# Continuous pressure and temperature monitoring in fast rotating paper machine rolls using optical FBG sensor technology

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## ABSTRACT

A fiber optic Bragg grating (FBG) sensor and interrogation scheme has been designed to capture the momentary peak pressure forces in the nip of two adjacent paper machine rolls. The spatial distribution of these nip forces along circumference and length of the roll, for production speeds of up to 2000 m/min are investigated. Additionally, this FBG sensor system measures the temperature distribution in the roll cover. FBG sensor embedding has been optimized for the implementation of pressure force measurements in various roll cover materials. High strength draw tower grating (DTG) sensor arrays were used for the embedding process combined with spectrometric interrogation and autonomous power supply technologies. This results in an extremely robust fiber optic sensor system for operation at rotation speeds of 700 rpm, equivalent to centrifugal accelerations of 300 G. These measurements enable immediate quality control during various stages of the high-speed paper production process.

**Keywords:** Fiber Bragg sensors, rotating sensor system, load distribution, temperature distribution, paper machine

## 1. INTRODUCTION

Paper machines are large-scale industrial facilities, with over-all length of 200 .. 600 m, sheet width 6 .. 12 m, and product speed up to 2000 m/min (scheme in Fig. 1). Roll pressure distributions along adjacent rolls define the quality and homogeneity of paper, especially in the press section (density, strength) and in the finishing calender section (surface quality).

On-line load monitoring of force and temperature distribution in paper machines is a challenging task for a fiber optic sensor system in industrial process control, especially given the large number of sensors in the composite roll cover materials (Fig. 2) and the wet environment. Fiber optical sensors such as Fiber Bragg Grating (FBG) sensors have their well-known advantages of low weight and small size as well as the capability of having multiple sensors in one line. The specific difficulties in this application come from the high rotation rates in the range of $\Omega \sim 700$ rpm at roll diameter $2R \sim 1$ m, resulting in a centrifugal acceleration $b = (2\pi\Omega)^2 \cdot R \sim 300$ G ($G = 9.81$ m/s²), and from the short contact times of the cover material in the nip with the requirement to measure simultaneously the full sensor network along the roll

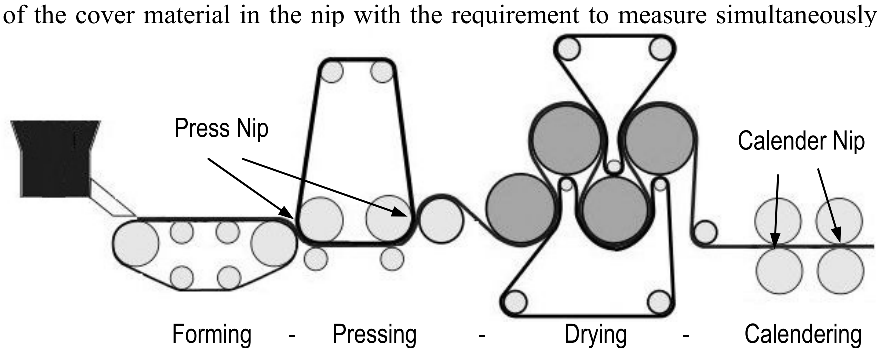


**Fig. 1** Scheme of paper fabrication process with important roll pressure nips in press and calender sections

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Measurements on rotating parts have been done using rotary joints, which are placed at the end of the engine shaft directly in the rotating axis [1,2]. These devices are steadily improving but they are still far away from being a long term device. The shaft ends are usually occupied by complementary bearings, gearboxes etc. prohibiting the placement of a rotating joint there. Other designs use light coupling devices, which are capable of coupling a sufficient amount of light to the FBG sensors in the rotating part at an off axis position [3,4]. The time of sight is extremely short for off axis light beam coupling, it requires extremely precise and stable orientated collimated beams, and the sensors are available only in a single position during the rotation.

