Fibre-optic structural health monitoring in the energy industry

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Abstract
Design and construction of fibre Bragg grating sensor systems are described for implementation of structural health monitoring in energy plants. Concrete application examples in conventional, renewable and nuclear energies demonstrate their versability and achievement potential.

Introduction
With general industrial progress, the demand for energy is rising, prices for fossil fuels and raw materials do as well. Power plant operators and designers look for diversification of power generating sources - besides conventional fossil fuel based power plants, nuclear fission plants are coming up (and fusion plants in a more distant future), and also renewable energy sources are gaining in importance. A recent boom of wind energy plants, in particular in China, India, and Australia, can be observed.
While operators focused formerly on reliability and availability and on extremely long lifetime of power components, the new design of power components aims at increasing efficiency and thereby using less material. Higher efficiency causes higher stress on materials and structures - extensive condition monitoring of power components is the necessary consequence [1].

Characterisation of sensors and monitoring systems
The monitoring tasks in the special conditions of energy facilities ask for the specific advantages of fibre-optic sensor systems:
- full electrical isolation, no interference with high voltage
- neutrality to electrical and magnetic fields, lightning safety
- explosion-proof
- embeddability of sensors and multiplexed sensor arrays in composites ("Smart Structures")
- low-loss, high-bandwith transmission of analogue measuring signals, in particular of spectrally encoding fibre Bragg grating sensors ("Remote Sensing").

The technical means are analysed, which make fibre-optic Bragg grating (FBG) sensors to an attractive solution for structural health monitoring in energy facilities: draw tower Bragg gratings of highest mechanical endurance (Fig. 1), sensor-specific fibre coating [2], packaging, and mounting technologies, robust low-cost and high-quality sensor interrogation technique ([3], Fig. 2).

Application examples
Requirements, design criteria, sensor system parameters, and experimental results of field tests of FBG sensor health monitoring systems will be reported from numerous practical experiences, which have been collected at IPHT Jena in collaboration with its partners in energy industry:
- Electrical generators: Temperature and strain/ vibration monitoring, both of them measured directly on the high-voltage current windings; monitoring of the homogeinity of cooling gas flow distributions in their clear spacings.
- Gas turbine: Temperature, strain/vibration, combustion gas flow. While silica based type II FBG temperature sensors operate at temperatures up to 800 °C, we report now sapphire fibre based FBG arrays with stability at temperatures T > 1600 °C (Fig. 3), which are fit for condition monitoring in next-generation high-efficiency turbines.

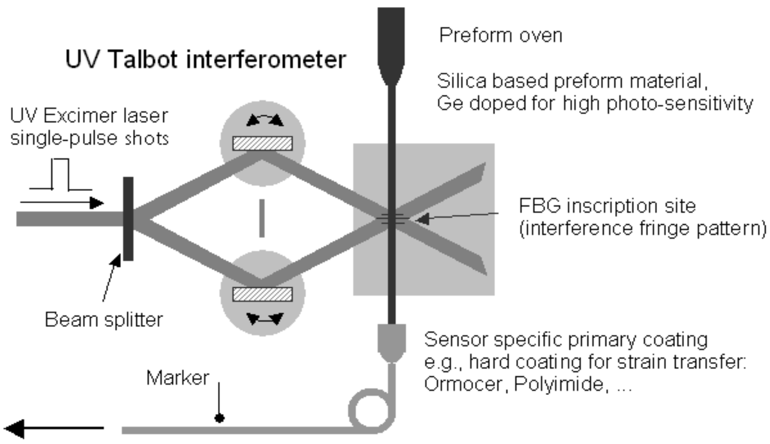

Fig. 1. Inscription technique for fibre Bragg grating sensor arrays at fibre drawing tower: stability to strain up to 6% [2].

