Keeping an Eye on Extrusion

Measurement of Diameter, Wall Thickness, Eccentricity and Sagging during Production

Online measuring devices with connected control are nowadays a standard in extrusion lines for online quality control, process stability and cost reduction. The article provides an overview on conventional as well as innovative measurement technologies and discusses their advantages and limits regarding their use in extrusion lines.

Manufacturers of hoses and tubes have been investing intensively in measuring and control technology as well as line control over the last years, aiming for an online quality control, process stability and cost reduction. Used test devices include, amongst others, gauge heads that measure the inner and outer diameter, the ovality, eccentricity as well as ideally the sagging (of the melt during the solidification at a too high viscosity) of the product during the extrusion process. The used measuring systems are based on varied technologies that have their strengths in different application areas.

Measuring the Diameter

For the measurement of the product diameter of hoses and tubes, two established techniques are used: Scanning as well as CCD line sensors.

The scanning method is based on a rotating mirror or a rotating disk, whereby a laser beam scans across the measuring field. In-between the rotating mirror and the light sensor, two lenses are arranged. The first lens diverts the laser beam almost parallel across the measuring field, the second lens onto a light sensor. The product is arranged between these two lenses and disrupts the laser beam, while it is scanned across the measuring field. Therefore, the product diameter is calculated by comparing the time the laser beam needs to pass the whole measuring field with the time the laser needs to scan the complete product surface (**Fig. 1**).

The measuring frequency depends on the rotation speed of the mirror and can be increased by the use of a polygon mirror. However, therefore, the mirror needs an identical surface finish. Often, an averaging from several measurements is necessary to achieve a high accuracy.

CCD line sensors work – compared to the scanning method – exclusively digitally and require no moving components. Therefore, accuracy, repeatability as well as the measuring rate are higher and a calibration is not necessary. Generally, line sensors can be used for measurements in two ways:

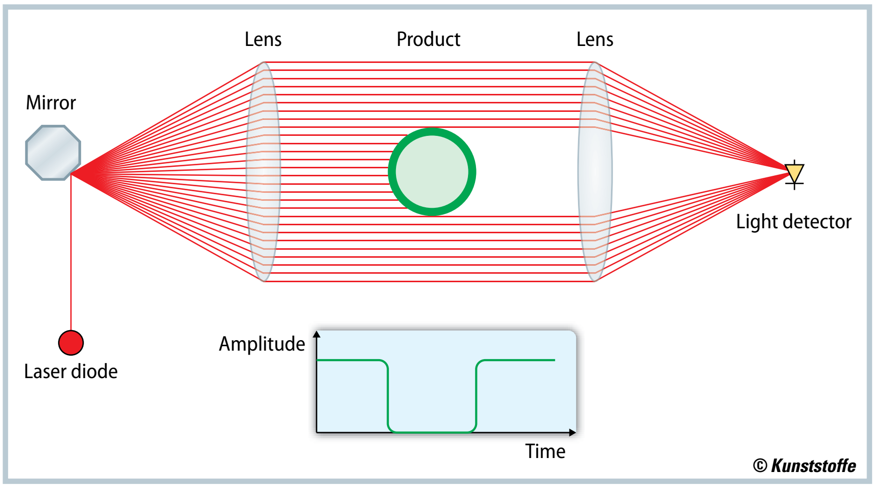

Fig. 1. Scanning method with rotating mirror: the time during which the sensor signal is shadowed determines the diameter (source: Sikora)