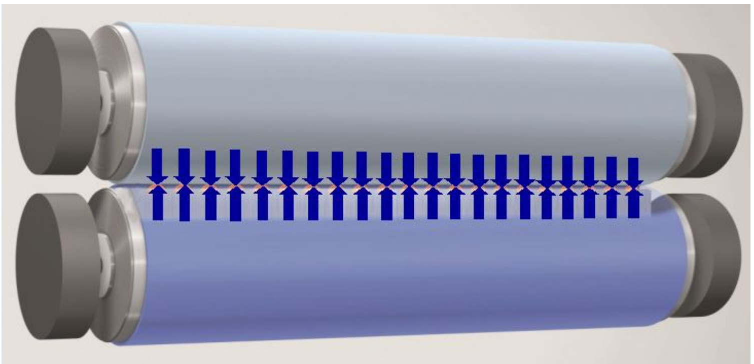

**Fig. 2** Scheme of the sensor task: measurement of the line pressure distribution along the contact between two adjacent rolls, i.e., along the nip line.

In order to obtain continuous measuring results during paper production, the task was to realize a sensor system, which is completely embedded in the rotating roll. The interrogation unit must be capable of withstanding the centrifugal forces, vibrations, and pollutions of a paper mill. Additionally, it requires autonomous power supply and wireless data communication for continuous on-line monitoring through the whole year.
The development of such a FBG sensor system - called NipVision™ [5] - is on its way from research lab to real industrial application including design, realization, operational parameters, and paper roll load monitoring results.

## 2. SENSORS & SENSOR SYSTEM

The FBG sensors in 800 .. 860 nm Bragg wavelength range are fabricated during the fiber drawing process, and therefore they are called Draw Tower Gratings (DTG®). This type of FBG writing technology was developed at IPHT and it is now commercialized at the company FBGS Technologies. In this process (scheme in Fig. 3), a silica based fiber preform material is Ge doped for achieving high photosensitivity. This preform is drawn to a single mode optical fiber. Each DTG is generated by using only one UV Excimer laser shot of 20 ns pulse duration. The Bragg grating writing setup consists of a modified Talbot interferometer for wavelength multiplexing of the DTGs.
With this procedure, spatially and spectrally customized DTG sensor arrays can be fabricated. The resulting single pulse DTG reflectivity is in the range of 20%. The sensors are resistant to tensile strain up to 6% and are proven to have long-term stability with reversible strain responses between 1 and 3% strain [6]. For application as strain sensor, a hard primary coating of an organic modified ceramic (Ormocer) is deposited immediately after grating inscription. Ormocer-coated fiber optic DTG sensors can be embedded with good adhesion into all roll covers like rubber, polyurethane, fiber-reinforced composites etc. Due to their mechanical strength and robustness, the DTG sensors are not damaged during the curing of the roll cover materials (130 .. 180°C, partially in steam atmosphere) nor by the wet paper mill during operation.

