Numerical modeling of fiber specklegram sensors by using finite element method (FEM)

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Abstract: Although experimental advances in the implementation and characterization of fiber speckle sensor have been reported, a suitable model to interpret the speckle-pattern variation under perturbation is desirable but very challenging to be developed due to the various factors influencing the speckle pattern. In this work, a new methodology based on the Finite Element Method (FEM) for modeling and optimizing Fiber Specklegram Sensors (FSSs) is proposed. The numerical method allows computational visualization and quantification, in near field, of changes of a Step Multi-Mode Fiber (SMMF) specklegram, due to the application of a Uniformly Distributed Force Line (UDFL). In turn, the local modifications of the fiber speckle produce changes in the optical power captured by a Step Single-Mode Fiber (SSMF) located just at the output end of the SMMF, causing a filtering effect that explains the operation of the FSSs. For each external force, the stress distribution and the propagations modes supported by the SMMF are calculated numerically by means of FEM. Then, those modes are vectorially superposed to reconstruct each perturbed fiber specklegram. Finally, the performance of the sensing mechanism is evaluated for different radius of the filtering SSMF and force-gauges, what evidences design criteria for these kinds of measuring systems. Results are in agreement with those theoretical and experimental ones previously reported.

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References and links

1. Introduction
Speckle phenomenon is associated to the interference of several laser waves with random phase distribution, that generates an optical distribution that can be described statistically. Although in the early years of the laser, this effect was considered as optical noise, nowadays, its optical and mathematical features are used in a great variety of engineering applications [1-5]. Likewise, when coherent light is launched in a multimode fiber, the propagation modes interfere at the output end of the fiber generating a speckle pattern which is known as intermodal noise in data transmission systems [6].
Sensing systems based on fiber speckle are known as Fiber Specklegram Sensors (FSS) and are supported on the possibility to measure external perturbations applied to multi-mode fibers by monitoring the optical changes on their associated fiber speckle patterns [7]. FSSs have been study in holographic, digital image processing, and power variation setups. Holographic FSSs have been studied, fundamentally, by using photorefractive crystals as registering media of a perturbed fiber speckle, making easier the implementation of dynamic optical correlation techniques [8-13]. In schemes based on digital image processing, the calculus of the normalized inner product of the modified specklegram, the analysis of the behavior of particular modes and the identification of the more representative speckle grains, have been used for constructing indicators to interrogate FSSs.[14-18]. Among the most interesting FSSs are those based on fiber structures (single-multi-single mode fibers), because they allow an interrogation by optical power variation. These systems are known as Power Fiber Specklegram Sensor (PFSS) [19-26]. As in any arrangement of FSS, in the case of PFSS the speckle pattern generated at the end of the SMMF is modified when an external perturbation is applied to the multi-mode fiber, therefore, when a SSMF is spliced to the multimode one, a filtering effect that translates the changes of the speckle pattern into optical power changes is reached. This element facilitates the interrogation of PFSSs and, therefore, offers many advantages over holographic and non-holographic image-based processing FSSs [24]. The main advantages are: very low response time, high stability, low cost, and easy implementation [25]. Likewise, PFSSs have been demonstrated in the measuring of either static or high frequency mechanical perturbations [23,24], in the determination of physical liquid properties [21], and, most recently, in configurations of fiber tapers for the determination of chemical characteristics of materials [26].

Regarding the performance of the PFSSs, there are reports about the influence of the characteristics of the setup (lasers characteristics, type of fibers, etc.) on the metrological performance of the sensors [19, 20]. In this sense, we experimentally demonstrated that a very important parameter in the performance of FSS is the fiber speckle grain size [24, 25]. However, although experimental advances in the implementation and characterization of FSS have been reported, a suitable model to interpret the speckle-pattern variation under perturbation is desirable but very challenging to be developed due to the various factors influencing the speckle pattern [27]. This fact, has limited the possibility of defining PFSS accuracy design strategies.

