Success story

Looking back at ABB's contribution to industrial robotics

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Industrial robots are omnipresent in discrete manufacturing across the world: increasing productivity, providing consistent high quality and improving workplace safety. The advancements made during the last 35 years have been significant. Initially, single robots were used for relatively simple and monotonous tasks in hazardous environments. Today, multi-robot synchronized systems are dealing with sophisticated assignments in flexible production cells. ABB has been a prime driver in this rapid development process.

The first industrial robot appeared in 1961 when a Unimate was supplied to General Motors for tending a die-casting machine. The Unimate – the brainchild of Joseph Engelberger, the "Father of the Industrial Robot" – was hydraulically driven, a technology that dominated the fledgling industrial robot business for its first decade. Then, in 1974, the Swedish company ASEA developed the IRB 6, the first all-electric industrial robot. This 6 kg capacity device was unique, not only in the drive system but also in its anthropomorphic configuration and its use of a microprocessor control system. It set new robot standards in the small footprint, the speed of movement and positioning accuracy, and gave rise to a number of IRB 6 look-alikes.

Electric-drive robots opened up new applications not possible with hydraulic machines, in particular arc welding. The first application outside of ASEA was the polishing of stainless steel pipe bends for the food industry at the Swedish company Magnusson. Its first IRB 6 was installed in 1974 1, with further units delivered in 1975 – these were robots that ran virtually nonstop in a dirty environment for over 25 years.

Spot welding continued to be the domain of the hydraulic robot until 1975, when ASEA launched the IRB 60, similar in design to the IRB 6 but with a 60 kg capacity. The first of these was supplied to Saab in Sweden for spot welding car bodies 2. Perhaps the "final nail in the coffin" of the hydraulic robot spot welder was the IRB 90, launched in 1982, which ASEA designed specifically for spot welding. It was a full six-axis device with integrated water, air and current (WAC) supplies built into the arm.

In the 1990s, ABB released its innovative Cartridge Bell System (CBS) for painting car parts, which is now being applied on automotive production lines worldwide.

Robots for painting

Still in the era of the hydraulic robot, a significant event took place in Norway, which later impacted ASEA's robot business. Trallfa, a small agricultural engineering company, was having difficulty in recruiting labor to paint its wheelbarrows and sought a solution through automation – a challenge taken up by a young engineer, Ole Molaug. In 1966, he developed the world's first painting robot driven by hydraulics 3. It differed from the Unimate in that it had continuous path control and programs were created by recording the spray patterns of a skilled painter onto magnetic tape. Initially, this automatic painter was used solely internally but such was its success that Trallfa decided to market it outside the company. Its first sale of the Trallfa TR 2000 was in 1969 to the Swedish company Gustavsberg for enameling standard bathroom installations such as bathtubs and shower trays.

In 1985, Trallfa was acquired by ASEA, and in 1988 – the year ASEA merged with the Swiss company Brown Boveri to form ABB – the company released its first electric drive painting robot, the TR 5000. Prior to this development, hydraulic drives were exclusively used for painting robots due to their intrinsic safety. The TR 5000, however, saw such safety achieved with electric drives, and their inherent benefits of speed, accuracy and electronic controls were brought to the painting process.

3 Early version of the Trallfa paint robot from 1969

1 In 1974, Magnusson AB became ASEA's first external robot customer. Manager Leif Jönsson together with Lennart Benz of ASEA monitor the installation.

2 The SAAB Model 99 of 1975 was an early spot-welding application.
Photo courtesy of SAAB

PERPETUAL PIONEERING

Later, in the 1990s, ABB released its innovative Cartridge Bell System (CBS) for painting car parts, which is now being applied on automotive production lines worldwide [1]. The system utilizes easily replaced paint cartridges to reduce paint and solvent waste, thereby cutting costs and reducing emissions, while at the same time offering a wider choice in paint colors.

Addressing the pollution created by the painting process, ABB continued to introduce innovative new technologies that dramatically reduced the human activity in polluted areas by enabling a fully robotized process [2].

For high-end automotive applications, the unique design and configuration of the wall-mounted FlexPainter IRB 5500 has created the largest and most flexible robot working envelope of any exterior car-body painting robot 4. It takes two FlexPainter IRB 5500s to handle jobs that up until now have required four paint robots. The results are lower cost – both initially and in the long run – faster installation, high uptime, improved reliability and greater energy efficiency.

