Industry 4.0 Awareness Seminar Report organized at Rajkot

Source: CMTI as on 24 Apr 2019

<p>| | | |</p>
<table>
<thead>
<tr>
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<tbody>
<tr>
<td>1.</td>
<td>Date of the Seminar</td>
<td>13th April, 2019</td>
</tr>
<tr>
<td>2.</td>
<td>Organizers</td>
<td>Department of Heavy Industry, Govt. of India &amp; Central Manufacturing Technology Institute, Bangalore</td>
</tr>
<tr>
<td>3.</td>
<td>Title of the seminar</td>
<td>Awareness Programme “Workshop on Smart Manufacturing &amp; Industry 4.0”</td>
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<tr>
<td>4.</td>
<td>Programme Schedule</td>
<td>(enclosed a copy in pdf)</td>
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<tr>
<td>5.</td>
<td>Report: suggested contents</td>
<td>(1) Main takeaway / good suggestions</td>
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<tr>
<td></td>
<td></td>
<td>Awareness about various Smart Enterprises and Industry 4.0</td>
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<tr>
<td></td>
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<td>Challenges in adoption of Smart Manufacturing</td>
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<td></td>
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<td>Role of Sensors and data acquisition in Industry 4.0</td>
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<td></td>
<td></td>
<td>Concepts of Smart Machines, Intelligent Machines and Smart Metrology</td>
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<td></td>
<td></td>
<td>Smart Foundry applications &amp; Case Study</td>
</tr>
<tr>
<td></td>
<td>(2) Clusters covered</td>
<td>Foundry &amp; Machining Cluster from Rajkot, Morbi, Surendranagar,</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Machine Tools Cluster from Rajkot, Surendranagar, Jamnagar</td>
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<td></td>
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<td>Brass cluster from Jamnagar</td>
</tr>
<tr>
<td>Item</td>
<td>Details</td>
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<tr>
<td>3.</td>
<td>Nos attended</td>
<td>119</td>
</tr>
<tr>
<td>4.</td>
<td>Success stories that need to be compiled / shared</td>
<td>NA</td>
</tr>
<tr>
<td>6.</td>
<td>List of Speakers with contact details</td>
<td>(enclosed a copy in MS Word)</td>
</tr>
<tr>
<td>7.</td>
<td>Presentations</td>
<td>(enclosed copies in pdf)</td>
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<tr>
<td>8.</td>
<td>Resource persons for providing consultancy, skilling, guidance etc.</td>
<td>NA</td>
</tr>
<tr>
<td>9.</td>
<td>Photographs</td>
<td>Jpeg images (enclosed)</td>
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</tbody>
</table>
| 10.  | Learning from the seminar | From organizers/ subject point of view for action in the next seminar to improve further. Learning outcome from the organiser’s perspective:  

(-)  
- More Industry specific case studies are to be covered  

(+)  
- Created awareness on futuristic technology of Smart Manufacturing & I 4.0  
- Seminars of this kind should be done at Rajkot in future also |
## Detailed Schedule

<table>
<thead>
<tr>
<th>Time</th>
<th>Programme</th>
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<tbody>
<tr>
<td>10.30 - 10.33</td>
<td>Saraswati Vandana</td>
</tr>
<tr>
<td>10.33 - 10.38</td>
<td>Lighting of Lamp</td>
</tr>
<tr>
<td>10.38 - 10.50</td>
<td>Welcome &amp; Introduction to CMTI by Director</td>
</tr>
<tr>
<td>10.50 – 11.00</td>
<td>Introduction &amp; Honouring the Guests</td>
</tr>
<tr>
<td>11.00 - 11.10</td>
<td>Address by Guest of Honour Jt.Secretary / Director, DHI</td>
</tr>
<tr>
<td>11.10 – 11.40</td>
<td>Address by Chief Guest Shri. P.G. Jadeja, CMD Jyoti CNC Automation Ltd.</td>
</tr>
<tr>
<td>11.40 – 12.00</td>
<td>Tea Break</td>
</tr>
<tr>
<td>12.00 – 12.45</td>
<td>Introduction to Smart Manufacturing &amp; Industry 4.0</td>
</tr>
<tr>
<td>12.45 - 13.30</td>
<td>Smart Machines &amp; Intelligent Machining</td>
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<tr>
<td>13.30 - 14.30</td>
<td>Lunch</td>
</tr>
<tr>
<td>14.30 – 15.00</td>
<td>Smart Sensors and Controllers</td>
</tr>
<tr>
<td>15.00 – 15.30</td>
<td>Precision &amp; Smart Metrology</td>
</tr>
<tr>
<td>15.30 – 16.00</td>
<td>Smart Foundry - A Case Study</td>
</tr>
<tr>
<td>15.45 - 16.45</td>
<td>CMTI Technologies and Technology Transfer Modalities</td>
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<tr>
<td></td>
<td>CMTI Regional Center Activities and Future Expansion Scope</td>
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**Head Office**  
: Tumkur Road, Bangalore – 560022; Website: [www.cmti-india.net](http://www.cmti-india.net)

**Regional Centre**  
: Centre for Advancement of Manufacturing Technology, NSIC Campus, Aji Industrial Area, Bhavnagar Road, Rajkot – 360003 Gujarat.  
  Ph: 0281-2384128  
  Email: cmtirc.cmti@nic.in
List of Speakers for Awareness Programme “Workshop on Smart Manufacturing & Industry 4.0” organized at Rajkot on 13\textsuperscript{th} April 2019.

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Speaker Details</th>
<th>Contact details</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Dr. Nagahanumaiah</td>
<td>Director, CMTI, Bangalore</td>
</tr>
<tr>
<td></td>
<td></td>
<td><a href="mailto:director.cmti@nic.in">director.cmti@nic.in</a></td>
</tr>
<tr>
<td>2.</td>
<td>Dr. N. Balashanmugam,</td>
<td>Jt. Director, CMTI, Bangalore</td>
</tr>
<tr>
<td></td>
<td></td>
<td><a href="mailto:balashanmugam.cmti@nic.in">balashanmugam.cmti@nic.in</a></td>
</tr>
<tr>
<td>3.</td>
<td>Prof. Amit Sata</td>
<td>Professor, Marwadi Education Foundation, Rajkot</td>
</tr>
<tr>
<td>4.</td>
<td>Shri. Prakash Vinod</td>
<td>Scientist-F &amp; Head NMTC, CMTI, Bangalore</td>
</tr>
<tr>
<td></td>
<td></td>
<td><a href="mailto:prakashv.cmti@nic.in">prakashv.cmti@nic.in</a></td>
</tr>
<tr>
<td>5.</td>
<td>Shri. V S Shanmugaraj,</td>
<td>Scientist-F &amp; Head, SVT, CMTI, Bangalore</td>
</tr>
<tr>
<td></td>
<td></td>
<td><a href="mailto:shanmugaraj.cmti@nic.in">shanmugaraj.cmti@nic.in</a></td>
</tr>
<tr>
<td>6.</td>
<td>Shri. K Nirajan Reddy,</td>
<td>Scientist-E &amp; Head, UPE, CMTI, Bangalore</td>
</tr>
<tr>
<td></td>
<td></td>
<td><a href="mailto:niranjan.cmti@nic.in">niranjan.cmti@nic.in</a></td>
</tr>
<tr>
<td>7.</td>
<td>Shri. Abhishek Suchak,</td>
<td>In charge – CMTI Regional Centre, Rajkot</td>
</tr>
<tr>
<td></td>
<td></td>
<td><a href="mailto:cmtirc.cmti@nic.in">cmtirc.cmti@nic.in</a></td>
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</tbody>
</table>
Industry 4.0
IIoT and Smart Manufacturing

Dr. Nagahanumaiah
Director, CMTI
Overview

• About CMTI
• Smart Manufacturing
• IoT-Big Data-IIoT
• Industry 4.0 @ DHI/CMTI
• Industry 4.0 Challenges, Facts and Roadmap
• Summary
CMTI Focus

Machines and Manufacturing Processes

Academia – IITs, IISc, CSIR International experts....

