Topography scanning as a part of process monitoring in power cable insulation process

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ABSTRACT

We present a novel topography scanning system developed for XLPE cable core monitoring. Modern measurement technology is utilized together with embedded high-performance computing to a build complete and detailed 3D surface map of the insulated core. Cross sectional and lengthwise geometry errors are studied, and melt homogeneity is identified as one major factor for these errors. A surface defect detection system has been developed utilizing deep learning methods. Our results show that convolutional neural networks are well suited for real time analysis of surface measurement data enabling reliable detection of surface defects.

KEYWORDS

Insulation homogeneity, machine learning, neural network, online monitoring, surface inspection, CV process, XLPE cable

INTRODUCTION

Modern trends towards smart manufacturing principles require more meaningful data from production processes. Constant monitoring of production quality is a key part in moving towards smarter process controls. During the power cable insulation process, the cable core is traditionally inspected by mainly diameter gauges and rarely by any precise shape or surface monitoring system. Furthermore, surface quality is monitored visually, and the inspection is not automated. Employing automated quality monitoring systems facilitates the use of machine learning methods as a part of process control and enables, e.g., the possibility for predictive maintenance as soon as slight variations in the product are measured.

A power cable insulation process consists of many phases, of which each have significance for the polymeric cable core quality. During the extrusion process each of the material layers are melted, mixed and distributed evenly around the circumference of the conductor. The used polyethylene materials contain peroxides, which are thermally unstable molecules, in order to crosslink the polymer chains. The crosslinking creates a network of polymer chains which allows for a higher operating temperature. Any issues during the extrusion process may lead to premature crosslinking, i.e. scorch, inside the extruder or crosshead, causing quality problems.

During the next phase, curing and cooling processes, the cable core is subject to high temperatures and undergoes significant thermal expansion simultaneously with the crosslinking process, and shrinking during subsequent cooling.

The thermal expansion and cooling cause changes in the core geometry, which are apparent in the core shape after the process. This process can cause cross sectional non-circularity, i.e. ovality, or flat areas at some parts of the core. Furthermore, inhomogeneous melt quality is visible after curing as local waviness. This is not to be confused with lengthwise diameter variation caused by the rotations of the screw. Diameter variation is typically across the whole cross section, whereas inhomogeneous melt appears as roundish bumps and indentations.

Neither of these geometrical issues are measured in typical high or extra high voltage production lines. We present a novel solution for measuring these geometrical quality metrics, a topography scanner measuring the core surface with laser displacement sensors. These quality metrics may be used towards smarter process control and for minimizing shape and diameter variations.

Optimizing core geometry has many benefits from insulation material saving to easier and better-quality joint and termination interfaces. We have conducted experimental work on modelling the geometrical changes as functions of process parameters. A wide range of trials have been conducted at a pilot vertical line at various conditions and with different constructions.

It has been shown previously, that the homogeneity of the extruded insulation material has significance for the dielectric strength of the core [1]. It is well known that there are remaining uneven mechanical stresses in the XLPE insulation [2]. Various studies have found decreased dielectric strength in specimens with residual stresses or mechanical strain [3-6].

On top of geometrical errors, the cable core may also be subject to local surface defects, such as scorched material embedded into the insulation or surface scratches from unintended contact with manufacturing equipment. We employ a machine learning based defect detection system to alert the manufacturer of any surface defects. The system is trained with purposefully manufactured defects made at a pilot vertical line, as well as with training samples received from cable manufacturers. Deep convolutional neural networks are shown to work well for this application, and we present key metrics of performance.

TOPOGRAPHY SCANNING SYSTEM

Our experimental setup is built upon a power cable surface scanning instrument that we have developed. This device was designed for measuring the surface geometry of power cable products in real-time in order to establish online quality metrics for the product and the production process. The device generates a detailed 3D mesh of a cable's surface geometry: a topographic map of the surface. This surface map is then used to compute analytic quality metrics for the product and for detecting the presence and type of surface defects, such as incisions, scratches,