Reconfigurable Machine Tools

Adopted from

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Current Manufacturing Systems

Manufacturing companies are using two basic systems:

1. Dedicated Machining Line (DML)
   DML contains machining stations with simultaneous operating tools that increase productivity

2. Flexible Manufacturing System (FMS)
   FMS contains CNC machines, which allows general flexibility, but has low productivity (single cutting tool operation).

If the requirement is (1) any mix at (2) any sequence
The FMS must have a parallel structure.
The parallel FMS is scalable but very expensive.

DQ047-01 Manufacturing Systems Week 4 / Lecture 1 2
Limitations of Current Mfg. Systems

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Dedicated</th>
<th>Parallel FMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Investment Cost</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>(if capacity utilized)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Productivity</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Flexible/Convertible (to part changes)</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Capacity Scalability</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>System Design Focus</td>
<td>Part</td>
<td>Machine</td>
</tr>
<tr>
<td>Simultaneous Operating Tools</td>
<td>Yes</td>
<td>No</td>
</tr>
</tbody>
</table>

The focus on the part at the design stage enables multiple-tool operation, and multiple-tool operation increases productivity.

Can we design a system that combines advantages of Dedicated and FMS?

Machine Tools in a System

**Dedicated Machine Tools**
- Custom Designed for One Set of Operation Requirements
- Low Cost
- Conversion between parts is Not Cost–Effective

**General Purpose Machine Tools (CNCs)**
- Designed for General Applications, Not Specific Requirements
- High Cost *(when part of a general purpose FMS)*
- Convertible: Part Program Easily Changed

**The Need: Reconfigurable Machine Tools**
- Custom designed for a set of operation requirements
- Moderate Cost
- Designed for cost–effective conversion
## RMS & RMT Characteristics

<table>
<thead>
<tr>
<th>Machine Level</th>
<th>Dedicated</th>
<th>RMS/RMT</th>
<th>FMS/CNC</th>
</tr>
</thead>
<tbody>
<tr>
<td>System Structure</td>
<td>Fixed</td>
<td>Adjustable</td>
<td>Adjustable</td>
</tr>
<tr>
<td>Machine Structure</td>
<td>Fixed</td>
<td>Adjustable</td>
<td>Fixed</td>
</tr>
<tr>
<td>System Focus</td>
<td>Part</td>
<td>Part Family</td>
<td>Machine</td>
</tr>
<tr>
<td>Flexibility</td>
<td>No</td>
<td>Customized</td>
<td>General</td>
</tr>
<tr>
<td>Scalability</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Simultaneous Operating Tools</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Cost</td>
<td>Low</td>
<td>Intermediate</td>
<td>High</td>
</tr>
</tbody>
</table>

RMS and RMT offer a higher ratio of productivity to investment cost compared with FMS, by combining advantages of CNC & Dedicated.

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### Conceptual RMT

Yoram Koren and Sridhar Kota, US Patent 5,943,750
Matching the Right System to Manufacturing Requirements

Production Requirements
- Part Mix (set of parts to be produced)
- Volume (amount produced per unit time for each part)
- Changes in Part Mix and Volume

Operation Requirements
- Set of Features to Produce
- Cycle Time for Each Operation
- Changes in Set of Features and Cycle Times

<table>
<thead>
<tr>
<th></th>
<th>DML</th>
<th>DMT</th>
<th>FMS</th>
<th>CNC</th>
<th>RMS</th>
<th>RMT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Part Mix</td>
<td>S</td>
<td>S</td>
<td>V</td>
<td>V</td>
<td>Fa</td>
<td>Fa</td>
</tr>
<tr>
<td>Volume</td>
<td>F</td>
<td>F</td>
<td>C</td>
<td>F</td>
<td>C</td>
<td>C</td>
</tr>
</tbody>
</table>

C: changeable; F: fixed; Fa: family; S: single; V: various

DML, FMS, RMS: Dedicated, Flexible, and Reconfigurable Machining System
DMT, RMT: Dedicated and Reconfigurable Machine Tool

Reconfigurable Systems

A reconfigurable manufacturing system (RMS) is designed to respond to the market by
- Changing the system configuration
- Changing the machine structure
- Changing the control architecture.

Reconfigurable machine tools (RMTs) are machines with changeable structure designed around part families.

The RMS may consist of CNCs, RMTs, and dedicated machines.
- The RMS combines advantages of DML and FMS.
- The RMS operates in a batch mode with short conversion times between batches.
RMT for Cost-Effective Scalability

Multi spindles increase productivity at the machine level

The number and locations of the spindle modules can vary

All spindles operating on the same part

Exactly the capacity needed ... Exactly when needed.

Scalable Configurations – Example
RMT Designed for a Part Family

This RMT is designed for a part family with inclined surfaces.

Reduced Cost & Enhanced Reliability:
Only the # of axes needed

Non-orthogonal 3-axis machine

1995 drawings

Exactly the functionality needed ...  ...Exactly when needed

Another Example: Changing spindles & structure
according to the material being cut (aluminum<>titanium)

Controls

DMT: Customized; Not Flexible, Upgradable, or Scalable
CNC: General Purpose; Flexible; Not Upgradable or Scalable
RMT: Customized; Flexible; Upgradable, and Scalable

Additional Challenges for RMTs

Dynamic Software Architecture
Multiple Independent Tools and Non–Orthogonal Axes
Integration of Heterogeneous Software and Hardware Components

Prototype RMT Controller
**Reconfigurable Machine Tool Simulator**

- PC-Based Controller
- Motion Control/PLC
- Shared Memory
- API
- 100 Hz
- Real Controller
- Factory Simulation Software

**Axis Simulation (Real-time C++ Application)**

- Axis Model
- Discrete Logic
- Shared Memory

**Real Machine Tool Axis**

- Device Driver

Replace Simulator with Device Driver for real machine tool hardware
Kinematic Synthesis

**DMT:** Customized, but inflexible.

**CNC:** Flexible, but typically has wasted functionality.

**RMT:** Customized for part family and, thus, can be cost-effectively converted.

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**RMT Kinematic Design Methodology**

Given: a particular task, Given: a set of machine modules?

INPUT: Task Representation on Parts

Library of machine modules

OUTPUT: A Synthesized RMT

• A prototype RMT was designed and is being built. It’s one of many possible RMTs.
**Structural Stiffness**

**DMT:** Customized, based on experience and FEA, for a specific operation.

**CNC:** Designed before requirements are known.

**RMT:** Customized, based on systematic tools, for a range of requirements. Non-rigid joints will require careful analysis.

Active, passive, or hybrid vibration isolation may also be utilized (Yigit and Ulsoy, 2000).

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**Example 1 - Part Change**

**Production Requirement:**
V8 initially produced, V6 may be produced in the future; however, only one will be produced at a time.

**Operation Requirement:** drill precision cam tower holes (i.e., holes where dowel pins are inserted to locate cam caps).

Dimensions, tolerances, and materials are the same; number and location of holes are different.
Example 1 – Prototype RMT

Three–Axis
Configuration

Two–Axis
Configuration

Example 2 – Feature Change

Production Requirement:
The same as example 1.

Operation Requirement:
Finish milling of inclined surfaces.

Dimensions, tolerances, and materials
are the same, inclined angle is different.
Example 3 – Cycle Time Change

Production Requirement:
The cycle time may need to be cut in half in the future.

Operation Requirement:
Simple prismatic part. Drill same pattern of holes on both sides

Conclusions

RMTs provide a viable solution when operations requirements vary within a prescribed bound.

Production and operation requirements have dramatic effects on RMT design.

RMTs require systematic mechanical and control design methodologies.