Govt, Industry, other Stakeholders

Mandate, SDGs

Industry, Academia, National imperatives

Opportunities

CMTI

Research - Technology - Training - Application

Incubation, Tryouts, Deployment, Product Dev., Services, to industries, stakeholders...

Knowledge

Research-Technology-Training-Application
What CMTI Would Offer

We Undertake Research, Develop Technologies and Machines, Train Manpower and Deploy into Industrial Applications

Ultra Precision Machine Tools
Special Purpose Machines
Sensors and Controllers
Textile Machinery
Aircraft LRUs and Test Rigs
Precision Metrology
Smart Manufacturing and Industry 4.0
Additive Manufacturing
Industry Employable Manpower (Skilling & Reskilling)
Technology Transfer and Incubation

MADE – IN – INDIA
Smart Machines & Aggregates - Metal Cutting

- Intelligent Ultra Precision Turning Machine
- Ultra Stiff Ultra Precision Diamond Turning Machine
- Projection Microstereo lithography
- Scanning Tunnelling Microscope

Ultra Precision Machine Tool Sub-Systems
- Hydrostatic Slide
- Aerostatic Spindle
- Spindle Error Analyzer

Nano Finishing
- Abrasive Flow Finishing Machine

Manufacturing & Fabrication Solutions
- Micro Mold & Needle Array
- Nano Finishing
- Abrasive Flow Finishing Machine

Surface Engineering
- DLC coated germanium lens, cutting tools and surgical blades
Design & Development-SPMs

- Centreless grinding machine for Automobile industry
- Perch on facing & boring machine for ship building industry
- Flexible multi gauging inspection system
- Parallel Kinematics Machine
- Vertical Planetary Mixing Machines - upto 5 ton
- Single and double cutter head Centerless Bar Turning Machine
- Performance Test Rig for Pumps
Product Development

High Speed Rapier Loom - 450

Twin Screw Continuous Mixer

Hydraulic Filters

Battery operated hydraulic system to charge parking brake accumulator of aircraft

Pressure Endurance tester

Pressure Impulse Test

Return Line

Supply Impulse

Extended
Test Rigs for Machine Tool Testing

Telescopic Cover Test Rig performance evaluation of telescopic covers of machine tool slides

Electro Hydraulic Force Exciter Dynamic behaviour study of machine tools and structures

Spindle Test Rig for performance testing
Vision Based Solutions

**MEDICAL INDUSTRY**

AUTOMATED INSPECTION OF SURGICAL SCREW FOR M/S ADLER MEDIEQUIP PVT LTD

- Dimensional Measurements 636 sizes of 30 features each
- Inspection Accuracy: 5-7 µm.

**AGRO INDUSTRY**

AUTOMATED INSPECTION OF DRIPPERS FOR M/S UDYOGI INDUSTRIES

- Detection of blocked holes, root flash & collar flash, broken edges, circularity of top and bottom sections
- Inspection rate of 600 p/min

**AUTOMOTIVE INDUSTRY**

AUTOMATED INSPECTION OF RETAINING BUSH FOR M/S FINE TOOLS INDIA PVT LTD

- Defects identified in injection mould component
  - Flash
  - Cracks
  - Black spots
  - Color variation
  - Missing feature
- Inspection rate of 3 p/sec

**ENGRAVED LABEL INSPECTION ON SCOOTER FRAME AND BARREL COMPONENT**

- M/s Forbes India (P) Ltd
- M/s Mico Bosch (P) Ltd
Additive Manufacturing

- Remanufacturing of Turbocharger for M/s Cummins Pune
- Remanufacturing of Pump Gear Shaft for HAL Engine Div. Bangalore
- Bi-metallic parts deposition (Steel on Al-Bronze) by DMD
- Honey Comb type Orifice (DMLS)
- Mould for Ball Bearing Retainer
- Model of Aircraft by Direct laser metal sintering

Material: Steel
- Mould for Ball Bearing Retainer: Built time: 4 hr
- Honey Comb Orifice Plate for fluid flow control in Nuclear application: Built time: 9 hr
Made in India

Research – Technology Development – Training (Machine and Manufacturing Processes)

Key Initiatives 2018-2024

- Smart Manufacturing Design and Demonstration Center
- Center of Excellence for Textile Machinery
- Indian Institute of Innovative Manufacturing (I^3M)
- Design Innovation and Manufacturing Excellence

Need:
- Bridging the Technology Gap
- Factoring Sectorial developments into Mfg.
- Adoption of latest technologies
- Driving Innovation
- Game changing
- Sustainable / Green Mfg.
- Skill development

Transformation:
- Support for Capital Goods Sector
- Support for Strategic Sector
- Embracing futuristic Technologies
- Enhancing scientific & technical expertise
- Augmentation & upgradation of facilities
- Up scaling of operations

Micro & Nano Manufacturing Innovation

Design Manufacturing

Smart Manufacturing

Additive Manufacturing

Sensor Technology

Automation & Machine Vision for Advanced Mfg

Skill Development

Outreach Programmes

Fluid Power Test Rig & Product Development

Improvement to Infrastructure (II&AA)

Sensor Technology
IoT – IIoT – Smart Manufacturing – Smart Factory
(The Manufacturing Revolution?)

Competitive Advantage in Market

Innovation; Responsiveness; Cost Effective; First to Market

Smart Enterprises
Predict – Digitize and Share – Analytics – Automate

I4.0
Manufacturing Revolution (Industry 1.0 to Industry 4.0)

**Industry 1.0**
FIRST
Industrial Revolution

Key Change:
Introduction of Mechanical Production Equipment driven by Water and Stream Power

18th Century Mechanical Loom

**End of 18th Century**

**Industry 2.0**
SECOND
Industrial Revolution

Key Change:
Introduction of mass Manufacturing Production lines powered by Electric Energy

Vintage Electric Conveyor Belt

**End of 19th Century**

**Industry 3.0**
THIRD
Industrial Revolution

Key Change:
Introduction of Electronics, PLC Devices, Robots and IT to automate Production

PLC Driven Robots

Q4 of 20th Century

**Industry 4.0**
FOURTH
Industrial Revolution

Key Change:
Introduction of IoT and Cyber-Physical Systems driven by Augmented Reality & Real Time Intelligence

Augmented Reality Driven CPS

Start of 21st Century
Electronics Innovation

IoT - IIoT – Smart Mfg. – Smart Factory

These “smart, connected products”—made possible by vast improvements in processing power and device miniaturization and by the network benefits of ubiquitous wireless connectivity—have unleashed a new era of competition.”

- Sensors & Actuators + Connectivity + Big Data & Analytics + Cloud Computing + Internet of Things

1933
First room thermostat introduced

1971
AlohaNet is first public wireless packet data network

1998
John Masey, Chief Scientist at SGI presents a paper titled “Big Data…and the Next Wave of Infrastrass”

1999
Cloud computing is introduced to the enterprise

2010
The IoT and interconnectivity create novel possibilities for electronics
IoT + Big Data = IIoT

- **Internet of Things (IoT):** Devices with electronics and sensors connected to public telecome network and internet

- **Big Data:** Large data sets that may be analyzed computationally to reveal patterns, trends, and associations, especially relating to human behaviour and interactions.

- **Industrial Internet of Things:** A network of physical objects, systems, platforms and applications that contain embedded technology to communicate and share intelligence with each other, the external environment and with people.

- **IoT + Big Data = Industrial Internet**
What is Smart Manufacturing?

