Paving the way to wireless fiber optic sensing applied to helicopter rotor blade instrumentation and monitoring

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ABSTRACT

Between 2018 and 2021, Airbus Helicopters and Safran Data Systems have conducted an innovation project called HIRIS in the frame of a European project aiming at developing a new wireless technology for helicopter rotor instrumentation and included operational Flight Tests on the field during 10 months and 60h flight hours.
In the meantime, the interest for Fiber Optic Sensing (FOS) technologies has grown up in the aerospace domain for various structural and environmental monitoring use cases. Safran Data Systems, Safran Tech and FiSens have paved a way to design an ultra-compact optical interrogator compliant with the airborne environments and integrated in a modular Data Acquisition Unit.
This paper aims at demonstrating that the latest wireless instrumentation techniques associated with innovative FOS technologies open the capabilities to instrument and monitor helicopter rotor elements such as Rotors blades with an unprecedented level of performances, reliability and low intrusiveness.

Keywords: Fiber Optical Sensing, wireless, rotor instrumentation, flight testing, health monitoring

INTRODUCTION

Acquiring helicopter rotor data is always a very sensitive point that requires at least “effort and special attention". This data acquisition is generally managed by a "physical link" (slip ring for example) whereas wireless products are now present everywhere with a technology more than promising.
In addition, new generation of sensor such as Fiber Optical Sensing offers exciting opportunities for better monitoring of helicopter rotor blades.

The objective of this paper is to show how the wireless technology was developed within the framework of RACER COUMPOUND HELICOPTER for Flight Test Instrumentation domain not withstanding that this wireless acquisition means will be used on a daily basis to monitor the data from the three rotors.
The paper provides an overview of this project, supported by the CEE (Horizon 2020/CS2), and from the initial requirement up to the operational results obtained during the flight test campaigns carried out on the H175.
The paper, based on the very last development of a new Fiber Optical Sensing technology, aims also to open the perspective of using such a wireless and Fiber Sensing application on helicopters in service in the frame of health monitoring system

PART 1: Wireless instrumentation of RACER compound helicopter Rotors

1.1 Introduction

In the frame of EUROPEAN program H2020 CLEANSKY2, AIRBUS HELICOPTERS lead the RACER compound helicopter development project.
RACER is a very ambitious challenge regarding the complete flight domain targeted but also the introduction of several breakthrough embedded technologies.

Concerning the Flight Test Instrumentation (FTI) purpose, this breakthrough technology supported by CEE CS2 is focused on the Wireless data transmission from the 3 rotors up to the fuselage.

Data acquisition and monitoring in rotating axis, usual for helicopter's rotors, are always very sensitive points which need at least ***"some effort and attention".***

Mainly this data acquisition is usually managed via a "physical link" (slip rings" for example).
But, the tendency is to try to use wireless products taking into account that this technology is more than promising However, despite some initiatives, no product on the shelf is fully compliant with operational expectation related to helicopter's rotors flight such as mechanical integration (CS29 amdt 2) or daily usage and flexibility including environmental condition (DO160G) and also power supply.

Based on this statement, AIRBUS HELICOPTERS Flight Test Dept. has proposed a wireless subject applying to helicopter rotors to the CEE Expert colleges.

The subject has been validated in the frame a CEE CS2 call for partner and SAFRAN DATA SYSTEM **HIRIS** project **- Helicopter Innovative Rotor Instrumentation System-** has been selected in order to develop a wireless data transmission system able to transfer from helicopter's rotors up to fuselage a large amount of data: *Grant Agreement number: 785411 — HIRIS — H2020-CS2-CFP06-2017-01.*

1.2 HIRIS PROJECT: from initial requirement up to technical solution

The initial requirement aims to answer to the following question/ challenge:

"Nowadays, for prototype operational Helicopters environment, are we able to transfer data (~30Mbit/s) from Rotor's up to fuselage for an entire flight by ***using Wireless technologies without usage of battery power supply*** *and with level of reliability comparable to a "wired technology"(TRL7) meaning* ***No data loss and high accuracy time tagging (~100ns)?***

The initial integration requirement is based on the schematic Fig.1.

