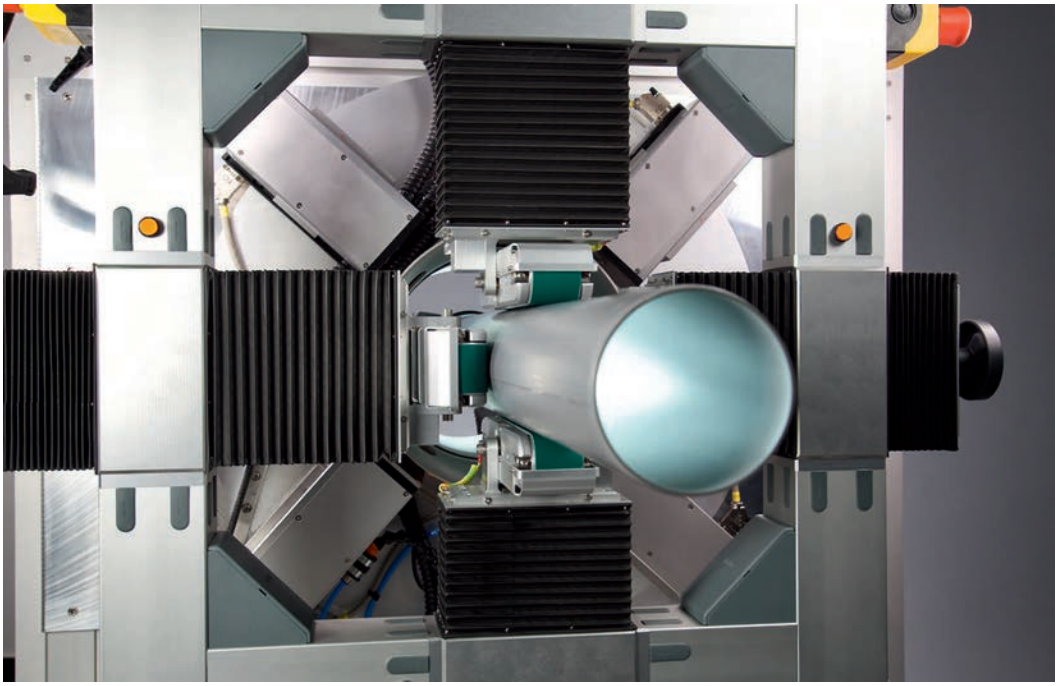
Inline Layer Thickness Measurement

Contactless Measurement with Terahertz Waves in the Micrometer to Centimeter Range

Terahertz technology supports contactless inline measurement in the micrometer to centimeter range. Wall thicknesses of pipes, hoses, and other extrusion products can be verified directly in the production process. Falling below the minimum thickness is identified immediately, thereby avoiding waste.



Terahertz inspection system for the inline measurement of pipe wall thicknesses. The wall thickness of single-layer and multi-layer pipes is determined simultaneously at four positions (© Fraunhofer ITWM)

The economical use of raw materials is the hallmark of efficient production processes. The use of materials must be at the lower limit of the defined requirements, without falling below it. At an assumed average mass throughput of approximately one ton per hour, 8000 production hours per year and a material value of EUR 1500 per ton, reducing the use of material by just one percent results in cost savings of EUR 120,000 per year [1].

Material savings can for example be realized by reducing wall thicknesses. However, falling below the minimum layer thickness must be avoided in order to prevent waste. Monitoring requires inspection systems that are integrated directly into the production process. The quality of a plastic pipe is defined by the key figures of diameter, wall thickness, ovality, and sagging (of the melt during solidification if the viscosity is too high). These have to be captured by an inline inspection system, ideally in real time and as early in the process as possible.

Limits of Established Methods

Ultrasound measurements have long dominated quality assurance and process monitoring in plastics production. The extruded material is exposed to ultrasound waves and their transit time is measured. This is used to calculate the wall thickness with the help of the material-specific sound velocity. Since the sound velocity is highly dependent on temperature, the temperature fluctuations common during extrusion make exact wall thickness measurement difficult. The technical effort is relatively high because ultrasound methods require a coupling medium such as water between the probe and the extruded material. Algae can also form in the water and impede the measurement [1]. Alternatively, laser-based sensors cap-

The Author

Dr. Joachim Jonuscheit has been Deputy Head of the Department Materials Characterization and Testing at Fraunhofer ITWM in Kaiserslautern, Germany, since 2006; joachim.jonuscheit@itwm.fraunhofer.de

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References & Digital Version

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- Read the German version of the article in our magazine ***Kunststoffe*** or at ***www.kunststoffe.de*** ture the outside diameter while X-ray-based sensors additionally determine the wall thickness and ovality. All required quality criteria are determined by combining both measuring techniques.

