METHOD FOR FIBER OPTIC STRAIN AND TEMPERATURE MEASUREMENTS OF RAPIDLY ROTATING AEROSPACE STRUCTURES

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Abstract

Rotating mechanical structures are commonplace in aerospace mechanisms, e.g. jet engines and helicopter rotors. Complex structures such as these will significantly benefit from "structural health monitoring" (SHM) during their lifetime, to ensure sound operation, to schedule maintenance, and even to provide early warning of imminent failures.

A generic approach for contact-less fiber-optic strain and temperature measurements in rapidly rotating structures is presented. This approach does not require optical ingress via the rotation axis, but rather relies on optical free-space coupling once every rotating cycle. In this work, strain-sensing of a body rotating at 5,000 rpm has been demonstrated, and other measurands, as well as higher speeds should be possible. Strain has been measured in-situ during rotation, and results agree very well with predictions. Such a method can be implemented to monitor rotating structures in-situ during operation.

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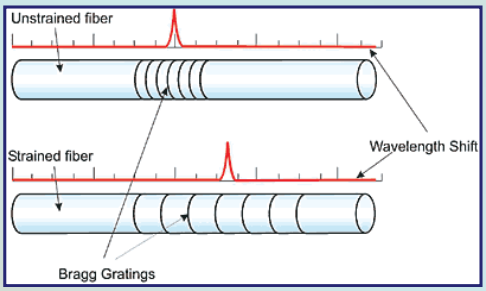
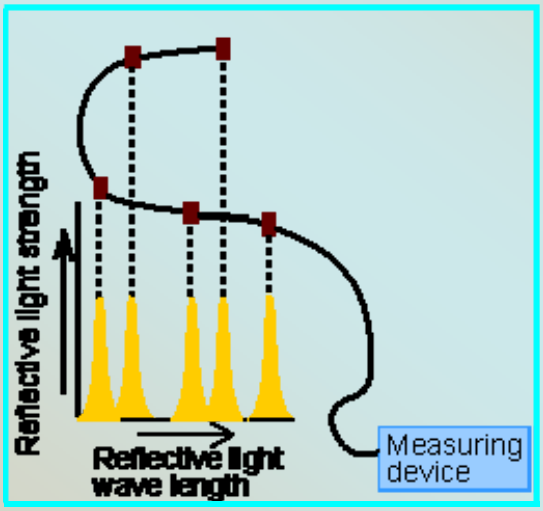
Optical Sensors based on Fiber Bragg Gratings



Are used to measure:
- Strain
- Temperature
- Pressure
- Torsion
- …

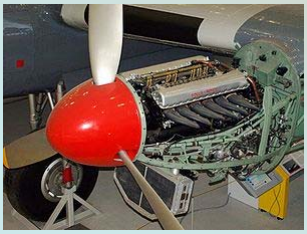
FBGs:
- Are tiny - ~1/4 mm dia.
- Immune to electro-magnetic radiation
- Withstand harsh environments (e.g. salty water)
- May be embedded in composite materials/structures
- May be multiplexed

Multiplexing FBGs

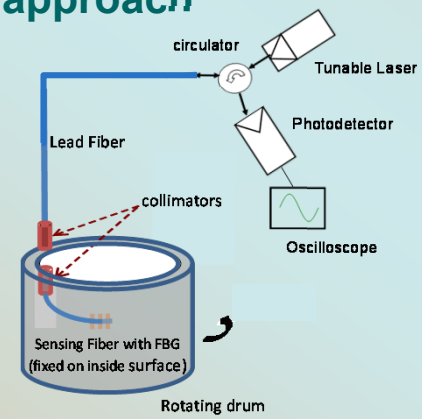


- Every FBG has its spectral regime that identifies it uniquely.
- All the measurands are deduced from the variations of all spectral responses.

