APPLICATION STORY


The Manfred Weck building houses a new machine shop that is part of RWTH Aachen University's machine tool laboratory

Thermal imaging at RWTH Aachen ensures aircraft turbine quality

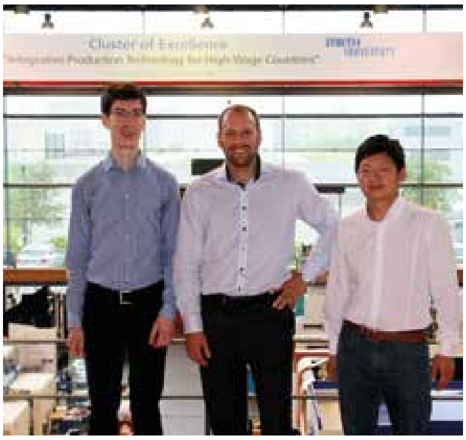
Thermographic examinations of the cutting zone when clearing nickel-based alloys

FLIR SC7600

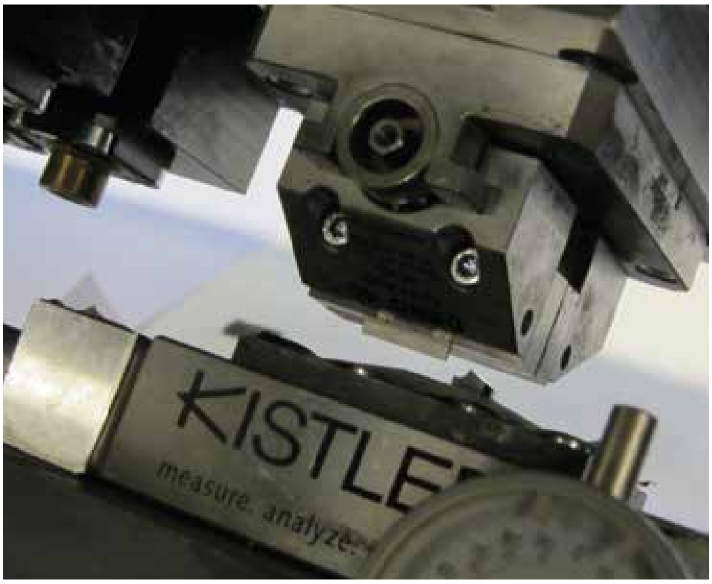
The research conducted by graduate engineers Matthias Brockmann and Sascha Gierlings of RWTH Aachen University's machine tool laboratory focuses on temperature as the primary variable in the machining process. This is a complex process due to the high speeds and relatively thin chips. These chips have a minimum thickness of 15 micrometers, and required a fast, high-resolution thermal imaging camera equipped with a macro lens. The Thermographic studies confirm some of the common theories but have also resulted in corrections to the theoretically expected distribution of temperatures, which has in turn lead to important insights, which help improve quality and workmanship. The machine tool lab researchers have been able to define process conditions that ensure the highest quality and productivity at the same time.

Two institutions, one philosophy
RWTH Aachen was founded in 1870 and currently serves about 38,000 students, including over 10,000 mechanical engineering students. RWTH is not only renowned in Germany as one of the most prestigious technical universities; it enjoys the unwavering support of the federal government through its excellence initiatives.

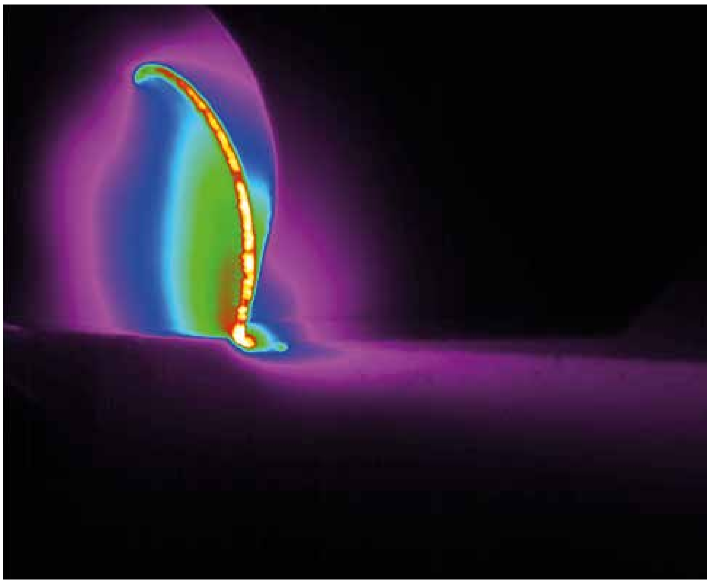
The machine tool laboratory (WZL) was founded in 1906. Today, the WZL and Fraunhofer IPT (Institute for Production Technology) jointly manage a budget of over 60 million Euros and employ approximately 830 highly qualified individuals (as of 2014). They focus on creating parts for aircraft engines and composite components for the aerospace and automotive industries.



