I. PROJECTS ACCOMPLISHMENT SUMMARY

A. Background:

Parties
The project is a relationship between the Society of Manufacturing Engineers (SME) and Lawrence Livermore National Laboratory (LLNL).

Background
The ability to assess the accuracy of machine tools is required by both tool builders and users. Builders must have this ability in order to predict the accuracy capability of a machine tool for different part geometry's, to provide verifiable accuracy information for sales purposes, and to locate error sources for maintenance, troubleshooting, and design enhancement. Users require the same ability in order to make intelligent choices in selecting or procuring machine tools, to predict component manufacturing accuracy, and to perform maintenance and troubleshooting. In both instances, the ability to fully evaluate the accuracy capabilities of a machine tool and the source of its limitations is essential for using the tool to its maximum accuracy and productivity potential.

This project was designed to transfer expertise in modern machine tool accuracy testing methods from LLNL to U.S. industry, and to educate users on the use and application of emerging standards for machine tool performance testing.

B. Description:

Scope
The project called for a series of workshops on machine tool accuracy characterization to be conducted for the benefit of U.S. machine tool builders and users. The workshops were organized and hosted by the Society of Manufacturing Engineers (SME). Workshop attendants paid a registration fee which was applied to expenses incurred by SME. The workshops were taught by personnel from LLNL. The American Society of Mechanical Engineers provided the appropriate standards as part of the instructional materials.

The project was designed to have a duration of eighteen months after approval. The project started in June 1992. The first six months were dedicated to creating a course syllabus and instructional materials for the instructor and handouts for the students.

The remaining twelve months were used to conduct the sessions and refine the materials. The workshop was offered five times during calendar year 1993 with one cancellation due to lack of early registration. All four workshops consisted of three full day sessions and one evening session, with about 2/3 classroom instruction and 1/3 hands-on demonstrations. A total of 129 technical personnel attended. Sufficient training documentation material was created to allow for continued educational activities to be conducted by representatives from industry. We were not able to develop any video taped material.
DISCLAIMER

 Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.
Locations and schedule:
1. Lawrence Livermore National Laboratory (LLNL), Livermore, CA, Jan. 12-14
2. Institute for Advanced Manufacturing Sciences (IAMS), Cincinnati, OH, Apr. 13-15
3. Nat'l Center for Tooling & Precision Components (NCTPC), Toledo, OH, Sept. 21-23
4. Midwest Manufacturing Technology Center (MMTC), Ann Arbor, MI Nov. 16-18

Deliverables:
The principal deliverable was education to the people attending the workshops. The participants received sufficient instruction and written material to apply and understand the testing methods used to evaluate a machine tool's accuracy and performance characteristics.

The secondary deliverable was the materials used to present the course. These included:
- a 4 volume set of transparencies for the classroom (instructor use)
- a copy ready master of reduced presentation material (for classroom handout)
- a copy ready master of 30 reference papers (also to be used for handouts)
- a glossary of terminology
- a bibliography of other references.

These were presented to SME at the completion of the project in January 1994. SME will use the material for other offerings of the workshop as part of their continuing educational program.

The deliverables were met. Evaluations from the attendees at the end of each workshop were very positive. Further follow-up has also been quite positive with several attendees sharing the information with others in their own organizations.

Technical Description
The technical content included these subjects:
- The deterministic philosophy as it applies to machine tools
- Machine and process error budgeting
- Current and emerging national standards (supplied by ASME)
- Parametric error testing
- Volumetric error testing
- Interpretation of results
- Methods for error compensation/correction
- History of machine tool testing
- Demonstration and "hands on" set-up with actual equipment

Background information was presented first with some equipment familiarization occurring during breaks. To enhance the program, a number of exhibitors were invited to the last two workshops to exhibit the latest in test equipment. They were available during breaks and after the session in the afternoon. Exhibitors were invited to participate in discussions and in one case an exhibitor set up additional demonstrations. Lectures were informal with as much audience participation as possible. The wrap-up session included a quiz problem with several parts and was used to illustrate the principles covered. It also included examples of mistakes and the pitfalls that can occur. All attendees were asked to make evaluations of the material and of the instructors. Summaries of these evaluations are provided in Appendix B.

Responsibilities:
LLNL Engineering was responsible for managing the project, developing the course outline, writing and editing the handout material, readying the handout text for duplication, creating visual aids, and providing the instructors and instruction. LLNL also hosted the first workshop. A total of five individuals from LLNL participated in the four workshops. Each workshop used three
instructors. It was necessary to have at least three to be able to cover the equipment set-up and simultaneous demonstrations.

The ASME contributed the printed codes and standards at no cost to the project. These included:

- ANSI B5.54-1991—Methods for Performance Evaluation of Computer Numerically Controlled Machining Centers
- ANSI B89.1.12M-1985—Methods for Performance Evaluation of Coordinate Measuring Machines
- ANSI B89.3.4M-1985—Axes of Rotation-Methods for Specifying and Testing
- ANSI B89.6.2-1973—Temperature and Humidity Environment for Dimensional Measurement

C. Expected Economic Impact:

The size of the economic impact is difficult to predict. The ability to fully evaluate the accuracy capabilities and sources of limitations of machine tools is central to improving productivity. Industry interest in metrology is definitely increasing. For example, Boeing-Wichita (see Appendix E) has instituted a program for purchasing new machines and improving the accuracy of existing machines based on the B5.54 Standard. They also have instituted a maintenance program that is so successful that they made a video for advertising. Lockheed-Sunnyvale has also developed a Machine Tool Variability Management System for rapidly analyzing accuracy using the standard tests (American Machinist, June 1992). The benefits are being recognized!

SME is continuing the series of workshops by offering a session at the NIST Great Lakes Manufacturing Center on November 1-3, 1994. Instruction will be provided by a small company, Independent Quality Laboratory, who will perform the instruction using the material that was generated in this partnership.

D. Benefits to DOE:

DOE's unique requirements for high-precision components often preclude the use of unmodified or domestic commercial machine tools. If U.S. machine tool builders can use rigorous parametric and volumetric accuracy evaluation methods as a tool for enhancing the capabilities of their products, DOE will have a broader and more reliable domestic base from which to select machine tools for nuclear weapons production, and procurement costs will be reduced. LLNL has acted as a center of expertise in precision engineering for the Department of Energy, other government agencies, and U.S. industry for over 30 years. This project is consistent with that role, and allows LLNL to maintain its technical base in an area critical to both DOE and U.S. industry.

