European Market Survey of Structural Health Monitoring Sensors for Wind Energy Applications

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1. Introduction

This report is a study of the European Structural Health Monitoring (SHM) market for Wind Turbines (WTs) and includes companies that manufacture and/or distribute SHM sensors and companies that provide an SHM service. The survey was performed by making an internet and literature survey of the European SHM market for WTs in 2024.

The methodology was to investigate the market country by country, to assemble the findings in a series of comparison tables and to draw conclusions. Each table will include the name of the company, the manufacturing/distribution company, the range of measurement (if applicable), the country that the company is located, the cost of the sensor (if available) and additional information about the sensor.

The report will be presented in the following way. The second section will describe the working principle of each sensor type, as well as summarized scientific information. The third section will show the tables of sensors with an explanation of how the top 3 sensors were chosen. The fourth chapter will discuss the selection and this will be followed by the conclusion. The Appendix will describe the main details about the companies listed.

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2. Sensor Principles

2.1 Introduction

Chapter 2 describes the working principle of the most common sensors available on the market. The following sensor types are described: strain gauges, magnetostriction, optical torque, reaction torque, Hall-effect, optical fibre and eddy current sensors.

2.2 Strain Gauge

Strain gauges are transducers which transform deformation in sensitive elements into electrical signals. The most common type is the resistive strain gauge.

The working principle of the strain gauge is based on the phenomenon that when an electrically conducting materials is stretched due to a tension force within its elastic limit, it will become narrower and longer, increasing its electrical resistance. On the other side, when an electrically conducting material is compressed by a longitudinal compression force without buckling, it will become shorter and broader, reducing the electrical resistance of the material [1]. The ratio of relative change in strain gauge resistance to the real mechanical strain is the Gauge Factor (GF), which can be described as:

$$GF = \frac{\Delta R/R}{\Delta L/L} = \frac{\Delta R/R}{\varepsilon} \tag{1}$$

where ΔR is the change of resistance (Ω), R is the original resistance of the material (Ω), ΔL is the change of length (mm), L is the original length of the structure (mm), and ε is the axial mechanical strain (mm/mm) [1]. An example strain gauge force sensor is shown in Figure 1.

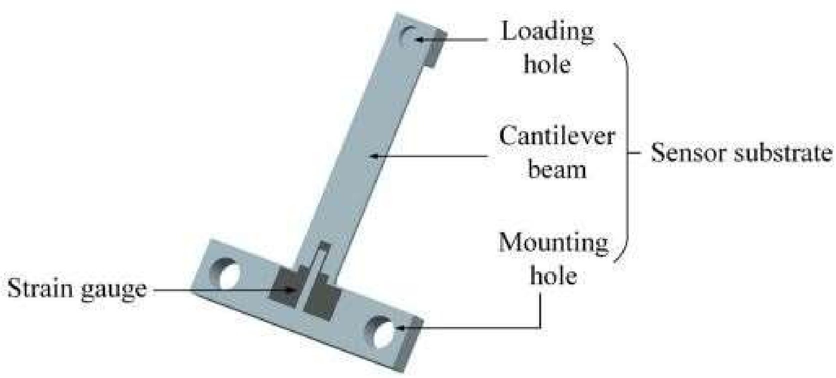

Figure 1: Example of a strain gauge based force sensor made by a 3D printer [2].

The output of strain gauges can be deformation, force (strain gauge based force sensor) or even torque (rotary strain gauge torque transducer) [2]. Figure 1 shows an example of a strain gauge based force sensor.

2.3 Magnetostriction

The torque applied on shafts can be assessed by applying the principle of magnetostriction [3-4]. A magnetostrictive material will change its shape when it is placed in a magnetic field. This phenomenon involves a bidirectional energy exchange between the magnetic and elastic field. This means that a magnetostrictive material can be used in both in actuator and sensor modes.

If a magnetostrictive material is subjected to a mechanical stress, its magnetic permeability will change because of the inverse magnetostriction effect. If, at this same time, the material is subjected to an alternating magnetic field produced by a coil with an alternating current, the magnetic flux density pattern will be changed as a result of the change of magnetic permeability. This effect is explored in the magnetostrictive transducer. The effect can be measured in a separate coil where the alternating magnetic flux will induce an alternating electromagnetic field, whose magnitude changes with the magnetic permeability of the material [3-4], as shown in Figure 2.

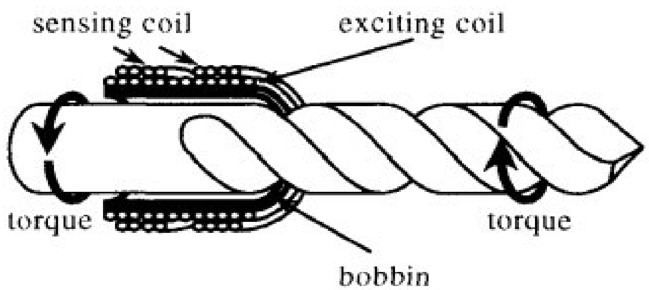

Figure 2: Schematics of the magnetostriction torque transducer [5].

The application of magnetostriction sensors in wind turbines is to measure the torque on both the low frequency and high frequency shafts. In general, wind turbines present 2 shafts inside the nacelle. The low frequency shaft is the one connected to the blades of the wind turbine. The high frequency shaft is connected to the electric generator. Between both shafts, there is a gearbox, responsible for shifting the low frequency rotational energy to high frequency rotational energy.

2.4 Optical Torque Sensor

The optical torque sensor can be considered in 2 parts. The first part consists of the sensing element (photo-interrupter) and the second part is the flexure, as shown in Figure 3. The photo interrupter can detect the slightest deformation on the flexure [6].

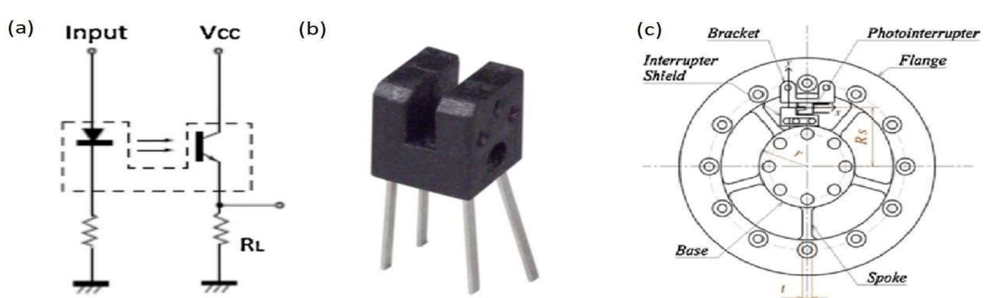

Figure 3: (a) The schematics of the photo-interrupter (b) Image of a photo-interrupter (c) the front view of flexure [6].

The photo interrupter consists of an infrared Light Emitting Diode (LED) on one side and a detector (photo transistor) on the other side. When a voltage is applied to the input side, the LED emits light and the photo transistor detect this light, generating an electrical current. This current is directly proportional to the intensity of the light detected by the transistor. The output current can be controlled by varying the voltage input or by controlling the amount of light sensed by the detector. The amount of light can also be controlled by inserting an interrupter shield between the LED and the sensor. Sliding of the shield changes the output current [6].

The photo-interrupter is very sensitive to the displacement of the interrupter shield placed in its field. The flexure is the main mechanical component of the torque sensor. The elastic elements of the flexure are called spokes, and these twist or deform when a torque or force are applied. Any torque generated by the motors is transmitted through the flanges to the inner ring via spokes, causing a deformation on it. This deformation creates an angle of twist that can be adopted to measure the generated torque of the joint [6].

