Paint robots in the automotive industry – process and cost optimization

ABB Flexible Automation GmbH is one of the world's leading manufacturers of paint robots. Most robots of this kind are installed in the automotive industry, the majority of them for coating car bodies. Current practice for such applications is to have 10 robots operating in one paint station. Further development of the robot control has extended its reach into the area of process control. Robots are also being used increasingly for sealing butt welds on vehicles.

The usual practice in the European automotive industry is for conventional automated spray and bell machines to be used to paint the car bodies. Paint robots are used predominantly for the interior areas, for example the passenger compartment, engine compartment, trunk, door entries and door rabbet. On some painting lines, points on the outer surface of the vehicle which cannot be reached by the external machines are coated afterwards by paint robots.

The trend in the Japanese automotive industry is also towards using paint robots for coating the outer surfaces. In Europe, the first company to do so was Peugeot, where pneumatic atomizers apply the second layer of basecoat metallic paint.

Some car manufacturers in Japan are now equipping this kind of robot with high-speed rotary atomizers in order to drastically reduce the number of atomizers per booth. Although this is mainly due to the geometry of the car body, there is also the added advantage of being able to use standardized equipment which can also be employed elsewhere in the plants. To what extent this trend will establish itself in Europe and the USA remains to be seen.

Robots for detailed surface painting

Paint robots for coating the interior of car bodies were first used in Germany at the beginning of the 1980s at Mercedes-Benz and BMW. In the following years, Opel, Volkswagen, Peugeot and Fiat also automated their painting facilities on a large scale. However, this initial enthusiasm had faded by the end of the decade, and no significant installations followed between 1990 and 1993. The use of paint robots for coating car body interiors was found to be more expensive than manual coating and the installations themselves were complex. Some of the installed robots were even dismantled.

Today, there are new signs of an upwards trend, partly due to productivity and quality improvement programmes that are being introduced in the industry. Recent investments at Mercedes-Benz and BMW reflect this situation.

A look at the development of robot technology in the last ten years allows a comparison of several key parameters and shows clearly how the versatility of the machines has improved. Electrically driven paint robots, which operate with much higher availability and require less costly maintenance, are now used exclusively. In addition, the painting speed has been increased by about 50 percent, while the dynamic accuracy of the path tracking and the absolute accuracy (referred to the target coordinates) have also improved (*Table 1*). Absolute accuracy with respect to a given point, for example, has improved from ± 4 mm to ± 1 mm, dynamic accuracy (referred to the path) from ± 25 mm to ± 6 mm.

Due to the short lengths of the painting paths, particularly in the engine compartment, the industry has also been focusing its attention on the acceleration of the machines. The importance of being able to vary the acceleration parameters became apparent at an early stage **1**.

In recent years, simulation has become an increasingly important feature of project engineering and a key factor in ensuring that the process will perform as required. The logical conclusion of this – off-line generation of programmes – is the state of the art for the present robot generation.

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Table 1:
Development of robot technology over the last decade

	1985	1995
Drive concept	hydraulic	electric
Painting speed TCP*)	800 mm/s	1,200 mm/s
Absolute accuracy, point	> ± 4 mm	< ± 1 mm
Dynamic accuracy, path	± 25 mm	± 6 mm
Acceleration	limited	variable
Off-line programmability	no	yes

*) Tool Center Point

Several of the plants operated by European automobile manufacturers are highly automated today. They include the VW plants at Hannover, Emden and Wolfsburg in Germany, Peugeot's plant at Souchaux, France, and the Fiat plants at Pomigliano, Melfi and Rivalta, Italy. Mercedes-Benz, BMW, and Opel, who began somewhat earlier, also use paint robots for specific jobs, more recently also on a large scale.

At an average of 40,000 vehicles per robot, the population density of paint robots in Europe is still way behind that in Japan, where there are 7,000 vehicles per robot. (The figure for Germany is 30,000, and for Italy 12,000 vehicles per robot.) Japan is also well ahead in the number of paint robots coming on stream annually.

The main reasons for the higher level of automation in Japan are a lack of skilled workers and the trend towards standardization of automation packages, which are developed jointly by the customers and suppliers. This latter factor has resulted in integrated production stations with many repetitive features.

In a painting booth of the kind customarily used for interior coating, the usual practice is for 10 machines to work on a car body: two manipulators for opening the engine hood and the trunk lid, four door openers and four paint robots **2**.

A new approach is to adopt the clean room concept for this application. The air management in the spray booth has been improved by providing bulkheads between the inside of the booth and the displacement axles and power supply equipment, which are located outside.

The functionality and performance capability of paint robot technology has greatly improved in recent years, and it was a logical development to also employ this technology to construct the handling devices, which are essential for fully automated paint shops.