The most important functional requirements of the means needed to perform RACER flight test are:

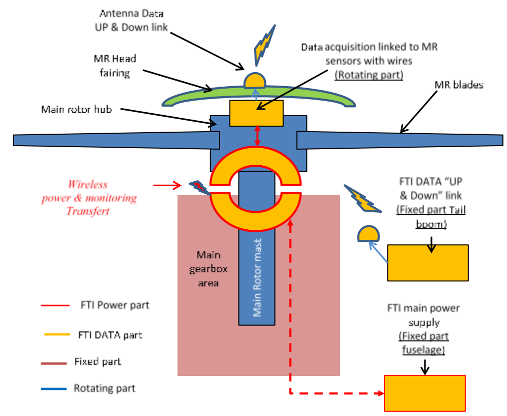

Fig.1: initial integration requirement

- Parameters type: Full/half/quarter bridges, temperature (PT100/ Type K), IEPE accelerometers, potentiometers but also include new technology such as numerical bus and/or Fiber Optical sensor
- Rotor rotational speed: 0 to 2500 rpm
- System fully settable by soft: FS range/bandwidth/offset….
- Temperature usage: -50 to +100°C and All Measurement temperature compensation: -40 to +85°C
- Accuracy/Ch. (all included with temperature drift) Less than 0,3% FSR
- Rotor data transmission by wireless link
- Power supply : DC power 16 to 40 V, wireless: **power by battery must be avoided (mandatory)**
- Data bus delivery format: Output of the system must be in ETH IENA format (compatibility with AIRBUS)
- Data time stamping: All data must be synchronized and time tagged following PtP time protocol (IEEE 1588) V1 & V2
- The configuration file must fully compatible with XIDML, XIDefML file format
- Mechanical integration : compliant with rotor head design without any fairing modification
- Mechanical design & Substantiation According with CS29 amdt 2 regulation & validated by AIRBUS
- Environmental constraint: Compliant with due Rotorcraft chapter DO160 G for temperature, vibration, humidity, shock, EMI/EMC.

1.3 SAFRAN DATA SYSTEMS HIRIS PROJECT: TECHNICAL SOLUTION

Based on XMA family product, HIRIS is designed for Rotor’s heads to be as less intrusive as possible than a fully wireless solution. HIRIS provides enhanced acquisition and synchronization performance as well as versatility, robustness and easy-to-use capabilities but induced the development of a complete new set of modules:

- **New mechanical interface / housing:**
  The housing of the HIRIS DAU has been designed to cope with the Rotor’s environment constrains in compliance with design mechanical rules according with CS29 amdt2 dedicated to Rotor’s part.

- **New Wireless data transmission & time tagging: XMA-WLS**
  This module leverages 2 well known technologies from the consumer world:
  - ✓ WIFI (band 5Gz) for data down link transfers up to 30Mbit/s and also up loading configuration /monitoring
  - ✓ UWB (band 3Gz) for uplink protocol time stamping data in rotating axis before WIFI transmission
  - ✓ Both signal are connected to 1 antenna through an dedicated diplexer

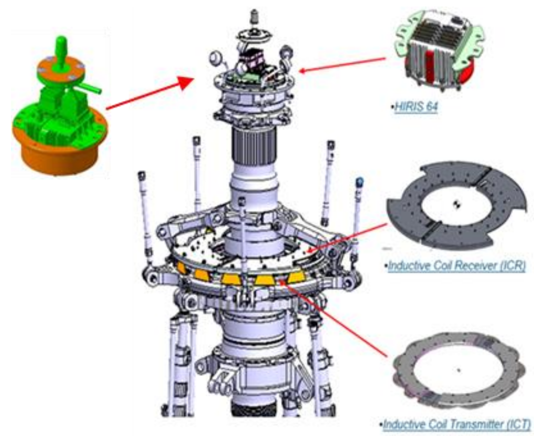

Fig.2: HIRIS installation scheme for the main rotor

- **New Strain gages acquisition board can support:**
  - ✓ Full-bridge, half bridge and quarter bridge acquisition on the same module providing 8 independent channels.
  - ✓ Input ranges go from +-128mV (+-500ppm FSR accuracy) down to +-4mV (+-1500ppm FSR accuracy) allowing a very low sensitive sensors.
  - ✓ Additional features like: Analog Zeroing, DC offset and Shunt calibration are also provided and improve the quality of the measurement.