Value Chain Network Based Manufacturing

- Dynamic plant configuration and readiness
- Dynamic product component/material configuration
- Dynamic inventory minimization & management
- Tracking & traceability

Mapping SAP information into operation

Business Systems, ERP

Supply Chain

Smart Grid

Customer

Distribution Center

Graphics courtesy of Rockwell Automation
Smartness in Manufacturing Value Chain

• **Smart Manufacturing Intelligence**
  – Deeper understanding of the manufacturing process through modeling and analysis
  – New capacity to observe and take action on integrated patterns of operation through networked data, information, analytics, and metrics
  – Dynamic management of energy and material resources

• **Smart Manufacturing Practice**
  – Generating and orchestrating the use of sensor-based, data-driven manufacturing intelligence
  – Applying integrated performance metrics constructed for real-time action
  – Reusing, scaling and repurposing integrated practice using a common infrastructure

• **Smart Manufacturing Execution**
  – Dynamic orchestration of decision/action workflows in heterogeneous environments without losing control of state
    • across different time constants and seams, including supply chain
    • multi-vendor discrete, continuous, operational and human/social applications
  – Applications that can share data and data that can share
<table>
<thead>
<tr>
<th>Smart Machine Line Operations</th>
<th>In-Production High Fidelity Modeling</th>
<th>Dynamic Decisions</th>
<th>Enterprise &amp; Supply Chain Decisions</th>
<th>Design &amp; Planning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Machine product management</td>
<td>Better management complex behaviors</td>
<td>Performance management global integrated decisions</td>
<td>Variability reduction</td>
<td>Design models in production</td>
</tr>
<tr>
<td>Benchmarking machine-product interactions</td>
<td>Rapid qualification components products materials</td>
<td>Untapped enterprise degrees of freedom in efficiency, performance time</td>
<td>Risk and compliance management</td>
<td>Product/material in-production ability</td>
</tr>
<tr>
<td>Machine-power manage management</td>
<td>Integrated computational materials engineering</td>
<td>Business operational tradeoff decisions</td>
<td>Tracking traceability genealogy</td>
<td>New product, material technology insertion</td>
</tr>
<tr>
<td>Adaptable machine configurations</td>
<td></td>
<td></td>
<td>External partner integration into business process</td>
<td></td>
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</table>
Smart Manufacturing Ecosystem

Smart Manufacturing Platform Open Infrastructure
• SM Software Marketplace

SM Value Proposition

Private Smart Manufacturing Platform Appliance

Applications
Context
Mapping

Data
Event Data
Time Series

Production Models
Calibration & Maintenance
Sensor Data

Traditional Manufacturing Automation
Environment and Software Tools

Suppliers
Line Operations
Distribution
Customers

Power Mgmt & Energy Grid
Heating - Furnaces
Sustainability & Safety
IIoT Integration

Figure 1: The adoption and impact path of the Industrial Internet

1. Operational Efficiency
   - Asset utilization
   - Operational cost reduction
   - Worker productivity

2. New Products & Services
   - Pay-per-use
   - Software-based services
   - Data monetization

3. Outcome Economy
   - Pay-per-outcome
   - New connected ecosystems
   - Platform-enabled marketplace

4. Autonomous, Pull Economy
   - Continuous demand-sensing
   - End-to-end automation
   - Resource optimization & waste reduction

Smart Manufacturing: Multi-Layered Seams, Time, Data & Action

Machines – People - Materials Dynamic Manufacturing Ecosystem

Design Data

Prototype

Materials & Process Tech

Product Manufacturing

Qualification

In Service

Macro Layer

Focus: 10x Multiple Pass Variability Reduction; Supply Chain Information

Meso Layer

Focus: 100x Event Variability/Tradeoff Adjustment; Dynamic Performance Mgmt.; Integrated Metrics

Micro Layer

Focus: Insertion, Qualification, ICME, High Fidelity Dynamic Operations

1000s control loops
Time – minutes

100s control loops
Time - hours

10s control loops
Time – days

Control & Automation

Source: SMLC
Multifaceted Innovation – IoT/IIoT – Smart Manufacturing – Smart Factory
IIoT Integration means...

Integration → Everything CONNECTED

RFID

Acquire → Aggregate → Analyze → Action

Increasing Value

Deep Learning: Intelligence from Big Data
**SMART Foundry 2020 (2016–2020)**

*Sustainable Metalcasting by Advanced Research and Technology*

**Goal:** Ultra-compact SMART Foundry, for sensor-driven automatic and economic production of small intricate metal parts with high quality

**PIs:**
- Dr. Savithri, NIIST, Trivandrum
- Dr. Sudip Kr. Samanta, CMERI, Durgapur
- Dr. A.M. Kuthe, VNIT, Nagpur
- Dr. G. Sutradhar, Jadavpur Univ, Kolkata

**Industry:**
- 3D Foundry Tech Pvt Ltd., Mumbai
- Atomberg Technologies Pvt. Ltd., Mumbai
- Aha 3D Pvt. Ltd., Jaipur
- Marcopolo Products Pvt. Ltd., Kolkata
- TREE Labs Foundation, Mumbai

**DST Sanction = Rs. 8,25,15,160**

**Co-PIs:**
- Dr. Arati V. Mulay, College of Engg., Pune
- Dr. Amit Sata, MEF College, Rajkot
- Dr. Atul Sharma, IIT Bombay, Mumbai
- Dr. Elizabeth Jacob, NIIST, Trivandrum
- Dr. J.V.L. Venkatesh, SGGS Inst., Nanded
- Dr. Mayur Sutaria, CHARUSAT, Anand
- Dr. Shyam Karagadde, IIT Bombay, Mumbai
- Dr. Vasudev Shinde, DKTE TEI, Ichalkaranji

**Mentors:** Prof. B. Ravi, IIT Bombay
- Dr. Nagahanumaiah, CMTI Bangalore

**Industry Contribution = Rs. 1,25,00,000**
Sustainable Metalcasting by Advanced Research and Technology

Proposed SMART Foundry 2020

Adding intelligence to manufacturing using Cloud, Big Data (from sensors) and Analytics
Smart Foundry

- Innovate
- Practice
- Dominate

Smart Foundry Business Model of Data

Smart Foundry Enterprise Management

Smart Foundry – Manufacturing (Data-Information-Man-M/c-Matl.)

Sensors, Data Acquisition: Device Integration & Orchestration

Process parameter, System controllers, Manpower

Autocast
3D Printing
Molding M/c
Melt - Pour

Foundry Resources

Data Valuation
Control Real Data – Corrected Data (actionable) (Proprietary/Shared)

Frog / Cloud Computing
Data Mapping – Process Analytics – Storage = C

Practice Valuation
Collective vs. Proprietary

Big Data

IoT

Process Diagnosis – Prognosis-Control = Knowledge

Knowledge to Wisdom

Company Business Model

Converting Data to Information

Foundry Operation Policy

Smart
Typical Foundry Data

Quality
- defect
- mold hardness
- mold strength

Pattern strength
- pattern
- density
- volume
- metal/Alloy
- min. thickness
- simulation results

Casting
- mold making
- mold temp.
- mold wt.
- GFN
- mixing ratio
- resin temp.
- catalyst temp.

Real time monitoring of:

Molding
- pouring
- pouring temp.
- furnace temp.
- heating chamber temp.

