Ivan ZAJAČKO, Miroslav CÍSAR, Ivan KURIC, Vladimir KOVÁČ, Tomáš GÁL*

EVALUATION OF DIAGNOSTICS OF THE PRODUCTION EQUIPMENT BY IMPLEMENTATION OF COMPUTATION METHODS

Abstract

We have been invited by industry to cooperate to address the processing of data obtained by diagnosing the production equipment in order to understand the production process in more detail, to establish mutual correlations between the individual parameters characterizing the manufacturing process and, at the same time, to discover possible connections in the obtained set of data showing hidden dependencies in manufacturing processes in production that primarily does not affect the manufacturing process itself but its presence is affecting distortion of the measured parameters possibly creating defects or deformities of the final product.

1. INTRODUCTION

The production line was subjected to diagnostic measurements on the manufacturer's premises during the test run. The manufacturer stated the problem of ensuring the constant quality of the rubberized steel wire that is output from the production line. The desired result of the data analysis of diagnostic measurements is to better understand the influence of manufacturing parameters to the manufacturing process. At the same time, it should confirm the predicted correlations between input parameters of the production process and to help set the optimal parameters of the production process allowing to reach permanently the maximum possible quality of the final product.

Following parameters have been identified for the diagnosis of the manufacturing line based on the empirical experience and the theoretical knowledge of the manufacturer:

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

* Ing. Ivan ZAJAČKO, PhD., Ing. Miroslav CÍSAR, PhD., prof. Dr. Ing. Ivan KURIC, Vladimir Kováč, Tomáš Gál, University of Žilina, Faculty of Mechanical Engineering, Department of Automation and Production Systems, Univerzitna 1, 010 26 Žilina, Slovakia.

Other collected parameters were supplemental in nature (they were additional parameters without direct effect on the final product).

Main parameters describing the success of the manufacturing process are the stability of thickness of rubberized wire and the uniformity of rubber layer characterized by the shape of the rubber and the integrity of the surface.

2. MEASUREMENT

To measure the diameter of the final product we used two types of non-contact sensors:

- Micro Epsilon ODC 2600 – LED based micrometer with an integral high-resolution CCD camera for geometrical measurements. Wire was measured in one axis with sample rate of 2,3kHz
- Keyence LS-903D – high-speed 2-axis optical micrometer with accuracy of 2μm and vibration resistance 10-55Hz. Wire was measured with sample rate of 16kHz

Speed of the wire was obtained from diagnostic output of variable-frequency drive inverter and measured by incremental speed sensor.

We predicted the dependence of quality of final product in relation to the of the extruder die length and wire speed. We determined the basic methodology for the diagnostics of manufacturing process that consists of complete set of measurements made at predetermined requested speeds for each die length of the extruder. We tested extruder dies with lengths ranging from 4.2 mm to 16.7 mm divided into 6 groups. Because of the persistent measurement error in one group it was excluded from the analysis.

The wire speeds were tested from 60 m/min to 240 m/min with step of 20 m/min.

After the measurement data was acquired we needed to filter out obvious measurements with errors, that would significantly reduce the quality of final set of measurements. Then we verified the results of correlations between the monitored parameters in production process.

By analyzing the data of real line speed from incremental speed sensor we determined that that the real speed is different from requested speed defined by operator in control system. To better understand speed relationships, we calculated the average speed (Avg AF2), median speed (Med AF2), speed amplitude (Range AF2), average absolute difference between requested and measured speed (Avg dAF2) and median absolute difference between requested and measured speed (Med dAF2). Avg dAF2 and Med dAF2 was calculated from all measurements in given range.

