

SENSORS FOR FULLY MECHANISED ARC WELDING

Contents:

- 1 Scope of application
- 2 Introduction
- 3 Definition of terms
- 4 Workpiece-related influences
 - 4.1 Accessibility
 - 4.2 Positional tolerances
 - 4.3 Geometrical tolerances
 - 4.4 Surface finish
 - 4.5 Groove geometries
 - 4.6 Welding positions
 - 4.7 Materials (aluminium and CrNi steel)
- 5 Installation-related influences
 - 5.1 Integration possibility
 - 5.2 Sensor guidance
 - 5.3 Design
- 6 Influences relating to measuring and regulation technology
 - 6.1 Accuracy
 - 6.2 Reaction time
 - 6.3 Disturbing variables
- 7 Process-induced influences
 - 7.1 Process types
 - 7.2 Arc blow
 - 7.3 Flux-cored wires
 - 7.4 Flux dispensing in the case of SA welding
 - 7.5 Welding speed
 - 7.6 Speed of reorientations
- 8 Concluding remarks
- 9 Bibliography

1 Scope of application

The technical bulletin deals exclusively with sensors which, according to their working principle, can be utilised for fully mechanised arc welding (search for the start of the groove and/or groove tracking) and serve to position the electrode relative to the welding groove and, if necessary, to regulate the welding parameters. Part 1 of this technical bulletin includes a representation of the physical working principles of various sensors. Part 2 considers the areas of application of the sensor systems, gives instructions about the utilisation potential and the restrictions of the systems and is planned as an aid for selection.

Neither the direct quality monitoring of the executed weld nor any of the procedures suitable for this are included in the area of responsibility of the sensors under consideration here (DVS 0954 technical bulletin entitled "Welding data as an aid for quality assurance in the case of automatic gas-shielded metal-arc welding" which is under preparation).

2 Introduction

The areas of application of the sensors for fully mechanised arc welding are just as diverse as the utilisation field of the arc welding processes. In this case, the utilisation of sensor systems generally serves the objective of safeguarding the quality of the welded joint in an efficient and economically viable way.

In this respect, the successful utilisation of the sensor systems depends, in particular, on the analysis of the outline condition as well as on the requirements on the demanded function of the sensor. The influencing variables can be systematically divided into the categories:

- workpiece-related influences
- installation-related influences
- influences relating to measuring and regulation technology
- process-induced influences

Three sensor principles have become widespread in practical application:

- optical sensors
- tactile sensors
- arc sensors

The description of the measuring principles on which these systems are based is included in Part 1 of this technical bulletin. The practical applicability of the individual systems is now to be dealt with below taking account of the influences specified above. Since three sensor principles (the optical sensors, the tactile sensors and the arc sensor) have essentially gained acceptance in practical utilisation, this technical bulletin also primarily refers to their specifications.

3 Definition of terms

The collective term "sensors for arc welding" is understood to relate to devices which, as a constituent of a fully mechanised welding installation, detect information about the position and, if at all possible, also about the geometry of the weld to be executed on the workpiece and provide it in a form which is suitable for the regulation of the position of the welding torch and, if at all possible, of the welding process variables according to the requirements set on the welding task.

4 Workpiece-related influences

In the list of the workpiece-related influences, the accessibility describes not only the sensor's possibility of reaching a position which is needed for the measurement of the component but also the sensor's property of not impairing the accessibility of the welding torch to the welding point. With regard to the positional tolerances, a distinction should be made between deviations in the component position and deviations in the torch manipulation. The two variables are superimposed on each other and result in both translatory and rotatory deviations between the welding torch and the groove. In most cases, it is sufficient to determine and compensate for the translatory deviations. The geometrical tolerances relate to the variation in the groove geometry. In the simplest case, this may be the formation of a gap between the groove edges. However, edge misalignment, angular tilting and a lack of or inaccurate groove preparation also lead to an impermissible change in the groove geometry. The surface finish has an influence as an essential criterion for the sensor reliability and the sensor accuracy. The suitability of the sensors is assessed with different groove geometries and welding positions as well as with the application of different materials.

4.1 Accessibility

In most cases, the increasing complexity of the weld path also means that the welding head has decreasing accessibility to the component. In the simplest case, a straight-line joint between two components is only impaired by clamping elements. The positioning of the welding head is often restricted in the case of a three-dimensional groove path with small radii and corners. Clamping elements hinder the accessibility in addition. Moreover, the positioning of a sensor is limited correspondingly.