(3D Printing)
- extruder temp.
- filling rate
- type of material

Software data
- Mold
- CAD
- simulation
- results

P = (W attraverso
N = (V attraverso
H = h + P

CMTI
www.cmti-india.net
Example: Automatic Molding Machine

Software: Module -A
- Mold design data
- Pattern design
- Methoding results

Material Data
- Sand test data
- Resin properties
- Hardner property

3D Printing Module –B1
- Pattern Actual data
- Pattern Material
- Non-functional data

Regularities

Machine & Controller

Investor / Board

Manager

Resources Machine
Plant Utility

Machine Data Module –B2
- Working (Spec.) limits
- Operation data
- Real (Sensor) data

Process Data Analytics

Customers
Smart Foundry Operation Version -1

- Process Display Unit
- Fettling & Finishing
- Melting and Gravity Casting
- Design & Process Simulation
- Finished Casting
- Castings with gates
- Sand Molds
- Plastic Patterns
- Tool design data
- Methoding data
- 3D Printing of patterns
Smart Foundry Operation – V2

Casting Design & Methoding
(SS @ Trivendurm)

Process Data Analytics
Pre-production - (EJ @ Triv.)
Post production: (AS @ Gj)

3D Printing of Pattern
(SS @ Trivendurm)

Board
(BR @ Mumbai)

Cloud

Sand Reclaimer & Quality Manager
(VS @ Kollhapur)

Regularities
(@ New Delhi)

Mold Making
(CMERI @ Durgapur)

Melting casting
(Mayur @ Anand)
SMART MANUFACTURING DEMO CELL @ CMTI

LEGACY MC 1

LEGACY MC 2

CMM

Washing station

RM and forgings

Assembly / Packaging & Shipping

Data cloud

Master controller with CAD/CAM, PLM, MIS, ERP

Tool hive with overhead transportation

Tool setting(Manual)

Physical Verification -RFID Tagging

Loading and unloading station(Manual)

Command & Feedback Signals

Management Information

Diagnostic Signals

G3

Real time health monitoring

Information flow and data management

AGV control station

Multitasking machine

Multitasking machine

REAL TIME HEALTH MONITORING
Technologies to be developed for SMART Factory Demonstration

• Smart Machines and Devices
  - Developing plug and play solutions to convert legacy machines to smart machines for specific benefits
  - Precision and multi functional smart machines
  - Sensors Technologies: CMTI focused develop MEMS based sensors for Temperature, Acoustics, Pressure and Flow measurement

• Manufacturing Process Modeling and AI
  - ANN based process models for metal cutting processes
  - Operation/process planning models

• IIoT for manufacturing
  - Machine to machine connection protocols
  - Cloud computing
  - Distributed manufacturing
Consortium

- Total Funding: 29 Crore under DHI capital goods scheme
- CMTI (DHI Funding) = 80%
- Industries = 20%
  - Indian Machine Tool Manufacturers Association (IMTMA) = 1 Crore
  - Utthunga Technologies Pvt. Ltd. Bangalore – 1 Crore
  - L&T Technology Services, Bangalore (discussions are in progress)
- Constraints
- Convincing Indian industries to invest on this Industry 4.0 initiative is still daunting task.
  - Poor awareness
  - No single and universal solutions that ensure RoI
  - Technologies need to be customized to specific industry
Smart Manufacturing Demo and Development Cell (SMDDC @ CMTI)

Objectives
Ingenious - Indigenous solutions to MSMEs

Smart Machines and Devices
Smart Manufacturing Protocols/Technologies
Industry Employable Manpower (Skilling & Reskilling)
Technology Transfer and Incubation
Smart Building Blocks for Legacy Machines - Mazak H400N – Legacy Machine

**Key Outcomes**
- Monitoring of Energy consumption
- Distinguishing Idle energy and production energy
- Power quality (Harmonic analysis done to ensure machine internal electrical health)
- Cycle time analysis based on power signature
- KPI such as Energy per piece and identify optimization potential through analytics to build a business case

**Scope: Smart Energy Management**

- Energy Monitoring
- Spindle Health Monitoring
- Machine Vibration Monitoring
- Hydraulic unit Monitoring
- Machine Cabinet Temp. Monitoring
- Coolant pH and Refractive index Monitoring
- Overall Machine Performance-OEE

**MAKE** | **MAZAK**
--- | ---
MODEL | H400N
Year of Manufacture | 1996
Machine Type | 4 Axis HMC
Control System | Siemens 828D
IOT Enabled SMART Metal Cutting Machine

Empower a Legacy Machine with Smart features to improve process efficiency

Sensor Modules
- Temperature: spindle coolant Temp.
- Pressure: Spindle coolant pressure
- Vibration: Machine health
- Evaluate TcP (tool center point) drift
- Energy: Downtime of the machine
- Vision: In-situ inspection / Quality

Benefits
- IOT enabled connected machine
- Remote access of machine health and process data
- Real time Machine health monitoring
- Predictive machine maintenance
- Energy monitoring
- Better process control
- Improved part quality
- Reduced machine down time
Snapshots of Web portal
Thermal Behavior of Machine (graphical)
Snapshots of Web portal
Machine Energy Monitoring (graphical)
A IOT enabled Control GUI has been developed to control the 3D printer in a closed loop. The following features have been implemented.

- Cloud based 3D printing by uploading G-code via Any internet connected device, i.e Mobile Phones & Tablets.
- Cloud based closed loop monitoring of process parameters & Temperature signatures of subsystems of 3D printer
- A complete live fabrication process can be viewed online via IOT process monitoring camera
A complete IOT based dash board has been developed for process monitoring of an additive manufacturing machine. It monitors temperature of extruder, base plate & motors along with ambient humidity inside the machine & with material feed monitoring.
SMART METROLOGY LAB

Smart Inspection Facility encompassing
- Smart Measuring Instruments
- Smart Quality Monitoring
- Smart Process Monitoring

**Smart Inspection Lab**
A smart inspection and data management application for digital metrology is setup. The application would collect, store, present digital data from Smart Bluetooth enabled instruments and data from other instruments/ equipments / gauges and CMM. Data analytics such as Cp, Cpk are also performed to provide process capability information.
Summary

• IoT + Big Data = Industrial Internet of Things

• What’s Different
  – Cheap hardware
  – Unlimited computing power
  – Internet everywhere

• Product/Service Hybrids
  – Change the way customers buy
  – Rethink your go to market strategy

• Innovate & Dominate – Capacity Building
Industry 4.0/Smart Factory Roadmap

- **What is Industry 4.0? Awareness???
  
  - Industry 4.0 is not a technology, it is the current trend that focus on data exchange and automation in manufacturing.
  
  - Predicting the process characteristics by acquiring the data, digitising, sharing and analysing this data to generate an information that can be used to control/monitor/enterprise operation in the entire value chain of product manufacturing.
  
  - For Example, in metal cutting Industry 4.0 focus must be on technological interventions that enhance spindle-on-time, reducing machine breakdown and change in machining conditions that ensure increase in productivity.
Industry 4.0/Smart Factory Roadmap

- **Prime headwinds in India**
  - Hard mindset for the change
  - Skilled manpower: Availability & retaining of the right manpower
  - Low technology maturity level: Many disruptive technologies are being developed in parallel, maturity level is low. Sustainability over a period might calls for additional investments in future.
  - High operational and MOR cost: Recurring cost is expected to be quite high owing to limited resources and proprietary technologies.
  - Cost vs. benefits: No universal technologies, customization?? One of the biggest questions in the minds of investors is whether I4.0 technologies will bring added market? If yes, will it be same for all?
Industry 4.0/Smart Factory Roadmap

• Developing technology building blocks & Customization
• Ingenious and Indigenous technologies
• Possible Approaches
  - Converting individual legacy machines into smart machines: The legacy machines to be embedded with appropriate sensors that acquire process conditions in-situ and process analytics using built-in process models.
  - Connecting the machines: The shop floor networking with appropriate M2M interfaces.
  - Connecting networked shop floors to public network: Use of cyber physical systems connects these networked shop floor to public network and internet.
  - Big data analytics and enterprises management (MES/ERP) depending on the scale of operation.
Capacity Building ..........

- Smart and Sustainable Manufacturing
  - Innovative products
  - Innovative processes
  - Machines and Systems
- Sustainable Supply Chain
- Creative Value Chain
- Skilled and Creative HR

What is Required

- Industry 4.0?
- Smart and Modular Machines
- IOT - Bigdata, Process Analytics

Sustainable Development
- Economy
- Technology and Human Resources
- Environment
- Society
- Education & Training

Innovation
Creativity
Product Innovation – Is it a Challenge?