The terahertz process as an optical method is contactless and non-destructive, making it suitable for inline verification (**Fig. 1**). This method has already proven its industrial maturity and suitability in numerous applications.

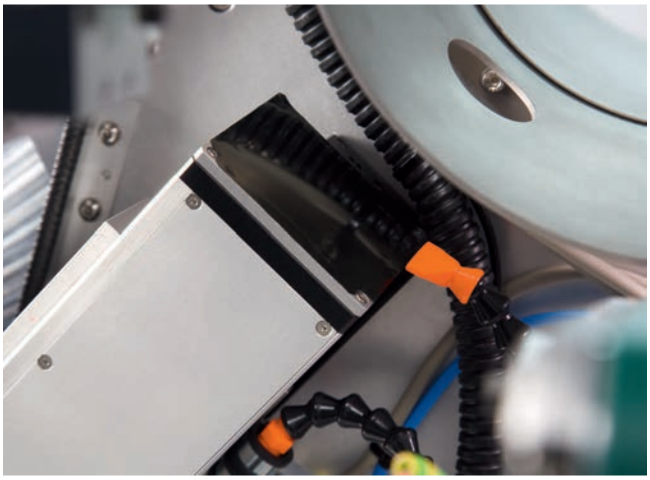

Fig. 1. Close-up of a terahertz sensor with flushing device to prevent the accumulation of water and dust on the viewing window (© Fraunhofer ITWM)

Fig. 2. Measuring setup with terahertz FMCW hand-held scanner: measurements in the field, for example on district heating pipes, are possible with the mobile terahertz sensor (© Fraunhofer ITWM)

Low Process Integration Effort

Terahertz waves are electromagnetic waves in the frequency range between millimeter waves and microwaves on the one hand and infrared radiation on the other hand. The former are used by radios, microwave ovens, and mobile phones, the latter by infrared cameras and remote controls. The frequency range of terahertz waves is between 100 GHz and 10 THz. That corresponds to the wavelength range from 3 mm to 30 µm.

The special properties of terahertz waves include their good penetration of electrical insulators such as ceramics, glass, and plastics. Nonpolar plastics such as polyethylene (PE) and polypropylene (PP) in particular are largely transparent for the waves. Polar plastics such as polyamide (PA) on the other hand exhibit relatively high absorption. Water and electrically conductive materials such as metals cannot be penetrated by terahertz waves well or at all, often acting as a mirror. Terahertz waves are non-ionizing and therefore safe for humans. This means the inspection system does not have to be shielded. Overall the technical effort is very low because coupling media as for ultrasound measurements are not required. This improves acceptance in production and lowers the integration costs.

In contrast to the sound velocity, optical parameters such as the refraction index and absorption coefficient are much less dependent on temperature. For many materials the temperature dependency can in fact be disregarded within tight frequency limits.

Measuring Method for Layers of Various Thicknesses

Two different terahertz techniques are used in principle. With the TDS method (time-domain spectroscopy), very short terahertz impulses are generated and their transit time is used to determine the thicknesses of one or more layers. The measuring range is between 10 µm and a few mm. The reproducibility is better »

