KUKA Systems | Portfolio

- **Aerospace**
  - Devices and equipment for structural components
  - Automated solutions for various process steps
  - Technology bricks as Drilling & Fastening, Sealing, Painting, etc.

- **Automotive**
  - Body Structures
  - Bonding Technology
  - Assembly & Test
  - Production Operations

- **Advanced Technology Solutions**
  - System solutions based on LBR iiwa
  - Location-flexible process stations with human-robot collaboration
Robots
- Small robots
- Small payloads
- Medium payloads
- High payloads
- Heavy duty
- Special models
- Sensitive robotics with the LBR iiwa

Software
- Controls
- Application modules
- Customer Service

Omnimove
KUKA Industries | Portfolio

- **Arc & Laser Solutions**
  - Welding cells and lines, arc and laser welding technologies and laser cutting

- **Casting Solutions**
  - Production solutions for the casting industry with presses, cells and lines

- **Advanced Welding Solutions**
  - Machines and robot-based solutions for friction and magnetarc welding joints

- **Technology Solutions**
  - Solutions for the manufacturing in the battery and solar industries

- **Customer Service und Technology Services**
  - Service, spare parts and technology consulting
- **Warehouse & Distribution Solutions**
  - Storage and retrieval machines for pallet and small-part high-bay warehouses
  - Warehouse systems: from small parts to single items to pallets

- **Healthcare Solutions**
  - Automated material transport (hospital pneumatic tube system)
  - Driverless container transportation systems
  - Automated solutions for hospital pharmacies
  - Automation in patient care sector (medication management)
Outlook | KUKA 2020

Sales revenue € 2.1 bn
12,102 Employees (incl. Swisslog)
2014

KUKA Aerospace
New Markets
China

New Products / Industry 4.0
Swisslog / E-Commerce

Growth ~100%

Sales revenue € 4 - 4.5 bn
2020
Megatrends | Changes to the Global Society

**Economic**
- Globalization
- **Flexibility and Versatility**
- Transport and logistics
- Value chain
- **Market, customer and consumption**

**Social**
- Demographic Change
- Urbanization
- Mobility
- Education, knowledge and work
- **Health and safety for employees**

**Ecological**
- Resource availability
- **Climate protection, sustainability**

**Technological**
- **Digitalization of the Manufacturing Industry**
  - Big Data, Internet of Things/M2M, Cloud Technology
  - Digitalization and knowledge management
  - Usability, next-level GUIs
  - Advanced Robotics (e.g. Human-Robot Collaboration), additive manufacturing (e.g. 3D print)
- Industry meets IT
- New materials and lightweight construction
- Medicine and healthcare

**Industry 4.0**
“Industry meets IT”
Connect components, systems and data of different systems with each other

Standardized Interfaces based on mainstream IT

Robots enable humans to network in the digital world

Intelligent robot systems support humans in the factory of the future

Sensitive and safe robot-based automation solutions (LBR iiwa)

Human in the Focus

“Industry meets IT”
Connect components, systems and data of different systems with each other

Standardized Interfaces based on mainstream IT

Robots enable humans to network in the digital world

Intelligent robot systems support humans in the factory of the future

Sensitive and safe robot-based automation solutions (LBR iiwa)

Human in the Focus
Smart Factory | We focus on three main Points

1. Human-Robot Collaboration
   - Demographic Change
   - Versatile Production

2. Intelligent control concepts enable the Connection to the IT—“Smart Platforms”
   - Digitalization of the Manufacturing Industry

3. Mobility
   - Holistic Concept for Logistics & Production
Social Change | Demographic Change leads to Changes in the Structure of Employment

Average age of workforce in 2014: ~ 50 years

@ VW more than 30k people will retire in the next 10 years and cannot easily be replaced

Example: Age structure VW Germany, total staff 2014

Total staff: 256k  green area: ~ 30k
Fourth Robotic Revolution | Next “Generation R”

Generation R – Dealing with Robots is just as natural as dealing with Smartphones for us today

First robotic revolution: Robot-based automation solutions

Second robotic revolution: Sensitive and safe robot-based automation solutions

Third robotic revolution: Mobile, sensitive and safe robot-based automation solutions

Fourth robotic revolution: Cognitive, mobile, sensitive and safe robot-based automation solutions

Innovation
Leverage of Automation | Human and Robot work Hand in Hand

Level of Automation

Manual Production | Human-Robot Collaboration | Full Automation

1. Human-Robot Collaboration

Leverage of Automation | Human and Robot work Hand in Hand
Smart Factory | We focus on three main Points

