



KNOWLEDGE INCUBATION FOR TEQIP, IIT KANPUR

## TEQIP Workshop on Machining Dynamics

July 18 - 22, 2016



Machine tools play a vital role in the development of nations. With this in mind a 5 day workshop on **Machining Dynamics** was organized at IIT Kanpur from July 18 – 22, 2016. This workshop was geared towards introducing those technologies that make possible higher utilization of machine tools.

The workshop introduced the essential theory to model machining processes, machine tool dynamics and models to characterize process-machine interactions to predict and avoid unstable chatter vibrations. Hands-on experimental testing of machine dynamics, cutting force characterization and chatter detection and avoidance enabled the participants to improve their understanding of this highly technical and non-intuitive field.

Engineering faculty, students, researchers in R&D labs along with personnel working in machine tool/cutting tool developer and user industries were the target audience. Learning from this workshop helped faculty to motivate students to address challenges faced by the manufacturing enterprise.

## Topics Discussed

- **Machining process modelling:**
  - Introduction to orthogonal and oblique cutting models.
  - Model milling processes to predict cutting forces.
- **Experimental characterization of turning and milling processes:**
  - Instrument machines to measure cutting forces.
- **Fundamentals of machine tool vibrations:**
  - Introduction to single and multiple degrees of freedom models.
  - Introduction to free and forced vibration analysis, and analytical modal analysis.
- **Experimental modal analysis:**
  - Instrument machines to measure dynamics.
- **Process-machine interaction chatter models:**
  - Introduction to machine tool chatter models.
- **Experimental characterization and avoidance of chatter:**
  - Instrument machines to experimentally detect and avoid chatter.
  - Strategies to experimentally detect and avoid chatter.
  - Demonstrations of improved productivity and machine tool utilization.
- **Advanced topics in control of machine tool vibrations and design to mitigate vibration**

## List of Speakers

- Prof. Mohit Law, IIT Kanpur
- Prof. Sounak Choudhury, IIT Kanpur
- Prof. Shakti Gupta, IIT Kanpur
- Prof. J Ramkumar, IIT Kanpur
- Prof. Pankaj Wahi, IIT Kanpur
- Prof. Ramesh Singh, IIT Bombay
- Prof. Abhijit Ganguli, IIT Delhi
- Prof. Jin, Xiaoliang, Oklahoma State University
- Shri. Mohanram, IMTMA, Bengaluru

## Participating Institutes

Institute	Number of Participants
M.J.P. Rohilkhand University, Bareilly	1
PES Institute of Technology, Bangalore	2
IFTM University, Moradabad	3

HBTI Kanpur	2
Government College of Technology, Coimbatore	1
PEC University of Technology, Chandigarh	1
UVCE, Bangalore University	1
Dr. BabasahebAmbedkar Technological, Lonere, Raigad	1
IIT Madras	3
MMMUT, Gorakhpur	3
G. B. Pant University of Agriculture and Technology, Pantnagar	2
Government Engineering College, Ajmer	1
BIET Jhansi	2
Kennametal Shared Services Pvt. Ltd	2
Dr. KalamCenter for Innovation, Bharat Fritz Werner Ltd., Bangalore	1
Ace Manufacturing Systems Limited, Bangalore	3
<b>Total</b>	<b>29</b>

### Workshop Schedule

#### July 18, 2016

<b>Time</b>	<b>Event</b>
8:30 – 9:00 AM	<b>Registration</b>
9:00 – 9:30 AM	<b>Overview</b> <i>Dr. Law IITK</i>
9:30 – 10:30 AM	<b>Orthogonal cutting</b> <i>Dr. SChoudhury, IITK</i>
10:30 – 11:00 AM	<b>Tea Break</b>
11:00 – 12:30 PM	<b>Oblique cutting</b> <i>Dr. S Choudhury, IITK</i>
12:30 – 2:00 PM	<b>Lunch Break</b>
2:00 – 3:30 PM	<b>Oblique cutting</b> <i>Dr. S Choudhury/Dr. Law, IITK</i>
3:30 – 4:00 PM	<b>Tea Break</b>
4:00 – 5:30 PM	<b>Milling process modelling</b> <i>Dr. Law, IITK</i>

