Automated wear pattern inspection

Sadler Fränz, edevis GmbH

WHITEPAPER

Abstract

Gearboxes are key components in power transmission within mechanical engineering, automotive engineering and power generation. Deviations in tooth flank contact lead to increased wear, noise and power losses – sometimes with serious consequences for reliability and service life. This is where the thermographic contact pattern inspection developed by edevis comes in: it records load-induced temperature patterns on tooth flanks non-contact and without the use of additives, thereby ensuring that power transmission takes place precisely at the defined contact point. The thermographic contact pattern inspection can be integrated into the manufacturing process as an automated quality control measure.

Introduction

The quality of the gearing determines the efficiency, smoothness and service life of a gearbox. This relationship is particularly evident in electric mobility: without the masking background noise of the internal combustion engine, gearing defects become immediately apparent acoustically and are instantly noticed by both drivers and quality inspectors. Yet its relevance extends far beyond the powertrain of passenger cars. Whether it be commercial vehicle gearboxes under continuous load, wind turbines with their extreme operating cycles, or industrial gearboxes in process manufacturing – wherever torque needs to be transmitted reliably, precise wear pattern inspection is essential.

Conventional testing methods reach their limits here. Manual dye application yields subjective results, is time-consuming and is difficult to integrate into automated production lines. Thermographic contact surface inspection bridges this gap: it measures temperature patterns on the contact surfaces non-contact, reproducibly and in real time, thereby making the contact surface accessible for fully automated 100% inspection without the need for chemical additives or subsequent cleaning.

Background

To date, particularly in the case of hypoid gearboxes, tooth contact testing has been carried out by applying dye and then assessing the results manually. To do this, a thin layer of dye (dye paste or varnish) is applied to the tooth flanks to be tested. When the gears are subsequently brought into mesh, the paint is removed at the points of contact through pressure or abrasion. The resulting image – for example, the displacement of an oil-resistant paste on the gearing – shows where the flanks are actually in contact. A specialist then visually assesses whether the position and size of the impressions correspond to the target condition.

In the event of deviations, adjustments are made – for example, by retroactively shifting the gears relative to one another (e.g. using shims) or by proactively adjusting the manufacturing parameters. Furthermore, all paint residues must be removed without leaving any traces prior to commissioning. However, the traditional contact pattern inspection using paint application has several disadvantages:

- Each inspection process requires the application of dye, the joining of the parts and subsequent cleaning, entailing increased time and labour costs

- The assessment is visual, often based on a cursory inspection. The result depends on the inspector's experience and interpretation.

- The mark shows only the aggregate contact pattern; often, due to time constraints, the contact point is inspected on only a partial segment of the gear. Local deviations at individual contact points may be overlooked.

- Manual ink application is difficult to integrate inline into automated production; 100% inspections are practically impossible to implement.

- Uneven or incomplete ink application can distort the image. These limitations create a need for a more objective, efficient method, which is where thermographic contact pattern inspection comes in.