2.5 Reaction Torque Sensor

A reaction torque sensor consists of a structure similar to a dynamometer using a lever arm [7]. The force on the load cell connected to the lever arm is multiplied by the length of the moment arm to calculate the applied torque. A general S-type low-capacitive load cell can be used to measure the torque in both directions in an effective manner. The assembly position of the lever arm to which the load cell is connected must be changeable in order to adjust the measurement range and sensitivity. When the motor rotates the weight arm, the load cell is stretched and compressed repeatedly. By applying the moment arm length by the load cell force, it is possible to obtain the torque [7]. Figure 4 shows a model of a reaction torque sensor.

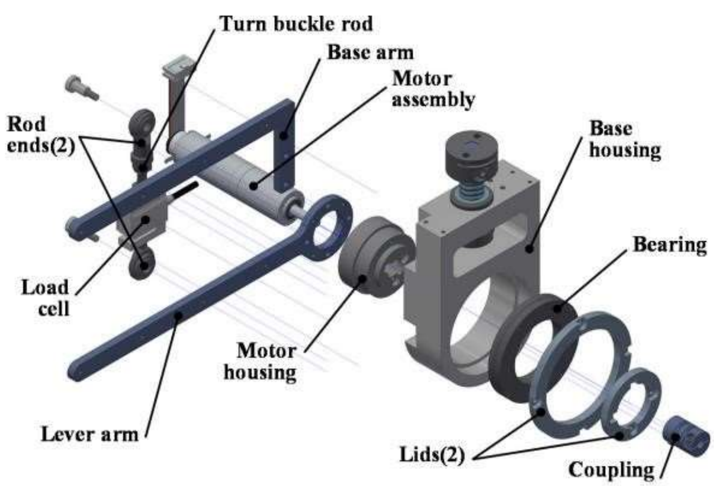

Figure 4: Model of a reaction torque sensor [7].

2.6 Hall-Effect Sensor

Hall-Effect sensors have been adopted in a wide range of low power industrial applications, such as magnetic field, position, direction, oscillation and speed sensing [8]. The Hall effect is the generation of a transverse voltage in a sample carrying an electrical current and exposed to a magnetic field. The Hall effect is the manifestation of the charge carrier transport phenomena in condensed matter, when the carriers are subjected to the action of the Lorentz Force, see Figure 5.

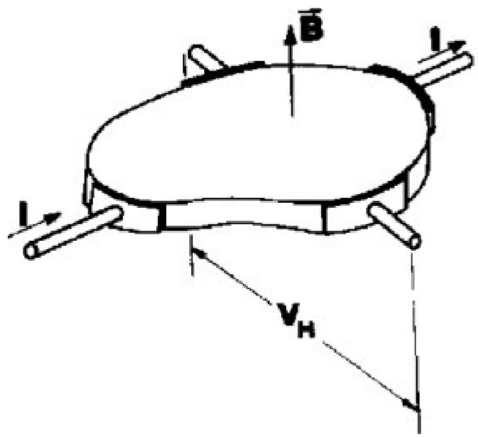

Figure 5: The Hall effect schematics in a conductor plate [9].

A Hall effect device consists of a thin plate of a conducting material, fitted with 4 electric contacts. A bias current I is supplied via 2 of the contacts (the current contacts) and the other 2 contacts are connected to 2 equipotential points, at or close to the plate boundary. If a magnetic field is applied to the sample, the Hall voltage appears between the sensing contacts (the Hall voltage is the output of the device), as shown in Figure 5. The formulation of the Hall voltage is:

$$V_H = \frac{I_x B_z}{nte} \quad (2)$$

Where I_x is the electrical current, B_z is the magnetic field and *n* is the charge carrier density, *e* is the electronic charge and *d* is distance.

2.7 Optical Fibre Sensor

Optical fibre sensors have the advantage of having immunity to electromagnetic interference, are lightweight, have a small size, high sensitivity and large bandwidth [10]. In some situations, optical fibre sensor systems are simply subsystem components instead of being a complete system. There are two main types of optical fibre sensors: distributed sensing and grating based sensing.

2.7.1 Distributed Fibre Sensing

Distributed fibre sensor technology is mainly based on optical scattering such as Rayleigh, Brillouin or Raman scattering, as shown in Figure 6. Local external perturbations along the sensing fibre such as temperature and strain can be detected by changing in amplitude, frequency, polarization or phase of the backscattering sensing light [10].

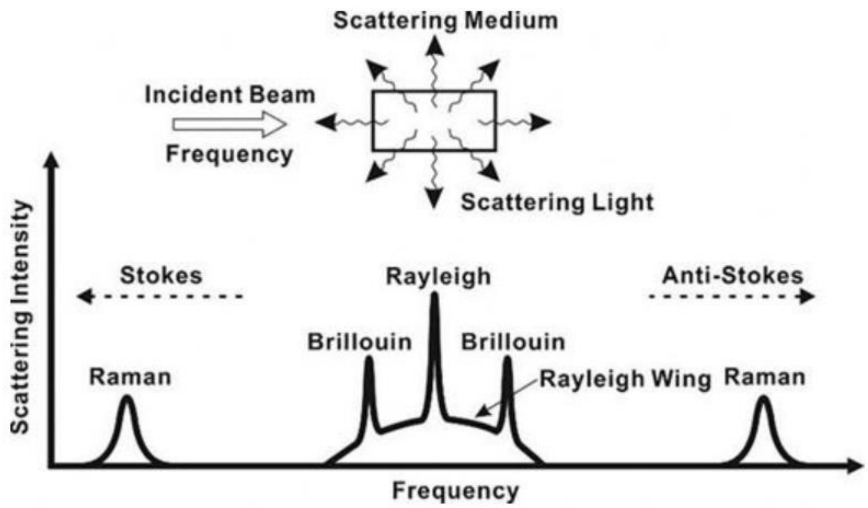

Figure 6: A typical spontaneous backscattering spectrum [10].

Rayleigh scattering is caused by the scattering of light from particles or other sources of refractive index with a fluctuation much smaller than the optical length wave. When light travels through matter (solid, liquid or gas), various photon-scattering mechanisms can occur. The origin of Rayleigh scattering in optical fibres is related to refractive index fluctuations resulting from density and compositional inhomogeneities that are frozen in the structure of the fibre during fibre fabrication. Rayleigh scattering is a linear type of scattering in which the frequency of the scattering signal remains the same as the incident signal. The principle of Rayleigh backscattering is shown in Figure 7 [10].

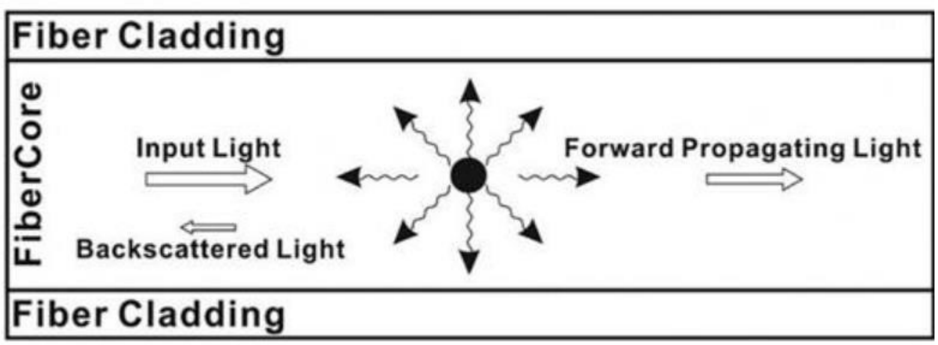

Figure 7: Scheme of Rayleigh backscattering in optical fibres [10].