- ✓ **New power supply unit <u>avoiding</u> battery**:

  The mandatory requirement forbid usage of any battery and the system must be operable as soon as the FTI 28VDC power is switched ON. Therefore the choice of power supply was focused on inductive power transmission inspired by QI standard (“TCHI”).

  The inductive power system is made up of 4 parts:
  IPCT: Inductive DC/AC power converter + 2 Inductive coil (ICT/ICR) + 1 IPR inductive power receiver within HIRIS DAU
  The yield is around 50%-60% when installed on the mostly metallic main rotor and the power efficiency of this inductive link is fully monitored in operation allowing real time survey.

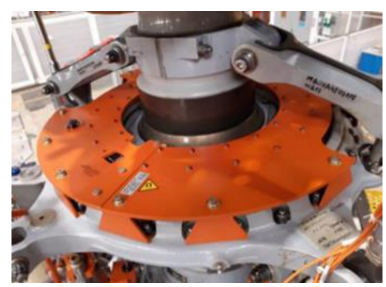

Fig.3: HIRIS inductive coils (ICT/ICR)

- ✓ **Without forget that the "eZ" SDS software suite** must be upgraded for compatibility with the new hardware module, but also implementation within "eZ" of a transformation gateway capable of converting the MDL format (native SDS) to the XiDML format, to be perfectly consistent with the software suite and compliant with AH usage …

Finally, the HIRIS RACER architecture proposed in the fig. 4 below includes in addition of the part installed on Rotor’s, the receiving hardware based on XMA system and enabling the data transfer over IENA Ethernet protocol.

1.4 HIRIS COMPLIANCE with mandatory standard:

- **Mechanical design according with CS29 amdt 2**
  - ✓ Initial statement: any mechanical issues of component installed on rotors may have a catastrophic impact on the safety of the helicopters.

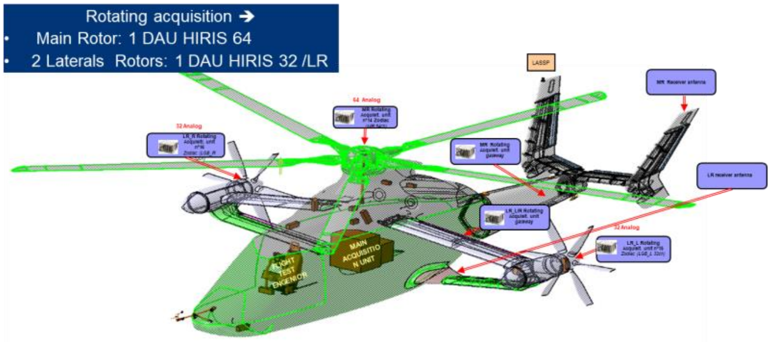

Fig.4: Overview of RACER compound helicopter FTI

Given these significant statement any HIRIS component installed on the rotor and/or near the rotor have been dimensioned and justified in accordance with the rules of definition compatible with the CS29 Amdt2 regulation applicable to helicopter rotor included the choice of material, the thickness of the parts, and the number/dimensioning of the fixing points….
All the drawings and substantiation document authored by SDS have been validated by the due CVE (Compliance Verification Engineer) from AIRBUS HELICOPTERS.
Finally after AIRBUS global safety installation analysis by due EXPERT domain and AH airworthiness department, HIRIS system has been declared safe to fly under AH DOA.

Environmental constraints according with DO160G ground tests:

The HIRIS system has to be compliant with the environmental constraints in usage following the D0160 G dedicated to rotorcraft.
Some requirements have been justified by equivalence with XMA qualification but some had to be <u>specifically addressed and tested</u> due to the importance of the subject on the safety aspect and also on the mandatory target to be reached for flight test purpose on helicopter’s rotors.
These DO160G tests were carried out in SDS facilities laboratory in order to identify compliance and/or deviations from the target and allow us to validate the authorization to fly for prototype purposes.

