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Inline density measurement for rock wool

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Abstract Distinguishing the density of rock wool is an important part in its production process. One available common option for inline measurements of the density is based on X-rays. Due to huge security requirements in realising such measurements, this method is very complex and expensive. This paper investigates a method to find a relationship between radar based measurements and the density of rockwool. This is shown by evaluating the measurements of amplitude and phase of several rock wool samples with different densities. The results show a linear dependency of the measured phase values and the surface weights of the given samples.

Keywords Rock wool density, radar, SAMMI, surface weight.

1 Introduction

The density of rock wool is one of the distinctive features for this common product. The quality of the material depends, among other criteria, on the weight per sqm and the homogeneity. Unfortunately, the same material properties which make rock wool a perfect isolation material for buildings make it difficult to measure the density and the density distribution of the product. Typically the weight is measured with an electronic balance after the production process. Because of the good isolation properties, typical inline measurement sensors like optical camera systems, ultrasonic sensors or thermal flow thermography cannot be used. The only technical approaches which are available on the market are density measurement systems based on X-rays. Based on the security requirements, the integration of X-ray systems into a running production process is complex. High frequency sensors offer an alternative for contactless inline density measurements and use non-ionizing radiation.

2 Hardware concept

To develop a cheap millimeter wave imaging system, it is necessary to minimize the number of active high frequency channels. The smallest number possible is a single channel sensor in combination with a 2D-mechanical scanner concept. The reduction of channels is possible through the fast measurement speed of high frequency systems. High frequency systems typically use no detector concepts, which allow update rates between several thousands and a hundred thousand measurements per second. Most scanning approaches move the high frequency sensor around the DUT in a reflection or transmission configuration. For a first test series, a rotating antenna concept was used to create a transmission image for one single frequency.

In combination with a focusing antenna, a lens system or a near field probe, these system concepts produce high resolution millimeter wave images. SAMMI [1] (see Figure 12.1) is based on a continuous wave (CW) signal system concept. The system can be roughly divided into three modules. There is a rotating transmitter module (TX), a rotating receiver module (RX) and in each case a stationary part for frequency generation and the processing of the received signals. In the transmitter path an active triple stage TX module is used to multiply and amplify the frequency up to 78 GHz. In the receiver path the received signal is converted down using a mixer. The stationarily generated frequency is used as LO and fed into the RX-Module. In the stationary RF processing, an IQ-Mixer is used for down-converting the received signal. Subsequently, the I- and Q-signals are fed to the ADC. The digital backend consists of two analogue digital converters (ADC), which are controlled and read out simultaneously by a digital logic built up on a field programmable gate array (FPGA). The arc, which is traversed by the antenna configuration eight times a second, has a diameter of 300 mm, corresponding to a circumference of 942 mm. To achieve an

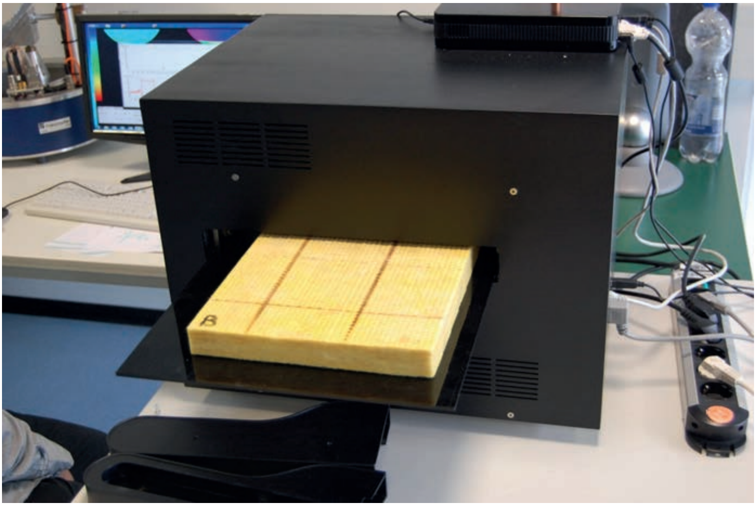

Figure 12.1: Photogaphy of a 20 cm times 20 cm large test object with the test system SAMMI (Stand Alone MM-wave Imager).

