The Role of Computer-Based Simulation in Manufacturing Laboratories

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Abstract

The manufacturing engineering laboratory experience has undergone a considerable amount of change in the last one hundred years. The fundamental failing of the modern manufacturing laboratory experience is that the students do not receive “hands-on” training with the processes. To address this problem, computer-based manufacturing process simulations may be employed. One such computer-based laboratory experience is described. The benefits and disadvantages of this approach are also discussed.

Introduction

Laboratories focused on production or manufacturing have been an integral part of the mechanical engineering curriculum for over a century. These laboratories originally concentrated on giving the student a significant “hands-on” experience with manufacturing processes. The students learned to run lathes and milling machines, make molds, create welded joints, etc. This intimate exposure gave the students very practical training on the inputs, outputs, and capabilities of the processes.

The emphasis on manufacturing and production in the mechanical engineering curriculum is greatly reduced from that of the past. At Michigan Technological University (MTU), for example, currently only one ten-week course in manufacturing processes is required. In place of manufacturing, the mechanical engineering curriculum has strengthened its focus on the design of mechanical and thermal systems. It may be merely a coincidence, but the demise of the manufacturing emphasis in the curriculum during the 1960’s roughly corresponds to when competitors in the world marketplace began to erode the market position of the U.S. The de-emphasis of manufacturing in the curriculum must be seriously considered as a possible explanation for the inability of U.S. industry to be as competitive as in the past.

The manufacturing laboratory experience is also different from that of the past. While students are still quite often exposed to a number of processes, they do not receive the practical training they once did. As a result, they are less comfortable and familiar with the processes. There are a number of factors that have potentially contributed to this change in the manufacturing laboratory experience:

- The general shift of the curricula from a focus on engineering design to engineering science. More emphasis is given today to the science of manufacturing than was given 40 years ago.
- The use of larger laboratory class sizes that do not allow the teacher to provide individual instruction.
- A reduction in the availability of suitable manufacturing equipment at colleges and universities.
- Liability in the case of students operating machines.
- The belief that engineers need not be intimately familiar with manufacturing processes - “leave that to technicians.”

The validity or “correctness” of the factors above may be argued; however, the students’ lack of knowledge relating to manufacturing processes is undeniable. We cannot turn back the clock, however, and it may be argued that going back to the “good old days” is not the solution anyway. An inescapable thought is that there is a lack of exposure to processes in the modern manufacturing laboratory experience. Since in many cases the processing machines are no longer available, the question then is how to provide the students the important features of the “hands-on” experience without physically working with the actual equipment. The answer may lie in the use of computer-based manufacturing process simulations.

Use of a Computer-Based Process Simulation

Since the 1940’s, manufacturing researchers have sought mechanistically characterize machining operations with prediction models. In these models attention has been given to predicting such performance measures as cutting forces, cutter and workpiece deflections, machined surface error, and surface finish. The goal of all this research is to develop decision-making tools for product designers and manufacturing process planners. The advent of computer technology has enabled the development of prediction models for complex machining processes such as peripheral milling. An effort is underway at MTU to develop and introduce peripheral milling laboratory exercise into the required manufacturing processes course. The laboratory experience not only familiarizes the student with the fundamentals of the milling process.
cess, but also promotes the idea that computer-based tools can be used for manufacturing decision-making.

In the milling laboratory exercise, the student is first acquainted with the geometry and mechanics of the peripheral milling process. For brevity, the full details of this development are not included here. The geometry of the milling process may be depicted as shown in Fig. 1. The geometry and kinematics of the process together describe how the area of contact (chip load) between the tool and work changes as a function of time. At a given instant in time, the forces acting on the cutter in the X- and Y- directions are proportional to the chip load. The coefficients that relate the cutting force to chip load are actually empirical functions, the parameters of which may be estimated from a few machining experiments.

![Diagram of Peripheral Milling Process]

Figure 1. Views of the Peripheral Milling Process: (a) Sectional Top View and (b) Sectional Side View

Once the student has been presented with the mechanics of how the forces in the peripheral milling process arise, attention is then given to the performance measure, surface error. Surface errors, or dimensional inaccuracies, result when the cutting forces are applied to the cutter and workpiece structures. Models for these structures are described, and the surface generation mechanism by which these deflections are imparted to the machined surface is also presented. Finally, the students are given an overview of the software that incorporates the cutting force prediction and surface generation mechanism.

With the analytical background for the peripheral milling process and model developed, the focus may then be directed to the actual process. The students are taken in groups of about twelve individuals to the manufacturing lab, and shown the milling process in person. They are instructed on how to set the radial and axial depths of cut, the table feed, and the spindle speed. They practice this instruction through the act of conducting one or two machining experiments - with help from a teaching assistant. During the machining experiments the cutting forces are measured and stored on the computer. The students are able to see the magnitude and characteristic shape of these force signals. They are also shown the machined surface error that was produced by the process. This experience gives the students some familiarity with the milling operation, and with the inputs to the process. What is lacking from this exposure is an understanding of how manipulations to the input variables changes a performance measure such as the surface error. Such an understanding simply cannot be achieved in the limited amount of time the student is exposed to the actual process.

Once the limited "hands-on" work in the actual laboratory is completed, the students take the results of their experiments and use them to develop the empirical functions the computer-based model requires to relate force and chip load. Once the empirical functions are developed, the process simulation is used to predict cutting forces for conditions comparable to those examined in the experimental study. These predicted force signals may be compared to the actual force signals obtained from the experiment to test the validity of the computer model. With a favorable comparison the student acquires additional confidence in the process simulation model.

To understand how the process variables impact the peripheral milling process, the students use the simulation model. Several variables are selected and examined. Figure 2 shows one comparison they might make in examining the process variables. As is evident, Fig. 2 displays the surface error generated by the side (periphery) of the cutter. The figure illustrates quantitatively the effect that table feed has on the dimensional accuracy of the process. Since increasing table feed increases both the error and the productivity, the students are also made aware of the types of trade-offs that must be dealt with in a typical manufacturing decision-making problem.

![Graph of Surface Error vs. Feed]

Figure 2. Effect of Table Feed on Surface Error (Based on Process Simulation)

The students are asked to summarize the results of their analytical and experimental investigation in a laboratory report. They must indicate the effect that each process variable examined has on several performance measures. The trade-offs that must be made in working with the peripheral milling process are also to be discussed.
Discussion

The computer-based laboratory experience that has been described differs substantially from most other laboratory assignments within the required manufacturing course at MTU. The other assignments also employ some actual experimental work with manufacturing processes, but these other experiences do not provide the students with an understanding of how all the variables impact the process. At best, they only provide the student with casual knowledge about the process. It is believed that working with the computer model provides for an understanding of the peripheral milling operation comparable or even superior to working with the actual operation.

Finally, as a manufacturing engineering educator, one of my missions is to excite students about manufacturing. A conversation with students or industrial practitioners reveals, however, that many students within the mechanical engineering curriculum shy away from manufacturing because it has a reputation as being “low-tech”. Students want to avoid getting their hands dirty in manufacturing, or view manufacturing as something for poorer students. The use of computer-based process simulation models may change this attitude, exciting and motivating many of these students to take additional classes in the field of manufacturing engineering.

References