#### July 19, 2016

<b>Time</b>	<b>Event</b>
9:00 – 10:30 AM	<b>Fundamentals of vibration</b> <i>Dr. Shakti Gupta, IITK</i>
10:30 – 11:00 AM	<b>Tea Break</b>
11:00 – 12:30 PM	<b>Free and forced vibration analysis</b> <i>Dr. Shakti Gupta, IITK</i>
12:30 – 2:00 PM	<b>Lunch Break</b>

2:00 – 3:30 PM	<b>Experimental characterization of machining processes</b> <i>Dr. Law, IITK</i>
3:30 – 4:00 PM	<b>Lunch Break</b>
4:00 – 5:30 PM	<b>Experimental characterization of machining processes</b> <i>Lab Session</i>

**July 20, 2016**

<b>Time</b>	<b>Event</b>
9:00 – 10:30 AM	<b>Chatter models for turning</b> <i>Dr. Law, IITK</i>
10:30 – 11:00 AM	<b>Tea Break</b>
11:00 – 12:30 PM	<b>Chatter models for milling</b> <i>Dr. Jin, OSU, USA</i>
12:30 – 2:00 PM	<b>Lunch Break</b>
2:00 – 3:30 PM	<b>Experimental modal analysis</b> <i>Dr. Law, IITK</i>
3:30 – 4:00 PM	<b>Lunch Break</b>
4:00 – 5:30 PM	<b>Experimental modal analysis</b> <i>Lab Session</i> <b>Condition monitoring of machines</b> <i>Dr. J Ramkumar, IITK</i>

**July 21, 2016**

<b>Time</b>	<b>Event</b>
9:00 – 10:30 AM	<b>Chatter models for micro-milling</b> <i>Dr. Jin, OSU, USA</i>
10:30 – 11:00 AM	<b>Tea Break</b>
11:00 – 12:30 PM	<b>Advanced topics on chatter in micro-milling</b> <i>Dr. Singh, IITB</i>
12:30 – 2:00 PM	<b>Lunch Break</b>
2:00 – 3:30 PM	<b>Nonlinearities in chatter</b> <i>Dr. Wahi, IITK</i>
3:30 – 4:00 PM	<b>Lunch Break</b>
4:00 – 5:30 PM	<b>Experiments on chatter</b> <i>Lab Session</i>

**July 22, 2016**

<b>Time</b>	<b>Event</b>
9:00 – 10:30 AM	<b>Advanced topics on chatter</b> <i>Dr. Wahi, IITK</i>
10:30 – 11:00 AM	<b>Tea Break</b>
11:00 – 12:30 PM	<b>Control of machine tool vibrations</b> <i>Dr. Ganguli, IITD</i>
12:30 – 2:00 PM	<b>Lunch Break</b>
2:00 – 2:45 PM	<b>Machine tool vibration - industry perspective</b> <i>ShriMohanram IMTMA</i>

2:45 – 4:00 PM	<b>Machine tool/cutting tool design to mitigate vibration</b> <i>Dr. Law, IITK</i> <i>Closing</i>
4:00 PM	<b>Tea Break</b>

### **Faculty Feedback**

#### **Workshop**

<i>Questions</i>	<i>Excellent</i>	<i>Good</i>	<i>Ordinary</i>
Clarity of communication about workshop	09	03	00
Organization of the sessions	12	01	00
Quality of lectures	13	01	00
Effectiveness of discussions	08	05	00
Effectiveness of learning experience	07	08	00
	<i>Appropriate</i>	<i>Short</i>	<i>long</i>
Duration of workshop	06	04	01
	<i>Definitely</i>	<i>Maybe</i>	<i>No</i>
Would you like to have more such sessions?	12	02	00
Would you like e-lectures by experts on special topics?	12	00	00
Suggest specific topic that you would like additional expert lectures on	<ul style="list-style-type: none"> <li>• Difference software used.</li> <li>• Experimental work.</li> <li>• Design &amp; development in m/c tool systems using m/c dynamics.</li> <li>• Manufacturing automation, non-conventional machining process etc.</li> <li>• Active damping</li> <li>• A course on how FEA modelling can be done for different manufacturing process biomaterial processing.</li> <li>• Modal analysis, non-linear chatter control in detail.</li> <li>• More practical sessions would be appreciated.</li> <li>• Advancement by materials technology advanced vibrations.</li> <li>• Advanced Tooling.</li> <li>• Relating Machine tool design.</li> <li>• More explanation on importance of variable and their practical applications.</li> </ul>		