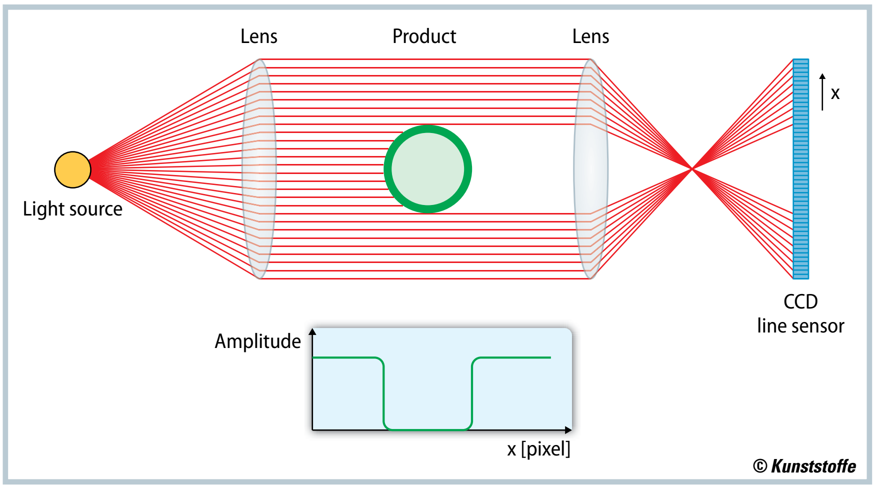

Fig. 2. Projection method by using optics with CCD line sensor (source: Sikora)

- In the first method an optics (lens) focuses a laser beam on a CCD line. By counting the darkened diodes from the shadow image of the object, the diameter is determined (**Fig. 2**).
- The second approach does not need cost intensive optics, because the laser directly illuminates the high-resolution CCD line and the diameter is calculated from the diffraction fringe (**Fig. 3**). The measuring rate is extremely high and only limited by the frequency of the CCD line sensors.

Gauge heads that work with the line sensor technology measure the diameter in two or three planes. They are capable of measuring opaque as well as transparent products from all kinds of material with a diameter from 0.05 to 500 mm – depending on the measuring system up to 500 mm. Some models offer up to 5000 measurements/per axis and second and therefore, as well a reliable detection of lumps and neckdowns.

Additional Measurement of Wall Thickness and Eccentricity

For applications where a diameter measurement is not sufficient, there are measuring systems suitable that measure in addition the wall thickness and the eccentricity of the products. Besides quality control and process optimization, the saving of plastic material and cost reduction play an essential role.

The ultrasonic technology is suitable for the classic measurement of the wall thickness of single layer products, but reaches its limits for online quality control of hoses and tubes – due to its function and dependence on material properties, the plastic's temperature and the coupling medium:

- For example, the ultrasound is not able to penetrate the aluminum layer that is used as a vapor barrier in composite pipes and is therefore not applicable for this application.
- Measuring rubber hoses, the ultrasound signals are largely absorbed by the porosity and absorption of the rubber so that they are also not reliably measurable. Furthermore, multi-layer rubber hoses contain typical fabric reinforcements, which divert the ultrasound echo and make a measurement impossible.

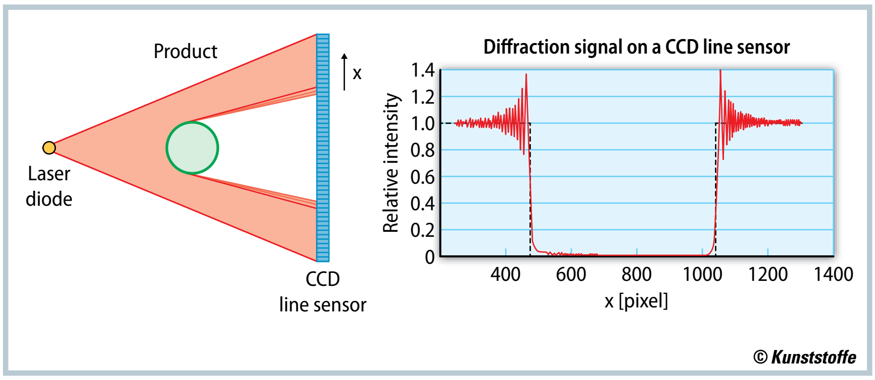

Fig. 3. Diffraction analysis of the CCD line sensor signal: the method does not need optics or moving parts (source: Sikora)

- The ultrasound measurement is usually realized in a water bath as the water is used as a coupling medium for the transmission of the sound. A precise temperature compensation is necessary as the propagation speed of the ultrasound, which is used for the calculation of the eccentricity, depends on temperature and material. This technology requires therefore a calibration. Further, an estimation of the wall thickness is typically only possible by combining the ultrasonic technique with an additional gravimetric system.

