An Ultrasonic Perspective on Cable Testing

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The benefits of ultrasound technology used in medical scanning applications have been available to assist medical staff and patients for almost a century. Continuous improvement in scanners and imaging software has increasingly improved the ability to confirm the best of health of the patient, or to improve the efficacy of decision making when complications arise. New thinking has arisen based on previously unseen images, and many new treatments for pre-natal conditions have been discovered.

Currently however, the use of ultrasound in industrial scanning has been largely limited to crack detection and wall thickness measurements in metal parts to assess welding and corrosion defects. By extending this technology for use with extruded polyethylene cables, Acuity Products now introduce the concept of 'whole cable non-destructive testing' to the future benefit of the cable industry.

Aim

The aim of the paper is not to try and provide a definitive guide to either cable testing or ultrasonic analysis, but to provide the reader – who may be unfamiliar with ultrasonics – with an overview of the attributes of this technology; and to consider issues such as, "How does ultrasonic testing fit in with the other forms of the testing currently used?", and "What performance is it desirable to require from ultrasonic testing?". Where, in this paper the nature of the ultrasonic testing considered is that provided by UltraScreen, i.e. testing that operates on-line in a production environment.

Ultrasonic Testing

Currently, cable testing is based around the visual inspection of the cable - either via slices of cable, in end-of-cable sampling processes, or via the use of oil bath procedures, for instance post-breakdown testing. And this fact is borne out by the 'visual' terminology that is used to describe contaminant features such as dark, black, opaque, translucent, etc. Now, colour is not a concept that has any meaning in ultrasonics and, just as an ultrasonic medical scanner can tell you nothing about the colour of the eyes of an unborn baby, so ultrasonic cable testing can tell you nothing about the colour of a contaminant!

Ultrasonic analysis is essentially based upon the analysis of reflections caused by local changes in acoustic impedance (Z) of materials – or to be more accurate the level of reflection is governed by the ratio of the local change in Z to its local average! Fortunately, within the context of the XLPE materials found in cable insulation and semi-conductor layers, some existing terminology maps very easily into this new ultrasonic 'Z' terminology! 'Metallic' particles are much higher Z than XLPE and so make very good reflectors, 'air or gas voids' are much lower Z, and so again make very good reflectors, and there is sufficient difference in the Z values of the insulation and semi-conductor materials to make the reflections at these boundaries useable too.

In fact, results from medical ultrasonics suggest that it only requires a relative change in Z of 1% to create a discernible reflection, and this gives rise to the view that features that are perhaps not amenable to visual inspection may be determinable, in the future, via ultrasonic analysis.

But that's for the future, for now it is important to realise that the capabilities of ultrasonic testing are driven by the acoustic properties of the materials, not their visual properties!

Comparison with other Cable Testing Methodologies

When people start to think about the performance capabilities they should expect from ultrasonic testing, they usually base these expectations on the results of end-of-cable slice testing – perhaps because this mode of testing provides the most accurate records of the measured size of contaminants? But is this an appropriate starting point?

In a nutshell, ultrasonic testing – in the form provided by UltraScreen - can be characterised simply as testing that operates on the production line, undertaking continuous testing and analysis and making decisions in real-time, based on an investigation of the whole cable, and required to operate at typical line speeds of 1 metre a minute. (Note, at this line speed, UltraScreen assesses the whole of the cable insulation and semi-conductor layers every 250 micron along the whole cable length).

On the other hand, end-of-cable slice testing is very much a post-production, off-line process, which makes no attempt to make decisions in real-time. And, if say on average 10cm of cable is analysed per kilometre produced, then only 0.01% of the cable length is actually assessed – so this is not a whole cable analysis technique as 99.99% of the cable remains unanalysed!

This difference between UltraScreen's whole cable testing strategy and the non-whole cable testing strategy of end-of-cable sampling is fundamental. To appreciate this, consider the ramifications of specifying that UltraScreen should detect and report the presence of a 30 micron protrusion pip size – a dimension that has often been quoted within the context of end-of cable slice testing.

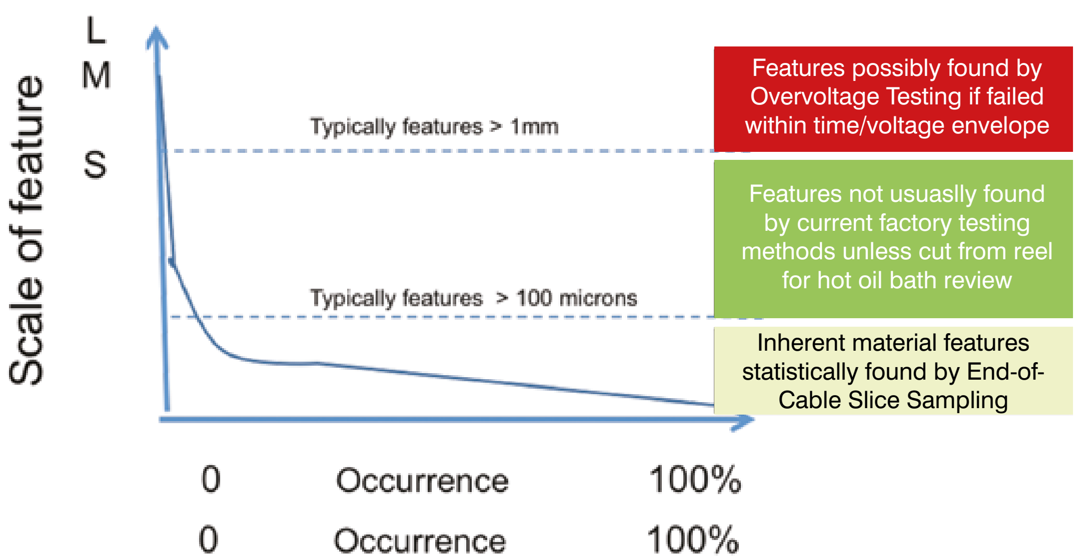
Now, we have discussed such issues with cable materials suppliers and, according to them, they would expect pips up to a size of 50 micron to be present even their highest quality material brands. So if such pip sizes are actually due to material properties, then it might be expected that such features would appear in, say, 50% of these 2mm thick, end-of cable slices. If so then the point to fully appreciate is that UltraScreen effectively scans 500,000 x 2mm slices per kilometre of cable. And so if, say, such features appear in 50% of these samples then they would generate 250,000 feature alerts per kilometre of cable – and of course 1 km is not a particularly long cable run!