- ✓ Temperature: DO160 G chap 4
- ✓ Vibration: DO160G chap8
- ✓ EMI/EMC: DO160G chap 20
- ✓ Power supply: DO160G chap 16 & 17

<u>In addition some tests not included in D160 have been also performed</u>:

- ✓ Rotation tests up to 2340 rpm (test bench limit)
- ✓ Data Time synchronization compliance to specification in order to insure that all data coming from the wireless link are accurately time tagged and synchronized with the DAU installed in fuselage. And finally specific tests within AH premises have been performed to verify the compliance with AIRBUS HELICOPTERS FTI processes and rules bases on IRIG 106 standard.

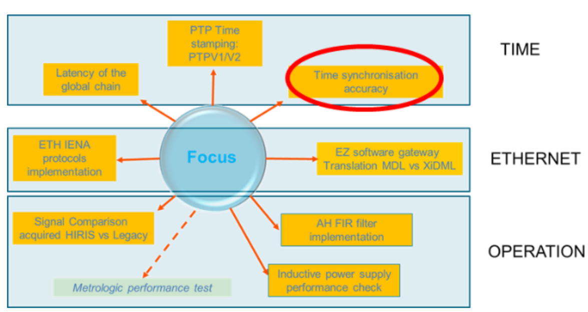

Fig.5: AH test plan

AH test plan have been focused on 3 families of tests**:**
TIME / ETHERNET / OPERATION

All tests conducted within SDS and/or AH facilities has been PASSED

1.5 HIRIS maturity Flight TESTS:

Base on Ground tests results and the statement of airworthiness "**HIRIS safe to flight**", the HIRIS prototype has been installed on H175 main Rotor and the **7th of June 2021 HIRIS 1er flight** has been performed. During this first flight, the complete flight envelope of the H175 was covered without any major issue on HIRIS system and no detrimental impact on the helicopter due to HIRIS installation.

Fig.6: HIRIS prototype mounted on H175 main rotor

Since this first flight, 60 flight hours over 10 months on the field have been performed and all the H175 flight spectrum had been tested. The main feedback related to HIRIS is the following:

Positive:

- Operability /reliability of HIRIS = 100%
- Configuration tested up to 64 channels up to 8192 sample/channel (~17Mbitps)
- Low effect on the wireless link due to Main Rotor mask effect
- No effect of the flight condition such as, Helicopter roll & pich attitude, air speed, altitude, vibration, rotor speed, temperature, radio com ….
- Inductive power supply stability & reliability within all flight domain from engine start up to nominal main rotor speed
- Wifi down link budget up to -60dBm & stable
- Data bit rate up to 17 Mbit/s without any impact on the WIFI budget level

Fig.7: HIRIS 1st flight on H175

Summary: Reminder the initial question, *"Nowadays, for operational Helicopters environment, are we able to transfer data from Rotor'……*and the answer is: YES WE ARE ABLE TO

-Use a wireless technology on daily basis on helicopter prototype environment to perform flight tests according with safety rules (CS29) and environmental constraints (DO 160G)
-Acquire & transfer a large amount of data with reliability equivalent of wired technology and included high accuracy of time tagging.
-Deliver power to acquisition means using a wireless technology easy to install on in service helicopters and without usage of any batteries.

1.6 NEXT STEPS TO COME: pave the future

Obviously, the **short term** next step to come is the HIRIS system installation on RACER Rotor's within the coming months in order to be able to perform the 1st flight.

On the mid-term, taking benefit of the modular architecture of HIRIS which will become soon a COTS product, it will be achievable to acquire data coming from new type of sensors such as MEMS sensors and/or Fiber Optical Sensors installed on rotors parts for pressures / vibrations / temperatures at blade level, for example, in order to increase knowledge on aerodynamic environment and due effect dynamic load.
Regarding MEMS sensors aggregated on the digital bus line, the technology already exists and HIRIS DAU is able to transmit this data thanks to its high data rate capacity.

Concerning Fiber Optical Sensor usage in helicopters environment, the technology is at the beginning and a new module is under development within SDS premises and first prototypes are under lab test. On midterm some test should be performed for prototype purpose with instrumented blades both legacy sensors and Fiber Optic Sensing.

PART 2: Fiber Optic Sensing technology

2.1 Origins of Fiber Optic Sensing

Fiber optics are well known in the field of telecommunications as they made it possible to reach higher and higher data transmission rates over longer and longer distances.