E. Benefits to Industry:

The U.S. has lost a significant share of the world market for consumer and industrial products in the past ten years. This is particularly true for the production of components requiring increasingly high levels of manufacturing precision. One approach to addressing this problem is to enhance the accuracy that can be obtained from commercial machine tools. This educational program was designed to allow both machine tool builders and users to rigorously assess machine tool accuracy capabilities and the sources of accuracy limitations, with the results of the assessments to be used to enhance production capability with existing tools.
F. DOE Facility Points of Contact for Project Information:

University of California  
Lawrence Livermore National Laboratory  
7000 East Avenue, L-292  
Livermore, California 94551

Project Leader: Donald L. Carter  
510-422-7719  
fax 510-423-2419

Project Manager: Carol Asher  
510-422-7618  
fax 510-423-7914

G. Partner and Points of Contact:
The Society of Manufacturing Engineers is a Michigan not-for-profit corporation (professional society) whose services to its members includes about 250 continuing education programs.

Society of Manufacturing Engineers  
#1 SME Drive  
P. O. Box 930  
Dearborn, Michigan 48121

Project Coordinator: Karen Chisnell  
313-271-1500 x542  
fax 313-271-2861

H. Project Examples (See Appendix)

A. Advertising mailer—
   There were two advertising brochures printed by SME and four mailings made during this project. The second is included in this report.

B. Attendee evaluation summaries—
   Evaluation by the attendees during the course is a requirement of SME of all their educational programs. The questions asked are shown on the evaluation summary. Three summaries are included for three of the workshops. Averaged scores for overall value ranged from 4.3 to 4.6 out of 5.0.

C. List of attendee's names and affiliation—
   Program rosters for all events are included with business affiliation and position. Titles included machinists and technicians to company presidents and sales managers to professors. Companies included the very large recognized names to the very small start-up businesses from all over the country. The diversity of the attendees helped to make the workshops more interesting to everyone since time was taken for questions and discussion. We found people not only sharing problems but also sharing their own solutions.

D. Photos from a workshop—
   One of the attendees shared some of his photos with us. They show three of the people who had active rolls in the instruction.

E. Letter of support to LLNL-Roger Werne—
   An attendee from Boeing shared some thoughts concerning the value of the workshop to the Boeing Co.

F. Continuation of Workshop by SME—
   SME is continuing to offer the workshop using a small business to provide instruction and equipment and the National Center for Tooling & Precision Components for a location. Included is the brochure.
II. Additional Information for DP-14:

A. Technical Issues
There were no technical issues encountered during the project. Originally the workshop was conceived to be 5 days long. It was shortened to 3 days at the request of SME since their experience showed that industry does not support 5-day training sessions nearly as well as 3-day sessions. We condensed the material into the 3 days by conducting concurrent demonstration sessions which required another person additional to the original plan.

B. Partner Contribution

The Society of Manufacturing Engineers provided the marketing, off-site administration, and on-site administration for each workshop. Marketing included the creation of brochures, mailing lists and labels, mailings, and advertising. Off-site administration included the pre-registration of participants, duplication, assembly, and binding of instructional materials, negotiation and arrangements for facilities, etc. On-site administration included the final registration, duplication and assembly of any additional materials, class room set-up, etc. They also arranged for one evening's dinner meeting where the history of machine tool metrology was covered.

The American Society of Mechanical Engineers was not a partner, however contributed copies of 4 ANSI Standards for each of the workshop attendees. The value of this contribution at market prices was about $18K.

C. Financial Summary
The summary of spending for LLNL and SME is shown below
C. Financial Summary (cont'd)

Totals expended by LLNL

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* It was recognized at the first TACT review in December 1992 that shortening the workshop from five days to three days placed a greater burden on the instructors to adequately present the hands-on demonstrations. At that review, we requested an additional $25K to handle an additional person's travel and preparation time to attend each workshop.

D. Documents:

There were no propriety information or inventions identified in this project. The presentation material is in the process of being copyrighted by LLNL.

LLNL

Donald L. Carter  
Jan. 9, 1995

SME

John McEachin  
2-1-95
Appendix (attachments)

A. Advertising mailer
B. Attendee evaluation summaries
C. List of attendee's names and affiliation
D. Photos from a workshop
E. Letter of support
F. Continuation of Workshop by SME (brochure)
EDUCATIONAL EVENT

Sponsored by the Society of Manufacturing Engineers in cooperation with the Machining Technology Association of SME

MACHINE TOOL METROLOGY (ACCURACY CHARACTERIZATION)

A comprehensive 3-day, hands-on workshop which educates machine tool users and manufacturers on the deterministic approach to testing and characterizing the accuracy of machine tools, including the use and application of ANSI/ASME standards.

September 21-23, 1993
National Center for Tooling & Precision Components (NCTPC)
Toledo, OH

November 16-18, 1993
Midwest Manufacturing Technology Center (MMTC)
Ann Arbor, MI

This workshop has been developed in cooperation with The Regents of the University of California and Lawrence Livermore National Laboratory under its Technology Transfer Initiatives Program, designed to transfer the latest technologies in machine tool accuracy evaluation to US industry, and with special support from the Codes & Standards Section of the American Society of Mechanical Engineers.

SEE THE LATEST IN MACHINE TOOL METROLOGY EQUIPMENT

Several distributors and manufacturers have been invited to display the latest in machine tool metrology equipment. During the informal tabletop sessions, which will be available each day after the sessions and during breaks, you will be able to find out what's available and have your questions answered on how to use this equipment.
MACHINE TOOL METROLOGY
(ACCURACY CHARACTERIZATION) WORKSHOP

September 21-23, 1993 • National Center for Tooling & Precision Components (NCTPC) • Toledo, OH
November 16-18, 1993 • Midwest Manufacturing Technology Center (MMTC) • Ann Arbor, MI

Workshop Description
This workshop provides an understanding of fundamental metrology principles and the application of these principles specifically to the testing of machine tools and coordinate measuring machines (CMM's). It stresses the importance of functionally significant tests and the proper use of terminology for describing these tests and subsequent results. Parametric test procedures as outlined in ANSI machine tool standards will be demonstrated. Emphasis will be placed upon the use and application of the emerging ANSI/ASME B5.54 Standard entitled “Methods for Performance Evaluation of Computer Numerically Controlled Machining Centers.”