Additional Suggestions	<ul style="list-style-type: none"> <li>• Lectures are mostly mathematical as the subject requires however, some physical demos (application) can be included to make it more interesting.</li> <li>• Lab visit to different labs &amp; industrial visit.</li> <li>• Collaboration of IITs with other educational organization may help in enhancing our knowledge.</li> <li>• Providing hard/soft copy of course material in advance will help get insight about the session.</li> </ul>
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### Teaching

Which subjects do you teach?	<ul style="list-style-type: none"> <li>• Engg. Mechanics, Strength of Material, Thermodynamics, Fluid Mechanics</li> <li>• Vibration analysis.</li> <li>• Manufacturing Science, CAD/CAM non-conventional.</li> <li>• Machine design, Mechanics, Strength of Materials.</li> <li>• CAM, Manufacturing Sc. &amp; Engg.</li> </ul>		
What is average student to teacher ratio in your institute?	<ul style="list-style-type: none"> <li>• 15:01</li> <li>• 16:01</li> </ul>		
<b>Questions</b>	<b>YES</b>	<b>NO</b>	
Do you have additional support for teaching (tutors, graders, teaching Assistants etc.)?	04	03	
Do you give class projects for UG classes?	06	01	
Do you give class projects for PG classes?	06	01	
Do you have sufficient resources for laboratory courses?	02	05	
	<b>Sufficient</b>	<b>Inadequate</b>	
Is the library/journal/e-connection support adequate?	06	02	
	<b>Definitely</b>	<b>May be</b>	<b>No</b>
Would you like to have common (TEQIP) repository of course material?	08	00	00
Would you like to visit IITK to participate in and develop course material (existing or new)	07	02	00

Would you like to participate in creation of the repository material (course files/lab, Manuals/question bank/etc)	05	03	00
	<i>e-courses</i>	<i>Works</i>	<i>Content</i>
How can IITK effectively help you prepare for	05	07	00
How can TEQIP help improve your teaching?	<ul style="list-style-type: none"> <li>• By TEQIP courses we obtain the exposure &amp; inside knowledge of subjects.</li> <li>• TEQIP help us to upgrade our knowledge level by conducting such types of workshops/programs etc.</li> <li>• TEQIP helped us to have an access of knowledge &amp; experience of the faculty of institute like IIT &amp; IIM through various courses conference/workshops.</li> <li>• Through intensive teaching &amp; providing funds for projects.</li> <li>• Understanding &amp; delivering the sub stuff.</li> <li>• By attending workshops and by e-courses we could do better.</li> <li>• Good knowledge sharing.</li> </ul>		

### Research

<i>Questions</i>	<i>Definitely</i>	<i>Maybe</i>	<i>No</i>
Would you like to visit an IIT for a visiting-faculty/ post-doctoral fellow, if offered (via-TEQIP)?	09	02	00
Would you like to share/use research infrastructure at IITK, if made available?	11	01	00
Would you like to conduct collaborative research with IITK?	11	01	00
Would you like lectures by experts (Indian and international) on niche research areas/topics?	10	00	00
Do you want special-topic conferences?	08	02	01