4 The FlexPainter IRB 5500

5 The IRB 6000 with its modular design concept was introduced in 1991 and became ABB's best-selling spot-welding robot.

The most recent addition to the range of painting robots is the IRB 52, an all-new compact painting specialist, designed specifically for painting small- and medium-sized parts for a wide range of industries. It provides an affordable, high-quality painting solution. Included in the paint function package is the Integrated Process System (IPS), which includes color change valves and air and paint regulation. This unique combination guarantees high-quality, accurate and consistent paint process control.

Evolution of robot mechanics

Such was the elegance of the IRB 6 design that its basic anthropomorphic kinematics with rotary joint movements can be seen in today's range of ABB robots. What has changed over the years is the speed, accuracy and space efficiency with larger working envelopes and more compact footprints.

ABB's first major advance in robot mechanics after the IRB 6 was the 10 kg capacity IRB 2000 launched by ASEA in 1986. In this second-generation design, backlash-free gearboxes replaced ball screw drives for the "hip" and "shoulder" axes, resulting in better space kinematics. But the other significant change was the switch from direct-current (DC) to alternating-current (AC) drive motors. AC motors deliver higher torques, are physically smaller than DC motors, are brushless and consequently easier to maintain, and have a longer life – features demanded by industrial users, particularly car manufacturers.

Flexibility and adaptability are features constantly called for by industrial robot users, and in 1991, ABB met these demands head-on with the heavy-duty (150 kg capacity) IRB 6000 5. Aimed primarily at spot welding and large component handling, the IRB 6000 was built on a modular concept with a range of base, arm and wrist modules so that it could be optimized for each user's needs. The IRB 6000 was also highly cost competitive through its lean design with 60 percent fewer parts than the IRB 90. It was ABB's most successful spot-welding robot with many large multi-robot orders from leading car manufacturers.

In 2007, the IRB 6620 made its debut. This dedicated spot-welding robot is light and compact – so small, in fact, that two of these robots can fill the space of its predecessor, the IRB 6600 [3,4]. The IRB 6620 has a payload of 150 kg and a robust wrist design capable of handling typical integrated-transformer spot-weld guns. The tool-mounting flange conforms to ISO standards for 200 kg and the robot comes with a dress package especially designed for spot welding. The robot is easier to install, has a lower investment cost and a wide working range. The concept of the robot specialist is beginning to take ground, offering more flexibility and economical solutions in industry.

ABB continues to develop its range of "power robots" based on a common design platform and has recently added a shelf-mounted variant (the IRB 6650S), extended payload versions of up to 235 kg capacity and IRB 6600 robots dedicated to press tending and pre-machining 6.

High-speed robots

While the anthropomorphic arm has dominated the scene for over 30 years, there are some high-speed small-part assembly and product-picking applications where the design is limited and other configurations have emerged.

One of the most successful designs was the SCARA (Selective Compliant Assembly Robot Arm), developed by Professor Hiroshi Makino at Yamanashi University and launched commercially by several Japanese robot manufacturers in 1981. ASEA introduced its own SCARA, the IRB 300, in 1987.

In 1984, ASEA developed what was believed to be the world's fastest assembly robot, the IRB 1000, which had a "pendulum" configuration with the arm suspended from a pivot. The arm's moving masses were concentrated at the pivot, minimizing the moments of inertia and resulting in accelerations of 2G within a working envelope much larger than possible with a SCARA.

But even these robots were not fast enough for online picking operations in such as the electronics and food industries. To meet this demand, ABB introduced the IRB 340 FlexPicker robot in 1998. Based on the Delta robot conceived by Professor Raymond Clavel at Ecole Polytechnique Fédérale de Lausanne (EPFL) in Switzerland, the FlexPicker is capable of 10G acceleration and 150 picks-per-minute cycle times, matching human operators in both speed and versatility when handling small items, such as electronic components and chocolates 7.

The development of the FlexPicker has been a key research and development focus, and in 2008, ABB will introduce the world's first second-generation high-speed picking robot, the IRB 360. The new robot features a higher payload and smaller footprint, and when combined with PickMaster software and the IRC 5 robot controller, this new robot system will further improve productivity and flexibility in packing operations.

Advances in control systems

While mainstream robot kinematics has continued on an evolutionary path, the control systems, operator interfaces – including human-machine interfaces (HMIs) – and software have changed beyond recognition. The control system for the IRB 6 developed in 1974, later designated the S1 and very advanced for its time, had just a single 8 bit Intel 8008 microprocessor, an HMI with a four-digit LED readout and 12 punch buttons, and rudimentary software for axis interpolation and movement control. The robot required specialist knowledge to program and operate.

