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Full Length Research Paper

Laser inspection of rubber profiles

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In the rubber industry, especially in the tire branch, inspection of shape and dimensions of freshly extruded rubber profiles which are components of a final product is an important problem. Accuracy of shape and dimensions of these profiles largely defines the quality of final product. Reviewed in this paper are existing solutions and inspection technologies which are in use for this type of problem. Proposed in this paper is a novel solution for the inspection of shape and dimensions which performs on a par with existing methods, while providing simplicity and cost effective design. The proposed solution employs a two-dimensional movement of a simple laser beam, which measures the distance rather than the laser plane whose reflected traces are analyzed as an image.

Key words: Rubber, tire, laser, measurement.

INTRODUCTION

In contrast to earlier periods, the rubber industry – especially its tire branch, has become a very sophisticated industrial sector. This implies that the quality of final product is of utmost importance. Rubber products are most often composed of a larger number of rubber components and additives. Some additives in rubbers have been found to cheapen the cost of production of a given rubber article; to enhance a set of mechanical properties, to increase longevity of the article in service or to facilitate various shaping process that rubber may be subjected to during manufacture (Akinlabi et al., 2011). In order to be able to guarantee the quality of final product, each of these components and additives must be accurate as regards material quality, shape, and dimensions (Munzinger et al., 2010; Bosse and Zlot, 2009). This is especially important for tire manufacture, where the quality of final product directly impacts the safety of passengers and goods which are transported by road vehicles using these tires.

Initial stage in manufacture of rubber product components is the extrusion of rubber profile. The quality and dimension of this profile depend on extrusion parameters. These parameters are set based on the results of profile and dimensional inspection immediately upon extrusion. As the rubber is at a high temperature at that moment, its surface is still deformable which precludes any type of contact measurement.

Various methods are used for this type of measurement. A vision-based measurement system which determines a 3-D reconstruction of the rubber profile section and performs dimensional measurements is presented in Anchini et al. 2006. Another method uses several cameras which produce a spatial image of the measured profile (Liguori et al., 2004). This method is seldom used due to equipment costs, and is employed only in case of expensive final products. For this type of measurement, laser devices are most frequently used. Lasers have a high radiation power focused on a very small area; laser light is highly chromatic and coherent (Erhardt-Ferron, 2000). One of them uses optical non-contact probe which measures location and orientation (normal vector) of the free surface (Ruey and Fang, 2011). The measurement system consists of five laser beam projectors which cast light on the measured surface, and a charge coupled device (CCD) camera which captures and processes the reflected light. The devices most often used are 'off line', which means that the extrusion line must be stopped so that a piece of rubber profile can be cut off for measurement and taken

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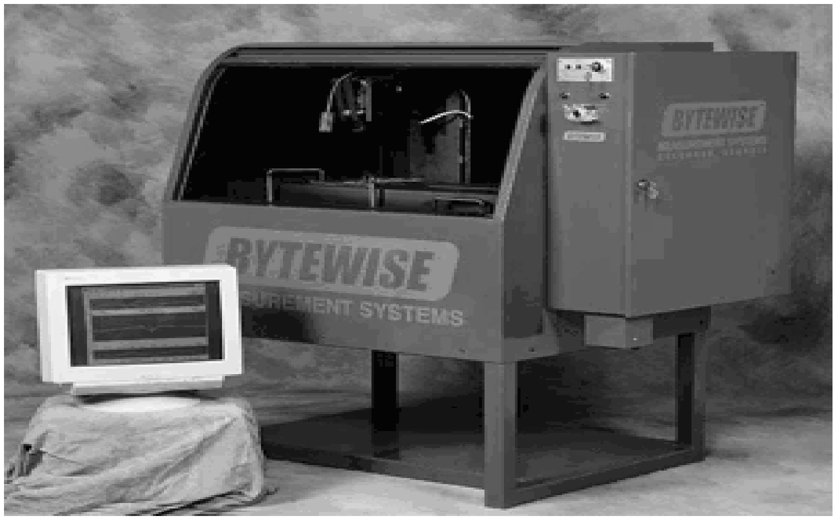