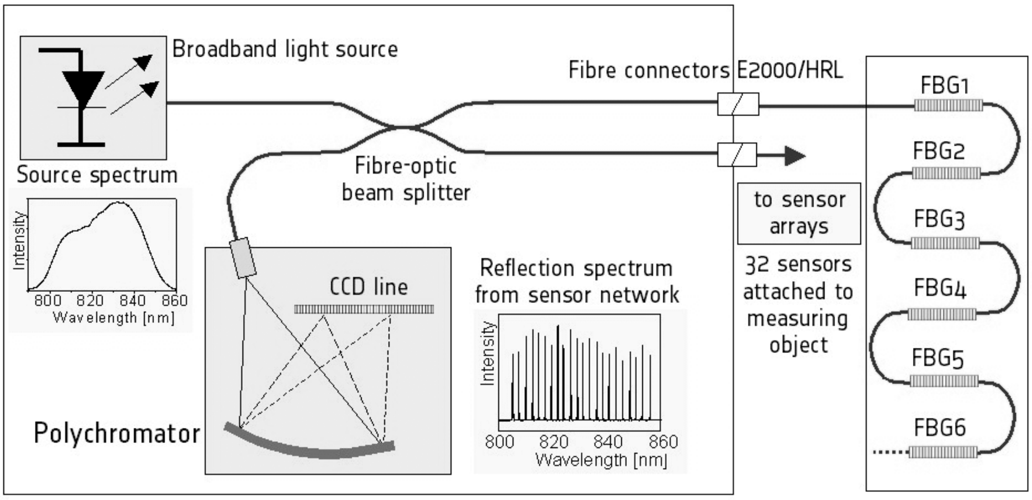

Fig. 2. Robust low-cost and high-quality FBG sensor array interrogation technique based on broadband illumination and polychromator read-out [3].

- Wind turbine: load monitoring of rotor blades of Enercon E112 (4.5 MW, blade length 53 m [4]).
- Hydrogen energetics: multi-purpose hydrogen vessel integrity FBG sensor system - strain measurement and detection of crack formation in high-loaded carbon-fibre re-inforced plastic composites; temperature and leakage monitoring of hydrogen as well.
- Nuclear fusion energy: strain and position monitoring of superconductive magnets (Fig. 4). While electrical strain gauges depend heavily on temperature T as well as magnetic field B within the operation ranges of the stellarator Wendelstein 7-X (T = 4 .. 10 K, B = 0 .. ±7 T), the respective thermo-optic and magneto-optic cross-sensitivities on strain sensor's Bragg wavelength correspond to maximum strain errors < 3 µε [5].

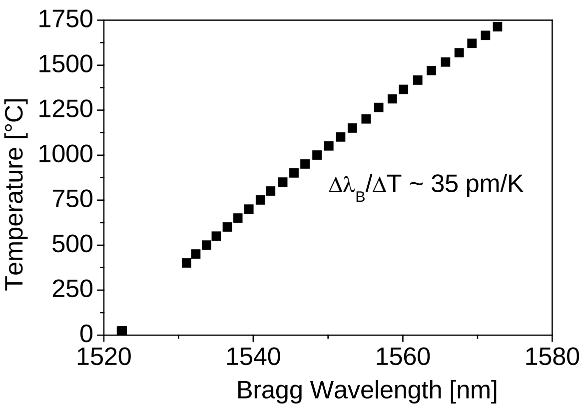

Fig. 3. fs-laser inscribed Bragg gratings in sapphire fibre reach operation temperatures up to 1700°C.

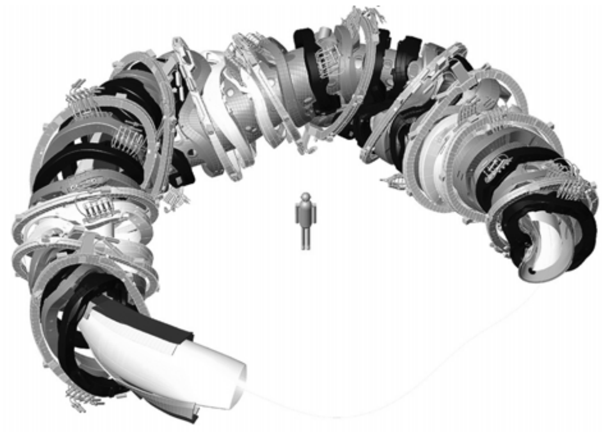

Fig. 4. Seventy superconductive magnet coils confine the plasma in the Stellarator nuclear fusion experiment [5]. Graphic: Max Planck Institute for Plasma Physics, Germany

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