What You’ll Learn
Upon workshop completion, you will be able to:
- Assess, characterize and understand the accuracy errors of a machine tool or CMM as well as perform the necessary tests for a particular application
- Create specifications based upon standards
- Compare accuracy of similar machines
- Make informed purchase decisions
- Prescribe the correct acceptance test procedures
- Predict the performance of a particular machine tool
- Communicate this information in a language that the machine tool community understands and accepts

Who Should Attend?
Manufacturing engineers and technicians concerned with machine tool productivity, including:
- Designers and builders
- Factory/assembly and field/service technicians
- Sales representatives
- Specification writers
- Technology educators
- Rebuilders
- Testing service technicians
- Machinists

Basic Skills/Prerequisites Required
- Familiarity with machine tools (e.g., lathes, milling machines, machining centers, measuring machines, etc.) functions, terminology and applications
- Proficiency with shop level math (trigonometry, algebra, geometry, etc.)

Workshop Features
Your registration fee includes:
- 1 copy of all presentation materials
- 1 copy of the following ANSI/ASME standards:
  - B5.54-1992, Methods for Performance Evaluation of Computer Numerically Controlled Machining Centers
  - B89.1.12M-1990, Methods for Performance Evaluation of Coordinate Measuring Machines
  - B89.3.4M-1985, Axes of Rotation Methods for Specifying and Testing
  - B89.6.2-1973, Temperature and Humidity Environment for Dimensional Measurement
- Hands-on testing experience in a machine shop setting
- Glossary of terms
- Lunch each day
- Tuesday evening dinner

SEE THE LATEST IN MACHINE TOOL METROLOGY EQUIPMENT
Several distributors and manufacturers have been invited to display the latest in-machine tool metrology equipment. During the informal tabletop sessions, which will be available each day after the sessions and during breaks, you will be able to find out what’s available and have your questions answered on how to use this equipment.

WORKSHOP ENROLLMENT IS LIMITED TO 30 PERSONS PER LOCATION—REGISTER EARLY TO ENSURE YOUR SPOT!

Two Ways to Save!
1. Member Discount—SME members can attend this event at a discounted rate (see “Event Schedule and Information”). For more information about joining SME, contact our Customer Service Center at 1-800-733-4SME(4763), 8 a.m. to 8 p.m. ET, Monday through Friday. Membership application and dues must be received at least 30 days prior to the event to qualify for the member rate for this event.
2. Group Discounts—Significant discounts are available for groups of three or more registering and attending this event together. For more information, please call the event administrator (see “Event Schedule and Information”).
Three hotels are in close proximity to NCTPC: Sheraton Westgate (419) 535-7070 ($69 single/$79 double); Red Roof Inn (419) 536-0118 ($24.99 single/$29.99 double); and the Secor Inn (419) 531-2666 ($44.95 single or double). Please call directly for reservations (there is no SME room block).

Save Money With In-house Training

In-house training saves time, money, and produces positive results. If you have several employees who could benefit from this or one of 500 other pre-developed educational events, call us at 1-733-4SME. Implant Education Services—Your Personalized Training Connection!

Three hotels are in close proximity to NMTTC: Red Roof Inn Ann Arbor (313) 995-5800 ($44.99 single/$51.99 double); Hampton Inn North (313) 996-4444 ($55 single/$60 double); and Holiday Inn North Campus (313) 769-9800 ($72 single or double).

Please call hotels in either location directly for reservations (there is no SME room block).

Three Ways to Register:
1. Call the SME Customer Service Center at 1-800-733-4SME(4763), 8 a.m. to 8 p.m. ET, Monday through Friday.
2. Complete the registration form and mail it to SME.
3. Fax your completed form to SME Customer Service at (313) 271-2661.

SME has the right to amend this program as necessary. In the event of a program cancellation, SME is not responsible for incidental costs incurred by registrants. It is recommended that refundable airline tickets be purchased.
## Appendix B. Attendee evaluation summaries

**CONFERENCE DIVISION EVALUATION**

**DATE:** January 18, 1993

**EVENT:** Machine Tool Accuracy Characterization Workshop (PILOT)
January 12-14, 1993

Lawrence Livermore National Lab, Livermore, CA CC# 29745

**ADMINISTRATOR:** Karen Kammerer, ext. 542

### ATTENDANCE

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### PROGRAM STATISTICS (based on 26 completed evaluation cards)

**A. Overall I would rate this event/session**

4.3 on a 5-point scale

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<td>3</td>
<td>2</td>
<td>1</td>
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</table>

(Based on the above scale)

1. The presentation(s) material was well organized. 4.5
2. The content was relevant to my work situation. 4.4
3. The content was appropriate for my experience level. 4.3
4. I learned something that can be applied to my work. 4.5
5. Sufficient time was allotted for the session(s). 3.9
6. The session(s) answered my questions on this topic. 3.9
7. Interactive activities (case studies, panel discussions, problem solving sessions) employed were appropriate. 3.8
8. The event/session met its stated objectives. 4.2

**B. Program History**

<table>
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<th>DATES</th>
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<th>#/ATTEND/RATE</th>
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**Appendix A—continued**

**Locations**

The September 21-23, 1993 Machine Tool Metrology Workshop will be held at the National Center for Tooling & Precision Components (NCTPC), 2600 Dorr St., Toledo, OH (419) 531-8340.

The November 16-18 Machine Tool Metrology Workshop will be held at the Midwest Manufacturing Technology Center (MMTC), 2901 Hubbard Road, Ann Arbor, MI (313) 769-4405.

**Lodging**

Three hotels are in close proximity to NCTPC: Sheraton Westgate (419) 535-7070 ($69 single/$79 double); Red Roof Inn (419) 536-0118 ($24.99 single/$69 double); Red Roof Inn (419) 535-7070 ($69 single/$29.99 double); and the Secor Inn (419) 531-2666 ($44.95 single or double). Please call directly for reservations (there is no SME room block).

Three hotels are in close proximity to MMTC: Red Roof Inn Ann Arbor (313) 996-5800 ($44.99 single/$51.99 double); Hampton Inn North (313) 996-4444 ($55 single/$60 double); and Holiday Inn North Campus (313) 769-9800 ($72 single or double). Please call hotels in either location directly for reservations (there is no SME room block). Room rates are subject to change.

