MODERN MATERIALS AND MANUFACTURING PROCESSES

John E. Neely

Richard R. Kibbe

John Wiley & Sons
World Publishing Corp

MODERN MATERIALS AND MANUFACTURING PROCESSES

John E. Neely
Instructor, Machine Technology, Ret.
Lane Community College, Eugene, Oregon

Richard R. Kibbe
Director, RRK General Machining and Manufacturing
Instructor, Industrial Technology
Oxnard Community College, Oxnard, California

John Wiley & Sons
World Publishing Corp

Authorized Reprint of the Original Edition,
Published by John Wiley & Sons, Inc. No part of
this book may be reproduced in any form without
the written permission of John Wiley & Sons, Inc.
This special Reprint Edition is Licensed for sale
in China excluding Taiwan Province of China, Hong Kong & Macao
Reprinted by World Publishing Corp. Beijing, 1990
ISBN 7-5062-0523-8

Cover photograph: Gabe Palmer/The Stock Market.

A number of illustrations have been reused with permission from Neely, White, Kibbe, and Meyer, *Machine Tools and Machining Practices*, Volumes I and II (copyright © 1977 John Wiley & Sons, Inc.) and John E. Neely, *Practical Metallurgy and Materials of Industry* 2 Ed. (copyright © 1984 John Wiley & Sons, Inc.).

Library of Congress Cataloging in Publication Data:

Neely, John E.
Modern materials and manufacturing processes.

Includes index.
1. Manufacturing processes. 2. Materials. 3. Metalwork. I. Kibbe, Richard R. II. Title.
TS183.N44 1987 670 86-15907
ISBN 0-471-81443-1

PREFACE

This textbook presents state-of-the art technology on materials and manufacturing processes in a style that can be understood by the typical technician or technology student. It is intended for vocational education students and technicians and for students in engineering technology.

The arrangement and format of chapters presents clear, sequential course material for any teaching system, whether competency based or traditional. Objectives at the beginning of each chapter clarify the goals of each chapter. Case studies and case problems are included where appropriate to promote thought and discussion on the part of the students. Questions and case problems may be used for review or examination purposes. Nearly 1000 illustrations and photographs complement the text.

This book is intended primarily for the survey course in materials and manufacturing processes. Rapidly growing technologies such as those found in the plastics and aerospace industries are emphasized. We not only discuss the specific materials and processes of manufacturing normally included in the survey course, but also, in a unique approach, show how those materials and processes are integrated into today's functioning manufacturing industry. However, this book does not provide a hands-on instructional system for the operation of machinery or the use of hand tools.

Part I, on materials and their applications, discusses frequently used materials such as metals, plastics, and rubbers, which are identified and classified. Their extraction from raw materials and their processing are presented in sufficient detail to enable the student to proceed to the study of product manufacturing from these materials.

Part II covers specific manufacturing processes. Conventional manufacturing processes including casting, cold and hot rolling, forming, forging, plastics molding, and joining of materials are discussed in detail. Newer processes and methods are presented where they apply.

Part III discusses the design, tooling, and production aspects of manufacturing. This part also introduces modern automation methods including CNC, CAD/CAM, industrial robotics, and Flexible Manufacturing systems (FMS), precursors to the totally automated factory of today and tomorrow. These topics include Computer Numerical Control (CNC), Computer-Aided Design (CAD) as a designer's tool, Computer-Aided Manufacturing (CAM), and the integration of these technologies as ICAM and CADAM.

In Part III we also discuss the way the manufacturing industry functions, job titles and general responsibilities, and how production manufacturing is accomplished. A separate chapter covers quality assurance and control aspects with particular emphasis on tolerances, production dimensional measurement, and calibration.

An extensive glossary is included at the end of the book. A complete instructor's manual is available from the publisher.