Distributed fibre sensing based on Brillouin backscattering uses the interaction of light with acoustic phonons propagating in the fibre. The Brillouin scattered light has a frequency shift proportional to the velocity of acoustic waves, which depends on the local density and stress of the glass (thus on the material temperature and strain). The sensing capability of this scattering phenomenon arises from the measurement of the distributed Brillouin frequency shift dependence on strain and temperature [11].

2.7.2 Fibre Bragg Grating (FBG) Sensor

Fibre Bragg Gratings (FBGs) are produced by a periodic modulation of the refractive index of the fibre core along the longitudinal direction [12]. It is based on the principle of a diffraction grating (a periodic change in the refractive index of the optical fibre core). When light travels inside the grating region, some portion of light gets reflected back from each grating plane. Every reflection portion of light combines to form one reflected beam of light. All the reflected light constructively adds up to form a backward reflected wavelength peak. The grating structure works as a mirror that reflects a certain wavelength and transmits the rest [12]. The measurement principle of a Fibre Bragg Grating sensor is shown in Figure 8.

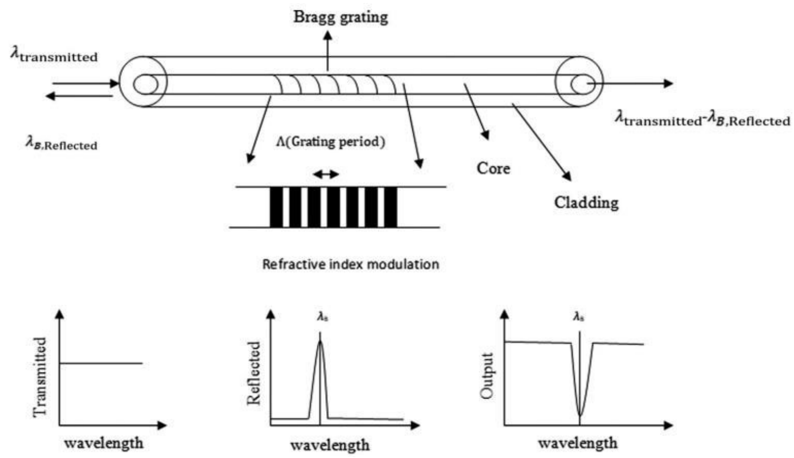

Figure 8: Schematics of Fibre Bragg Grating along the transmitted, reflected and output spectra [12].

This optical fibre sensing system can be used in multiplexing schemes and this is an advantage of using gratings. The multiplexing features of optical fibre allow the use of a common source and detection system for an array of fibre-optic sensors.

2.8 Eddy Current Sensor

The eddy current sensor is based on the extraction of energy from an oscillating circuit [13]. The energy is necessary for the induction of an eddy current in an electrically-conductive medium. A coil is stimulated with an alternating current, causing a magnetic field to form around the coil. If there is an electrically conducting material in this magnetic field, eddy currents are induced which create a magnetic field, according to Faraday's Law. This field acts against the field of the coil, which also causes a variation in the impedance of the coil. This change can be collected by a controller by looking the change in amplitude and phase position of the sensor coil [13]. The advantages of adopting the eddy current sensing are wear-free and non-contact measurement (as shown in Figure 9), high precision, high temperature stability, applied for ferromagnetic and nonferromagnetic materials, measurements up to 100 kHz [14].

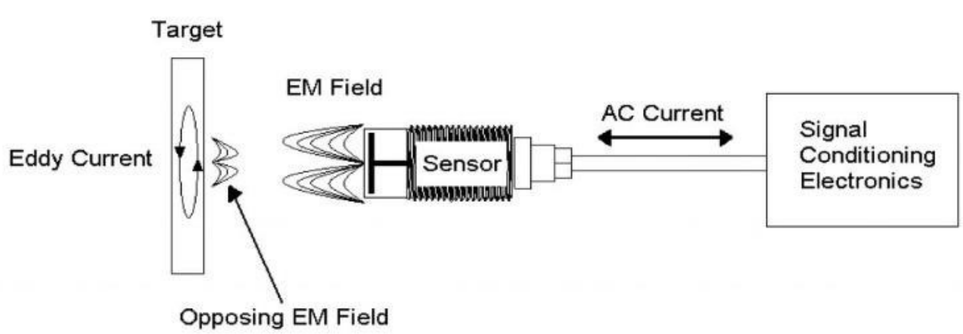

Figure 9: Schematics of Eddy current sensing [14].

3. Market survey

3.1 Introduction

In this section, the list of sensors in each category for Structural Health Monitoring of wind turbines will be presented, followed by the selection of the top 3 sensors for the respective application.

3.1.1 Abbreviations of Countries

Table 1 shows the country abbreviations using the report. The abbreviation NK means *Not Known*.

Table 1: List of countries and their abbreviations

Country	Abbreviation
Austria	AU
Belgium	BE
Croatia	HR
Denmark	DK
Finland	FI
France	FR
Germany	DE
Greece	GR
Italia	IT
Norway	NO
Poland	PL
Portugal	PT
Spain	ES
Sweden	SE
Switzerland	CH
The Netherlands	NL
Turkey	TR
United Kingdom	UK
Worldwide	WW

3.2 Accelerometers

In wind energy, accelerometers are used to detect anomalies in vibration profile (such as misalignment and unbalancing) in the low frequency and high frequency shafts of wind turbines. In general, the range of frequency for these vibrations is between 0.5 Hz and 10 kHz [15]. Therefore, the best sensors for this application are the ones which operate in this bandwidth. The Table 3 shows the list of accelerometers.

Table 3: List of accelerometers

Company	Sensor	Principle	$fmin$ (Hz)	$fmax$ (kHz)	Country	Price (euros)	Notes
Allen-Bradley	Serie 1443	NK	0,2	26	PT	NK	
Althen	EGCS-D5	Piezoelectric	0	10	NL	NK	
Althen	KS76C100	Piezoelectric	0,12	24	NL	NK	Low noise, high resolution
Althen	KS96B10	Piezoelectric	0,6	10,5	NL	NK	
Althen	SM102	NK	0,5	10	NL	NK	360º cable fitting
Althen	SM103	NK	0,5	10	NL	NK	360 cable fitting, armoured cable
Althen	ASC P311A25	Piezoelectric	2	10	NL	NK	For rotary gearbox monitoring
ASC	ASC P101A15	Piezoelectric	0,3	10	DE	NK	Uniaxial
ASC	ASC P311A15	Piezoelectric	1,5	12	DE	NK	Uniaxial
Bay	PE BST 901	NK	0,6	10,5	DE	NK	Uniaxial for low amplitudes
Bay	PE BST 903	NK	0,15	12	DE	NK	Triaxial for low amplitudes
Bay	PE BST 98	NK	0,15	11	DE	NK	Uniaxial for low amplitudes
botnroll	ADXL335	Capacitive	0,5	1,6	PT	18.35	3-axis analogue
Bruel & Kjaer	CCLD	Piezoelectric	1	25	ES	NK	
Distrilec	LIS3DHTR	Capacitive	1	5,3	CH	1.56	
Distrilec	LIS2DH12TR	Capacitive	1	5,3	CH	2,9	
Distrilec	LSM6DSOTR	Capacitive	0,1	3,2	CH	6,5	
Distrilec	ADXL345BCCZ	Capacitive	1	3,2	CH	6,5	
Dollenmeier	7284 triaxial	Piezoelectric	1	10	CH	NK	
Dollenmeier	7280AM7	Piezoelectric	1	13	CH	NK	
Dollenmeier	7270A	Piezoelectric	1	10	CH	NK	
Dollenmeier	7270AM7	Piezoelectric	1	10	CH	NK	
e-geoshop	Accelerometer	NK	NK	NK	GR	530	Limited information
Farnell	Kemet VSBV203-B	Piezoelectric	10	15	ES	159	No amplifier required
Farnell	TE-connectivity 1-1000288-0	Piezoelectric	100	100	ES	36	Piezoelectric film sensor
Farnell	MPU-6050	NK	4	8	TR	8.80	
Farnell	TE-connectivity 1-1000288-0	Piezoelectric	100	100	TR	32	
Farnell	Kemet VSBV203-B	Piezoelectric	10	15	TR	159	
HBK	TYPE 4394	Piezoelectric	1	25	DK	NK	
HBK	Type 4511-011	Piezoelectric	1	15	DK	NK	
HBK	Type 4516	Piezoelectric	1	20	DK	NK	
HBK	Type 4523	Piezoelectric	1	15	DK	NK	
HBK	Type 4527	Piezoelectric	0,3	10	DK	NK	
HBK	Type 4528-B	Piezoelectric	0,3	10	DK	NK	
HBK	Type 4529-B	Piezoelectric	0,3	12,8	DK	NK	