1. Human-Robot Collaboration
   - Demographic Change
   - Versatile Production

2. Intelligent control concepts enable the Connection to the IT – “Smart Platforms”
   - Digitalization of the Manufacturing Industry

3. Mobility
   - Holistic Concept for Logistics & Production
2. Software | Connection to the IT world

[+] Mainstream IT & standardized Interfaces

[+] Human-Robot Collaboration

[+] Flexible automation with mobile and autonomous robots

[+] Sensor-based applications for Smart Solutions

[+] Multi-kinematics for robot systems
Communication | Evolution of Networking

Human 2 Human

Human 2 Machine

Machine 2 Machine

→ Leads to new Eco Systems
Smart Factory | We focus on three main Points

1. Human-Robot Collaboration
   - Demographic Change
   - Versatile Production

2. Intelligent control concepts enable the Connection to the IT – “Smart Platforms”
   - Digitalization of the Manufacturing Industry

3. Mobility
   - Holistic Concept for Logistics & Production
3. 

- Transformation of logistics know-how from warehousing and distribution to production logistics
- Gripping and handling concepts with the LBR iiwa
- Warehouse systems are completely independent of the order size
- Bottlenecks are reported automatically, projection based on empirical data
- Intelligent combination of automation and logistics know-how for an integrated production solution
- Flexible and versatile equipment for material handling
Smart Factory in Automotive | Matrix Body Shop
Smart combination of Automatization and Logistics for handling and production
Versatile and flexible equipment leads to a flexible and scalable production
Re-usable assets → MFEE (Multi Functional End Effector, MRP Mobile Robotic Platform, Omnimove)
Industry 4.0 | Software and Hardware Solutions required

- Software Solutions
  - Energy Efficiency Tool
  - Simulation of Material Flow
  - Unit Price Optimization

- KUKA Mobil Robot Platform MRP

- KUKA Multi-Functional End Effector MFEE

- KUKA Mobil Robot Platform MRP
Outlook | KUKA sets Trends in Automation
Introduction

Process description

- Plunging in
- Wellig
- Welding
- Retracting

Friction heat is generated

Source: iwb, TU Munich
Introduction

FSW Technology Landscape

Material Universe
- All kinds of Aluminum (Al) alloys
- Al + Fe
- Al + Ti
- Al + Mg
- Mg + Mg
- Polymer based Thermoplastics

Welding Depth
- Milling/Gantry Machines: 0.3mm to 100mm
- Robot: 0.3mm to 8mm (extended from 8mm to 15 mm)

Machines
- Robots
- CNC Milling Machines
- Gantry Machines

Current User Markets
- Auto (OEM + Suppliers)
- Aerospace
- Rail (Metro Transport)
- Shipbuilding
- Extrusions
- Wind Energy
- Consumer electronics
- Medical Equipment..... & many more

source: Airbus-IW
Introduction – FSW Application

welding of fuselage of the Eclipse 500 Business Jet

structural component of the McLaren 12 C
(source: McLaren)

structural component of the Panoz Esperante
(source: Friction Stir Link)
Introduction – Application fields

shipbuilding  (HSC Gotland Ferry)  (source: Internet)

Electronic components manufacturing

railway manufacturing  Shinkansen  (source: Internet-Hitachi)
Relevant machines for FSW

German Engineering. Since 1898.

KUKA. The key figures.

KUKA YOUR IDEAS.

Sustainability. An integral feature of our corporate culture.

KUKA. Diversity & flexibility.
Different machine concepts suitable for FSW

- **Special FSW machines**
  - Source: ESAB

- **CNC milling machines**
  - Source: Heller

- **Parallelkinematic Systems (Tripods, Hexapods)**
  - Source: Airbus-IW/KUKA

- **Articulated arm robots**

Relevant machine types for FSW
### Comparison

<table>
<thead>
<tr>
<th></th>
<th>FSW Machine</th>
<th>Milling Machine</th>
<th>Parallel-Kinematics</th>
<th>Articulated Arm Robot</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>▶</td>
<td>▶</td>
<td>▶</td>
<td>▶</td>
</tr>
<tr>
<td>Stiffness</td>
<td>▶</td>
<td>▶</td>
<td>▶</td>
<td>▶</td>
</tr>
<tr>
<td>Space Requirement</td>
<td>▶</td>
<td>▶</td>
<td>▶</td>
<td>▶</td>
</tr>
<tr>
<td>Working Area</td>
<td>▶</td>
<td>▶</td>
<td>▶</td>
<td>▶</td>
</tr>
<tr>
<td>3D-Capability</td>
<td>▶</td>
<td>▶</td>
<td>▶</td>
<td>▶</td>
</tr>
<tr>
<td>Welding Depth</td>
<td>▶</td>
<td>▶</td>
<td>▶</td>
<td>▶</td>
</tr>
<tr>
<td>Invest</td>
<td>▶</td>
<td>▶</td>
<td>▶</td>
<td>▶</td>
</tr>
</tbody>
</table>

