CLAIMS

1. System (1) for monitoring by optical fiber (3) an object/structure (2) for the measurement of vibrations comprising:

– said optical fiber (3) associated with said object/structure (2) and having one end connected to a circulator (4) and a terminated opposite end;

– a source (5) of symbols emitting N_C input signals ($s_n(\tau)$ n=[0,..,N_C−1]) with each input signal comprising sequences of input symbols (σ_i i=[0,..,N_S−1]), said sequences of input symbols (σ_i i=[0,..,N_S−1]) being configured to generate circulating matrixes ($\widehat{\boldsymbol{S}}_n(\tau)$) having full rank, said N_C input signals ($s_n(\tau)$ n=[0,..,N_C−1]) generating an input vector ($\mathbf{s}(\tau)$);

–a multi–carrier OFDM –Orthogonal Frequency Division Multiplexing– modulation block (6) that receives said input vector ($\mathbf{s}(\tau)$) and that is configurated to modulate a light beam (13) emitted by a laser source (12) by means of an OFDM modulating signal (x(m); *R[x(t)], I[x(t)]*) to determine a sensing signal ($s_{IN}(t)$) with N_C subcarriers, said OFDM modulating signal being generated on the basis of the input vector ($\mathbf{s}(\tau)$);

– said circulator (4) being adapted to send said sensing signal ($s_{IN}(t)$) to said optical fiber (3) and to receive a backscattered signal $S_{OUT}(t)$ with N_C subcarriers;

–an OFDM demodulation block (19) which receives said backscattered signal $S_{OUT}(t)$ and a second light beam (13') of intensity proportional to the intensity of said light beam (13), said OFDM demodulation block (19) being configured to demodulate the backscattered signal ($S_{OUT}(t)$) determining an output vector ($\mathbf{u}(\tau)$) with N_C output signals ($u_n(\tau)$ n=[0,..,N_C−1]) which include backscattered symbols (ε_i i=[0,..,N_C−1]);

–a processing unit (20) which receives said output vector ($\mathbf{u}(\tau)$) and said input vector ($\mathbf{s}(\tau)$), the processing unit (20) on the basis of respective N_c reference vectors ($\bar{R}_n\, n = 0,..,Nc-1$) of said optical fiber (3) and of N_C vectors of antecedent

symbols ($\bar{s}_n(\tau)$) of said sensing signal ($s_{IN}(t)$) generates a deformation vector ($\boldsymbol{v}(\boldsymbol{\tau})$) of said optical fiber (3) which allows to determine said vibration measurement,

said N_C reference vectors ($\bar{R}_n$ n=[0,..,N_C−1]) being determined for each of said N_C subcarriers of said sensing signal ($s_{IN}(t)$) considering unperturbed conditions of said optical fiber (3),

said N_C reference vectors ($\bar{R}_n\, n = 0, .., Nc - 1$) being calculated on the basis of said circulating matrixes ($\widehat{\boldsymbol{S}}_n(\tau)$) having full range.

2. System according to claim 1, characterized in that said OFDM modulation block (6) comprises:

- an OFDM modulation unit (7) which is configured to receive and process said N_C input signals ($s_n(\tau)$ n=[0,..,N_C−1]) to determine an OFDM digital modulating signal (x(m)) with N_C orthogonal subcarriers, each digital modulating signal OFDM (x(m)) comprising a continuous sequence of said N_S input signals (σ_i i=[0,..,N_S−1]);

- a digital analog converter (10) which is configured to receive the OFDM digital modulating signal (x (m)) to generate a multi-carrier OFDM analog modulating signal (*R[x(t)], I[x(t)]*) with N_C orthogonal subcarriers;

- an opto-electronic modulator I/Q (14) which receives said OFDM analog modulating signal (*R[x(t)], I[x(t)]*) and is configured to modulate said light beam (13) and to generate said multi-carrier sensing signal ($s_{IN}(t)$).