Figure 1. Bytewise machine for 'off line' measurement of profile shape and dimensions

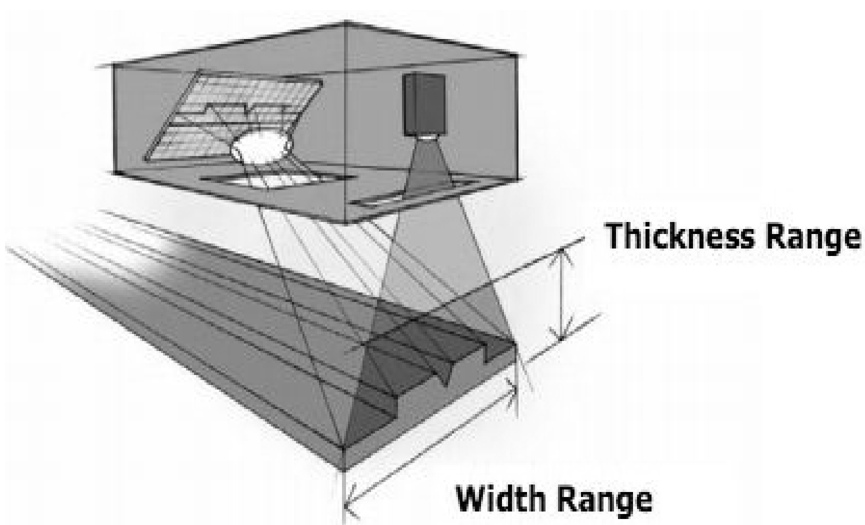

Figure 2. Principle used in machines for laser measurement of profile shape and dimensions (Bytewise measurement Systems, 2004).

to the measurement machine. Shown in Figure 1 is a Bytewise measurement machine which is one of the most widely used machines in the tire industry, (Bytewise Measurement Systems, 2004).

The principle used in machines for laser measurement of profile shape and dimensions is shown in Figure 2.

The laser plane is reflected off the measured profile and registered on the screen. Here, user can see the nominal profile shape, as well as the real one which is generated by the reflected laser plane. This image can be analyzed by naked eye, or, alternatively, the digital image generated by a CCD camera is analyzed (Figure 3). This equipment is highly expensive and susceptible to external influences.

'In-line' device is another type, which is less frequently used, but is more practical in use, and performs on a par with the previous device, without the need to stop the extrusion line for sampling (Figure 4).

In this case, the digital image analysis must be performed, while the results of image analysis displayed on screen look like those shown in Figure 3. It should be noted that this image changes dynamically during measurement. A method similar to the previously considered is used for the real-time detection of curvature of rolled products. It is based on optical triangulation by lasers, and a three dimensional surface reconstruction. The system operates 'in line', uses laser stripe, and a CMOS matrix camera for signal detection and processing

