The European Robot Initiative for Strengthening the Competitiveness of SMEs in Manufacturing

Physically harmless and low-cost kinematics
Why Physically harmless Robots?

Human Robot Collaboration:

- Mixed manual/robot manuf.
- Fenceless installations
- Programming by demonstration
- Interactive failure handling
- Robots learning by experience
- Assistant robot tasks
- Mobile robot tasks
Human Robot Collaboration: New Large Work Space PKM Concept
Productive Manufacturing

SME-manufacturing applications

- Arc welding
- Spot welding
- Laser welding
- Gluing
- Painting
- Water Jet cutting
- Plasma cutting
- Laser cutting
- Mechanical cutting
- Glass cutting
- Grinding
- Polishing
- Deburring
- Drilling
- Riveting
- Fettling
- Cleaning
- Milling
- Machine tending
- Pick and place
- Palletizing
- Material handling
- Assembly
- Disassembly
- Measurement
- Food handling
- Food processing

SME-manufacturing branches

- Metal
- Wood
- Rubber
- Plastics
- Glass
- Foundry
- Furniture
- Food
- Scrap handling
Physically harmless and low-cost kinematics

Use Cases and Requirements for novel Robot Designs for Flexible Manufacturing

- New kinematics Design
- Novel high Density Drives
- New Force/Torque Sensors
- Variable Stiffness Joint
- Test-beds and Realizations
Use Cases Fettling in SME Steel Foundry

- Loading
  - Cutting
    - Grinding
      - Deflashing
        - Unloading
Requirements from End User

- Cell construction to be able to be readily introduced into a foundry area
- A need for a robust construction which will withstand the presence of foundry ‘dust’
- It is likely that cells would be constructed to achieve individual activities, i.e. burning or fettling rather than multi-tasking
- A need to have teach in shop floor operation with ease of use and flexibility
- Protected from general human interaction during processing, yet access during teach in.
- Ease of loading and removal of parts
- Protection of the robot from and burning or grinding operation
- Ease of repair or replacement for and component parts
- Low requirements for foundations or other civil needs
- Cost effective and general low overall cost
- More accurate processing and cutting - repeatable operations
- Reduction in post cutting operations
- Higher productivity and continuous operation independent of operator
- Improving skill level of operatives
- A turntable with support fixture is required
- The turntable should be capable of being located across the working envelope
- The Cti support fixture needs to be evaluated using the simulation software
- Cable access for the burner needs to be introduced with minimal interference with robot flexibility of operation.
- The robot wrist/fixing plate needs to be designed to allow the easy attachment of the burner and grinder end effectors
- Consideration needs to be given to the ability of the demonstrator to withstand the rigours of a foundry atmosphere, i.e. sliders and dust
- Civil fixings for the component parts of the robot should be normal industrial flooring or similar
- Power requirements should be normal industry practice
- The cell concept should allow ready access for castings by mechanical means, crane or fork lift.
- Adequate protection should be applied to the robot workings to protect from burning and grinding operations.
- Teach in programming is essential for ease of use and rapid operation
- The use of a teach in programming process will automatically avoid the possibility of collision problems.
- Add issues concerning safety for the involved workers!
Requirement from Fettling Processes

- Positional accuracy for cutting 0.5 mm, 50 mrad
- Positional accuracy for deflashing 0.2 mm, 100 mrad
- Force accuracy for grinding +/- 5 N
- Maximum force (disc -> cup grinding) 200 N
- Maximum process speed: 100 mm/sec
- Maximum acceleration: 3 m/s² process, 10 m/s² otherwise
- Calibration time tool: < 3 -> 10 minutes
- Calibration time typical casting: < 5 minutes
- Programming time for typical casting: <10 minutes/process
- Time for education of craftsman: < 3 day
- (Calibration time of CAD models: <5 minutes) Utgår
- Time for automatic compensation of fixturing errors: < 2 minutes
- Loading/unloading the casting.
- Supporting a weight of up to 1.5 tonnes.
- Handling castings within a defined envelope, nominally 1.5m x 1.5m x 1.5m,
- Ability to rotate the casting through 180 degrees.
- Accurate indexing to defined orientations around a vertical axis for fettling and finishing operations.
- Pay off time < 2 – 2.5 years
Summary of Requirements

1. Low cost (Purchase and operational)
2. Easy to use, Teach and run
3. Equal to operator skills of today (No CAD man)
4. Robot and equipment robust in Foundry environment
5. User friendly, SAFE for operator
6. High stiffness and bandwidth
**R&D Team Demonstrator 1 Robot**

**GÜDEL**
- Linear guide ways
- Robot support
- Integration

**ABB**
- PKM robot with wrist
- IRC 5 - robot control
- Programming concept
- Manual guidance

**visual components**
- Simulation tool

**ITIA**
- Virtual Prototyping
- Design optimization

**Fraunhofer**
- Force/Torque Sensor

**Norton Cast Products LTD**
- User know-how
- Casting samples

**University of Coimbra**
- Speech comm.

**Castings Technology International**
- Tooling (Oxy burner and grinder)
- Support unit for casting
- System simulations and integration
- User know-how
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New kinematics Design

Novel high Density Drives

New Force/Torque Sensors

Variable Stiffness Joint

Test-beds and Realizations
Cell- and Robot Simulations

Work Space Design with 3DCreate
Design optimization

Multi Rigid Body Dynamics Simulations

Elastostatics Simulations

FEM Analysis

Elastodynamics Simulations
Benefits with the Kinematics Design

Actuators Fixed to Robot Framework
Only axial forces in 6 links

- Low moving arm mass
- High mechanical bandwidth
- Mechanically not redundant assembly