J.E.N.
Eugene, Oregon

R.R.K.
Oxnard, California

ACKNOWLEDGMENTS

The authors are most grateful to the companies and individuals who have contributed materials and help in preparing this text. Special thanks go to Eugene Aluminum & Brass Foundry, Hergert's Industry, Lane Community College, and Lockheed-California Company who granted access to their facilities for photography and for supplying illustrations and technical information.

Ajax Magnothermic Corporation, Warren, OH
Alewijnse Electrical Engineering, Environment System, Nijmegen, Holland
Allis Chalmers, Milwaukee, WI
Aluminum Company of America, Pittsburgh, PA
American Die Casting Institute, Des Plaines, IL
American Iron & Steel Institute, Washington, DC
American Motors, Southfield, MI
American Society for Metals, Metals Park, OH
Apex Broach & Machine Company, Detroit, MI
Armco Inc., Specialty Steels Division, Middletown, OH
Automated Finishing Incorporated, Menomonee Falls, WI

Baird Corporation, Bedford, MA
Barrington Automation, Fox River Grove, IL
Bethlehem Steel Corporation, Bethlehem, PA
Beuhler LTD, Lake Bluff, IL
Bird-Johnson Company, Walpole, MA
Boeing Commercial Airplane Company, Seattle, WA
Bracker Corporation, Pittsburgh, PA
Buck Chuck Company, Kalamazoo, MI
Buffalo Forge Company, Buffalo, NY
Bureau of Mines, Albany, OR
Burlington Industries, Greensboro, NC
Buss-Condux, Inc., Elk Grove Village, IL

CHR Industries, Inc., New Haven, CT
Chrysler Corporation, Detroit, MI
Cincinnati Milacron, Cincinnati, OH
Cincinnati Milacron Plastics Machinery Division, Batavia, OH
Clausing Machine Tools, Kalamazoo, MI
Coherent, Palo Alto, CA
Colt Industries, Crucible Specialty Metal Division, Syracuse, NY
Consolidated Metco, Inc., Clackamas, OR
Consulate General of the Netherlands, Economic Section, NY

Del Manufacturing, Oxnard, CA
Disogrin Industries Corporation, Manchester, NH
Dixon Industries Corporation, Bristol, RI
DoALL Company, Des Plaines, IL
Dover Publications, New York, NY
Ductr Mfg., Eugene, OR
DuPont Company, Engineering Polymers Division, Wilmington, DE

ESAB North America Incorporated, ESAB Robotic Welding Division, Fort Collins, CO
Ethan Allen, Danbury, CT
Eugene Aluminum & Brass Foundry, Eugene, OR
Exxon Company, Houston, TX

Federal Products, Providence, RI
Fellows Corporation, Springfield, VT
Ford Motor Company, Dearborn, MI

Gates Learjet, Phoenix, AZ
General Motors Corporation, Detroit, MI
Giddings and Lewis, Fond du Lac, WI
Gleason Machine Division, Rochester, NY
Globe Amerada Glass Company, Elk Grove Village, IL
Goodyear Tire and Rubber Company, Akron, OH

Hamilton Caster & Mfg. Co., Hamilton, OH
Heck Industries, Redford, MI
Hergert's Industries, Drain, OR

Illinois Gear, Chicago, IL
Intergraph Corporation, Huntsville, AL

Japax Incorporated, Kanagawa, Japan
John Wiley & Sons, Inc., New York, NY

Kearney and Trecker, Milwaukee, WI
Kennametal Inc., Raleigh, NC
Kevex Corporation, King of Prussia, PA

L.S. Starrett Company, Athol, MA
Landis Tool, Waynesboro, PA
Lane Community College, Eugene, OR
Laserdyne, Eden Prairie, MN
Laserfare, Johnston, RI
Leland Balber Associates, Pittsburgh, PA
Libby-Owens-Ford, Toledo, OH
Lidköping Mekaniska Verkstads AB, Sweden
Lockheed-California Company, Division of Lockheed Aircraft Corporation, Burbank, CA
Louis Levin & Son, Inc., Culver City, CA
LTV Steel Company, Cleveland, OH