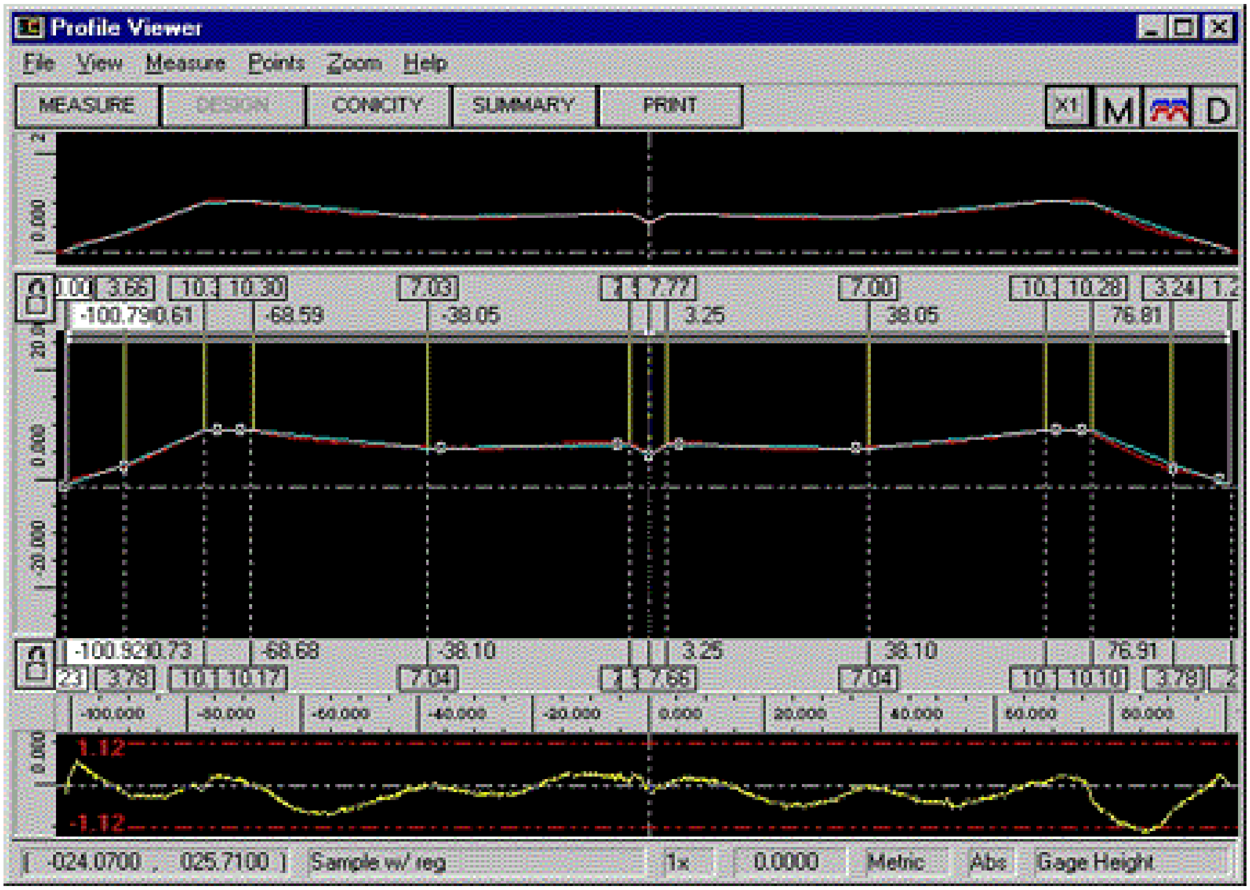

Figure 3. Measurement result derived from analysis of a digital image

Figure 4. Machine for 'In Line' measurement of profile shape and dimensions.

(Molleda et al., 2010). Also described in the literature is a laser-, non-contact, electro-optical system for automated measurement and inspection of external dimensions of products which move at high speeds (Ward and Brew, 2009). Similar to this, an 'in line' system is reported which allows monitoring of a 'roll-to-roll' production process. It

