Online Film Thickness Measurement in Practice at Audi

An online film thickness measuring system for process control and stabilisation has been in use at Audi in Ingolstadt, Germany, since mid-2000. Audi is the first car maker worldwide to use such a system in the OEM finishing of car bodies.

The measuring system, called PaintChecker compact, has been developed especially for use in industrial and automated coating processes to allow the process to be monitored and controlled immediately after application. The use of the measuring system as a stationary unit as well as on robots (Figure 1) or multi-axis mobile units in the direct vicinity of the finishing process offers a multitude of possibilities and is the key technology for modern, automated finishing lines.

Design of the Online Measuring System

The complete system consists of one or two 6-axis robots each fitted with a sensor head. Before the system was built, the entire process was designed and tested using RobCAD computer simulation in order to determine the optimum robot motion for achieving the desired measuring point matrix on the different vehicle bodies (Dürr APT, Germany).

Apart from the optimisation of the measuring process for the "line tracking" procedure, an additional optical proximity sensor for collision control was integrated into the measuring heads. The entire measuring station was successfully installed and put into operation at Audi in Ingolstadt in the space of just one month, both during ongoing production and at production-free weekends.

After calibration of the measuring system for the different colourgroups and coating systems, measurement now takes place fully automatically as each body moves through the finishing line. For each body, a network of approximately 800 individual measuring points is measured fully automatically. The average of every five measured values is then calculated in order to gain a clearer overall picture of the measured data. The minimum distance between the points (matrix) is 20 mm.

The process reliability is 0.8 µm over the whole film thickness area. In the application described here, the measuring system works with a repetitionfrequence of 10 Hz. This means that, in combination with the robot motion, approximately 400 individual measurements are taken online per measuring head, or around 800 online measurements on each body.

Figure 1: The robot moves the laser measuring system to any point on the body.

The measurements are taken continuously with a relative motion of the robot to the body of 200 mm/s (12 m/min), which is compensated for passively by the measuring system by optical means.

Manual Film Thickness Measurement is No Longer State of the Art

Most of the methods and equipment used so far for film thickness measurement in the automotive industry and other coating processes work with contact, and can therefore only be used on the dry coating after curing (for example, eddy current measuring systems). This means that, depending on the length of the oven (i.e. the number of bodies being cured) as well as the time required for the curing process and the measuring or reaction time required for manual film thickness measurement after curing, there is a considerable delay before one can intervene in the application process to make any necessary changes. What is more, manual film thickness measurements can only be carried out by taking random samples.

Typically, bodies are also taken at regular intervals from the ongoing finishing process at different coating stages and measured manually in a quality audit. In some cases, if coating defects are discovered, a considerable number of coated bodies have to be reworked in a so-called repair loop or, if reworking proves to be too expensive, they may even have to be scrapped. This also blocks the ongoing production process, thus causing additional costs. Furthermore, the use of sample bodies for measurement leads to increased costs and manpower requirements whenever new colours or new coating systems are introduced.

From today's point of view, these disadvantages are no longer acceptable

for meeting the demands of modern finishing processes.

The Film Thickness as a Key Parameter

The film thickness plays a key role in complex application processes. Film thickness measurement allows conclusions to be drawn, for example, about the surface quality, the colour or the gloss of a finished body, so that, if necessary, one can intervene in the ongoing process in order to control or stabilise it. Shorter and shorter product cycles, stricter environmental legislation, higher customer demands on the end product and continuous technological change have considerable consequences on the plant and process technology in modern paintshops. Especially in large-volume production, a very high degree of automation is taken for granted today in order to fulfil the increasing quality demands within an acceptable cost framework. This trend is set to continue in the future.

Integration of the Measuring System into the Ongoing Process

The PaintChecker online film thickness measuring system was integrated into the paintshop at Audi AG in Ingolstadt in four project stages.

Stage 1: Checking and confirming the functionality of the measuring system and confirming the reproducibility of <1 µm for the coating measurement at the technical laboratory of Dürr Systems GmbH in Bietigheim-Bissingen (Germany) and during a trial run on a two-axis positioning unit in the finishing line at Audi in Ingolstadt (detailed report in "Automotive Surface Technology 2000").

