Diagnostics of the Wire Coating Production Line by Implementation of Computation Methods

Ivan Kuric
Department of Automation and Production Systems
University of Zilina, Faculty of Mechanical Eng.
Zilina, Slovak Republic
e-mail: ivan.kuric@fstroj.uniza.sk

Miroslav Cisar
Department of Automation and Production Systems
University of Zilina, Faculty of Mechanical Eng.
Zilina, Slovak Republic
e-mail: miroslav.cisar@fstroj.uniza.sk

Ivan Zajacko
Department of Automation and Production Systems
University of Zilina, Faculty of Mechanical Eng.
Zilina, Slovak Republic
e-mail: ivan.zajacko@fstroj.uniza.sk

Tomas Gal
Department of Automation and Production Systems
University of Zilina, Faculty of Mechanical Eng.
Zilina, Slovak Republic
e-mail: tomas.gal@fstroj.uniza.sk

***Abstract*—If we want to understand and manage any manufacturing process, it is necessary to ensure its objective and detailed description in real time. Diagnostic tools and methods are used for this purpose, but often they contain isolated descriptions of each process parameter. For the diagnosis to be as accurate as possible, we need to ensure a comprehensive collection of parameters describing the manufacturing process, which usually creates a very large set of data. A sufficiently large set of data obtained by diagnostic process enables us to discover, in addition to the obvious characteristics of the manufacturing process, also the hidden correlations between the parameters of the manufacturing process that allow us to understand the mutually affecting phenomena in the production process by implementing progressive and modify them to improve the results of the manufacturing process. Application of progressive methods in the complex diagnosis of the manufacturing process is the subject of our research.**

Keywords-production diagnostics, computation methods

I. INTRODUCTION

The understanding of processes in production and its parameters is essential part of designing of production resources and equipment. However, lots of production processes are affected by various physical phenomena that are not fully understood in terms of practical applications what makes such processes difficult to comprehend. In the industry usually, it is difficult to spend enough time on detailed research which does not necessarily brings direct positive results. Because of these and other reasons, it is ideal to involve research and educational institutions, such as universities, to industrial projects same as we were invited to cooperate in project relative to described experiments that involved the processing of data obtained by diagnosing the production equipment. The main reason of our involvement was to establish mutual correlations between the individual parameters of the manufacturing process, to discover possible relations in the measured data, and to find application that can improve production process itself.

The diagnostics measurements were performed on production line during test run on manufacturer's premises to ensure quality in terms of the size and coherency of the rubber coating on steel wire as the product of examined part of production line. The rubberized wire, as semi product, is wound to the form of bead bundle later on the production line what requires intermittent movement, but process of coating requires continuous smooth movement in order to keep required quality. Therefor the production line contains wire buffer to balance out the discontinuities of movement required by production process of final product.

In order to simplify initial measurements and process analysis of measured data, measured data was limited to following parameters according to experience of production line operators and other knowledge of manufacturer:

- Diameter of the final product
- Speed of the wire moving thru examined part of manufacturing line
- Extruder die length

II. DESCRIBTION OF THE PRODUCTION LINE

The most important parameter mentioned above is the diameter of coated wire as it is directly bound to quality, integrity, and thickness of the rubber coating. The character of process and line itself requires non-contact measurement. To ensure reliability of measurement, two different measurement devices was used, namely Micro Epsilon ODC 2600 and Keyence LS-903D.

The basic parameters of these units relevant to performed measurements are listed in Table 1. Both measuring devices are non-contact and uses optical principle of measurement and can be equipped with pneumatic blower unit that prevents collecting of dirt on optics what can render

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measurement ineffective due to dusty environment in production site. However, during the measurement the air blowers were not installed in order to prevent unnecessary vibrations caused by air stream.