Unlike previous reports about dynamical behavior of FSS, in this work we reconstruct the intensity profile of a SMMF specklegram under several conditions of stress. In particular, we present an analysis that allows numerical visualization and quantification, in near field, of the changes of the intensity distribution of the SMMF specklegram due to the changes of the stress distribution in the fiber, which are induced simulating a UDFL. In turn, this produces changes in the optical power captured by a SSMF located at the end of the SMMF, causing a filtering effect. The stress profile of a SMMF (62.5/125 NA=0.12) subjected to a UDFL, is calculated numerically by FEM taking into account a plane-strain model. The birefringence maps are recovered by means of the elasto-optical theory [28-32]. Using these results, for each value of the external force, in the solution by FEM of the wave equation [33-35], the electric field distribution is obtained. All the allowed propagation modes in the SMMF are calculated and vectorially superposed in order to reconstruct the fiber speckle pattern for each stress condition. Finally, the performance of the sensing mechanism is evaluated for SSMF of different radius, through the integration of the power on circles of different diameters, indicating the area of the filtering fibers at the output end of the SMMF. This procedure evidences clear design criteria for these kinds of measuring systems and, the effects of the force-gauges in their performance. Additionally, results are in agreement with those recently published showing that the sensitivity of the FSS depends on spatial speckle filtering window [36].
2. Description of the model for simulation

In this section, the methodology to calculate speckle patterns generated by SMMFs submitted to external forces, is presented. Subsection 2.1, addresses the photo-elasticity theory in order to calculate changes of the refractive index in terms of strain and stress. Subsection 2.2, presents the stress and strain states due to specific external forces. Subsection 2.3, shows the electromagnetic model for the calculation of the perturbed speckle patterns.

2.1 Photo-elasticity analysis

In agreement with the photo-elasticity theory, the variations in the refractive index of a medium submitted to mechanical strain, using tensor notation, are given by [28]

\[
\Delta n_{ij} = \Delta \left( \sqrt[n]{n_i^j} \right) = P_{ijkl} S_{kl}.
\]

(1)

Where \( i, j, k, l = 1, 2, 3 \) \((1 = x, 2 = y, 3 = z)\), \( B_{ij} \) is the impermeability tensor, \( n_{ij} \) is the refractive index tensor, \( P_{ijkl} \) is the strain-optical tensor (or strain-optical coefficients) and \( S_{kl} \) is the strain tensor.

If the changes of the refractive index are small, from Eq. (1) is obtained that

\[
\Delta n_{ij} = n_{ij} - n_0 I_{ij} \approx -\frac{n_0^3}{2} P_{ijkl} S_{kl},
\]

(2)

where \( n_0 \) is the refractive index for mechanical perturbation-free material, \( I_{ij} \) is the identity tensor. Now, by means of the Hooke law [37], the mechanical strain \( S_{kl} \) and the mechanical stress \( \sigma_{kl} \) are related by the equation:

\[
S_{kl} = \frac{1}{Y} \left[ (1 + \nu) \sigma_{kl} - \nu \delta_{kl} \sigma_{mm} \right],
\]

(3)

where \( Y \) is the Young modulus, \( \nu \) is the Poisson ratio, \( \delta_{kl} \) is the Kronecker delta and \( \sigma_{mm} = \sigma_{11} + \sigma_{22} + \sigma_{33} \) is the trace of the stress tensor, being \( m = 1, 2, 3 \). For fused silica (isotropic material), Eqs. (2) and (3) are simplified to

\[
\Delta n_i = n_i - n_0 \approx -\frac{n_0^3}{2} P_{ikl} S_{kl},
\]

(4)

\[
S_k = \frac{1}{Y} \left[ (1 + \nu) \sigma_k - \nu \sigma_{mm} \right],
\]

(5)

where \( n_0 \equiv n_i, S_{kk} = S_k \) and \( \sigma_{kk} = \sigma_k \) (Here, the Einstein summation convention is not applied, therefore \( \sigma_{mm} \) can be redefined as \( \sigma_{mm} = \sigma_{11} + \sigma_{22} + \sigma_{33} \)). \( P_{ikl} \) is the reduced strain-optical tensor, \( n_i \) is the index vector, \( S_k \) is the strain vector (or vector of unit deformations) and \( \sigma_k \) is the stress vector along principal directions.

