First turnkey delivery of robotized assembly lines for car engines and cylinder heads

The robotized cylinder head and engine assembly lines at the Opel car factory in Kaiserslautern, Germany, make it one of the most advanced of its kind in the world. Designed and installed by ABB as a turnkey system, the project has set new standards for logistics, floor-space requirements, economy and productivity. Zero-defect production was given the highest priority during planning and realization of the assembly lines. Robot stations, special-purpose machines and manual workstations have been combined in a way that optimizes the plant configuration and achieves maximum benefit for the plant operators.

The end of 1996 saw carmaker Opel take into operation one of the world's most advanced engine and cylinder head assembly lines at its plant in Kaiserslautern, Germany. Covering a total area of 7,000 m^2, two highly automated production lines with 32 ABB jointed-arm robots assemble engine blocks and cylinder heads for the 16-valve Ecotec diesel engine at the rate of one every 48 seconds **1**. Approximately 270,000 units leave the precision-controlled assembly lines every year. ABB is the first supplier to deliver turnkey such a complex line to a carmaker. In all, planning and construction of the assembly lines took two years.

The plant was developed and built by ABB Flexible Powertrain Assembly GmbH of Langenfeld, Germany. As the center of excellence for assembly automation within the ABB Group, the company specializes in, among other things, flexible, robotized lines for the assembly of vehicle power trains. To date, its engineers have built more than 60 assembly lines with a total of over 400 robots.

The automated assembly lines are custom-built to take account of the carmakers' different requirements and production strategies. Although standardized parts are used, almost every project is based on a different concept. Using advanced engineering tools and test set-ups, and by working together with the customers, the development team finds solutions which optimize productivity and economy for individual projects.

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New plant concept

The new cylinder head and engine plant at Opel in Kaiserslautern also has a custom-built assembly line. It is based on a completely new concept called 'Daisy Plus'. All of the automated stations are situated along the main line, from which so-called 'team loops' branch off. Within these loops are the areas in which the manual work is performed by groups of 6 to 8 workers. The conveyors for the final assembly of the engine blocks and cylinder heads are designed as closed loops. To save energy and operating costs, all of the hydraulic systems have been eliminated from the concept.

Advanced assembly concept

The advanced assembly concept has kept the overall system at Kaiserslautern very compact and has substantially reduced the cost of operation and maintenance. The main advantages offered by this concept are:

- Manual and automated assembly work are kept separate.
- Assembly workers operate in teams instead of individually along the lines.
- The main assembly line is fully automated.
- Component parts are delivered to stations on the outside of the assembly lines.

As a result of the fourth benefit, transport distances and times are shorter and component parts in transit are kept to a mini-

View of the cylinder head and engine assembly lines at the Opel car factory in Kaiserslautern, Germany. The plant, which is based on a completely new ABB automation concept, is one of the most advanced of its kind. **1**

mum. The considerably shorter delivery routes for the parts also lower the capital costs.

Jointed-arm robots as 'prime movers'

The main items of equipment on the assembly lines are 32 ABB six-axis jointed-arm robots of type IRB 3400 and IRB 6000. All the robots are fitted with ABB S4 controllers. The controllers ensure fast, precise movements and path tracking, plus simple operation and optimum adaptability to production requirements. In addition, 47 automated stations fit component parts to the engine blocks and cylinder heads. Seven other areas with a total of 37 manual workplaces are decoupled from the automated processes, as are certain logistics areas. Other important zones are the inspection and test stations, an ergonomically optimized workpiece transport system and the control system.