In parallel, fiber optics found rapidly growing use in the field of sensing for various applications: energy, civil engineering, transportation and many others such as smart factories, biomedical…

The integration of fiber optic sensing systems in an increasing number of fields is made possible thanks to intrinsic characteristics of fiber optics. These specifications allow fiber optics to reach environments where conventional sensors cannot operate and densify the sensing capacity.

The main advantages of fiber optic sensors are: reduced weight and size, immunity to Radio Frequency Interference and no emitted Radio Frequency, compatibility with ATEX environments and harsh environments (high temperature and/or irradiated environments), high density of sensing points along the fiber optic and good metrological performances.

2.2 Fiber Optic sensing Technologies:

Fiber optic sensing technologies share a common architecture. The "brain" of the system is the interrogator, it consists of the active components that generate and collect light and the necessary electronics for data processing and transmission. The interrogator is coupled to the sensing fiber optic which will reach the DUT (Device Under Test).

The schematic architecture of a fiber optic sensing system is shown in figure 8.

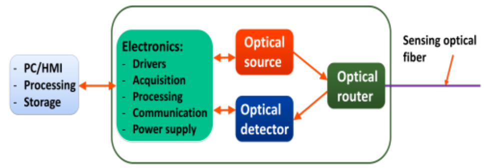

Fig. 8: Block diagram of fiber optic sensor interrogators

FOS technologies can be classified into three main families:

- **Distributed sensing systems**: these systems allow to measure a high number (up to tens of thousands) of sensing points along the optical fiber. They are based on different backscattered phenomena (Rayleigh, Raman and Brillouin). Both OTDR (Optical Time Domain Reflectometry) and OFDR (Optical Frequency Domain Reflectometry) principles can be used to perform distributed fiber optic sensing. The drawback of these systems is the sampling rate which is quite low (in the order of the second) regarding the massive quantity of processed data. The distributed sensing systems perform various types of physical measurements such as vibrations measurement or temperature using DTS.
- **Quasi-distributed sensing systems: t**hese systems allow to measure a moderate number (up to approx. 100) of sensing points along the fiber optic. They are mostly based on FBGs (Fiber Bragg Gratings) which mainly utilize Wavelength Division Multiplexing (WDM). These systems can reach sampling rates up to tens of kilohertz. The Quasi-distributed sensing systems perform various types of physical measurements such as temperature, strain and displacement.
- **Point (Punctual) sensing systems: t**hese systems allow to measure a single sensing point generally located at the tip of the fiber. They are based on several techniques (Interferometric cavities such as Fabry-Perot, power modulation…). They are often used for dynamic and static pressure measurement. The sampling rate can exceed 100kHz.

2.3 Challenges in the field of aeronautics

Fiber optic sensors technology is already widely used in different fields of application. For the aeronautic field, its use implies to take into account specific challenges related to harsh environments:

- Interrogator: Capacity to be embarked (weight, volume), environmental stress (temperature, vibration, sealing…).
- Reliability: Due to the long lifetime of the devices, strong environmental constraints (thermal cycling…) and metrology (drift, hysteresis…).

- Metrology: Maintain the performance targeted by the application (acquisition frequency, number of sensors and measurement channels, accuracy, noise and stability ...).
- Integration: Ensure the integration of sensors, routing fibers along different paths and in harsh environments (Curvature radius, how to fix fibers, mechanical protection, maintenance…).
- Costs: Systems must be at an affordable price to be considered for deployment on a larger scale.

2.4 Focus on Fiber Bragg Grating technology

Fiber Bragg gratings (FBG) are known for more than 40 years [5] and consist in general of periodic changes of the refractive index within an optical waveguide leading to the reflection of a certain wavelength resonant to this refractive index pattern (fig. 9).

Fig.9: Basic principle of fiber Bragg gratings: a periodic refractive index modification leads to a reflection of a specific resonant wavelength.

Spectroscopic techniques are obviously some of the most common tools to analyze reflected wavelengths of light. However, for about one hundred years the construction of dispersive high-resolution spectrometers has been following the same pattern: light enters the spectrometer through a narrow slit, a mirror or lens is used to collimate the light on a diffractive grating and finally a second imaging optic is used to create the wavelength resolved light distribution on a detector (e.g. [6]).