This basically results in the requirement to utilise sensors with the smallest possible construction size.

Optical and tactile sensors can measure internal corners to a limited extent only since they either do not reach the corner themselves or prevent the welding torch from reaching the corner.

In the case of external corners or external radii, the sensor must be guided in such a way that the groove remains visible at all times.

Sensor components may be destroyed in the event of an unintended collision between the workpiece and the sensor.

4.2 Positional tolerances

The positional tolerances which should be compensated for by a sensor constitute the superimposition of the positional tolerances of the workpiece on the guiding tolerances of the installation.

The positional tolerances of the workpiece result from the tolerance of the geometry and the inaccuracies of the clamping. In the case of complex components, this results in:

- deviations of the centre of the groove
- deviations of the start and end of the groove
- edge misalignment
- angular deviations
- gap width tolerances

Another factor is the possible thermal distortion during the processing of complex components by means of welding technology.

The deviations in the guiding accuracy of the installation have a superimposed effect and are dependent on the axis position. Torch positions protruding by far have higher deviations than stiff, short axis positions.

The total of these deviations should be detected and compensated for with the sensor. Since the measuring point and the joint do not coincide for optical and tactile sensors, further calibration is necessary. This is the balancing between the measuring point of the sensor and the TCP (tool centre point) of the welding head.

4.3 Geometrical tolerances

As already described, tolerances of the component geometry and of the component position also lead to a variation in the groove geometry.

The compensation for the tolerances of the groove geometry extends beyond the simple readjustment of the welding position. Adaptive process control is required for this purpose.

The simple approach of using the natural compensation capacity of the welding process is widespread, i.e. the welding process is carried out within a robust process window which covers the expected groove tolerances. The welding parameters are not adjusted.

However, it makes sense to adjust the welding parameters in individual cases with wide tolerances of the groove geometry. Sensors which supply unambiguous information about the geometrical deviation and allow the installation to be controlled with regard to the adjustment of the welding parameters are needed for the adaptive regulation of the welding parameters. In particular, the optical sensors which permit any possible adjustment of the weld volume when the groove cross-section is changed should be named here.

4.4 Surface finish

The surface finish of the components is relevant to all the sensors.

Optical sensor systems need surfaces which are as uniform as possible and cause only slight changes in the reflection behaviour. Any soiling of, rust on and damage to the surface impair the measuring accuracy, as does any reflection from the surface.

The functioning capacity of tactile sensors is also impaired not only by soiling but also by lines, cutting burrs or welding spatter.

Surface coatings which have an effect on the stability of the arc (e.g. soiling, irregular coatings or also corroded surfaces) impair the signal quality for arc sensors.

As a rule, technical surfaces which are suitable for welding in industrial fabrication also satisfy the requirements of the sensors. The influence on the sensor functionality must be checked in each individual case.

4.5 Groove geometries

With all three primarily utilised sensor principles (optical sensors, tactile sensors and sensors evaluating process parameters), the groove geometries must exhibit certain characteristics. In the case of the **arc sensors** (systems evaluating process parameters), there must be an unambiguous correlation between a change in the distance and the relevant position. In this respect, one essential aspect is that it is not typical to measure the groove geometry through the arc but instead the molten pool surface below the arc. As an approximation, it may be said that the measured values constitute an assessment of the change in the penetration profile which is covered by a molten layer with a low thickness.

As far as the **optical systems** are concerned, attention must be paid to the smallest possible resolution. The groove must exhibit unambiguous geometrical characteristics which can be precisely assigned within the resolution of the system. The butt joint with the smallest gap width and without any edge misalignment continues to be the most problematical case.

As far as the **tactile sensors** are concerned, a component edge to be scanned must also unambiguously refer to the groove position. This component edge to be scanned does not inevitably have to be the groove itself. The butt joint with a zero gap is often the most difficult case here as well.

4.6 Welding positions

Particularly in the event of welding out of position, the process window available for the compensation for component tolerances is smaller for arc welding. In most of these cases, the torch positioning is only corrected. Weaved welding torch manipulation is not yet supported by all the optical sensors.