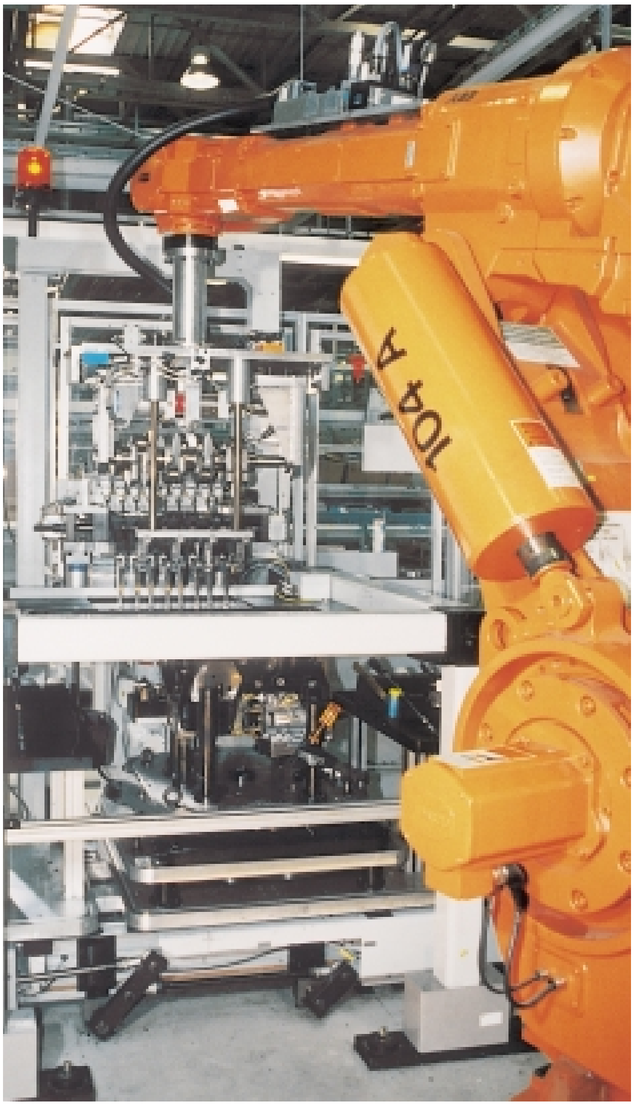
Service-friendly, zero-defect production

Zero-defect production was one of the design goals set for the plant. Precision work is absolutely essential for this. For example, the robot fitting the crankshaft has to work with an accuracy of 5/100 mm **2**. This kind of precision has the advantage that it also largely eliminates the need to provide repair and standby stations.

Safety and service-friendliness is given a high priority at every stage in the assembly process. The automated stations are screened off by a high-strength, transparent enclosure offering an uninterrupted view of the assembly units **3**. This 'open station' concept allows quick and easy maintenance of the robots.

Engine assembly

In the first station on the engine assembly line a robot takes the cylinder blocks from the parts production area and fixes them to special-purpose workpiece pallets. While the robot is doing this, a central computer is already loading the relevant data and specifying the next steps in the two-hour production process for each engine block. All of the manufacturing data is coded and transmitted by a read/write unit to an electronic data carrier on each



2 ***ABB jointed-arm robots are the centerpieces of the two new assembly lines. Their high precision makes them ideal systems for engine assembly operations, for example for fitting the crankshaft, which requires an accuracy of 5/100 mm.***

3 ***The 'open station' concept adopted for the plant allows fast and simple maintenance, trouble-shooting and repairs to be carried out without interrupting production. Movable, transparent protective devices shield the work areas with the robots.***

of the pallets. The assembly progress is also stored in this data carrier. Data telegrams sent to the cylinder-head line ensure that the cylinder heads are transferred to the production process in the right sequence.

