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Aerostatically sealed non-contacting paperboard porosity measurement device

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Abstract

Measurement of paperboard porosity on-line during the manufacturing process allows controlling the process with a shorter feedback loop than when measuring samples from the end of the process offline in a laboratory.
In a previous study, the authors proposed a paper porosity measurement instrument based on sealing the paperboard sample with an air bearing and presented measurement results for stationary samples of paper. This study expands on the previous study by introducing a measurement device, that requires access to only a single side of the measured sheet. The investigated device seals a measurement volume against the paper sheet with a porous aerostatic bearing, and uses a vacuum groove to control the gap height between the measurement device and the measured sheet. The performance of the device was investigated with two paper samples of varying permeability and varying seal supply pressure. Additionally, the air gap height was measured with a laser displacement sensor.
The results of the study show that the seal supply pressure has an effect on the measured permeability value. The gap heights for the measured samples were 2.5 µm and 4.4 µm. The study provided corroborative evidence for viability of the investigated device.

aerostatic bearing, aerostatic seal, in-process measurement

1. Introduction

Measurement of paperboard permeability is a vital part of quality control of various paper and cardboard grades. Commonly, porosity measurement devices seal a measurement volume against the paperboard sample and have a means of generating a pressure difference across the sides of the paperboard [1, 2]. In some methods, the paper sheet is additionally supported by a mesh or a grid, so that higher pressure differences can be utilized [3, 4]. In devices which support the paper web from both sides, it is possible to use overpressure on one side of the sample. In contrast, devices that are placed only on one side of the sample, vacuum is commonly used.

The Bendtsen method for air permeability measurement is specified in the ISO 8791-2:2013 standard [5]. The method is well suited for offline measurements, as the measurement device is sealed against the paper sheet with contacting seal. However, non-contacting sealing would allow for measuring, for example, a paper web traveling past the sensor.

This paper presents a novel non-contacting porosity measurement device utilizing aerostatic bearings as seals and investigates its feasibility in stationary conditions.

2. Methods

The developed measurement device consists of porous graphite aerostatic bearing elements, a measurement chamber and a vacuum groove. The device and the measurement setup are shown in Figure 1. The vacuum groove is used to stabilise the paper track against the bearing. The graphite aerostatic bearing elements are used to seal the vacuum areas between the device and the measured paper sample. The device has three bearing elements with invidual air supplies: inner and outer seal, and edge bearing. A cross-sectional view of the measurement device is presented in Figure 2.

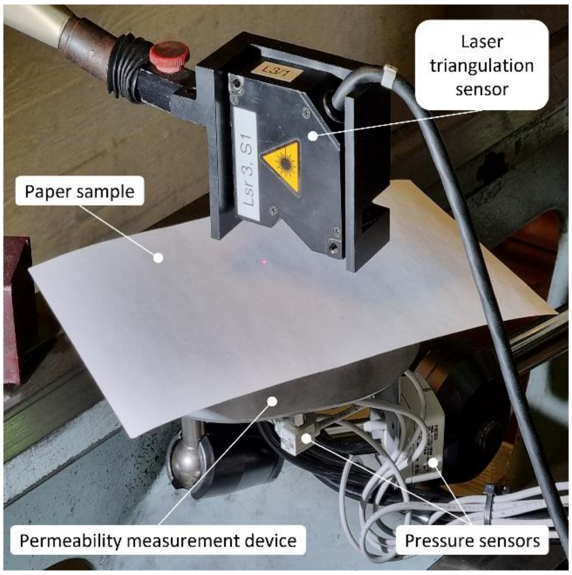

Figure 1. Measurement setup. The laser used in the gap height measurements is positioned between the inner and outer seal elements.

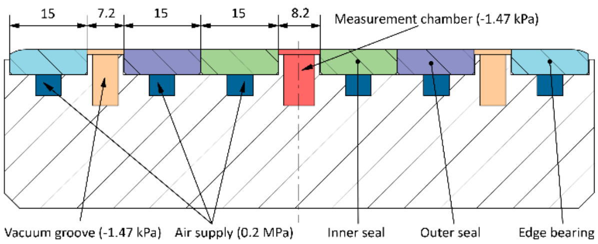

Figure 2. Cross section view of investigated measurement device, with dimensions of bearing faces and vacuum areas.

The measurement device was operated at the same pressure difference of 1.47 kPa across the measured paper sample as the conventional Bendtsen method permeability measurement devices. As in the previous research [6], the bearing elements feed air also into the measurement chamber, increasing the measured air flow out of the measurement chamber. Therefore, the bearing is split such that the inner and outer halfs have separate air supply lines and flowmeters. The split of the bearing helps in the division of the airflow from the bearing into the measurement chamber and the vacuum groove around the bearing.