From left to right: The engineers Roland Müller of the Fraunhofer Institute for Production Technology, Sascha Gierlings and Matthias Brockmann of the machine tool laboratory at RWTH Aachen.



When comparing the sizes of chips from the thermographic studies, the requirements for the experiment become apparent.



The reward of the work: The first thermal images were still far away from the quality of this thermographic image, but already showed the same moment of temperature distributions between the work piece (bottom), chip and tool (directly to the right of the chip).

The WZL works in close cooperation with Fraunhofer IPT. "Two institutions, one philosophy: all aspects of production technology" is how the two institutions understand their partnership.

Thermographic examinations of the cutting zone when clearing nickel-based alloys

Around 2010 the WZL and IPT obtained an experimental research commission to study the production-related thermal stress of the nickel-based alloys used in aircraft turbines.

This study was the result of an accident blamed on microscopic cracks in the borehole of a turbine component. Discovering which production conditions impact the ability of manufacturers to maintain the highest quality standards of heavily stressed components can be a matter of life and death.

Which structures are being studied?

While some engine components, like turbine blades, can be damaged in flight without inevitably causing harm to people, breaking a turbine wheel is almost always disastrous. Therefore defined material properties, such as geometry, surface roughness, and hardness, have to be maintained, even on the finished surfaces. Structural changes to the edges of a surface, like micro-hardness, micro-structural anomalies (layers of deformation, phase changes, etc.) and a component's residual stress are also crucial in this regard.

The impact of the cutting process on the piece being worked

Important parameters for the cutting process include speed, the strength or thickness of the chip, as well as the material removal rate, all of which affect the quality of the material and the temperatures experienced during the process. At low cutting speeds and low chip thickness (moderate effective material removal rate), the quality of the component should theoretically be the highest. In practice however, in addition to a very low level of productivity, problems are caused by built-up edges. Very high processing speeds, thicker chips and high material removal rates, however, cause increased tool wear and degraded work piece quality due to excessive heat. Therefore process parameters have to be kept within an optimum thermal range, in which quality and productivity are both as high as possible.

In the Kelvin tradition: from model to experiment

Throughout all research activities, the central question in Aachen is: What exactly happens during the manufacturing process? Even today many of the processes remain a mystery for researchers. In other words, theoretical models may exist, but experimental investigation was not possible in the past. "For example, as early as the 19th century, thermal cutting processes were examined by William Thomson, who later became known as Lord Kelvin, after whom the scientific temperature scale was named", explains Matthias Brockmann from the WZL.

Of course much had happened since the days of Lord Kelvin when the WZL engineers began experimentally investigating the cutting processes of high-strength metal alloys at high cutting speeds at the turn of the millennium. But still no one had actually seen the precise temperature distribution during machining, as the technical requirements for such visualization simply did not exist.

The turbine wheel (MTU Aero Engines GmbH) consists of a heavy, high-strength nickel alloy.

The benefits of thermography

This has changed quite a bit in the time since, especially with the advent of thermal imaging using high-quality, cooled thermal cameras that allow for non-destructive inspection methods that allow the continued use of the work piece under inspection without restriction. Plus, actual test data can be detected and interpreted even during the manufacturing process. Decisions can be made based on this, which can save time and money. The value of a highly complex work piece like a turbine wheel increases with the degree of processing at different stages of its production. If problems are discovered in the material properties at an early stage of processing, the manufacturing process can be aborted to avoid unnecessary costs.

Unexpected challenges

What may at first sound like an ideal use for thermography, turned out (as expected by the WZL and IPT engineers) to be a highly complex task, requiring the discovery of solutions to many new challenges.

"Four weeks passed from the first trials using a thermal imaging camera to actually obtaining a thermal image that could be used for analysis", explains Matthias Brockmann to illustrate the difficulties that the team had to solve. These included precise calibration of the camera, which was difficult due to the low emissivity of nickel alloys.

Every material radiates thermal radiation above absolute zero. The emissivity of a body indicates how much radiation it emits in comparison to an ideal heat radiator (called a black body). Different materials emit thermal radiation at different levels. "Common" emissivity levels are 0.81 (such as coal) or 0.94 (e.g. beechwood). Bare or even polished metal surfaces often have emissivity levels as low as even 0.3. Such low emissivity makes it difficult to determine the actual surface temperature despite the use of a high-performance thermal imaging camera.