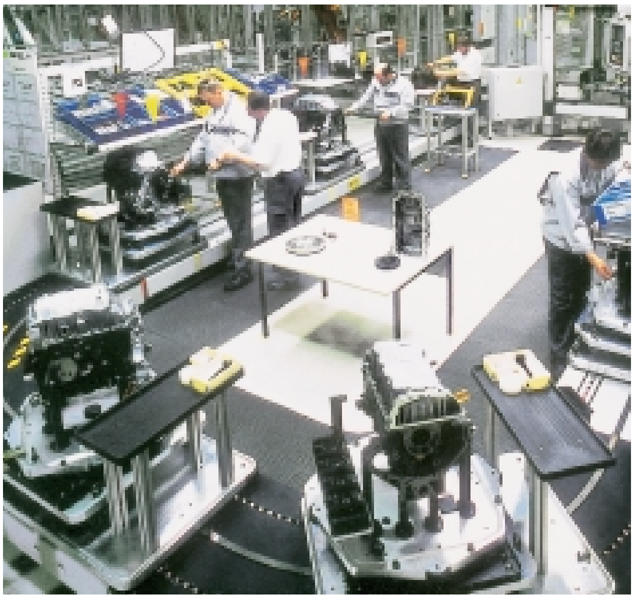
Team loops

Team loops were used in Kaiserslautern for the first time for engine assembly lines. Inside each loop, all of which are connected directly to the main line by transfer stations, six to eight workers at a total of 37 manual workplaces fit parts to the engine **4**.

In the transfer stations the workpiece pallets from the main line are placed on special loop pallets, which are then transported past the workers at an ergonomically optimum height of 300 or 800 mm and a constant speed of between 1 and 3 m/min **5**.

Assembly errors are practically eliminated from the team loops by the combination of highly trained workers and standardized operations. Additional automatic control and inspection mechanisms make use of light signals to guide the workers as they take parts from the racks. A visual and audible alarm is triggered if, for example, a wrong part is taken.

A typical operation is the fitting of the main bearing shells. The engine block and crankshaft are manufactured with very small production tolerances, which are compensated for by differently dimensioned bearing shells. The correct bearing shell class for an engine block is marked on the pallet and read in by the process control system when the unit enters the team loop. Light signals in this loop tell the workers which bearing shells are the right ones, and a light barrier checks that the right shells are taken.



The manual workstations are located within so-called 'team loops', which are decoupled from the main assembly line. Control mechanisms guide the personnel through the standardized work routines. **4**

Coupling stations transfer the partly assembled units to the team loops on special pallets. The stations are designed according to ergonomic principles. **5**

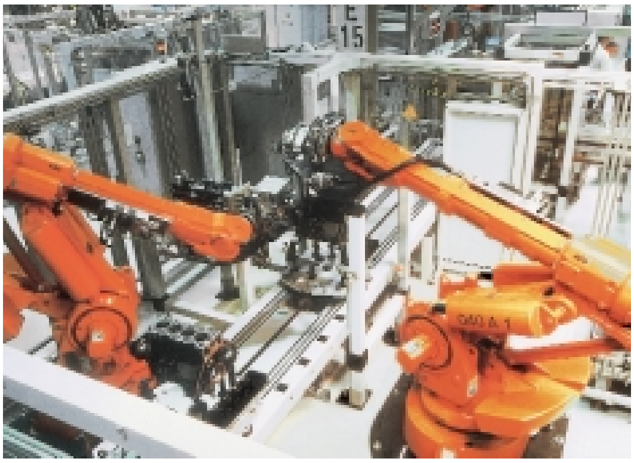
Robots fit the fuel injection pump

Two ABB robots in the same production cell are responsible for bolting the fuel injection pump onto the engine **6**. One takes the pump and places it ready for the other robot, which mounts it on the engine block and bolts it in position. The method used to insert the 16 inlet and outlet stud bolts is also special: the nutrunning spindles are inserted, with the help of the robots, by sequentially positioning a feed-head and blowing the studs into the respective chucks. Use of a single head for the blowing operation reduces the cost of assembly (and dismantling) considerably. Fully automatic methods are also used to fit the flywheels and couplings **7**.