Company	Sensor	Principle	$fmin$ (Hz)	$fmax$ (kHz)	Country	Price (euros)	Specific data
HBK	Type 4535-B	Piezoelectric	0,3	10	DK	NK	
HBK	CCLD	Piezoelectric	0,2	12,8	DK	NK	
IFM	VSA008	Capacitive	1	10	PT	264.30	
KK wind solutions	Accelerometer	NK	NK	NK	PL	NK	For WT nacelle applications
Luchsinger	3215M1	Piezoelectric	1	10	IT	NK	360 cable orientation
Luchsinger	3256A1	Piezoelectric	1	10	IT	NK	D=0.5 inches H=0.62 inches/ good cost x benefit
Luchsinger	3255A2	Piezoelectric	1	10	IT	NK	D=0.5 inches H=0.91 inches/ good cost x benefit
MIP	KS823B	Piezoelectric	0,2	10	FI	2195	3-axis
MIP	WT202	NK	0,5	10	FI	NK	Specific for wind turbines
MIP	AC294	NK	0,3	10	FI	NK	For condition monitoring
MIP	WT203	NK	0,5	10	FI	NK	Specific for wind turbines
MIP	AC144	NK	0,6	10	FI	NK	Focused in condition monitoring
MIP	KS963.100	Piezoelectric	0,15	10	FI	NK	
MMF	KS813B	Piezoelectric	0,2	10	DE	NK	Triaxial
MMF	KSI84AP-1-10k	Piezoelectric	1000	10	DE	NK	Triaxial, for gearboxs & bearings
Mouser	ADXL1005	NK	100	20	TR	59	
Mouser	LVEP050-TO5	Piezoelectric	1	11	TR	117	
Orione	Delta OHM HD-2070	NK	0,5	20	IT	NK	
PCE instruments	PEC-VT	NK	10	10	FR	1516	Sensor+device
PM instrumentation	ASC3511	Capacitive	0	7	FR	NK	Monoaxial
PM instrumentation	KS903B	Piezoelectric	0	11	FR	NK	3-axis
PTrobotics	Velleman VMA208	NK	1,6	0,8	PT	6	3-axis digital
SAFRAN	VS1000	Capacitive	0	7	CH	NK	
Sensor UK	ASH-A	NK	2	7	UK	NK	Small dimension
Sensor UK	ASP A,B,C	Piezoelectric	1,5	16	UK	NK	Small size, built-in amplifier
Sensor UK	GSAT-A900	NK	NK	NK	UK	NK	Compact 3D angular accelerometer (+-900 º/s)
Tinytronics	ADXL345	NK	1,5	8	NL	8.50	
Tinytronics	MPU-6050	NK	4	8	NL	8.50	

In general, the prices of accelerometers vary widely from 2.90 to 2195 euros. It is notable to mention some specific accelerometers in the table:

- The accelerometers are WT202 and WT203 from MIP (Finland) have a suitable range of frequencies for wind turbines (0.5Hz to 10 kHz) and the company focusses on wind energy applications.
- The Bruel & Kjaer (Denmark) accelerometers, in particular the Type4527, Type4528-B and Type4535-B offer a wide range of frequencies n Denmark between 0.3 Hz to 10 kHz.
- Also the KS823B accelerometer from MIP (Finland) is suitable for lower frequency applications (0.2 Hz to 10 kHz).

There is limited information for many sensors. Cost commonly depends on quantity ordered, use of installation service (if necessary) or acquisition of data analyser.

3.3 Force sensors

In wind energy applications, force sensors are used to monitor the structural health of bearing of the low frequency and high frequency shafts of wind turbines. The level of force that is applied on bearings of wind turbine shafts can reach 2 MN [16]. Table 4 presents the list of force sensors from European companies.

Table 4: List of force sensors

Company	Sensor	Principle	Fmax (kN)	Land	Price (euros)	Specific data
Althen	ALF205	NK	2000	NL	NK	Load cell for low-speed shaft bearings
Althen	ALF317	NK	1000	NL	NK	Load cell for low-speed shaft bearings
Althen	ALF327	NK	2000	NL	NK	Load cell for low-speed shaft bearings
Althen	FN3002	NK	2000	NL	NK	Load cell for low-speed shaft bearings
Althen	FN3000	NK	1000	NL	NK	Load cell for low-speed shaft bearings
Althen	ACSDHR	NK	1000	NL	NK	Load cell for low-speed shaft bearings
Althen	Fibre optics load cell	Fibre optics	NK	NL	NK	Customized
Farnell	Omega LC8400 213	NK	890	DK	1307	
Farnell	Omega LCWD-200k	NK	890	DK	1550	
Farnell	Omega LCWD-200k	NK	890	TR	1544	
Farnell	Omega LC8400 213	NK	890	TR	1312	
Georg Buttner	Compression load cell B-DJ	NK	2500	DE	NK	Compact design
GTM	DR series	NK	2500	DE	NK	Broad sensitivity characteristic spectrum
GTM	RF series	NK	10000	DE	NK	
GTM	Reference KTN-D	NK	5000	DE	NK	Broad spectrum of measurement
Huggenberger	pre 2000/190/80	Strain gauge	2000	CH	NK	
IST-AG	KZ-011	NK	0,3	CH	86	
IST-AG	Customized sensor	NK	NK	CH	NK	Customized sensor
Sensor technology	Wireless sensor	Strain gauge	100	UK	NK	For stress monitoring of shaft bearings
Sensor UK	LUK-A	NK	2000	UK	NK	Tension/compression load cell, for low frequency bearings
Simstrument	LC270	NK	2000	UK	NK	
Simstrument	LC210	NK	2500	IT	NK	
TDG	Load cell	NK	1500	TR	NK	
Wika	Compression F1227	NK	2200	HR	NK	
Wika	F1270	NK	2700	HR	NK	
Xsensors	XCR-171	Strain gauge	20000	CH	NK	
Xsensors	X-138-L	NK	1000	CH	NK	
Xsensors	Ring XC-170	NK	3000	CH	NK	

According to the Table 4, the price of the force sensors ranges from 86 to 1550 euros. Some specific sensors are:

- The LUK-A from SensorUK (UK), LC270 from Simstrumenti (Italy), ALF205, ALF327 and FN3002 from Althen (The Netherlands) and Pre2000/190/80 from Huggenberger (Switzerland) are suitable for wind energy applications, based on their force measurement range.
- Also notable is the Compression force sensor F1227 from Wika (Croatia). This sensor reaches 2.2 MN, at the maximum of its measurement range.
- The LC210 sensors from Simstrumenti (Italy), the DR series force transducer from GTM (Germany) and the compression load cell B-DJ from George Buttner (Germany), also have a high maximum force measurement.

