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Analysis of Sensors for Vibration and Nip Forces Monitoring of Rubber Coated Rollers

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Abstract

To improve the efficiency of printing or coating processes for paper products the velocity of the web and the roller width can be increased. However, these measures bring about deformations of the rollers, heating effects and streak print defects due to undesirable oscillations. This paper presents new sensor technologies for measuring the axial and circumferential distribution of contact pressure along the nip. This work is required for further research on active vibration damping of rollers. The sensors are applied underneath the elastomer covering of the rollers and must be applied without affecting mechanical features or causing a fall off in the quality of the product. In the paper different new measurement techniques are evaluated and compared to state-of-the-art technologies considering dynamic behaviour, sensitivity, linearity, applicability and accuracy. The sensors are integrated into a test rig simulating the rollers of a printing or coating machine. The results are presented in detail and an outlook is given on further research towards active vibration damping.

Introduction

The work presented in this paper contributes to a research project which aims to enhance the productivity of printing and coating processes at equal or improved quality standards by means of innovative technology. Due to increased roller width and web velocities, the vibrations restrict significantly the quality and efficiency of the printing or coating processes. Approved methods like balancing of the rollers and maximizing the bending stiffness have come to technical limits.

One new approach is online monitoring and optimal adjustment of roller systems. Furthermore active components for vibration damping seem to be promising for optimisation of roller systems. Firstly, active counter oscillations by highly dynamic displacements of the roller bearings by piezoelectric actuators and magnetic bearings are proposed and developed in the project. Fig. 1 shows a roller with piezoelectric actuators in the bearings.

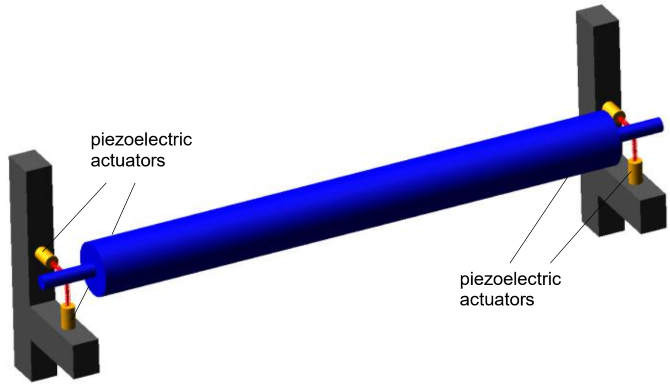

Fig 1: Roller with piezoelectric actuators in the bearings

Measuring the axial and circumferential distribution of contact pressure along the nip is necessary for active vibration damping of rollers. New sensor technologies for measuring the contact pressure distribution both in axial and circumferential direction along the nip are required. The sensors are applied underneath the elastomer covering of the rollers. The measurement results are affected by the pressure transfer through the rubber. Furthermore, the transfer characteristic of the rubber material is influenced by temperature effects in the material. The sensor calibration is a crucial issue and has high relevance for subsequent application in active vibration damping and feedback control.

Moreover, the sensors and the signal conditioning have to be mounted on the rotating rollers. Thus, problems concerning signal transfer and the impact of unbalances caused by the measurement equipment have to be considered.

In the following chapters, different innovative sensor technologies, which are currently under development, are discussed for monitoring and optimal adjustment of roller systems. To test and evaluate the sensor a test rig was set up.

Test rig

The test rig presented in Fig.2 simulates three rollers system of a coating or printing machine and is used to investigate the sensor's efficiency. It contains a pneumatic cylinder (4) which presses the load roller (anilox roll) (1) against the rubber coated roller (plate cylinder) (2) by applying a defined force to (1). Both move to the supporting roller (impression cylinder) (3) until desired contact pressure is achieved. The force sensor (5) is the reference for sensor's calibration.