**Save Money With In-house Training**

In-house training saves time, money, and produces positive results. If you have several employees who could benefit from this or one of 50 other pre-developed educational events, call us at 1-800-733-4SME. Inplant Education Services—Your Personalized Training Connection!
Workshop Schedule—Both Locations
Check-In:
7:30 a.m.-8:15 a.m.
(Tuesday only)
Course Hours:
8:15 a.m.-4:30 p.m. (daily*)
Lunch Break:
12:00 noon-1:00 p.m.
(daily)
Evening Dinner with Speaker:
6:30 p.m.-9:30 p.m.
(location to be announced)
*Ending time is firm; please make airline departures accordingly
• AM/PM refreshment breaks
• No smoking in meeting room

WORKSHOP ENROLLMENT WILL BE LIMITED TO 30 PERSONS PER LOCATION—REGISTER EARLY TO ENSURE YOUR SPOT!

Workshop Outline
Guest instructors and machinists may be invited to participate.
Contact SME for an updated agenda for the location you wish to attend.

Tuesday Dinner Speaker: James B. Bryan, “Evolution & History of B5.54 Tests”

Please Note: Wear casual and safe clothing appropriate for the machine shop.

I. Accuracy Characterization—An Introduction
• Advantages and benefits
• Driving forces behind ANSI machine tool standards
• Higher tolerances
• Smaller lot sizes
• Need for a unified language and concise terminology

II. Fundamentals and Philosophies of Machine Tool Metrology
• Rigid body and flexible behavior
• Error motion and degrees of freedom
• Deterministic theory applied to machine tools
• Abbe Principle
• Sensitive and nonsensitive functional application
• Thermal effects

III. Selection of Measurement Instruments
• Application—advantages and disadvantages
• Basics of use
• Data output

IV. Test Procedures
• Determination and logic of testing sequence
• Individual test description and demonstration

V. Usage of Information from Tests
• Creating specifications—builder and user
• Historical record keeping
• Analysis
• Error budgeting
• Application to ANSI standards (B5.54)

Workshop Instructors
Donald L. Carter, mechanical engineer at LLNL; over 15 years experience in precision machine design and machine tool metrology; a member of the ANSI/ASME B5.54 committee that drafted the standard “Methods for Performance Evaluation of CNC Machining Centers.” Herman Hauschildt, senior machinist and supervisor at LLNL with more than 30 years experience in machine tool building, rebuilding, metrology and tool servicing. James B. Bryan, mechanical engineer and consultant with more than 35 years experience in the field of precision engineering and machine tool metrology; member of 7 ANSI/ASME machine tool related standards committees including the B5.54, and recipient of the 1977 SME International Medal for Research in Manufacturing.

Course Fee:
SME members: $715
Nonmembers: $815

Questions?
Contact Karen Kammerer, SME staff, at (313) 271-1500, ext. 542.
Appendix B. Attendee evaluation summaries

CONFERENCING DIVISION EVALUATION

DATE January 18, 1993

EVENT: Machine Tool Accuracy Characterization Workshop (PILOT)
January 12-14, 1993
Lawrence Livermore National Lab, Livermore, CA CC# 29746

ADMINISTRATOR: Karen Kammerer, ext. 542

ATTENDANCE

| Members | 3 Speakers | Nonmembers | 0 Exhibitors | 27 Total Paid Attendance | 0 Gratis |

Budgeted Attendance

PROGRAM STATISTICS (based on 26 completed evaluation cards)

A. Overall I would rate this event/session

4.3 on a 5-point scale

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</table>

(Based on the above scale)

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8. The event/session met its stated objectives. 4.2

B. Program History

| DATES | CITY, STATE | #/ATTEND/RATE |
WHAT ARE THE STRENGTHS OF THIS WORKSHOP?

- Engineering content, technical knowledge of instructors, equipment available for examination.
- LLNL's precision engineering expertise. Notebooks with overhead slides is an excellent idea.
- The instructors. The instructors were extremely knowledgeable and easy to listen to.
- Knowledge of the instructors.
- LLNL is certainly knowledgeable on these topics and do the things they say.
- High level of knowledge and experience of the presenters.
- Depth of experience of presenters and their ability to use it - especially where additional illustrations were requested.
- Technical knowledge of teachers - written information.
- The technical and practical expertise of the instructors.
- Documents provided! (vol II selected reading) are great! The hands-on demonstrations are very good and that style should be enhanced and increased.
- It did a pretty good job of presenting the underlying issues of machine tool metrology.
- Methods presented followed by practical demonstrations.
- Top notch instructors.
- Experience of people presenting topics.
- The knowledge the speakers have on this topic. The use of hands on training.
- Personnel know the topic well.
- Experience of presenters.
- Absolutely great course content.
- Technical knowledge of presenters; hands-on activities.
- The knowledge of the speakers.
- Depth of diverse experience in machine tool application, STD & special of the speakers.

ADDITIONAL COMMENTS

(number of responses = 1 unless otherwise indicated)

- Class room needs more aisle space
- Room with better access to a restroom would be more convenient. Having coffee & rolls at start was nice. Room was satisfactory chairs were comfortable. "Hands On" demos were good.
- Smaller groups for shop demos. Videos showing technical set-ups of laser check outs.
- This course basically applied to lab, conditions and not a normal production area.
- Better explanation of nomenclature before usage, use clearly defined objectives of experiments.
- Functional tolerancing
- All in all an excellent pilot effort.
- If all machine tool customer's used these test at supplier's, I wonder what their reception would be?
- Smaller groups with longer hands-on sessions would be beneficial. Overall, I feel this course is essential for technical personnel who are involved with machine tools.
Appendix B  continued

Machine Tool Metrology
Evaluation

September 21-23, 1993

Section A:

<table>
<thead>
<tr>
<th></th>
<th>Content</th>
<th>Delivery</th>
<th>Visuals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Don Carter</td>
<td>Very Good/Excellent</td>
<td>Very Good/Excellent</td>
<td>Very Good</td>
</tr>
<tr>
<td>James Bryan</td>
<td>Very Good/Excellent</td>
<td>Very Good</td>
<td>Very Good</td>
</tr>
<tr>
<td>Herman Hauschildt</td>
<td>Very Good</td>
<td>Very Good</td>
<td></td>
</tr>
<tr>
<td>Carl Chung</td>
<td>Very Good</td>
<td>Very Good</td>
<td></td>
</tr>
</tbody>
</table>

Section B:

1. The presentation(s) material was well organized.
2. The content was relevant to my work situation.
3. The content was appropriate for my experience level.
4. I learned something that can be applied in my work.
5. Sufficient time was allotted for the session(s).
6. The session(s) answered my questions on this topic.
7. Interactive activities employed were appropriate.
8. The event/session met its stated objectives.