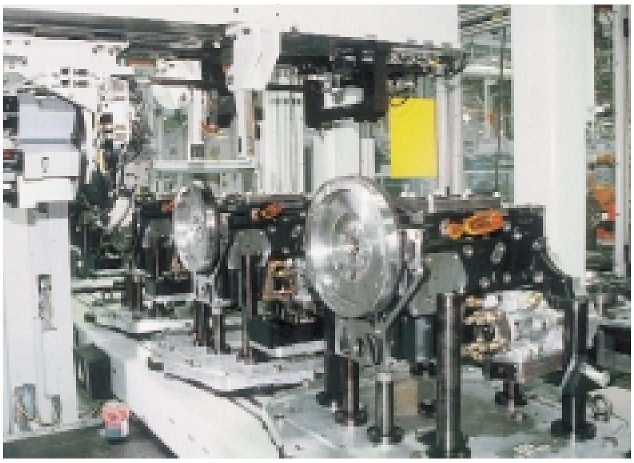
Cylinder head assembly

The fully automated assembly of the cylinder head takes place in 21 stations. Complex operations, eg the fitting of the camshaft and injection nozzles or positioning of the valves and tappets, are performed by robots **8**. The entire cylinder-head line is supervised by just three workers, whose jobs include filling the racks with parts and operating the four repair exits.

Two jointed-arm robots fitting the injection pumps – an eye-catching feature of the Opel plant in Kaiserslautern **6**



Fully automatic station in which the flywheel is fitted **7**



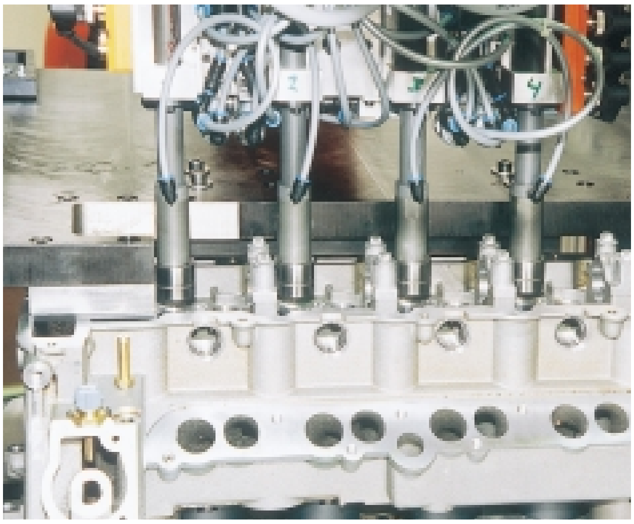


ABB Flexible Powertrain GmbH in Langenfeld, Germany, holds patents on several complex automated operations, including the fitting of the valve collets. **8**

Robots 'marry' the engine blocks and cylinder heads, which arrive from their respective assembly lines. **9**

The cylinder-head assembly area is the only one in the entire system with repair exits and temporary buffers. For example, a repair exit is located after the fitting of the valve collets, while a loop which can handle up to five pallets with defective workpieces is located after the leakage test. A temporary buffer has been added with room for up to 30 workpieces (five different types of head are presently being assembled). These workpieces can be taken from the store as required and inserted wherever they are needed to ensure the correct engine assembly sequence.

The fully assembled cylinder heads are afterwards transported to a cell where robots 'marry' them to the corresponding engine blocks **9**.

Operation of the assembly lines is synchronized

The different product variants and the synchronized, sequential assembly of the engine blocks and cylinder heads make high demands on the controls and plant management system. The control system, which is responsible for synchronization and control of all the assembly operations, is mostly standardized and based on a decentralized, modular concept. This concept is one of the platforms that guarantee the user-friendliness and flexibility of the system. Other contributing factors are the standard control panels in the automated stations **10** and the ground-level, modular transport system **11**.

Quality assurance

Highest quality is guaranteed on the one hand by the high-precision, automated stations with the robots, and on the other by test stations equipped with laser systems, which are integrated in the lines. For example, a computer-controlled test station checks the engines for leakages in the oil and cooling-water circuits. At another station, units are run up to 1,000 rev/min and their operation thoroughly checked. This 'cold test' system detects faulty units and marks them for removal and repairs. In addition, the complete unit has to pass an eight-minute running-in test.

