Non Destructive Testing of Fabric Weight in the Weaving Process

Yves-Simon GLOY 1, Thomas GRIES 1, Gerhard SPIES 2

1 Institut für Textiltechnik der RWTH Aachen University, Aachen, Germany
Phone: +49 241 8023470, Fax: +49 241 802422; e-mail: yves.gloy@ita.rwth-aachen.de
2 BST ProControl GmbH, Rengsdorf, Germany; E-mail: spies@p2t.de

Abstract
Within the German Cluster of Excellence "Integrative Production Technology for High-Wage Countries", at the RWTH Aachen University, self-optimising production systems are investigated. Within this scope, the weaving process is analyzed. Weight per area is a major product quality of woven fabrics. Integration of sensors into the loom to monitor and control the weight per unit area is investigated online. Conductive sensors are not suitable for such a measurement. This is because the sensors are very sensitive to vibrations and changes in humidity of surroundings. X-ray sensors show very good results in monitoring the product quality online. Thus control loop to regulate the fabric weight per area using X-Ray sensors is developed and described in this work.

Keywords: Weaving, Product quality control, X-Ray sensors, Capacitive, Fabric weight

1. Introduction

Online quality control is used in textile processes like woven fabric production, non-woven production etc., where rolled goods are produced. Online quality control in the weaving process is still a field of research. As an example, vision based quality control systems are on the market [1]. These system compare the fabric image with a benchmark image. Systems for objective camera based measurement are still in development [2].

In addition, weight is a major property of fabrics. So far, no online monitoring or control of weight of fabric on a loom is known. Therefore, research on appropriate sensors to monitor and control systems to regulate fabric weight per unit area on a loom will be presented. Two classes of sensors are investigated - capacitive and X-ray sensors.

2. Capacitive sensor to monitor fabric weight

Capacitive sensors can be used to monitor mass of yarns. Such a sensor is shown in figure 1. It is a parallel-plate capacitor. The capacity of a parallel plate capacitor is determined by

\[ C = \frac{\varepsilon_0 \cdot \varepsilon_r \cdot S}{d} \]

where \( C \) = capacity; \( \varepsilon_0 = 8.854 \times 10^{-12} \), \( \varepsilon_r \) = dielectric relative constant, \( S \) = area and \( d \) = distance.

Authors describe that by putting a yarn between the plates, the dielectric relative constant values change and thus the capacity also changes. By doing so, Carvalho et al. say a relationship is established between the capacity and the yarn mass [3].

![Capacitive sensor](image)

Figure 1. Capacitive sensor [4]

In order to research the functionality to monitor fabric weight during weaving, the sensor is installed between breast beam and cloth beam of a loom as shown in figure 2.
The functionality of the sensor was tested with a twill 3/1 cotton fabric. The weaving machine was running at 700 rpm during the measurement of fabric weight with the capacitive sensor. Weft density was changed between 8 and 17 picks per cm. In total 64 measurements were conducted. The results of the measurement are shown in figure 3. It is visible, that the capacitive sensor shows a big deviation in the range of values, therefore the sensor is not suitable to monitor fabric weight during weaving.

A major explanation for the behaviour is the vibration of the loom during weaving which showed an influence on the sensor signal. Furthermore, by changing weft density, contraction of the fabric changed. Since the sensor is used at the edge of the fabric, also the fabric area inside of the sensor changed. There was not the same area of fabric measured during the trails. It also has to be kept in mind that the sensor behaviour is dependent on the humidity and temperature of the surrounding. It must also be taken into account that since the sensor was installed on the edge of the fabric, the selvedge of the fabric was measured. It is known from literature that the fabric weight per unit length on the selvedge is different as compared to the fabric basis weight. This is because the pick density of the selvedge is different in comparison to the fabric.

![Figure 2. Capacitive sensor installed on a weaving machine [5]](image)

Figure 2. Capacitive sensor installed on a weaving machine [5]

![Figure 3. Comparison of capacitive sensor signal at two different weft densities](image)

Figure 3. Comparison of capacitive sensor signal at two different weft densities

3. **X-ray sensor to monitor fabric weight**

Radiometric absorption can also be suitable for monitoring fabric weight during weaving. Such an X-ray sensor uses absorption of the X-ray beam depending on the mass and density of the material. This absorption can be related to the fabric weight. Radiometric absorption is described by the Beer-Lambert law:
\[ I = I_0 \cdot e^{-\mu \cdot l} \]

where \( I \) = Intensity of the beam, \( I_0 \) = original intensity of the beam, \( L \) = length of beam into the substance, \( e \) = Euler's number, about 2.718, \( \mu \) = the attenuation coefficient. The attenuation factor of a material is obtained by the ratio of the emergent and incident radiation. When using the mass attenuation coefficient, this equation is

\[ I = I_0 \cdot e^{-\mu \cdot \rho \cdot l} \]

where \( \rho \) = the density, \( \mu / \rho \) = the mass attenuation coefficient and \( \rho \cdot L \) = the area density known also as mass thickness. The area density can also be described as

\[ \rho \cdot l = \frac{m}{A} \]

where \( m \) = total mass of the object and \( A \) = total area of the object [6].

BST ProControl GmbH, Rengsdorf, Germany offers such radiometric absorption system with accelerating voltage less than 5kV, such systems need no permission in order to be used in Germany. The sensor is suitable for measurements between 50 and 1000 g/m² with a resolution of 0.1 g/m² and an accuracy of 0.3 g/m². Installation of sensor in the loom is shown in figure 4.

