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Fractal mapping of thermograms for defects detection in pipe

Thermography monitoring of steady heating by the electrical current and further cooling of the stainless steel pipe with both the artificially-made hidden defects on its internal surface and 'as-fabricated' defects was carried out using the IR imager Fluke Ti32. Fractal mapping approach, based on the numerical triangular prism method, was applied to study an evolution of thermal inhomogeneities. It was found, the hidden defects could be localized using the fractal post-processing of thermographic data sets. Filtering of the fractal maps and fractal gradients of thermograms provides more accurate segmentation of the thermal inhomogeneities induced by the artificial corrosion-like hidden defects on the internal surface from the 'as-fabricated' imperfections in the bulk such as rollings, than direct filtering of thermograms by temperature values.

Key words: *thermografy, hidden defects, pipe, fractal analysis*

Рассмотрена техника проведения термографического контроля участка трубы из нержавеющей стали, содержащей искусственно сделанные дефекты на внутренней поверхности, нагреваемого электрическим током и находящемуся в последующем в режиме охлаждением. Анализ термограмм и оценка эволюции на них тепловых неоднородностей выполнялась с применением картографического подхода, основанного на методе числовой треугольной призмы. Было обнаружено, что скрытые дефекты можно локализовать с помощью фрактальной пост-обработки наборов термографических данных. Фильтрация фрактальных карт и фрактальных градиентов термограмм обеспечивает более точную сегментацию тепловых неоднородностей, вызванных искусственными коррозийно-скрытыми дефектами на внутренней поверхности, на фоне производственных артефактов, таких следы прокатки,

Ключевые слова: *термография, скрытые дефекты, труба, фрактальный анализ.*

Розглянуто техніку проведення термографічного контролю ділянки труби з нержавіючої сталі, що містить штучно зроблені дефекти на внутрішній поверхні. Труба при цьому попередньо нагрівається електричним струмом і знаходиться в подальшому в режимі охолодженням. Аналіз термограм і оцінка еволюції на них теплових неоднорідностей здійснювалась із застосуванням картографічного підходу, заснованого на методі числовий трикутної призми. Було виявлено, що приховані дефекти можна локалізувати за допомогою фрактальної пост-обробки наборів термографических даних. Фільтрація фрактальних карт і фрактальних градієнтів термограм забезпечує більш точну сегментацію теплових неоднорідностей, зумовлених штучними корозійно-прихованими дефектами на внутрішній поверхні, на тлі виробничих артефактів, таких сліди прокатки,

Ключові слова: *термографія, приховані дефекти, труба, фрактальний аналіз.*

Introduction

Integrity of pipelines is of great importance at the nuclear power plants (NPPs) because their disrepairs problems are not only expensive but dangerous and risky for the safe operation of NPPs. IR-monitoring is a complementary method for assessment of degradation of the NPP's piping systems. The advantages of thermal imaging in this case are non-distructness, relative easiness of measurements together with acceptable price. Nowadays, IR cameras have good temperature resolution, but thermal images are still noisy and with small pixel resolution compared to the modern visible-light cameras. So, their information capacity is poor, and it is hard to observe the mild changes in temperature to reveal defective effects, especially in industrial conditions.

The main purpose of our research was the development and improvement of the IR thermography control methods for the NPPs, particularly to monitor the cooling water supply systems. In [1], it was noticed, that fractal analysis is a perspective technique for increasing the thermograms informativeness. While the pipelines carry the hot water from the steam reactor, providing the cold water supply, it is possible to observe the temperature deviations on the pipes surfaces. Thus, these deviations should be simulated to study the heat conductivity processes that enables detection of defects. Such approach provides the useful information about the condition of the pipes walls. As a test sample a steel pipe with some defects has been prepared. We tried to understand new opportunities of the fractal post-processing employed for the thermographic data taken during heating and cooling of the pipe. It is assumed, the fractal properties of thermograms are caused by two main factors. First, the physical object under investigation could be characterized by the fractional dimension D_{frac}, which affects on the object's thermal conductivity. Second, existing noise along with the hardware-induced distortions in thermograms could be fractal-like. The concept of the fractal nature of thermographic data is still ambiguous, and requires a comprehensive exploration.