4.7 Materials (aluminium and CrNi steel)

At present, the arc sensor equipment for the MIG welding of aluminium cannot yet be regarded as the state of the art. For TIG welding, the arc sensor equipment may be used with aluminium materials too. In the case of optical systems, consideration must be given to the material-induced reflection factor of the surface. To the greatest possible extent, tactile systems are independent of the selection of the material.

5 Installation-related influences

Amongst the installation-related influences, the integration possibility describes the presence and technical specifications of interfaces for the communication with the sensor system. The sensor guidance designates the possibility and accuracy of the sensor to achieve the relative movement between the field of vision of the sensor and the groove. The design of the sensor describes the differences between directly coupled sensors and sensors which are active in their own processing step isolated from the welding process.

5.1 Integration possibility

This determines whether the possibilities of the sensor system can be exploited to the full and how easily a sensor-guided installation can be operated.

5.1.1 Parameterisation

The parameters are related to the sensor functions, i.e. the parameterisation of a tactile sensor differs extremely from that of an optical sensor. Although most of the intelligent sensor systems are computer-controlled, it is nevertheless necessary to parameterise the expected groove in order to avoid any incorrect evaluations. Typical parameters describe the shape of the groove, the reference point to be found or to be followed and also values which relate to the sensor system and allow the sensor data to be evaluated in the case of difficult surfaces. The attachment of the sensor can also be parameterised. The crucial factors here are not only the advance but also the angle in relation to the component and/or tool as well as the working direction. These parameters are often specific to every groove or weld and are summarised correspondingly. During the initial installation or the programming, these parameters are input either into the installation

computer or into the sensor computer depending on the installation concept and, in automatic operation, determine the sensor-guided positioning of the tool or of the installation.

5.1.2 Interfaces

Here, a distinction is made, amongst other factors, between the physical, electrical and ISO-layer links. The interface must transfer control values such as instructions and, if necessary, installation information as well to the sensor system and positional or corrective data to the installation. In addition, sensor parameters and status reports are exchanged between the installation and the sensor. The most important physical links are:

Analog/digital: Here, the sensor is controlled by digital signals and the status reports and the parameter set selection are also transferred digitally. The sensor sends positional data, mostly as corrective data, and the measured groove values, such as the gap and the height misalignment, via analog channels. In some cases, an additional analog channel is used in order to transmit the current welding speed to the sensor.

Serial: The communication between the sensor and the installation is carried out via a defined exchange of telegrams which, depending on the implementation, not only controls the sensor and transfers measured data but also permits the complete parameterisation of the sensor system by the installation. Electrically, a distinction may be made between the simple V24/RS232 interface and the more robust RS422 or RS485 interface. The speed of the data transfer is a restriction of the serial interface. For this reason, this interface may be used for high-speed applications to a limited extent only.

Ethernet: Although this form of the interface was originally intended as a network application, the Ethernet interface can be used for most applications. This interface is robust, quick and easy to wire.

Bus interfaces: These include the CAN bus (Profibus or Interbus), the field bus and similar buses. Bus interfaces are robust and relatively quick with a capacity for the exchange of comprehensive information but are being ever more superseded by the Ethernet interface for cost-related reasons.

5.1.3 Load-bearing capacities

Consideration must be given to the additional load-bearing force requirements of a sensor which is fastened to the manipulator / robot arm. The important factors here are not only the weight of the sensor but also the hose package connected with this and the fastening and/or the changing holder if the sensor is to be deposited. The distance away from the robot flange and also the influence on the dynamics of the manipulator, particularly at higher travel speeds, should not be neglected either.

5.1.4 Potential separation

The potential of the sensor interface, particularly of the optical sensors, must be separated from the potential of the manipulator so that the measured values are not distorted. The sensor head must be attached in an isolated form. Especially in the case of arc welding, the welding current must be prevented from flowing via a sensor head.

5.1.5 Calibration (TCP)

The correct assignment of the sensor to the tool (TCP in order to describe the tool position and orientation) must be guaranteed. Due to the often rough operation, either the sensor or also the tool / welding torch may lose the correct assignment to each other. A calibrating rail is used for checking purposes and, in the case of some systems, serves to automatically recalibrate the assignment of the sensor system to the tool and the manipulator/robot. It is advisable to periodically carry out the automatic calibration/measurement of the system.

5.2 Sensor guidance

The best sensor can only obtain good results if the sensor-specific parameters such as the corrective method, the advance, the additional axes as well as the field of vision, the wear and the robustness are optimum.