3. System according to claim 1, characterized in that said OFDM demodulation block (19) comprises:

-an opto-electronic demodulator I/Q (15) which receives said backscattered signal ($S_{OUT}(t)$) with N_C subcarriers and said second light beam (13'), the opto-electronic demodulator I/Q (15) is to generate an OFDMR analogue demodulated backscattered

signal ($\Re[y(t)]$, $\Im[y(t)]$) with N_C subcarriers;

-an analog to digital converter (16) that is configured to digitize said OFDM analogue demodulated backscattered signal ($\Re[y(t)]$, $\Im[y(t)]$) generating an OFDM digital output signal (y(m)) with each subcarrier comprising a continuous sequence of said backscattered symbols (ε_i i=[0,..,N_S-1]);

-an OFDM demodulation unit (18) which is configured to receive and demodulate said OFDM digital output signal (y(m)) in order to generate the output vector ($\mathbf{u}(\tau)$) that comprises said N_C output signals ($u_n(\tau)$ n=[0,..,N_C-1]).

4. System according to claim 1, characterized in that said optical fiber (3) is divided in length (L) into a number Nz of subsequent points which define N_Z spatial discretization cells, said deformation vector ($\boldsymbol{v}(\boldsymbol{\tau})$) comprising deformation values for each spatial discretization cell, said number N_Z being calculated by means of the equation

$$N_Z = \frac{2\gamma\, L\, B_A}{v_g}$$

wherein

L is the length of said optical fiber (3);

γ is a predefined variable;

B_A is the measurable acoustic band of said optical fiber (3),

v_g is a group speed of said optical fiber (3).

5. System according to claim 1, characterized in that said processing unit (20) is equipped with a processing module (21) comprising a perturbation estimation block (22), said perturbation estimation block (22) being configured to generate said deformation vector($\boldsymbol{v}(\tau)$) by receiving:

-said output vector ($\mathbf{u}(\tau)$) with said N_C output signals ($u_n(\tau)$ n=[0,..,N_C-1]);

-said N_C reference vectors ($\bar{R}_n$ n=[0,..,N_C-1]) of said optical fiber (3),

$-N_C$ vectors of antecedent symbols ($\bar{s}_n(\tau)$) obtained from respective first sliding window blocks (23_n with n=0,…,N_C−1) receiving respective Nc input signals ($s_n(\tau)$ n=[0,..,N_C−1]) of said input vector ($\mathbf{s}(\tau)$).

6. System according to claims 4 and 5, characterized in that said perturbation estimation block (22) comprises an estimate of the perturbation for each spatial discretization cell of said optical fiber (3), said deformation vector ($\boldsymbol{v}(\tau)$) being determined using circular matrices according to the equation:

$$\boldsymbol{v}(\tau) = \left(\boldsymbol{N}^T(\tau)\boldsymbol{N}(\tau)\right)^{-1}\boldsymbol{N}^T(\tau)\boldsymbol{u}(\tau)$$

wherein a computation matrix N(τ) is defined by:

$$\boldsymbol{N}(\tau) = \begin{bmatrix} \bar{s}_{\mathbf{0}}(\tau) \circ \bar{R}_{\mathbf{0}} \\ \bar{s}_{\mathbf{1}}(\tau) \circ \bar{R}_{\mathbf{1}} \\ \vdots \\ \bar{s}_{\boldsymbol{N_C-1}}(\tau) \circ \bar{R}_{\boldsymbol{N_C-1}} \end{bmatrix}$$

said calculation matrix N(τ) being a matrix ($N_C \times N_z$) with N_C the number of subcarriers and N_z the number of said carriers discretization cell into which the optical fiber (3) is divided, the rows ($\bar{s}_n(\tau) \circ \bar{R}_n$) of said calculation matrix (N(τ)) being obtained by multiplying the vectors of antecedent symbols $\bar{s}_n(\tau)$ by the reference vectors ($\bar{R}_n$ n=[0,..,N_C−1]), each of said reference vectors ($\bar{R}_n$ n=[0,..,N_C−1]) comprising a reference value for each discretization cell of said optical fiber (3).