A precise interrogation of FBG wavelengths by means of a spectrum analysis requires a high optical resolution in the order of 0.1-1.0nm. To date this parameter can only be achieved by extending the overall optical path within a common spectrometer expanding the light cone essentially illuminating more lines or grooves of a diffraction grating. Unfortunately, this leads to bulky, heavy, and expensive devices with low light and energy efficiency.

In [7] and [8] FiSens first presented a fiber-integrated spectrometer which overcomes these limitations.

Utilizing this proprietary process FiSens also creates a precise periodic formation of ellipsoid nanostructures within the core of an optical fiber. By this patented apparatus [8] FiSens can encode all components for optical imaging usually needed for a common spectrometer (slit, lens or mirror, diffraction grating, lens) directly into the core of an optical fiber (Fig. 11). The resulting spectrometer requires only a second component: a detector (e.g., CMOS) to be placed in a lateral focal plane next to the fiber to capture all outcoupled and diffracted light with high intensities.

2.5 Fiber-Integrated Spectrometer:

To obtain an actual optical image at a predefined lateral focal distance to an optical fiber it is necessary to chirp the spacings between each point of the fiber-integrated diffraction grating. For instance, for a spectrometer in the visible region the required spacings between the grating points for the most efficient first order diffraction grating is in the range of 0.5µm with a change of the period of only slightly more than 10nm. Therefore, an extremely precise and reproducible setup for the PbP fs-laser inscription is required.
In the example shown below a diffraction grating has been simulated to support the simplest geometry for an actual visible spectrometer: a parallel positioning of detector and fiber and a wavelength sensitivity over the entire visible spectrum between 400 nm and 800 nm.

Figure 10 depicts simulated directions of constructive interference for different wavelengths: the Bragg angles for the first, the last and one pair of neighboring points in the middle of the grating are visualized. Additionally, the resulting focal position for each wavelength is marked. In this case the combined image appears quite symmetrically curved to the waveguide and the overall error for a parallel placed detector is minimized.

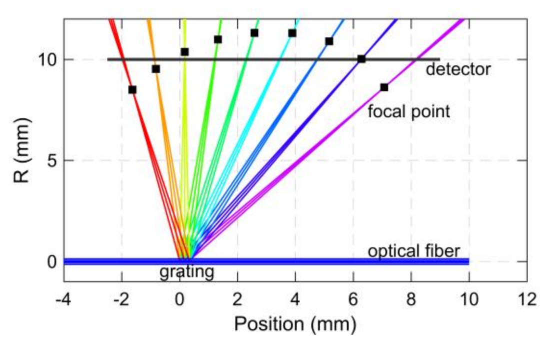

Fig.10: Simulated directions of constructive interference of two neighboring points at the beginning, the middle and the end of an aspheric chirped grating

Applying the results of these brief simulations a fiber integrated spectrometer for the visible range has been created and no pre- or postprocessing has been performed on a polyimide coated standard single mode fiber.

Figure 11 shows the fiber-integrated diffraction grating positioned above a simple sheet of paper, first illuminated by a red diode laser of 650 nm (a) and afterwards by a white light LED (b).

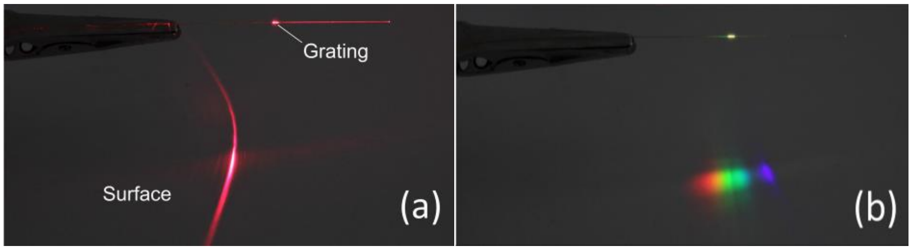

Fig. 11: a) red diode laser, b) white light LED imaged on a flat surface from a chirped first order PbP processed fiber-integrated diffraction grating by femtosecond laser pulses.