5.2.1 Corrective method

This could also be designated as the interface concept. Here, there are generally three different possibilities of utilising sensor data in the installation/robot. These are:

Raw data link: Here, the sensor sends the current sensor data to the higher-level installation/robot controller, mostly without any further preprocessing. The higher-level controller then filters the sensor data and implements the corrective data directly at the TCP in real time. This method has the advantage that the sensor system does not have to be notified of the current position or speed of the TCP. All the values which do not relate to the sensors are taken directly from the installation/robot controller.

Tool/TCP corrective link: Some interfaces require corrective data / measured data of the sensor system in relation to the TCP either in tool coordinates or basic coordinates. In the former case, the sensor system needs advance data and the current position or speed in real time. In the latter case, the orientation data of the tool is also needed in addition. The sensor system carries out the data preprocessing and the analyses. The sent data is transferred in a "filtered" form.

Master concept: Sensor systems which measure not only the positional data but also orientational data in 6D can carry out the checking via the robot/manipulator and guide the tool along the groove in real time.

5.2.2 Necessary advance

Due to the principle, arc sensors do not have any advance.

For optical and tactile sensors, an advance is required for various reasons. The advance depends on the accessibility, the process and the processing speed. Ideally, the measurement should be as close as possible to the TCP. The size of the tool / welding torch restricts the accessibility; the welding spatter and the arc may impair the measurement. The arc and the welding spatter are process-dependent, e.g. the work can be performed extremely near the TCP in the case of TIG processes without any cold wire feed. The processing speed is composed of the sensor computing time, the transfer time and the installation controller computing time. The advance should be designed in such a way that enough time is available for the processing of the measured data. For most of the modern sensor systems, interfaces and processes, this requirement does not entail any restrictions. The mechanically stipulated advance conditions and process effects such as the welding spatter and the arc remain dominant.

5.2.3 Additional axes / field of vision

With all the upstream sensors, it is necessary that the groove remains in the field of vision of the sensor. Particularly in the case of three-dimensionally curved paths, this entails a requirement for a sensor system. The larger the field of vision of the sensor is, the coarser the resolution is. In order to counteract this and in order to guarantee the optimum orientation of the tool, additional axes can align the sensor to the groove in an optimum way. These additional axes may be rotating axes which are controlled by the installation. Furthermore, the additional degree of freedom of another axis improves the accessibility to the component.

5.2.4 Wear

Almost all the optical sensors are protected by protective glass and spatter guards. Air or shielding gas is used as rinsing in order to prevent the protective glass from being misted up by fumes. Separate or also integrated water cooling protects the sensor from process and application heat and may prevent the adhesion of welding spatter. Due to the location, it may also be necessary to utilise heating integrated into the sensor in order to keep the sensor at the working temperature in the event of cold effects from the outside. The normal wear parts would be the protective glass, the spatter guards and, if necessary, the cables. Subject to the prerequisite that there is regular maintenance which makes provision for the changing of the wear parts, for the cleaning of the sensor and for the checking of the cooling, a sensor may be expected to have a long service life.

Tactile sensors are subject to wear at the scanning body. Depending on the surface conditions, this must be regularly checked and compensated for.

In the case of the arc sensors, the contact tube wear in particular leads to a deterioration in the signal quality. The regular replacement of the contact tubes for a stable welding process is typically sufficient in order to preserve the sensor functionality.

5.2.5 Robustness

The robustness is decisive for the sensor choice. The sensor must definitely take account of the process conditions, especially for all the welding applications. Not only welding spatter, thermal effects and welding fumes but also radiation effects such as UV light, laser light and heat become noticeable here. Another factor relates to the somewhat rougher handling conditions which require a robust sensor. The users should already convince themselves of the robustness of a sensor before the utilisation. It is often sufficient to make an inquiry to users of similar systems.

5.3 Design

The upstream sensors differ not only in their structural shape but also in their functioning method which is divided into two groups:

5.3.1 On line - Upstream

The advantages are no or only slight cycle time losses and direct compensation in the case of distorting components as well as process control by measuring the gap and the height misalignment.

5.3.2 Off line - Static measurement also with a changing tool

In the event of an adequate cycle time and applications with little distortion caused by process effects, it is enough to measure the component statically and to adapt the path program correspondingly. The off-line sensor is also utilised for applications in which the accessibility is not sufficient for an upstream sensor. The sensor can be attached in a protected position and also offers a more cost-favourable solution in some cases.

