). The absence of any lateral load cannot produce additional strains superimposed to the original stretching ones and the stresses release cannot be monitored by any strain sensor because it is a “constant strain process” (the counterpart of the creep process, a “constant stress process”).

In other words the stresses can be completely released and the original strains due to the initial stretching remain constant. In these conditions it is really impossible to monitor the release of stresses of the GEM foils.

Then, even if it seems funny, the monitoring of the release of the stresses can be done only if there is a lateral load q that induces additional strains related, in some way, also to the loss of tension, i.e. to the stresses release.

In the GEM foils there are no many choices: for instance that lateral load can be due to the difference of the electrostatic fields between the two sides of the foil; that load is very small if compared to the weight one and it is continuous, an essential feature for any monitoring; no matter it is small: its function is to “perturb” in a stable way the flatness of the foil and induce some additional strains; of course the smaller lateral load q is, the smaller is the additional strain to be monitored; another source of that lateral load could be a small tilt of the chamber respect to the vertical position in order to add some weight component.

The present work shows elementary considerations to evaluate these additional strains (second high order strains) in terms of $\mu\varepsilon$ (microstrain: $1\mu\varepsilon = 10^{-6}\varepsilon$) to be compared to the sensitivity of the FBG sensors.

The small values of the induced additional strains and the eligible location of the sensors (just on the middle of the four sides of the trapezoidal chamber) make that monitoring an extreme difficult task.

2 First and second order strains

A rectangular membrane is taken into consideration because its solution is very well known [1] as the lateral deflection (1) satisfying the differential equation (2) where ε_x^{II} and ε_y^{II} are the second order strains; in Fig. 1 the $2a$ side is the averaging of the trapezoidal ones:

$$z = \frac{16qa^2}{s\pi^3} \sum_{n=1}^{\infty} \frac{(-1)^{n+1}}{(2n-1)^3} \left\{ 1 - \frac{\cosh[(2n-1)\pi y/2a]}{\cosh[(2n-1)\pi b/2a]} \right\} \cos \frac{(2n-1)\pi x}{2a} \quad (1)$$

$$\frac{\partial^2 z}{\partial x^2} + \frac{\partial^2 z}{\partial y^2} = -\frac{q}{s} \quad ; \quad \varepsilon_x^{II} = \frac{1}{2} \left(\frac{\partial z}{\partial x} \right)^2 \quad ; \quad \varepsilon_y^{II} = \frac{1}{2} \left(\frac{\partial z}{\partial y} \right)^2 \quad (2)$$

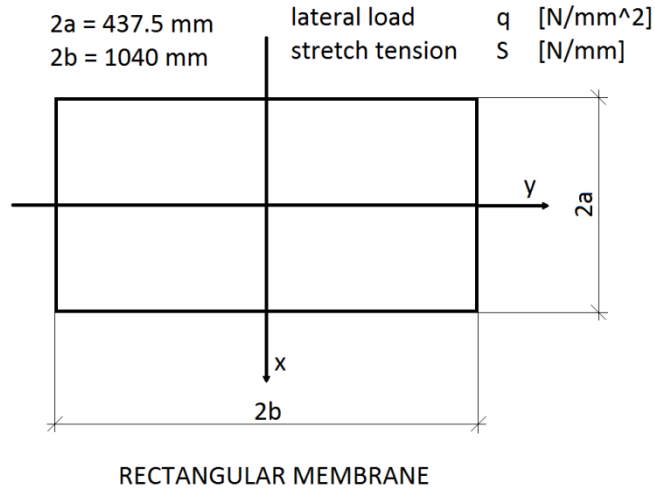


Figure 1

The second order strains ε_x^{II} and ε_y^{II} are usually infinitely smaller than the first order strains ε_x^I and ε_y^I (3) due to the initial biaxial stretching procedure as will be showed later; the mechanical properties are [2]: $E = 11112.4 \text{ MPa}$ and $\nu = 0.34$ (Young modulus and Poisson ratio) of a typical $t = 60 \mu\text{m}$ thickness GEM foil stretched at $S = 1 \text{ N/mm}$:

$$\varepsilon_x^I = \varepsilon_y^I = \frac{S}{tE} (1 - \nu) \quad (3)$$

Note that the first order strains ε_x^I and ε_y^I are constant all over the membrane while the second order strains ε_x^{II} and ε_y^{II} are strongly dependent on x and y .

3 Eligible strain sensor locations

Since the first order strains remain constant during the stresses release process then the strain sensor should measure only the second order strains changes and must be placed where they get the maximum values; from (2) it can be easily demonstrated that the square of the derivative $\partial z/\partial x$ take the maximum at $x = a$; $y = 0$ and $\partial z/\partial y$ take the maximum at $x = 0$; $y = b$, Fig. 2:

$$\begin{cases} \left. \frac{\partial z}{\partial x} \right|_{\substack{x=a \\ y=0}} = -\frac{8qa}{s\pi^2} \sum_{n=1}^{\infty} \frac{1}{(2n-1)^2} \left\{ 1 - \operatorname{sech} \left[\frac{(2n-1)\pi b}{2a} \right] \right\} & (\text{point A}) \\ \left. \frac{\partial z}{\partial x} \right|_{\substack{x=0 \\ y=b}} = -\frac{8qa}{s\pi^2} \sum_{n=1}^{\infty} \frac{(-1)^{n+1}}{(2n-1)^2} \operatorname{tanh} \left[\frac{(2n-1)\pi b}{2a} \right] & (\text{point B}) \end{cases} \quad (4)$$

