

# USE OF CARBON-FIBRE SENSORS TO DETERMINE THE DEFLECTION OF COMPOSITE-BEAMS

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## 1 Introduction

The Carbon-Fibre Sensor (CFS) consists of a standard carbon fibre roving (Toray T300B 1K) with electrically connected endings which is embedded in a GFRP-patch (Fig. 1.). Based on the piezoresistive effect [1, 2] of carbon fibres, the CFS can be used for strain measurement and microcrack detection [3, 4]. A strain sensitivity of  $k = 1.71$  was determined up to a strain level of  $6000 \mu\text{m}/\text{m}$  for a CFS embedded in a laminate with a Poisson ratio of 0.28.

Concerning this paper a CFS configuration was investigated to determine the deflection of fibre reinforced plastic (FRP) beams. A preliminary study on a glass fibre beam was conducted, where the application was the carbon fibre reinforced plastic (CFRP) table of a computer tomography (CT) scanner. In opposite to metals, CFRP fulfils the X-ray transparency, which is necessary to get the picture quality sufficient for medical diagnosis. Thus, the embedded CFS also is a proper sensor, which can also be used in the case of the CT table. It is required that the metallic wiring isn't part of the scan plane.

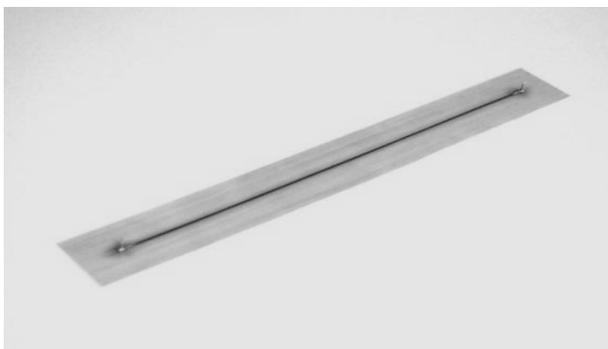


Fig.1. Carbon-Fibre Sensor (CFS)

Due to the deflection of the CT table the images can be readjusted to result in an improved medical attendance.

## 2 Integral strain measurement method

Based on the piezoresistivity the CFS measures the strain along its length. This integral strain measurement method can be defined by:

$$\frac{\Delta R}{R_0} = k \frac{1}{l} \int_0^l \varepsilon(x) dx \quad (1)$$

$k$	strain sensitivity
$l$	length of the sensor fibre
$R_0$	initial electrical resistance
$\Delta R$	change of the electrical resistance
$\varepsilon$	strain level

Concerning beam theory the following relations are given for small beam deflection:

$$\varepsilon^*(x) = e \cdot y'' \quad (2)$$

$$y = \iint \frac{\varepsilon^*(x)}{e} dx dx \quad (3)$$

$y''$	beam curvature
$y$	beam deflection
$\varepsilon^*$	strain of the outer fibre
$e$	distance from the neutral axis

For a beam with constant bending stiffness and one-dimensional curvature the slope of the beam can be measured by means of CFS. Assuming that the CFS starts at the clamping support ( $x = 0$ ), the slope  $y'$  at  $x = l$  becomes:

$$y'(x=l) = \frac{l}{ke R_0} \Delta R \quad (4)$$

This shows that the slope  $y'$  of the beam can be determined directly by the integral strain measurement method. The deflection  $y$  of the beam can be performed by numerical integration. And the quality of the results depends on the number of CFS used, the sensor configuration applied and the complexity of the loading. For the problem considered in this paper the following calculation was applied:

(5)

$$y(x=l) = \sum_{j=1}^m \left( y'(x_j) - \frac{y'(x_j) - y'(x_{j-1})}{2} \right) \cdot (l_j - l_{j-1})$$

$m$  number of CFS

### 3 Sensor configuration

To avoid any influence of the metallic wiring, u-shaped CFS were used to ensure that no metal elements were part of the scan plane for all operation positions. Fig. 2. shows the bending of a cantilever beam caused by the loading  $F$ . Five CFS are positioned at the top of the cantilever beam. The wiring is located at the clamping support.

