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Force Control for Machining Applications
Facts about ABB

- Headquarters: Zurich, Switzerland
- About 109,000 employees in around 100 countries
- Orders in 2006: $28.4 billion
- Revenues in 2006: $24.4 billion
- Listed on Stockholm, Swiss & New York exchanges; traded on virt-x

- A leading power and automation technology company with strong market positions in its core businesses
- Core business organized into 5 divisions; Power Products, Power Systems, Automation Products, Process Automation, and Robotics
What we offer: divisional structure and portfolio

- **Power Products**
  - Sales: $7.4 billion
  - Transformers, high- and medium-voltage switchgear, breakers, automation relays

- **Power Systems**
  - Sales: $4.5 billion
  - Substations, FACTS, HVDC, HVDC Light, power plant & network automation

- **Automation Products**
  - Sales: $6.8 billion
  - Low-voltage products, drives, motors, power electronics, and instrumentation

- **Process Automation**
  - Sales: $5.4 billion
  - Control systems and application-specific automation solutions for process industries

- **Robotics**
  - Sales: $1.3 billion
  - Robots, peripheral devices and modular manufacturing solutions for industry

- Market-leading positions in most key product areas
- Integrated solutions for grid reliability, productivity and energy efficiency
- Robust global value chain to serve established and emerging markets
- Extensive global network of value-added channel partners
Key Facts: ABB Robotics

- About 4600 employees worldwide
- 2006 revenues $1.3 billion

Key Deliverables:
- Industrial robots and software
- Standardized manufacturing cells for material handling, welding, cutting, painting, etc.
- Turnkey solutions in press automation, body-in-white, paint processes, power train assembly
- Product, system and asset services

Customers Served:
- Automotive and Tier 1 suppliers
- General industries such as foundry, metal fabrication, plastics, electronics, consumer

Over 140,000 ABB robots installed worldwide
Contents

- Introduction
- Project objectives, execution and result
- Features, benefits and technical solutions
  - FC Pressure
  - FC SpeedChange
  - Graphical User Interface
- Did we meet our objectives?
- Early adopters
- Availability & Requirements
- Product offer
- Application examples
- Videos
33 years of robotized finishing

“The world’s first electrical robot sold in 1974 was for grinding and polishing of stainless steel tubes.”

ABB was an innovator and has become #1 in robotized finishing

We intend to stay as the leader

IRB 6 sold by ABB in 1974 to Magnusson in Genarp, Sweden
Why is machining not fully robotized?

- Only large batch sizes have been feasible
- Programming time has been far too long to permit frequent product change overs
- Difficult application with many parameters
- Robot arms have not been suitable for all applications

**DEFINITION**

*Machining includes:*
- Grinding
- Deburring
- Polishing & Linishing
- Buffing
- Milling
- Sawing
- Deflashing
- Sanding
- Etc.
Changing values and demands

- **End of an era - Manual Cleaning**
  - Inconsistent part quality, high scrap and reclaim rates
  - Hazardous, dirty work environment
  - High injury rate and long-term health problems
  - Low availability
  - Difficult to recruit personnel
  - Low status
  - Labor intensive and expensive operation

- **Beginning of an era - Robot Cleaning**
  - Consistent high product quality
  - Reduced tooling costs
  - High availability
  - Safe environment with less risk of injuries
  - Safe environment
  - More attractive & rewarding workplace
  - Positive, high-tech image
  - Improved recruitment possibilities
  - Long-term profitability
Expectations in robotized machining

“Process needs to be more accurate and consistent”

“Programming time needs to be drastically reduced”

“Tools have to last longer”

“Engineering and optimization has to be reduced”

“The robot must perform within its limits”

”Cycle times need to be shortened”
ABB’s robotized machining strategy

RobotWare Machining FC (Force Control) supports in both directions

Flexibility  Accuracy

Future  Today  Future

Manual machining  

CNC-machine
ABB’s Project objectives for machining applications

- Quality improvements
  - Process results – secure controlled contact force

- Ease-of-use
  - Programming in process parameters instead of positions
  - Programming time – save up to 90%

- Productivity
  - Cycle time – saving up to 20%
  - Tool life time – Improved with up to 20%
Project execution – Main features