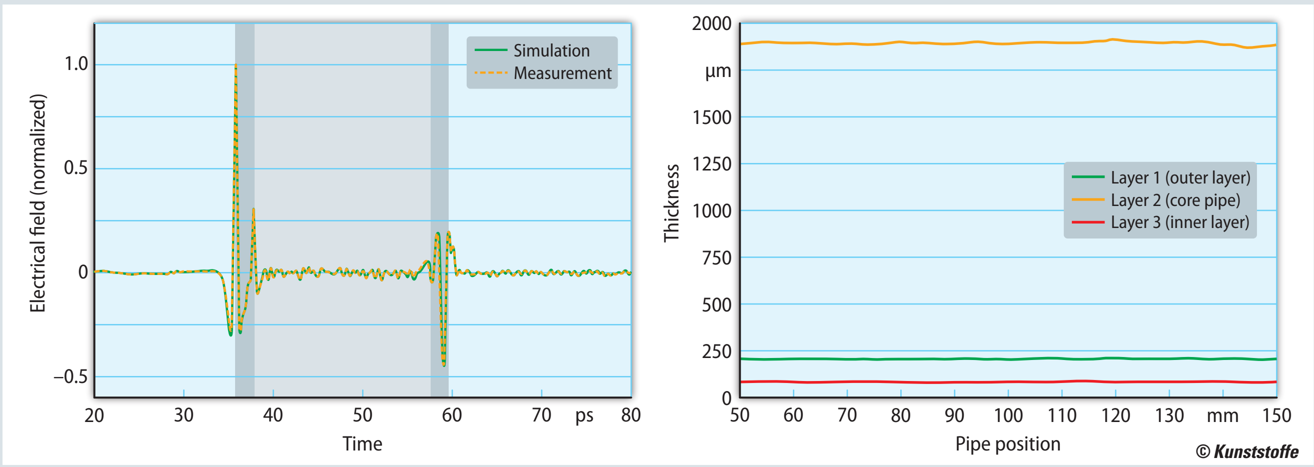

Fig. 3. Wall thickness measurement on a foamed PP pipe. Left: measuring signal and simulated signal sequence used for evaluation. Right: examination of the individual layers along the pipe with 40 measurements per second (source: Fraunhofer ITWM)

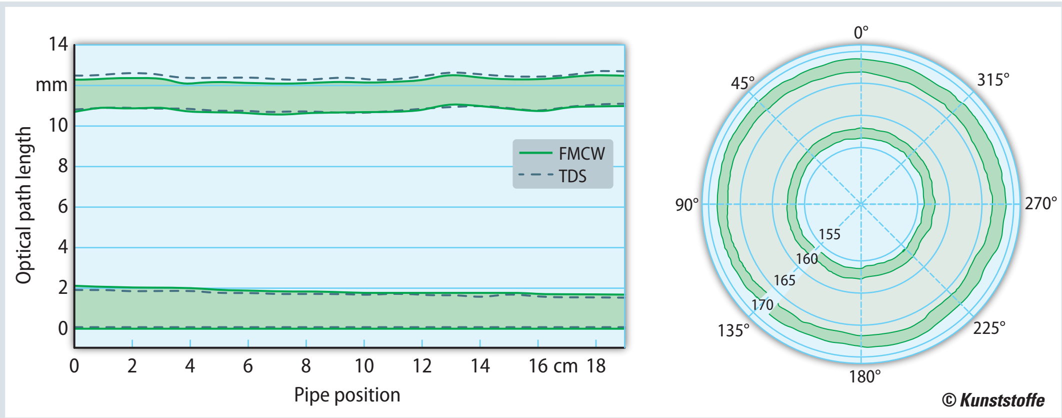

Fig. 4. Left: comparison of the measured wall thickness of the individual layers along the pipe. The optical path length corresponds to the product of the geometric thickness and the refraction index (approx. 1.7). Right: distribution of the measured wall thicknesses along the pipe circumference (source: Fraunhofer ITWM)

than 1 µm. Up to 50 thickness measurements per second can be carried out using this method [2]. The second method is based on an FMCW radar (frequency modulated continuous wave) and supports layer thickness measurements in the range from 1 mm to several centimeters. Transit time measurement is again used to determine the thickness. Single and multiple layers are measured with measuring frequencies of up to 5000 measurements per second [3]. Both measuring methods can be integrated into an inline inspection system.

A mobile system is available for the inspection of large, fixed objects or in the field, for example after welding plastic pipes or insulating district heating pipes. District heating pipes cannot be inspected using ultrasound because the insulation is made of foamed materials that dampen the sound too much. A mobile terahertz system has been developed for these measuring tasks (**Fig. 2**).

Practical Benefits

Benefits of the terahertz technology at a glance:

- Contactless and non-destructive measurement of wall thicknesses, ovality, sagging
- Can be used in the hot and cold sections of the extrusion line
- Measuring and display of results in real time
- Straightforward integration without coupling medium or radiation protection
- Can be adapted to pipe diameters from a few millimeters to meters
- Suitable for smooth, corrugated, foamed, and multilayer pipes and hoses

Application Examples from Pipe Production

In the examples, the wall thickness of single and multi-layer smooth pipes is to be measured directly after the extruder and before the first cooling section in order to keep the process control section as short as possible. Conventional ultrasound systems cannot be used here due to the elevated pipe temperature and the plastic core on the inside of the pipe. However, the use of the terahertz technology was successfully demonstrated here. Both examples use a foamed pipe, but with different wall thicknesses. A PP plastic pipe with a foamed core was examined in the first example (**Fig. 3**). For reliable thickness determination with a low wall thickness, the signal is evaluated through a comparison of the measurement and a simulation in real time.