McGraw-Edison Company, Power Systems Division, Pittsburgh, PA
Magnaflux Corporation, Chicago, IL
Martin Marietta Corporation, Bethesda, MD
The Minster Machine Company, Minster, OH
Miller Electric Manufacturing Company, Appleton, WI
Mittler Machine Corporation, Providence, RI
M. L. Sheldon Plastics Corporation, New York, NY
MTI Corporation, Paramus, NJ
Mueller-Phipps International Corporation, Poughkeepsie, NY

National Machinery Company, Tiffin, OH
Niagara Machine & Tool Works, Buffalo, NY
Nikon Incorporated, Instrument Division, Garden City, NY
Northrop Corporation, Hawthorne, CA

Oregon Portland Cement Company, Portland, OR

Pacific Machinery & Tool Steel Company, Portland, OR
Parker Hannifin Corporation, Cleveland, OH
Pennsylvania Pressed Metals, Inc., Emporium, PA
Pierce Corporation, Eugene, OR
Plastics Machinery Incorporated, Williamston, MI
Porter, Westbrook, ME
Positech Corporation, Laurens, IA
Pottstown Machine Company, Pottstown, PA

Republic Steel Corporation, Cleveland, OH
Rhino Robots, Champaign, IL

Sandusky Foundry & Machine Co., Sandusky, OH
Saunders Equipment, Inc., Cold Spring, NY
Siempelkamp Corporation, Buffalo Grove, IL
Siempelkamp Corporation, Marietta, GA
The Stanley Works, New Britain, CT
Storage Technology, Louisville, CO

Teledyne Wah Chang Albany, Albany, OR
Testing Machines Inc., Amityville, NY
Tinius Olsen Testing Machine Co., Inc., Willow Grove, PA
TRW Cutting Tools Division, Augusta, GA
TVT Die Casting & Mfg. Inc., Portland, OR

United States Steel Corporation, Pittsburgh, PA

Unitron Instruments, Inc., Plainview, NY

Warner & Swasey, Sheffield Measurement Division, Dayton, OH
Wellcraft Marine Corporation, Sarasota, FL
Wheaton Industries, Wheaton Glass Division, Millville, NJ
Whirlpool Corporation, Benton Harbor, MI

CONTENTS

INTRODUCTION TO MATERIALS AND MANUFACTURING

Few human enterprises represent a more aggressive and dedicated use of time, energy, money, and material resources than the activities of extracting or otherwise making raw materials and then processing these materials into the endless line of products that make the modern life-style possible. Since the first appearance of humankind on this planet, **manufacturing,** the processes and methods of converting materials into different forms and products, has gone hand in hand with human development. Many examples of toolmaking by ancient humans have been discovered. With tools, ancient peoples were able to shape natural and ultimately synthetic materials for weapons, shelters, and other products that could be traded or sold, thus generating both commerce as well as demand for more, different, and improved types of materials and manufactured products. The desire and demand for exotic materials and products stimulated the explorer and the trader to travel to the far corners of the earth.

Such exploits created needs for higher technology in manufactured products. Navigational instruments and accurate maps are examples. These items were essential in order to make these voyages of discovery safer, more reliable, and to better ensure that the trader would return safely with the materials that were in such demand. Such factors stimulated the maximum efforts in design and materials application available at the time.

As ancient peoples gathered together to avail themselves of products, services, and materials, manufacturing societies began to develop and the structure for villages, towns, and ultimately cities was established. The increasing concentrations of people created needs for much improved manufacturing methods to supply demands. Specialty trades and crafts developed rapidly. This in turn created a need for faster methods of production, met by harnessing the power of animals, water, steam, and finally nuclear energy to power manufacturing machinery.

