Presentation Outline

• Evolution in Machining for aerospace
  – Structural part dimension
  – Machining of “difficult” materials
  – From machine tool to machining system

• Adaptation and decentralized automation
  – Distributed control
  – Virtual automation networks
  – Metamodeling and language oriented development
Adaptation in Manufacturing Systems

- The overall capacity of a manufacturing systems builder evolves to improve its performance in a high competitive market.
- A manufacturing system family evolve to improve its performance in a manufacturing niche.
- A manufacturing system evolves through various re-configuration steps to adapt to a dynamic manufacturing environment.

Machining of aeromobile structural part

- Structural part dimension increases
- Removed material volume increases
- Machining time should decrease
Machine Structure: JetFive
(Eureka project 2267/E)

• Linear motor 5 axes machining center
• Gantry control on all axes
• Axes strokes motors and thrusts
  • X 14,000mm 2+2 Fanuc L15000/C2
     Max Thrust 60,000N
  • Y 2,000mm 2 Fanuc L15000/C2
     Max Thrust 30,000 N
  • Z 500mm 2 Fanuc L9000/B
     Max Thrust 18,000 N
• Universal tilting head prototype
  • A axis +/- 30 degrees
  • C axis +/- 180 degrees
• Tilting table with integrated vacuum clamping system

JetFive/L

• Linear motor 5 axes machining center
• Gantry control on all axes
• Work Area Dimension:
  • X from 3,000 to 19,000 mm
  • Y 2,000 mm
  • Z 600 mm
• HSK-A80/HSK-A63 Spindle
  • Speed 20,000rpm
  • Power up to 75kW
  • Torque 200Nm
  • Forward bearing 100mm
• HSK-A100 Spindles
  • Speed 6 / 8 / 14,000rpm
  • Power up to 75kW
  • Torque fino a 1000Nm
  • Forward bearing: 130mm
Machining of titanium alloys

- Roughing at low speed and maximum depth
- Special tool development
- High torque electrospindle (beyond 3.000 Nm)
- Machine structure with high dynamic and static stiffness
- 5 Axes, high speed finishing milling, boring and drilling

Adaptation of JetFive Process Unit

- High stiffness, stable structure, balancing on Y axis for heavy heads
- Electrospindle providing 7.640 Nm torque at low speed (up to 500 rpm)
Horizontal head with double electrospindle

Horizontal head cutting parameters

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Material removal rate

![Material removal rate chart](image1)

Tilting head for 5 axes machining and automated head changer

Electrospindle providing 94.5 kW power and 1822 Nm torque at 4000 rpm speed for 5 axes machining
Flexible Machining Systems

Flexible Automation: Perceived drawbacks

- Complexity
- Slow and uncertain ROI
- Bad “reputation” between shop floor personnel
- Difficulties in managing (frequent) unattended events:
  - Unplanned machine downtimes
  - Tool breakages
  - Raw/casted part delivery delays
  - Quality control failures
- Difficult application of industrial accounting practices
Flexible Automation: Potential Advantages

- Set-up cost reduction:
  - Increasing flexibility
  - Increasing productivity (in a turbulent production environment)
- Redefinition of the man-machine relationship
  - Rational approach to solve problems arising during manufacturing operations
From sensors to production plan …and beyond

Key Element in FMS: Supervisory control

- Flexible automation coordination
- Real time monitoring of resources status:
  - Units
  - Pallets
  - Fixtures
  - Parts
  - Tools
- Operation description and part-program management
  - Dynamic management of CNC memory
- Execution of a production plan
  - Real time dispatching of part to machines
  - Priorities and balancing of production orders
Adaptation: a better comprehension of modularity

Exploration

Exploitation

Modularity is a **process**

A module is a **reusable** unit

**Adaptation**

Enabled by technological and methodological advancement

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**Trend in automation**

**Trend towards distributed systems**

More “intelligence” on lower levels
From hierarchies to agencies

Conventional Hierarchical Control

ERP
MES
SCADA
Control & Field Devices

PABADIS approach

Office level
Factory level
Field level

mobile Agents

ERP

PABADIS-PROMISE approach

Office level
Factory level
Field level

product Agents

resource Agents

Virtual Automation Networks

Remote Industrial Domains / subsidiary / customer sites
Industrial Domain
Industrial Backbone
Industrial Segment
Individual industrial sub domains
Real-time domain