The reference measurements were made with the o-ring sealed measurement device presented during previous research [6]. The reference measurements were also made according to the Bendtsen method, with 1.47 kPa pressure difference across the sample.

The measured flow values were scaled in relation to the measurement area of each device. The investigated device used a slot with radiused ends as the measurement area. The center-to-center distance between the end radii was 30 mm and the width of the slot was 8.2 mm. In the reference device, the measurement area was a 25 mm diameter circle. In contrast, the Bendtsen method flow measurement uses a 31.5 mm diameter circle as the measurement area. Thus, the measured permeability values were scaled in relation to the measurement area to be comparable to the Bendtsen method.

Two measurements were made of two different paper samples with the developed device. A measurement of the effect of seal supply pressure on the measured permeability value, and a measurement of the gap height between the seal and the measured paper sheet. The paper samples used were ordinary printing paper, referred to as sample 1, and a coated paper with lower permeability, referred to as sample 2.

In the permeability measurements, the bearing supply pressure was adjusted in the range of 0.15 MPa to 0.25 MPa, and the vacuum groove and the measurement chamber were set to vacuum of -1.47 kPa.

In the gap height measurements the bearing air supply was intermittedly turned on, and the displacement of the paper sheet on the bearing was measured with a Matshushita NAIS LM 300 laser triangulation displacement sensor. The measurement was repeated 5 times for each sample, and the measured displacement was averaged. Thus, the gap height is obtained as the mean displacement of the paper sheet with the air supply on and off.

The measurement data was recored using a NI CDAQ-9174 chassis and a NI 9220 analog input module. During each measurement, 20000 samples were taken with a 1 kHz sampling rate. The pressure and the flow into each bearing supply channel was measured separately, and the pressure and the flow out of the measurement chamber was measured. The relevant sensors and their accuracies are presented in Table 1.

Table 1. Specifications of sensors in the measurement setup. The accuracy is presented as a percentage of the full-scale value.

Sensor	Type	Scale	Accuracy
Chamber pressure	SMC PSE550	0-2 kPa	1%
Bearing pressure	SMC PSE540A	0 – 1MPa	1%
Chamber flow	SMC PF2M702	0.02 – 2L/min	3%
Bearing flow	SMC PF2M702	0.02 – 2L/min	3%

3. Results

The permeability measurements with varying seal supply pressure are shown in Figure 3. The mean gap height measured at 0.2 MPa seal supply pressure was 2.5 µm for sample 1 and 4.4 µm for sample 2.

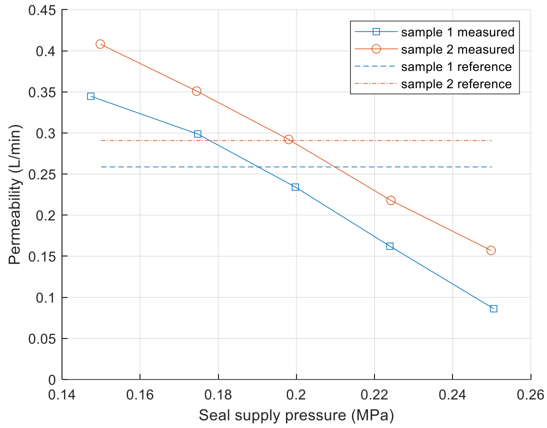

Figure 3. Measurement results with investigated device in comparison to o-ring Bendtsen reference device.

4. Discussion

This study focused on the feasibility of permeability measurement with aerostatic bearing based measurement devices, started in the previous study by the authors [6]. Improving on the previous study, the presently investigated a single sided measurement device did not mark the paper samples during measurements. Furthermore, the gap height measurements show that there is a gap between the measured sample and the bearing element.

The permeability measurements show that the measured permeability value is dependent on the seal supply pressure. One possible contributing factor to the error in the permeability measurement is that instead of flowing into the measurement chamber, some of the air supplied to the inner bearing escapes by flowing through the paper sheet itself. This phenomena would reduce the measured permeability values.

Further investigations could be directed on decoupling the permeability measurement from effects of the bearing elements used as the seals for the measurement chamber. Potential methods include improved model of the air flow in the gap between the paper and the bearing element. Alternatively, a correction curve or table could be implemented. Further, measurements of continuous samples at various running speeds should be made after the accuracy of the method can be validated for vast range of potential permeabilitites in stationary conditions.

The measurement results show that the investigated device can be feasible for on-line measurements of the permeability of paperboard, but the topic requires further studies.

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