Rotating aerospace structures

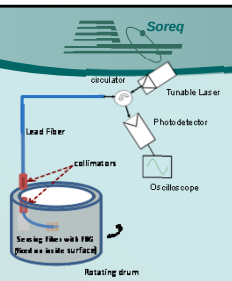


Merging both technologies: Conceptual approach

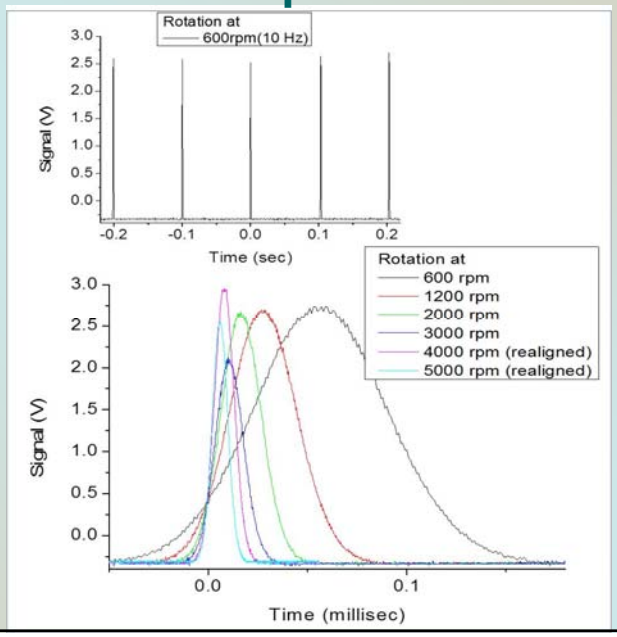


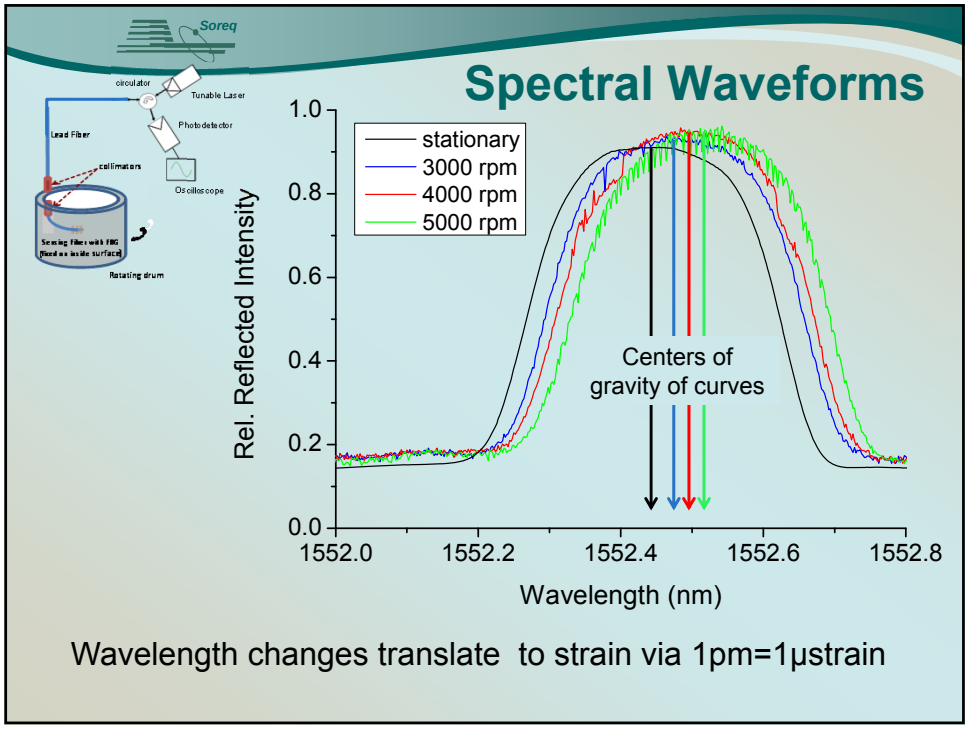
- Separation into "sensing fiber" and "lead fiber" with attached collimators.
- A "sensing fiber" with FBGs is attached to the rotating structure.
- A stationary "lead fiber" connects to the optical interrogation system.
- Both collimators meet once every turn, and light passes from lead to sensing fiber (and back).