Section C:

Overall I would rate this event/session **Excellent/Very Good**.

Section D:

1. **Strengths of the program:**
   - Material is relevant to the shop problems that we face today
   - Expert Instructors
   - Shop floor demos and instruction
   - Good hands on, this was well presented
   - Experienced people
   - Concept on machine performance in “deterministic” approach was excellent
   - Quality and professional knowledge of the instructors
   - Great technical experience behind the teaching.
   - Helps me to get the most out of available technology
   - Timing and content
   - Tour with Vendors and having them demonstrate practical applications was a plus.
Appendix B  continued

2a.  Suggested topics to be added:

- Shophands on should be distributed on the 1st and 2nd day
- Hands on small projects on different machines
- More visuals and hands on so the theory can be understood through practice
- Somewhat more emphasis on fundamentals and more emphasis on how laser and other measurement devices and test works.
- More information on straightedge reversal and relationship with the axis of rotation
- Additional publications on the deterministic philosophies
- Names of and availability to test equipment (ref. LVDT)
- Cutting tool test
- Use of spindle probing - precautions, applies, etc...
- Math material could be presented better

2b.  Suggest topics to be deleted:

- Some discussions were over the head of some attendee, keep Ph.D. discussions off-line
- Rearrange the presentation on testing after time used on demonstration

3.  Additional comments on this event:

- SME should make two reference books available (Circular Test and Testing Machine Tools)
- Tuesday dinner format was good, excellent opportunity to share with others
- Speed up lectures with hourly breaks, breaks can be trips to the shop floors to help break up the long lecture
- Provide bag or box to carry books home
- Very beneficial to my work
- Tell attendees before seminar (weeks in advance) to leave space in luggage for course material, send maps to hotels and site in advance. Inform hotels of seminar schedule and location.
- Instructors could talk louder and at the students
- Dinner at the Toledo Club and Jim's talk was worth while
- Excellent lunch!!
- This is the best that I have ever attended
- Less class time and more hands on
- Excellent format
- When debugged, this workshop will advance the field of metal working and precision engineering.
- Excellent!
- Have SME sell the book "The Circle Test"
- Day one overheads didn't match handouts.
- Classroom tables are to narrow (front to back), hotel was poor.
Appendix B  continued

Machine Tool Metrology Evaluation  
November 16-18, 1993

Section A:

<table>
<thead>
<tr>
<th>Instructor</th>
<th>Content</th>
<th>Delivery</th>
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</thead>
<tbody>
<tr>
<td>Sam Thompson</td>
<td>Very Good/Excellent</td>
<td>Very Good</td>
<td>Very Good/Excellent</td>
</tr>
<tr>
<td>Don Carter</td>
<td>Very Good/Excellent</td>
<td>Very Good</td>
<td>Very Good/Excellent</td>
</tr>
<tr>
<td>Herman Hauschildt</td>
<td>Very Good/Excellent</td>
<td>Very Good</td>
<td>Very Good/Excellent</td>
</tr>
</tbody>
</table>

Section B:

1. The presentation(s) material was well organized. Agree
2. The content was relevant to my work situation. Agree
3. The content was appropriate for my experience level. Agree
4. I learned something that can be applied in my work. Strongly Agree
5. Sufficient time was allotted for the session(s). Agree
6. The session(s) answered my questions on this topic. Agree/Strongly Agree
7. Interactive activities employed were appropriate. Agree/Strongly Agree
8. The event/session met its stated objectives.

Section C:

Overall I would rate this event/session Very Good.

Section D:

1. Strengths of the program:
   - Expert Instructors
   - Equipment.
   - Timely, give some time to hands-on experience to help tie the principle together.
   - Introducing a great standard for US machine related industry, methods and concepts of machine tool metrology.
   - Analysis of machine metrology tests and testing were strong.
   - Establish definitions of terms associated with machine errors.
   - Participation of experts with real world experience in machine tool metrology.
   - Well informed instructors, with clear and concise visuals aids and material.
   - Explain how easy mistakes can be made in out setups and how to plan for them.
   - Good visuals and supporting photos.
   - This subject will be coming up as a more serious consideration for industry as a whole, and this presentation should be expected to be more in demand in the future.
   - Lab or hands-on work to match the lecture.
   - Disappointed Jim Bryan was not here to meet.
   - Enjoyed dinner and the interaction with instructors and students.
Appendix B  continued

2a.  Suggested topics to be added:

- More case studies.
- More practical examples of equipment and set-ups.
- More vendor participation.
- It seems one sided, i.e. LLNL.
- Transportation of machine linkage errors synthesis, compensation of machine volumetric errors.
- More time on CNC.
- More hands-on activities.
- Have a diagram of how laser beam works, and post it near the laser set up on the machine so it would be easier to understand the setup for each test.
- Advancement in laser tech, equipment and software more variety of actual case studies.
- Controller adjustments. "Real Life Tolerances or Ball Park Figures," so terms were over my head.
- Techniques for actually aligning the laser were only covered at the demos the last day, maybe they should be part of day 2. Also, day 3 could use some visuals.
- More test results.

2b.  Suggest topics to be deleted:

- Don't spend so much time on introduction, all that can be read in B5.54.
- Reference to many ideal (diamond lathes) machines.