image resolution in range of one millimeter or less, the data acquisition must record at least 1000 points of measurement per round. Since amplitude an phase value must be recorded for each pixel, the number of data points sums up to 2000 measurements per round (minimum requirement). The built-in control logic assures that both channels (I/Q) are sampled synchronously, which is vital for the amplitude and phase calculation later on. For the proof of concept the further data processing (like transforming the measured arcs of pixels into a rectangular image) has been implemented on a computer. The antenna system was realized with a dielectric tip. For the tip, polyethylene (PE) with a relative permeability of 2.25 was used.

For a second test series, a motorized, linear XY-scanner stage was used in combination with a dielectric tip antenna. The system consists of two linear stages, which scan a two-dimensional grid to create the image. A program controls the frequency generation as well as the recording of the signals and the motor positions. It can even provide some simple signal processing like standardization of amplitudes etc. The antennas mounted in the system are dielectric waveguides with their tips cut in an appropriate angle. The outer dimensions correspond to the inner dimensions of classical waveguides. Angle and length of the tips determine the gain of the waveguides, similar to horn-antennas. The advantage of this kind of antenna is the flexibility of the waveguide. As the wave is guided mostly outside the waveguides, the antennas are placed very carefully to avoid any contact with other parts of the measurement system. This system was connected to a vector network analyzer, which allows the measurement of a wider frequency spectrum.

3 Test samples

For a first test series, four samples with different densities were selected. All probes have the same thickness and structure. The only difference is the density of the four samples (see Table 12.1).

Table 12.1: Samples for the test measurement.

mineral wool	weight [g]	surface [m^2]	Surface weight [kg/m^2]
D1	35.1357	0.0225	1.5616
E1	29.8223	0.0225	1.3254
B1	40.7342	0.0225	1.8104
C1	43.8869	0.0225	1.9505

4 Measurements

Especially the amplitude measurements show only minimal differences between the wool samples. Like measurements with X-ray systems, the attenuation coefficient for all samples is very low and differences between the samples are very small. In contrast to the amplitude measurements, the phase results show a strong dependence on the density of the investigated material samples (compare Figure 12.2).

For a deeper analysis, we compare a measurement along a reference line (see figure 12.3). The comparison of the attenuation shows a strong

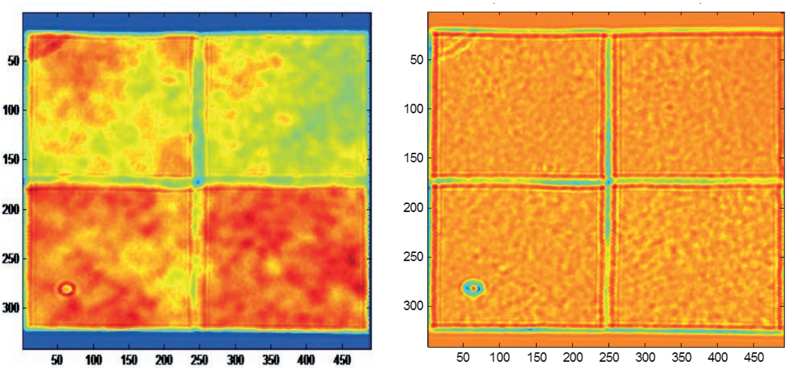

Figure 12.2: Phase measurement (left) and amplitude measurement (right)