- Integrate sensor signals into the servo loop for quick and accurate response
- Design special robot programming (GUI and RAPID) instructions for easy use and programming supporting process requirements
- Design Force Control for different sensor configurations
  - 6 Degree of Freedom (DOF), 1 DOF or spindle torque input
  - Sensor to be mounted on the robot or stationary
- Force definition is at Tool Center Point – no need for calculations
- Make RobotWare Machining FC available for MultiMove applications
Results – Tactile sensing makes robots smart

- **Force controlled robots**
  - Creates precision without the expense of being precise
  - Higher quality parts - Gentler material removal
  - Adaptive cycle time for each part condition
  - Shorter programming time
  - Longer tool life

- **Features which highly facilitate the use of robots for machining applications**
  - FC Pressure
  - FC SpeedChange
  - FC Machining graphical user interface
Position Control vs. Force Control

**Position control**
Path and speed is constant independent of the contact forces. Bad quality and risk of burning the material and damaging the tool or the robot.

**Force control**
Force in the sensor controlled direction and speed along the surface is constant. Path is adapted to curvature of the surface. Controlled Material Removal Rate.

**Normal Position control**
- Constant speed
- Linear path

**Force control**
- Constant speed
- Controlled force

**FC Pressure**
- Variable speed

**FC SpeedChange**
- Constant force

Controlled Material Removal Rate.
FC Pressure – Features

- Improved process quality and programming through force controlled motion perpendicular to the surface
- The robot will always keep a constant force against the surface
  - The robot will follow the curvature of the surface
- Input type
  - Force sensor, 6 DOF or 1 DOF
- Typical applications
  - Grinding of water taps, turbine & propeller blades
  - Polishing of lap tops, mobile phones, water sinks
  - Buffing of bumpers, speakers, chrome engine covers
FC Pressure – Customer values

- Easy to program and re-configure with GUI
  - Up to 90% time savings for programming
  - Lead through programming and automatic path learning
- Higher quality level - better surface finish
- Able to handle variations in parts
- Minimized risk of damage to work objects, tools & robot
- Predictable tool wear
- Improved working conditions
  - Minimize injury and health risk for personnel including long term illnesses like “white finger”

Example: Turbine blade
1 week ➔ 1-2 hours
FC Pressure – Technical solution (1)

- **Features**
  - Follow parts curvature
  - Remove material for surface finish
  - Apply constant pressure

- **Force control direction**
  - Normal direction of the path $Z_P$
  - Given constant contact area, remove the same depth
  - Force control accuracy critical to surface finish (5N can make a difference)

- All other directions position controlled
FC Pressure – Technical solution (2)

- Turbine blade belt grinding test

Grinding Force Comparison

- Position Control
- Force Control

Constant reference force
The solution, force control function:

- Disables traditional position control in the compliant direction
- Activates a sensor based velocity control in the compliant direction
FC SpeedChange – Features

- Improved cycle time on a predefined path
- Controlled material removal rate based on the force acting on the tool (process forces)
  - Allow programming at maximum process speed and automatically slowing down when process forces are too high
  - Increased path accuracy
  - Minimized risk of damage to work objects, tools & robot
- Input types
  - Force sensor, 6 DOF
  - Spindle current or torque (analogue voltage input)
- Typical applications
  - Grinding unevenly distributed material
  - Milling along an edge
  - Deburring along a contour
  - Deflashing unevenly distributed excess material along a parting line
FC SpeedChange – Customer values

- Higher productivity
  - 20% shorter cycle time
  - Able to handle variations in location of burrs, flashes or other defects
- Easy to program and re-configure with graphical user interface
  - Drastically reduced manual tuning of program
  - Up to 90% time savings for programming
  - Easy to learn for users and integrators
  - Lead through programming and automatic path learning
- Minimized risk of damage to work objects, tools & robots – less need for operator supervision
- Predictable tool wear and extended tool lifetime
- Reduced vibrations
- Improve working conditions
  - Minimize injury and health risk for personnel

Example: Turbine blade
1 week ➔ 1-2 hours
### FC SpeedChange – Technical solution (1)

- **Features**
  - Follow programmed path curvature
  - Maintain constant material removal rate
  - Configurable speed controller

- **Force control direction**
  - Speed changes along the path (Xₚ)

- All directions are position controlled

- Signal representing process forces without using force sensor
  - For example - analogue output from spindle based on current or torque

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FC SpeedChange – Technical solution (2)

- **Process description (example: 3-level logic speed control, flexible number of levels allowed)**
  1. Robot machining at a specified speed
  2. At a pre-defined value the speed is reduced
  3. When the speed is reduced, the force acting on the tool is reduced
  4. When the force is reduced to a pre-defined value, the speed is increased
  5. Robot machining at a specified speed