The laser light shows one singular bright red line, which focuses on the targeted distance from the core of the fiber at approx. 13 mm. For this wavelength a second order scattering occurs at a too small angle to leave the fiber due to total internal reflection. This second order is coupled to the cladding and coating of the fiber and results in an additional reddish glow beyond the grating. The white light leads to a clearly resolved rainbow including the LED-typical gap before the blue-UV region.

This fiber-integrated spectrometer represents the main building block for the analysis of reflected FBG wavelengths and can detect them with high optical resolution and light intensity.

2.6 Ultra-compact FBG-Interrogator

To accomplish the construction of an ultra-compact and high-performance FBG-Interrogator it is mandatory to inject high optical power into the waveguide, routing it to the FBG sensors and back to the spectrometer.

One highly space-consuming optical component within FBG-Interrogators is the routing of the optical fiber itself by means of optical circulators, couplers, switches, or fiber loops. By introducing the spectrometer into the optical fiber, the whole routing of it can be drastically reduced.

As seen in Fig 12. FiSens uses a bi-directional approach around a single monolithic optical fiber. The optical power of the light source is directly guided through the fiber-integrated spectrometer a first time while being routed to the FBG sensors. Since the fs-laser induced grating diffracts light at different angles dependent on the direction of light impinging on it, the light guided from the light source is outcoupled into an adverse direction and eliminated in a stray light trap. Only the light back reflected from the FBG sensors are directly imaged on the CMOS detector.

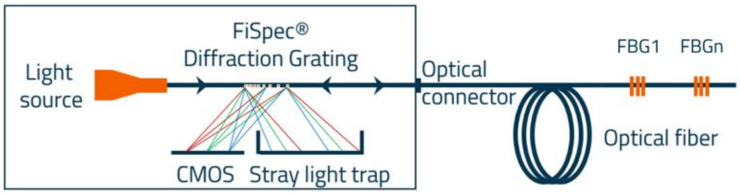

Fig. 12: Schematic illustration of a patented [4] FBG Interrogator around a single monolithic optical fiber.

Furthermore, the choice of operating wavelength for light source, detector and optical fiber plays a critical role. It is advantageous using 850nm over 1550nm due to the detector being silicon-based and only half the size. The higher attenuation at this wavelength can be neglected for applications of fiber lengths ranging up to 500m. The advantages of 850nm over 1550nm are:

- FBG sensor length of only 1-3mm for pin-point spatial resolution
- Critical fiber bending radius of only 5-6mm for tight routing
- Highly reduced costs and proven availability of CMOS detector
- CMOS detector with pixel-to-pixel pitch down to 5,5µm enabling high resolution

One of the key challenges with optical spectrometers and FBG-Interrogators are their ambient temperature dependent wavelength-drift. This effect occurs due the thermal expansion of detector and optical components. By shrinking the spectrometer build-up to only two very narrowly spaced components (i.e. fiber-integrated diffraction grating and detector) this effect can be reduced by several factors. Utilizing advanced materials like Invar36 around these two components can further minimize this effect. However, this alone will not be sufficient for a robust and stable sensor signal.

To overcome the full problem and stabilize the base line of the FBG sensor signal over the full operating temperature one can either actively thermally control the spectrometer (e.g., Peltier element) or passively compensate any base line drifts of the spectrometer using reference sensors inside the spectrometer. Hence, the most obvious solution is to use one FBG sensor of the available spectrum inside the single monolithic fiber of the FBG-Interrogator itself. This internal reference FBG sensor measures any changes in the device temperature and compensates against it.

2.7 Adding Fiber Sensing capability to a compact modular data acquisition unit

The XMA modular data acquisition unit designed by SDS, has been selected by major aircraft and rotorcraft manufacturers for more than a decade. The modules that compose this device can be of different types: analog and digital acquisition modules, video acquisition modules, data storage, data transmission (wired or wireless), software customization (by hosting and running user defined algorithms) and hardware customization (by hosting and powering user defined electronics).

Fig. 13: Example of XMA modular Data Acquisition Unit with 6 modules and a power supply

Among all the challenges anticipated, the mechanical integration of the FBG interrogator has been the first roadblock encountered. The volume offered by an XMA module housing is rather limited (50x80x11mm) as originally designed to high-end fine pitch electronics parts and not optical components. The other challenges are the electrical interfacing (powering and data communication) and the synchronization / time stamping in order to provide consistent time aligned measurements that can be correlated with the other types of measurements.

