THIN FILM SENSOR SYSTEMS – UNIVERSAL AND INDIVIDUAL
A high degree of product individualisation and adaptable, resource-efficient (large-scale) production characterise the future forms of industrial production—Industry 4.0. Autonomous, self-controlled and, above all, sensor-supported production systems are the basis for the fourth industrial revolution. Thin film based sensory systems offer the ideal prerequisites for application orientated solutions and innovations in industrial production processes. The Fraunhofer IST is a leader in the area of thin film sensory systems and has developed broad cross-industry expertise in sensory systems, film development and micro structuring.

During the production process, universally applicable sensor modules reliably and precisely supply data regarding temperature or force distribution in the main load areas for dynamic on-line process regulation.

The DiaForce® Layer System
The piezoresistive thin film sensors developed at the Fraunhofer IST are based on the amorphous hydrocarbon layer DiaForce®. A thin structured chromium layer is applied, using wet chemistry and photolithography. Thin film systems combine high wear resistance with piezoresistive performance, and enables direct measurements in the main load areas. This high-tech layer varies in thickness between 3-9 µm, can be used universally and is applied either directly to the surface of components or to inserts.

<table>
<thead>
<tr>
<th>Specifications of DiaForce® film</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hardness</td>
</tr>
<tr>
<td>Young’s modulus</td>
</tr>
<tr>
<td>Friction coefficient</td>
</tr>
<tr>
<td>Film thickness</td>
</tr>
<tr>
<td>Specific resistance</td>
</tr>
<tr>
<td>K* = ∆R/(∆F · Ro)</td>
</tr>
</tbody>
</table>

The advantages of integrated thin film sensory systems
- Measurement of parameters such as force, pressure, temperature and wear
- Measurements take place directly in the main stress areas
- On-line process monitoring
- Optimization of production processes
- Reduction of reject
- Time reduction prototyping of up to 30 percent
- Improvement in product quality
- Verification of simulation results
- High material efficiency
- Universal and cost efficient integration

Our offer
- Individual design of the sensor modules, adapted to the machine geometry
- Development of standardized sensor modules
- Individual development and optimization of the thin film sensor systems to the customer’s production conditions
- Consulting and training
## SENSOR MODULES FOR DEEP DRAWING TOOLS

Deep drawing is one of the forming techniques with the largest range of applications. Classic processes use a rigid tool, which, in its simplest form, consists of a drawing punch, a blank holder and a die. The area of application ranges from the manufacture of simple tin bowls to complex formed body parts for the automotive industry. The cost effectiveness of drawing processes is reduced by the occurrence of misshaped parts, cracks, and wrinkles. The causes of this are mainly process parameter variations, such as material parameter variations. In order to be able to produce high quality products with good cost effectiveness using drawing processes, the process control must be designed faultlessly and be reproducible. The key: process relevant information, which is available on-line and allows dynamic process guidance through suitable process procedures. Variations are evened out and the amount of rejected material is minimized through the use of integrated thin film sensor systems. For this purpose, the Fraunhofer IST is developing novel sensory thin film systems, which come into direct contact with the workpiece to be formed, and create very precise measurements of sheet feeder movements.

### The Advantages
- Measurement of the movement of the steel sheet with a precision of up to 100 µm
- Wear resistant thin film sensor system
- Long-term measurement stability
- Simple integration of the sensor module into the worktool

---

These developments are the results of the project ORUM (Optimized Control of Forming Processes by Means of Integrated Thin Film Sensor Systems), which is promoted within the framework concept “Forschung für die Produktion von morgen” (Research for tomorrow’s production) of the BMBF (Federal Ministry of Education and Research), project reference 02PU2040. It was supervised by the project sponsor, the Karlsruhe Research Center (PTKA), Division of Production and Manufacturing Technologies (PFT).
Piezoresistive thin film systems are applied to the load-region surfaces of force sensors at the Fraunhofer IST. The force sensors are pencil-shaped base bodies. They can be easily integrated into the most diverse plant concepts, and there they can locally measure the operating and wear conditions under extremely high load forces.

The Sensor Pins
The complex formed tip of the sensor pin, which has a length of 20 mm and a diameter of 8 mm, is the seat of the sensory DiaForce® layer system, which is applied using a PACVD process. The structuring of the chromium electrodes takes place using electrophoresis resist. As demonstrated in Figure 1, two force measuring structures can be found on the raised end of the pin, with the contact areas placed on the oblique area of the pin. This film system also uses a silicone and oxygen modified hydrocarbon layer as top coating. It serves as the insulation and wear protection layer.

Application in the ball screw
Using the piezoresistive DiaForce®-thin film system on force measuring pins smart ball screw can be created. Three base bodies are placed in the spindle nut in a 120° pattern; therein they measure the fitting forces, as well as the operating and wear conditions during the movement of the ball screw. In this way, it is possible to realise a spatial resolutioned measurement of the pressure conditions.