Tab. 1. Table of stability of speed in measurement ranges

Speed AFS [m/min]	60	80	100	120	140	160	180	200	220	240
Avg AF2	48,94	68,44	84,77	103,38	119,06	135,82	153,80	171,59	184,74	219,60
Med AF2	48,66	69,02	83,52	101,81	117,69	134,95	152,20	169,12	185,68	236,08
Range AF2	11,56	18,63	22,68	17,67	23,822	22,74	24,39	28,80	36,48	40,52
Avg dAF2	11,36	14,63	17,09	19,74	23,13	26,51	28,76	32,13	36,37	41,58
Med dAF2	11,13	14,76	17,15	20,24	22,98	26,06	28,69	31,48	34,62	43,15

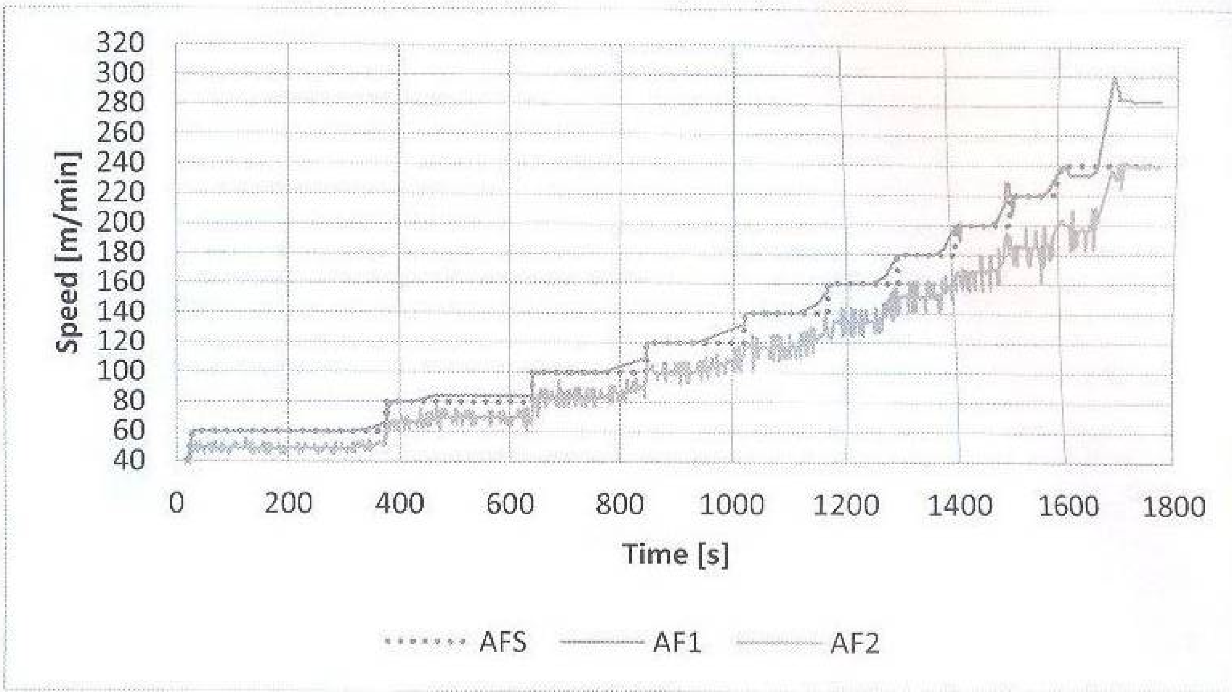

Fig. 1. Speed over time

Analysis of the obtained data unambiguously displayed a correlation between parameters characterizing stability of the final shape of rubberized steel wire and speed of the manufacturing line. Stability of the final shape is determined by diameters measured X and Y axis that are perpendicular to each other. Optimal shape is circular. Manufacturer of production line is making enormous effort to achieve optimal shape and make the manufacturing line resistant to external effects that can cause deformations of shape. Extreme manifestation of deformity is compromise of integrity of rubber on wire or missing rubber on parts of wire. To better understand diameter relationships, we calculated the average diameter (Avg WDA), median diameter (Med WDA), diameter amplitude (Range WDA) values were aggregated to requested speed ranges.