The lure of employment in manufacturing industries and the availability of manufactured products that would make life easier and more pleasant, contributed greatly to the industrialization and urbanization of much of the world. Great manufacturing centers developed, usually located close to fundamental sources of such raw materials as coal, oil, and iron ore, prime ingredients on which industrialization is built. In today's world, a vast international manufacturing society exists that aggressively makes use of all newly developed technology both in materials development and application, as well as in manufacturing processes.

In today's world of exotic materials and high technology, modern manufacturing technology is constantly changing and growing. New methods of accomplishing production and applying new materials become available almost daily. No matter how current information is in this area, it becomes obsolete rapidly as new technology comes on line. Although most of the well-established processes of manufacturing products will always be with us, the differences will come in how these processes are used. New applications of standard processes will, at the same time, create new processes. New materials will also create new processing methods. The manufacturing technologist of today and tomorrow must be well versed in materials application and in the standard processes but will always be looking forward toward new applications of these materials and processes as well as toward the development of entirely new processes. Manufacturing of the future will become more specialized, making it more difficult for the technologist to keep informed of this rapidly changing and expanding technology.

The central purpose of this textbook is to present an overview of materials science, a survey of traditional as well as high technology manufacturing processes, and a look at manufacturing systems in the computer high technology age.

THE MANUFACTURING ECONOMY —PAST, PRESENT, AND FUTURE

By the middle of the nineteenth century, a truly remarkable revolution, the Industrial Revolution, which had its beginning two centuries before, was well established. Goods formerly made by hand were now made by machine and the era of large-scale mass production had begun.

The effects of the Industrial Revolution have been far-reaching. Cheap production of goods in large quantities, now the order of the day, has raised the standard of living for many people in industrialized societies. The Industrial Revolution has formed the basis of the modern life-style that most of us take for granted. General industrialization has for the present also provided almost unlimited employment opportunities for anyone willing to participate in the working world.

In the latter half of the twentieth century, a new industrial revolution, one of computers and space-age high technology, is taking place. Like that of the past century, this new technology will have far-reaching effects. However, we are now more than 100 years further down the road of technological development. Thus, the effects of the current industrial revolution will be much more far reaching than anything even dreamed of in the past centuries.

Modern industrial technology has already given us the power and the tools to be far more productive with much less need for people to do the work of manufacturing. It is not to be denied that modern technology has made the life-style of the modern industrial society even more easy, convenient, and filled with incredible products, most of which are within the purchasing power of the average person living in that society. However it may have temporary negative effects as well—for those who are not prepared to work in a high technology, computerized, and automated manufacturing world.

In addition, the gradual industrialization of less technologically oriented societies throughout the world is moving ahead, perhaps at a slower pace but always in a steady forward direction. We of the established industrial world could, for much of the past 50 years, take little notice of this advance as our technology was always well in front of that in less developed countries.

As the wage demands of the old established industrial societies rose over time, manufacturers sought to take advantage of the lower wage structures generally prevalent in emerging countries. Thus, the great migration of manufacturing from the established industrial societies to the emerging countries began and still continues to the present day.

What have been the results of this migration? It is true that manufacturing industries that have moved abroad have for some years been able to operate under more favorable wage structures. However, the very industries that these manufacturers sought to staff with cheaper labor have, by a natural evolution, raised the standard of living for workers in the countries where the industries were located. More jobs have been created, and with jobs have come higher pay and the ability of industrial workers to buy not just necessities but goods that make life easier and more pleasant. This factor plus the often diligent attitude of foreign workers toward their jobs and the resultant high level of productivity and quality, have brought industrial revolutions similar to our own in emerging countries. This process is continuing unabated and now presents intense competition to our domestic employment and economy.

Manufacturers, seeing the same problems as before, have moved on to the remaining even less developed countries, thus initiating the process over again. The effects have been and will continue to be far-reaching. In those countries where the technology and industrialization occurred first, a diligent attitude toward productivity coupled with an almost limitless market in the established industrialized world for the products produced has for the first time, placed the technical leadership of the established industrial old world in question.