A foamed polyvinyl chloride (PVC) pipe was examined in the second example. Here the individual layers are thicker and therefore accessible for both terahertz techniques. The measurement results of the two methods agree very closely (**Fig. 4**). An additional measurement with the terahertz FMCW handheld scanner along the circumference captures the thickness variation of the individual layers.

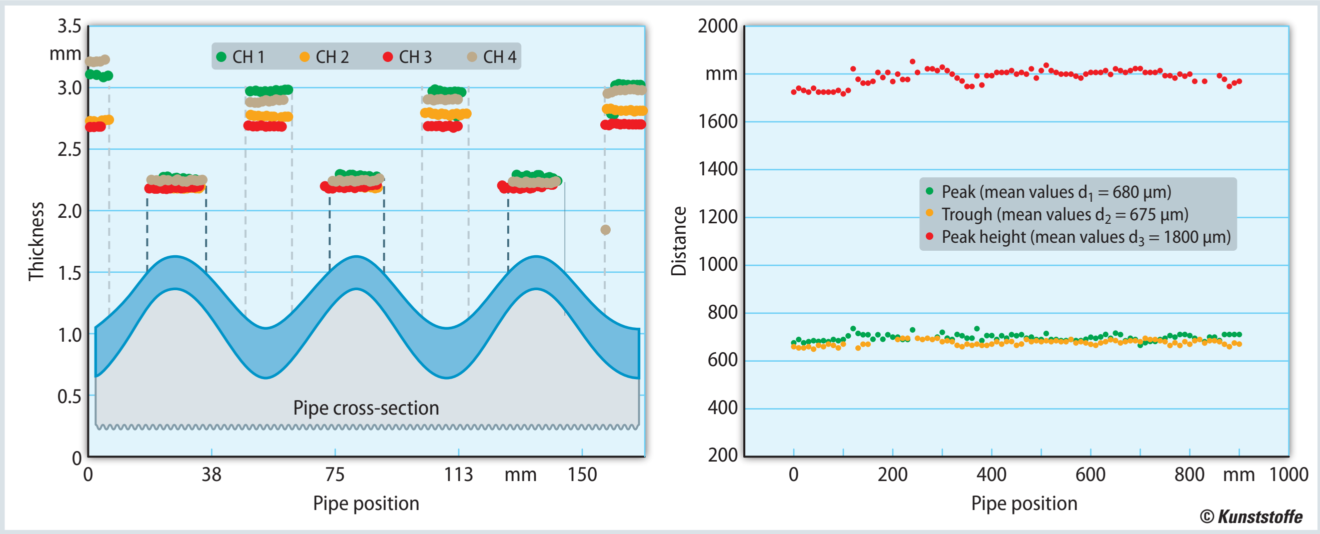

Fig. 5. Wall thickness measurement on corrugated pipes. Left: measurement at four positions (CH1–4) along the circumference. The peak height is 3 cm, the diameter is 130 mm, and the feed rate is 4 m/min. Right: the distance between two peaks is 2.3 mm and the feed rate is 400 mm/s (source: Fraunhofer ITWM)

Inspection of Corrugated Pipes in the Process

Corrugated pipes cannot be examined in the production process using ultrasound due to their surface structure. The tighter the corrugation, meaning the more corrugations per unit of distance, the less well can the pipe be inspected. Terahertz inspection on the other hand is contactless and suitable for measuring corrugated pipes. Note that sufficient signals reach the detector only from pipe positions that lie nearly perpendicular to the incident measuring beam. The two corrugated pipes that were examined differ in the number of peaks per unit of distance and the peak height (height difference between peak and trough) as well as the pipe diameter, wall thickness, and feed rate (**Fig. 5**). In both cases the wall thickness was determined in real time.

Outlook

The terahertz technology is a measuring technique with multiple uses that is ready for industrial use, of great benefit in the plastics industry in particular, and will continue to gain popularity in the coming years. Aside from hardware development in the last few years, the key to solving numerous application technology challenges lies in signal modeling and processing. Meanwhile several terahertz methods are available. In addition to applications in pipe production, this technology is also being used successfully to measure the thickness of hoses and coatings on plastics, for example to measure the paint thickness on coated bumpers. ■