3.4 Torque sensors (low frequency)

In general, the wind energy industry adopts 2 rotating shafts for collecting energy from wind, one directly connected to the blades (the low frequency shaft) and the other is connected to the generator (high frequency shaft). Between them there is a gearbox for changing the rotation frequency in order to optimize the generation of energy. Due to the long length of the blades, the torque applied on the low frequency shaft reaches 1.3 MN.m [17]. Table 5 shows the list of companies in Europe that manufacture torque sensors for low frequency shafts. Unfortunately, the prices of these sensors are not easily available.

Table 5: List of torque sensors for low frequency shaft

Company	Sensor	Principle	T_{max} (kN.m)	Land	Price (euros)	Specific data
GTM	Torque transducer MF	NK	150	DE	Unknown	
IST-AG	Customized sensor	NK	Customized	CH	Unknown	Customized sensor
Luchsinger	Torque measuring flange	NK	500	IT	Unknown	Measures until 500 kN.m, wireless power supply, f=10 kHz

The sensor selection is discussed below:

- The Customized torque sensor from IST-AG (Switzerland) allows the range of measurement of the sensor to be selected.
- The Torque measuring flange from Luchsinger (Italy) approaches the required torque of 1.3 MN.m with a range of up to 500 kN.m.
- The torque transducer MF from GTM (Germany) measures until 150 kN.m.

As seen in the Table 5, there are not many options for high level torque sensors due to the difficulty of measuring this magnitude of torque.

3.5 Torque sensors (high frequency)

As introduced Section 3.4, the wind turbine has 2 shafts (low frequency and high frequency). The high frequency shaft is connected to the generator and the highest torque that is applied is 12.7 kN.m [17]. Table 6 shows the companies in Europe that manufacture torque sensors for high frequency shaft applications.

Table 6: List of torque measurement sensors (high frequency)

Company	Sensor	Principle	Tmax (kN.m)	Land	Price (euros)	Specific data
Althen	SGR 510/520	Strain gauge	13	NL	NK	Max. 30,000 RPM (high frequency shaft)
Althen	SGR 530/540	Strain gauge	13	NL	NK	Max. 30,000 RPM (high frequency shaft), limited space
Althen	Rotating sensor	Infrared	27	NL	NK	Max. RPM= 15,000
Althen	01165-01171	Reaction sensor	22,6	NL	NK	
Core sensing	Core flange	NK	10	DE	NK	
GTM	DM-TN	NK	20	DE	NK	
IST-AG	Custom	NK	Custom	CH	NK	Customized sensor
Luchsinger	Flange torque meter 5000	Magnetostriction	15	IT	NK	Measure to 15 kN.m/RPM=2500 (high frequency shaft)
Melectric	Torque measurement	NK	10	DE	NK	Optionally with speed and acceleration measurement
Schaeffler	Torque sensor	NK	20	CH	NK	
Sensor Technology	SGR 510/520	Strain gauge	13	UK	NK	Measures to 13 kN.m and 30,000 RPM (high frequency shaft)
Sensor Technology	SGR 530/540	Strain gauge	13	UK	NK	As 510/520 but for environment with space limitations

Unfortunately, the prices of the sensors are also not available. Notable sensors are:

- The customized sensor from IST-AG (Switzerland) allows the selection of the frequency range.
- The torque transducers SGR510/520 and SGR530/540 from Sensor Technology (UK) or Althen (The Netherlands) have a measurement range very close to that required (13 kN.m).
- The Flange Torque Meter 500 from Luchsinger (Italy) uses magnetostriction and reaches a measurement range of 15 kN.m.

3.6 Acoustic sensors

Acoustic sensors can be used to detect damage in wind turbine blades. Some systems use active excitation from a loudspeaker. The microphone/sensor can be inserted inside the blade or attached to the tower. With the information obtained by the sensor, it is possible to infer that there is a damage in the wind turbine blade. The range of acoustic frequency of the signals collected is between 200 Hz and 20 kHz [18]. Table 7 is the list of acoustic sensors.

Table 7: List of acoustic sensors

Company	Sensor	Principle	f_{min} (Hz)	f_{max} (kHz)	Land	Price (euros)	Specific data
Bruel Kjaer	Type 4138	NK	6,5	14	ES	NK	
Digikey	MP23DB01HPTR	NK	20	10	NL	2	
distrelec	ABM-720	NK	50	16	BE	1,2	
HBK	Type 4193-B-004	NK	0,07	20	DK	NK	
HBK	Type 4193-C-004	NK	0,07	20	DK	NK	
HBK	Type 4193-L-004	NK	0,07	20	DK	NK	
IDS	IDS microphone sensor	NK	20	16	UK	79	Non-industrial uses
IDS	GO direct sound sensor	NK	100	15	UK	134	Non-industrial uses
MIP	Free field microphone 146AE	NK	3,15	20	FI	NK	
MIP	GRAS 147EB	NK	3,15	20	FI	NK	
MIP	GRAS 46AF	NK	3,15	20	FI	NK	
Mistras	Mistras sensors are included in Section 3.10 Condition Monitoring Systems						
Mouser	IMP23ABSU	NK	20	80	NL	2,41	
Mouser	IMP34	NK	100	10	NL	2	
Mouser	MP34DT05-A	NK	100	10	NL	1,52	
Mouser	VEK-H-30108-000	NK	100	10	CH	71	
Mouser	FB-BW-30335-000	NK	300	3	CH	53	
Mouser	EM-24446-C36	NK	100	10	CH	26	
Mouser	FG-23329-P142	NK	100	10	CH	30	
Mouser	MM20-33639-000	NK	100	10	CH	9,35	
Mouser	KAS-700-0149	NK	13	13	CH	28,3	
Mouser	KAS-700-0147	NK	30	14,5	CH	28,3	
Mouser	VEK-H-30108-000	NK	100	10	DK	76	
MRA	MRA GRAS	NK	3	80	PT	NK	
Orione	Delta OHM HD2110	NK	16	20	IT	NK	
Robotshop	RM-VELL-06W	NK	50	20	FR	5,51	
RS	Infineon	NK	20	20	NL	1,07	Reel of 1000 pieces

The prices range from 1.20 to 28.30 euros. Some specific sensors are:

- The RM-VELL-06W from Robotshop (France) is the closest to the required range of frequency. The disadvantage of this sensor is that it is necessary to make an enclosure on it to avoid environment disturbances.
- The Fonometro HD2110L from Orione (Italy) has a measurement range from 16 Hz to 20 kHz.
- The Free field microphone 146AE, GRAS 147EB and GRAS 46AF from MIP (Finland) contains a suitable enclosure for the noise measuring application.

3.7 Electromagnetic sensors

This section present the sensors that adopt electromagnetic phenomenon to perform structural health monitoring. Table 8 presents sensors that adopt electromagnetic phenomenon for different sensing applications in wind energy.