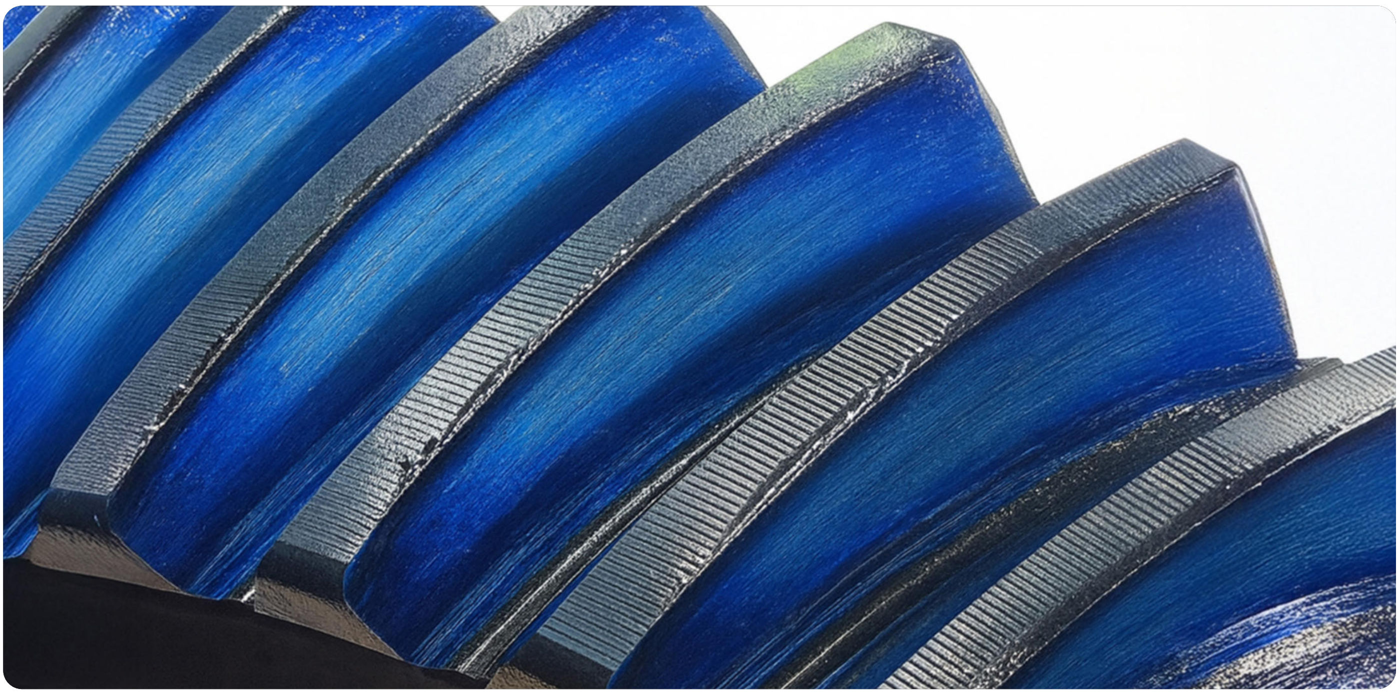

Fig. 1: Conventional contact pattern inspection using ink paste

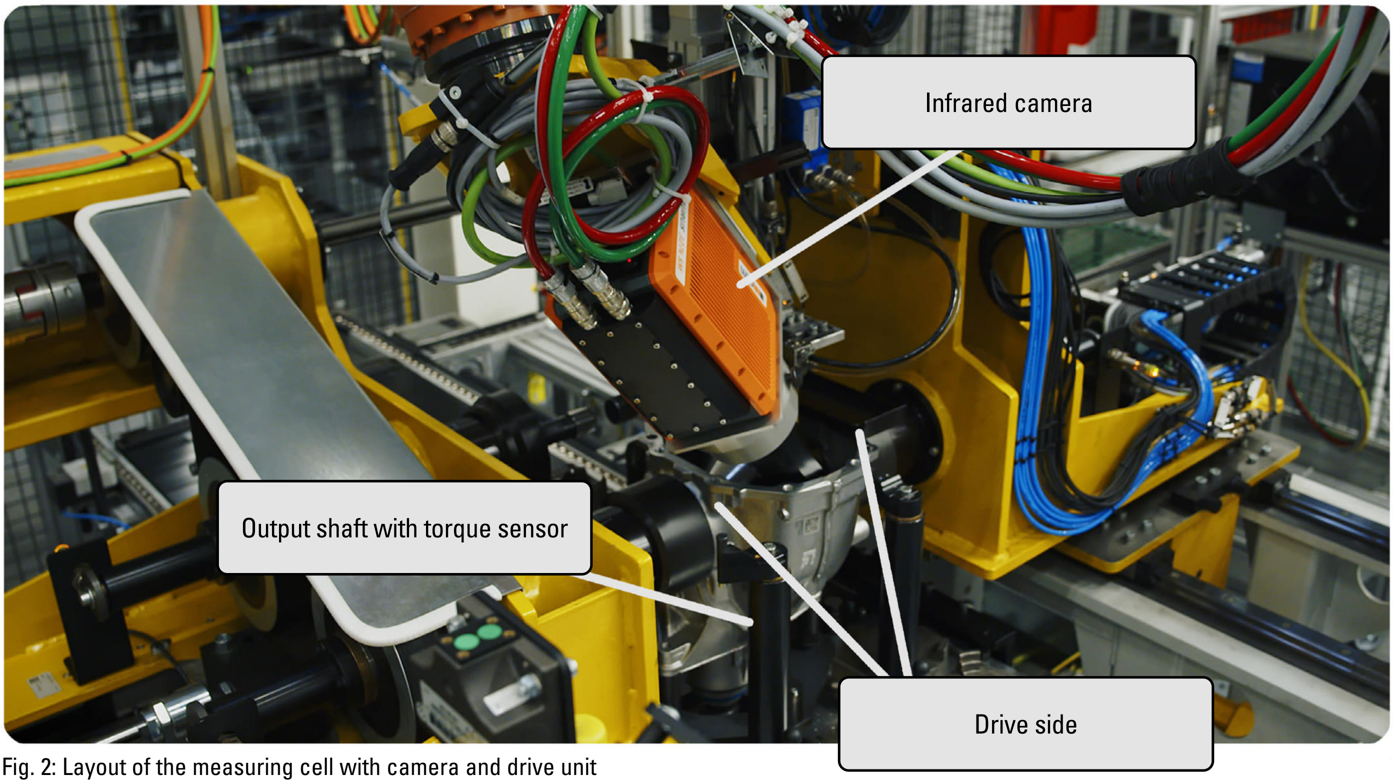

Fig. 2: Layout of the measuring cell with camera and drive unit

Thermographic pattern inspection

In thermographic contact pattern analysis, the contact pattern of a gear pair is visualised using the resulting thermal images. Under a defined mechanical load, the friction between the tooth flanks (rolling-sliding) generates a characteristic thermal pattern. This pattern is captured by an infrared camera for both the leading and trailing flanks, accurately mapped to the tooth geometry, and the position and shape of the contact pattern are then analysed.

System architecture and measurement setup

The test system consists of an automated load test bench with a drive unit, a thermal imaging camera and associated sensor technology (see Fig. 2: Layout of the measuring cell with camera and drive unit). The gearbox under test is fitted with torque transducers between the input and output sides and operated at a defined torque. The infrared camera is aligned so that it captures the meshing tooth flanks of a gear. The synchronised control and evaluation software coordinates all components. This ensures that the camera records defined sequences whilst the drive motors are controlled accordingly. At the same time, the software processes the captured thermal images; the measurement data is analysed in real time and thus provides a relevant control variable for upstream manufacturing and assembly processes.