For example, the influx of high quality goods manufactured abroad and imported into the United States for sale at an often much cheaper price, has continued unabated for many years. The results are only too evident. Jobs in the domestic economy have been lost, and manufacturing industry has not always countered by keeping up with modern trends in automation, productivity, quality control, and worker efficiency. Foreign manufacturing, often operating in a very favorable unrestricted business environment, and often with the total support of local governments, has been able to take better advantage of modern technology and is engaged in an effective program of operating modern and efficiently run industries.

If the industrial structure of the old industrial societies is to remain intact and the standard of living is to remain at a high level, it is of paramount importance that the entire industrial and manufacturing community adopt new attitudes toward how manufacturing can be done efficiently and competitively. The worker, who is in the end responsible for industrial output, must be treated well, but, at the same time, quality work and high productivity must be maintained. Manufacturing industries must put to use all of the modern tools necessary to accomplish efficient quality production in the high technology age. The production worker of today will give way to the computerized robot of tomorrow and must therefore look ever forward to the future, or lack thereof, for his or her job skills.

It is a sure bet that product manufacturing in the future will be done on a more automated level of high technology and automation. Many of the products that will soon be commonplace have not even been designed yet, but as they are, more and more high technology manufacturing systems and methods will have to be created to produce them.

Automation trends, already at a high level in manufacturing, will become ever more the preferred method of production. **Flexible manufacturing systems (FMS)** (Figure 1), the forerunners of completely automated factories, already on line in many industries, will become commonplace as computer controlled automatic machines take over most of the mundane work heretofore done by fairly low-paid manual labor. The need for operating personnel will be minimized in this system, as robot operated transporters move workpieces automatically between manufacturing stations. **Industrial robots** (Figure 2) will perform the routine tasks of loading and off-loading parts into computer numerically controlled machining centers (CNC).

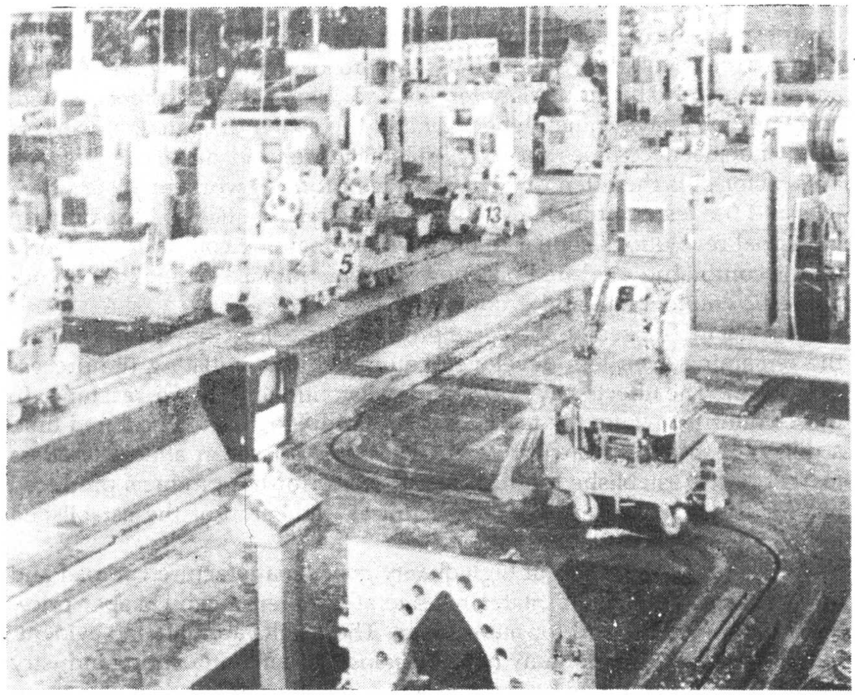

Figure 1
The flexible manufacturing system (FMS) with automated workpiece handling and transfer (Kearney and Trecker).