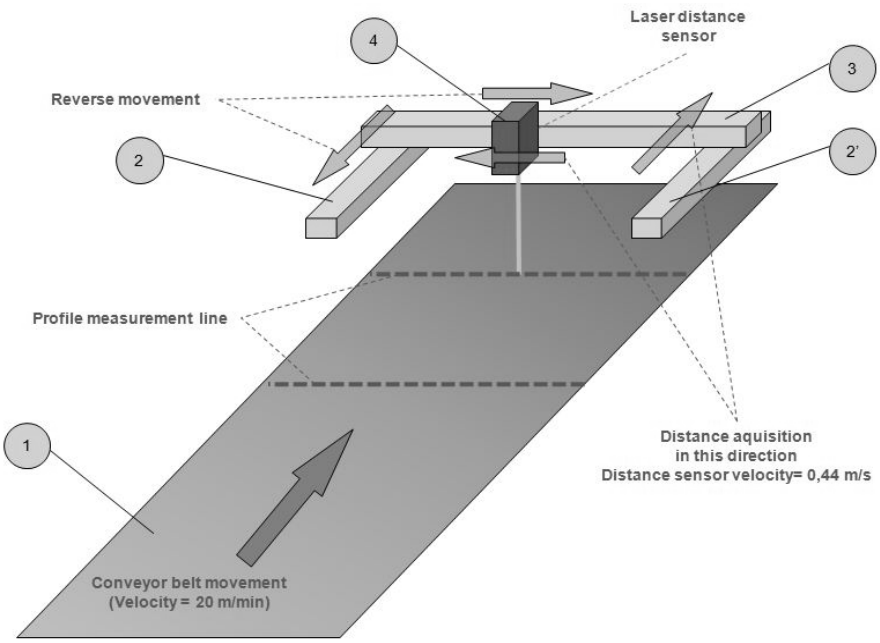

Figure 5. Operating principle of the proposed solution.

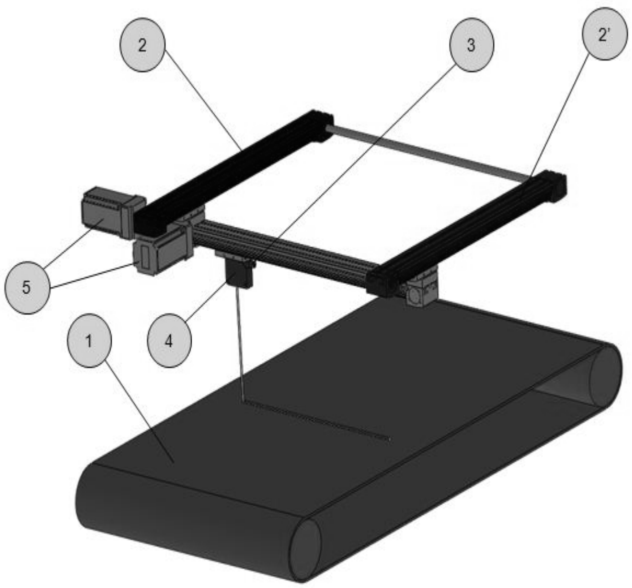

Figure 6. Technical realization of the proposed principle.

allows a wide range and high accuracy 3D monitoring of flexible electronic products and components which are manufactured in 'roll-to-roll' technology (Zhaoyang et al., 2008). Although the reviewed methods have their advantages, this paper focuses on their main drawback: the use of highly expensive equipment which, in addition, is also susceptible to environment; it is worth noting that the operating environment for 'in-line' measuring is far more aggressive than that for 'off line' equipment.

MATERIALS AND METHODS

The analysis of available technology, work conditions, and quality of final products in a Serbian tire factory, lead to a conclusion that 'in line' measuring yields superior results, with smaller number of measurements per unit time. Interference is slow and occurs rarely. Continuous control of profile is not necessary. This allowed another approach to 'in-line' measuring which is based on a two-dimensional manipulator driven by the laser distance sensor.

The sampling speed of an „in-line" system is equal to the camera speed, that is, the speed of image processing software. Depending on the camera and software, the time required equals 25 to 80 m/s. Analysis of tire production in Serbia showed that such sampling frequency is not necessary. The proposed solution is given in Figure 5.

In Figure 5, 1 denotes the conveyor belt which carries the extruded profile. Denoted by 2 and 2' are the drives (axes) which enable longitudinal movement of the measuring device 4. 3 is the drive (axis) which is supported by drives 2, and 2', and which provides transverse motion of the measuring device. Drives 2, 2', and 3 are synchronized with each other, as well as with the conveyor belt speed, which enables the measuring device to operate in a straight line, normal to the direction of conveyor belt movement.

Technical realization of the proposed principle is shown in Figure 6. It features a 2D gantry manipulator. The drives for longitudinal movement are 2 and 2' (active, and passive axis), while 3 is the drive for transverse movement. Both drives are run by step electromotors, 5. The laser distance sensor, 4, is located on the slider for axis 3.