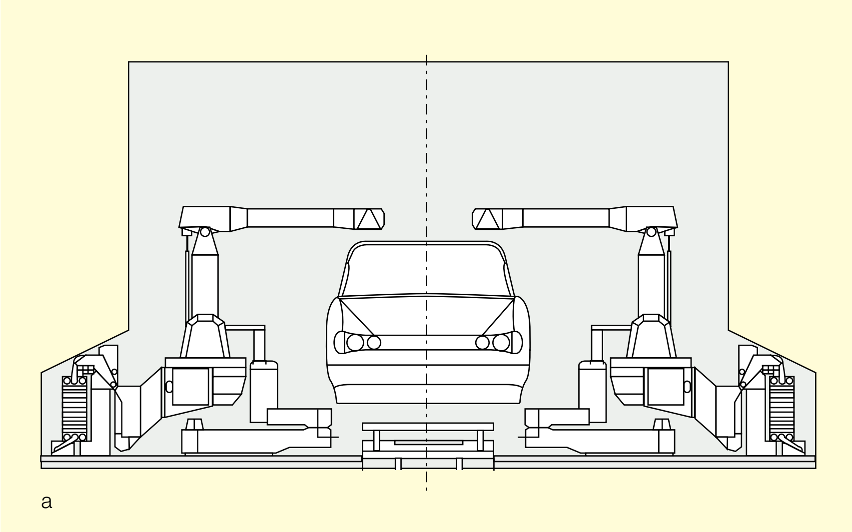
Paint robot working inside the engine compartment **1**

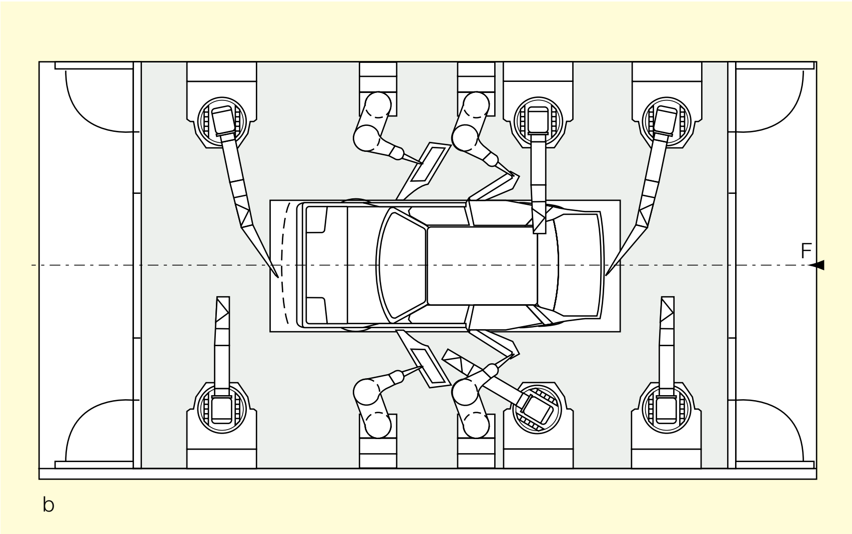
Causes of downtimes

The operating statistics for facilities already installed show that the causes of many of the disturbances involve problems with the preliminary processes, for example the non-reproducible position of the attachment parts.

The sensor technology integrated in the robot control allows an increase in process reliability. Examples are a sensor device for determining the position of the doors and hoods, while another sensor detects torque values for the purpose of checking that the forces used in gripping and opening movements will not be so strong as to cause parts to be torn off. Every device also features a status monitoring function for determining whether the door or the hood is really open or really being held. Painting does not begin until the object is in position.

Some paint shops use templates for the handling tasks. Although this can simplify the handling process, production is not necessarily more reliable because they introduce an additional source of potential error. This is due to the need to check and ensure the dimensional accuracy and proper positioning of the templates. Since the templates are recycled on the production line, they are subject to wear and have to meet almost the same requirements as tools.





A typical paint station for painting the interior of car bodies. The incorporation of the displacement axis in the cabin design is a feature of the clean wall concept and improves air management in the spray booth. **2**

a *Front view of a paint station*
b *Plan view of a paint station with 10 robots*