The X-ray technology is based on an imaging principle, which does not require an adaptation to materials and no coupling medium. The technology is independent of the temperature of the material, which makes it possible to integrate an X-ray measuring device directly into an extrusion line without any additional efforts and calibration. The system is either installed directly after the extruder (hot measurement) or at the end of the line (final quality control). A 4-point online measurement provides the measuring values for the wall thickness, the eccentricity, the inner and outer diameter and the ovality. The system usually measures up to three different material layers. These measuring values are visualized numerically and graphically in the form of the tube/pipe cross section in real-time and enable the user to perfectly center the extrusion tool.

X-ray technology ensures a precise measurement of all product parameters independent of environmental or material influences. Particularly efficient is the use of an X-ray measuring system in combination with a processor system for automatic control of the line speed or screw speed under consideration of the minimum wall thickness. Thus, on the one hand the quality of the hose is ensured, on the other hand, thanks to the setting to the minimum value, there is not more material used than needed.

X-ray technology is available for products with a diameter from 0.65 mm, »

Fig. 4. X-ray measuring system in a tube extrusion line (© Sikora)

depending on the measuring device up to 270 mm (**Fig. 4**). The low X-radiation of under 0.5 µSv/h is significantly below the German valid limit of 3 µSv/h: A human is exposed to an average effective dose of ca. 100 µSv on a return flight from New York to Frankfurt. This corresponds to 200 times of the radiation that such a measuring device generates.

Measurement of Large Plastic Tubes

For the dimension measurement of large plastic pipes starting at a diameter from 110 mm, as they are used in the building and service area, the above-described technologies can be used. Nevertheless, these technologies reach their limits either functionally (ultrasound) as well as regarding the costs, the limited measuring ranges and number of measuring points on the circumference of the product (X-ray) or the limitation in the measurement of the outer diameter only (laser). A further technology for quality control is currently tested: It uses terahertz pulses, which activate a powerful fiber laser that is aimed at the material. The wall thickness is determined by means of the reflected echoes from the inner and outer boundary layers. The usage of this technology for the measurement of larger wall thicknesses and materials with a high damping, as for example PVC, is, however, limited. Furthermore, the durability of the laser is limited and the costs are very high.

An innovative, significantly less expensive technology for the dimension measurement and recording of the sagging is the radar technology FMCW (Fre-