Tab. 2. Table of stability of diameter in speed range

Speed WDA [m/min]	60	80	100	120	140	160	180	200	220	240
Avg WDA [mm]	1,11	1,09	1,06	1,04	1,06	1,06	1,12	1,13	1,11	1,08
Med WDA [mm]	1,12	1,10	1,06	1,04	1,06	1,06	1,12	1,13	1,11	1,08
Range WDA [mm]	0,10	0,07	0,05	0,11	0,04	0,09	0,20	0,23	0,10	0,15

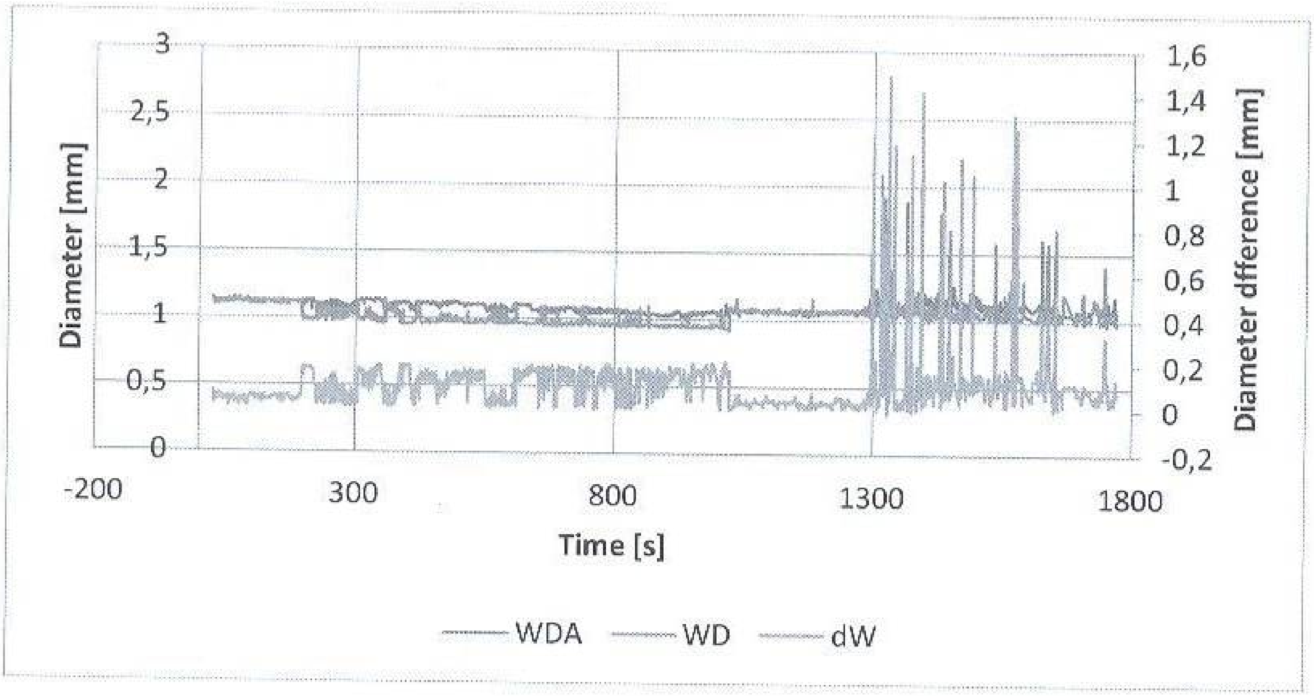

Fig. 2. Wire diameter over time

By analyzing requested speed, real speed and differences between we obtained information characterizing the speed ranges.