- **Extra feature**
  - It is possible to create a user defined routine when encountering excessive material
FC SpeedChange – Technical solution (3)

**Force vs. Speed**

![Graph showing Force vs. Speed](image)
The easy way of programming

- Main components
  - Graphical User Interface (GUI) - programming tool
  - Lead Through Programming
  - Automatic Path Learning
  - Testing of the path running the actual process will be possible within the GUI
  - Export of the final result to include in the original robot program
The easy way of programming

- Graphical User Interface, on the teach pendant featuring icon based program structuring and overview
The easy way of programming

- Lead Through Programming,

with manual guidance to teach the rough machining path
The easy way of programming

- Automatic Path Learning,
  using Force Control features to accurately follow and record the true path on the surface or along an edge.
Graphical User Interface - Examples

- FC Pressure
- FC SpeedChange

Click to view videos

2min 5sec 6min 35sec

Total real time for programming and path learning
Technical features

- Lead Through Programming and Automatic Path Learning on the teach pendant for easy, quick and accurate programming
- Instructions for programming FC Pressure and FC SpeedChange
- Instruction to setup gravity compensation and sensor offset calibration
- Instructions for defining reference values (desired force, speed change parameters or movement)
- Instructions for defining recovery function for FC SpeedChange
- Instructions for supervision
- Functions returning data about load, detected forces or process status
Did we meet customer expectations?

“Process needs to be more accurate and consistent” ✓

“Programming time needs to be drastic reduced” ✓

“Tools have to last longer” ✓

“Engineering and optimization has to be reduced” ✓

“The robot must perform within it’s limits!” ✓

”Cycle time needs to be shortened” ✓
Application example – Cleaning iron casting

■ Problem
  ■ Take excess metal down to dimension of part in one operation

■ Description of the way in which FC can be used
  ■ FC can be used to control the robot to employ a strategy in the cleaning program that takes multiple passes through heavy gates that exceed the capability of the media in one pass

■ Benefit
  ■ All parts are cleaned to the same dimension in one cycle of the robot. Maximum throughput achieved.
Application example – Surface grinding

- **Problem**
  - Achieve a consistent grinding result. Make the system easy to program

- **Description of the way in which FC can be used**
  - FC is used to maintain a constant force on the part during the process.

- **Benefit**
  - The part surface is ground equally on the complete surface. The media use is optimized.

Videos – see next slide
Application example – Surface grinding

Position control  

Click to view videos

Force control
Application example – Sand a wooden guitar

■ Problem
  ■ Constant force is a requirement and must be controlled accurately to preserve the finish

■ Description of the way in which FC can be used
  ■ FC can be used to monitor and control in real time the sanding process

■ Benefit
  ■ Quality finish and minimal cycle times

The traditional way
Application example – Cleaning overflash

Problem
- Minimize cycle time. Flash location and thickness cannot be predetermined

Description of the way in which FC can be used
- FC can be used to control the travel speed of the robot system to go fast where minimum flash is encountered, slow for heavy flash

Benefit
- Reduced cycle time for the process, higher productivity for user.
Availability & Requirements

- Available for single robot and independent MultiMove system
- Process forces need to be measurable and noise level moderate (induced from process)
- Tool weight + sensor weight + process force needs to fit within load diagram
Product offer: Function Package Force Control Machining

- RobotWare Machining FC
  - FC Pressure
  - FC SpeedChange
  - Graphical user interface for Machining
- Axis computer plus
- Sensor
  - 6 DOF Force/Torque sensor
  - Cable management between sensor and controller
  - Data acquisition board for the sensor
- Testing and verification
Product offer: Function Pack Force Control Machining

FP FC IRB140
FP FC IRB4400
FP FC IRB2400
FP FC IRB66XX / 76XX

ABB
Product offer: Flex Finishing Cell Grinding

Scope of Supply:
- IRB 140F including FP Force Control
- Manual 2 Station Turn Table
  - Including 8 valves
  - Including 16 Digital Inputs
- Base Plate including Cell Housing
  - Including Exhausting Funnel
- 3kW Spindle with automatic Tool change System
  - Including Cooling Device
  - Including Frequency Transformer
- Tool buffer for 5 tools
- Safety Equipment
  - Including Safety PLC
- HMI (Human Machine Interface)
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