Materials and Techniques

The stainless steel pipe sample with a thickness of 4 mm, 80-mm-diameter and 1-m-long was prepared. Its external surface was relatively smooth (but not polished), preliminary cleared from paint. A few hidden defects were made on its internal surface (Fig. 1) to simulate electrochemical corrosion and fluid flow. We made 4 pits of different penetration depth in the pipe wall. Typical alternating current (220 Volts, 5 A, 50 Hz) was applied to heat the prepared sample during 33 min. Stationary IR monitoring of steady heating and cooling processes was carried out using the thermographic imager Fluke Ti32 with matrix resolution of 320x240. The detected peak temperature was around 360 K and the initial temperature was 287 K. Thermograms were taken every 30-60 s.

To reveal the low-resolution changes in heat propagation, which accompanied the defects, the D_{frac}-distributions of the obtained thermographic data sets were examined. D_{frac} were statistically calculated according to the classic Clarke's triangular prism surface area method

(1986) [2], the modified Clarke's method proposed by Qiu in 1999 [3], eight-pixel, max-difference and mean-difference methods introduced by Sun in 2006 [4]. In this work, we used both the step size squared as well as the step size in the log-log regression line. The step size increment was variable: arithmetic, geometric or divisor-step [2-5]. The geometric-square frames with variable side length were employed over all data sets with the unary moving step for calculation of the local D_{frac}. It is worth noting, that such right squared form of frames were employed to minimize possible distortions in the D_{frac}-maps. The mentioned numerical algorithms as well as supplementary decoding and visualization were implemented in Delphi Embarcadero XE2 trial. The codes, compiled executive files for Win7 and test materials could be found at [6].

Results

During heating and cooling some temperature inhomogeneities were visually found in the thermographic data without any additional numerical analysis. The vertical characteristic traces of the 'as-fabricated' rollings in the pipe's wall were observed distinctly (Fig. 2, 3). Several grooves on the initially rough external surface were detected. However, no clear hot signs induced by the artificial defects were noticed, even using the bi-threshold filtering of thermograms.

The fractal mapping gave more promising results. Estimations of D_{frac} were quite different and significantly variable depending on the type of numerical methods throughout the whole time set of thermograms. The most suitable approach, which provided us good indication of defects, was the arithmetic step 4-quadrangles Clarke's method with squared slope and 9-element frame size (Fig. 4). It enabled distinguishing of the temperature irregularities provoked by the hidden artificial pits, however, blurred other imperfections. The main useful information lied in the long tail of the lognormal-like D_{frac}-distribution (Fig. 4, 5), and using its peaks we separated the hidden defect thermal irregularities. The developed technique distorted inhomogeneities to stretched form, which could be influenced by the squared frame shape. D_{frac}-spectra also became much smoother and wider with the increase of the frame size.

Conclusion

It was showed, that using the fractal mapping may be applied to thermographic data to enhance the detection of some irregularities induced by slight deviations of thermal conductance in the bulk. Post-processing by the triangular prism methods helped to localize the contours of the artificial defects. However, the obtained areas of pits merged with thermal signal of the shallow elongated grooves on the external rough surface that complicated analysis.

The fractal dimensions spectra are quite sensitive to the chosen calculation procedure and the imager settings. It is unclear why fractal analysis with large frames enables separation of the hidden pits, contrary to blurring the rollings well-recognized on the thermogram. So, these aspects need to be clarified in further studies.