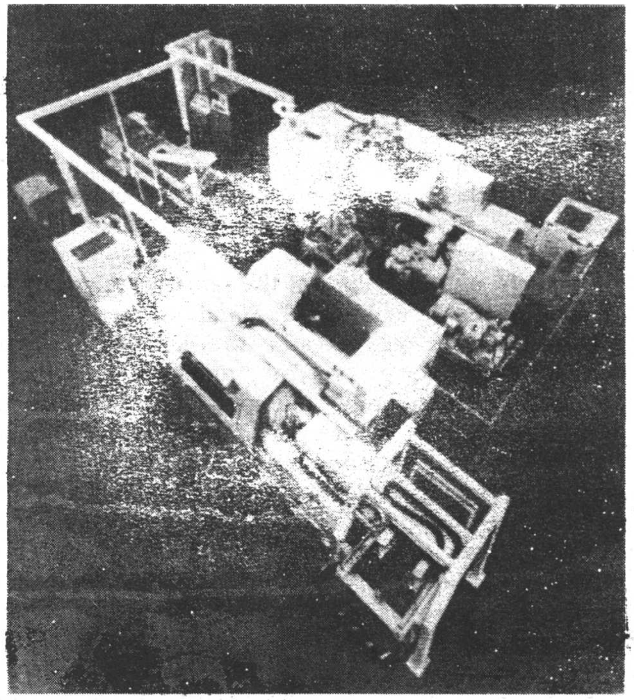

Figure 2
FMS work cell for CNC turning. The robot (center) loads and off loads parts for both machine tools (Cincinnati Milacron).

High technology is really not new. It has been with us since the first recorded manufacturing efforts, as each developmental age in manufacturing applied the latest available materials, tools, and methods to manufacturing requirements. Until now, however, most manufacturing industries still needed people to operate machines to turn out product units.

The computer, with its considerable ability to make decisions in process control applications, is already replacing people in the manufacturing process. As computer technology becomes more sophisticated, its decision-making powers will increase proportionally and thus its abilities for multitasking and decision making will increase as well. Artificial intelligence (AI) technology is presently under rapid development This will give computers even more decision-making power, making them even more versatile and in more complete control of routine as well as sophisticated mass production

THE COMPUTER INFLUENCE IN MANUFACTURING

Throughout the long and interesting history of technological development, many contributions have been made. First there was metallurgy, making available a wide selection of metals for toolmaking and manufactured products. The Industrial Revolution of the eighteenth and nineteenth centuries brought the age of machine-made mass produced goods. Electronics, especially solid state and integrated circuit (IC's or chips) technology, has made instant communication available to practically everyone on earth. Thus the message of what is available in manufactured goods has reached ever-widening markets.

All of these technological advances have transformed industry and society as a whole. However, the effect of the computer will be much more extensive than any technological device yet developed. This concept of computer control of processes is extremely significant in that it has and will continue to profoundly and forever change the way in which manufacturing is accomplished.

Does this mean that computers will control everything including the actions of people? The answer to this question is a definite no. However, the computer will aid those people who do direct the actions of people not just in manufacturing but in all phases of life.

The exact result of computers and computerized automation trends in manufacturing on the future worker is uncertain. However, it is sure that the factory worker of the future will have to become more of an electromechanical technician instead of being the simple machine tender of today's semi-automated factory.

The technician will have to learn broader skills, acquiring a more complete knowledge of electrical/electronic and hydraulic systems, transactional mechanisms, general mechanical skills, and very likely a working knowledge of computer systems and computer programming. For those not willing to learn new skills or accept retraining, future employment prospects at a suitable pay level may be limited. However, the skills and abilities of people with an open mind and a natural desire to understand how things work and how to operate, maintain, and repair complex electronic/mechanical machines are likely to be in demand.