7. System according to claim 1, characterized in that each of said subcarriers comprises a sequence of input symbols ($s_i(\tau)$) of the first subcarrier translated by a number of times equal to the N_C index of the subcarrier itself, according to the equation:

$$\bar{s}_n(\tau) = \bar{s}_0(\tau - n)$$

8. System according to claim 1, characterized in that said

processing unit (20) comprises a calibration module (25) configured to estimate for each subcarrier Nc of said sensing signal ($s_{IN}(t)$) a corresponding reference vector ($\bar{R}_0,..,\bar{R}_{Nc-1}$) calculated with said unperturbed optical fiber (3), said calibration module (25) comprising:

-N_C first sliding window blocks (23_n n=0…N_C-1) which are configured to receive respective input signals ($s_n(\tau)$) n=[0,..,N_C-1]) and to generate corresponding vectors of antecedent symbols ($\bar{\boldsymbol{s}}_{\boldsymbol{n}}(\boldsymbol{\tau})$);

-N_C second sliding window blocks (24_n n=0…N_C-1) which receive respective output signals ($u_n(\tau)$ n=[0,..,N_C-1]) to generate corresponding vectors of antecedent backscattered symbols ($\bar{\boldsymbol{u}}_{\boldsymbol{n}}(\boldsymbol{\tau})$);

-N_C estimation blocks (26_n n=0…N_C-1) configured to receive corresponding vectors of antecedent symbols ($\bar{\boldsymbol{s}}_{\boldsymbol{n}}(\boldsymbol{\tau})$) and corresponding vectors of antecedent backscattered symbols ($\bar{\boldsymbol{u}}_{\boldsymbol{n}}(\boldsymbol{\tau})$) to generate a corresponding reference vector ($\bar{R}_n$) for each discretization cell of each subcarrier Nc, said reference vector ($\bar{\boldsymbol{R}}_{\boldsymbol{n}}$) being calculated by:

$$\bar{R}_n = \left(\boldsymbol{S}_n^T(\tau)\boldsymbol{S}_{\boldsymbol{n}}(\tau)\right)^{-1}\boldsymbol{S}_n^T(\tau)\bar{u}_n(\tau)$$

wherein $\boldsymbol{S}_n(\tau)$ is a matrix $N_S \times N_z$ obtained from the circulating matrix $\widehat{\boldsymbol{S}}_n(\tau)$ associated with the vector of antecedent symbols ($\bar{\boldsymbol{s}}_{\boldsymbol{n}}(\boldsymbol{\tau})$) by eliminating the last $(N_S - N_z)$ columns.

9. Monitoring method using optical fiber (3) for the measurement of vibrations of an object/structure (2) characterized by:

- associating with said object/structure (2) said optical fiber (3) which comprises an end connected to a circulator (4) and a terminated opposite end;

-generating an input vector ($\mathbf{s}(\tau)$) with N_C input signals ($s_n(\tau)$ n=[0,..,N_C-1]) including sequences of input symbols (σ_i

$i=[0,..,N_S-1)$, wherein said sequences of input symbols (σ_i $i=[0,..,N_S-1]$) are configurated to generate circulating matrixes ($\widehat{\boldsymbol{S}}_n(\tau)$) having full rank,;

-determining a sensing signal ($s_{IN}(t)$) with N_C subcarriers by modulating a light beam (13) by an OFDM Orthogonal Frequency Division Multiplexing modulation by means of an OFDM modulating signal (x(m); *R[x(t)], I[x(t)]),* generat*ing said* OFDM modulating signal (x(m); *R[x(t)], I[x(t)])* on the basis of said input vector (**s**(τ));

-probing said optical fiber (3) by sending said sensing signal ($s_{IN}(t)$) and by receiving a backscattered signal $S_{OUT}(t)$ with N_C subcarriers;

- determining an output vector (**u**(τ)) with N_C output signals ($u_n(\tau)$ $n=[0,..,N_C-1]$) demodulating said backscattered signal ($S_{OUT}(t)$) by an OFDM demodulation by means of a second light beam (13') with intensity proportional to said light beam (13), said N_C output signals ($u_n(\tau)$ $n=[0,..,N_C-1]$) comprising backscattered symbols (ε_i $i=[0,..,N_S-1]$);