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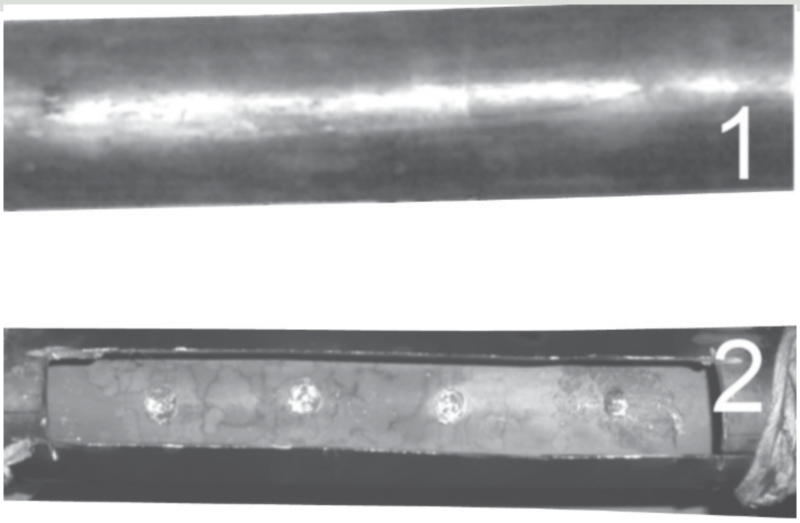

Fig. 1. Pipe sample: *1 - external surface for IR monitoring, 2 – internal surface with artificial defects*

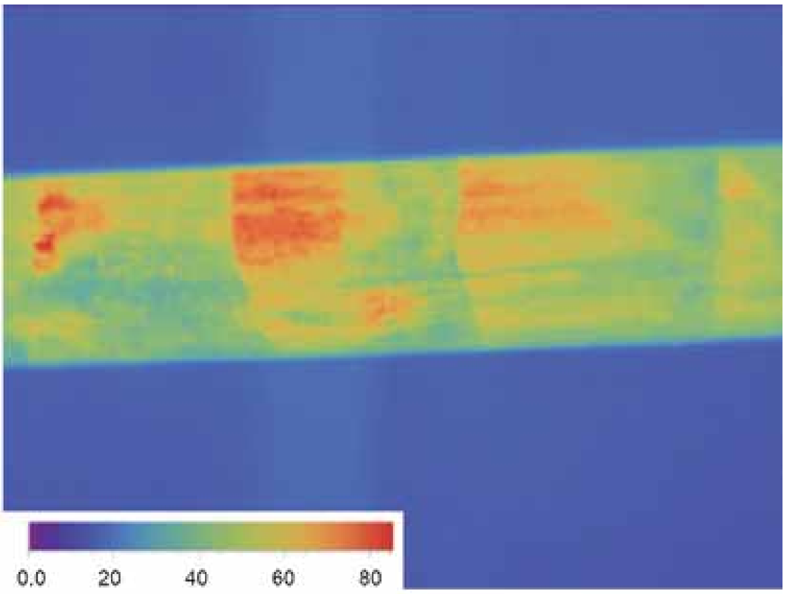

Fig. 2. Thermogram of pipe at maximal temperature

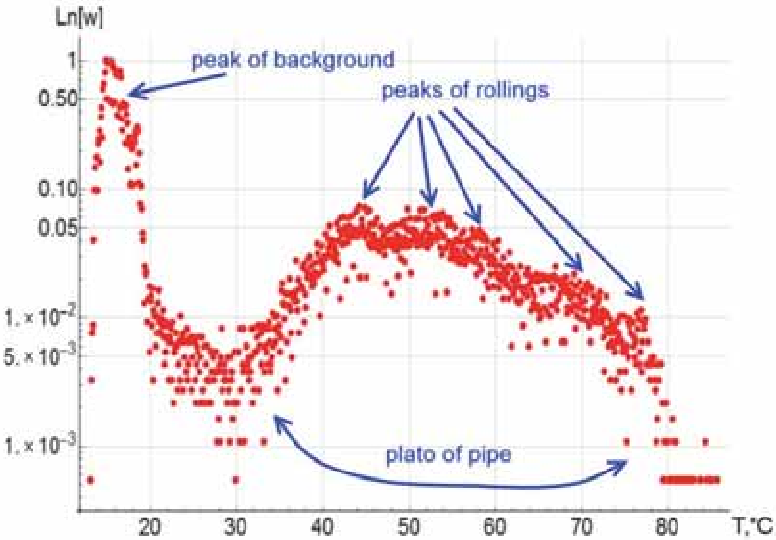

Fig. 3. Logarithmic normalized probability temperature distribution of the thermogram shown at Fig.2.