How can TEQIP help improve your research?	<ul style="list-style-type: none"> <li>• Can arrange extra-talks apart from sessions with experts for better understanding of the topics.</li> <li>• TEQIP help us by conducting visiting research programs and by other events to do some new R&amp;D work in our field of specialization.</li> <li>• It might help to build our machines in better way.</li> <li>• TEQIP helped us to process various apparatus &amp; instruments useful for different research to various conference also help us to progress effectively.</li> <li>• Through focussed workshops and funds for thrust area projects.</li> <li>• By making more collaboration with other institution with IITs/NITs and conducting collaborative workshops, lectures.</li> <li>• Frequent meetings with professors here &amp; workshops conference etc.</li> <li>• Inviting more people from industry and selecting more specific topic and more lab or experimental setup will help</li> </ul>
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### **Student Feedback**

#### **Workshop**

<i>Questions</i>	<i>Excellent</i>	<i>Good</i>	<i>Ordinary</i>
Clarity of communication about workshop	08	02	00
Organization of the sessions	10	00	00
Quality of lectures	05	05	00
Effectiveness of discussions	05	04	01
Effectiveness of learning experience	04	06	00
	<i>Appropriate</i>	<i>Short</i>	<i>Long</i>
Duration of workshop	05	05	00
	<i>Definitely</i>	<i>Maybe</i>	<i>No</i>
Would you like to have more such sessions?	10	00	00
Would you like e-lectures by experts on special topics?	09	00	00



Suggest specific topic that you would like additional expert lectures on	<ul style="list-style-type: none"> <li>• Laminates &amp; composites (Material Science)</li> <li>• Composite Materials</li> <li>• Non traditional machining, composite materials, super conductors joining process.</li> <li>• Soft computing technique along with MATLAB</li> <li>• Mathematical modelling in machining.</li> <li>• Robotics.</li> <li>• MATLAB, Ansis software learning</li> <li>• Vibration control in MK tool structure.</li> </ul>
Additional Suggestions	<ul style="list-style-type: none"> <li>• Please also orientate us about the career or future scope as we are related to design engg.</li> <li>• All lectures should be in morning session and lab sessions in evening afternoon session.</li> <li>• Arrange such workshops again.</li> <li>• 5 days time is not sufficient for such like innovative workshop. Please increase number of days and decrease time duration little bit per day.</li> <li>• There should be more lectures from industry people.</li> </ul>

### Learning

<i>Questions</i>	<i>Yes</i>	<i>No</i>
Do you get enough class projects?	08	00
Is the learning adequate?	08	00
Do you have sufficient resources for laboratory courses?	07	01
What is your area of specialization	<ul style="list-style-type: none"> <li>• Design &amp; Production Engg. (Laminates &amp; composite)</li> <li>• Composite Materials.</li> <li>• Unconventional Machining/LBM</li> <li>• Productivity and industrial Engg.</li> <li>• Manufacturing</li> <li>• MTD</li> <li>• Robotics</li> <li>• Manufacturing Science &amp; Technology</li> </ul>	
	<i>Sufficient</i>	<i>Inadequate</i>
Is the library/journal support/e-connection	05	02
	<i>Definitely</i>	<i>Maybe</i> <i>No</i>

Would you like to have common (TEQIP) repository of course?	06	00	00
Would you like to visit IITK to attend specialized courses?	08	00	00
Would you like MOOCS/e-resources based courses?	08	00	00
How can TEQIP help improve your learning?	<ul style="list-style-type: none"> <li>• Please arrange at least one workshop on laminates &amp; composite, so that it could help me to improve my project or thesis quality.</li> <li>• By conducting workshops and conferences.</li> <li>• By the proper communication before starting workshops by mail/SMS.</li> <li>• By conducting laboratory experiments that gives practical value and by helping in using IIT Kanpur laboratory to TEQIP funded institutions so that they can learn and improve quality of students.</li> <li>• Providing e-resources.</li> <li>• Upload practical or e-lab.</li> </ul>		

### Research

<i>Questions</i>	<i>Definitely</i>	<i>Maybe</i>	<i>No</i>
Would you like to visit an IIT for a short visit/internship/post-doctoral stint, if offered (viaTEQIP)?	09	00	01
Would you like to share/use research infrastructure at IITK, if made available?	09	01	00
Would you like to conduct collaborative research with IITK faculty?	09	01	00
Would you like lectures by experts (Indian and international) on niche research areas/topics?	10	00	00
Do you want special-topic conferences?	09	01	00

How can TEQIP help improve your research?