Objective assessment and identification of the load distribution

The process of analysing thermographic tread pattern inspections can be divided into four steps, as shown in Figure 3. The aim is to obtain an objective and quantitatively measurable representation of the actual tread pattern from the thermograms captured.

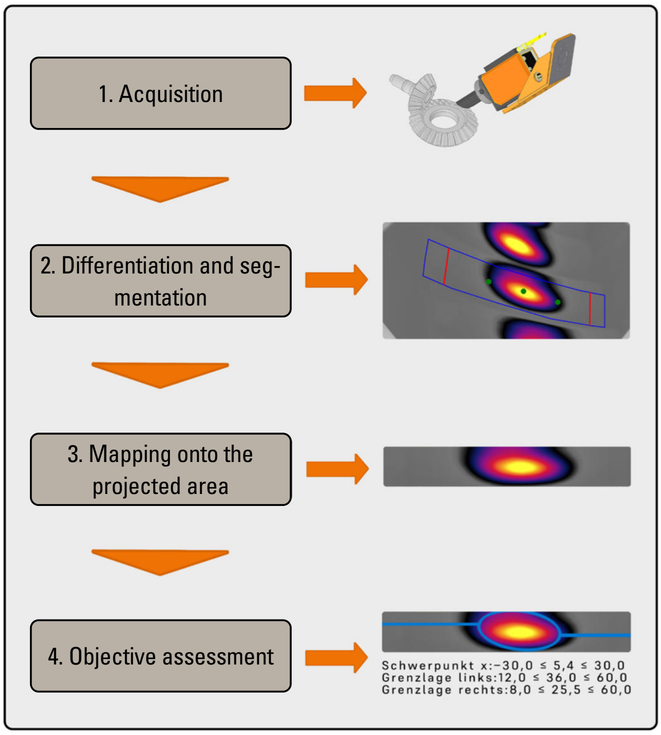

Fig. 3: Procedure for thermographic wear pattern analysis

1. Data Acquisition

First, raw image data of the tooth flanks in the IR spectrum is acquired under various load conditions. These datasets form the basis for the subsequent difference calculation.

2. Difference Calculation and Segmentation

In the next step, the measurements are compared. A difference calculation is used to eliminate background components, thereby revealing the temperature increases caused by contact. The difference images reveal the areas where the tooth flanks were actually in contact. This is followed by the segmentation of relevant areas: an algorithm identifies the contact areas within the region of interest (ROI) on the tooth flank and separates them from non-contact areas.

3. Rectification to the projected surface

As the tooth flank appears distorted due to its curvature and the camera perspective, the segmented contact image is mathematically rectified. This geometric projection transfers the detected contact image onto a flat surface that corresponds to the actual tooth flank geometry. This allows the contact image to be analysed metrologically and compared with CAD data or target contours.