F *Transport direction*

From robot control to process control

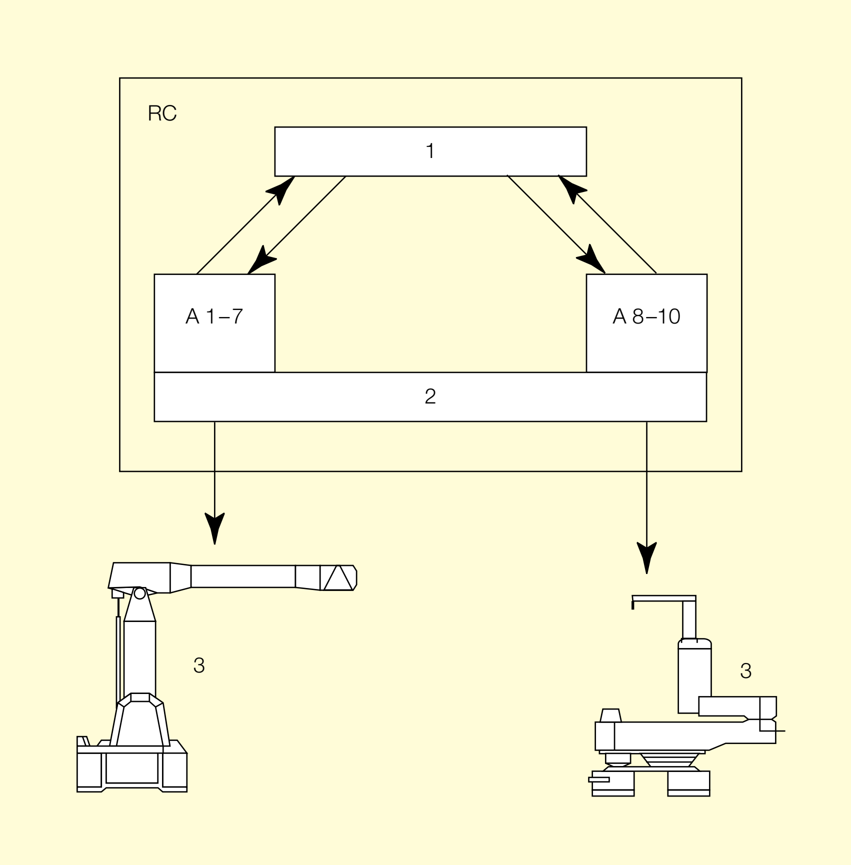
The new generation of robot controls is the result of development work that has seen them evolve into powerful process controls, designed first and foremost to control and check the machine, but also to monitor and control all the parameters that are relevant to the process.

Features that characterize modern, state-of-the-art controllers include multimotion control, process multitasking and system visualization.

By increasing the power of the process computers, it has become possible for a single robot controller to monitor and control two separately operated manipulators **3**. Although this solution offers better economy and reduces the amount of space required, it has the drawback that two manipulators will shut down in the event of just one fault occurring. However, this disadvantage is countered effectively by the high availability of the controls.

The good performance of the controls is especially apparent in connection with process multitasking, ie, the parallel processing of data and functions relevant to the robot and/or process. These functions can be grouped as follows:

- Motion control, ie, the control of robot motion along the preprogrammed paths.
- Communication with the peripheral equipment, data exchange with other and overriding controls via digital I/Os and serial data exchange.
- Applications engineering for monitoring and controlling the process parameters ‘paint quantity’ and ‘air flow rate’: when processing two-component materials, this also applies to



Control and monitoring of two manipulators with one robot controller (multimotion control) **3**

RC *Robot controller*
A *Axes*

1 *Main computer*
2 *Position control loop*
3 *Manipulators*

the monitoring of the mixing ratio and, for multicolour operation, the integration of the colour change technology.

- Process visualization and on-line editing; the process parameters are prepared graphically and shown to the operator in real time. This makes it possible for the process to be monitored continuously, and allows fast trouble-shooting when disturbances occur.

The diagram in **4** shows how a paint robot station can be incorporated in a production system.

A major factor in car body painting continues to be the coating process itself. Today, the industry talks of real-time coating, whereby, in this context, 'real time' means that all the coating data relevant to the application are processed in relation to coordinates. It was by making use of this capability that it became possible to adjust the change in spray-jet geometry with path and point accuracy as a function of the actual robot motion. This requires automatic compensation of all the response and control delays whenever individual robot parameters are changed.

The problem was solved through hardware and software integration of the applications engineering in the robot mechanics and control. Switching the atomizer with point and position accuracy has resulted in a further reduction in the paint consumption – on the one hand due to the switching process itself, and, on the other, due to the spray-jet geometry being matched with the object. A substantial reduction in overspray is achieved in this way.

Ten robots in each paint booth

The basic control diagram in **5** shows the configuration for the integrated applications engineering. Either a 4- or 12-ms cycle is used to process the parameters. The response of the applications system has become very important in view of the higher robot displacement speeds which are customary today. The following response times can be achieved with the described technology:

- Response by the paint control for a change in volume flow of 0 to 600 cm^3/min, measured at the gun 50 ms
- Response by the air volume control for an adjustment from 0 to 500 l/min 70 ms

In each case, the transient lies within a maximum error window of 10 ms.