Indian Education System:
- Science and Engineering study are in isolation
- School Education is rather percentage focused
- No active and participatory learning
- Example: Manufacturing is taught by faculty who had never operated lathe

Social Obligation
- No importance to own passion
- We rather think more for comfort of next generation

Limited resources
- Look for Jugaad innovation: low cost solution and short cuts
- Low risk and short sight deliverables
- Passion towards imported technology that ensure RoI immediately

Poor Networking
- Throw on the wall approach: Everyone brings idea and thinks it works for everyone
- No room for other’s views
- Social status: Religions, political ideologies
- Poor ethical standards
Product-Process: Come with Engineers

- To package and serve processed water
- Four parts? List.....
- Are they same?
- What are the differences?
- Guess, how they are being manufactured?

- Four parts?: Bottle, cap, label, water
- Are they same?: No

- Say difference?
  - Material? ....different
  - Geometry and size? ..... different
  - Accuracy? ..... Non-uniform

- Making?
  - Process?...... different
  - Time?...... Different
  - Cost? ...... different
Separate but Collaborate and Cooperate

- 15-16 components
- 4-5 material
- Size all are different
- Highly precise

- How do you make?
  - Different processes
  - Measurement and testing
  - Precision assembly
CAR: Smart and Reliable but Economical

- ~ 15,000 parts
- Varieties of material
- Huge number of manufacturing processes
- Varying degree of assembly accuracy
- Manufactured by different vendors
- As an user, I want...
  - More features
  - High level of comfort
  - Looks good
  - Big/small
  - Cost? ... It should be less
  - Time? ... Today, if not now
- Do you think manufacturer’s job is easy?
- I am not a manufacturing engineer, am I responsible?, Is it my headache?....
- Everyone in the chain
  - Designer, control engineer, supplier, customer....
Manufacturing – Serves for All

- Removing material
- Shaping material
  - Change in phase
  - No phase change
- Adding material
- Assemble atoms
Active Learning

Why plan for ‘Active’ Lectures?

Problem of Attention span

Psychological constraints on learning:

Concentration drops with sustained and unchanging low level activity (such as sitting and listening), but to follow lecture content concentrated effort is required).

Students attention is typically maintained for _______ minutes???
Experiential Learning

I hear and I forget. I see and I remember. I do and I understand. – Confucius (Chinese Philosopher)
Academia – R&D Lab. - Industry

How can you do “active learning” in mathematics?

That just won’t work in engineering

We can’t afford to spend time to teach them skills that are unrelated to the core subjects?

PBL, isn’t that what we have been doing for the last 20 years with our student projects?

Retention, motivation, engagement, learning, blah!!
Policy and Management

- Multi-Institutional Pan India Consortium
- Sustainable Technology Development is Systematic Process - Follow Deming cycle
- Active learning is the key for great success
- Like minded people for right cause - Mantra
Conclusions

• First motivate ourselves to motivate others

• Our junior colleagues and students are the seeds of today and are the crops of the future

• Active learning is the key in Science and Engineering Education

• Students attention is typically maintained for ___ minutes???

• Made for India – Our weakness

• Make in India – Our Process

• Made in India – Our Pride
THANKS!

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Ph. 9449842675
Smart Machine tool and Intelligent Machining

Prakash Vinod
Scientist-F & Head-Nano Manufacturing Technology Centre
Central Manufacturing Technology Institute, Bengaluru
Outline

1. Introduction
2. Features of a smart machine tool
3. Introduction to Intelligent machining
4. Development of an Intelligent Ultraprecision Machine Tool
5. Intelligent Machining – CMTI initiatives
Introduction

- **Smart machine** is an intelligent device that uses machine-to-machine (M2M) communication and are able to make decisions and solve problems without human intervention.

- An **Intelligent machine tool** takes the CAD data, the materials and the set-up plans as inputs and can take autonomous decisions and produce accurate machined parts with quality, machine condition and productivity data as outputs.

- Machining processes evolved around Sensing, process model, knowledge base and process control is **intelligent machining**.

- Development of technology for smart machine tools and intelligent machining is one of focus area of CMTI activities.

- Improvement in accuracy of products, along with productivity and ease of operation is our targets for technology development in this domain.
Main Features of a smart machine tool

1. Adaptation to Changing conditions
2. Open Architecture CNC and sensor interface
3. Extensive Information processing capability
4. Real time compensation of Geometrical & Thermo-elastic displacement errors
5. Sensor based machine condition monitoring, Self Diagnostics
6. Tool condition monitoring
Main Features of a smart machine tool

1. Vibration and chatter control
2. Sensor based Process monitoring
3. Models for machining processes, Integration of sensory input with stored models and process optimization/Control
4. On Machine Metrology and automatic handling of work piece accuracy
5. Provision for sharing & storing knowledge, IOT enabled
Concept of a Intelligent machine tool

- Database
- Supervision
- CL Data Generation
- Servo Control
- Machine Drive
- Operator

Designed performance, Work material, accuracy required, workpiece geometry, Depth entry and exit

LEVEL 1

LEVEL 2 (Cutting Force, Temperature....)

LEVEL 3 (ON/OFF-line improvement with component measurement)

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Smart Machine tools – Enabling Technology – Recent developments

- Cloud Computing
- Big Data
- Cloud robotics
- Internet of Things
- Industry 4.0
- Digitalization
- IoT
- AI
- Automation

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What is Intelligent Machining

Machining processes
- Metal cutting
- Grinding

Sensors

Process Models

Intelligent Machining
Software Structure of Intelligent Machining

Data from the sensors

Filtering

Information
Features which condense important signal information

Learning

Knowledge:
Tool wear state,
Workpiece surface quality,
Process control
Benefit from Intelligent Machining

1. Enhance reliability
2. Improved accuracy
3. Increase efficiency
4. Prevent damage
Development of an Intelligent Ultra Precision Turning Machine
Intelligent Ultra Precision Turning Machine (iUPTM)

A state-of-the-art smart machine with intelligent features, developed by CMTI, for producing non-ferrous, IR and polymer components with optical quality. I UPTM a world-class, next generation machine tool with in-built intelligence.

Applications: Electro-optics, Space, Defense, Ophthalmic Industries, Photonics

Intelligent Machine error compensation
- Real-time Positioning,
- Geometrical & Thermo elastic error compensation taking feedback from sensors mounted on machine

Open architecture Motion Control
- Can integrate user-developed control algorithms

Intelligent Ultra Precision Turning Machine (iUPTM) developed at CMTI

Intelligent Machine Diagnostics
- Spindle & Slide Health Monitoring
- On Machine Spindle balancing
- Sensor fault detection
- Tool condition monitoring

Remote monitoring, diagnostics & control through internet

Intelligent Machining & Prognostics
- Surface error predictions for intelligent machining

Diamond Turned Mirrors on CMTI’s iUPTM for industrial applications
iUPTM – Features

Intelligent Ultraprecision Turning Machine

- Modular, Future upgradeable
- Open Architecture Motion Controller
- Linear Motor driven Aerostatic slide
- Natural Granite base
- Pneumatic Vibration isolator
- Sensors (Vibration, force, Temp., AE, Pressure, etc)
- Mist coolant system
- Vacuum holding of Job, Vacuum assisted chip extraction

Intelligence

- Real time machine error Correction (Geometric, positioning & thermally induced)
- Real time diagnostics (machine health, tool wear)
- Real time Prognosis
- On machine Dynamic Balancing
- Adaptive Control
- Intelligent machining
Real-time geometrical error compensation module

- Development of error synthesis model using HTM method
- Formulation of error correction vector for the X axis and Z axis
- Error mapping using laser interferometer system for measurement of linear position error, straightness error, orthogonal error, and angular errors
- Designing the neural network and training it with the measured data.
- Extracting the key network parameters (weights and biases) and programming the real-time calculations.
- Development of a ‘C’ program for real-time calculation of errors for compensation using error correction vector

Block diagram of Real time Geometrical error compensation module
Real Time Geometrical error compensation module - Volumetric error plot for correction
Geometrical error correction of X-axis in real time through NN based program