![Figure 4. X-ray sensor installed on a weaving machine](image)

The functionality of the sensor was tested with a twill 3/1 cotton fabric. The weaving machine was running at 700 rpm during the measurement of fabric weight with the x-ray sensor. In addition, fabric weight was determined by DIN EN 12127. The results of the measurement are shown in figure 5. It is visible, that the X ray shows nearly the same linear behavior as the measurement according to DIN EN 12127, thus it is suitable to monitor fabric weight per area on a loom.

![Figure 5. Comparison of measurement of fabric weight (DIN EN 12127) and X-ray sensor signal](image)
4. Closed-loop control of fabric weight

In order to realise a closed loop control for the fabric weight per area, the step response of the system is analyzed, shown in figure 6 and 7. It is obvious, that weft density is the perfect actuating variable to control fabric weight.

![Figure 6. Step response of X-Ray sensor on changes of picks per cm during weaving](image1)

It is also visible, that the system has a high dead time (around 210 s). The dead time is depending on the picks per cm, the speed of the loom, and distance between fabric edge and X-Ray sensor. It can be calculated using the following formula

\[ T_t = l \cdot \frac{\rho}{rpm} \]

where \( T_t \) = dead time, \( rpm \) = speed of loom, \( \rho \) = picks per cm, \( l \) = length between fabric edge and X-ray sensor.

In summary, the plant can be described by a \( PT_1T_T \) model where the dead time is depending on the actuating variable. \( PT_1T_T \) model is described as

\[ G_p(s) = \frac{K \cdot e^{-T_t \cdot s}}{1 + T_1 \cdot s} \]

Because there are not many delay elements and because of the dead time a PI Controller is suitable for closed loop control of the fabric weight. The PI controller is described as:

\[ G_{PI}(s) = K_p \left( \frac{T_n \cdot s + 1}{T_m \cdot s} \right) \]

In addition, because the dead time is very high compared to the other values, a Smith Predictor is suitable to obtain a good closed loop control [7].
Closed control loop is programmed using the soft SPS software ibalogic V4 form IBA AG, Fürth, Germany. The program is connected via TCP/IP to the control of loom in order to adapt the weft density. The principal of the closed loop control program is shown in figure 8.

![Diagram of closed loop control with Smith predictor](image)

**Figure 8. Closed loop control with Smith predictor for fabric weight per area**

### 5. Validation

Validation of closed control loop is done on Picanol nv, Ieper, Belgium air jet weaving machine. As warp and weft 730dtex f2 PES is used. The warp density is 20 threads/cm. The machine is running at 700 rpm and the weave pattern is a twill 1/3. For calibration, the program lets the machine run with two weft densities 12 and 20 picks/cm. The program automatically monitors the X-ray sensor response by these two setting points. The fabrics weight per area is determined by DIN EN 12127 and the results in table 1 were obtained.

<table>
<thead>
<tr>
<th>Picks per cm</th>
<th>12</th>
<th>20</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fabric weight per area [g/m²]</td>
<td>325.5</td>
<td>259.6</td>
</tr>
<tr>
<td></td>
<td>330.3</td>
<td>257.6</td>
</tr>
<tr>
<td></td>
<td>328.5</td>
<td>262.4</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td><strong>328.1</strong></td>
<td><strong>259.9</strong></td>
</tr>
</tbody>
</table>

In order to prove that the closed control loop is working, desired fabric weight per area of 280 g/m² was set into the program. The course of the X-ray sensor signal; picks per cm and offset during control is shown in figure 9.

![Graph of closed control loop of fabric weight during weaving using a Smith predictor](image)

**Figure 9. Closed control loop of fabric weight during weaving using a Smith predictor**
It is visible, that the machine reaches the needed weft density after approximately 30 seconds. Because of the dead time of the system, the x-ray sensor monitors the right fabric weight per area around 210 seconds later. Weight of this fabric was determined again after DIN EN 12127. The obtained results are shown in table 2. The desired fabric weight per area was reached with an accuracy of 0.4 g/m².

<table>
<thead>
<tr>
<th>Picks per cm</th>
<th>Fabric weight per area [g/m²]</th>
<th>Average [g/m²]</th>
<th>Desired fabric weight per [g/m²]</th>
<th>Difference [g/m²]</th>
</tr>
</thead>
<tbody>
<tr>
<td>14,2</td>
<td>279,5</td>
<td>279,3</td>
<td>280</td>
<td>0,4</td>
</tr>
<tr>
<td></td>
<td>278,3</td>
<td>280,0</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>280,3</td>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>

### 6. Summary and Outlook

Control of fabric properties during weaving is important regarding costs and resource efficiency. In this paper, a way to control the fabric weight per area is demonstrated. An X-Ray sensor is installed in a loom and a closed loop control is realized. The validation of the closed loop control shows that it is possible to obtain a fabric with desired fabric weight per area. Picks per cm is used as reference variable. In addition, it is also known, that the warp tension has an impact on the fabric weight [8]. By changing the warp tension, crimp of warp and weft in the fabric is changed and thus the fabric weight. Therefore, warp tension can also be used to control the fabric weight. In addition, calculation models to predict fabric weight per area are known. These models can help realize model predictive control loops.

On-going research at ITA is looking at model-based self-optimization of the weaving process. The optimization is based on warp tension. The model-based approach can be expanded by using fabric properties like the fabric weight [9].

### 7. Acknowledgements

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