The Advantages
- Long-term stable recording of characteristics
- Can be used in main stress areas
- Easy integration
- Flexibly adjustable geometry of the force measuring pins
- Circuit paths width of 50 µm are feasible
- Complex structuring over edge areas
- Small size
- Cost efficient integration into existing plants possible

Detection of the pretension torque in static trials on the test bench.

This research and development project was funded by the BMBF (Federal Ministry of Education and Research) within the framework concept “Mikrosysteme 2004-2009” and was supervised by the VDI/VDE-IT.
SENSOR SYSTEMS FOR CUTTING PROCESSES

Incorrectly die-cut sheet metal parts or tool failures reduce the cost efficiency of cutting processes. There is increasing demand for on-line monitoring systems. Reduction in cutting clearance and tool wear have an immediate impact on cutting forces. Due to their small size, the thin film sensors, based on the DiaForce® layer system can measure the cutting force directly in the force flow of the tool without any disturbing influences.

The Advantages
- On-line monitoring of cutting processes
- Reduction in rejected material and costs for material
- Can be individually integrated
- Can be used universally in the direct force flow of cutting tools
- High hardness of 15-30° GPa
- Long-term stable measurement of the cutting forces

Integration of thin film sensor systems
A sensory three-layer system is applied to standard steel plates. By using chemically wet-etched 200 nm thin chromium electrodes on the sensor film, spatially resolved pressure conditions can be measured in various areas. In order to protect the sensory structures, an insulating friction and wear protective layer completes the system. A flex board gets in contact with the contact pads of the sensors, and transmits the signals from the tool to an electronic system that processes them. Using software developed for the cutting process, deviations in the cutting process can be spotted early and resolved, e.g. breakage of a tool edge or a welded-on layer in the cutting die.

Diagram: Characteristic curves of the thin film sensor system from trials at 1, 2000, 4000 and 6000 lift in comparison.

The IGF project 16113 BG of the European Society of Thin Films — EFDS, Gostritzer Strasse 63, 01217 Dresden, was supported by the AiF within the framework of the programme for support of communal research and development (IGF) by the Federal Ministry of Economics and Technology according to a resolution of the Federal Government.

1+2 Sensory force measuring pin. Left production steps, right: integrated into a flange nut.

3 Cutting process sensor module.
SMART WASHERS

In industry, screw joints are used frequently. A requirement is a clearly defined pretension that remains the same throughout the entire life cycle. Usually, a torque wrench is used for fitting, however, this often sets the required torque in place only very imprecisely. As a result, the screws used are often over-dimensionalized. Here, e.g. the dynamically loaded screw connections with the sensory DiaForce®-thin film system can help with savings in weight and costs.

There are two different types of washer systems: The open sensor system with the foil electrode on the piezoresistive surface. In the closed system, the electrode is deposited directly onto the sensor layer, and thus has almost one-hundred percent contact with it. Both variants can be used universally.

Possible areas of application
- High rack shelving up to high building construction
- Production plants
- Wind power stations
- Bridge construction
- Wheel fitting
- Conveyor belt monitoring

The Advantages
- Long-term stable, static and dynamic measurement of forces
- Universally applicable measuring system
- Monitoring of screw joints
- Design according to customer demand, with individually adjustable geometry
- Integral and local measurement of forces
- Smaller and more flexible to adapt to the currently commercially available measuring systems

1 Components of an open washer sensor system. Two single sided DiaForce® coated washers and a steel foil electrode.

2 Washer sensor system with soldered measuring wires.

3 Washer sensor system with integrated RFID chip.
**Washer as a Closed System**

The sensory washer system with the closed thin film system shows a linear change of resistance depending on the load. The electrode structures are manufactured according to the request of the customers, and allow spatially resolved measurements.

In addition to the use of established wire-based data recording, we also offer a new “smart” washer with RFID transmission*. This enables a precise, reliable and continuous measurement of forces and pretension, even in mobile systems. Examples for areas of application include conveyor technology or security related screw joints in wind power stations.

![Characteristic linear resistance curves of the closed sensor system.](image)

*y = -1010x + 584821*

**Washer as an Open System**

In open systems, the measurement of forces takes place integrally over the entire electrode foil. The characteristic curve can be partitioned into two areas (see figure below): A low stress area (I) from 0 to 300 N, with a large change in resistance per Newton and a high stress area (II) from 300 N, in which the characteristic curve has a lower change in resistance.

![Characteristic resistance curves during holohedral force effect.](image)

*These results were obtained as part of the project InUse (smart washer for measuring forces in screw connections), promoted by the Federal Ministry of Economics and Technology according to a resolution of the Federal Government in a project consortium with the firms Eilhauer GmbH, Mikrosensys GmbH, the Institute for Transport Technology and Automation and the Fraunhofer-Institute for Surface Engineering and Thin Films IST.*
CONTACT
Fraunhofer Institute for Surface Engineering and Thin Films IST
Bienroder Weg 54 E
38108 Braunschweig
www.ist.fraunhofer.de

Dr.-Ing. Saskia Biehl
Phone +49 531 2155 604
saskia.biehl@ist.fraunhofer.de