Characteristics of advanced automation concepts in the automobile industry

The automobile industry began to install robot systems on final assembly lines and in paintshops at a relatively early stage in their development. In spite of this foresight, costly special-purpose machines continued to be used for a long time for engine assembly. It was not until market conditions changed and the need to reduce costs became paramount that carmakers also began to exploit the robot's potential for optimization in this area. The benefits in cost, quality and flexibility easily offset the initial cost of the plant. Today, the automobile industry invests every year some US$ 300 million in automated lines for the assembly of vehicle power trains. The change in attitude is market-driven, with the industry offering new car models at increasingly shorter intervals whilst at the same time making huge efforts to reduce both capital and production costs. At the present time, Opel produces about 60 engine variants in a product mix that includes 'one-off' orders. It is expected that this figure will grow to 150 variants in the foreseeable future. Against this background, the advantages offered by computer-controlled machines that can be continually adapted to new requirements become especially important, not least because of how they increase lifetime and availability.

High-precision assembly

Flexible, high-precision production and assembly processes are a key factor in the manufacture of modern engines, which have to combine maximum economy with ecological soundness. Opel's newly developed Ecotec engine, which unites four-valve technology, direct injection and turbocharging, is typical of such units. 2-liter and 2.2-liter versions, with 82, 100 or 120 horse-power, are available. Features of the newly developed engines include optimized fuel consumption and exhaust emissions, plus a new type of valve control with only one camshaft. Instead of opening just one valve, as usual, each cam opens two (intake or exhaust) valves via a bridge. This reduces the friction in the valve mechanism by about 30 %, resulting in a fuel saving of up to 17 %. The emissions also lie approximately 20 % lower than the values given in the pertinent EU standard.

In terms of flexibility, jointed-arm robots are far superior to the specialized, almost 'rigid' automatic production machines that were installed in the 1980s. This superiority is largely due to the fast pace at which robot technology has progressed in the meantime. Over the last ten years or so, computer-controlled robotic systems have developed increasingly into a high-quality, moderately priced 'standard' component for such applications.

Flexible and economic robotic systems

Modern robots are not only faster than their predecessors. Their load-handling capacity of up to 180 kg is also considerably larger, as is their work envelope, which has been increased from 4 to 5 m. New, innovative controllers have also drastically improved the precision with which they work. Assembly operations that require an accuracy down to 1/10 mm and less at speeds of 2 m/s can be mastered today without difficulty.

The economy of jointed-arm robots has risen significantly and their availability stands today at almost 100 %. Prices have dropped by half over the past ten years. Also, robotized automation systems are easily expanded and adapted to new requirements; all that is needed when new product variants are added is reprogramming of the software.