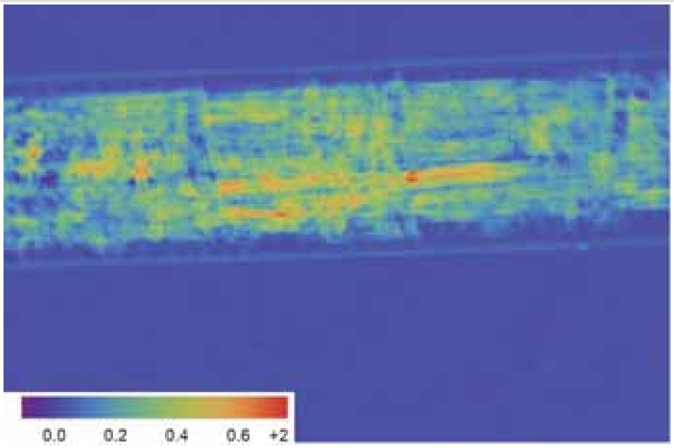

Fig. 4. Fractal map of the thermogram presented at Fig. 2.

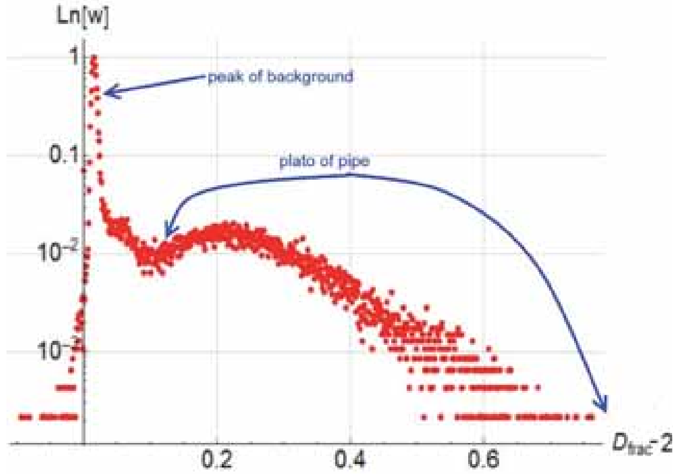

Fig. 5. Logarithmic normalized probability distribution of D_{frac} of the map shown at Fig. 4.

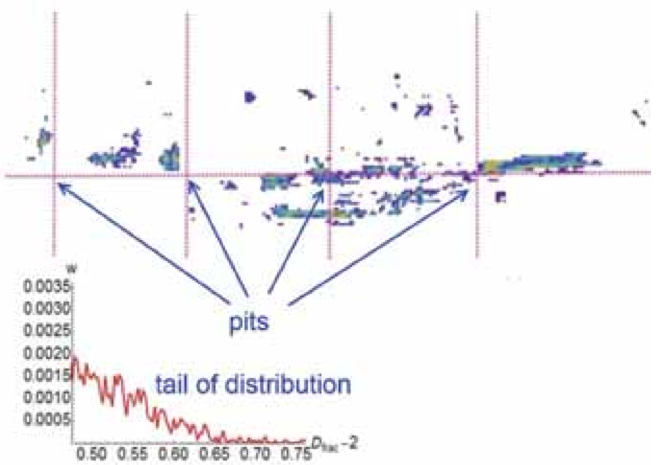

Fig. 6. Filtered fractal map with the pointed exact geometrical positions of pits.

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