TABLE I. BASIC PARAMETERS OF USED MEASURING DEVICES

	Micro Epsilon ODC 2600	**Keyence LS-903D**
Measurement range	0,3÷40mm	0,3÷30mm
Repeatability	±0,1 µm	±0.1 µm
Measuring/sample rate	2,3 kHz	16 kHz
Light source	Red LED	Green LED
Count of measured axes per unit	1	2

Normally there is no measurement of wire diameter integrated on the production line, for purpose of measurement both measuring devices were temporarily integrated to production line according to simplified diagram of production line (Figure 1). The measuring devices was placed next to the extruder as it is the last element of coating unit and wire does not significantly change its geometric parameters after leaving the coating unit.

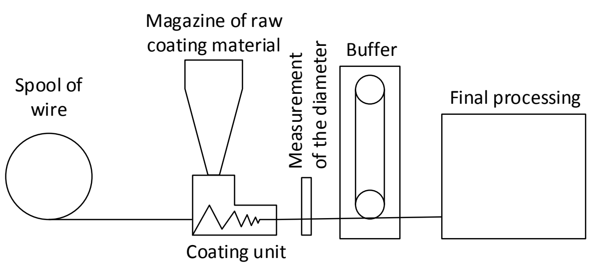

Figure 1. Simplified diagram of production line

The implementation of measurement of diameter of the coated wire to the real-life production is difficult as in most cases there are multiple parallel wires processed together using multi-die extruders. The production with parallel wires prevents implementation of the diameter in perpendicular axes as they are close together and also there would be necessity to measure multiple diameters with one sensor. Also, the wires are vibrating in various directions and amplitudes and sometimes they are touching each other what would cause more problems with measurement data analysis.

The wire speed was obtained from production line control system as diagnostic output of variable-frequency drive inverter and also by measuring by incremental speed sensor in order to compare relevancy of these two sources.

Experiment itself was performed by gradually increasing wire speed in certain limits according to normal settings of production line and measurement was repeated for each of six extruders that differs by length (4÷16mm). The speed of wire was increased in increments of 20m/min from 60m/min to 240m/min same as when production line is starting up.

III. DATA PROCESSING

Data was acquired in form of changes of measured parameter and time of that change read from PLC controlling the production line. The data measured with Micro Epsilon ODC2600 that exceeded 300% of median value of diameter were filtered out as we suspect that most of such were affected by wire vibrations in one axis. The parameters of filter were selected by method of trial and error to select the most effective way of the data analysis. The semi periodic characteristic of the data that were filtered out because of significantly increased amplitude suggests that the source of the deviations is movement of buffering mechanism. The buffer is source of significant vibrations as it repeatedly moves large weight up and down as it buffers the coated wire during interruption of its retraction at output, required by product finishing phase. Amount of measure points that has to be filtered out to get usable data for analysis is negligible and it is between 0.43% when using die length 9.213mm and 0.67% when using die length 4.258mm.

The differences in diameter measured by Micro Epsilon and Keyence devices, are similar to diameter measured in X axis and Y axis measured by Keyence as shown at examples of graphical analysis in charts at figures 2 and 3. The green stripes at the charts separates the zones with different speeds and represent acceleration of production line to the next speed increment. These differences hold the value, except at speeds exceeding 160 m/min when using extruder die lengths 4.258 and 6.722 mm, we suspect that because the short length it introduces vibrations.