Applying an agile methodology, SDS, Safran Tech and FiSens have decided to follow an iterative roadmap to integrate and ruggedize the FBG interrogator in the XMA product thanks to the XMA-PRO and EXT modules which are off-the-shelf modules dedicated to host custom third party electronics in a standard XMA module housing.

Thanks to the novel approach brought by FiSens and design simplification an ultra-compact FBG-Interrogator has successfully been integrated into the XMA form factor. (see Fig. 15). This first prototype of XMA-FBG combines a set of beneficiary properties:

- Dimensions of only 50x80x20mm
- Reduced weight of only 160g
- Low power consumption ~1W
- Simultaneous detection of all sensors (up to 30 FBG) without dead times
- High Precision of 1µe (@100hz, σ)

Fig. 15: 1st aerospace grade FBG-Interrogator prototype supply

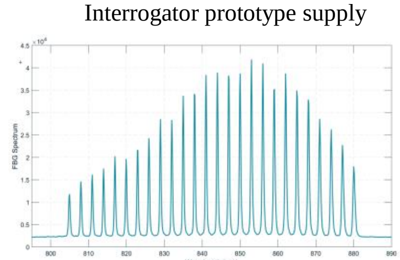

Fig. 16: FBG spectrum at 808-880nm

The next steps will be to characterize the design in temperature, vibration/shocks and to run a first set of EMI/EMC testing. If needed, the design will be adapted following the same agile methodology.
Then, if all these test runs well, the target is to fly this first version of the XMA-FBG module on various test vehicles (fixed-wing and rotary-wing aircrafts) in order to meet quickly real flight conditions and to assess the benefits of this highly integrated FBG interrogator in a mature DAU.

2.8 Benefits of miniaturization and integration

Compared to stand-alone FBG interrogators, the miniaturization and modular approach offers the following benefits:

- **Mechanical installation in the test vehicle**: whatever the content of the XMA stack, only four mounting screws are required.
- **Scalability**: one or several FBG modules can be hosted in a single stack whatever the form factor: XMA-CORE8, XMA-CORE16 or XMA-ROTOR
- **Versatility**: capability to mix fiber sensing measurements with heterogeneous data types in the same data acquisition unit: legacy analog sensors (resistive strain gages, accelerometers, RTDs, thermocouples, pressure sensors,…), digital (avionic buses), discretes, video acquisitions,…
- **Homogeneous connectors**: obviously, the interface with the optical fiber implement a specific connector but data communication of the XMA-FBG module uses standard XMA microComp D-type connector.

Fig. 17: XMA-ROTOR with 2 FGB interrogators + 5 other modules

- Electrical powering of the XMA-FBG modules comes from the XMA power supply module (XMA PSI / PSS) through the backplane and therefore take benefits of a fully isolated, DO-160 / MIL-STD704 qualified design.
- **Full integration** in SDS instrumentation system: configuration, synchronization, stand-alone or distributed architecture, wired or wireless network capability, standard compliant data stream (IRIG-106, IENA, …), on board recording, processing or telemetry,…
- **Ruggedization**: the ultra-compact FBG Interrogator will take benefits of the flight proven mechanical architecture of the XMA in order to be compliant with the demanding environments of flight-testing.

CONCLUSION

The collaboration between AIRBUS HELICOPTERS and Safran Data Systems demonstrated that a full wireless instrumentation of a helicopter rotor offering the same level of performance as a wired one is achievable.

The collaboration between FiSens, Safran Tech and Safran Data Systems has led to a first successful integration of a downscaled FBG interrogator. Some maturation steps still needs to be tackled but the first results are already promising.

The combination of both wireless technologies and Fiber Optic Sensing technologies, fully integrated in mature and comprehensive flight test instrumentation system opens new perspectives for helicopter blade instrumentation.

In additions, the maturity test plan run on H175 has demonstrated that this technology could be deployed on any in-service helicopters in the frame of health monitoring usage enabling monitoring of dynamics system at rotor level. A Wireless Fiber Optic Sensing system qualified to helicopter rotor head environments would open the way to a major improvement in the health monitoring system and would give the opportunity to manage and support flight safety and maintenance in operation.

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