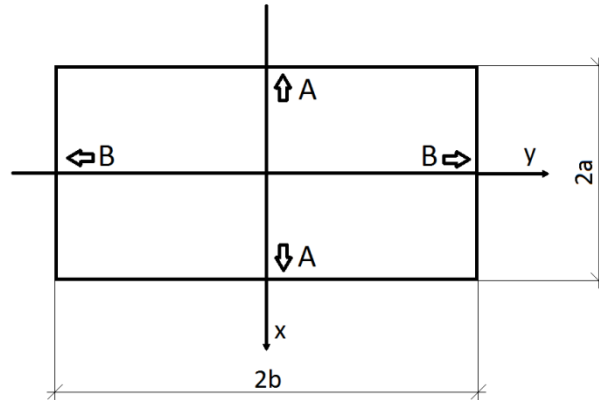
From (4) $\varepsilon_{x,max}^{II} > \varepsilon_{y,max}^{II}$; rearranging to gain more convergence of the series:

$$\left. \frac{\partial z}{\partial x} \right|_{\substack{x=a \\ y=0}} = -\frac{qa}{s} \left\{ 1 - \frac{8}{\pi^2} \sum_{n=1}^{\infty} \frac{1}{(2n-1)^2} \operatorname{sech} \left[\frac{(2n-1)\pi b}{2a} \right] \right\} \quad (5)$$

And finally considering only the first term:

$$\varepsilon_{x,max}^{II} = \frac{1}{2} \left(\frac{qa}{s} \right)^2 \left\{ 1 - \frac{8}{\pi^2} \operatorname{sech} \left(\frac{\pi b}{2a} \right) \right\}^2 \quad (6)$$

For instance $\varepsilon_x^I = \varepsilon_y^I = 1500\mu\epsilon$ while $\varepsilon_x^{II} = 0.032\mu\epsilon$ after the initial stretching in the horizontal position (own weight).



eligible high order strain sensor locations

Figure 2

Note that the strain sensors placed in the middle of the foil ($x = y = 0$) are completely useless since the second order strains ε_x^{II} and ε_y^{II} vanish there.

4 Monitoring sensitivity

Whatever the lateral load $q \neq 0$ the maximum deflection is:

$$f = \frac{q(2a)^2}{8S} \left[1 - \frac{32}{\pi^3} \operatorname{sech} \left(\frac{\pi b}{2a} \right) \right] \quad (7)$$

That expression can be kept valid up to small values of the tension S that decreases during the stresses release (loss of tension); Table 1 show the second high order strains ε_x^{II} considering the monitoring of a horizontal GEM foil subjected to its own weight.

Table 1: Sensitivity for $q = 1.21 \cdot 10^{-6} \text{ N/mm}^2$ (horizontal position)

f [mm]	ε_x^{II} [$\mu\epsilon$]	S [N/mm] and (% loss of tension)
0.028	0.032	1.00 (-00.0%)
0.100	0.427	0.28 (-72.5%)
0.150	0.961	0.18 (-81.7%)
0.300	3.846	0.09 (-90.8%)
0.500	10.683	0.06 (-94.5%)
1.000	42.731	0.03 (-97.2%)

Table 2 show the sensitivity for a lateral load of $q = 0.24 \cdot 10^{-6} \text{ N/mm}^2$ which is about 20% of the previous lateral load (if considering the own weight then that load correspond to a tilt of the chamber of about 12 degrees respect to the vertical).

Table 2: Sensitivity for $q = 0.24 \cdot 10^{-6} \text{ N/mm}^2$ (12° from vertical)

f [mm]	ε_x^{II} [$\mu\epsilon$]	S [N/mm] and (% loss of tension)
0.005	0.001	1.00 (-00.0%)
0.018	0.014	0.30 (-69.7%)
0.027	0.031	0.20 (-79.8%)
0.054	0.125	0.10 (-89.9%)
0.090	0.346	0.06 (-93.9%)
0.180	1.384	0.03 (-97.0%)

5 Conclusions

The previous tables shows that the sensitivity of an FBG sensor (of the order of $1 \mu\epsilon$) is reached only when about the 82% of the initial tensioning is away in an horizontal position; in the “quasi” vertical position that sensitivity is reached only when the 97% of the initial tensioning is lost; probably the real lateral load q is much more smaller than that last one, making the additional strains very far from the FBG sensitivity; before these conditions only dark i.e. the stresses release in these very optimistic loads can be theoretically detected when it is in the extreme final phase only, apart the real capability to get $1 \mu\epsilon$ resolution in an environment where multiple factors play (temperature, pressure, chemical compounds, humidity, frame dilatation).

Secondarily the FBG sensors should be placed closest to the middle of the sides of the chamber (Fig. 2) where there are badly tensioned regions due to the current adopted stretching method with screws; in that regions the strains are high sensitive to the different tightening of the neighboring screws and their non-uniformity make the reading of the so small second high order strains not easy.

Bibliography

- [1] S.P. Timoshenko and J.N. Goodier (1934), Theory of Elasticity, Third Edition, McGraw-Hill International Editions.
- [2] G. Raffone (2010), CMS Trapezoidal GEM Foil Structural Analysis, LNF-10/20(IR) Note, September 20, 2010.