If we replace Eq. (5) in Eq. (4), \( \Delta n_i \) in terms of the stress vector is obtained

\[
\Delta n_i \approx -C_{ik} \sigma_k,
\]

(6)
where $C_{ik}$ is the stress-optical tensor. Eqs. (4)-(6) in matrix notation:

$$
\begin{bmatrix}
\Delta n_1 \\
\Delta n_2 \\
\Delta n_3
\end{bmatrix} 
\approx \frac{n_0^3}{2} \begin{bmatrix}
P_{11} & P_{12} & P_{12} \\
P_{12} & P_{11} & P_{12} \\
P_{12} & P_{12} & P_{11}
\end{bmatrix} \begin{bmatrix}
S_1 \\
S_2 \\
S_3
\end{bmatrix}
= - \begin{bmatrix}
C_1 & C_2 & C_2 \\
C_2 & C_1 & C_2 \\
C_2 & C_2 & C_1
\end{bmatrix} \begin{bmatrix}
\sigma_1 \\
\sigma_2 \\
\sigma_3
\end{bmatrix},
$$

(7)

where $P_{11}$ and $P_{12}$ are called strain-optical coefficients. Likewise, $C_1$ and $C_2$ are the stress-optical coefficients, which can be written as [28]

$$
C_1 = \frac{n_0^3}{2Y} \left( P_{11} - 2\nu P_{12} \right),
$$

$$
C_2 = \frac{n_0^3}{2Y} \left( -\nu P_{11} + (1-\nu) P_{12} \right).
$$

(9)

The case of an optical fiber submitted to a UDFL is shown in Fig. 1(a). In this condition, it is plausible to assume refractive index invariability along the propagation direction of light in SMMF. This condition is called “the plane strain approximation” and can be well described if $S_3 = 0$. In this way, using Eq. (8) it is obtained that $\sigma_i = \nu \left( \sigma_1 + \sigma_2 \right)$. Finally, the refractive index along the main birefringence axes can be expressed in terms of the transversal position by using the strain-optic coefficients as

$$
n_1 \approx n_0 - \frac{n_0^3}{2} \left( P_{11} S_1 + P_{12} S_2 \right),
$$

$$
n_2 \approx n_0 - \frac{n_0^3}{2} \left( P_{12} S_1 + P_{11} S_2 \right),
$$

$$
n_3 \approx n_0 - \frac{n_0^3}{2} \left( P_{12} S_1 + P_{11} S_2 \right).
$$

(10)

or in terms of stress-optic coefficients as [29]

$$
n_1 = n_0 - C_1 \sigma_1 - C_2 \left( \sigma_2 + \sigma_3 \right) \approx n_0 - \left( C_1 + \nu C_2 \right) \sigma_1 - C_2 \left( 1 + \nu \right) \sigma_2,
$$

$$
n_2 = n_0 - C_1 \sigma_2 - C_2 \left( \sigma_3 + \sigma_1 \right) \approx n_0 - C_2 \left( 1 + \nu \right) \sigma_1 - \left( C_1 + \nu C_2 \right) \sigma_2,
$$

$$
n_3 = n_0 - C_1 \sigma_3 - C_2 \left( \sigma_1 + \sigma_2 \right) \approx n_0 - \left( C_1 \nu + C_2 \right) \sigma_1 - \left( C_1 \nu + C_2 \right) \sigma_2.
$$

(11)

2.2 Elastostatics theory

In elastostatics, the inertia forces may be neglected [37]. Here, the stress field $\sigma_{ij}$ must satisfy the equilibrium equation without body forces Eq. (12), the compatibility equation Eq. (13) and the boundary conditions Eq. (14) (See Fig. 1(b))

$$
\sigma_{ij, i} = 0,
$$

(12)
\[
S_{ij,km} + S_{km,ij} - S_{ak,im} - S_{jm,ik} = 0, 
\]
(13)

\[
T^{(a)}_i = T^{(a)}_j, \text{ or } u_i = u_j^0 \text{ on } \Gamma, 
\]
(14)

where \( S \) is given by Eq. (3), \( T^{(a)}_i = \sigma_j \hat{n}_j \) is the tractions vector being \( \hat{n}_j \) the normal unit vector on the boundary \( \Gamma \); \( u_i \) is the displacement vector, related to the strain field by \( 2S_{ij} = u_{ij} + u_{ji} \). Here, \( \sigma_{ij}, S_{ij,km}, u_{ij} \) represent \( \partial \sigma_{ij}/\partial x_j \), \( \partial^2 S_{ij}/\partial x_i \partial x_m \partial u_j/\partial x_j \), respectively.

Fig. 1. (a) SMMF under a UDFL, (b) FEM element grid and (c) description of an element and its nodes.

In this work, Eq. (11) is used for calculating the induced birefringence in the whole section of the sensing fiber (core and cladding of the SMMF), due to a vertical UDFL.