The first breakthrough in setup and programming came with the S2 introduced in 1981. Based on two Motorola 68000 microprocessors, the S2's HMI or "teach pendant" incorporated a joystick for intuitive jogging and positioning of the robot axes. Also introduced were the concept of the tool center point (TCP) and a new programming language, ARLA (ASEA robot programming language). These features enabled easier and quicker programming and setup for both experienced and untrained robot users.

Other new software for the S2 included limited process software such as arc-welding functions and built-in weld timers for spot welding, and a kinematics model of the robot arm. The latter exploited in the IRB 6000 enabled the robot to gain a level of performance not limited by the physical stiffness of the physical structure, and was ABB's first step along the road to the complete dynamic and kinematics modeling available in today's products.

A dramatic advance in robot control was the IRC 5 control system, which could simultaneously control up to 36 axes through a new function, MultiMove.

The S3 control unit introduced in 1986 differed from the S2 mainly in its switch to AC drives, such as for the IRB 2000 series. The next big change came with the S4, launched in 1992 and which many at ABB regarded as big an advance as the introduction of the IRB 6 and S1. Over 150 man-years went into developing the multi-microprocessor S4, which could control six external axes, all welding parameters as well as the robot's own six axes.

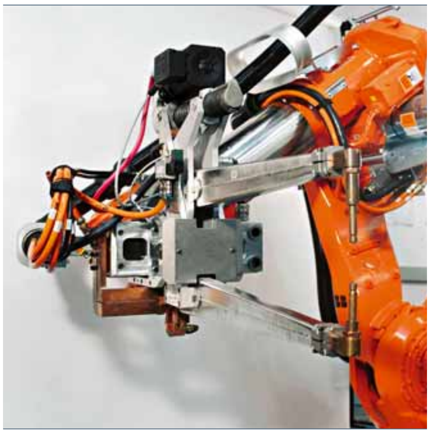
The S4 controller was designed to improve two areas of critical importance to the user: the man-machine interface and the robot's technical performance. A vital key to the former was the Windows-style teach pendant. It was the same familiar environment as used in PCs with dropdown menus and dialogue boxes, so that setup and operation of the robot was simplified. At the same time, programming was made easier through a new, open multi-level programming language, RAPID, with the flexibility to develop or adapt functions to meet each user's specific needs.

Dynamic modeling

The concept employed by ABB to improve robot performance with the S4 was "motion control," using smart software functions rather than purely increasing mechanical performance. The foundation of this motion control is a complete dynamic model of the robot held in the S4 and is the basis of QuickMove, a function in which the maximum acceleration in any move is determined and used on at least one axis so that the end position is reached in the shortest time. As a result, cycle time is minimized and is not dependent purely on axis speeds.

Another feature emanating from dynamic modeling is minimal deviation from the programmed path, which is applied in TrueMove. This function ensures the motion path followed is the same whatever the speed and obviates the need for "path tuning" when speed parameters are adjusted online.

6 Holding a spot-welding gun



7 The FlexPicker in action

But once again ABB has not rested on its laurels and has continued to develop and improve its motion control technologies. ABB robot users can now benefit from even faster cycle times and greater precision with the introduction of ABB's next generation of motion control technology. The second-generation versions of ABB's QuickMove and TrueMove technology help users achieve up to 50 percent better path performance and a 20 percent reduction in cycle times without compromising quality. Featuring enhanced control algorithms, QuickMove and TrueMove offer even greater accuracy at high speeds. ABB robots can now outpace competitor cycle times by as much as 30 percent.

FlexFinishing and Force Control

Another recent leap forward in robot applications is ABB's development of a FlexFinishing system featuring RobotWare Machining FC (force control) for delicate operations – specifically, for grinding, deburring and polishing castings [5]. The unique robot application, launched in 2007, combines five innovative elements:

- Use of the latest ABB robot controller, IRC 5, with its high-speed sensor interface
- A programming environment that allows the robot to find the optimum path itself
- A feedback loop to control the pressure of the tool
- A feedback loop to adjust the speed of the tool
- An easy-to-use, pre-engineered product offer

The application allows simple and efficient programming by using the force sensor to define the trajectory for the robot movement – the operator simply moves the robot by hand to teach it the rough path. The robot automatically follows the part, recording the exact path and generating a robot program. The application comprises advanced sensor signal processing, mathematics, logic solution and a graphical user interface for quick, intuitive and accurate hands-on programming.

This innovative approach not only improves the quality of the finished parts, but it also reduces overall programming time by up to 80 percent, reduces the cycle time of the robot by 20 percent and extends the lifetime of the grinding tools by 20 percent.