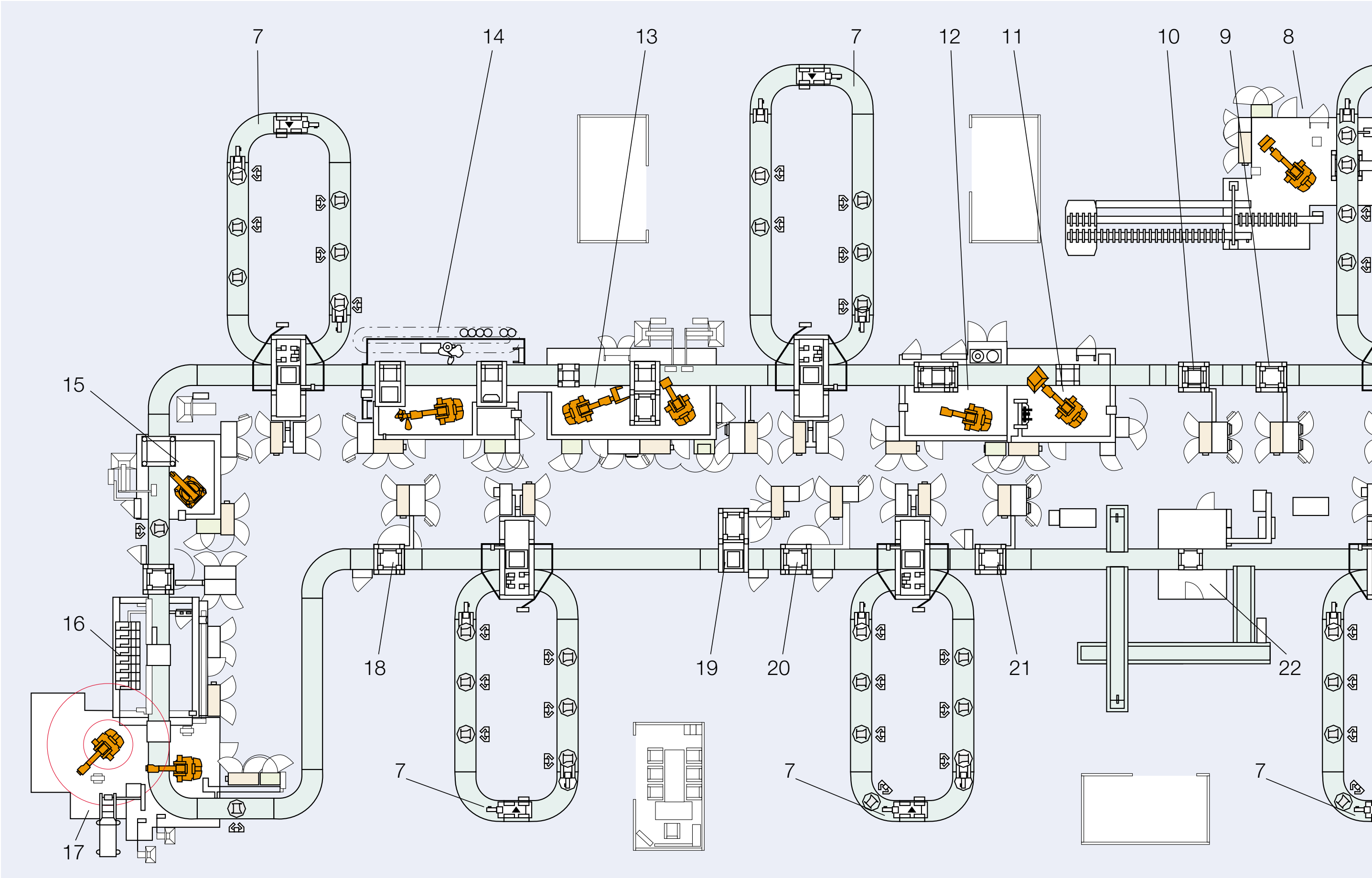
Integration of modular automation components

Additional automation components, such as programmable controls, production control systems, modular workpiece transport systems and state-of-the-art drive, measuring and test technology, can also be integrated. Innovative, customized systems can therefore be built which offer far better quality, availability, productivity and cost-effectiveness than conventional automation concepts.

Increasingly, system specialists are taking over the planning and design of such lines. With their extensive know-how and field experience, robot manufacturers have developed into full-fledged suppliers of complete assembly automation systems. ABB Flexible Powertrain Assembly GmbH, acting as a turnkey supplier, works closely with customers in planning, developing and installing robotized assembly lines all over the world.

Standardized control panels support the goal of zero-defect production by providing a uniform operator interface for the plant personnel. **10**