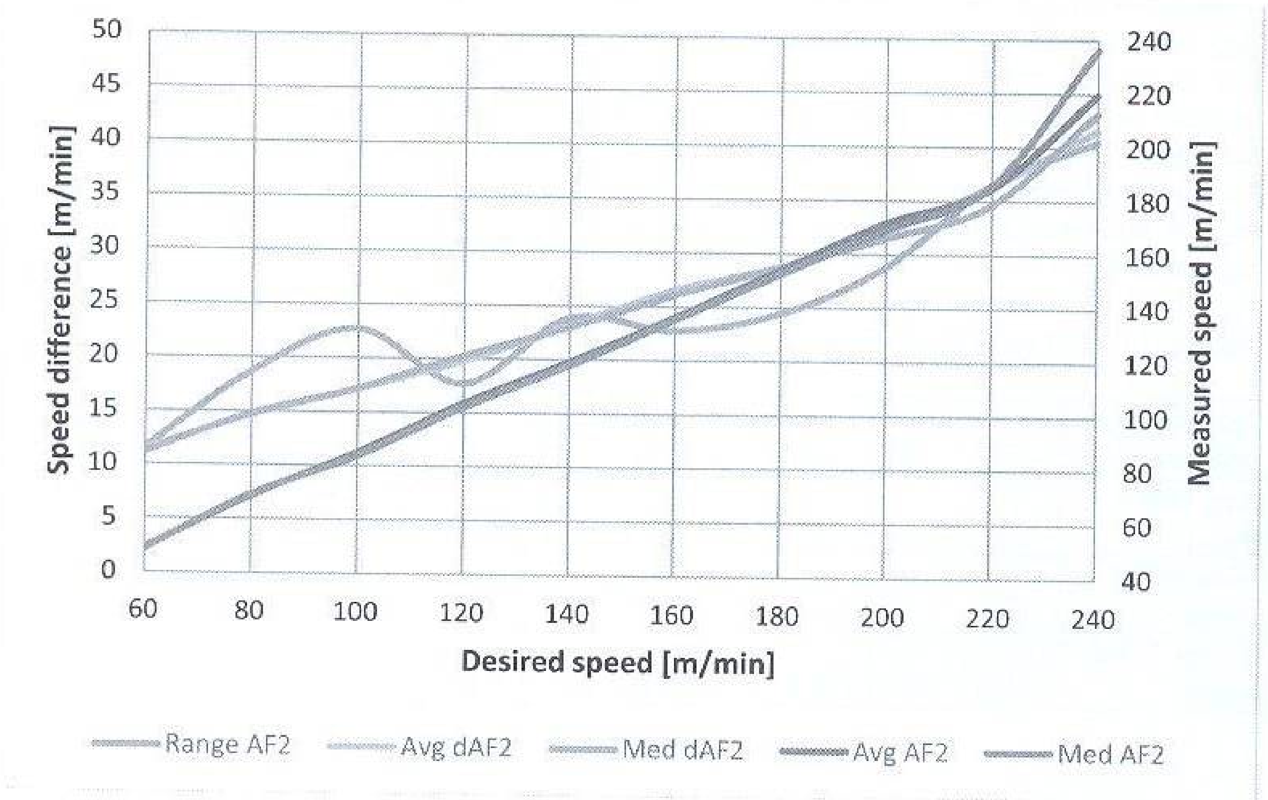

Fig. 3. Speed characteristics

In the next chart we can see the correlation between measured speed and rubberized wire diameter.