Next generation robot safety

To ensure the safety of people working with industrial robots, humans and robots were traditionally separated by fences, and expensive safety equipment was necessary [6]. In 2007, ABB made it possible to replace this costly safeguarding equipment with SafeMove, which features independent, compact, efficient and reconfigurable electronic motion safety technology.

SafeMove is an independent computer housed in the cabinet of ABB's fifth-generation industrial robot controller, the IRC 5, and allows the reliable, fault-tolerant monitoring of robot speed and position, and the detection of any unwanted or suspicious deviation from the norm. If a safety hazard is detected, SafeMove executes an emergency stop, halting the robot within fractions of a second. SafeMove offers functions such as electronic position switches, programmable safe zones, safe speed limits, safe standstill positions and an automatic brake test, which allows more flexible safety setups. The result: Robots and humans can collaborate and work safely and efficiently side by side.

In 2008, ABB will introduce the world's first second-generation high-speed picking robot, the IRB 360.

Coordinated multi-robot control

A further dramatic advance in robot control was made by ABB in 2004 when it launched the fifth-generation IRC 5 control system. An outstanding feature of IRC 5 is its ability to simultaneously control up to four ABB robots plus work positioners or other servo devices – a total of 36 axes – in fully coordinated operation through a new function, MultiMove.

Controlling up to four robots from a single controller minimizes installation costs and brings quality and productivity benefits. It also opens up completely new application possibilities: Two arc-welding robots can work in tandem on the same workpiece and deliver even heat input and eliminate distortion due to shrinkage on cooling; several robots can in concert handle a single flimsy workpiece to prevent bending; and two or more robots can lift a load larger than the capacity of the one robot.

In seeking a lean solution for robot control, ABB developed a modular

concept for IRC 5 8, in which functions are logically split into control, axis drives and process modules, each housed in identical standard "footprint" cabinets. These may be stacked, placed alongside each other or distributed up to 75 m apart. Installation is made even simpler by the two-cable link between modules, one carrying safety and the other Ethernet communications. The modular arrangement also means the system may be cost-effectively specified to match the customer's immediate, exact needs, while still readily expandable to meet future demands.

In 2007, the modularity of the robot controller was further extended by the introduction of the Panel Mount variant. The new version is supplied in chassis form for mounting in the user's or machine builder's own control panel. This configuration makes it easy to meet special requirements such as hygienic systems with stainless steel enclosures, and systems that can withstand washdown cleaning. Providing all the functionality of the existing fully enclosed controllers, the new models are just 250 mm deep, thus saving both space and energy.

Intelligent operator interface

Although complex, setting up and operating a multi-robot cell with fully coordinated motions was made easier with FlexPendant, the world's first open robot operator interface unit, developed for the IRC 5[1]. The joystick is retained not just for jogging each robot but also for manipulating all four robots as a single entity in synchronism, a feature unique to ABB.

FlexPendant has its own computing power with open-system PC architecture. It set new standards in ease of use and flexibility of operation with a full-color touch screen, on which are displayed Windows-style menu-driven pages. Pages with familiar icons and graphics are available for different user levels, and new ones may be created to suit a user's needs and applications. FlexPendant simplifies all aspects of robot cell operation, from setup and program loading through process development and cell operation to reporting and servicing.

Virtual robot technology

In 1994, when ABB brought out the S4 controller, it also introduced Virtual Robot™ Technology, a unique concept in which simulation of a robot system on a PC utilizes code similar to that which drives the real physical robot. In 2004, the second-generation Virtual Robot™ was launched alongside the IRC 5. In this version, even more controller code is simulated, so there is total transparency between the virtual controller and the real IRC 5 controller. Consequently, programs developed offline are accurate and run "first time, every time," helping to reduce lead times and setup costs.

With this technology at its core, ABB introduced RobotStudio to achieve true offline programming and customization. RobotStudio utilizes Visual Studio Tools for Applications® technology, which is used in conjunction with the actual robot system software controls for robot simulation. This way ABB reduces risk by visualizing, simulating and testing robotic solutions without interrupting production. Optimization of robot programs increases productivity and generates higher part quality and output, thereby maximizing the profitability of robot systems.

Standardized manufacturing cells

Answering the demand of manufacturers to offer more choice and lower production costs, ABB developed FlexLean, a solution that makes robot cells more adaptable, easier to install and more economic on space [7].