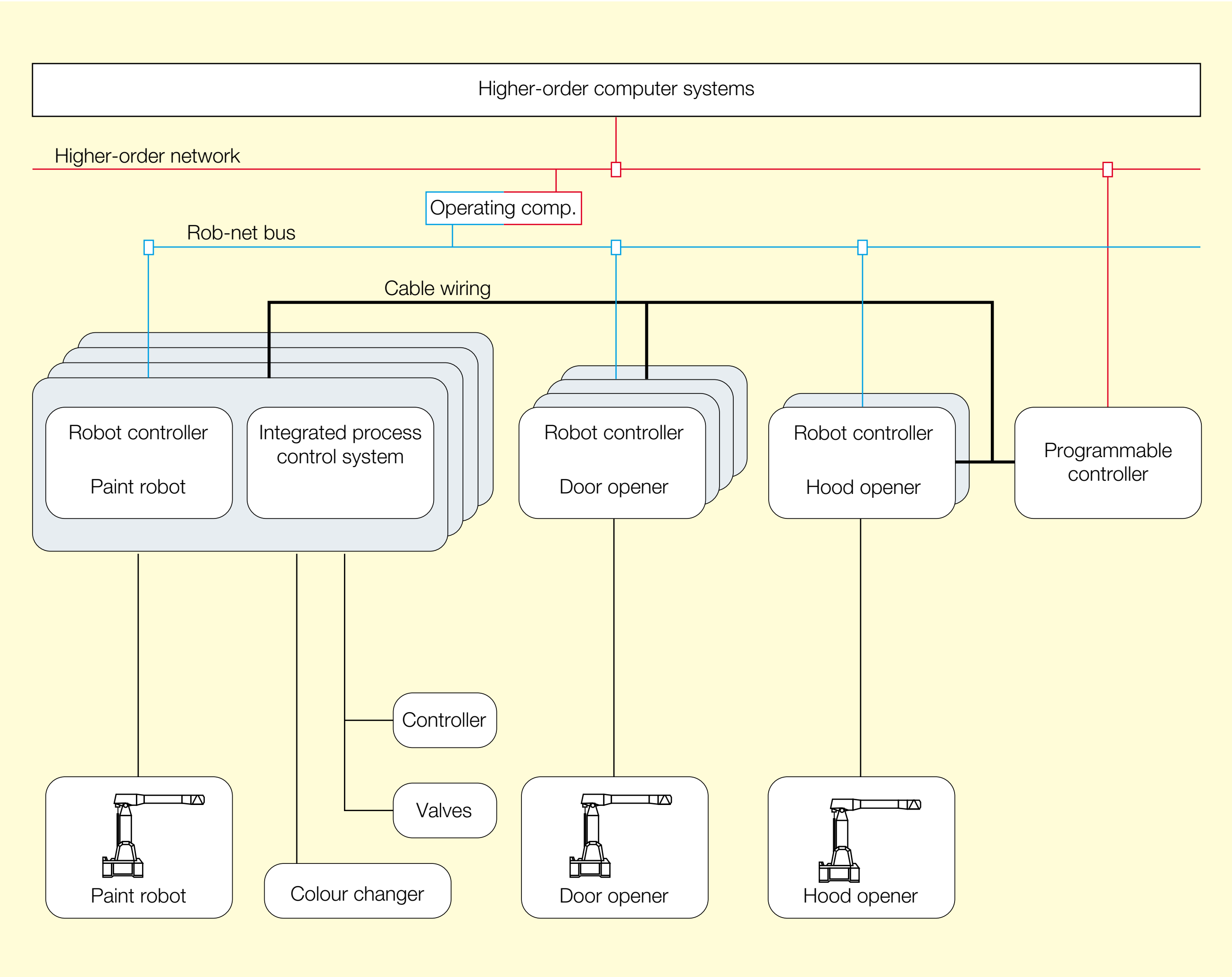
Conventional metering technology is not capable of such values. The communication between the computer systems alone requires processing times of the same order of magnitude, and then there are the control cycles to consider. The disadvantage of this configuration is therefore the measurable increase in paint consumption that results from the required lead times, even when these amount to only milliseconds for a single spray process.