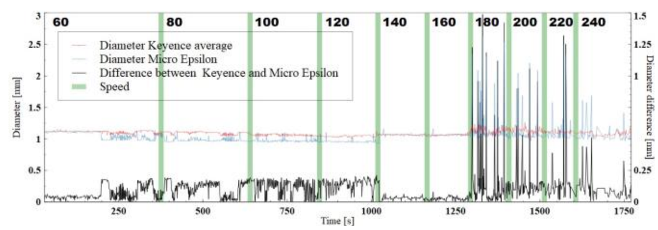

Figure 2. Diameter measurment die length 4.258mm

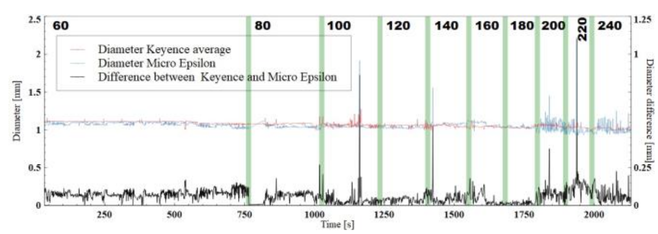

Figure 3. Diameter measurment die length 11.744mm

The analysis showed that the values measured by both devices are equivalent, therefore in order to make analysis simpler and more reliable we decided to use only diameter measured by Keyence device as it is more resilient to vibrations due its higher measuring rate and it also allows comparison of dimension measured in two perpendicular axes and determine the circularity of coating and detect its deviation and its relation to changes of other monitored parameters.

The circularity of coating is important parameter as its instability promotes formation of cracks in coating that can result to large uncoated areas, peeling of coating rubber, and unacceptable defects in final products or even production line jams. Therefor the stability of circularity can be considered to be an indicator of quality of the production.

We plotted the stability of circularity in all speed ranges (figures 4. and 5), circularity in these charts is expressed as difference in wire diameter measured in two perpendicular axes as the percentage of its average diameter. To increase readability of the plots and to better understand the trends in measured data, the plot also contains the central moving average of data thru 11 samples.

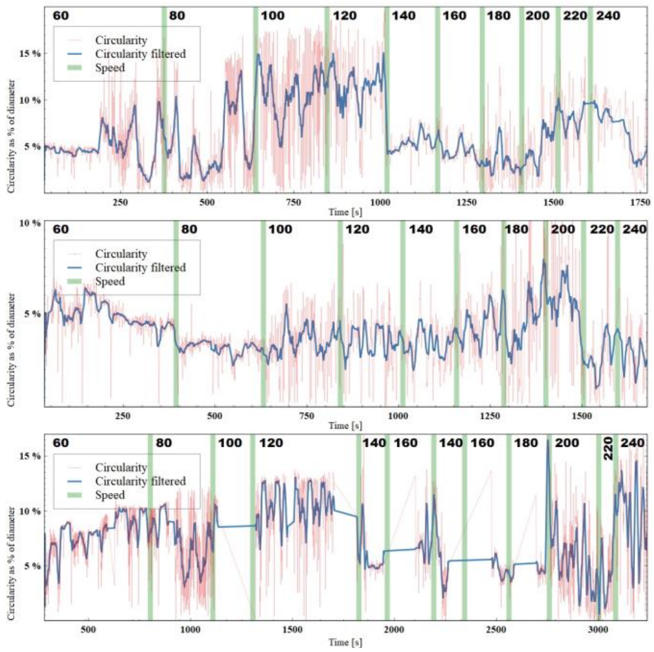

Figure 4. Circularity (die lengthts 4.258, 6.722, 9.213mm)

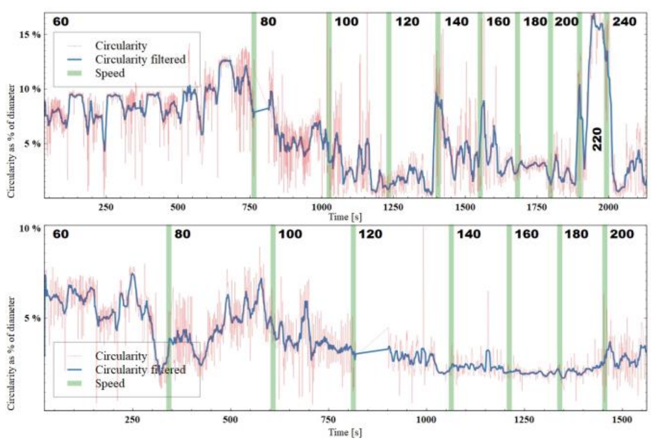

Figure 5. Circularity (die lengthts 11.744, 16.700mm)

The charts above take time of measurement into account what allows us to monitor real time changes during the measurement. However, such measurement does not fully take into account the fact that the real wire speed does not always match with the desired one as the real speed have to be adjusted because of limited buffer capacity, to balance out amount of wire in buffer, and to reduce dynamic effects of processing wire to final product at the end of the production line. The variations of the real wire speed are important and inseparable part of production process and therefor it cannot be disabled in control system (regardless it is technically possible to do so) not even for purposes of the experiment.