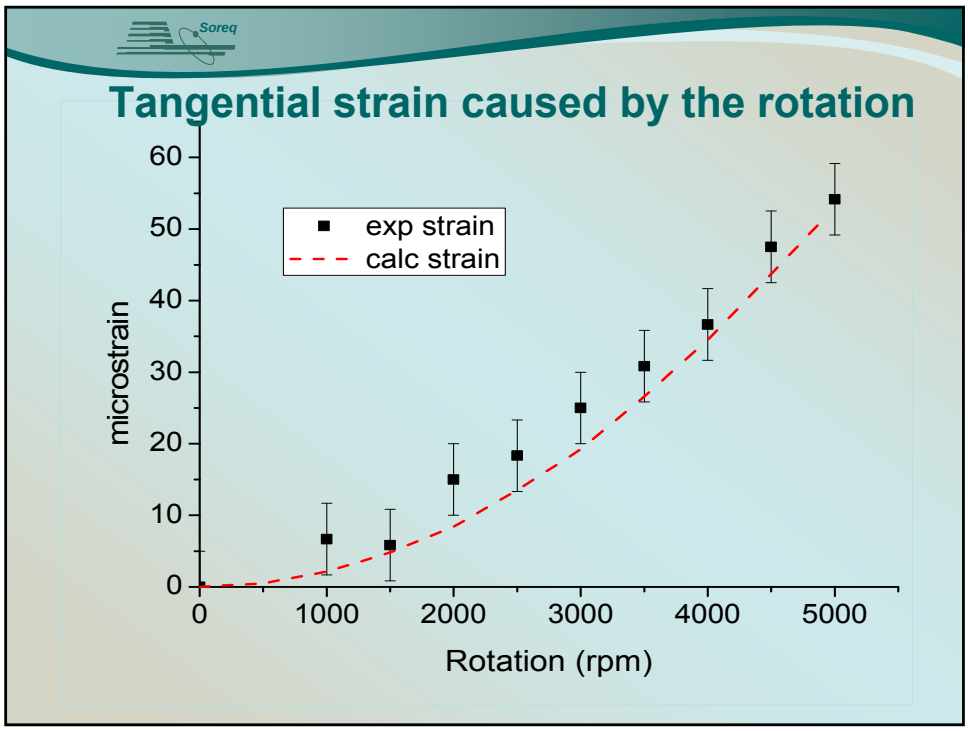
Temporal Waveforms



- Wavelengths are slowly scanned
- Maximum of temporal curve is registered for each wavelength




Soreq
Spectral Waveforms
circulator
Tunable Laser
Photodetector
Lead Fiber
collimators
Oscilloscope
Rotating drum
stationary
3000 rpm
4000 rpm
5000 rpm
Rel. Reflected Intensity
1.0
0.8
0.6
0.4
0.2
0.0
1552.0
1552.2
1552.4
1552.6
1552.8
Wavelength (nm)
Centers of
gravity of curves
Wavelength changes translate to strain via 1pm=1μstrain


Soreq
Tangential strain caused by the rotation
exp strain
calc strain
microstrain
60
50
40
30
20
10
0
0
1000
2000
3000
4000
5000
Rotation (rpm)

Summary

- Fiber-optic strain measurements performed in a structure rotating at up to 5,000 rpm.
- Measurements at higher rotation rates and of other measurands are possible.
- Measurement time: several minutes.
- Does not require access to the rotation axis.
- Applications: aircraft engines (piston or gas turbines) helicopter blade engines, wind turbines, etc.