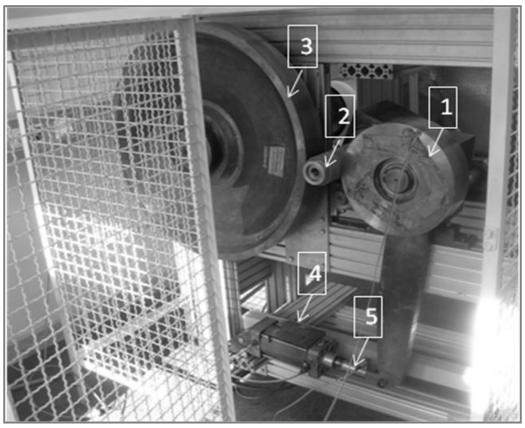

Fig. 2 Test rig
1-load roller, 2-rubber roller, 3-supporting roller,
4-pneumatic cylinder, 5-force sensor

Sensors

A goal of the research project presented in this paper is to develop a sensor to measure the pressure along the nip during operation. Some of the requirements of the sensor are:

- *Applicability*. The sensor must be thin and applicable to curved surfaces without affecting the quality of printing image in the flexography.
- *Dynamic range*. The sensor should be able to measure the rapid change of the pressure in the nip. The sensor's characteristics must be stable and repeatable with low hysteresis.
- *Sensitivity*. The sensor should be able to detect the contact forces in the nip, by applying the sensor underneath the printing plate made of rubber, plastic, or some other flexible material.
- *Feasibility*. The sensor should be easy to produce, inexpensive and robust.

Different types of sensors have been applied on the test rig:

- underneath the rubber coated roller, as shown in figure 3 are

a) piezoelectric paint
b) piezoelectric discs

- on the surface of the load roller

c) piezoelectric film
d) strain gauge

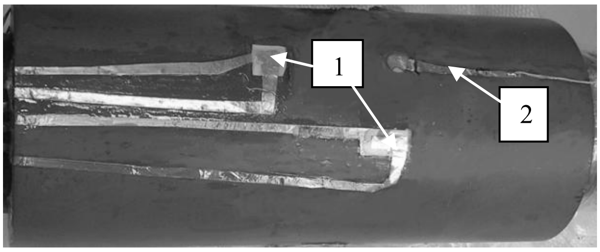

Fig. 3 Applied sensors on the plate cylinder
1 - piezoelectric paint; 2 – piezoelectric disc

The first three sensors contain a piezoelectric material, which creates a measurable charge under force or deformation. Piezoelectric sensors are limited to dynamical measurements because these output signal decay in milliseconds.

a) Piezoelectric paint is a thick-film material used to make dynamic strain sensors to measure vibration [1]. A high quantity of lead zirconate-titanate (PZT) particles 1 μm in diameter was mixed into a water-based paint [2], which can be sprayed or coated on any conductive flat or uneven surface. Successful laboratory tests of the piezoelectric paint have already been realized at the University of Newcastle upon Tyne supervised by Prof. J.M. Hale.

Some problems had to be overcome when applying the water-paint directly on the steel surface. The steel rusted and the paint lost contact. So the piezoelectric paint has been coated by a copper film as shown in fig. 4. The paint creates a dielectric substrate of the piezoelectric sensor, which is actually a plane capacitor. The thickness of the piezoelectric paint is 90 μm, and it is important to achieve a uniform substrate thickness in order to obtain a sensor with a homogeneous sensitivity. The sensor will be poled by applying a high-voltage source onto sensor's wires to orientate the crystal structure of piezoelectric material. Good results are obtained by using a 300 V electrical voltage by a room temperature of 25°C.