The modular transport system, which is at ground level, is a typical feature of the new, user-friendly and flexible line concept, known as 'Daisy Plus'. **11**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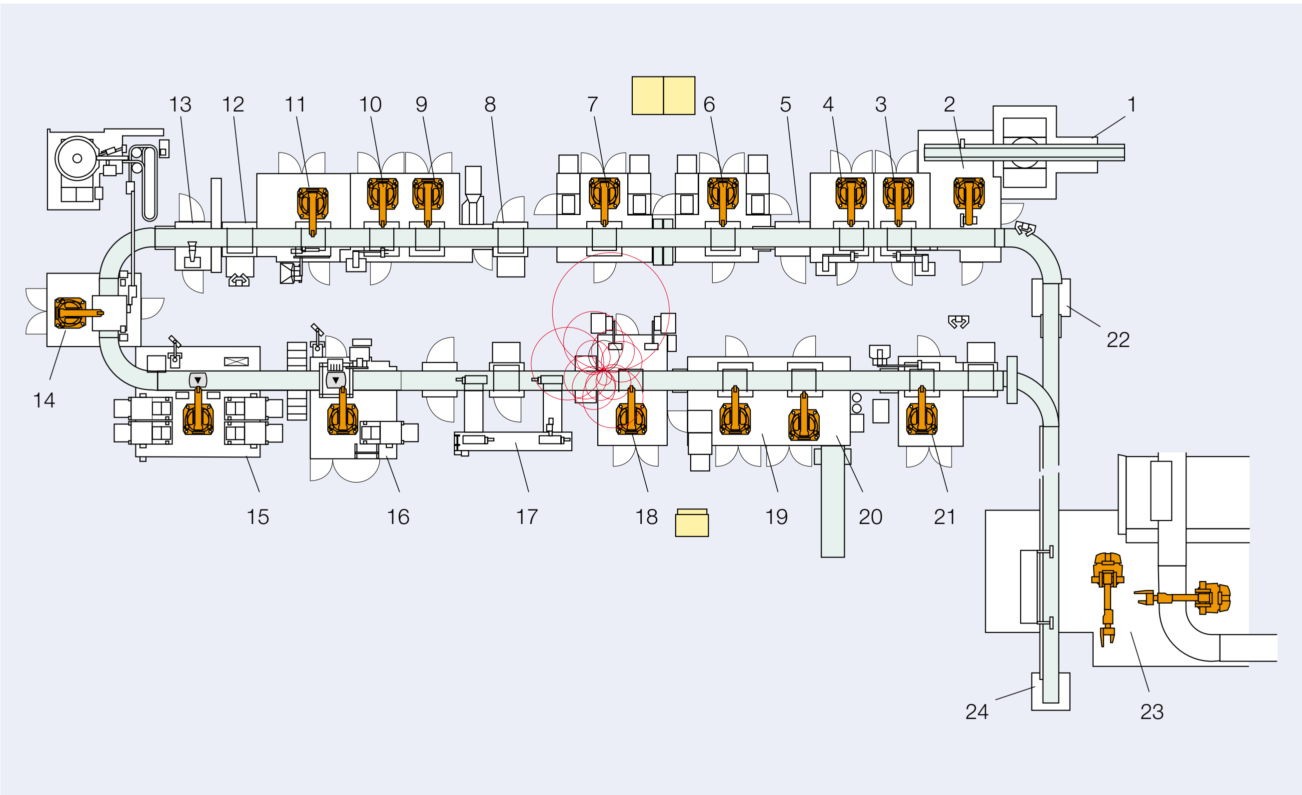
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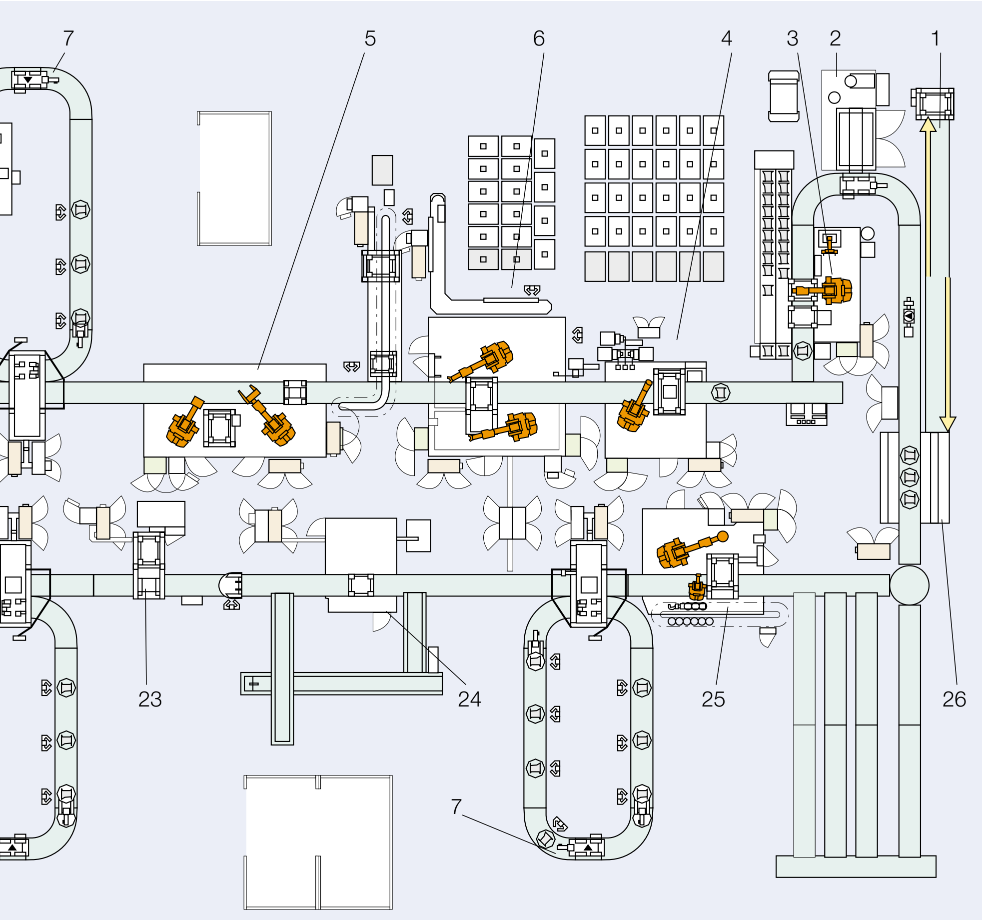