"We are also dealing with a high speed process in this case, which means the thermography camera has to be able to take several hundred pictures in a second (800 images in this case) to capture the actual moment of cutting," adds his colleague Sascha Gierlings. "Due to the fact that the chips in the trials are often only a few micrometers thick, we needed to use a macro lens, which is capable of resolving even the smallest structures."

Selection criteria for the camera

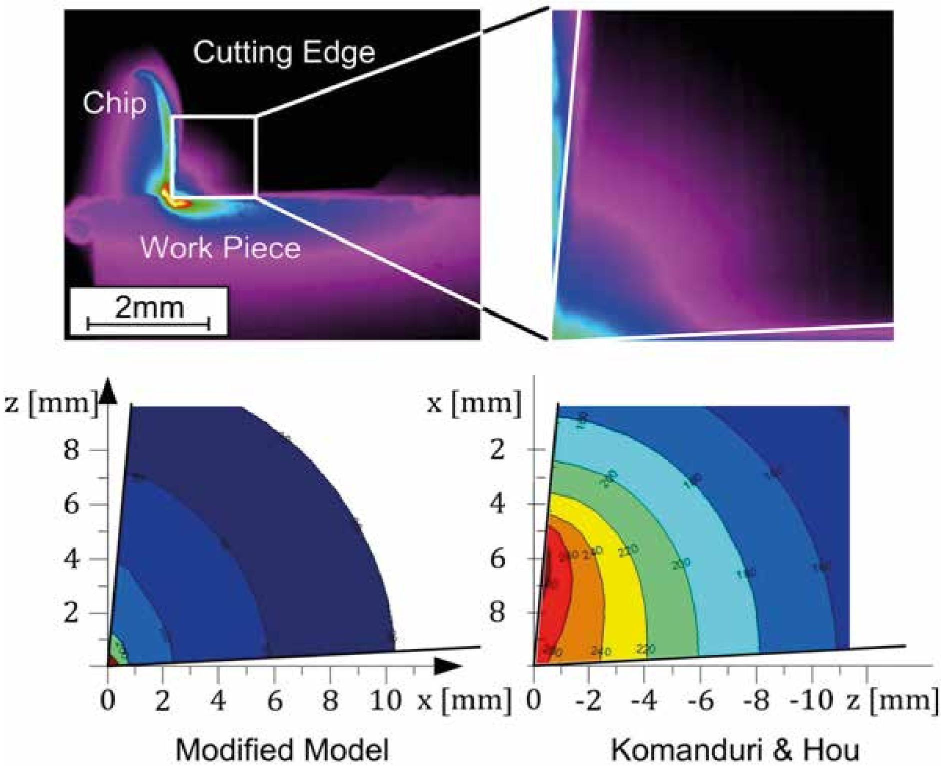
All of these factors came into play when selecting which thermal imaging camera to use. In 2010 the WZL opted for the FLIR SC7600. The camera is equipped with a cooled quantum photodetector with 640 x 512 pixels and has the necessary speed, high resolution, and an optional macro lens. The high level of accuracy, which can only be achieved using a cooled thermal imaging camera with its Indium-Antimonide (InSb) detector, its high resolution and its partial image mode for high image refresh rates were key selection criteria.

Faster, high-resolution - the best is just good enough for the R & D application.

In 1/4-frame partial image mode, the FLIR SC7600 achieves a refresh rate of up to 800 Hz, which is equivalent to 800 individual images in a single second. Only at this high speed, can the researchers experimentally answer their most pressing questions. "The questions that interest us are: Where does the heat energy go that is released during machining? Into the chips? In the work piece or into the tool?" Sascha Gierlings explains, and his colleague Matthias Brockmann adds: "For this reason, resolution and frame rate can never be high enough. For our tests, we actually need the best thermal imaging cameras available." The researchers are using the FLIR software Altair to analyze raw data.

Reciprocal calibration

To calibrate the SC7600 optimally, the WZL researchers used a specially designed 2-color pyrometer, which – despite its name – is not the same as industrial point pyrometers, which are available for under 100 Euros. In this case, the pyrometer consists of a fiber optic cable, which measures only two specific, narrowly defined wavelength ranges, but with very high accuracy. The researchers use this data to calibrate the thermal imaging camera – and vice versa. "We are probably the only institution worldwide, which has both a scientific thermal imaging camera like the FLIR SC7600 and a 2-color pyrometer, which has a price similar to that of the camera and is produced only on order", explains Matthias Brockmann. With this particular testing setup, the team managed to visualize the exact temperature distribution during machining in such good quality for the first time anywhere in the world. "It's a special moment when you see a thermal image for the first time that is described in every physics textbook, but which has never been measured or checked", adds Sascha Gierlings.

