15. 
Welding Robots
Increased quality requirements for products and the trend to automate production processes along with increased profitability result in the use of industrial robots in modern manufacturing, Figures 15.1 – 15.2. Since robots have been introduced in industry in the 70s, their most frequently fields of application ranged from installation jobs up to spot welding, and seam welding.

The definition says that an industrial robot for gas welding is an universal movement automaton with more than three axes which are user-programmable and may be sensor-controlled. It is equipped with a welding torch and carries out welding jobs.

Core of a modern robot welding cell are one or more seam welding robots of swan neck type. Normally, they have six user-programmable axes; so they can access any point within the working range at any orientation of the welding torch. To extend their working range, robots may be installed in overhead position. A further extension of the working range can be achieved by installation of the robot onto a linear carriage with Cartesian axes. Such 'external' axes are also user-programmable, Figure 15.3.
To turn the workpiece in the welding-favourable downhand position and to ensure accessibility to any joints, workpiece positioners are used as external axes which are steered by the robot control. Multi-station cycle tables are often used to increase profitability of the complete system installation. The operator feeds and removes the welded workpiece on one side, while the robot is welding on the other side.

The robot control is the centre of an industrial robot system for arc welding, Figure 15.4. It provides and processes all information for robot mechanics, positioner, welding unit, safety equipment, and external sensors. The robot program transforms information into signals for control of robot- and positioner-mechanics as well as welding power source. Communication with external systems is possible by a host or master computer.

Modern industrial robot controls are build as multi-processor controls due to the multitude of parallel calculations and control functions. Figure 15.5 shows the internal structure of such a control. Individual assemblies which are designed for special jobs and equipped with an own micro-processor are linked with the host computer via the system bus. The host controls and coordinates the actions of the components based on the operating system and the robot program. Examples of
such assemblies, which are mostly installed on individual printed boards, are e.g. the axes computers. They are responsible for calculation of movement and for control of power units of the individual axes. To control the drive motors, two interconnected control loops per axis are available which control speed and position of each axis.

Further assemblies control the display screen, the manual programming unit (PHG); these assemblies are responsible for communication with the welding power source, external sensors, and peripheral units via digital and analogue in- and outputs and field bus systems. Or they complete the data transmission with external control systems. To reduce downtimes in the case of malfunction, some robot controls can be connected via internet with telediagnosis systems of the robot manufacturer to support service personnel during troubleshooting and commissioning.

Programming of welding robots can be carried out in different ways which are distinguished in On-Line (programming at the robot) and Off-Line (programming out of the robot cell), Figure 15.6.

The robot is manually guided along the later track with decoupled drives during Play-Back programming. The path of the track is recorded and transformed into a corre-
A common technique to program a robot is the Teach-In procedure. During Teach-In programming, with the help of the manual programming unit, the welding torch is moved to notable points of the groove to be welded which are stored with information about position and orientation. In addition, track parameters must be entered, like e.g. type of movement and speed or welding parameter sets.

During sensor supported Teach-In programming, the path progress through some typical points is only roughly indicated. Then the accurate path is picked-up by sensors and automatically calculated in the robot steering control. Afterwards the movement program is supplemented by additional information about e.g. welding parameter sets.

Textual programming belongs to mixed procedures. The sequence program in form of a text file is created on an external computer and is then transmitted to the robot steering control. Figure 15.7. The recording of the position of points is carried out in the same way as with Teach-In programming: moving into position and recording.
Macro-programming is also regarded as a mixed method which shortens programming time at the robot, Figure 15.8. Macros are structured processing sequences which are created online to fulfil working functions and which can be repeated for further similar working functions. Geometry macros contain information about torch guidance to produce certain joints or joint sections. Welding technology parameters for individual welding situations are summarised in welding macros. This applies for torch positioning, torch inclination, relative position of beads to root and welding parameters.

Using a collection (can be created online or offline) of such macros, the programming time can be shortened for workpieces with often repeated welding jobs, e.g. steel construction when welding stiffeners and head plates.

Using offline programming practice, the programming work is shifted out from the producing robot cell. This avoids unproductive stoppages and allows for economic-viable, limited number of pieces to be reduced.

During textual programming, the 3-dimensional point coordinates and torch orientations are entered into an external computer in a manufacturer-specific program language. To achieve a complete program sequence, each instruction must be entered individually.

Figure 15.9

Graphical Simulation of Robot Movement

Figure 15.10

Programm Functions of Robot Controls
The graphical offline programming uses CAD data for modelling the complete robot working cell and parts to be welded. Planning of the path is carried out with CAD functions directly at the workpiece which is displayed on a screen. In most cases, the programming systems provide a graphical simulation of the movement, e.g. to check for collisions between torch and workpiece, Figure 15.9. For the following transformation of the program into the robot control, a calibration between model and physical robot working cell is required.

In the case of knowledge-based offline programming, the operator is supported by integrated expert systems when it comes to creation of robot welding programs, e.g. for determination of job-specific welding parameters. However, checking and adapting the program must be carried out by the operator.

Modern robot controls provide the programmer with some functions for movement control and for modification of program sequence, Figure 15.10. PTP movement (point to point) serves to move the robot in the space. All axes are controlled in such a way that they reach
their set-point at the same time. Thereby the actual path of the torch depends on kinematics of the robot and on current position of the axes.

A linear interpolation (CP procedure, continuous Path), Figure 15.11, is used for accurate movement along a straight line, e.g. movement to weld start point or welding. The active point of the tool 'arc' (Tool-Centre-Point, TCP) is moved along a straight line between two programmed points, adapting torch angle and torch inclination between the two points.

Circles and graduated circles are entered by means of circle interpolation programs, Figure 15.12. Then the orientation of the torch can be adapted through turning the knuckle axis or 6th axis of the robot and the value of spill-weld at the end of the seam can be indicated.

Speed of the torch is user-programmable and, if required, can be superimposed by an oscillation. To control the program run, commands are available for: repeated loops, conditional and unconditional program jumps, waiting periods, waiting for inputs, and working with sub-programs.

The software of modern seam welding robots contains – as special functions – 3-dimensional transformations and mirroring of programs and partial programs, palletising functions, processing sensor data and commands for communication with other robot controls (Master/Slave operation) as well as with external computers, Figure 15.13.

Figure 15.13