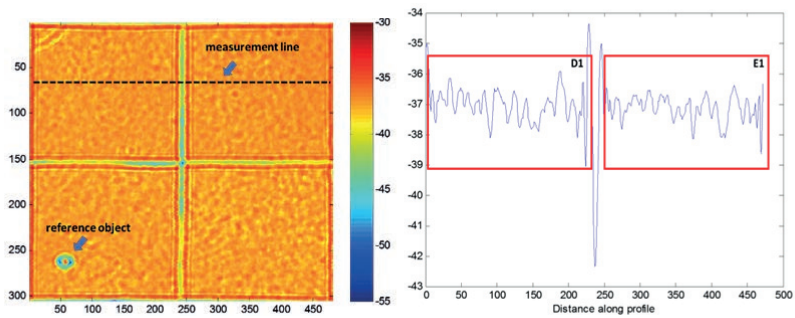

Figure 12.3: Amplitude measurement (left) and attenuation along the selected reference line (right)

fluctuation along the selected measurement line. There are only minimal differences between the two samples. Like the results from X-ray measurement systems, the small differences allow an estimation for the surface weight only through an average value over many measurement points.

With the phase measurement, high frequency sensors can measure the time delay which is caused whenever the electromagnetic wave transfer a dielectric medium. In contrast to a simple amplitude measurement, phase measurements offer a high sensitivity for even the smallest changes in the dielectric medium. Figure 12.4 shows (comparable to the amplitude measurements in figure 12.3) the measurement along a randomly selected reference line over 2 material samples. Other than the amplitude measurement, the phase measurement shows a small but relevant phase difference between the 2 samples. As estimated, the inhomogeneity of the material causes a strong fluctuation along the reference line. For an exact estimation, a mean value over a larger number of measurement points must be created.

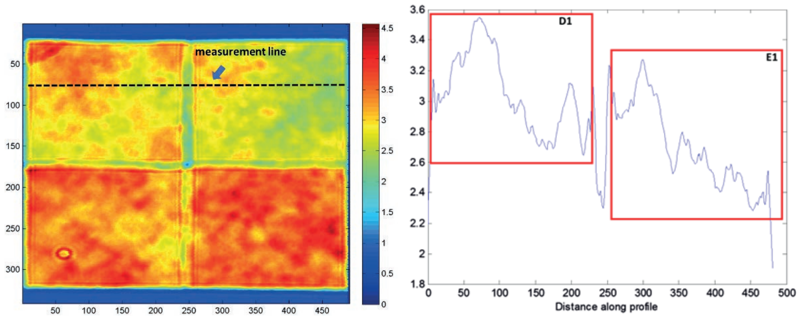

Figure 12.4: Phase measurement (left) and phase distribution along the selected reference line (right)

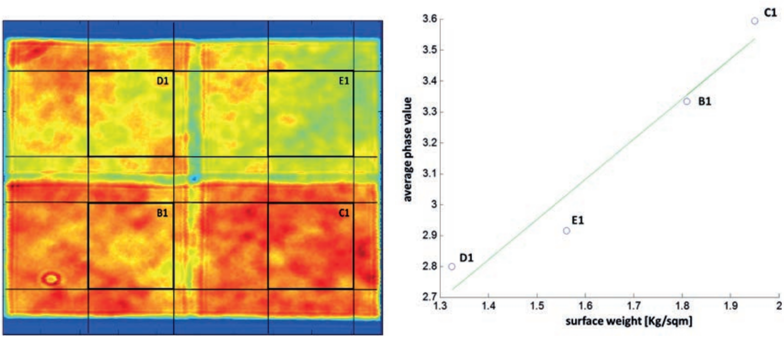

Figure 12.5: Grid creation of phase measurements (left) and appropriate mean phase values for every probe grid (right)

To evaluate how useful the mean value for the determination of the surface weight is, an average phase value over a test area is formed. The four selected test areas have equal dimensions. Figure 12.5 shows the four mean values. When comparing the values with the surface weight from table 12.1, a linear relationship between the mean values and the different material densities can be observed, visualized through the trend line in figure 12.5.

5 Summary

The paper demonstrates that the density distribution of stone wool can be measured by high frequency signals. In this the distinguished amplitudes show only small differences between the samples with different surface weights. But the analysis of the phase information offers a good alternative. Thus it was shown that the phase is related to the surface weight.

References

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