The refractive index for stress-free core, \( n_{0co} \), is calculated by using Sellmeier equation Eq. (15) for fused silica [27].

\[
n_{0co}^2 (\lambda [\mu m]) = 1 + \frac{0.6961663\lambda^2}{\lambda^2 - (0.0684043)^2} + \frac{0.4079426\lambda^2}{\lambda^2 - (0.1162414)^2} + \frac{0.8974794\lambda^2}{\lambda^2 - (9.896161)^2}, 
\]
(15)

where \( \lambda \) is the wavelength in the vacuum.

Refractive index of the cladding was computed from the \( n_{0co} \) and numerical aperture \(( NA = \sqrt{n_{0co}^2 - n_{cl}^2} ) \). The main birefringence maps, \( \Delta n_1 \) and \( \Delta n_2 \), are shown in Fig. 2(a) and (b), respectively. There, it is possible to observe the birefringence effect due to the application of the force, in accordance with [31].

The stress vector is calculated by solving the Eqs. (12)-(14) with FEM in the software Comsol Multiphysics 4.2. Properties of the simulated fiber are shown in Table 1 [27, 30]. Von Mises-principal stresses calculated with Eq. (16) for \( F = -1.0 \text{N/mm} \hat{y} \) are shown in Fig. 2(c)

\[
\sigma_{VM} = \sqrt{\frac{1}{2} \left[ (\sigma_1 - \sigma_2)^2 + (\sigma_1 - \sigma_3)^2 + (\sigma_2 - \sigma_3)^2 \right]}. 
\]
(16)
Fig. 2. SMMF under an UDFL. (a) change in $X$ and (b) $Y$ of the refractive index, and (c) Von Mises-
principal stresses distribution in cross section for $\vec{F} = -1.0\, N/mm$.

| Table 1. Properties of the SMMF Used in the Simulation with NA=0.12 |
|---------------------------------|-----------------|-----------------|
| Parameter                      | Core            | Cladding        |
| Diameter [μm]                  | 62.5            | 125             |
| Density [kg/m$^3$]             | 2201            | 2201            |
| Young modulus: $Y$ [GPa]       | 72.6            | 72.6            |
| Poisson ratio: $\nu$           | 0.164           | 0.164           |
| First strain-optical coefficient: $P_{11}$ | 0.121          | 0.121           |
| Second strain-optical coefficient: $P_{12}$ | 0.270          | 0.270           |
| First stress-optical coefficient: $C_{1}$ [GPa$^{-1}$] | 0.000691        | 0.000691        |
| First stress-optical coefficient: $C_{2}$ [GPa$^{-1}$] | 0.004386        | 0.004386        |
| Refractive index stress-free: $n_0$ at 632.8 nm | 1.4570          | 1.4521          |
| Refractive index stress-free: $n_0$ at 1064 nm | 1.4496          | 1.4447          |
| Refractive index stress-free: $n_0$ at 1630 nm | 1.4431          | 1.4381          |
| Refractive index stress-free: $n_0$ at 2940 nm | 1.4206          | 1.4156          |

2.3 Electromagnetic modeling

Once the birefringence maps are obtained it is possible to simulate the fiber speckle patterns
for each stress condition on SMMF. The allowed propagation modes in the SMMF are
calculated using the vector wave equation for a monochromatic wave:

$$\nabla \times \nabla \times \vec{E} - k_0^2 n^2 \vec{E} = 0,$$

where $\omega^2 \mu \varepsilon = k_0^2 n^2$, $\omega$ is the angular frequency, $\varepsilon$ is the electric permittivity of the material, $\mu_0$ is the magnetic permeability of the vacuum, $\vec{E}$ is the electric field and $n$ is the refractive index distribution of the fiber cross-section, that can be expressed as
\[
\mathbf{n} = \begin{bmatrix}
n_1 & 0 & 0 \\
0 & n_2 & 0 \\
0 & 0 & n_3 \\
\end{bmatrix}.
\]