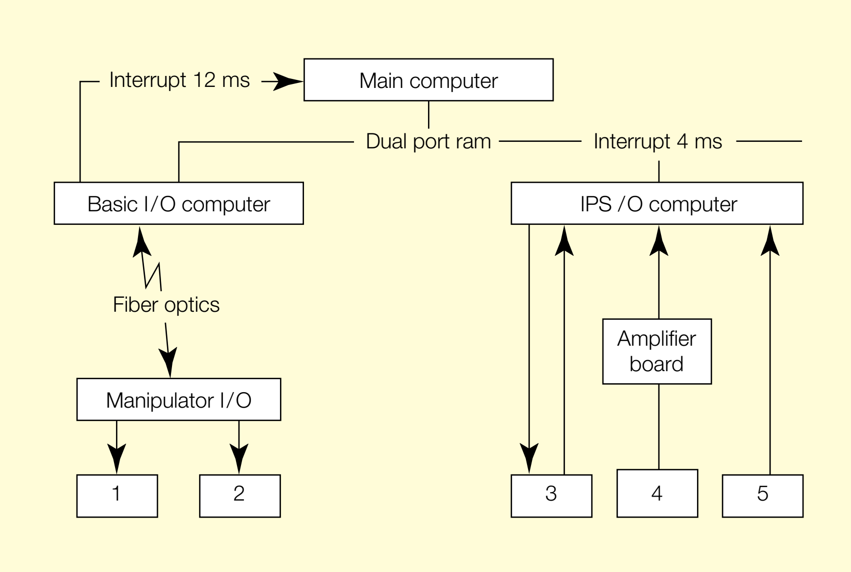
To allow this complex technology to be used in a user-friendly way, ABB developed operator interfaces that can be designed to suit the application. All the user data are transmitted on-line, using simple graphics, via a direct data exchange (DDE) interface to a central operating computer, where they are displayed. The collected data may also be used for further processing, for example for displaying production statistics, recording quantities consumed, measuring availability, and for performing disturbance analyses, etc. Another advantage is that all the data can be further processed using conventional PC programs, such as Windows.

The start-up of the installation is also of interest, for example after type changes, change of the paint material, or incorporation of a new colour tone. Paint shop operators know well the importance of being able to adjust the key process parameters to the daily requirements. As the ideal paint process (ie, one which stays stable over a full year) does not yet exist, a tool is needed which can respond quickly to changes in the environmental and supply conditions. An editing system is integrated in parallel with the visual display system described above, making it possible for the operator to adapt all parameters relevant to the robots and the process. This off-line tool, called CAP for Computer Aided Programming, allows a cross-adaptation of data applying to two successive car bodies and also supports start-up of the system as well as reliable production and process optimization for the current production run.

The use of new technologies allows the realization of further potential for reducing costs, for example through a reduction in the interfaces when using integrated applications engineering, combining several kinematic units by means of multimotion control, and reducing the cost of the project engineering by using standardized protocols and software for the inter-robot communication. This ultimately shortens the commissioning and start-up phase. About one third of the total investment for a robotized paint cell goes on personnel costs **6**. It is therefore just as important to reduce the planning costs – and thereby reduce the interest on the

Incorporation of a robot booth in a production system for process multitasking **4**



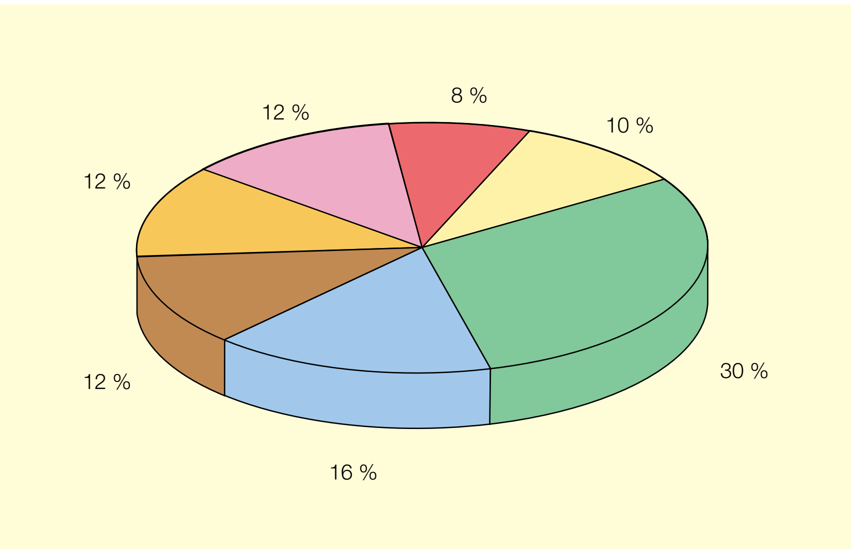


Control diagram for integrated applications engineering **5**

1 *Gun needle control*
2 *Paint admission pressure, air flow rate*
3 *Metering pump control*
4 *Pressure sensors*
5 *Air flow rate measurement*
IPS *Integrated paint system*

Breakdown of investment costs for a robotized paint booth **6**

Green	*Robots*
Blue	*Process engineering*
Brown	*Handling devices*
Light-brown	*Control, operation*
Purple	*Project management, engineering*
Red	*Assembly*
Yellow	*Programming, commissioning, training*