MANUFACTURING AND YOU

For those who afford themselves of proper training, opportunities in manufacturing will abound. However, the future employee at any level in manufacturing will have to undergo broader and more complex training than at any time in the past.

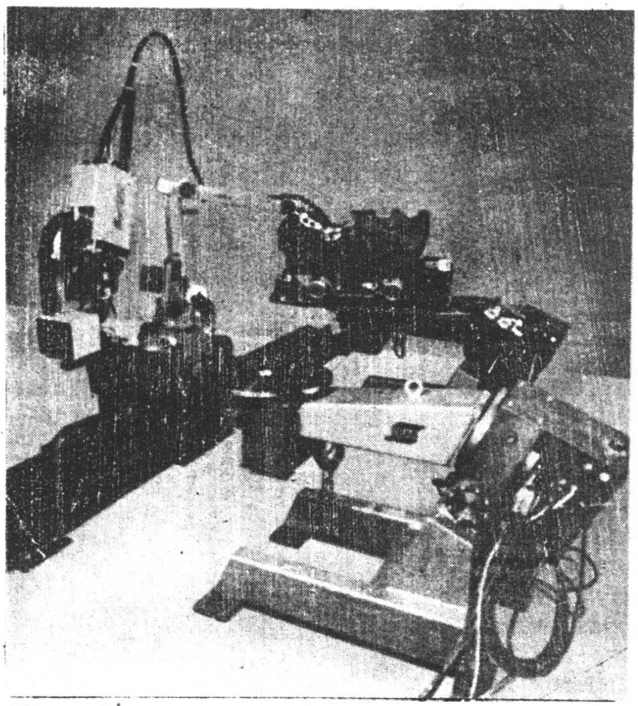

Figure 3
Robot welder welds a gear case mounted on one of two workpiece positioners (ESAB Robotic Welding Division).

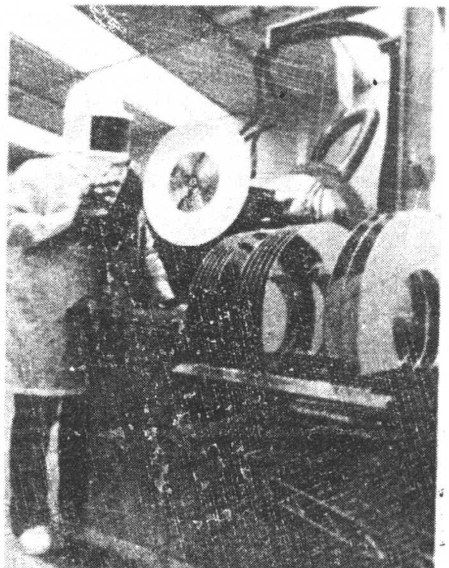

Figure 4
Production technician assembles laser computer disks in an ultra-clean room environment (Storage Technology).

Trade Level Opportunities

At the trade level, many of the repetitive production jobs that now are done by minimum wage employees will be eliminated as automation such as computer numerical control **(CNC)** and industrial **robotics** take over. Robots will become more and more sophisticated and capable, and as they do they will move further into the areas of the skilled trades such as welding (Figure 3). The robot welder can, in many situations, actually out-perform its human counterpart in both quantity and quality on many welding tasks.

The higher level skilled trades, such as **tool and die** making, will always be in demand, but preparation for these jobs will require several years of diligent training. Much of the machine operator's work will be automated as numerical control of machine tools is more fully integrated with robotic systems. The **general machinist** will be needed, but only in sufficient numbers to produce one-of-a-kind prototypes and few-part batches and support machine repair and agriculture requirements.

The **production technician,** an individual who has broad training in electric/electronics, mechanical/hydraulic systems, and computers will probably have the brightest future in trade-level manufacturing jobs. Even though the capability of modern and future automated computerized manufacturing systems is truly amazing, the equipment and control systems are complex and will require constant and careful maintenance. The production equipment technician will have to be able to quickly diagnose problems and effect repairs rapidly and efficiently so that it can be placed back in production as soon as possible.