As a first approximation for 2D case, Eq. (17) can be solved as an infinite waveguide where the refraction index is supposed constant along the propagation axis (Z-direction). Here, the electric field can be computed by FEM (See more details in [32-34]). To calculate the field by FEM, the fiber cross-section is discretized into small elements and Eq. (17) is computed for each element (See Fig. 1(b) and (c)). After calculating the electric field \( \mathbf{E} \) for each node, and for the \( M \)-modes supported by a SMMF, \( M \approx 2\left(\frac{a\pi NA}{\lambda}\right)^2 \) with \( a \) being the core radius, they are vectorially added in order to recover the speckle field. Total power on an area \( A \), can be written as [6]

\[
P = \int_{A} I dA,
\]

being \( I = \frac{1}{2} c \varepsilon_0 n_0 |\mathbf{E}|^2 \) the intensity of the electromagnetic wave. Thus, applying Eq. (19) to each element of the discretization and adding, gives the total power on \( A \):

\[
P \approx \sum_{e} P_e = \frac{1}{2} c \varepsilon_0 n_{0,\text{core}} \sum_{e} |\mathbf{E}_e|^2 A_e,
\]

where \( e \) denotes that the sum is over all elements. \( P \) in Eq. (20) simulates the power captured by the filtering fiber of core diameter \( d \) at the output end of the SMMF, carried towards the photodetector in an experimental setup. The approximation of Eq. (20) is valid when the cladding radiation modes are negligible, i.e., for short filtering fiber lengths.

3. Fiber specklegram analysis
Following the procedure described in the previous sections, fiber speckle patterns generated by the propagation of light in the SMMF, detailed in Table 1, were calculated for several wavelengths. The calculation was based on FEM and implemented by using Comsol Multiphysics 4.2. In Fig. 3, the first twenty modes calculated at 1630nm are presented. In Fig. 4, the formation process of the fiber speckle as the propagations modes are included in the sum, is illustrated for the same wavelength.
Fig. 3. Electric field distribution for the first 20 modes of propagation calculated by FEM for $F = 1N$ in the SMMF at 1630 nm.
In Fig. 5, the fiber speckle patterns calculated at 632.8 nm, 1064 nm, 1630 nm and 2940 nm are presented. Average diameter of the speckle grains can be statistically estimated in terms of the NA as: $D \approx \lambda / NA$ [24]. According to the last expression, the average diameter of the speckle grains should be 5.27μm, 8.86μm, 13.58μm, and 20.75μm, respectively, in total agreement with the intensity distributions of Fig. 5.

For the analysis, the black circles in Figs. 5 and 6 represent the area subscribed by the filtering fiber, located at the end of the sensing multimode fiber, in a typical arrangement of PFSS. A strong influence between the core diameter of the filtering optical fiber $d$, the grain speckle size $D$ and the performance of the sensor has been experimentally observed and reported in [24, 25]. In turn, controlling the laser wavelength and the numerical aperture of the multimode fiber can modify the fiber speckle size.

In our proposal, the performance of a PFSS for different filtering fiber diameters, is analyzed. The calculation was developed at 1630 nm and using the SMMF described in Table 1. In these conditions the average speckle diameter is $D \approx 13.58 \mu m$. In Table 2 the ratio between $D$ and the core diameter $d$ for several filtering fibers are presented. This ratio can offer information about the quantity of light that could arrives to the detector and, i.e., the percentage of the filtered power (See Table 2, Figs. 7 and 8), becoming a key parameter for the specklegram sensors design.
Fig. 5. Simulated speckle patterns for $F = 1N$ in the SMMF at (a) 632.8nm, (b) 1064nm, (c) 1630nm and (d) 2940nm. The circles indicate the detection windows (filtering fiber) of diameter: 2, 4, 8, 16, 32 and 62.5 μm, thus illustrating the captured power of each window.

In Figs. 6-8, the fiber speckle patterns calculated for different conditions of stress, the response of the sensing structure for different probe tips (filtering SSMF) and, the effects of the calibration gauges, are presented respectively. This methodology allows visualization of the fundamental operating mechanism of PFSS and, therefore, the understanding of the high sensibility of these systems. That is, small mechanical perturbations can affect several propagation modes, which in turn causes appreciable effects on the local distribution of the fiber speckle pattern (see Fig. 6). Thus, it is possible to observe that a mechanical perturbation on a SMMF generates a little deformation of the fiber speckle, that can be translated into optical power changes by using an adequate probe tip (SSMF), which must be located at the output end of the multimode sensing fiber. Moreover, the optimization of the dimensions of the filtering fiber can improve considerably the performance of the sensor.
Fig. 6. Snapshots of the simulated speckle patterns in the SMMF at 1630 nm for various values of $F_{\text{gauge}}$.

Table 2. Ratio Between $D \approx 13.58\mu m$ at 1630\mu m and the Core Diameter of the Filtering Fibers $d$.