Rather than analyze the entire line which defines a single cross section of the extruded rubber profile, the proposed solution measures profile thickness at a predefined number of points. The sampling speed of the measurement of profile shape and dimensions is 1.4 s, which is the time required by the system to travel along the cross line on the extruded rubber profile. The

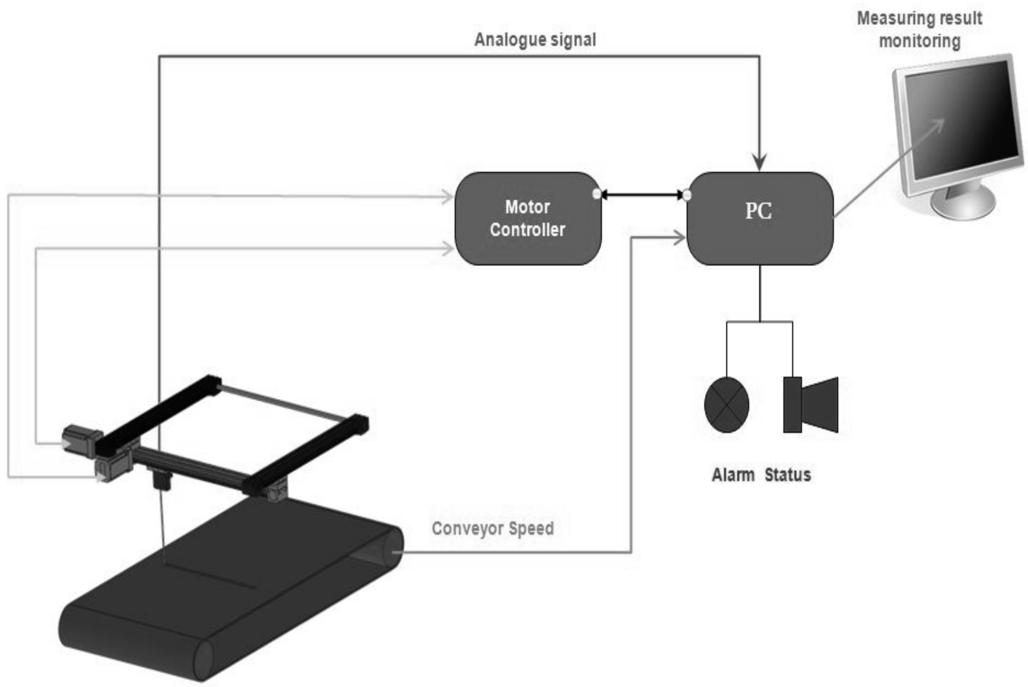

Figure 7. The proposed system for the inspection of extruded rubber profiles.

switching frequency of the laser used for distance measuring is up to 1000 Hz, and thus does not represent a critical factor in this case. The complete system is shown in Figure 7.

Fundamental to operation of this system is a PC which is used for data acquisition on the conveyor belt speed. This data is used to synchronize the motor controllers of both drives in the two-dimensional manipulator. In addition, the PC's A/D converter receives the measurement signal from the laser distance sensor. The dedicated PC software processes the sets of measured data, and compares them to predefined, required values. In case of deviation, the system sets off an alarm, followed by immediate correction of extrusion parameters.

One limiting factor of this system is the A/D converter which defines and limits the number of measuring points to 70, that is, the processing time for a single measuring point equals 20 m/s.

RESULTS

The prototype system is shown in Figure 7. It is supported by a test version of the software which allowed device calibration and accurate display of results. Measurement results obtained by the prototype system were compared with the predefined values. The same cross sections of extruded profile were also measured 'off line' using a Bytewise machine.

The results of a typical measurement are shown in Figure 8. Bearing in mind that the symmetry of extruded profile plays an important role in profile inspection, the x-axis values which represent profile width are given relative to the axis of symmetry. The y-axis shows the corresponding values of profile width. The measurements were performed on a machine which is used for extrusion of one of the tread plies. The black line in the diagram represents the preset parameters – the ideal dimensions of the extruded profile. The green line represents the results obtained by the prototype device. The blue line represents control measurement on the Bytewise 'off line' machine.

DISCUSION

It was established that the tested prototype had difficulties defining the profile in places where the abrupt changes of profile shape took place in various directions. For example, this was especially emphasized when measuring the central contour of the extruded profile (left and right to the profile width, marked 0). In places where the profile changed shape in a gradual fashion, the measurement results were almost identical to those obtained on the machine used as a reference. This is due to discrete measurements at the predefined number of points on the profile.