3.  Additional comments on this event:

- Machine tool qualification evaluations with alignment lasers - GM just issued a laser alignment spec. for new and rebuilt machinery and equipment.
- Found the reading very valuable - if programs repeated, continue to have LLNL involvement - wealth of knowledge that the presenters have is important to the success of the workshop.
- Classroom conditions were very poor, hard to hear the instructors, class was suppose to be limited to 30. This was too large of a group with limited hands-on experience, this was not a workshop.
- Perhaps an analysis between a good repeatable machine compared to a non-repeatable machine. Overall this was a good program, I enjoyed the slide show.
- The workshop and presenters were excellent.
- Strengthen applications of techniques in industry, provide insights into inspection of large machines.
- Very good course and professionally presented.
- Much was wasted debating terminology.
- Location was good but a fair weather location like Florida, Texas or California would be better.
- Hands-on, visuals, reference material, group interaction, after hour dinner meeting were worthwhile.
- Sales representatives have their place at the conference, but not at the expense of other participants.
- Evening session went well.
- Limit group to 25 - 30 people.
- Would be nice to see this taught to graduating Manufacturing Engineers or even Machinists. We need to educate the country to be compete in manufacturing.
Kirt Babuder  
Director  
National Acme  
Cleveland OH

Roger Becker  
Calibration Technician  
Intermedis Orthopedics Inc  
Austin TX

Jeff Biggers  
Technologist  
3M  
Optics Technology Center  
Petaluma CA

John C Bollinger  
Assistant Professor  
San Diego City College  
San Diego CA

Matt Cavanaugh  
Supervisor  
Intermedis Orthopedics Inc  
Building C  
Austin TX

Frank Christian  
Sr QA Engineer  
Industrial Tools Inc  
Ojai CA

Marc Curtis  
Manufacturing Engineer  
Spectra-Mat  
Watsonville CA

Edward Faley  
QA Specialist  
Defense General Supply Center  
Indl Plant Equipment Repaid  
Mechanicsburg PA

John Freddie  
Machinist  
Sandia National Labs  
8284-1 Process Dev & Fab Dept  
Livermore CA

John O Hammond  
Sales Manager  
Dimensional Contron Corp  
San Carlos CA

Richard A Hildner  
Staff Member  
Los Alamos National Lab  
Los Alamos NM

Robert D Johnson  
Measurement Planning Supv  
Caterpillar Inc  
Quality  
Aurora IL

Dean Kunde  
Mechanical Engrg Tech  
Naval Aviation Depot  
Naval Air Station North Island  
San Diego CA

Thomas Kurfess  
Assistant Professor  
Carnegie Mellon University  
Mechanical Engrr Dept  
Pittsburgh PA

Don Martin  
President  
Lion Precision  
St Paul MN

Jim McDaniel  
Process Engineer  
Intermedis Orthopedics Inc  
Building C  
Austin TX

Mike Mewhort  
Process Engineer Technician  
Carbomedics  
Austin TX

Bob Plilkey  
Dimensional Metrologist  
Sandia National Lab  
Livermore CA

Richard Polacek  
R&D Manager  
Industrial Tool Incorporated  
Ojai CA

Linford Richardson  
Consultant  
Canoga Park CA

Larry L Rochester  
Member of Technical Staff  
Rockwell International  
Canoga Park CA

Charles T Schmitz  
Machinist  
Sandia National Labs  
8284-1 Process Dev & Fab Dept  
Livermore CA

Jack Sherman  
Mechanical Engrg Technician  
Naval Aviation Depot  
Naval Air Station North Island  
San Diego CA

Frank E Thomas  
Maintenance Technician  
Carbomedics Inc  
Austin TX

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Caterpillar  
Peoria IL

Wesley Walker  
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Building C  
Austin TX
John Adams
Field Sale Engineer
Federal Products
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Charles Butcher
Instructor
Muskingum Area Tech College
Zanesville OH

David H Duey
Vice President Development
Intra Corporation
Westland MI

Myron Haisler
NC Programmer
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Austin TX

Tony Hudak
Quality Assurance Manager
Colony Tool Co
Solon OH

Thomas Kagle
CNC Programmer
Intermedics Orthopedics Inc
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Bob Luce
CNC Programmer
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Indianapolis IN

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Larry Frandson
Plant Manager
Remmele Engineering Inc
Big Lake MN

Chris Hosier
Inst for Adv Mfg Science
Cincinnati OH

Guy R Hughes
Inst for Adv Mfg Science
Cincinnati OH

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Pittsburgh PA

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Columbus IN

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Robert P Monroe
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Chris Richards
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Dale Ortlip
Quality Assurance Engineer
Remmle Engineering
St Paul MN

Bob Severson
President
Manufacturing Performance
Story City IA

Mike Owens
Inst for Adv Mfg Science
Cincinnati OH

Tim Sisson
Inst for Adv Mfg Science
Cincinnati OH

PROGRAM ROSTER FOR 2975193
MACHINE TOOL METROLOGY
CINCINNATI, OHIO
04-13-93 04-14-93 04-15-93
RUN DATE 04/08/93 TIME 05:39 P.M.
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<th>Title/Position</th>
<th>Company/Location</th>
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<td>Tom Allen</td>
<td>Carrier Corp.</td>
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<tr>
<td>Joseph Brault</td>
<td>Manufacturing Supervisor</td>
<td>Boston Digital</td>
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<tr>
<td>David M Burgett</td>
<td>Supervisor</td>
<td>General Electric</td>
</tr>
<tr>
<td>Robart Clotch</td>
<td>Engineer</td>
<td>Boston Digital</td>
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<tr>
<td>Troy Dell Ornano</td>
<td>Quality Engineer</td>
<td>Cincinnati OH</td>
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<tr>
<td>Rick DiMartino</td>
<td>Lead Inspector</td>
<td>Milford MA</td>
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<tr>
<td>John Fletcher</td>
<td>Engineer</td>
<td>Boeing Commercial Airplane</td>
</tr>
<tr>
<td>Jack Gallagher</td>
<td>Member of Technical Staff</td>
<td>Sandia National Lab</td>
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<td>Richard Garow</td>
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<td>Guo-Rao Huang</td>
<td>Engineer</td>
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<td>Engineer</td>
<td>Chating Hsinchu Taiwan 310 ROC</td>
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<td>AL J Lesnarsi</td>
<td>Technical Director</td>
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<tr>
<td>Rich Leonard</td>
<td>Applications Engineer</td>
<td>Minneapolis MN</td>
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<tr>
<td>Gary Mandolfso</td>
<td>Applications Engineer</td>
<td>Hewlett-Packard</td>
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<tr>
<td>William D Mark</td>
<td>Sr Scientist</td>
<td>Applied Research Laboratory</td>
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<td>William Machthab</td>
<td>Director-Industry Relations</td>
<td>NCTPC</td>
</tr>
<tr>
<td>ESLayed A O'Ready</td>
<td>Professor</td>
<td>University of Michigan</td>
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<tr>
<td>Jim Pollock</td>
<td>Shop Manager</td>
<td>NCTPC</td>
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<tr>
<td>Jeff Prenga</td>
<td>Tooling Engineer</td>
<td>ST Optics Technology Center</td>
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<td>Israel Salinas</td>
<td>Master Machinist Support Engineer</td>
<td>General Motors</td>
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<tr>
<td>Ronald Schelle</td>
<td>Process-Central Coordinator</td>
<td>Westinghouse Electric Corp</td>
</tr>
<tr>
<td>Carol Hutt</td>
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<tr>
<td>Booting CMMCa</td>
<td>Machinist</td>
<td>Wichita KS</td>
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Fred Schierloh  
VP Technology  
NCTPC  
Toledo OH