- Please arrange some conferences on “Laminates & Composite”.
- By organizing class room course on recent developments in various fields of mechanical engineering.
- By providing this type of workshops to us for a long duration.
- Please help us by giving opportunity to work at IITK collaborative research work this will definitely help in improving my research.
- Providing lab facilities.
- Please Provide more such kind of workshops
- Give up facility to conduct our ideas.
- It provides the opportunity to meet experts in a specific area.

## **Outcome**

This workshop was very successful in terms of participation and feedbacks from participants were very encouraging too. Out of the 29 participants who registered, 26 of them were present for the workshop. This workshop was divided into three modules:

- Machining Process
- Machining Dynamics
- Process Machine Interaction

With this in mind, we drew on the expertise available within IITK, India and the U.S.A to deliver a workshop which would enable participants to learn from the best domain experts in their fields. The workshop was very well received and all sessions were very interactive. The participants were highly appreciative of how the workshop was structured from start to finish and of how the learning in classroom teaching translated to hands-on experimental sessions.

### **Participating in the program, we hope has enabled participants to:**

- Gain knowledge about fundamental mechanisms limiting machine tool productivity
- Appreciate the role of virtual prototyping in first-time- right solutions
- Understand influence of machine tool dynamics on machining
- Gain hands on training on measurement of machine tool dynamics
- Diagnose conditions leading to machine tool chatter
- Optimally select tools and machines for high-performance cutting
- Appreciate the role of virtual prototyping and machining dynamics in:
  - designing machining processes for improved productivity
  - designing high-performance machine and cutting tools from a dynamics perspective

## **Organizer's Report**

**Workshop coordinator: Dr. Mohit Law, IIT Kanpur**

### **Background:**

Machine tool performance and productivity is fundamentally limited by machining process induced vibrations. When these vibrations become unstable, i.e. when the machine tool system chatters, the chatter vibrations can damage the work piece, break the tool, damage the spindle and its bearing, and also damage the machine itself. To avoid such vibrations, machine tools are often operated conservatively, resulting in underutilization of such high-value assets by a factor of two or more. This underutilization results in huge economic losses to all industries that use machines to make products. Given that machine tools play a vital role in the development of nations, it is necessary for fast industrializing nations as ours to push the barriers limiting machine tool performance by relying on technology driven solutions. To fully harness a machine's capacity it becomes imperative to employ technologies that enable better resource utilization.

Keeping this in view, the Department of Mechanical Engineering with the support of TEQIP organized a five day workshop on “Machining Dynamics” from 18 – 12 July 2016 at IITK to introduce the science behind technologies that make possible higher utilization of machine tools. The workshop was designed to introduce the essential theory to model machining processes, machine tool dynamics and models to characterize process-machine interactions to predict and avoid unstable chatter vibrations. Hands-on experimental testing of machine dynamics, cutting force characterization and chatter detection and avoidance was also carried out to enable the participants to improve their understanding of this highly technical and non-intuitive field.

Engineering faculty, students, researchers in R&D labs along with personnel working in machine tool/cutting tool developer and user industries were the target audience. Learnings from this workshop it was hoped will help participants to address challenges faced by the manufacturing enterprise. Learnings it was hoped will also motivate practical solutions for some industrial problems.

### **Objectives:**

Objectives of the workshop were to:

1. Introduce concepts of machining dynamics and virtual manufacturing, with the aim of:
  - Physics – based machining process optimization
  - Designing high-performance machine and cutting tools
2. Introduce hands-on experimental characterization of machining processes, dynamics and chatter vibrations. Laboratory sessions demonstrated use of experimental methods for machining diagnostics and avoidance of vibrations
3. Pedagogy – to introduce a balanced approach to machining dynamics related subjects at the UG/PG levels. Topics covered:

- Machining process modelling
- Dynamics and vibrations of machine tool systems
- Process-machine interactions models












**Course content:**

Course content was designed to cover in-depth fundamentals of machining process modelling, dynamics and process-machine interactions models for modelling chatter and avoiding it.