4. Objective evaluation and feature extraction

In the final step, the relevant parameters are automatically calculated from the rectified surface. These include, in particular, the position of the centre of gravity of the contact point relative to the tooth flank. Based on defined target values and tolerance limits, the algorithm determines whether the gear meets the requirements.

Advantages of thermographic contact pattern inspection

Temperature data can be quantitatively analysed, which ensures repeatability and comparability. Furthermore, thermography achieves a very high level of sensitivity and resolution: even subtle contact deviations become visible as temperature differences, with sub-millimetre precision depending on the size of the tooth. Furthermore, thermography allows for the individual assessment of each tooth pair, which are evaluated separately rather than simply obtaining an overall impression. This enables conclusions to be drawn regarding potential noise generation.

Thermographic occlusal surface inspections are significantly faster than manual occlusal surface inspections, both in terms of preparation and post-processing as well as measurement time. This enables 100% inspections in series production. Automation reduces the manpower required to carry out the inspections, and eliminates costs for labour and consumables (dye, cleaner).

Automation and Documentation

With thermography, every inspection result is automatically available in digital form and can be fully documented. This ensures traceability and provides a benchmark for upstream manufacturing steps, whilst also enabling trends or patterns to be identified. The automatic analysis of thermograms guarantees rigorous assessment based on fixed criteria. The analysis algorithm determines whether a contact pattern falls within the tolerance limits. Overall, this transforms the load pattern inspection from a manual inspection process into a digitally integrated process step that can also be used to optimise the manufacturing process.

Fig. 4 Live display of the thermographic results

Fig. 5: External view of the test rig

Integration into existing processes

Thermographic load profile testing is suitable for in-line use and can be integrated into existing production lines. To test both flanks – the tensile flank and the compressive flank – the gearbox is loaded in both torque directions. This requires a drive concept capable of applying both driving and braking loads. If the tension and compression flanks are to be recorded separately, an additional handling system – such as a 6-axis robot – is required to reposition the camera for each flank direction. If only one flank is being examined, this handling step can be omitted. In enclosed or highly complex assemblies, design modifications or additional optical components such as mirrors or IR windows may therefore be necessary. As metallic surfaces reflect IR radiation and external heat sources distort the measurement image, the test area is thermally shielded. Targeted encapsulation of the measurement zone decouples the infrared measurement from external interference and ensures reproducible measurement conditions.

Certain economic factors should also be taken into account. Due to the high inspection speed, integration is particularly worthwhile for medium to high production volumes or complex assemblies. For very small production runs or simple components, the conventional method may suffice. Typically, the thermography station replaces a manual test bench and can be installed in its place or, to save space, in locations where a conventional test bench would not fit. With early planning regarding installation space, cycle time and interfaces, the system runs stably and reliably once set up.

Conclusion

Thermographic coating inspection fills a gap that traditional ink-based methods are structurally unable to address: it delivers objective, reproducible results – with precise edge definition, leaving no residue, and suitable for the cycle times of mass production. Where manual testing methods fail due to subjectivity, the need for cleaning and a lack of automation, edevis's thermography system enables 100% testing under real-world load conditions.

The technology is currently in productive use in the automotive sector. As demands on gear quality in commercial vehicles, industrial gearboxes and power generation systems grow, so too does the potential for application – wherever torque needs to be transmitted reliably and failures are costly.