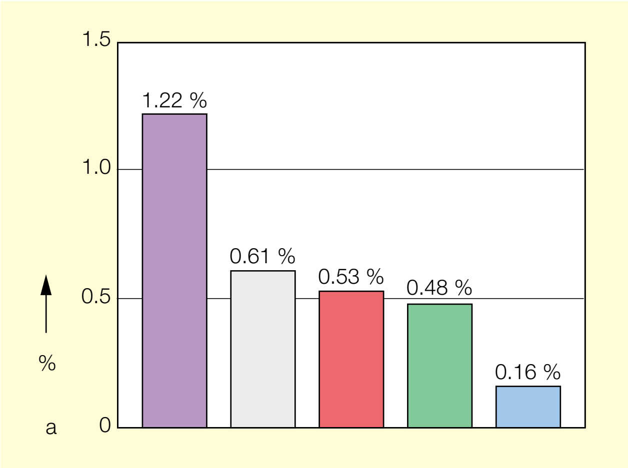


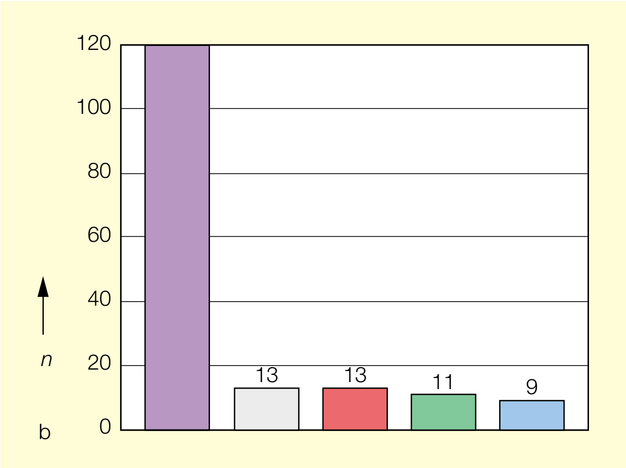
committed capital – as it is to shorten the commissioning time. Consequently, the manufacturer and the client have a mutual interest in taking full advantage of the potential for reducing the capital investment costs.

Also of significant importance to the operator are the process reliability and system availability. The described visual display system allows a marked improvement in this area. The window technique that is used provides information in a systematic way, while also increasing the transparency of the paint shop layout. By making operation easier, the risk of maloperation is reduced. The visual display system also supports preventive maintenance. Since the process is checked and events are recorded, trouble-shooting is made easier. This and the fact that the operating instructions are 'integrated' in the system reduces downtime. As the availability analysis of a robotized paint booth **7** shows, the potential for improvement that still exists in all areas can be realized to further improve the availability.

In summing up, three chief reasons can be given for automating the interior coating process:

- Job humanization: work in a paint shop is physically strenuous and detrimental to health, as absentee figures show. The need for the workplace to be humanized is of primary importance. This includes the creation of workplaces for maintenance and repair.
- Reduction in paint material: reducing the overspray lessens the environmental impact of paint shop operation. On average, the saving amounts to 0.5 l paint per car body, compared with painting by hand. This figure also takes into account the higher flushing agent losses during colour changes.
- Improvement and stabilization of the coating quality, plus a higher first-run





Robot booth availability analysis **7**

a *Event record analysis: availability 97%*

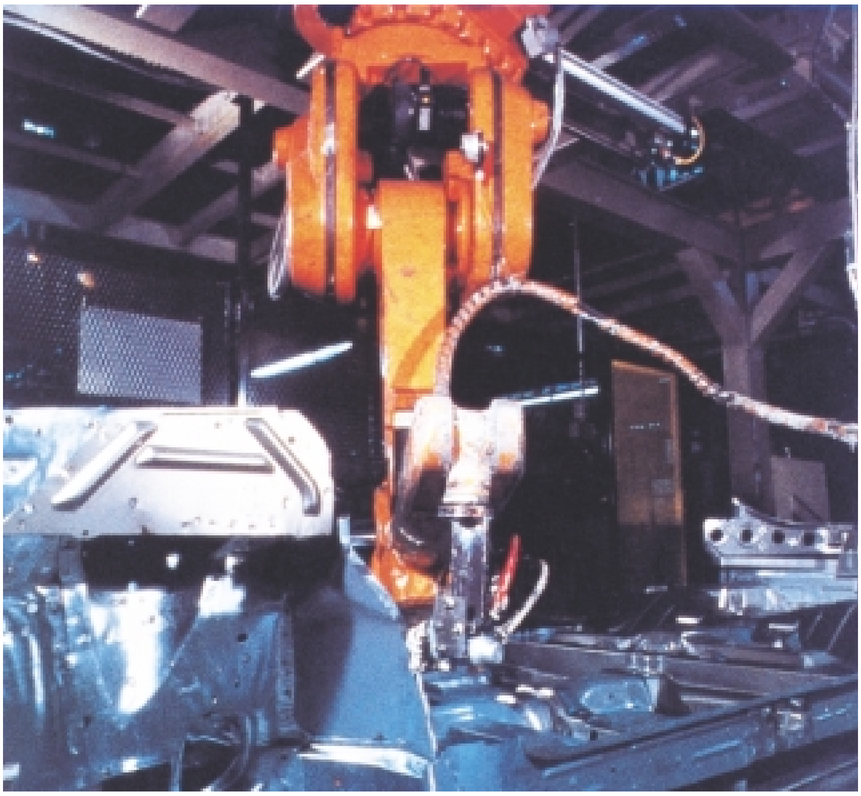
b *Disturbance rate (by number of events)*