And what have these 250,000 feature alerts revealed about the cable that wasn't already known? Because, for such features to be found regularly in the end-of cable slice testing there has to thousands of them in the cable because the slice testing only assesses 0.01% of the cable length – so if there weren't thousands of them they wouldn't regularly appear in the slice testing

So is it really desirable to require a process that is assessing the whole cable to replicate an analysis performance comparable to a process that assesses only say 0.01% of the cable?

If not, then how does such ultrasonic testing fit in which other current testing methodologies and what performance is it desirable to require from such a process?

The figure below attempts to set out a framework within which such issues can be considered, by graphing – in a purely illustrative manner – the variation of the scale of a contaminant feature, with its level of occurrence within a cable run. And it simply says that the smaller the feature the more likely it is to be perhaps an artefact of the materials used or the production process, and thus such features are likely to occur throughout the whole cable, whereas as the features become of a larger scale then they appear increasingly intermittently within the cable length.



In terms of end-of-cable testing, what this framework shows is what we've already discussed, and that is that such a testing methodology can only really pass comment on those small scale features that are found throughout the whole cable, because this testing methodology does not directly test 99.99% of the cable and so to say something about this large untested section, the explicit assumption has to be made that the sample length tested is representative of every such sample length throughout the cable.

At the other end of the feature scale axis, features are found by PD or overvoltage testing when they are large enough to produce partial or complete electrical breakdowns within the voltage/time envelope of the testing applied.

Now whilst these numbers are not meant to be definite, discussions with industry experts would suggest that by small scale features, dimensions less than about 100 micron are implied, and by large scale features, dimensions greater than about 1 millimetre are implied! Whatever the exact definition of these terms, what is clear from the figure above is that there is a large range of 'medium scale' features that are currently not being detected because they are either too small to show up in a PD or overvoltage test, or occur too infrequently to be found by the end-of-cable sampling.

And it is these medium scale features, that are left undetected in the cable, that current studies are identifying as being the major cause of in-service cable failures, because whilst they may be too small to cause a breakdown within the voltage/time envelope of the testing applied in the factory, the assessment is that the 'electric tree' structures they spawn are the cause of premature, in-service, cable breakdowns.

What Analysis Performance is it desirable to require from an On-line Ultrasonic Analysis?

Given that the on-line ultrasonic analysis, as facilitated by UltraScreen, is a whole cable analysis process, the suggestion is that the performance that it would be desirable to require from such processing should not be based on a current process that is not whole cable, but should be derived by a comparison with current whole cable testing methodologies.

The problem that this presents is that there are currently no other whole cable testing methodologies that work on-line, and can provide real-time, feature detection, decision-making feedback! And so, accepting that there are no direct comparatives, the best guide comes from the figure above which identifies that the role for on-line ultrasonic analysis is really to look for 'medium scale features throughout the whole length of the cable', although of course large scale features will be detected as well!.

Pragmatically, what this means is that it would be desirable to require such an ultrasonic process to detect features with scales typically in excess of 100 micron, and this is the basis of the more detailed performance specification defined in the UltraScreen Technical Specification!
Thus to summarise, the capabilities of the on-line ultrasonic testing process – as provided by UltraScreen - relative to other testing methodologies can be presented as follows:

Methodology	End-of-Cable Sampling	UltraScreen Testing	PD or Overvoltage Testing
On-line/Off-line	Off-line	On-Line	Off-line
Real-time Decision Making	No	Yes	No
Extent of Cable Analysis	0.01% typical	100%	100%
Nature of Feature Detectable	Small–Scale <100 micron Typically	Medium/Large-Scale >100 micron typically	Large-Scale >1mm typically
Geometric Assessment	Yes	Yes	No
Invasive/Destructive	Yes	No	Yes

Note

This paper has focussed deliberately on the capability of the on-line ultrasonic analysis provided by UltraScreen, but it should be clearly understood that if an ultrasonic process was required to replicate the current end-of-slice sampling analysis then such equipment could be designed to meet the small scale feature detection parameters characterising this form of analysis. But this would be a completely different machine which would carry out its analysis in non-real-time, via the cut face of the cable slice, not in real-time via the outer screen of the cable as UltraScreen is required to do!

About the author

Dr Gareth Humphreys-Jones is the Technical Director of Acuity Products Ltd and has been actively involved in the development of UltraScreen for the last three years.

He has a doctorate in Applied Mathematics and has specialised in Signal, Image and Data Processing for the last 30 years designing algorithmic software primarily for defence systems in areas including sonar, sonic, radar, EW, ESM and communication technologies.

He has also undertaken government funded studies into the measurement of Man Made Noise, and EMC issues of Software Defined Radio, as well as carrying out novel analysis into system noise reduction within the context of top end Hi-Fi equipment. He also worked for five years, contracted to the UK DTI, as the Industrial Technology Translator for the High Power RF Faraday Partnership.

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