However, as can be seen from the diagram, the measurements were very good. Deviations of the results obtained by the tested prototype from those obtained by the reference machine were below 0.1 mm. The results also comply with the required profile.

Conclusion

In this paper were analyzed existing methods and

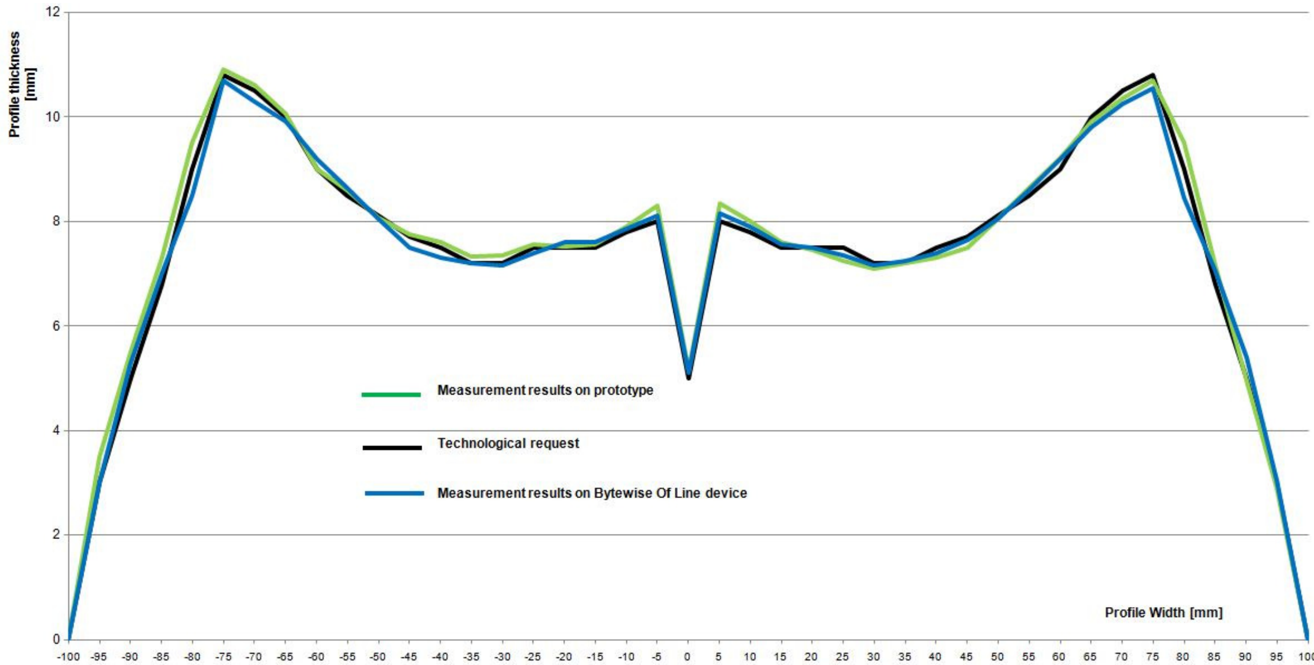

Figure 8. Measurement results obtained by experimental prototype.

devices for the inspection of dimensions and shape of extruded rubber profiles. Various methods of non-contact measurement were considered, with emphasis on laser measurement. Based on the conducted analysis, a new measurement device and method were proposed, which measure the profile thickness using a simple laser beam, without additional optical and mechanical system.

Although the measurement results obtained by the prototype device were somewhat less accurate than those obtained by the reference machine, they are still sufficient to allow valid inspection of extruded profile shape and dimensions. In the course of the experiment, the quality control of final product was performed continuously, and the obtained results were completely normal.

Advantages of the proposed device lie in its simple design, and a much lower susceptibility to environment (temperature, dirt, etc.). On top of this, the price of such device is two or three times lower than that of conventional solutions which are in wide application today.

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