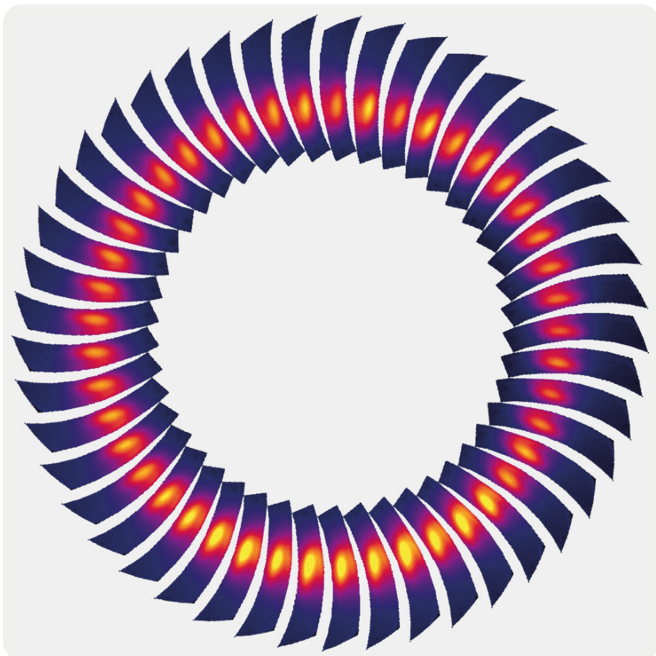

Fig. 6 Load-bearing surfaces

Technical specifications

Test head:	
Weight of inspection head	5.5kg
Dimensions	(410 x 145 x 175) mm
Working distance (test head - workpiece)	few mm
Heating mechanism	passive heating (friction)
Infrared camera:	
Maximum frame rate	280 fps
Camera field of view	21°
Thermal resolution (NETD)	20 mK
Sensor resolution	640 x 512 px
Spectral range	3-5 µm
Operating parameters:	
Typical measurement duration	10 seconds (typically), plus handling time
Gearing	hypoid and involute gearing
Gear coating	bound or plain
Gear material	Steel, aluminium, polymer
Maximum cable feed length	30 metres between the inspection head and control cabinet, robot-capable
Data transmission	Gigabit Ethernet
Interface to PLC	ProfiNet, OPC UA, TCP/IP, other on request

Sample presentation of results from thermographic image analysis

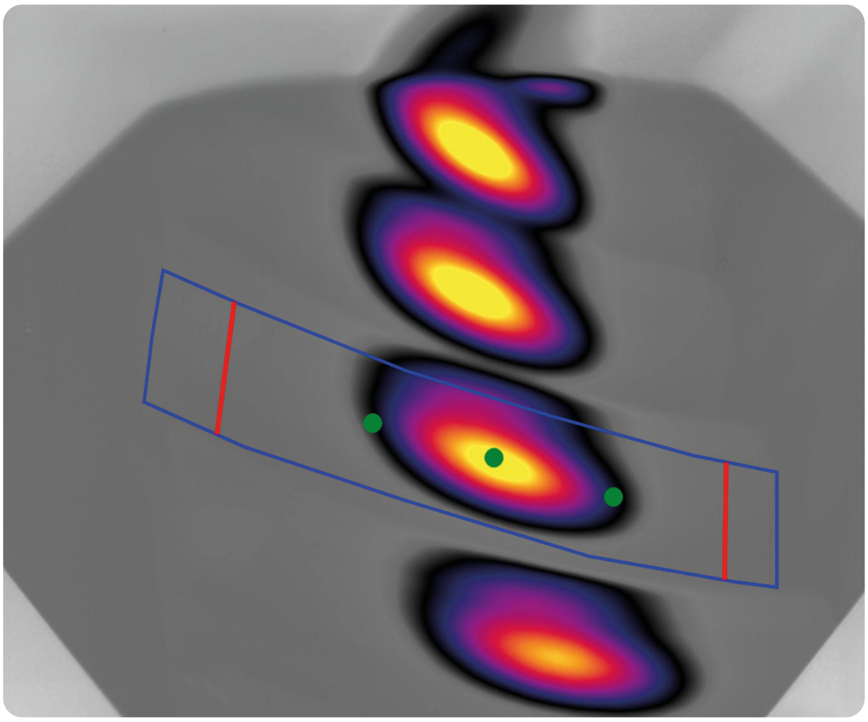

Fig. 7 Results screen

Center X:	–30,0 ≤ 5,4 ≤ 30,0
Left lmits:	12,0≤ 36,0 ≤ 60,0
Right limit:	8,0 ≤ 25,5 ≤ 60,0

Figure 7 shows an example analysis of a load distribution pattern determined using thermography. It illustrates the calculated centre of gravity and the limit positions in the x-direction. The values given are intended to illustrate the principle of analysis and do not represent generally applicable limit values.

edevis – enhanced defect visualization

Based in Leinfelden-Echterdingen, edevis GmbH has specialised in imaging-based, non-destructive testing using active thermography since 2004. The company develops and supplies testing systems for the inspection of materials and components – from feasibility studies through to fully integrated production-scale systems.

The fields of application include the testing of fibre-reinforced structures, crack testing on metallic components and the inspection of welded and joined joints.

In the company's own test laboratories, customers can evaluate technologies with minimal effort before proceeding to series testing. In addition, edevis offers training on systems and procedures – both in-house and on-site at the customer's premises.

The testing systems are currently in use in the automotive, aerospace, medical technology, plant engineering and research and development sectors.

www.edevis.com

Contact

edevis GmbH

Wilhelm-Haas-Straße 2
70771 Leinfelden-Echterdingen
Tel. +49 711933077-20
www.edevis.com

learn more