The diameter of the coated wire can be expressed as function of the speed of the wire at least to some extent as there is lots of other parameters. This is especially clear at the chart for the longest used die (Figure 6. bottom). The scatter charts show that there are speed ranges at which the diameter off coating is more stable and also there are some “unstable zones” these characteristics can be included to the control system of production line in order to avoid setting the speeds at which there is higher risk of error emerging and change speed in steps that skip problematic ones instead of slower continuous change of speed.

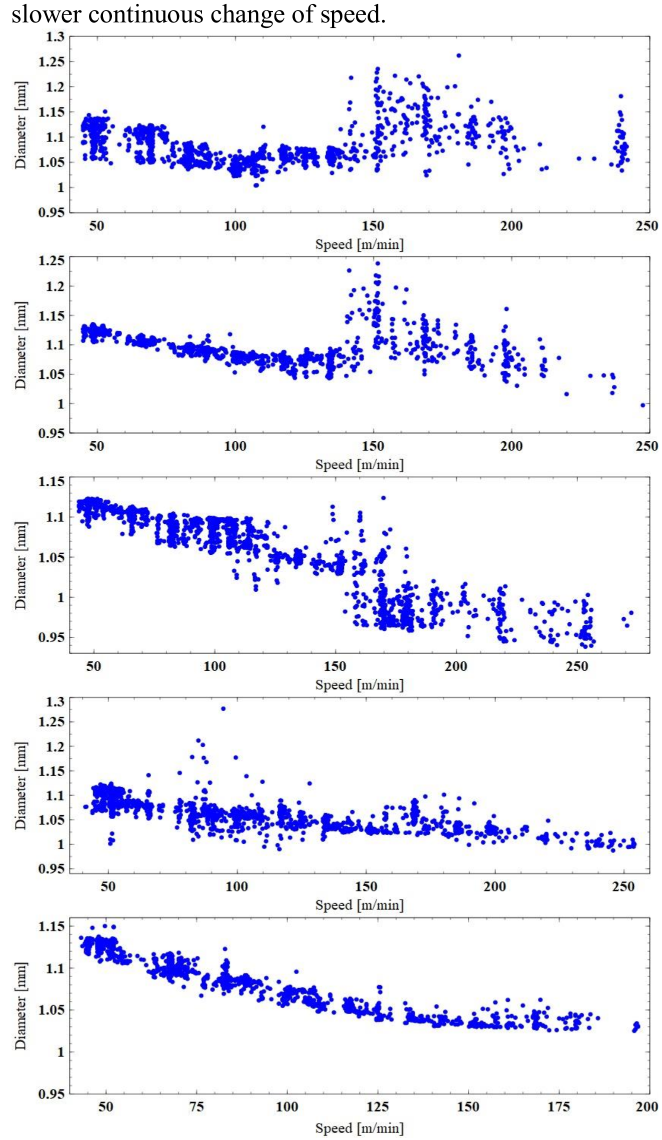

Figure 6. Wire diameter at die lengthts 4.258, 6.722, 9.213, 11.744, 16.700mm

However, such changes in control algorithms will change the elevation rate of the buffer that can led to increase of vibrations and other negative effects and therefor it would require extensive testing in real life environment before full implementation to all production sites. So called “stable zones” that describes speed ranges more suitable for production are important to recommend optimal speed rates for individual extruder dies. In order to increase informative value of the scatter chart for such purpose, the measured data were clustered by the desired speed according the settings available in control system (Figure 7.). The dispersion of values in individual clusters represents the stability of coating diameter. The smaller the dispersion is the more suitable is the speed for given die length. The methodic used for data analysis can be further improved to implement different types of coating material in order to further improve recommendation of parameters and establish optimal procedures for determining appropriate production parameters on production lines that lacks devices for measuring wire diameters or if necessary create additional equipment that would be easily attachable to production lines and additional software to analyze measured data and determine which parameters are suitable for actual setup and used materials.