Stage 2: Integration and start-up of the whole measuring system on an existing finishing line for the A3 at Audi in Ingolstadt. The demands on the operator of the system were kept to a minimum and the graphic user interface "EcoPaint Screen" was specially adapted for online film thickness measurement. The visual representation allows the operator to quickly localise and correct variations in film thickness.

Figure 2: Synchronous scanning of the freshly coated body using two six-axis robots in tracking operation (throughput operation)

Stage 3: Fully automatic film thickness measurement over the whole body, with approximately 800 individual measurements per body. In addition to the continuous graphical and numerical visualisation of the measured values and archiving in a higher-level database, the measuring system automatically warns the operator if the coating is too thin or too thick or if there is a deviation from the desired film thickness distribution on the different bodies.

To ensure that potential coating defects are recognised and corrected in good time, the projected trend of the film thickness curve is monitored and displayed. A problem zone representation allows the film thickness to be observed with regard to selected problem areas on the body over any period of time.

Stage 4: A fully automatic control circuit to feed the measured data back to the basecoat finishing line is currently being installed, to allow the process parameters to be monitored and controlled without manual intervention.

The Online Film Thickness Measurement Process

Figure 3 shows the result of an online film thickness measurement using the PaintChecker immediately after conversion of the finishing line to a new colour.

In the graphic representation, those areas in which the coating is too thin are indicated by red dots and those areas in which the coating is too thick by yellow dots. The areas marked with green dots are those in which the film thickness values are within the specified tolerances or limit values. Magenta-coloured dots represent faulty measurements. If the film thickness is above or below the limit values, the operator is automatically warned by visual and acoustic signals, to allow the necessary intervention to be made immediately on the basis of the measured values.

In this example, the coating was first of all not optimally applied after conversion to a new colour. The operator was then able to make the necessary adjustment to the electrostatic application unit in order to optimise the film thickness distribution. During adjustment, the changes can be directly monitored online. The measurement of the film thickness immediately after the application process (the time between application and online measurement is two minutes) makes it possible to manually correct any defects within just a few minutes. The correction carried

out by the operator ensured that the film thickness distribution on the body was optimised, thus achieving a homogeneous film thickness distribution over the whole body.

Film Thickness Optimisation in the Ongoing Process

In a further example, the optimisation of the film thickness was carried out during the ongoing process. Using the measuring system in combination with modern robot technology, the film thickness curve is represented online for each body. Figure 4 shows the measured values for 14 successive bodies plotted in one graph in order to determine film thickness curves and problem areas and to check the continuity of the coating process. The aim is to produce the minimum possible film thickness evenly over the whole body. On the basis of the measured values from the online film thickness measurement, the application experts from Audi were able to achieve the desired result in a very short time, for example by changing the flow rate to the spray guns or by trying out different combinations of process parameters.

The upper part of Figure 4 shows the film thickness curve for the right-hand side of the body, for which an optimisation was carried out. The lower part shows the film thickness distribution on the left-hand side of the body without optimisation.

Reducing Film Thickness by between 15 and 20%

By carrying out an optimisation, it was possible to achieve an average reduction in the film thickness of approximately 2 µm (equivalent to 15-20%) over the whole body for the majority of colours. In addition to considerable savings in material and fewer repair loops, this also leads to a reduction in environmental pollution. The first-run-rate was considerably increased.

Statistics Provide Information on the Type and Frequency of Defects

All measured values and series of measurements are assigned to the corresponding body and stored in a higher-level database. These data can be used, for example, to compile statistics on the type and frequency of defects as well as on the film thickness curves and the tendencies for a whole day, week or month. If complaints are received at a