Linear Error VS Position

Pitch Error VS Position

Yaw Error VS Position

Roll Error vs Position

Vertical Straightness Error Vs Position

Horizontal Straightness Error VS Position

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Geometrical error correction of X-axis in real time through NN based program.
The Thermal induced displacement Errors can be reduced from 50 micrometres to 3 micrometres with the compensation system.
Improvement in Machining accuracy with Real Time thermal error compensation

**Problem Statement:** The radius used to go out of specification after machining of 5 to 6 components.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radius (mm)</td>
<td>3.288 ± 0.001</td>
</tr>
<tr>
<td>Form (µm)</td>
<td>1.2</td>
</tr>
</tbody>
</table>

Spherical profile component machined in DTM

---

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Real-time Thermal Error Compensation Strategy for Precision Machine tools

- Real-time Temperature Acquisition
  - "C" Program reads the temperature values
  - "C" Computes the thermal deformation errors based on NN
- Motion Controller - Position correction
  - Writes the deformation errors in global variable

Part program/user program
- Task 1
- Task 2

Real-time thermal error compensation module ("C" program) and offset correction

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Online Health Monitoring Of Machine Tool Spindle

Features:

• Autonomous, in-situ spindle health monitoring system based on sensor feedback
• Online spindle problem identification using frequency analysis.
• HMI provides “a basic window for machine operators” and another window for “advanced diagnostics” with alarms.

Tools used

• LabVIEW for Data Acquisition, Signal Processing and Human-Machine interface layers
• MATLAB for Health Assessment and Prognostics layers
• Vibration Data accusation & FFT analysis using NI DAQ Card/Labview has been tried out
• HMI Development & Diagnostics using Labview
Tool Condition Monitoring in Ultra Precision Machining

Diagram showing the process:
- Signal - sensor
- Cutting forces: $F_x, F_y, F_z$
- Signal processing
- Decision making
- Data processing
- Result
**Features:**

- The system has Sensors, Signal processing stages, Tool wear estimation & Decision making systems.
- User-friendly human-machine interface for decision making.
On-Machine Dynamic Balancing

Flow Chart for balancing module

Tools Used:
- Accelerometer & Tacho Probe/Encoder
- Matlab Data Acquisition/
  LabVIEW
- Data Acquisition Card
- Connector Block
Optical Tool Set Station (OpToSS):

- Tool Radius Measurement
- Tool Position offset (X & Z)
- Tool Height Setting (within 6µm)
- Tool Inspection (Damage & Wear)
- Light Intensity Control for Diamond & CBN Tools

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Accuracy</strong></td>
<td>≤ 5 µm</td>
</tr>
<tr>
<td><strong>Kinematic mount</strong></td>
<td>≤ 1.6 µm</td>
</tr>
<tr>
<td><strong>Repeatability</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Resolution</strong></td>
<td>0.8 µm</td>
</tr>
<tr>
<td><strong>Approx. Weight</strong></td>
<td>2.5 Kg</td>
</tr>
</tbody>
</table>

(Ergonomically designed for ease of handling and mounting)
Optical Tool Set Station (OpToSS)
Sensor Failure Detection using Principal Component Analysis

- In iUPTM, multiple sensors are used for error compensations, diagnostics, and prognosis.
- Any failure in those Sensors can cause process disturbances, loss of control, and loss of performance.
- Sensor degradations are difficult to detect and identify due to correlative interactions.
- Automatic detection and identification of sensor faults is an asset for effective monitoring and control of the process.

Pre-Process

Reference Data (from sensors) → Scaled data → Covariance → Eigen Values & Eigen Vectors → Number of PCs → PC Related Eigen Value, Vector → SPE Limit

New Data Test

Scale New Data → Calculate Transform matrix → Calculate residual → Calculate individual score → Detecting Fault → Contribution plot
IOT Enabled “SMART” Metal Cutting Machine - empowering a Legacy Machine @CMTI

Smart features

Sensor modules
- **Temperature**: Machine thermal plot
- **Vibration**: Machine health
- **Evaluate TcP**: (tool center point) drift
- **Pressure**: Spindle coolant pressure
- **Energy**: Downtime of the machine
- **Vision**: In-situ inspection / Quality

Machine Tool: Milling Machine (5 axis VMC)

Dashboard

Outcome
- Generate diagnosis reports / action plan
- Classify reports based on severity
- Enable deep dive information for better process understanding
- Establish data base for further analytics

Outputs
- IOT enabled connected machine
- Remote access of machine health and process data
- Real time Machine health monitoring
- Energy monitoring
- Better process monitoring
- Reduced machine down time

Dashboard

Energy Monitor

Spindle Health Monitoring

Part Quality Check

Output

Generate diagnosis reports / action plan

Classify reports based on severity

Enable deep dive information for better process understanding

Establish data base for further analytics
A IOT enabled Control GUI has been developed to control the 3D printer in a closed loop. The following features have been implemented.

- Cloud based 3D printing by uploading G-code via any internet connected device, i.e. Mobile Phones & Tablets.
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- A complete live fabrication process can be viewed online via IOT process monitoring camera.
A complete IOT based dash board has been developed for process monitoring of an additive manufacturing machine. It monitors temperature of extruder, base plate & motors along with ambient humidity inside the machine & with material feed monitoring.
PREDICTION OF SURFACE FINISH IN DIAMOND TURNING PROCESS
Design of experiments

### Machine Specifications

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Max. Work piece Size</td>
<td>400 mm Dia.</td>
</tr>
<tr>
<td>2</td>
<td>Surface Finish (Ra)</td>
<td>≤ 10.0nm</td>
</tr>
<tr>
<td>3</td>
<td>Speed range, rpm</td>
<td>50-7000</td>
</tr>
<tr>
<td>4</td>
<td>Load Capacity</td>
<td>85 Kg</td>
</tr>
<tr>
<td>5</td>
<td>No. of Axes (X,Z,C)</td>
<td>3</td>
</tr>
</tbody>
</table>

**Work piece:** Aluminium 6061 T6, Shape: Flat

**Tool:** Natural mono crystalline diamond tool, Zero Rake angle, nose radius of 3mm.

**Vibration measurements:** Uniaxial Piezo-electric accelerometer and Vibration analyser

**Surface roughness measurements:** Optical Profiler
Independent variables:

- Cutting conditions:
  - Speed (S)
  - Feed (f)
  - Depth of Cut (doc)

- Vibration from Process:
  - Vibration in tangential cutting force direction, Vx
  - Vibration in feed direction, Vy
  - Vibration in thrust cutting force direction, Vz

Dependent variable: Surface finish

The final equation obtained to estimate the surface finish is:

\[
\text{Surface finish} = 5.7356 - 0.0003S - 0.0018f + 0.0313doc + 48.0286Vx - 197.563Vy + 150Vz
\]
Neural network architecture for prediction of surface roughness
## Prediction of Surface Roughness