FlexLean, launched in 2006, is built upon the "FlexiBase" principle, which offers a compact modular robot cell in which the robots, controllers and cabling are pre-mounted on a platform. At the heart of the FlexLean concept lies the recognition that customized solutions, multiple technical specifications and dedicated software are major causes of costs and engineering uncertainty. FlexLean offers automotive manufacturers both geometrical assembly and respot[2] cells that come

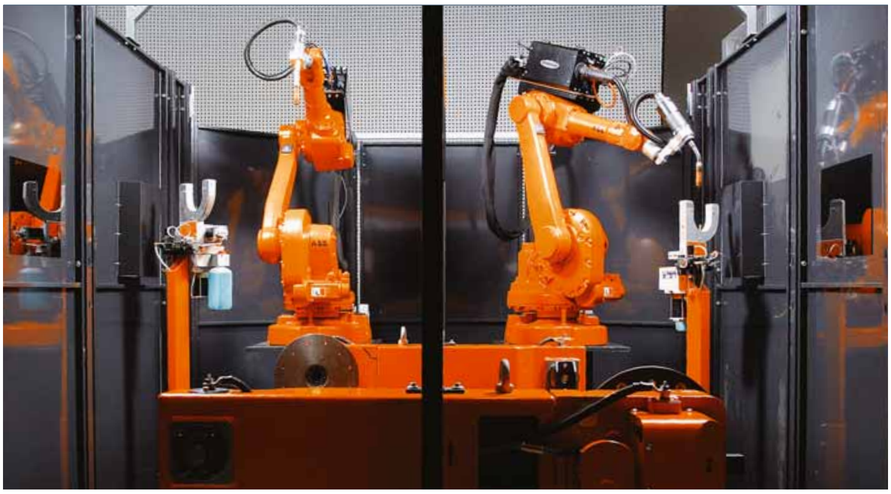
Footnotes

[1] See also **Brorsson, I., Sjöberg, R., Liberg, A.** Do-it-yourself robotics. *ABB Review* 2/2006, 58–61.

[2] Respot is the process providing the final weld after initial welds are used to hold the parts in position.

8 The modular controller IRC 5 has the capability to control multi-robot applications.

9 A FlexArc® cell with two robots working together



with a choice of pre-defined configurations and a broad range of robotic products. This robot technology and standardization results in cells that can produce so cost-efficiently that they can compete with manual labor in low-cost countries.

Another addition to the range of standardized cells is FlexArc® – a complete arc-welding package 9. It includes all the components necessary for robotic arc welding: robots, the IRC 5 robot control system supporting the coordination of multiple robots, positioners, and welding equipment. Customers can choose between several single- or multi-robot production solutions. All internal cables have been routed and connected in the factory. Again, all cell components are mounted on a common base, eliminating the need for on-site engineering work. Software has been pre-configured for simple setup and operation. The customer must simply unwrap the package, place the cell in the desired location, connect the power cable, air pressure and shielding gas, program the robot (or download a program from RobotStudio, ABB's offline programming system) and start production. As a packaged solution, a FlexArc® cell can be moved within or between different production facilities. This allows engineers to design highly flexible plant layouts that meet today's demands for rapid changeovers.

Remote service

With ABB's installed base of more than 160,000 robots, reduced performance or problems with the robots can significantly impact production [8]. When a service engineer has to travel to the robot's site to assess the problem, time and money are lost. But with ABB's remote service technologies, developed in 2007, equipment downtime and on-site maintenance efforts are significantly reduced.

The technology is embedded in the robot controller and reads the internal data, sending it directly to a remote service center, where the data is automatically analyzed. By accessing all relevant information on the robot conditions, the support expert can remotely identify the cause of a failure and provide fast support to the end user to restart the system. Many issues can hence be solved without traveling, thereby saving energy and reducing emissions. Where field intervention is necessary, the resolution at the site is rapid and minimal, supported by the remote diagnostics system. The automatic analysis not only gives an alert when a failure with the robot occurs, but also predicts a difficulty that may present itself in the future. At any time and from anywhere, a user can verify robot status and access important maintenance information about that robot system by logging into ABB's MyRobot Web page.

Since ASEA presented the first all-electric microprocessor-controlled robot in 1974, industrial robotics has advanced beyond all recognition. ABB has continued its pioneering developments, culminating in today's comprehensive range of industrial robots, robot controllers and associated software. In the intervening 30-some years, positioning accuracies have improved from 1 mm to 10 microns, user interfaces from a 4-digit LED readout to a full Windows touch-screen display and computing power from 8 kb to 20 GB or more. At the same time, reliability has increased to 80,000 hours MTBF (mean time between failures) and costs have plummeted so that today, the robot price is half in actual terms than it was just 15 years ago. The world of the industrial robot is well past its early dawn.

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