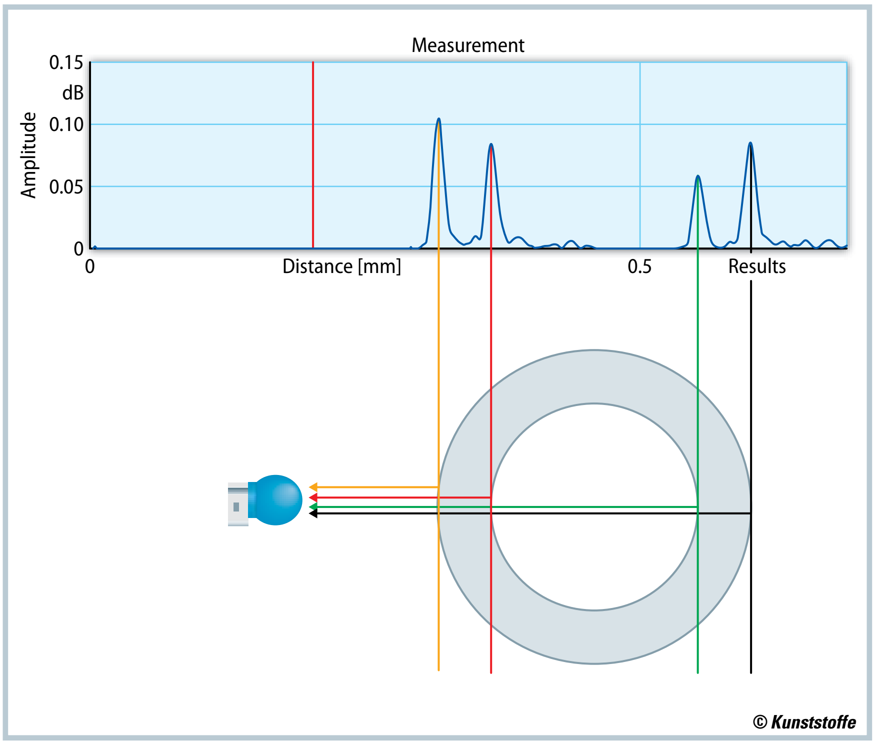

Fig. 5. Measuring principle on the basis of millimeter waves technology: From the run time difference of the reflected signals diameter, wall thickness and sagging can be determined (source: Sikora)

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References & Digital Version

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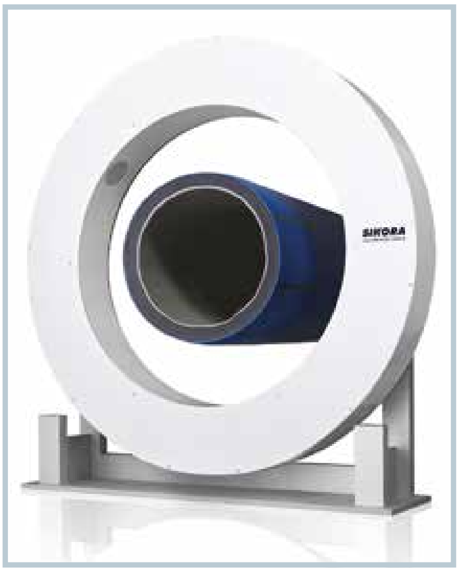

Fig. 6. For large plastic tubes: Measuring system for tubes up to 3200 mm outer diameter on the basis of the millimeter waves technology

quency Modulated Continuous Waves) [1]. These systems work within the sub-terahertz range and are already used for some time in the automotive technology for distance measurement. They are based on semiconductor technology, are inexpensive and practically not limited regarding their lifespan. Within the chosen area from 80 to 300 GHz the absorption of plastic materials is low and their wall thickness can be measured. One or two continuously rotating transceivers continuously send and receive frequency modulated millimeter waves while moving around the tube. As an alternative, a static system measures selectively the wall thickness and outer and inner diameter of a tube with two transceivers at four points. A rotating gauge head is used when the complete measurement of the wall thickness around the whole circumference of the tube is required. In this version, also the sagging is measured and displayed precisely.

The measurement uses the time difference of the signals that are reflected by the boundary layers of the front and back site of the plastic material (**Fig. 5**). The measurement is realized with an accuracy of few micrometers and a measuring rate of 500 single measurements per second. The models on the basis of millimeter waves technology measure products with a diameter from 110 to 3200 mm precisely, around the complete circumference, with no need for coupling medium and independent of temperature or type of plastic. Furthermore, the measuring system determines the relevant material parameters for dimension measurement itself, which makes a calibration by the user redundant. In addition, the technology provides information for optimum centering the extrusion product via thermal control of the extrusion tools. Thereby, the measuring values are used to ensure an optimal concentricity and minimal wall thickness.

Conclusion

With the increasing quality requirements during the production of hoses and tubes, the precise and reliable quality control for plastic pipes during extrusion and thus the Non-Destructive Testing (NDT) becomes significantly important. Furthermore, an efficient usage of materials for cost saving is in focus. Measuring and control systems continuously monitor and control important product parameters. Thereby, hose and tube manufacturers may choose from various technologies with different functions and diverse applications.

The laser technology offers a reliable online measurement of the diameter from 0.05 to 500 mm. X-ray measuring systems measure in addition the wall thickness and eccentricity of products with a diameter up to 270 mm. A further innovative technology, based on millimeter waves, is used for extrusion lines where large plastic pipes up to 3200 mm are produced (**Fig. 6**). The technology is applicable for different material types and measures common tube dimensions as well as the sagging precisely. Which measuring technology should be used in an extrusion line depends, therefore, on the application area and the requirements of the user regarding measuring and control technology for quality assurance, process optimization and cost saving. ■