Table 8: List of electromagnetic sensors

Company	Sensor	Principle	Land	Price (euros)	Specific data
Althen	HSM12	Hall-effect	NL	NK	Speed sensor applied to gearbox
Althen	HSM18	Hall-effect	NL	NK	
Althen	HSM22	Hall-effect	NL	NK	
Althen	P500	Inductive	NL	NK	Frequency response 10 kHz
Dehn	Dehn sensors are included in Section 3.10 *Condition Monitoring Systems*				
Elfa	RND 410-00376	Hall-effect	SE	4	
Elfa	RND 410-003769	Hall-effect	SE	5	
elfa	MHR 12G2501	Hall-effect	SE	302	
elfa	VGS-T-1000	strain gauges	SE	613	
Farnell	Linear Touchless Hall effect position sensor	Hall effect	WW	65	Can detect small strains in WTB
Farnell	Hall-effect gear tooth speed & direction sensor	Hall effect	WW	52	Speed and direction sensor. Applied on gearbox
Farnell	Hall-effect gear tooth speed & direction sensor	Hall effect	DE	48	Speed and direction sensor. Applied on gearbox
HBK	Magnetic transducer	Optical sensor	DK	NK	Vibration measurement using magnetic field
IDS	Magnetic field sensor	Hall effect	UK	98	Measure magnetic field. Requires adaptations for small strains
Keyence	Digital displacement inductive sensor	Eddy current	UK	NK	Can detect vibrations (40 kHz) on the shafts
Keyence	Inductive gauging sensor	Eddy current	UK	NK	Measure until 10 mm of displacement
Luchsinger	Linear Strain gage	Strain gauges	IT	NK	Unidirectional measurement (for deflection on WTB)-needs cable
Luchsinger	T-rosettes	Strain gauges	IT	NK	2D measurement for deflection on WTB, needs cable
Luchsinger	Inductive Eddy current displacement sensor	Eddy current	IT	NK	Measure position, vibration (up to 100 kHz) and displacement (ideal for shafts)
Megatron	Contactless linear transducer	Hall-effect	DE	NK	Detects small oscillating movements

Company	Sensor	Principle	Land	Price (euros)	Specific data
MIP	Eddy current sensor DP1001	Eddy current	FI	NK	Measure shaft vibration and displacement
MIP	Eddy current sensor DP100851	Eddy current	FI	NK	Measure shaft vibration and displacement
MIP	AC velocity output HS160	Piezoelectric	FI	NK	For shaft applications
MIP	MIP	Piezoelectric	FI	NK	
Mouser	AH3968-WT-7	Hall-effect	CH	1,02	Detect rotation speed of shaft. Can be applied on shafts of the WT
Mouser	AH3975-WT-7	Hall-effect	CH	1,13	Detect rotation speed of shaft. Can be applied on shafts of the WT
Mouser	AH3978Q-WT-7	Hall-effect	CH	1,13	Detect rotation speed of shaft. Can be applied on shafts of the WT
Mouser	Linear position sensor 20LHE2AWA1P30	Hall-effect	TR	101	Detect displacements on Gearbox
Mouser	Speed sensor SNDH-H	Hall-effect	TR	87	Accurately sense ferrous material movement
Sensor UK	NG inclinometer	Capacitive	UK	NK	range:+-80deg. Ideal for measurement of the inclination of the tower

The price varies from 1.02 to 613 euros. Specific sensors are:

- The HSM12 from Althen (The Netherlands) is able to assess the rotational speed of shafts using the Hall-effect phenomenon.
- The NG inclinometer from SensorUK uses the capacitive principle to measure the inclination. For structural health monitoring in a wind turbine, it can be placed in the tower to measure the tilt of the structure.
- The inductive edge current displacement sensor from Luchsinger (Italy) uses Eddy current phenomenon to measure vibration, displacement and position of the shafts of wind turbine.

3.8 Optical sensors

Table 9 shows the list of optical sensors.

Table 9: List of optical sensors

Company	Sensor	Principle	Land	Price (euros)	Specific data
Acalbfi	Fibres optimised Rayleigh-Brillouin	Optical sensor	FR	NK	Ideal for measurement of deflection on WTB
Althen	Strain gauge	Fibre optics	NL	NK	Deformation monitoring of WTB
Althen	FDRF605 sensor	Triangulation	NL	NK	Measures position, displacement, surface profile, deformation, vibration up to 500 mm
Di-soric	WRB glass fibre optics	Optical sensor	DE	NK	Diverse length and material of coating
Di-soric	KL plastic fibre optics	Optical sensor	DE	NK	
DSE	O2DS Z laser scanner	Optical sensor	DK	NK	Determine the distance from the sensor to some surface
Elfa	Fibre optic 120mm	Optical sensor	SE	27	
Elfa	Fibre optic 400mm	Optical sensor	SE	55	
Elfa	Fibre optic cable 800mm	Optical sensor	SE	68	
Farnell	Fibre optic E3X-HD	Optical sensor	DK	264	
Farnell	Fibre optic FX-300	Optical sensor	DK	138	
Farnell	Fibre optic through beams	Optical sensor	DK	328	
Farnell	OMRON E3X-HD44	Optical sensor	TR	265	
HBK	Laser Tachometer probe	Optical sensor	DK	NK	Focused on the wind turbine applications
HBK	Photoelectric tachometer probe	Optical sensor	DK	NK	Contactless, rotational speeds up to 20,000 RPM
HBK	MM-0012 tachometer	Optical sensor	DK	NK	Displacement measurement
Interlab	Epsilon sensor	Fibre optics	PL	NK	High spatial resolution in strain measurement
Interlab	Solifos Brussen	Fibre optics	PL	NK	high strain sensitivity used for strain sensing
Interlab	OS3100	FBG	PL	NK	Optical strain gauge based on FBG
Interlab	OS8100	FBG	PL	NK	High sensitivity tilt sensor, for tower inclination
Keyence	Digital fibre optic sensor	Fibre-optics	UK	NK	Ideal for measurement of deflection on WTB
Keyence	High-speed optical micrometer	Optical sensor	UK	NK	For misalignment and irregular shaft vibrations (to 16 kHz)
Keyence	LK-G series	Optical sensor	UK	NK	High-accuracy (0.02%) laser displacement sensor (can be used on shafts)
Tarucca	Tarucca sensors are included in Section 3.10 *Condition Monitoring Systems*				
Wenglor	Tactile sensor	Optical sensor	DE	NK	
Wenglor	Barrier principle	Optical sensor	DE	NK	

Their prices vary from 27 to 328 euros. Specific sensors are:

- The high-speed optical micrometer from Keyence (UK) is able to detect misalignment and irregular vibrations (up to 16 kHz) on the low frequency and high frequency shafts of wind turbine.
- The FDRF605 Laser triangulation sensor from Althen (The Netherlands) adopts laser measurements to measure position, displacement, surface profile, deformation, vibration up to 500 mm. It is suitable for shaft applications.
- The Interlab Epsilon sensor (Poland) has a high spatial resolution in strain measurements. It is suitable for stress analysis of the bearings of both low speed and high speed shafts.

3.9 Other sensor types

Table 10 contains other sensor types, not included above.