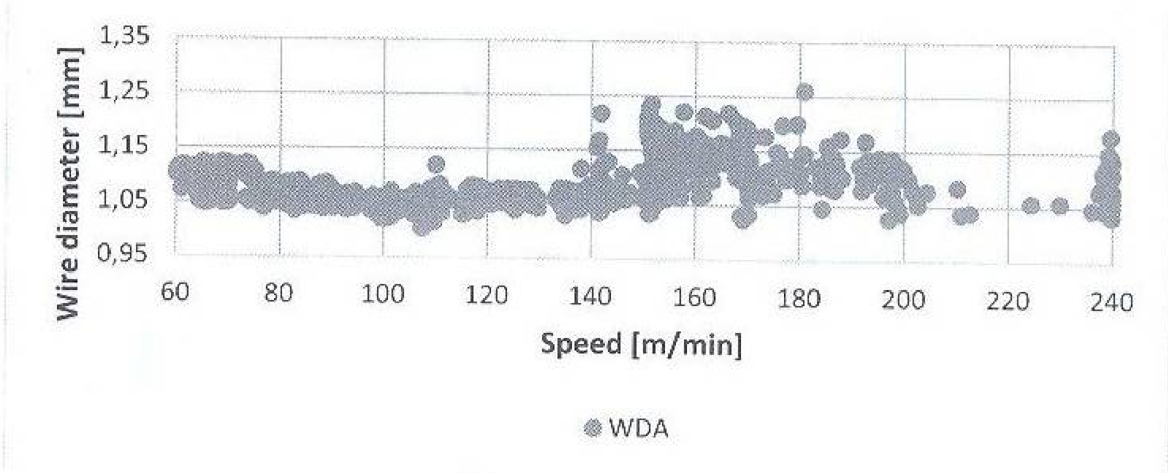

Fig. 4. Speed vs. wire diameter

Lastly, we can see the wire diameter ranges grouped by requested speed and their stability.

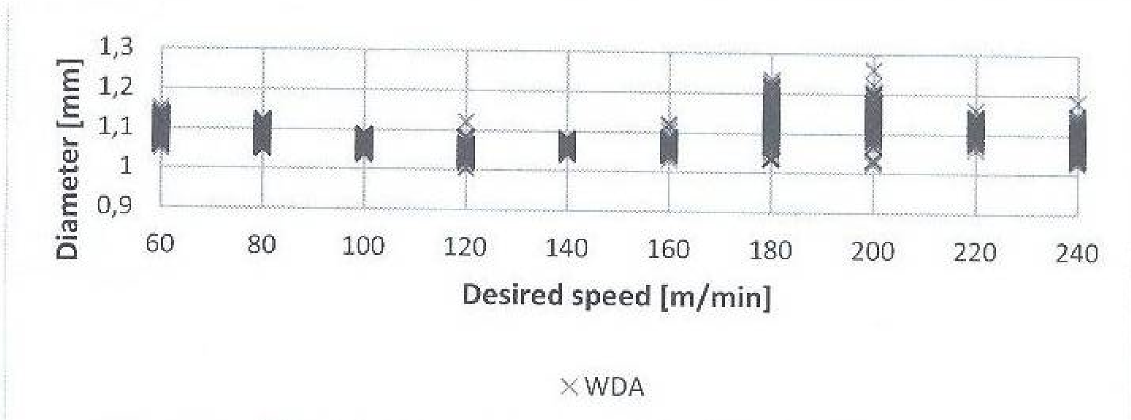

Fig. 5. Wire diameter grouped by desired speed

3. CONCLUSIONS

Since we are currently conducting the initial diagnostic measurements on the manufacturing line, we can state the following identified facts that have significantly negatively affected our acquired data set:

- Vibrations caused primary by manufacturing processes, and secondary by dynamic properties of manufacturing line were not measured. Based on the stability of cross section measurements of rubberized wire, vibrations have a very likely a direct negative effect on the measured parameters. Presence of vibrations in the transverse direction have obviously a direct effect on the cross-section of the rubberized wire, and the presence of vibrations in the longitudinal direction influences the consistency or thickness of the rubber coating. We predict the effect of the longitudinal vibration component to the measurements of real speed of wire.