The characteristics are:

- necessary advance
- additional axes / field of vision
- wear
- robustness

6 Influences relating to measuring and regulation technology

In the case of the influences relating to measuring and regulation technology, the accuracy describes the sensor's capacity to precisely detect and process the tolerances. The reaction time encompasses the time span from the time when the tolerance is reached in the sensor's field of vision to the complete compensation by the installation. Disturbing variables are essentially electromagnetic radiation but also fumes and dusts whose development is inextricably connected with the welding process.

6.1 Accuracy

6.1.1 Measuring accuracy

In the case of optical sensors, the measuring resolution and the measuring accuracy must always be seen in connection with each other. The measuring resolution is determined by the chosen imaging scale and the resolution of the image converter element used. Moreover, the measuring accuracy is influenced by the applied evaluation algorithm. In most cases, the sensor suppliers indicate the measuring resolution. However, the measuring accuracy is crucial for the exactness of the measured variables. Furthermore, the

measuring accuracy is influenced by the chosen measuring range. Therefore, losses with regard to the measuring accuracy must be accepted with an increasing measuring range.

In the case of tactile sensors with electromechanical transducers, the measuring accuracy is influenced by the resolution of the analog or digital primary detector.

Arc sensors use the welding process itself as a source of information and their measuring accuracy therefore depends on a large number of process-dependent parameters. These are, for example, the material, the weaving frequency, the weaving shape, the weaving width, the arc type, the wire diameter and the weld preparation.

6.1.2 Guiding accuracy

The guiding accuracy of a sensor system for the path tracking is composed of the total of the inaccuracies of all the systems involved such as the primary detector, the signal processing, the data transfer as well as the handling machine.

In addition to the measuring accuracy, the compensation for the trailing error which results from the sensor advance or trailing in the case of optical and tactile sensors has the greatest influence on the guiding accuracy. Since the measuring and welding points coincide in the case of arc sensors due to the principle, this error does not occur here.

6.2 Reaction time

6.2.1 Measuring intervals

In the case of optical sensors, the measuring frequency is the limiting factor for the dynamics with which sensor-assisted weld tracking can be carried out. In principle, it is true that more stringent requirements with regard to the measuring frequency are set on sensor systems which are to be utilised in the case of welding processes at higher welding speeds, e.g. laser welding. The measuring frequency is dependent on the type of the scanning (scanning, linear array camera ...) and on the type of the detector chip (CMOS, CCD ...).

In the case of tactile sensors, the measuring interval directly depends on the inquiry frequency of the connected guiding machine.

In the case of arc sensors, the measuring interval primarily depends on the weaving frequency of the welding torch or of the arc in the case of magnetic arc weaving. The type of the downstream signal processing may also have an influence.

6.2.2 Data transfer

The sensor system is integrated into the installation or robot controller by means of control technology using suitable interfaces. In the simplest case, the exchange of data merely encompasses the transfer of a digital signal, e.g. when a threshold value in the sensor system is exceeded. However, comprehensive communication between the robot and the sensor which includes the exchange of status information, robot coordinates, values measured by the sensor etc. is required in most cases for on-line terms of reference such as during the weld tracking. Since every robot and installation controller is equipped with the most diverse interfaces, the sensor manufacturers are confronted with the problem that the sensor systems should be equipped with almost all the common interfaces (analog, digital, serial, bus systems etc.).

6.2.3 Compensation

The compensation for disturbing variables which are induced by the principle (trailing errors) or are coincidental (process noise) serves to increase the guiding accuracy and may take up processing times which may noticeably decrease the reaction time of the overall system.

6.3 Disturbing variables

6.3.1 Radiation

Since the signals should be detected as near as possible to the welding point, the particularly extreme radiation on the process side in the range of the spectral sensitivity of the image converter element frequently leads to disturbances in the signal in the case of optical sensors. Although most sensor systems take special optical and evaluation technology measures in order to suppress any disturbances, the functioning capacity of the sensor must be investigated anew for every application because of the diverse welding processes.

No influence is known in the case of tactile sensors and arc sensors.

6.3.2 Welding fumes

Optical sensors are equipped with protective glass against welding fumes. Depending on the welding application, these must be cleaned at regular intervals since the signal quality may otherwise be influenced in the form of attenuation.