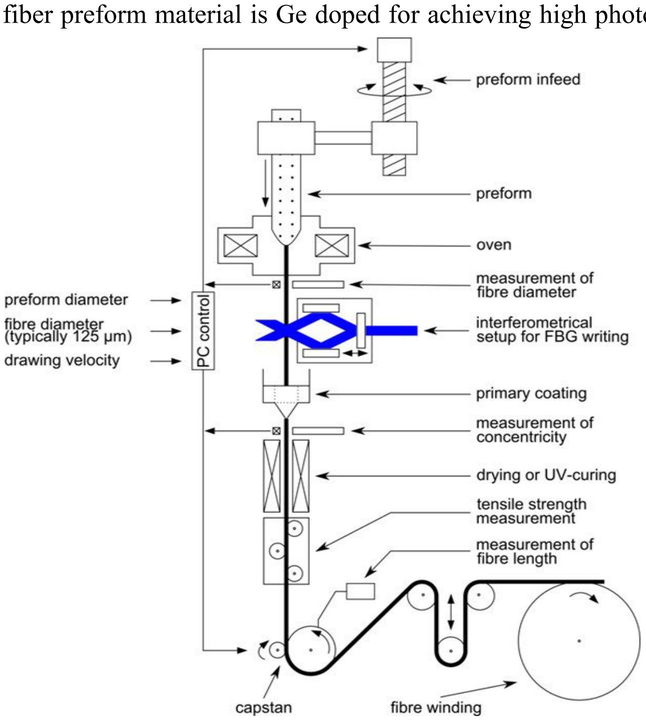


**Fig. 3** Draw tower grating (DTG) inscription setup

The interrogator consists of a broadband illumination SLD (800...860nm wavelength range) and a polychromator readout of reflected Bragg wavelengths (Fig. 4). The polychromator with imaging diffractive grating and CCD detector line performs a simultaneous measurement of all sensors, especially well-suited for monitoring fast-varying strain states along sensor arrays. The compact and robust version interrogates up to 32 sensors. The measuring duration is defined by the illumination duration of the light source, which can be kept down in the range of µs.

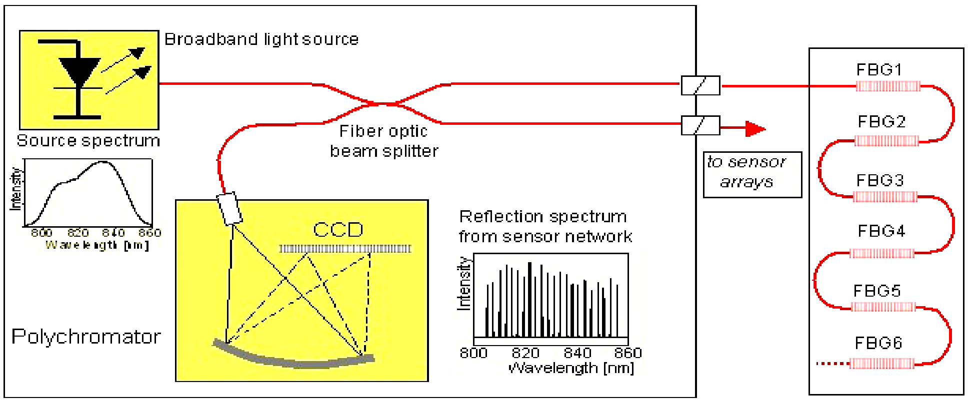


**Fig. 4** FBG sensor interrogator setup with broad-band light source and polychromator spectrometer

This interrogator was already developed for high environmental load conditions, it passed NASA assessment for manned spacecraft application [7] (vibrating accelerations 10 G rms, 20 G shock, vacuum/temperature cycles), and it was later used in a slow-rotating application of wind energy deployment for turbine blade bend monitoring [8].

The construction principles for fast-rotating application are based on circular-symmetric component positions (scheme in Fig. 5). Because there is no long-term data about operability of the key opto-electronic components under steady high acceleration, investigations were performed to assess the fiber-coupled light sources, fiber couplers and connectors, diffractive gratings from different manufacturers, as well as the mounting principles for operation up to 300 G.

Because the monitoring system is designed for continuous load data measurement and transfer, an uninterruptible energy supply powers the opto-electronics as well as a continuous wireless data communication.

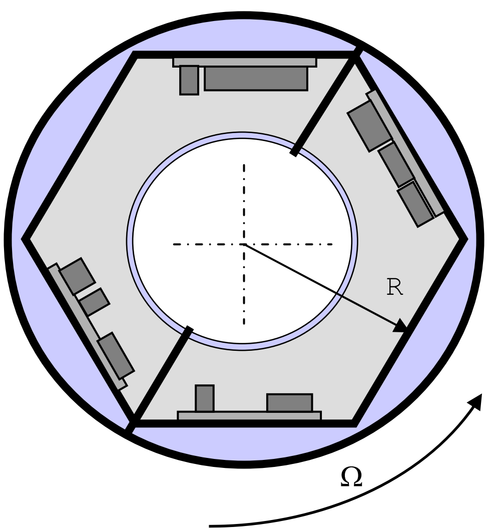


**Fig. 5** Scheme of circular-symmetric arrangement of system components for high-G stability

## 3. MONITORING RESULTS IN AN INDUSTRIAL APPLICATION

Fig. 6 shows an installation example of the NipVision pressure load monitoring system in the press section of a paper machine. Functionality of the nip pressure monitoring system was tested by application of pressure differences to the bearings at both ends of the press roll. Results are presented in Fig. 7: The embedded FBG sensors respond instantly and reversibly to the changes of the pressure distribution, and enable the papermaker for the first time to adjust the required even load distribution along the roll according to load measuring results.