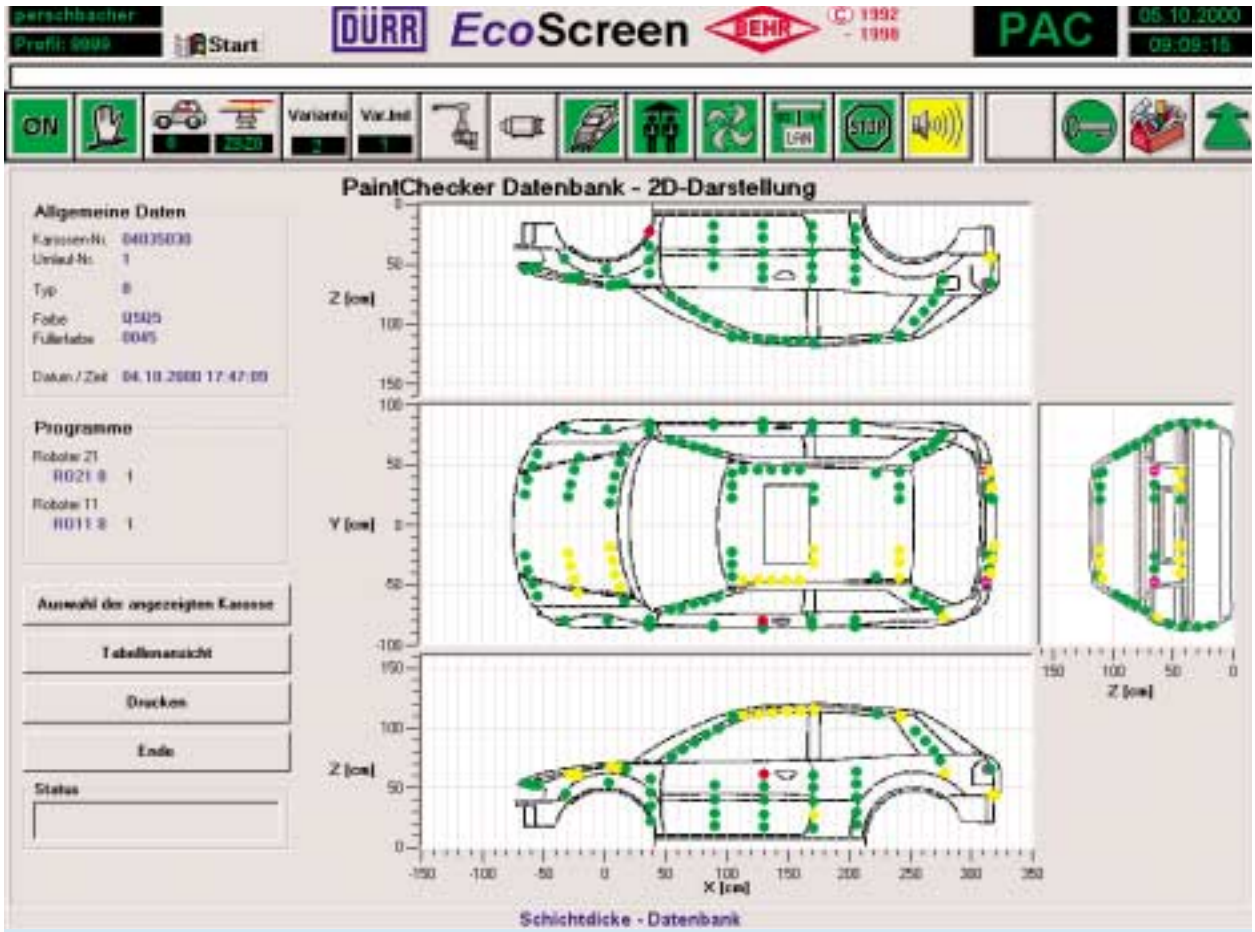

Figure 3: The visualisation of this measurement result shows the film thickness distribution on the body of an Audi A3 before optimisation