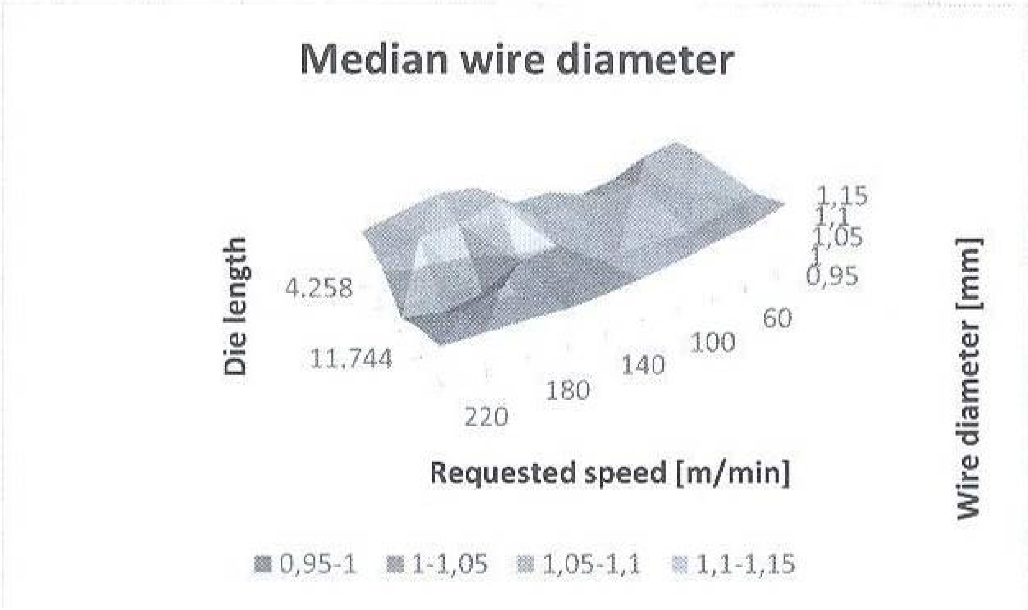

Fig. 6. Median wire diameter grouped by desired speed when different die length is used

- We recommend replacing a single-axis micrometer Micro Epsilon ODC with Keyence LS903D micrometer that has properties that make it especially suited to be used in measurement process to achieve more accurate results.
- We recommend measuring the diameter of wire in four axes separated by 45degrees, by using two LS903D micrometers to determine the circularity of the wire.
- We recommend measuring the amplitude of wire vibrations in at least two axes.
- It is recommended to carry out test measurements of the diameter of the rubberized wire in static position after manufacturing to the eliminate the uncertainty of measurement by vibration of the wire when moving in the production line.

We determined with high degree of certainty that effects influencing the stability of manufacturing process are length of extruder die and speed of wire in manufacturing line. In our next research we will focus on adding the appropriate sensors to obtain more and higher quality data about manufacturing line. Extended data collection will allow us to refine our mathematical model of manufacturing line. We will also collect more data points to allow us to use higher level of data processing thru deep learning systems thus revealing possible hidden correlations between the non-interdigitating parameters of the manufacturing process.

Acknowledgment: This work was supported by the Slovak Research and Development Agency under the contract No. APVV-16-0283

References

[1] KURIC I., et al.: *Analytical Intelligence Tools for Multicriterial Diagnostics of CNC Machines.* Advances in Science and Technology Research J., ISSN 2299-8624, vol. 10, No. 32, 2016, 59-64, online

[2] DORNFELD D., DAE EUN LEE.: *Precision Manufacturing.* Springer, New York USA, 2008, ISBN 978-0-387-32467-8

[3] SAPIETOVA A., SAGA M., NOVAK P.: *Multi-software Platform for Solving of Multibody Systems Synthesis.* Communication - Scientific Letters of the University of Zilina, vol.14, No. 3, 2012, 43- 48

[4] MARINESCU I. D.; ISPAS C.; BOBOC D.: *Handbook of machine tool analysis.* CRC Press, 2002

[5] BIRKS A. S., GREEN R. E., MCINTIRE P.: *Nondestructive testing handbook.* American Society for Nondestructive Testing, 1991, 575-584