**Fig. 6** Rotating fiber optic Bragg grating sensor system NipVision at press section roll axis of paper machine

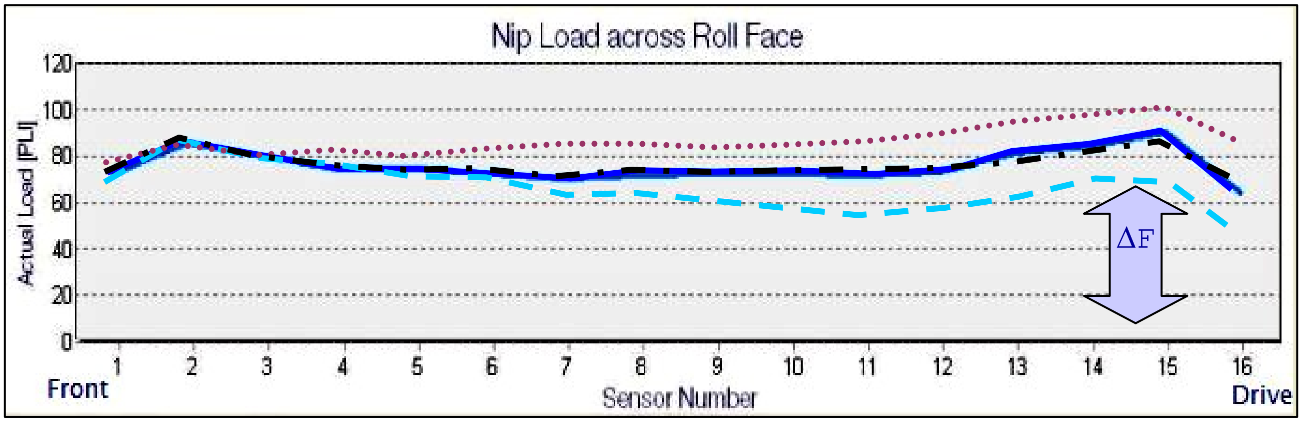


**Fig. 7** Results of load measurements along roll at different working pressure applications:
solid line (blue) - average working pressure 48 psi, roll load in equilibrium. Working pressure changes at drive side:
dashed line (cyan) -8 psi; dotted line (brown) +2 psi; dot-dash line (black) - working pressure back to equilibrium.
(Load maximum at both ends of roll corresponds to a special cover profile.)

The sensor fiber (200 µm diameter, including coating) proved not to interfere with the roll cover. Load measurements by FBG sensors are performed simultaneously, in contrast to piezo-sensors with multiplexing only along a helix around the roll.
Load measurements by FBG sensors deliver not only the nip pressure but also the distribution of temperature in the roll cover detecting hot-spots before failures.

## 4. SUMMARY AND OUTLOOK

A complete FBG sensor system, 'NipVision', has been developed, of high mechanical strength based on a polychromator read-out of DTG sensor wavelengths, for monitoring pressure load and temperature distributions in the roll cover of paper machines. Unlike conventional systems, it operates at centrifugal forces up to 300 G. It proved successful in several paper mill installations. The system and resulting data are continuously available to the papermaker, preventing overload, abnormal wear, web breaks, or detachment of roll cover. The availability of such monitoring results is the pre-condition for the development of a Smart Roll with adaptive load profile providing further increases in product quality.
The reported application -measurement of temperature and strain distributions in fast-rotating parts- may be extended to even higher mechanical loads, e.g., in the rotors of power generators and turbines at rotation rates of 50 .. 60 Hz. System development for operation at corresponding maximum centrifugal accelerations of about 3000 G is under investigation.

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