Yin-Lin Shen  
Assistant Professor  
George Washington University  
CMEE Dept  
Washington DC

Steve VonBorsetel  
Carrier Corp  
Syracuse NY

Mark Watt  
Vice President Sales  
DRW Consulting  
Bethany CT

Phillip White  
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Nagesh Sonti  
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Applied Research Laboratory  
State College PA

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Development Engineer  
Eastman Kodak  
Rochester NY

Donald K Watt  
DRW Consulting  
Bethany CT

Ken Wayne  
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Hewlett Packard  
Santa Clara Division  
Santa Clara CA

Leon Whaley  
President  
Carrier Corporation  
Syracuse NY

Paul C Witkowski  
Mfg Engineering Specialist  
Ford Motor Company  
Dearborn MI
Appendix C continued
Appendix D. Photos from a workshop

Donald Carter, left, demonstrates the electronic differential levels as a method of measuring angular motion of a linear slide on a special purpose measuring machine.

Herman Hauschildt, right, points to the attachment of the retroreflector mirror to the spindle while demonstrating the set-up for performing a volumetric performance test (Diagonal Displacement using a laser interferometer) on a CNC machining center.

Samuel Thompson, far right, explains how to align the laser with the direction of travel of the linear slide on a manual milling machine.
October 26, 1994
GLH/LIB/rdp
3-6630-94-164

Roger Werne
Associate Director for Engineering
Lawrence Livermore National Laboratory
PO Box 808, L-125
Livermore, CA 94551

Dear Mr. Werne

Subject: TECHNOLOGY TRANSFER-LLNL/SME

On November 16-18, 1993, we attended the Machine Tool Metrology Workshop, a Cooperative Research and Development Agreement (CRADA), between LLNL and the Society of Manufacturing Engineers. The training from the workshop is being applied throughout the company. Numerous machines are now being measured on a six month cycle to determine machine capability, target maintenance, and to look at trend changes. The information presented was vital to the success of applying the B5.54 standard. In Wichita, we have incorporated the ballbar and laser diagonal tests invented by your facility. We find the information meaningful and necessary. The manuals presented at the workshop are being routed to Equipment Engineers and other groups associated with machine performance. The scientists at LLNL have applied fundamental physical principles to develop and apply new technology to machine tools. The dissemination of this type of knowledge is essential if we are to improve our manufacturing processes.

Attached are two memos that recognize the importance of this technology. The Boeing memo is a result of the Metrology Workshop that Don Carter developed. Boeing Seattle is scheduling the SME workshop for their employee’s training of the standard.

The contacts made from the workshop are also noteworthy of mentioning. Joe Drescher of United Technology was also an attendee and we have regular phone conversations discussing this technology. Bob Hocken also assists us with technical consulting, which is again a result of attending the workshop and becoming familiar with the B5.54 standard.

If US industry is to become world competitive, this Technology Transfer Initiative should continue.

Loyd Bishop
Metrology Specialist
Org. 3-6630 Mail Stop K78-17
Telephone (316)523-1360

Garrett L. Hill
Physical Metrology Supervisor
Org. 3-6630 Mail Stop K78-17
Telephone (316)526-3120

cc: Don Carter
Manufacturing and Materials Engineering Division
Lawrence Livermore National Laboratory
PO Box 808, L-292
Livermore, CA 94551

Enclosures: (2)
Subject: Evaluation of the BCAG Wichita Machine Tool Certification program using the B5.54 Standard.

On September 28, 1994, Michael Badger, (Boeing representative for the B5.54 related "Machine Tool Accuracy Initiative") presented a proposal to implement a plan for using the B5.54 for purchasing new machines and improving the accuracy of existing NC/ CNC machines.

The presentation was made to Ernie Shaw [Manufacturing Business Unit (MBU) Director] and Neil Falk [Machining/ Skin & Spar MBU Manager] et al.

The improvement to existing NC/CNC machine accuracy currently underway using the ASME B5.54 Standard at the Wichita Division was pointed to as a model for BCAG Fabrication Division and as the leader in applying some of this new technology within the Boeing Company.

After the presentation and following discussion Mr. Shaw said more information was needed on the potential benefits before making a decision on the proposal to implement a program for improving the accuracy of machine tools using the B5.54 Standard.

Mr. Shaw requested that a person representing the Wichita program be invited to Fabrication Division, Auburn Washington, on October 25th to participate with Senior Management in a four hour review of a process standard document for the "Introduction of Reliable New Equipment and Processes".

The team that developed the "Introduction of Reliable New Equipment and Processes" document will spend most of the time reviewing it with their customers. This team will be asked to make a recommendation at this review to either include or not include the ASME B5.54 as a reference standard for the purchase of new CNC Machine Centers.

Loyd Bishop, Facilities Metrology Services was contacted and has agreed to come to Auburn to represent Wichita Division in this review.

The facts and data from Wichita's application of the B5.54 methods will influence the decision to include the B5.54 as a reference standard and also will provide a history on the benefits for improving the accuracy of existing machine tools.

Thank you for your cooperation,

Michael Badger
Quality Engineering
BCAG Fabrication Division
8 (206) 931-9915

Denton Schimming
Quality Engineering Supervisor
BCAG Fabrication Division
8 (206) 351-1515
Dear Mr. Bishop:

Thank you for affording me the opportunity to review the videotape on the Machine Tooling Capability. The presentation on the use of drift, ball bar, linear displacement and laser diagonals was very informative. The benefits of the use of laser diagonals in establishing target baseline data, in targeting maintenance, and in identifying task capacity are definitely worth the effort in incorporating laser diagonal checking.

We are very appreciative of your willingness in sharing this information with us. Again, thank you for your thoughtfulness.