In the case of tactile sensors, any coatings which welding fumes cause on the scanning elements must be removed regularly. No influence is known in the case of arc sensors.

6.3.3 Electromagnetic disturbances

All the sensors which work with electrical or electronic components must, in principle, be protected against electromagnetic disturbances. The necessary measures include the electrical shielding not only of the primary detectors and the control units but also of their power supply as well as of the complete cabling. In particular, pulsed processes and welding processes which utilise HF ignitions frequently generate strong spurious radiation.

7 Process-induced influences

The process-induced influences are understood to be special interactions between the welding process and the sensors which have an effect on the applicability or the parameterisation.

7.1 Process types

While a change in the welding process parameters or even in the arc type does not generally constitute a problem in the case of optical and tactile systems, parameterisation is often difficult for arc sensor systems here. This is particularly applicable to frequent changes in the parameters.

7.2 Arc blow

Any arc blow leads to an unintended deviation of the weld position on the components. Arc sensor systems can compensate for this to a limited extent since the arc root itself serves as a part of the measuring chain. Any arc blow should basically be avoided.

7.3 Flux-cored wires

In principle, it is often possible to utilise arc sensors for flux-cored wires but this should be checked in each individual case. The evolution of fumes which occurs to an increasing extent on many occasions impairs the applicability of the optical sensor systems. As a rule, tactile systems are not impaired by the utilisation of flux-cored wires.

7.4 Flux dispensing in the case of SA welding

Due to the flux dispensing for submerged-arc welding, a large advance of the groove measuring systems is chosen in most cases. The installation technology must take account of this.

7.5 Welding speed

If weaving is used during the application of arc sensors, this may limit the welding speed.

7.6 Speed of reorientations

Rapid reorientations often constitute a stringent requirement on the mechanical equipment of the welding device. In most cases, any arising vibrations also have direct effects on the signal recording of the sensor systems. These effects must be minimised if possible.

8 Concluding remarks

The given overview characterises the state of the art at the time of printing. It will be correspondingly adjusted from time to time on the basis of information which continues to be received and relates to existing or newly developed sensor systems.

DVS does not guarantee the correctness of the compiled information about the technical properties of the sensors.

9 Bibliography

- DVS 0922 Industrial robot system for gas-shielded arc welding, Parts 1 - 5
- DVS 0927-2 Sensors for fully mechanised arc welding, influence of the workpiece geometry and the fabrication conditions on the utilisation possibilities
- DVS 0939 Tolerances in the case of fully mechanised gas-shielded metal-arc welding and welding with industrial robots
- DVS 0954 Welding data as an aid for quality assurance in the case of automatic gas-shielded metal-arc welding

The following people have collaborated in the elaboration of the technical bulletin:

Dr. Jörg Gollnick	Böhler Schweißtechnik Deutschland, Düsseldorf
Dr. Wolfgang Kölbl	Meta Vision Systems, Eynsham, Great Britain
Bruno Benedict	Robo-Spy, Möchling
Rainer Class	Daimler AG, Stuttgart
Thomas Eder	FRONIUS International, Wels, Austria
Bernhard Eiber	Roboter-Anlagen-Technik, Linz
Dr. Heiko Falldorf	Falldorf Sensor, Bremen
Ulrich Grimm	Grimm Schweißtechnik, Hamburg
Dr. Thomas Kohler	KUKA Controls, Augsburg
Reinhard Kutzner	MEL Mikroelektronik, Eching
Michael Lang	ABB Automation, Friedberg
Markus Maurer	VITRONIC Dr.-Ing. Stein Bildverarbeitungssysteme, Wiesbaden
Reinhardt Mielke	Volkswagen, Wolfsburg
Dr. Eckhard Oster	WELTRON Prozessautomation, Wilnsdorf
Dr. Martin Oster	MECOS, Wilnsdorf
Wolfgang Queren-Lieth	DVS, Düsseldorf
Dr. Thomas Rienmüller	Reis Maschinenfabrik, Obernburg
Dr. Johannes Stelter	AmaTec Robotics, Germering
Hans-Richard Tradt	KUKA Systems, Augsburg
Konrad Willms	ISF, RWTH Aachen
Dipl.-Ing. Ulf Würdemann	Daimler AG, Hamburg