![Source: iwb, TU Munich]

1*) → Articulated arm robots represent a flexible tool, which are suited for FSW on thin profiles (tested from 0.3 mm to 8 mm Al alloy, 2xxx, 5xxx, 6xxx, 7xxx).
Available FSW Platforms

**Parallel Kinematic Machines**

**Advantages**
- high payload & stiffness
- accuracy
- 3D-capability

**Limitations**
- cost
- workspace

**Gantry-Type FSW Machines**

**Advantages**
- high payload & stiffness
- accuracy
- workspace

**Limitations**
- cost
- non reconfigurable

**Modified Machining Centres**

**Advantages**
- low cost
- high payload & stiffness
- accuracy

**Limitations**
- workspace

**Serial Industrial Robots**

**Advantages**
- low cost
- payload
- 3D-capability/workspace
- reconfigurable

**Limitations**
- stiffness
- low dynamics

Source: Eclipse Aviation
Source: MAKINO
Source: CNRC

Flexible Automation in Aerospace
KUKA Group | Otto Kellenberger | April, 2016 | Page 31
Today 
Heute

Future 
Zukunft

Source: ZLP Nord-Süd, DLR
History of RoboFSW

Start 2003 -> request from SAPA

2004 / July  -> request from EADS

2005 / Feb   -> Consortium
       - Airbus, EADS
       - iwb, KUKA Roboter

2007-> order for electrical spindel
       and new robot to CNRC Montreal
       also to BMW

2008       -> finish Airbus project
2009       -> FSW robot to AUDI
2010       -> Eurocopter + LTH (casting)
2011       -> electronic ind.
2012       -> electronic ind.
2013       -> automotive (Daimler)
2014       -> railway (Hitachi), aero (ShinMaywa)
2015       -> aero
Capability of a high payload articulated arm robot

The „RoboFSW“ consortium for evaluation (2004)

At the beginning
Initial - classic FSW system (2004)

Robot
• KUKA KR500
• modified to realize higher process forces – KR 500MT

Welding head
• hydraulically driven
• rotation speed up to 2800 rpm

Process forces
• force sensor between flange and welding head
• process force controlled without any additional axes

Source: AIRBUS –IW Laboratory
Capability of a high payload articulated arm robot

**Force controlled welding mode without additional axes**

![Graph](image)

- **Fx**
- **Fy**
- **Fz**
- Axial tool position

**plunge in phase**
**welding phase**

Source: iwbiAirbus - IW
Capability of a high payload articulated arm robot compared with other FSW Machines (Heller and ESAB)

Without Quality difference between the machines - Benchmark:
- modified milling machine
- KUKA articulated arm
- esab FSW laboratory machine

Source: iwb / Airbus-IW
Results - capability of the robot welds

Properties of resulting Butt joints

2,3-mm 2024-T3 Butt weld

Properties of resulting Lap joints

1,6-mm 7075-T6 stringer on 2,3-mm 2024-T3 skin

- Equivalent cross sections were observed for Butt and Lap welds
- Good correlation between tensile properties of robotically-welded butt welds compared to FSW machine


Push button for more weld examples
Results - capability of KUKA robot

Engine currents at different loads
(most loaded engine, medium range)

→ process forces of up to 10 kN can be achieved in every basic end-effector orientation (in defined Positions of robot work room more Process forces; on request scalable up to 18 KN)

source: iwb / Airbus-IW
Actual classic FSW system package

1. KUKA KR 500-3 MT
2. KUKA KRC4 8.2
3. Integrated spindle drive as 7th axis of the robot control cabinet KRC4
4. Spindle (~45Nm, 3500-5000 rpm)
5. Technology cabinet
   - Hydraulic unit
   - Spindle coolant unit
   - Safety PLC (Siemens ET200s F-CPU)
   - Interface for customer cell
6. Energy supply including K-Box

Picture: KUKA ROBOTER
Development \(\rightarrow\) success

First robot solution 2004

Solution 2015

Innovation Award