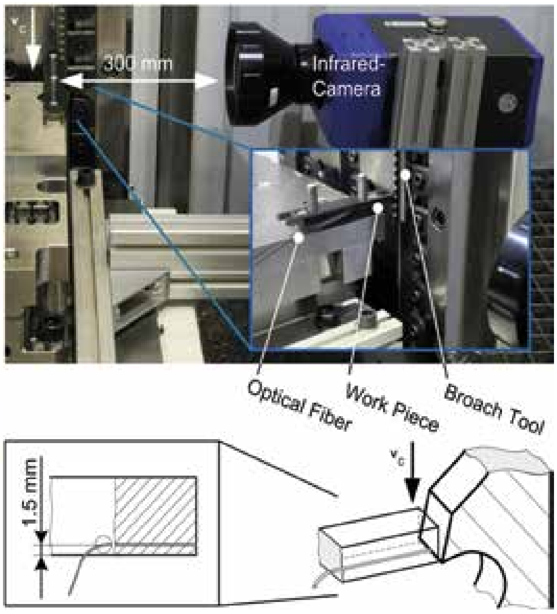


On the top left: the infrared image of the chip, work piece and cutting edge. To the right of this: the area that shows something different than expected according to the standard model of Komanduri & Hou. A modified model is the result (lower left).

Close cooperation between the university and the manufacturer

"We know what happens in front of the camera", Sascha Gierlings explains. "As the camera manufacturer, FLIR knows what is happening with the data in the thermal imaging camera itself. Therefore, close cooperation with application engineers from FLIR was important for us. For example, we're interested in whether there is an error correction function for inappropriate pixels in the camera. If this is the case, it would distort our measurements. Therefore we were keen to get raw, unprocessed data from the camera. For our purposes, it is much more useful to know which pixels we should ignore rather than just having a pretty picture."

Gierlings specifically praises the FLIR application engineers for their continued cooperation. "FLIR was clearly not interested in just selling an expensive camera." And FLIR of course benefits from being closely involved in the research, as it receives suggestions for further product development.



The experimental set-up combines the FLIR SC7600 (infrared camera) with the optical fiber of the 2-colour pyrometer. In the example, the tool is moving down. As part of the experiment, a chip of just a few micrometers is removed From the tiny work piece at very high speed.

Know-How, training and scientific meetings

The engineers Brockmann and Gierlings conveyed the necessary expertise for using the highly complex FLIR SC7600 in typical university fashion: "First the appropriate literature, such as the FLIR R & D brochure, had to be prepared to provide the technical background", Sascha Gierlings explains. "Then Dr. Raphaël Danjoux from the FLIR training center ITC came to Aachen for three days to configure the camera together with the university team and clear up any questions. And the remaining 50% is experience - trial and error gleaned from 3 years of constant, regular testing. I have more than a terabyte of infrared data on the server." And not without pride, he adds that in May of 2014, Aachen had its 8th student complete their master's thesis on this subject.

Matthias Brockmann and Sascha Gierlings also visited the infrared conference infraR&D in Hanover in April 2012 and organized a "FLIR day" in Aachen the same year. Thus the scientific exchange is continuing.

Outlook

In the near future, the WZL and IPT teams will be defining standardized process conditions, which do not allow any material weaknesses to even arise in the production process. But the team already has their eye on other applications. For example, Sascha Gierlings casually mentions high-speed cutting (HSC). In this cutting procedure, the cutting speed and feed rate are much higher due to a very high tool rpm: "If the right parameters are determined for this, much of the thermal energy is transferred to the chips and this does not adversely affect the work piece." This is a challenge for the top-notch thermal imaging camera models, which the development team at FLIR Advanced Thermal Solutions is glad to take on.

FLIR X6580sc

In order to do even more detailed analysis RWTH Aachen recently also acquires a FLIR X6580sc thermal imaging camera. Thermal images of 640 x 512 pixels show you the smallest of details and assure excellent measurement accuracy, while fast dynamic scenes will be accurately recorded up to 355 Hz in full 640x512 resolution and up to 4500 Hz using a 320x8 subwindow.

The FLIR X6000sc Series thermal imaging cameras are designed to provide the best thermal measurement performance together with the most advanced connectivity. They are ideal for Scientists and R&D professionals that are working on the most demanding applications. All FLIR's knowledge is concentrated in this full featured, yet compact camera, providing ultra-sensitive and accurate measurements. State-of-the-art connectivity and ease of use allow the user to concentrate on the experiment and not on the camera.

For more information about thermal imaging cameras or about this application, please contact:

FLIR Commercial Systems AB
Luxemburgstraat 2
2321 Meer
Belgium
Tel. : +32 (0) 3665 5100
Fax : +32 (0) 3303 5624
e-mail: flir@flir.com