- High speed, acc. and acc derivative control
- High performance positioning and path tracking control
- High controller stiffness
- High force control performance
- High repeatability and static accuracy
- Fast collision detection and short braking distance
- Low power consumption and low forces
- Improved safety
- No moving cables
- Scalable and modular
- Easy to assemble and disassemble
- Low temp coeff with carbon arms and structure

Patents granted
New Components

- Rack protection system
- Lightweight Joints
- High stiffness roller blocks
- Modular Framework
Modularity
(Linear Actuator)
(High stiffness Roller Block)

Patent granted
Lightweight high stiffness joints
3 DOF
Scalable
Diamond Like Carbon
High precision adaptive machining
Standard ball bearing balls
Kinematics and Calibration
Force Control

Switch -> Added feedback path -> Switch

Switch -> Normal data path -> Switch

IRC5

Lab Prototype
Lund University
Physically harmless and low-cost kinematics

Use Cases and Requirements for novel Robot Designs for Flexible Manufacturing

New kinematics Design

Modular Wrist and Servo Actuator

New Force/Torque Sensors

Variable Stiffness Joint

Test-beds and Realizations
Modular lightweight Wrist
Lightweight Servo Actuator

- Gear Module
- Motor Module
- Harmonic Drive Gear
- Patent pending
- New Brake Concept
- Capacitive Encoder
- 20 poles stator
- Patent granted
Demonstrator 1 Robot: Performance Data

PKM:
Repeatability: 7 / 13 micron
Volumetric accuracy: 150 micron
Lowest eigen frequency: 47 Hz
Stiffness: 2 – 20 N/micron
Arm system weight: 15,8 kg
Max load (mech): 125 kg
Max load (actuators): 40 kg

Linear Actuators:
Stiffness: 200 – 400 N/micron
Actuation force: 600 N

Servo Actuators in wrist:
Weight: 2.3 kg
Speed: 50 rpm
Power: 140 W/kg
Repeated Torque: 70 Nm/kg
Static Torque: 40 Nm/kg

Joints:
Stiffness: 100/200 N/micron, kg

Carbon Tubes (50/40, 100 GPa):
35 N/micron
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Test-beds and Realizations
Force/Torque Sensor

MEMS-structure

(\textit{Micro-Electro-Mechanical System})

Steel Transducer

Tool
MEMS Sensor Chip
MEMS Tests
Force Sensor Spring System
MEMS attachment Tests

Glue performance
Force Sensor Transducer and Electronics

Patents pending
A new single Si-chip based 6DoF F/T-sensor developed
Comparison with commercial expensive sensor show good results
Full demonstrator available
SMEs will benefit from low fabrication costs (mass production)
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Variable Stiffness Joint

Test-beds and Realizations
Human Robot Collaboration: Variable Stiffness Joint
The Variable Stiffness Joint

low stiffness

high stiffness
Active Vibration Damping

**Advantage:** low mechanical damping → low losses

**Disadvantage:** high compliance in VS-Joint!

→ **Solution:** Active vibration damping

No vibration damping  With vibration damping
Human Robot Collaboration: Safety evaluation
New insight: no significant improvement in safety, BUT

1. Large performance increase
2. Protection of the robot joint
“Human-friendly & high performance” joint design for “human-like performance” needs a fundamental paradigm shift!
Performance increase with a VS-Joint

Throwing with a Stiff Joint

Drop Kick
Performance Properties

<table>
<thead>
<tr>
<th></th>
<th>Stiff Joint</th>
<th>VS-Joint</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed</td>
<td>3.06 m/s</td>
<td>6.35 m/s</td>
</tr>
<tr>
<td>Kicking range</td>
<td>1.6 m</td>
<td>4.05 m</td>
</tr>
<tr>
<td>Impact joint torque</td>
<td>85 Nm</td>
<td>10 Nm</td>
</tr>
</tbody>
</table>

higher link speed!  
higher throwing and kicking range!  
much lower impact joint torque!
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Variable Stiffness Joint

Test-beds and Realizations
Test bed: Vertical actuation and Dual Drive
Test bed: Scaling of Robot for WP R5

- Dual motor drive
- New joint supervision concept
- Real Time Java Control
- Microsoft Robotics Studio
- Force Control
- Lead Through
- Platform for Education in Mechatronics

Patent granted
Demonstrator 1 Robot: Lightweight Tool for grinding, slitting and deflashing
Demonstrator 1 Robot: Slitting and Grinding
Demonstrator 1: Process results

Slitting results
Demonstrator 1: Tool for Precision Cutting

Patent granted
Demonstrator 1: Cutting

- Programming with voice commands
- Demonstration: Oxyfuel Cutting
Demonstrator 1: Process results

Oxy-fuel cut feed head stub

After grinding
Demonstrator 1: SME Workshop
Summary

Physically harmless and low-cost kinematics

Güdel
Lund University
ABB
ITIA-CNR
CTI
Fraunhofer ISIT
Univ Coimbra
Visual Component
Noroton Cast
DLR, KUKA

Team

Use Cases
Modular Cell Design
Virtual Prototyping
Modular Robot Design

Linear Actuators
3 DOF Joints
Control
Dual motor drive
Education Robot

Lightweight Servo Actuator
Force Sensor
VS Joint
Slitting and grinding tools
Oxy-fuel burner