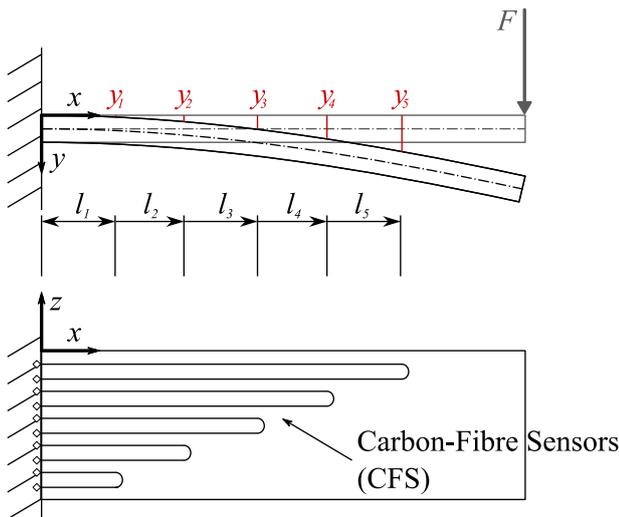


Fig.2. Side and top view of a cantilever beam with five u-shaped CFS.

In a preliminary study the theoretical approach was verified by means of a GFRP cantilever beam. The beam had a length of 600 mm and five, u-shaped CFS were used (100, 200, 300, 400, 500 mm). A similar configuration was used to determine the deflection of the CT table. Ten u-shaped CFS with different lengths (250, 500, 750, 1000, 1250 mm) were placed in the longitudinal direction of the table. Following equation (5) the deflection could be approximated by numerical integration of the different CFS signals. Electrical half bridges were used for temperature compensation.



Fig.3. Small GFRP cantilever beam to verify the theoretical approach.

### 4 Manufacturing

The CFS consists of an ex-PAN fibre (Toray T300B) with 1000 filaments. For fibre preparation, a galvanic process was applied based on a nickel electrolyte. A current of 40 mA was applied for 30seconds in order to intercept a coating at the end of the fibre only. The electrical connection was finalized by soldering pins. A tool was used to stabilize the u-shape of the CFS by means of manual resin impregnation (Fig.4). Springs at the clamping tool provided a constant tension force along the roving. For stabilization a hot curing and two-component epoxy resin adhesive with low viscosity was used (EP310 S). The impregnated fibre roving was cured in an oven at 180 °C for 1.5hours.

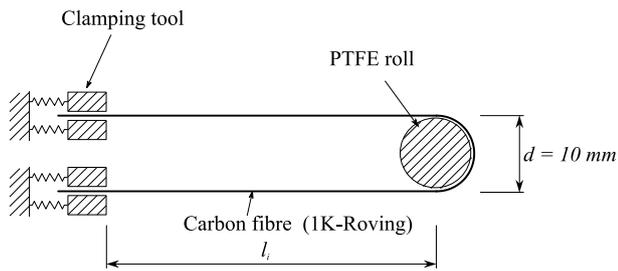


Fig.4. Manufacturing tool for u-shaped CFS.

In a second step the stabilized CFS were bonded to the beams. For the CT table a glass layer was used for electrical insulation (Fig.5). An epoxy resin (Bakelite L20 with hardener EPH 573) and vacuum curing (12hours at RT) was applied. The same procedure was used for the CT table and the small cantilever beam for the preliminary study.



Fig.5. Underside of the CT table applied with ten, u-shaped CFS. Wiring attached to the support. CFS- Length varied from 250 - 1250 mm.

## 5 Experimental

Half-bridges were used by means of additional, unstressed plates with CFS to compensate for temperature. In case of the GFRP beam the feeding voltage of the amplifier (HBM Spider 8) was 2.5 V. And in case of the CFRP table the feeding voltage of the amplifier (HBM MGCplus) was 1.0 V.

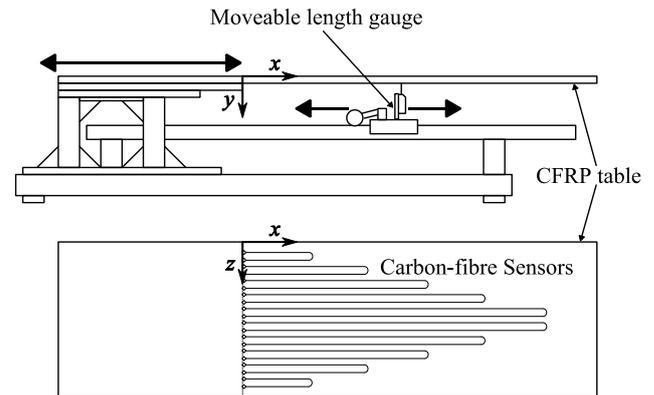


Fig.6. Side and bottom view of the experimental setting of the CT table.

The measured deflection was controlled by means of a length gauge (Heidenhain-MT60), which was installed beneath the table (Fig. 6.).