<table>
<thead>
<tr>
<th>$d$ (\mu m)</th>
<th>$D/d$</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>6.79</td>
</tr>
<tr>
<td>4</td>
<td>3.40</td>
</tr>
<tr>
<td>8</td>
<td>1.70</td>
</tr>
<tr>
<td>14</td>
<td>0.97</td>
</tr>
<tr>
<td>16</td>
<td>0.85</td>
</tr>
<tr>
<td>22</td>
<td>0.62</td>
</tr>
<tr>
<td>42</td>
<td>0.32</td>
</tr>
<tr>
<td>62.5</td>
<td>0.22</td>
</tr>
</tbody>
</table>

As can be visualized in Fig. 7, if the size of the probe tip (Filtering fiber) is very small in comparison with the speckle size, changes in the structure of the fiber speckle pattern cannot be detected. Likewise, if the size of the probe tip is comparable with the dimensions of the SMMF, the changes of the energy captured by the detector are negligible. However, it is possible to appreciate that for specific diameters of the filtering fiber, the energy changes due to the same mechanical perturbation are higher, which evidences the existence of an optimization condition for the choosing of this parameter.

To evaluate quantitatively the performance of the PFSS for different filtering fiber diameters and variable stress conditions, the intensity of the pattern was evaluated by means of Eq. (20). To modify conveniently the performance of the sensor, it is possible to apply a gauge-force which will define a calibration condition that determinates parameters such as linearity and sensibility of the system. For the calculation, this force will determine a baseline...
for the measurements of the force ($F - F_{\text{gauge}}$). Likewise, the power captured by the probe tip associated to the gauge-force is used as a reference power ($P/P_{\text{gauge}}$). Likewise, the power captured by the probe tip associated to the gauge-force is used as a reference power ($P/P_{\text{gauge}}$). Figs. 7 and 8, show the dependence of the sensitivity and linearity of the sensor as a function of the gauge-force and the diameter of the filtering SSMF, respectively. In Fig. 7, the effect of the gauge-force is shown. There can be observed that when the gauge force increase, the sensor is more linear but the sensitivity decreases. It evidences that, in these types of sensors, metrological characteristics as linearity, sensitivity and dynamic range, can be tuned mechanically, what is an important result for the implementation of any FSS. On the other hand, in Fig. 8 can be observed that the maximum sensitivity is achieved for a filtering window of appropriated dimensions, specifically, when the filtering fiber has dimensions similar to the average speckle size.

These results are in agreement and are complementary to the experimental ones previously shown in [24, 25, 36]. From Fig. 8, it is also possible to conclude that when the diameter of the filtering fiber (SSMF) is much smaller or much bigger than the average speckle size, the arrangement does not translate efficiently external perturbations into optical power changes. It is due, in the first case, to the absence of a filtering effect and, in the second case, to the low energy coupling. Unlike of these conditions, when the probe tip has an appropriated dimension, appears a strong and measurable response of the sensing structure (See curves red, dash blue, dash green and black in Fig. 8). In the particular case, it is clear that this condition is optimized with filtering fibers of core diameter between 8 µm - 22 µm, i.e., when $D/d$ ratio is around 1.0. Finally, as the proposal evaluates the performance of a fiber speckle pattern created by a multimode fiber on a region of interest defined by a circular section that can be associated to another fiber of lower core diameter, these results are very important for practical implementation of any kind of FSS and, specifically, for those based on power measurements.

Fig. 7. Sensitivity and linearity of the sensor for different calibration points at 1630 nm with a filtering SSMF of 14µm of diameter.
4. Conclusions

In this work, a new methodology to analyze Fiber Specklegram Sensors by using the Finite Element Method (FEM) was presented. In particular, the proposed methodology allowed reconstructing the intensity profile of a SMMF specklegram under controlled conditions of stress and, in turn, the evaluation of Fiber Specklegram Sensors interrogated by optical power variation (PFSS). All the propagation modes supported by a SMMF, for each stress condition, were calculated and superposed for reconstructing perturbed fiber speckle patterns. Then, the performance of the PFSS was evaluated for different radius of filtering fiber and force-gauges. It evidences that, in these types of sensors, metrological characteristics as linearity, sensitivity and dynamic range, can be tuned mechanically, being this an important result for the implementation of any FSS. The analysis allowed for the first time, under a deterministic scheme, the formal identification of design criteria for this kind of measuring systems. Results are in agreement with experimental ones previously reported.

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