Sincerely,

[Signature]

HARITON C. SPRINCEANU
Chief, Equipment Engineering Section

---

Loyd Bishop
M/S K 78-17
Boeing Commercial Airplane
P.O. Box 7730
Wichita, KS 67277

March 31, 1994
**MACHINE TOOL METROLOGY (ACCURACY CHARACTERIZATION)**

*June 6-8, 1995 ★ October 17-19, 1995*

**National Center for Tooling & Precision Components ★ Toledo, Ohio**

This 3-day demonstration workshop will show machine tool users and manufacturers how to test and characterize the accuracy of machine tools, including the use and application of ANSI/ASME standards.

**Workshop Description**

This workshop provides an understanding and application of fundamental metrology principles specifically to the testing of machine tools and coordinate measuring machines (CMM's). It stresses the importance of functionally significant tests and the proper use of terminology for describing these tests. Parametric test procedures as outlined in ANSI machine tool standards will be demonstrated.

**What You'll Learn**

- Assess, characterize and understand the accuracy errors of a machine tool or CMM as well as perform the necessary tests for a particular application.
- Create specifications based upon standards and communicate this information in a language that the machine tool community understands and accepts.
- Compare accuracy of similar machines and predict performance.
- Make informed purchase decisions.
- Prescribe the correct acceptable test procedures.
- Learn misconceptions of "pitch error" compensation.
- Discover importance of proper foundations.

**Who Should Attend?**

- Designers and builders
- Factory/assembly and field/service technicians
- Sales representatives
- Specification writers
- Technology educators
- Rebuilders
- Testing service technicians
- Machinists

**Basic Skills/Prerequisites Required**

- Familiarity with machine tools (e.g., lathes, milling machines, machining centers, measuring machines, etc.) functions, terminology and applications.
- Proficiency with shop level math (trigonometry, algebra, geometry, etc.).

**Do you have 15 or more people that you could send to this workshop? CALL KAREN CHISNELL AT 1-800-733-4763 TO ARRANGE TO BRING THIS PROGRAM TO YOUR COMPANY!!**

*SEE REVERSE SIDE FOR REGULAR REGISTRATION INFORMATION*
Appendix F  continued

Workshop Instructor
Robert F. (Bia) Callaghan, Jr., SME, is Chief Engineer at Independent Quality Labs, Inc. and has over 22 years experience in precision tool and machine design and metrology. He is a member of the ANSI/ASME committees B89.1.12 and B5.54 for the performance evaluation of CMM's and CNC machining centers.

Workshop Location/Lodging
All sessions of the Machine Tool Metrology workshop will be held at the National Center for Tooling & Precision Components (NCTPC), 2600 Derr St., Toledo, OH (419) 531-8340. Three hotels are in close proximity to NCTPC. Please call directly for reservations (no room block available and rates are subject to change). Government rates and other discounts may be available. Clarion Inn (419) 535-7070 ($69 single, $27.99 single); Red Roof Inn (419) 536-0118 ($27.99 single, $240 plus tax double). Comfort Inn (419) 531-2666 ($46 single).

Questions? Call Karen Chisnell, SME at (313) 271-1500, ext. 542.

Three Ways to Register:

1. Call the SME Customer Service Center at 1-800-733-4SME (4763) between 8am-6pm EST Monday through Friday.
2. Complete registration form and mail to SME.
3. FAX completed form to SME Customer Service at (313) 271-2861.

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REGISTRATION INFORMATION
TO ATTEND: Complete the registration form and mail to P.O. Box 6028, Dearborn, MI 48121-6028.

REGISTRATION INFORMATION: Registration fees must be paid in advance of the program. The fee includes attendance at all sessions, group lunches, coffee breaks, and all reference materials. Your program materials and credentials will be prepared and waiting for you at the registration area. Attendance must be limited and only preregistered, pre-paid registrants will be guaranteed access to the event. ON-SITE REGISTRANTS, with payment, will be admitted on a space-available basis.

CANCELLATIONS: Registrations cancelled 7 days (or less) prior to the program are subject to a $50 service charge. Checks are refundable minus the $50 service charge. You must obtain a cancellation number from our registrar to verify cancellations. Participants with confirmed registrations who fail to notify SME of a cancellation prior to the program are subject to the full fee. On-site cancellations are subject to a 50% service charge.

TAX DEDUCTION: An income tax deduction may be allowed for expenses of education (including registration fees, travel, lodging and meals) undertaken to maintain and improve professional skills (Treas. Reg. Sec. 1.162-5). Deductions for business and educational meals are generally limited to 80% of the cost. The sponsor(s) will be subject to this limitation for meals provided by the sponsor(s). It is presently unclear whether the limitation will be applied to the participant as well. Participants should consult a tax advisor to determine whether this limitation is applicable.

METHOD OF PAYMENT: All checks should be made payable to SME in U.S. funds. Registration and payments must be made before the program date to guarantee admittance. If payment has not been received prior to the program date, you will be asked to guarantee payment against a credit card (VISA, MasterCard, Discover, or American Express) or provide a company or personal check, money order, or traveler's checks. We suggest that if your payment has not been mailed to SME at least 2 weeks prior to the event that you plan to pay on-site. You may register by phone using your VISA, MasterCard, Discover, or American Express credit card.

EDUCATION/STUDENT REGISTRATIONS: Educational discounts are available to qualified full-time faculty or full-time students for many events. To take advantage of these discounts, educators and students must respond in writing with verification of full-time college or university status. NO PHONE REGISTRATIONS, PLEASE. For complete registration information, contact the Customer Service Department of SME.

☑ YES, I will attend the "Machine Tool Metrology" workshop on June 6-8, 1995 in Toledo, OH (CC# 2932895)
☑ YES, I will attend the "Machine Tool Metrology" workshop on October 17-19, 1995 in Toledo, OH (CC# 2933995)

SME Members: $795 Nonmembers: $895

Please Type or Print

NAME
TITLE
COMPANY
DIVISION
COMPANY MAILING ADDRESS (Include street and/or P.O. Box, City, State, Zip Code and Country)

TELEPHONE ( )
FAX
Area Code Ext.

☑ SME Member No.
☑ SME Affiliate No.
☑ Nonmember

METHOD OF PAYMENT
☑ Payment enclosed
☑ This confirms telephone registration to a credit card (please complete this section)

Check one: VISA MASTERCARD DISCOVER AMERICAN EXPRESS

Signature

Card# __________________ Exp. Date __________

SME CODE: 8