- Machining process modelling:
  - Introduction to orthogonal and oblique cutting models.
  - Model milling processes to predict cutting forces.
- Experimental characterization of turning and milling processes:
  - Instrument machines to measure cutting forces.
- Fundamentals of machine tool vibrations:
  - Introduction to single and multiple degrees of freedom models.
  - Introduction to free and forced vibration analysis, and analytical modal analysis.
- Experimental modal analysis:
  - Instrument machines to measure dynamics.
- Process-machine interaction chatter models:
  - Introduction to machine tool chatter models.
- Experimental characterization and avoidance of chatter:
  - Instrument machines to experimentally detect and avoid chatter.
  - Demonstrations of improved productivity and machine tool utilization.
- Advanced topics in control of machine tool vibrations and design to mitigate vibration

**Contribution:**

This workshop was envisaged to introduce in-depth fundamentals of machining process modelling, dynamics and process-machine interactions models for modelling chatter and avoiding it. With this in mind, we drew on the expertise available within IITK, India and the U.S.A to deliver a workshop which would enable participants to learn from the best domain experts in their fields. We had a total of 26 hours of lectures and an additional 6 hours of hands-on laboratory sessions. We had three modules: one on machining process modelling, one on dynamics, and one on process-machine interactions. These were delivered by respective experts as under:

Module 1 Machining process	Module 2 Machine dynamics	Module 3 Process – machine interactions	
 Dr. S Choudhury IITK	 Dr. Shakti Gupta IITK	 Dr. P Wahi IITK	 Dr. R Singh IITB
 Dr. Mohit Law IITK	 Shri Mohanram IMTMA	 Dr. A Ganguli IITD	 Dr. X Jin Oklahoma USA
	 Dr. Mohit Law IITK	 Dr. Ramkumar IITK	 Dr. Law IITK

The details of the various lectures and labs that were conducted are included as attachment (Annexure-1). We are extremely thankful to the lab staff: Mr. S.K. Verma, Mr. A Gangwar, and Mr. S. K. Pandey who helped tremendously in setting up the lab sessions, in preparation and operation of the machines, and in running of the labs on all three of the five days of the workshop.

### **Feedback from the participants:**

Out of the 29 participants who registered, 26 of them were present for the workshop. We had a mix of faculty from private and government aided colleges, faculty from other sister IITs, students (PhD/MTech) from all over the country, and some participants from the machine tool and cutting tool industries in India.

The workshop was very well received and all sessions were very interactive. The participants were highly appreciative of how the workshop was structured from start to finish and of how the learning in classroom teaching translated to hands-on experimental sessions. Many of the participants had never before done any such experiments as they did during the workshop. Participants were also appreciative of the how the workshop demonstrated how physics works, in that; they were able to relate the utility of models for machining process optimization and in designing high-performance machine and cutting tools.

Overall, we believe that this was a very successful workshop. It was the first workshop of its kind in India, and we hope that this motivated interest in the field of machining dynamics which can translate to renewed interest and focus on fundamental research and activity to strengthen the manufacturing enterprise in the country.

### **Key take-aways from the workshop for the participants**

Participating in the program, we hope has enabled participants to:

- Gain knowledge about fundamental mechanisms limiting machine tool productivity
- Appreciate the role of virtual prototyping in first-time-right solutions



- Understand influence of machine tool dynamics on machining
- Gain hands on training on measurement of machine tool dynamics
- Diagnose conditions leading to machine tool chatter
- Optimally select tools and machines for high-performance cutting
- Appreciate the role of virtual prototyping and machining dynamics in:
  - designing machining processes for improved productivity
  - designing high-performance machine and cutting tools from a dynamics perspective

**Acknowledgements:**

In the end, we sincerely thank the TEQIP team. They made an impeccable arrangement for the program and also took care of all the necessary details (posters, dinners, tags, etc). This workshop would not have been successful without their constant support.