<table>
<thead>
<tr>
<th>Exp. No.</th>
<th>Measured Ra (nm)</th>
<th>By ANN</th>
<th>By MRA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Measured Ra (nm)</td>
<td>% Error</td>
<td>Estimated Ra (nm)</td>
</tr>
<tr>
<td>1</td>
<td>6.48</td>
<td>0.04</td>
<td>6.25</td>
</tr>
<tr>
<td>2</td>
<td>6.46</td>
<td>0.21</td>
<td>6.21</td>
</tr>
<tr>
<td>3</td>
<td>6.39</td>
<td>0.05</td>
<td>6.02</td>
</tr>
<tr>
<td>4</td>
<td>6.94</td>
<td>9.60</td>
<td>6.58</td>
</tr>
<tr>
<td>5</td>
<td>6.97</td>
<td>1.45</td>
<td>6.75</td>
</tr>
<tr>
<td>6</td>
<td>6.08</td>
<td>0.19</td>
<td>5.98</td>
</tr>
<tr>
<td>7</td>
<td>4.74</td>
<td>9.70</td>
<td>4.87</td>
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<tr>
<td>8</td>
<td>6.09</td>
<td>0.07</td>
<td>6.25</td>
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<td>9</td>
<td>5.44</td>
<td>1.20</td>
<td>6.39</td>
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<td>10</td>
<td>5.94</td>
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<td>5.55</td>
<td>0.00</td>
<td>5.79</td>
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<td>12</td>
<td>5.29</td>
<td>0.22</td>
<td>5.02</td>
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<td>6.42</td>
<td>0.33</td>
<td>6.75</td>
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<td>5.99</td>
<td>5.05</td>
<td>6.08</td>
</tr>
<tr>
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<td>0.13</td>
<td>6.34</td>
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<tr>
<td>16</td>
<td>6.14</td>
<td>4.99</td>
<td>6.32</td>
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<td>0.68</td>
<td>4.86</td>
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<td>5.89</td>
<td>0.13</td>
<td>6.12</td>
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<td>6.33</td>
<td>0.54</td>
<td>6.48</td>
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<td>5.26</td>
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</tr>
<tr>
<td>25</td>
<td>5.67</td>
<td>6.85</td>
<td>5.55</td>
</tr>
</tbody>
</table>
Comparison of measured and estimated values of surface roughness
Results of the validation experiments using On Machine roughness prediction module
Thank you
Spindle Health Monitoring of the Machine

- Frequency: 4.42 Hz
- Max. Vibration Amplitude X: 0.00 g
- Max. Vibration Amplitude Y: 0.01 g
- Max. Vibration Amplitude Z: 0.00 g
- Unbalance Fault: ●
- Looseness Fault: ●
- Misalignment Fault: ●
- Structural Resonance: ●
- Tool Wear: ●
- Abnormal Process Parameters: ●
- External Disturbances: ●
- Spindle speed limits: ●
Smart Sensors & Controls

V. Shanmugaraj
Central Manufacturing Technology Institute (CMTI)
Bangalore
Internet of Things (IoT)
Smart Sensors & Controls

Smart Manufacturing (IIoT)
Smart Sensors & Controls

Sensors

- Macro (Conventional)
- Micro (MEMS – Micro Electro Mechanical Systems)
Smart Sensors & Controls

**Sensors**
- Temperature (upto 10Hz)
- Pressure
- Flow
- Force
- Torque
- Accelerometers (upto 20 KHz)
- Load Cells
- Acoustic (1 MHz)
- Displacement
- Velocity
- RFID
- Gyroscopes
Temperature Sensors

- RTDs (Resistive Temperature Detecting)
- Thermistors
- Thermo-couples

- Factors
  - Temperature Range
  - Sensitivity
Pressure Sensors

- **Absolute** – A Sensor that Measures Input Pressure in Relation to a Zero Pressure – **Altitude Measurement**

- **Differential** – A Sensor that Is Designed to Accept Simultaneously Two Independent Pressure Sources. The Output Is Proportional to the Difference Between the Two Sources – **Airspeed Measurement**
Smart Sensors & Controls

Flow Sensors

- Variable Area (rotameters)
- Rotating Vane (paddle & turbine)
- Positive Displacement
- Differential Pressure
- Vortex Shedding
- Coriolis Mass
- Ultrasonic
Smart Sensors & Controls

Force Sensors
  – Piezo electric
  – Strain Gauge

Torque Sensors
  – Strain Gauge
Smart Sensors & Controls

Accelerometers

- Piezo Resistive
- Piezo Electric
- Strain Gauge
- Inductive
Smart Sensors & Controls

Load Cells
- Tensile
- Compression
- Bending Beam
- Strain Gauge

Displacement Sensors
- Capacitive
- Eddy Current
Smart Sensors & Controls

Transduction Principle

- Change in Voltage
- Change in Current
- Change in Resistance
- Change in Capacitance
- Change in Impedance
- Change in Magnetic Field
Smart Sensors & Controls

• Outcome
  – Machine status monitoring
  – Higher Productivity
  – Lower down time of the machine
  – Preventive maintenance
  – Better utilization of Resources
Precision and Smart Metrology

K. Niranjan Reddy
Scientist - E & Head – UPE
CMTI, Bangalore.
If You Measure

“Do it with Utmost Care”

and

“Remember the Measuring Errors”
The Science of Precision Measurement

“METRO” & “LOGY” are Greek Words

Meaning

“Measurement” and “Science”

Respectively
Metrology Started in Ancient Egypt in 2750 BC

First Unit of Length Was Cubit

Cubit - Length of the Reigning Pharaoh's Forearm
• Started in 1775 with Wilkinson machining a \( \phi 1800 \) mm bore to 1 mm accuracy

• Today conventional precision machining is being carried out to dimensional accuracies of 1 \( \mu \)m on 100 mm length
Dimensional Accuracies Since 1900
What is 1 μm

Human hair
φ 50 μm

1 nm = 1/1000 μm
What is 1 arc sec

Human hair $\phi$ 50 $\mu$m
The Goal of Metrology

- Accept good products
- Reject bad products
- Better to reject few good ones than to accept a few bad ones
Classification of Metrology

- Dimensional Metrology
- Surface Metrology
- Co-Ordinate Metrology
- Mass Metrology
- Force Metrology

and So on .....
BASIC TERMINOLOGIES
RESOLUTION (of a displaying device)

Smallest value that can be indicated by the displaying device.

or

Smallest difference between indications of a displaying device that can be meaningfully distinguished.
**ACCURACY**

Closeness of agreement between the result of measurement and the true value of the measurand.

**PRECISION**

Closeness of agreement between the results of successive measurements of the same value of a quantity carried out under identical conditions at short intervals of time.

(Precision is also called Repeatability)
Precise but not Accurate

Accurate but not Precise

Precise and Accurate
REPRODUCIBILITY

Closeness of agreement between corrected results of measurements of the same value of a quantity when the measurements are made under different conditions.

RELIABILITY

The ability of an item to perform a required function under stated conditions for a stated period of time.
Material measure or physical property which defines or reproduces the unit of measurement of a base or derived quantity.
Types of Measurement Standard

- Fundamental or Absolute Standard
- International Standard
- National or Primary Standard
- Reference Standard
- Secondary Standard
- Working or Standard
TRACEABILITY

The concept of establishing valid calibration of a measuring standard or instrument by step-by-step comparison with better standards up to an accepted national or international standard.
Primary Standard of Length (Metre)
Established by Interferometry

Secondary Standard of Length
Verified by Interferometry

Grade “00” Slip gauges Calibration Grade
Verified by Interferometry

Grade “0” & “1” Slip gauges
Verified by high magnification comparator

Grade “2” Slip gauges
Verified by high magnification comparator

Work piece
Verified by suitable gauging practice

The metre is defined as the length of the path travelled by light in a vacuum in $\frac{1}{299\ 792\ 458}$ second.
Length Traceability at CMTI

SI Unit ‘Metre’

NPL - India

Grade ‘K’ Slip gauges
Reference Standard

Mahr (DAKKS) - Germany

Grade ‘K’ Slip gauges
(Special set for GBC)
Reference Standard

Gauge Block Comparator

DKD (DAKKS) - Germany

Step Gauge
Reference Standard

Step Gauge
Secondary Standard

Grade ‘K’ Slip gauges
Sec Standard

Grade ‘0’ Slip gauges
Sec Standard

Grade ‘K’ & ‘0’ Slip gauges

Grade ‘1’ & ‘2’ Slip gauges

Metrology Equipment/Machine Tools

Step Gauge/Caliper Checker/Check Master
Factors affecting the Accuracy of Measurements

- **S**: Factors affecting the Standard
- **W**: Factors affecting the Work-piece
- **I**: Factors affecting the Measuring Instruments
- **P**: Factors affecting the Person
- **E**: Factors affecting the Environment
Environmental Effects:

- Room Temperature
- Part Temperature Stabilization
- Temperature Variation
- Humidity
- Vibration Level
- Dust Level
- Air Flow
- Lighting
Precision Metrology Laboratory at CMTI