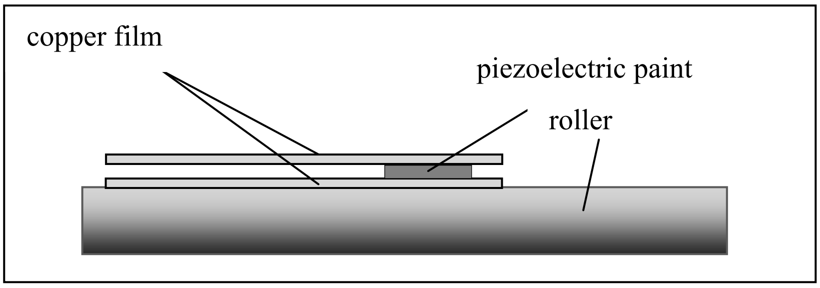

Fig. 4 Piezoelectric paint sensor

b) Piezoelectric discs are a well known inexpensive technique and form usually actuators by stacking them. The sensors are integrated into the surface of the roller and protected by applying a thin epoxy resin coating [5].

c) *Piezoelectric film* sensors consist of rectangular piezo-ceramic rods sandwiched between layers of adhesive and electroded polyimide film [6]. They measure distributed solid-state deflection. The film can be a sensor as well as an actuator. It has been applied in circumferential direction on the load roller. The active length is 12 cm, so that only a part of the sensor is pressed in the nip of the rollers.

d) *Strain gauges* were applied directly on the roller underneath the rubber. Measuring mechanical quantities by strain gauges is a popular and well known technology. It's based on the principle that the resistance of a conductor changes by its stretching or compressing. The presented results come from a sensor applied in circumferential direction.

A comparison of advantages and disadvantages of these sensors are presented in Table 1:

Sensor	*Advantages*	*Disadvantages*
piezoelectric paint	flexible, can be sprayed on any conductive surface, will not affect the quality of printing image	complicate procedure to make a sensor each sensor sensitivity have to be measured is not available on the market no datasheet
piezoelectric disc	inexpensive available on the market	nonlinearity high voltage signals piezoceramics are brittle
piezoelectric film	flexible and very thin available on the market	ceramics can be deteriorated by pressing directly on the sensor
strain gauge	flexible available on the market well known technology	pressing directly on the sensor is no standard application

Table 1 Comparison of sensor's properties

First measurement results with the four different types of sensors are shown in figures 5-7.

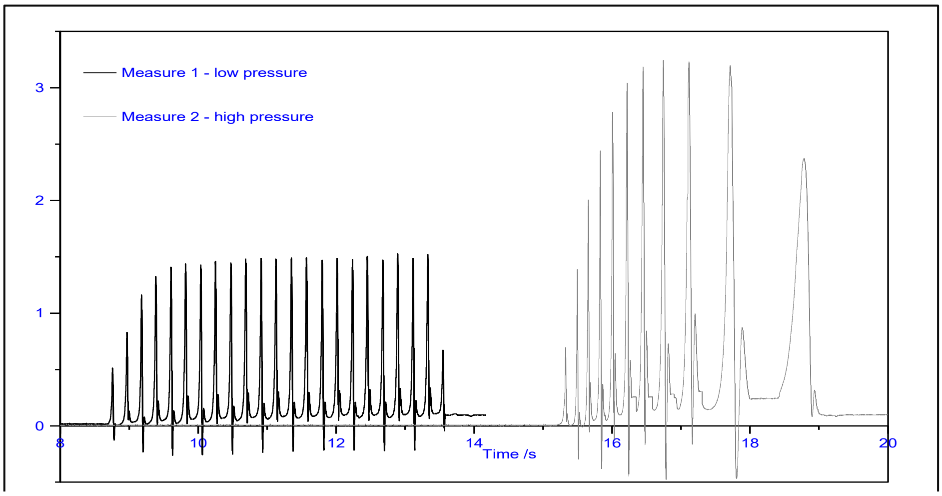

Fig. 5: Piezoelectric paint – the nip pressure is first increasing and then decreasing