Industrial WLAN domain
Mobile devices
Public and Private Telecommunication Networks/Internet
Single device integration (e.g. telecontrol)

Intrinsic safety domain

resource Agents
Design of modular production system:
Integrated Design Methodology

- Control design
- Functional decomposition
- Bottom-Up Approach
- Top-Down Approach
- Manufacturing Plants
- Machining Centers
- Workarea
- Machines
- Unit
- Module
- Groups
- Sensors & actuators
- Device
- Elementary components
- Components Aggregation
- Mechanical Design

Model Driven Development of Embedded Control

- Model
- Development
- Embedded
- Control
- MEDEIA
- FP VII Strep ICT-2007-2-211448
- (1/2008 - 12/2010)
Meta Modelling and Language Driven Development

- **Abstract syntax (Meta-models)**
  - Domain concepts, element properties and composition rules
- **Semantics (Model Transformation)**
  - Generation of executable artefacts
- **Concrete syntax (Model Editing and Exchanging)**
  - Human usable notation
  - Persistency support
  - Interchangeable format

Key enabling technology for power users

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Programming of complex clamping/unclamping sequences

Context: Machining of structural parts for airplanes
Problem: How to program a variety of clamping devices
- Different part types
- Different clamping techniques (Hydraulic, Pneumatic, Mechanical)
- Different sensors and actuators
- Different timing
- Safe Integration with manual activities
PLUS: A DSL for Programming Clamping Sequences

- A clamping/unclamping program is a **sequence** of phases.
- Each **phase** is made by different steps.
- In a step, it is possible to **check** the status of various sensors or to **change** the status of various effectors.
- Different **sensors** and **effectors** are specified for each fixture.
- Sensors and effectors are mapped to **PLC variables**.

**Diagram:**

- Supervisor
- LAN
- PLC
- Field bus

**PLUS: Abstract and Concrete Syntax**

```plaintext
sequence op10 desc(Open and close clamp1)
  phase 1 desc(Open clamp)
    actuate off(closeClamp1)
    check on(clamp1Open) off(clamp1Close) 2 5
  end
  phase 2 desc(Close clamp)
    actuate on(closeClamp1)
    check on(clamp1Close) off(clamp1Open) 2 5
  end
end

fixture myFixture
  sensor clamp1Open 0
  sensor clamp1Close 1
effector closeClamp1 100
end
```
PLUS Program Semantics

• A program is any precisely defined model of a solution to some problem in some domain, expressed using domain concepts

• Language semantics is defined by its runtime execution environment

• For PLUS DSL its RTE is made by:
  – A generator of bytecode transforming program instructions in a model executable by a PLC
  – The bytecode interpreter running on the PLC

Network Part Program and Model Driven Process Plan Execution

• Dated DSL ISO 6983
  – needs to improve and to raise abstraction level in modelling machining operations to perform advanced control of the machining process

• Network Part Program method
  – explicitly based on the development of a new DSL, its supporting tool and its run-time environment

• Influenced by the Step-NC project
  – association between machining operation and manufacturing feature creates a machining working step

• High level of abstraction to represent process plans provides support:
  – to control process cycles step by step
  – to manage unexpected events
  – to automatic restart and to execute incomplete cycles

• Actually under investigation inside an Italian national research project (NetPP 1/2007 – 12/2009)
Conclusions

- Product evolution pushes process evolution and requires integration in production systems
- The increasing complexity of flexible production systems, and their extended life-cycle, need proper management to become as transparent as possible
- Adaptive machining systems requires:
  - Better modularity conceived as a process, integrating mechanical and control engineering, to discover reusable automation components
  - More “intelligence” on lower levels
  - Better network infrastructure
  - Formalization and seamless models of production processes and resources
Thank you!

MCM Product: Horizontal axis machining centers

- HSK-A63
  - Rapid feeds 120 m/min.
  - Pallet dimensions 500x500

- A.C. axes 22,000 degrees/min.
- HSK-A80 / HSK-A63
- Linear axes rapid feeds 70 m/min.
- Pallet dimensions 3,000x2,000
Flexible Automation.