The table of the CT scanner was loaded, using different dummies (83 - 200 kg). It has to be considered that the table can be moved in the longitudinal direction. Therefore the bending length varied from 0 to 2000 mm. The quality of the CFS measuring system was determined for different operation positions. The bending length was increased stepwise from 200 to 2000 mm.

Since the CT table was curved in the transverse direction, the position of the neutral axis was determined. The distance of each CFS from the neutral axis  $e$  was used to transfer the strain signals to the reference plane.

Additional strain gauges were positioned next to the CFS to determine the neutral axis. Figure 7 shows the results of the method. Different loadings (1-9) were applied and the measured values of two strain gauges with different distances to the  $x$ - $z$ -plane added up to straight lines. The extended lines intersected in one point. This intersection point provided the distance of the neutral axis to the  $x$ - $z$ -plane.

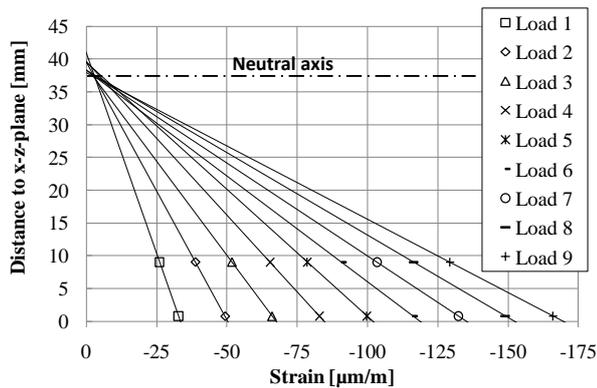


Fig.7. Diagram to determine the neutral axis of the CT-table.

## 6 Results

Figure 8 shows the results of the small cantilever beam. The difference between the deflections measured for  $y = 20$  mm by means of the CFS and the length gauge is less than  $\pm 0.2$  mm, demonstrating the applicability of the integral strain measurement method. Due to non linear effect the difference at higher deflection is greater ( $\pm 0.8$  mm).

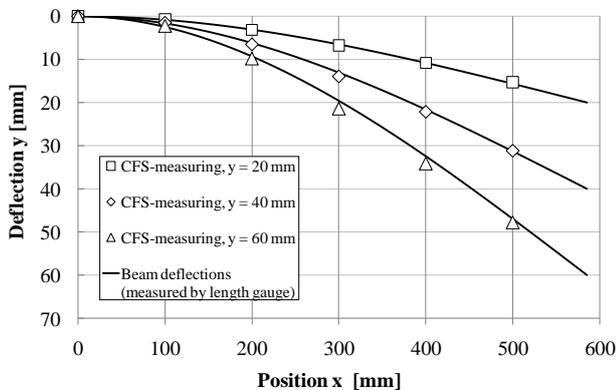


Fig.8. Deflection of the small cantilever beam measured by the CFS and the length gauge.

Figure 9 shows typical signals of the CFS for the CT table. The weight applied was 100 kg and the operation position varied stepwise from 0 to 2000 mm and back to 0 mm. At each stop the deflection of the table was controlled, using the length gauge. Also in the case of the CT table the deflection of the table could be determined with an accuracy of  $\pm 0.3$  mm for different operation positions.

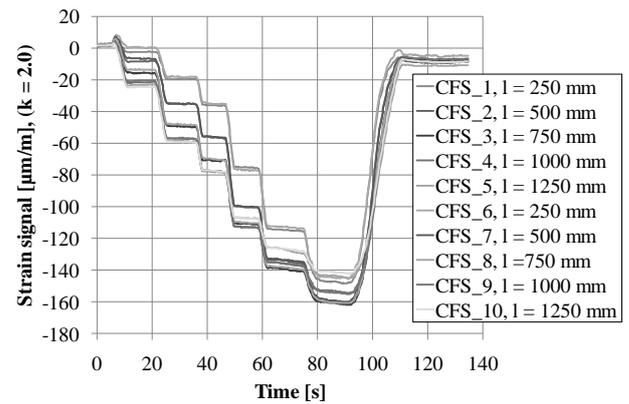


Fig.9. CFS signal of the CT table for a weight of 100 kg and different operation positions, ranging from 0 to 2000 mm.

## 7 Conclusion

The integral strain measurement method of carbon-fibre sensors (CFS) can be used to determine the slope of a beam in bending directly. Metallic wiring within the beam can be avoided if u-shaped CFS are applied. This sensor configuration was verified to determine the deflection of the CFRP table of a CT scanner.

## References

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