Table 10: List of other sensors

Company	Sensor	Principle	Land	Price (euros)	Specific data
Contelec	Vert-X 05E	NK	CH	NK	
Contelec	Vert-X 60E	NK	CH	NK	
e-geoshop	Wireless triaxial tiltmeter	NK	GR	430	Able to calculate the deflection of the structure with respect to the baseline
elfa	Overspeed monitor	NK	SE	168	Compact evaluation unit for speed monitoring
GTM	Multicomponent transducer MKA	NK	DE	NK	Measure force (4 MN) and torque (200 kN.m) at the same time
GTM	Multi-axis transducer LVS	NK	DE	NK	Measure force (250 kN) and torque (5 kN.m) at the same time
IDS	Vernier Rotary motion Sensor	NK	UK	267	2D measurement of rotational position, velocity and acceleration. Range: up to 30 RPM
IDS	Go direct rotary motion sensor	NK	UK	267	Obtain angular position, velocity and acceleration. Range up to 30 RPM. Wireless
Keyence	Positioning sensor	NK	UK	NK	Able to detect misalignment on the shafts
Ph parker	Tilt sensor	NK	ES	NK	Obtain changes in orientation and detect misalignment and unbalancing
Piher	Tilt sensor	NK	ES	NK	Measure inclination, tilt and angle. Can detect misalignment and unbalancing
PM instrumentation	Miniature Extensometer	NK	FR	NK	Detect strains and deformations in shaft
Rockwell	Eddy current	NK	PT	NK	Measures vibration and phase/speed of shaft
TGD	Uniaxial high sensitivity tiltmeter	NK	TR	NK	Measures WT tower inclination
TGD	Linear potentiometer	NK	TR	NK	Measures crack growth in WTB
Wika	Inclination sensor	NK	HR	NK	Detect orientation angle relative to gravity

The price ranges from 168 to 430 euros. Sensors are:

- The Multicomponent transducer MKA from GTM (Germany) is able to detect force and torque for bearing applications.
- The Vernier Rotary motion sensor from IDS (UK) measures rotational position, velocity and acceleration for shaft applications.
- The Positioning sensor from Keyence (UK) can detect misalignment in the wind turbine.

3.10 Condition Monitoring Systems

The companies that perform structural health monitoring in Europe are presented in Table 11.

Table 11: List of condition monitoring companies

Company	Service	Land	Price (euros)	Specific data
Alava	Structural monitoring of blades, tower & foundation	ES	NK	Uses dynamic structural analysis, IRT, electrical testing, ultrasound analysis and oil analysis
Bachmann	Bachmann	AU	NK	Uses accelerometer, inclinometer, strain gauges, atmospheric sensor to perform SHM on WT
Beanair	Beanair	DE	NK	Use accelerometers & inclinometers for SHM of bridges
BES group	Condition monitoring	UK	NK	Vibration, acoustic and thermal monitoring of shafts
Censeive	Dynamic monitoring of offshore windfarms	FR	NK	SHM of the foundation of the mast
Censeive	Wireless monitoring of structures	FR	NK	Applied to bridge, but can also be applied to wind turbine Blade
Dehn	Lightning strike sensor	DE	NK	Applied on wind turbine blade
Deritend	Gearbox solutions	UK	NK	Provide laser alignment and condition monitoring (noise and vibration) of gearbox
Dimense	Measuring structures and environment	FI	NK	Measurement and monitoring of infrastructure structures
Eologix-ping	Smart Sensor for holistic blade health monitoring	AU	NK	Detects ice, damages on blades (using acoustic emission) and lightning strikes
Eriks	Vibraconnect	UK	NK	Online vibration monitoring, ideal for shaft applications
Eriks	Gearbox repair and upgrade	UK	NK	Applied specifically on gearbox. Use thermal and vibration analysis
Fibresail	Fibresail monitoring	NL/PT	NK	Focus on shape and curvature to determine the structural behaviour of the WTB
Fraunhofer	Fraunhofer	DE	NK	Use optical fibres to detect deflection on composites. Can be adopted in WTB
Full circle	Full circle wind turbine repair and maintenance	NL	NK	Service specialized in maintenance of WT but do not specify which methodology is adopted
Heidenhain	Structural health monitoring	NL	NK	Adopt ESR electro-optic sensor to measure strain, vibration and oscillation on wind turbines
Inventec	Inventec SHM	NL	NK	Uses Brillouin backscattering to measure strain
kiwa	Wind energy testing, certification and inspection	TR	NK	Analysis of foundation, mast, rotor blades, alternators and mechanical parts
Kkwind	Turbine condition monitoring	DK	NK	Adopt vibration monitoring technology to identify damages
Mistras	Mistras	NL	NK	Inspection on bearings, blades, coupling, gearbox, nacelles, tower, turbine using acoustic emission
Norwep	Structural health monitoring	NO	NK	Load and motion sensor for monitoring of cable, foundation and tower of WT
ONYX	Turbine predictive maintenance	ES	250 k to 5 M	Analyses pitch bearing, blade root connections, blade, main shaft, drivetrain, gearbox, tower and foundation

Company	Service	Land	Price (euros)	Specific data
OSMOS	Mechanical behaviour of bridges	FR	NK	Use optical fibres to detect deflection on Bridges. Can be applied on WTB
RS	Condition monitoring	UK	NK	Uses vibration and thermal analysis
Rubix	Condition monitoring service	UK	NK	Vibration analysis to detect wear, fatigue and failure in shafts
SGS	SGS asset monitornig	IT	NK	Lack of information in the website
SHM system	SHM system	PL	NK	Use accelerometers to measure vibration during the construction of buildings
Spectra	Condition monitoring	UK	NK	Perform thermal and vibration analysis to monitor the condition of machines
SPM instruments	Online monitoring of wind farm in Sweden	UK	NK	Vibration analysis of gearbox, bearing and WT shafts
SVIBS	Artemis modal analysis	DK	NK	Use modal analysis to detect damages
SYSCOM	SYSCOM	CH	NK	Evaluate the vibration of the ground in a WT farm due to the mining activity
Tarucca	Structural health monitoring	NL	NK	Use photonics and AI driven IoT solutions for SHM
TDG	TDG Structural Health Monitoring	TR	NK	Monitor vibration, acceleration, tilt, deformation, cracks and corrosion of civilian structures
Teleco Group	Teleco group Dynamical SHM	IT	NK	Applied on civilian structures. Uses accelerometers
TUV SUD	TUV SUD	DE	NK	Inspect on transmission, blades, tower and foundation of Wind turbines
Vallen	Vallen	DE	NK	Adopt acoustic emission solutions and strain gauges to monitor bridges
Vibsens	V6000 Condition monitoring	TR	NK	Measures vibration, displacement & speed
Vibsens	V400 compact machinery protection system	TR	NK	Monitors absolute and relative shaft vibration, speed
Vibsens	VA2000 Sound and vibration	TR	NK	Combines many instrument together
West aquila	West Aquila SHM	IT	NK	Use accelerometer to make SHM on Basilica destroyed by earthquake
Woelfel	Woelfel	DE	NK	Condition monitoring of blades, tower and rotor

These section compares the companies that perform structural health monitoring.

- Heidehain (The Netherlands) uses ESR electro-optic sensor to measure strain, vibration and oscillation on wind turbines.
- SPM instruments (UK) uses vibration analysis of gearbox, bearing and shafts of wind turbines for online monitoring of wind farms
- TUV SUD (Germany) performs inspections on transmission, blades, tower and foundations.
- Woefel (Germany) elaborates condition monitoring of blades, tower and rotor in wind turbines.
- Eologix-ping (Austria) detects damages in blades and the tower using acoustic emission.
- Bachmann (Austria) uses accelerometers, inclinometers, strain gauges and atmospheric sensors to perform Structural Health Monitoring on Wind Turbines.
- Partner companies in the AIRTuB-ROMI project are Mistras, Tarucca and Dehn.

4. Summary

In the previous sections, the sensor list has been presented in tables to facilitate the choice of sensors. Sensors types analysed are accelerometers, force sensors, torque sensors, microphones, electromagnetic sensors, optical measurement sensors and other sensors.