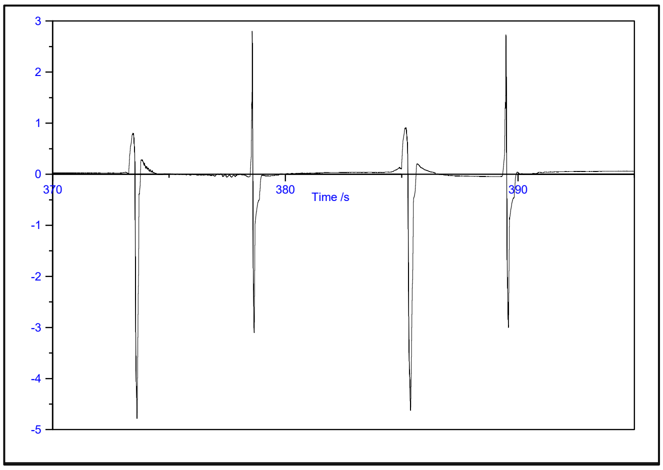

Fig. 6: Piezoelectric film

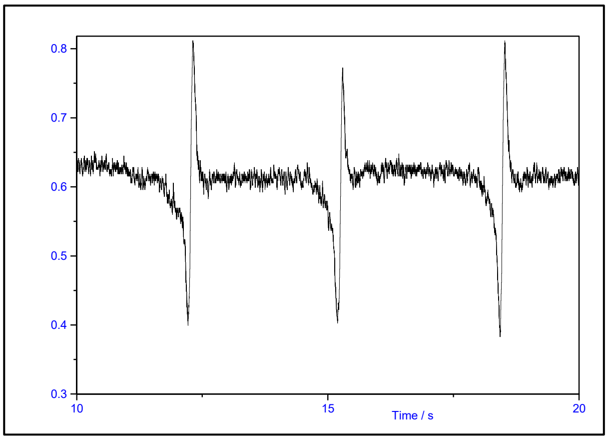

Fig. 7: Strain Gauge – constant pressure in the nip

These three presented sensors show a good correlation between sensor's signal and the calibrated force sensor.

The most important feature of the sensors for our application is that they have to give a reproducible signal which is depending on the pressure in nip of the rollers. We tested all sensors with different pressure levels. Fig. 5 shows that piezoelectric paint fulfills these requirements in an excellent way. The nip pressure is increasing by bringing the three rotatable rollers in contact and decreasing when the pressure disappears.

The signal of the piezoelectric discs was not repeatable although nip pressure was kept constant. The reason may be that the discs are brittle and cannot be fitted exactly to the roller surface so that there is no defined contact between the rubber coating and the discs. Therefore the results are not presented.

The piezoelectric film sensor also shows good repeatable results and has the advantage that due to its length the nip pressure can be measured for a quite long time so that overlaying vibration (e.g. natural frequencies) can be also measured. Fig. 6 presented measuring results by rotating to the left (negative signal) and by rotating to the right (symmetrical amplitude).

The strain gauge show also repeatable nip pressure dependent results and have the advantage of a simple state-of-the-art technology.

Because it is aimed to apply all presented sensors under the rubber coating and there is no analytical way to determine the sensitivity it is necessary for all sensors to develop a procedure for calibrating the sensors. Durability aspects have to be investigated. There is a lot of experience with strain gages, piezoelectric films and piezoelectric discs in other applications. Therefore no durability problems are to be expected in our application under the rubber coating. The piezoelectric paint, which is very promising for our purpose, is a new technology without experiences concerning durability. Endurance tests in a printing device will be carried out in near future.

Conclusions and outlook

Starting from a set of special requirements for developing an adequate sensor in order to measure the vibration of rubber coated roller some types of sensors are presented in this paper. It could be shown that the piezoelectric paint as well as piezoelectric film and strain gauges show reasonable results and good correspondence with the control measurements with a calibrate force sensor. This is notable, because the sensors were applied under the rubber coating. Solutions have been found for an application of the sensor without affecting the printing image.

The next steps will be the improvement of the new developed sensors and of the calibration procedure for the sensors after implementation in the rubber coated roller. After that these sensors will be integrated into the control loop of the active vibration damping. The actual physical states of the roller measured by the sensors are the feedback information and provide the input signal to a controller which is implemented on a digital signal processor (DSP). The output of the controller drives the actuators, which will be used for realization of active vibration damping of printing or coating roller systems.

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