Layout of the engine assembly line at the Opel plant **12**

1 *Buffer test area*
2 *Pallets washed*
3 *Cylinder crankcase loaded on pallet*
4 *Sleeves pressed into cylinder crankcase*
5 *Bearing cover bolts removed and placed with main bearing cover on pallet*
6 *Injection pump fitted*
7 *Team loop: pallets run at constant speed, workers fit parts to moving objects*
8 *Crankshaft placed in position*
9 *Main bearing cover bolts tightened*
10 *Connecting-rod bearing cover bolts tightened*
11 *Piston projection measured*
12 *Needle bearings and radial shaft sealing ring fitted*
13 *End cover bolted in place*
14 *Flywheel fitted and bolted in place*
15 *Oil sump bolted in place*
16 *Engine turned, cylinder head seal fitted*
17 *Cylinder head and bolts fitted*
18 *Cylinder head bolted in place*
19 *Control timing set and central bolt inserted*
20 *Bottom part of intake bolted in place*
21 *Top part of intake and rocker cover bolted in place*
22 *Leakage test*
23 *Engine filled with oil*
24 *Final operating test*
25 *Coupling fitted*
26 *Transfer from assembly line to test area*

Layout of the Opel cylinder head assembly line, with 16 ABB robots and 21 automated stations **13**

1 *Start*
2 *Cylinder head mounted on pallet*
3 *Spring plates fitted*
4 *Valve stem seals fitted*
5 *Cylinder head turned, valve guide lubricated*
6 *Exhaust valve fitted*
7 *Intake valve fitted*
8 *Leakage test*
9 *Valve springs fitted*
10 *Spring plates fitted*
11 *Valve collets fitted*
12 *Laser check of collet assembly*
13 *Unit shaken to remove foreign bodies*
14 *Tappets fitted*
15 *Injection nozzles fitted*
16 *Traverse fitted*
17 *Leakage test*
18 *Inlet/outlet studs fitted*
19 *Valve bridges fitted*
20 *Camshafts fitted*
21 *Heater plug fitted*
22 *Pallet cleaned*
23 *Cylinder head stored*
24 *End*

Optimized combination of manual workplaces and robot stations

A key characteristic of ABB assembly concepts is the substitution of complicated, dedicated machines by modular, flexible automated stations in the form of 'standard machines'. Other special features are independent automated stations, separation of the transport system from the automated stations, and a modular, decentralized control system. Several patents are held by the company for especially complex operations, such as the automated fitting of the valves and tappets. The aim is always to achieve the combination of automated and manual workstations with maximum benefit for the customer **12**, **13**.

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