Notable accelerometers available in the European market include the WT202, WT203, AC294 and KS823B sensors, from MIP, Finland. The selection criteria adopted was based on having a suitable frequency range to measure the shafts of wind turbines. Among the force measurement sensors, are the ALF205, ALF327 and FN3002 sensors from Althen, The Netherlands, Huggenberger pre 2000/190/80 from Switzerland, LUK-A from SensorUK, in the UK and LC270 from Simstrument, in Italy. Also of interest are the compression force sensor F1227, from Wika, Croatia, the compression load cell B-DJ from Georg Buttner, Germany, the DR series force transducer from GTM, Germany and LC210 from Simstrument, Italy. The criteria for this selection was based on the proximity of level of force applied on the bearing of low frequency shafts of wind turbines.

An analysis of torque measurement sensors for low frequency shaft application identifies the customized sensor from IST-AG, Switzerland, the torque measurement flange from Luchsinger, Italy, and the Torque transducer MF from GTM, Germany. The proximity to the amount of torque obtained in low frequency shafts of wind turbines is the criteria of selection for these sensors. Options for torque measurement sensors for high frequency shaft application, include customized sensor from IST-AG, Switzerland, the Torque transducers SGR 510/520 and SGR 530/340 from Althen, The Netherlands and the Flange Torque meter 5000 from Luchsinger, Italy. The selection criteria is based on the proximity to the torque applied on the high frequency shafts of wind turbines.

Next acoustic sensors are compared. Notable sensors are the RM-VELL-06W sensor from Robotshop, France, microphone Delta OHM HD2110 from Oriene, Italy and the Free field microphone 146AE, GRAS 147EB and GRAS 46AF, from MIP, Finland. The selection criteria was based on the proximity of acoustic frequency range of the signal collected in wind turbines. Selected from the electromagnetic sensors as suitable for wind turbine applications are the HSM12 from Althen, The Netherlands, the NG inclinometer from SensorUK, and the Inductive Eddy Current Displacement Sensor, from Luchsinger, Italy. The comparison of optical measurement sensors identified the Highspeed Optical micrometer from Keyence, UK, the FDRF Laser Triangularization Sensor from Althen, The Netherlands and the Interlab Epsilon Sensor, from Poland.

Sensors for wind turbine applications from the other sensors include the Multicomponent transducer MKA, from GTM, Germany, the Vernier rotary motion sensor from IDS, UK and the Positioning Sensor from Keyence UK. The criteria adopted for the selection is based on the personal opinion of the author which is the best alternative for wind turbine applications.

The comparison of Structural Health Monitoring service companies for wind energy identified Heidenhain, the Netherlands, SPM instruments, Sweden, TUV SUD, Germany, Woelfel, Germany, Eologix-ping, Austria and Bachmann, Austria.

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Appendix

Table A1 shows additional contact information for selected companies mentioned in the report.

Table A1. Contact information for selected companies

Company	Address	E-mail	Telephone	Website
Althen	Verrijn Stuartlaan 40, Rijswijk, 2288 EL **The Netherlands**	sales@althen.nl	+31 7039 2442 1	https://www.althensensors.com/nl/
Bachmann	Kreuzäckerweg 33 6800 Feldkirch **Austria**	info@bachmann.info	+43 5522 3497-0	https://www.bachmann.info/en
Dehn	Hans-Dehn-Str. 1 92318 Neumarkt **Germany**	international @dehn.de	+49 9181 906-0	https://www.deh n-international.co m/en
Eologix-ping	Waagner-Biro-Strasse 124, 8020 Graz **Austria**	office@eologi x.com	+43 3169 3121 5100	https://www.eologixping.com/en/
Georg Buttner	Teckstr. 41, 73734 Esslingen **Germany**	contact@gbuettner.de	+49 7113 4512 00	https://www.gbuettner.de/english/
GTM	Philipp-Reis-Straße 4-6 64404 Bickenbach **Germany**	contact@gtmgmbh.com	+49 6257 9720-0	https://www.gtm -gmbh.com/en/
HBK	Schutweg 15a 5145 NP Waalwijk **The Netherlands**	info@bnl.hbm .com	+45 7741 2000	https://www.hbkworld.com/en/
Heidenhain	Copernicuslaan 34 6716 BM Ede, **The Netherlands**	info@heidenhain.nl	+31 3185 8180 0	https://www.heidenhain.nl/
Huggenberger	Via Pedemonte 5 CH-6715 Dongio **Switzerland**	info@huggenb erger.com	+41 4472 7770 0	https://www.huggenberger.com/
IDS	Unit 8 The Courtyard, Stenson Road, Coalville, Leicestershire LE67 4JP **United Kingdom**	support@inds.co.uk	+44 1530 8325 00	https://www.ind s.co.uk/
Interlab	ul. Kosiarzy 37 paw. 20 02-953 Warszawa **Poland**	interlab@inter lab.pl	+48 2284 0818 0	https://www.interlab.pl/en/
IST-AG	Stegrütistrasse 14 CH-9642 Ebnat-Kappe, **Switzerland**	info@istag.com	+41 7199 2010 0	https://www.istag.com/en
Keyence	Altius House, 1 North Fourth Street, Milton Keynes, MK9 1DG, **United Kingdom**	ukinfo@keyen ce.co.uk	+44 1908 6969 00	https://www.keyence.co.uk/

Company	Address	E-mail	Telephone	Website
Luchsinger	Via Bergamo 25 – 24035, Curno (Bergamo) **Italy**	info@luchsinger.it	+39 3546 2678	https://www.luchsinger.it/it/
MIP	Palokorvenkatu 2 FI-04250 Kerava **Finland**	sales@mip.fi	+35 8505 7123 44	https://www.mip.fi/en/
Mistras	Hofweg 15, Spijkenisse, 3208 LE **The Netherlands**	ronald.meeuwsen@mistras.nl	+31 1024 5032 5	https://www.mistrasgroup.com/netherlands/
Orione	Via della Moscova 27 - 20121 Milano **Italy**	info@orionesrl.it	+39 0265 9655 3	https://www.orionesrl.it/
Robotshop	Koperslager 8 6422 PR Heerlen **The Netherlands**	support@robotshop.com	+33 8019 0234 2	https://eu.robotshop.com/
Sensor technology	Apollo Park, Ironstone Lane, Wroxton, Banbury, OX15 6AY **United Kingdom**	webinfo@sensors.co.uk	+44 1869 2384 00	https://www.sensors.co.uk/
Sensor UK	Sensors UK Ltd 135a Hatfield Road, St Albans AL1 4JX **United Kingdom**	sales@sensor suk.com	+44 1727 8593 73	https://www.sensorsuk.com/
Simstrument	Via Merendi 42, 20007 CORNAREDO (MI) **Italy**	info@simstru menti.com	+39 0297 0030 39	https://www.simstrumenti.com/en/
SPM instruments	Unit 11, Forty8 North 48-56 Duncrue Street Belfast BT3 9BJ, **Northern Ireland**	info@spminstrument.co.uk	+44 1706 8353 31	https://www.spminstrument.co.uk/
Tarucca	TU/e Campus - Alpha Het Eeuwsel 57 5612 AS Eindhoven **The Netherlands**	LetsTalk@tarucca.com	+31 6826 2517 6	https://www.tarucca.com/home
TUV SUD	Westendstraße 199 80686 München **Germany**	info@tuvsud.c om	+49 8957 91-0	https://www.tuvsud.com/en
Wika	Industrial estate De Berk, Newtonweg 12 6101 WX Echt **The Nederlands**	info@wika.nl	+31 4755 3550 0	https://www.wika.nl/
Woelfel	Max-Planck-Straße 15 97204, Höchberg, Bavaria **Germany**	bernd.woelfel@woelfel.de	+49 4052 4715-266	https://www.woelfel.de/en/