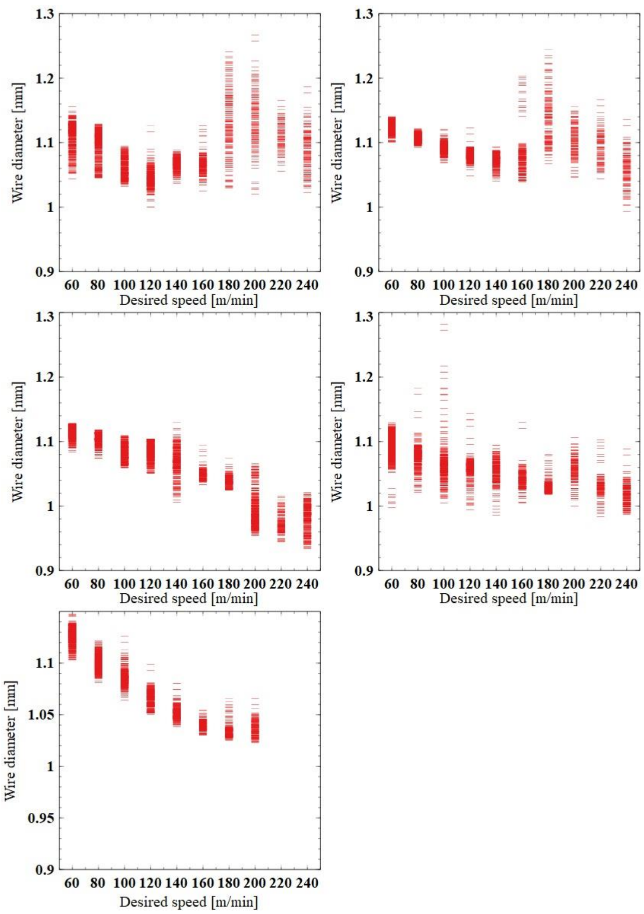

Figure 7. Wire diameter at die lengthts 4.258, 6.722, 9.213, 11.744, 16.700mm clustered by desired speed

IV. Conclusion

Different extruder dies lengths have distinct speed ranges or so called “stable zones” that can be characterized by better circularity parameters and its increased stability. However, the effect of vibrations, especially vibrations of the wire, to the stability of coating circularity is not yet known and we recommend further study in this area which should also cover measurement and analysis of the vibrations. Especially the vibrations of the wire, extruder die, and other relevant parts of the production line in order to locate and possibly eliminate its source if necessary.

With extruder die lengthening speed at which the diameter range is minimal is shifting to higher speeds up to 180 m/min and coating thickness is decreasing with increasing speed. We get the best results when using die lengths 11.774 and 16.700 mm, when the die length is less than 11.744 mm the maximal usable speed is up to 160 m/min after that diameter variance increases exceedingly.

These initial measurements showed us that we can see some dependencies between measured parameters, but also that there are many unknown influences to wire coating parameters.

All of the measurement data was collected directly from the PLC during standard production run in short time period during which we were unable to directly affect the production parameters. Therefore, lengths of measurement when using different dies are not similar and there are intervals where the measurement points are not available at all (especially when using die length 9.213mm). This makes using designs of experiments (DoE) or similar methodologies difficult to implement. Main purpose of the measurements and thus aim of this paper was to do preliminary analysis of measured data and to help to design a comprehensive measurement protocol that will provide guidance for the follow-up research.

We strongly recommend developing a more thorough measurement protocol and procedures that would allow us to do additional, more precise, measurements ideally in controlled environment on production line at manufacturer’s premises. We recommend measuring also vibrations in different parts of production line, measuring parameters of extruded material, measuring the wire parameters after manufacturing, measuring the wire coating surface quality in order to gather larger amount of more consistent data that would allow more detailed analysis. These and similar measurements are necessary to create tools and procedures for optimization of production regardless if it is on already deployed production line or on new one.

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