NABL Accredited Dimensional Metrology Lab

Lab conforms to ISO/ IEC 17025:2005

Measurement of Dimension, Form, Surface Texture and Gear Parameters

“India’s one of the kind metrology lab that is housed 6m below ground”
Temp: 20 ± 0.5°C
Vibration: < 0.2 μm
Noise: <60 dB
Clean Room Class: 10,000

“India’s one of the kind metrology lab that is housed 6m below ground”
Dimensional Metrology at CMTI

Ultra Precision Co-ordinate Measuring Machine

Co-ordinate Measuring Machine

Gauge Block Interferometer
Surface Metrology at CMTI

- Form profiler
- Roughness Tester
- Flatness interferometer
- Optical Profiler
Current Status: In the country most of these artefacts (>90%) are being imported.
Technical Data
Graduation Pitch : 0.1 mm
Graduation thickness : 12 µm
Grating Accuracy : < 2 µm

<table>
<thead>
<tr>
<th>Range</th>
<th>L</th>
<th>W</th>
<th>T</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-150 mm</td>
<td>175 mm</td>
<td>20 mm</td>
<td>5 mm</td>
</tr>
<tr>
<td>0-10 mm</td>
<td>75 mm</td>
<td>20 mm</td>
<td>5 mm</td>
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</tbody>
</table>

Linear Standard Glass Scales

Angular Standard Glass Scale

In-house facility used:
1. Femtosecond laser micromachining system
2. Confocal Microscope
3. Ultra Precision CMM
Transformative Forces Reshaping the Future of Metrology

- Big Data
- Augmented Reality
- Simulation
- Additive Manufacturing
- Industrial Internet
- Cyber Security
- Enterprise Integration
- Inline Inspection
The need for Smart Metrology

Correct Decisions

Reliable Information

Reliable Data

Smart metrology

Zero-defect products
## Smart Metrology Challenges

<table>
<thead>
<tr>
<th>Category</th>
<th>Challenges</th>
</tr>
</thead>
<tbody>
<tr>
<td>Product flow</td>
<td>• Measurement time&lt;br&gt;• Accessibility of features&lt;br&gt;• Motion and handling...</td>
</tr>
<tr>
<td>Environment</td>
<td>• Temperature&lt;br&gt;• Humidity&lt;br&gt;• Vibrations, contamination...</td>
</tr>
<tr>
<td>Diversity</td>
<td>• Multiple features per product&lt;br&gt;• Variation between products</td>
</tr>
<tr>
<td>Data handling</td>
<td>• Task-specific uncertainty,&lt;br&gt;• Numerical accuracy and Data integrity&lt;br&gt;• Data fusion from multiple sensors...</td>
</tr>
</tbody>
</table>
Factors to consider in adapting Smart Metrology

INLINE METROLOGY

NON-CONTACT: OPTICAL AND LASER SYSTEMS

ROBOTS
Smart Metrology Lab

Manual Inspection Data

Auto Ballooning

CMM Data

Cloud / Server

Inspection Reports

Wireless Measuring Instruments Data

Quality Control
<table>
<thead>
<tr>
<th>Smart Inspection</th>
<th>Smart Data Management</th>
<th>Smart Quality Management</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Automatic generation of Inspection Data sheet</td>
<td>• Integration across</td>
<td>• Improved Traceability</td>
</tr>
<tr>
<td>• Wireless exchange of inspection data</td>
<td>• Inline</td>
<td>• Statistical Process control data (Cp,Cpk)</td>
</tr>
<tr>
<td></td>
<td>• Manual</td>
<td>• Customized Inspection reports</td>
</tr>
<tr>
<td></td>
<td>• CMM Inspection</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Real Time Data Visualisation</td>
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</tbody>
</table>

Smart Metrology Lab
Smart Inspection

Smart Inspection Facility encompassing

- Smart Measuring Instruments
- Smart Quality Monitoring
- Smart Process Monitoring

Smart Inspection Lab
A smart inspection and data management application for digital metrology is setup. The application would collect, store, present digital data from Smart Bluetooth enabled instruments and data from other instruments/equipments/gauges and CMM. Data analytics such as Cp, Cpk are also performed to provide process capability information.
The system was developed for comparing manufactured dimensions of the components with that of the designed dimensions, record the deviations and indicate whether the component can be accepted, rejected or needs rework.

- Automatic gauging significantly cuts down the inspection time
- Eliminates human measurement error
- Measured data is stored and accessed from the PC for statistical analysis.
- Online correction for the dimensional variation by automatically feeding the result of inspection to CNC system

**Highlights:**

- Automated Measurement of Internal Thread Parameters, Form Errors and Dimensions
- 18 Parameters measured and documented in just over 3 minutes
Multi Sensor Implementations

Parallel Sensor Implementation on a Co-ordinate Measuring Machine

Changeable Sensor Implementation on Surface Texture Measuring Device
Automated Integrations

Faster metrology due to the automated integration of a CMM into material flow by Robot loading.
Measurement of X-offset / Tool Radius as well as automatic quick correction for it from direct measurement of a production asphere.
Success is a new dimension.

One stop solution for a complete range of dimensional, form, gear and surface roughness measurement & calibration accredited by NABL.

From Ultra precision CMMs to Gauge block interferometer, Flatness interferometer to Nano surface optical profiler, our calibration services guarantee your success.

Thank you

Central Manufacturing Technology Institute, Tumkur Road, Bangalore – 560022
Central Manufacturing Technology Institute
A Forerunner in Manufacturing Technologies

Abhishek Suchak
Scientist B
Centre In-charge
Central Manufacturing Technology Institute
(Regional Centre-Rajkot)

Rajkot, 13.04.19
Regional Centre

Catering industries across India

Background Image: SEM image of cross section of layered Electroless plating of Nickel
About Rajkot Centre

- CMTI established a Regional Centre in Rajkot in 2002 operating from NSIC campus.
- Supports industries in Dimensional Metrology and Material Testing
- Supports MSMEs in and around Gujarat and Western belt of India

Current Beneficiaries
Objectives

- Services to SMEs in the field of Dimensional metrology, Material and Metallurgical Testing.
- Provide consultancy services to industries in the region for establishing manufacturing, test and calibration facilities and transfer of advanced manufacturing technologies to enable faster growth of industries.
- Transfer of latest technologies to the industries through training, seminar and workshops.
- To provide Practical Metrology knowledge to the Engineering Students through workshops.
Facilities

- **Calibration and Inspection**
  - Facilities :-
    - Slip Gauge Comparator
    - CMM
    - Form Tester
    - Surface Roughness Tester
    - Electronic Level
    - Digital Height Gauge
    - Pressure Gauge Calibration

- **Material analysis and Metallurgical services**
  - Facilities :-
    - Spectrometer for Ferrous & Non ferrous Alloys
    - Hardness Tester
    - Metallurgical Microscope
    - Image Analyser
Facilities

Measurement & Scanning

Facilities :-
- 2D/3D Dimension Measurement
- High Precision Measurement
- Reverse Engineering
- Form Measurement analysis
- Profile Measurement & Scanning etc.

(Co-ordinate Measuring Machine)  (Form Tester)

Machine Tool Testing

Facilities :-
- Laser Measurement System
- Ball Bar System etc.
Scope of Future Expansion

CMTI Regional Centre-Rajkot

Offering technological consultancy through in-house R&D, Measurement and Calibration services and Human Resource Development
Scope

• NABL Accreditation
• Gear Testing Machine & Software to analyze Pressure angle, Module, Teeth Profile etc.
• Contour Measuring Machine to cater more complex profiles
• CAD lab to assist MSME in Reverse Engineering
• Coating Thickness Machine to measure coating thickness
• CAM Profile Measuring Machine to check CAM profiles
• Upgradation of Existing LMM to serve various components
• Dedicated Training Programmes for Industries, Engineering Students & Engineering Faculties
Thank you
Looking forward to hear from you