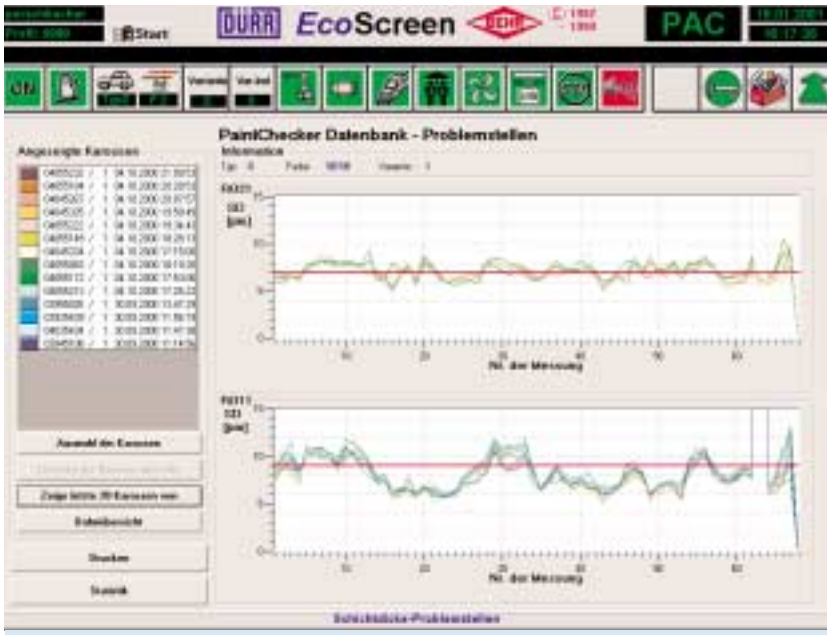

Figure 4: Visualisation of the measured values from 14 bodies with and without optimisation.

later date, the plant operator or the car manufacturer always has access to the data recorded during production by entering the corresponding vehicle number.

In a further step, the system control will be fully automated, thus achieving a level of process reliability that will make intervention by the operator almost superfluous, allowing the system to be stabilised in a very short time and the film thickness to be optimised.

Before the PaintChecker measuring system was installed, these defects would not have been detected until the vehicle was already in the final finish area or possibly at the next random check – and with a considerable time delay.

Calibrating the Measuring System

In the run-up to the system launch, extensive tests were carried out both at OptiSense in Bochum and in the paintshop at Audi in Ingolstadt in order to determine the influence of the substrate on the measuring result and therefore also to allow the measured value for the still wet base coat to be converted into a value for a dry film thickness (calibration basis). Due to the still high water or solvent content of the freshly applied base coat after a flash-off period of between 1 and 2 minutes, the photothermal measurement shows the recently applied wet base coat to be much thicker than the cured electrocoat and primer-surfacer at the time of measuring. The error caused by the substrate makes up only between 1/20th and 1/30th of the measuring result and is therefore negligible.

The online film thickness measurement is carried out while the paint is still wet, immediately after it has been applied. Calibration allows the measuring system to determine the dry film thickness from the data obtained from the wet coat.

The measuring system is calibrated completely on the finishing line in order to take account of process-related influencing factors in the calibration.

First of all, the film thickness distribution of the primer on a test body (electrocoat plus primer-surfacer) is determined at precisely defined points using an eddy current thickness metre. Then, a clearly recognisable film thickness wedge (5-15 µm) is applied to the test surface (bonnet) using a specified robot and application programme on the finishing line under production conditions. Immediately after the application, the sensor head is moved precisely to the pre-defined measuring points and the film thickness is measured online using the PaintChecker measuring system.

After the base coat has been cured (without the clear coat), the same points are measured once again with a template using the eddy current thickness gauge. Due to the exact assignment (<5 mm) of the differential data generated by the eddy current method, the distribution of the base coat thicknesses can be compared to the PaintChecker measurements obtained for the wet coat, thus allowing the calibration parameters to be determined and stored in a parameter file. The standard deviation achieved for the calibration is 0.8 µm. The main source of error for the calibration is in the calculation of the differential film thicknesses from the eddy current measurements and the inaccuracy of the eddy current thickness gauge. The online film thickness measurement offers a much higher accuracy and reproducibility.

Measuring Film Thickness Online with an Accuracy of 1 µm

Even with a rough determination of the substrate, the dry film thickness can be measured with an accuracy of below 1 µm. Audi is leading the way and is the first company in the world to use this cutting-edge technology which will revolutionise the finishing process in the whole automotive industry and the field of industrial coating. ■

The author: Dipl.-Ing. Manfred Hayk, Dipl.-Phys. Georg Nelke, OptiSense GmbH & Co. KG, D-Bochum
Tel.: +49 234 / 70 99 0-0
e-mail: hayk@optisense.com
Dipl.-Wirts.-Ing. Bekim Maxharraj, Dürr Systems GmbH, D-Bietigheim-Bissingen,
Dipl.-Ing. Jörg Perschbacher,
Dr.-Ing. Andreas Lindenthal,
Audi AG, D-Ingolstadt