Multi-pallet flexible manufacturing cells

Parallel-machine Flexible Machining Systems

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Focused Flexibility Mfg. Plant

- Designed to deal with a specific production problem
- Configured to provide the exact amount of flexibility
- Re-configured to adapt to changing requirements

MCM S.p.A.: Facts & Figures

- Start activities in 1978
- Revenues: 60M€
- Personnel: 220 employees
- MCs per years: 80
- MCs installed since 1978: 1900
- Subsidiaries in France, Germany and USA
Company Strength Points

- Great production flexibility
- High precision and availability
- Extreme product customization
- Acknowledged quality and technological know-how
- Effective and fast maintenance services
- Capability to provide “turn-key” manufacturing plants

MCM Organization
Tilting head prototype

- High stiffness in a compact solution integrating axis A inside the envelope of the C axis.
- Tilting head hosts an electrospindle providing 100HP power and 200Nm torque at 20,000 rpm speed
- Mechanical group of axes A and C are mounted inside a mobile sleigh corresponding to the Z axis
- To reduce overall envelope only the C axis use direct drive (torque motor), while A uses a traditional ball screw drive.

A Axis
- Axis stroke: -30° +30°
- Speed: 6.28 rad/s
- Torque S1: 1356 Nm
- Torque S6: 5086 Nm
- Drive: 2 DC motors and screw-balls
- Axis weight: 340 Kg

C Axis
- Axis stroke: -180° +180°
- Speed: 6.28 rad/s
- Torque S1: 2658 Nm
- Torque S6: 3676 Nm
- Drive: torque motor
- Axis weight: 365 Kg
FMS Management Headaches

It is difficult to make flexibility really available and hence to manage flexible capacity

- to take decision on production task activation
- to set priority levels for production tasks
- to show resource needed by the current production, in order to prepare tools and fixtures
- to know in advance lot termination dates

An *unflexible* production plant does not allow to effectively solve a complex production problem

A *flexible* production plant offers better tools to cope with complex production problems but it makes evident the management complexity level
FMS Management Advantages

Flexible manufacturing plants allow:

- Parallel execution of different part types
- Real time selection of part types based on effective resource availability
- To work during unmanned shifts
- To work efficiently pallet with different part types (or different phases for the same part type)

Such a flexibility is needed to cope with complex production environment, characterized by:

- High variability in volumes and mix
- Resources shared by different operations
- Turbulent productive environment (difficult materials, frequent production changes)

Resource monitoring and process tracking

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## Operative Production Planning

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### Decentralized Automation

- **Expected benefits**
  - Flexibility
  - Vertical integration
  - Robustness (through redundancy)
  - Set-up and reconfiguration

- **Need more intelligence on lower levels**
Decentralized Automation: consequences

- Technology provider
  - Automatic integration of automation components
  - Configurable automation functions
- Machine supplier
  - Functional models of automation units
  - Parametric interfaces
- System integrator (and/or power users)
  - Control engineering derives from models of production process and of machines
  - Requires formalization and seamless models

Decentralized automation: balance

<table>
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<th>Benefits</th>
<th>Risks</th>
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<tr>
<td>Effort shifts to early phases and benefits in plant realization commissioning and reconfiguration</td>
<td>High project-independent investments</td>
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<tr>
<td>Long term reuse of automation units</td>
<td>Rising internal complexity of single units</td>
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Work Cycle Development Problems

- Error detection inside ISO code is difficult
  → Simulation of CNC Program and machine kinematics
- Difficulties in documentation and feedback for correction on ISO code
- Difficulties in overall planning an optimization of ISO code (change in tool sequence)
  → Shop Floor Programming Supporting Tools

CAM (off line programming) → SFP (Shop Floor Programming) (on line programming)

Part Geometry (Import of IGES, DXF, ...)

Process Operation → Tool Selection → Verification (Simulation Software) → Post-processor
Sequence Definition

NetPP: Dynamic Execution of non-linear Process Plans

- Disadvantages of traditional part programs
  - Difficulties in programs modification and errors correction;
  - Difficulties in optimisation of operations sequence;
  - Difficulties in process cycle optimisation during execution;
  - Difficulties in exploiting the potentialities of a flexible production system;

- Network Part Program (Net.P.P.)
  - Easy writing and correction of work cycles;
  - Optimisation of operations sequence;
  - Cycle optimisation during execution;
  - Better exploitation of potentialities of a flexible production system;
Network Part Program: New Machining Concept

• Programming
  – Explicit Machining Model
  – Reuse of tool path
  – Increasing productivity and reducing errors
  – Explicit multi-clamping fixture configuration
  – Explicit multi-face pallet configuration

• Execution
  – Optimized execution of multiple operations on complex multi-clamping fixtures
  – Machine time saving, executing only loaded components
  – Safe continuation after failure
  – Tool sharing optimization