Purple	*Applications engineering*
Light-grey	*Operator error*
Red	*Positioning, handling*
Green	*Robots, handling devices*
Blue	*Control*

success rate and a reduction in touch-up work. Although quantification of this cost item is most difficult, it is a fact that all fully automated systems have a higher success rate than semi-automatic systems for first runs.

Future development of robot technology will concentrate on increasing the payload. This is necessary in order to be able to fully integrate high-speed rotary atomizers for water-based paint into this robot concept. Conventional atomizers weigh 2 to 4 kg, bells or high-speed rotary atomizers 8 to 10 kg. At the present time, the paint robots are designed for loads from 6 to 8 kg. In addition, modular concepts for the axes are being developed which will increase the flexibility of robot integration in existing systems and make it possible for applications to be tailored in a product-oriented way. Further potential for reducing costs exists in the robot manufacturing and operating (maintenance) areas, involving the reduction of com-

Robots being used for underbody coating **8**



Robot sealing welds on the raw car body **9**

ponents and harmonization with other robots that are manufactured in large numbers, for example for use on spot welding lines.

Experience with sealing robots

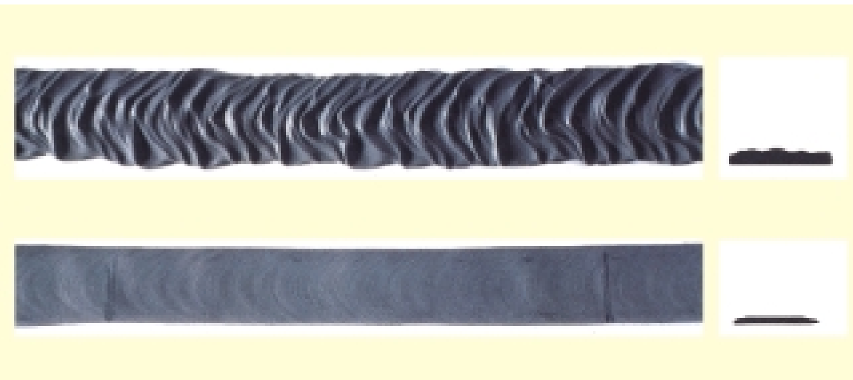
The application of PVC materials by robots was one of the first automation projects to be undertaken in the automobile industry, with robots being used for underbody coating as early as the mid-1970s. The main reasons given at the time still apply today: humanization of the workplace and less heavy overhead work. Initial experience with these robots led to a strong growth in their deployment in the PVC application area. At the present time, more than 500 robots are being used across Europe for underbody coating **8**.