- generating a deformation vector ($\boldsymbol{v}(\tau)$) by processing said output vector (**u**(τ)) and said input vector (**s**(τ)) on the basis of respective N_C reference vectors ($\bar{\boldsymbol{R}}_{\boldsymbol{n}}$ $n=[0,..,N_C-1]$) of said optical fiber (3) and of N_C vectors of antecedent symbols ($\bar{\boldsymbol{s}}_{\boldsymbol{n}}(\boldsymbol{\tau})$) of said sensing signal ($s_{IN}(t)$), and

determining said N_C reference vectors ($\bar{\boldsymbol{R}}_{\boldsymbol{n}}$ $n=[0,..,N_C-1]$) for each of said N_C subcarriers of said sensing signal ($s_{IN}(t)$) considering unperturbed conditions of said optical fiber (3), and

calculating said N_C vectors of antecedent symbols ($\bar{\boldsymbol{s}}_{\boldsymbol{n}}(\boldsymbol{\tau})$) on the basis of said circulating matrixes ($\widehat{\boldsymbol{S}}_n(\tau)$) having full rank of said sequences of input symbols (σ_i $i=[0,..,N_S-1)$.

10. Method according to claim 9, characterized by the fact of estimating said deformation vector ($\boldsymbol{v}(\tau)$) on the basis of:

-said output vector **u**(τ) with said N_C output signals ($u_n(\tau)$

n=[0,..,N_C−1]);

−said N_C reference vectors ($\bar{R}_n$ n=[0,..,N_C−1]),

−said N_C vectors of antecedent symbols ($\bar{\boldsymbol{s}}_{\boldsymbol{n}}(\boldsymbol{\tau})$) which are obtained from corresponding first sliding window blocks (23_n con n=0,…,N_C−1) receiving respective input signals ($s_n(\tau)$ n=[0,..,N_C−1]) of said input vector ($\mathbf{s}(\tau)$).

11. Method according to claim 9, characterized by the fact of estimating for each subcarrier Nc of said sensing signal ($s_{IN}(t)$) a corresponding reference vector ($\bar{R}_n$ n=[0…N_C−1]) calculated with said unperturbed optical fiber (3), said reference vector ($\bar{R}_n$ n = [0 … N_C−1]) being calculated by providing:

−generating Nc vectors of antecedent symbols ($\bar{\boldsymbol{s}}_{\boldsymbol{n}}(\boldsymbol{\tau})$) using N_C first sliding window blocks (23_n n=[0…N_C−1]) which receive respective input signals ($s_n(\tau)$ n=[0,..,N_C−1]);

−generating N_C vectors of antecedent backscattered symbol ($\bar{u}_n(\tau)$) using N_C second sliding window blocks (24_n n=[0…N_C−1]) which receive respective output signals ($u_n(\tau)$ n=[0,..,N_C−1]);

− dividing said optical fiber (3) in length L into N_z spatial discretization cells;

−generating a corresponding reference vector ($\bar{R}_n$ n=[0,..,N_C−1]) for each discretization cell of each Nc subcarrier using N_C estimation blocks (26_n n=[0…N_C−1]) configured to receive corresponding vectors of antecedent symbols ($\bar{\boldsymbol{s}}_{\boldsymbol{n}}(\boldsymbol{\tau})$) and corresponding vectors of antecedent backscattered symbols $\left(\bar{u}_n(\tau)\right)$;

−calculating said reference vector ($\bar{R}_n$) by means of the equation

$$\bar{R}_n = \left(\boldsymbol{S}_n^T(\tau)\boldsymbol{S}_{\boldsymbol{n}}(\tau)\right)^{-1}\boldsymbol{S}_n^T(\tau)\bar{u}_n(\tau)$$

wherein $\boldsymbol{S}_n(\tau)$ is a matrix $N_S \times N_z$ consisting of the circulating matrix $\widehat{\boldsymbol{S}}_n(\tau)$ associated with the vector of antecedent initial symbols $\bar{s}_n(\tau)$ and eliminating the last ($N_S -$

N_z) columns, each circulating matrix ($\widehat{\boldsymbol{S}}_n(\tau)$) associated with each vector of antecedent initial symbols ($\bar{s}_n(\tau)$) having full rank.