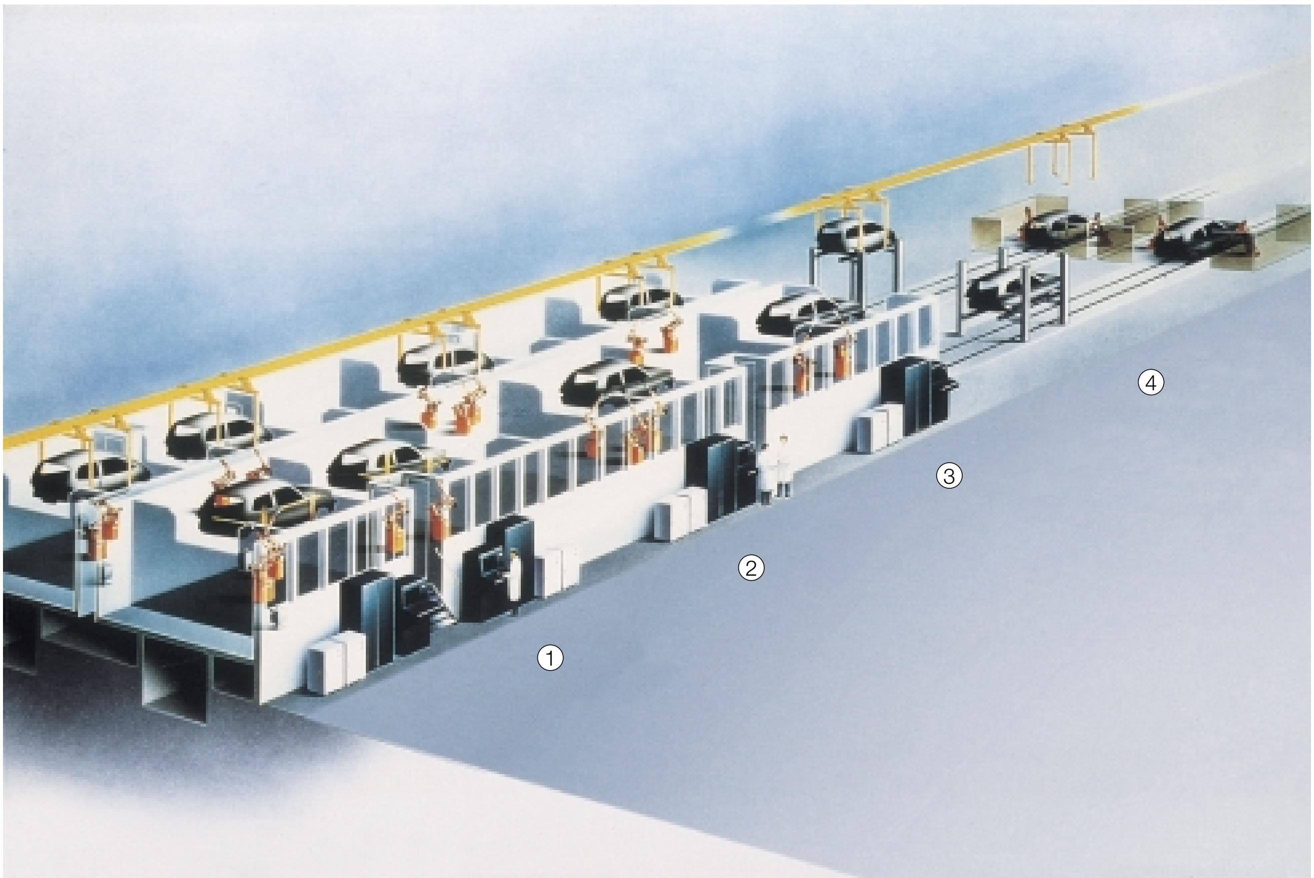
Besides surface coating, a field of activity that is growing and will be important in the future is weld sealing. The first robot systems to be installed for this work in Europe began operating in the mid-1980s, for example with Volvo in Torslanda. Some of the early experience with these systems was negative, and a slow-down in the installation of further systems for sealing interior welds followed. Nevertheless, weld sealing, at least on the raw car body, is the present state of the art. The combination of a high level of automation and reproducible positioning of parts facilitates easier application of the different sealants and adhesives. Experience in the processing of these materials can also be made use of for paint applications.

ABB has worked closely together with an automobile manufacturer to develop an innovative spray process for sealing tasks involving the raw car body. This process has also been used for the first time for weld sealing, more specifically in connection with a fully robot-integrated applications engineering package suitable for use in the PVC area **9**.

Building on the experience with paint systems and modular interfaces, it was possible here, too, to integrate the applications technology in the robot control. The method of application used is of considerable importance for weld sealing, which could be significantly improved as a result. A more accurate nozzle, achieved by working with narrower production tolerances, allows reproducible spray images. In combination with a modified nozzle configuration, this has produced more uni-

Weld sealing. The weld image exhibits a more uniform and flatter surface with robots than with manual sealing (top). **10**





Simulation of a system for weld sealing on car underbodies and for applying a protective coating **11**

1 *Weld sealing on underbodies*
2 *Surface underseal*
3 *Underseal with partially thicker layers*
4 *Stone chip coating*

form and flatter surfaces **10**. Pressure control with volume compensation has proved its worth for metering.

Butt welds are sealed using an airless method which ABB successfully automated in the mid-1980s. Moreover, material for manual touch-up can also be provided for hard-to-reach welds. Cost-effective solutions were also developed for the robots themselves. Whereas paint robots had previously been used mainly to apply sealing materials, process robots from other fields (eg, arc welding) are now also being used. The simplified control concept used for all the robots (ie, the modular structure of the robot control with modular interface and software) and the high performance capability of today's computers combine to effectively reduce first-time costs. **11** shows how weld sealing and the protective coating of the underbody can be fully automated with the help of process robots.

Ongoing development will also improve the weld sealing process. While sensing of the position of the car body with image processing systems is the state of the art, there is a need for the kind of high-speed weld search and trace systems which ABB has been using for years for inert gas welding. Only through the use of such sensor technology will it be possible to further automate the interior weld sealing process. Presently available computer power provides a good platform for the development of this technology.

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