High technology production technicians will be specialists at their work. They will assemble and test delicate high precision equipment, often in controlled environments. In Figure 4 the technicians are assembling a laser computer disk with very large memory capacity. This precision equipment must be handled in an ultraclean room environment.

Middle Management Levels

The future in manufacturing for the college trained **industrial engineer (IE), industrial technologist (IT), manufacturing engineer,** and **applications engineer** will also be bright. As automated manufacturing systems are put in place, the industrial, manufacturing, and applications engineer will be needed for plant facilities, tool, jig, and fixture design (Figure 5), robot and numerical control programming, and implementation of all aspects of the production manufacturing system (Figure 6). As with the production technician, the industrial technologist and manufacturing engineer will need to have broad training in materials applications, com-

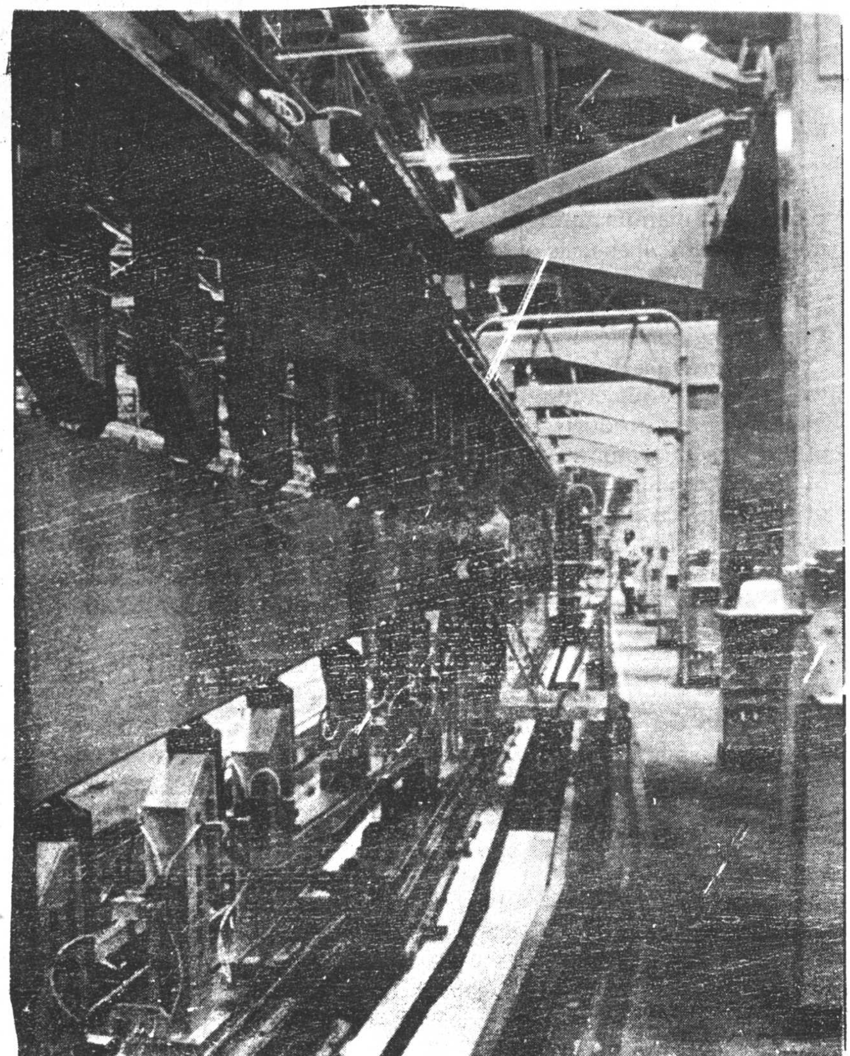

Figure 5
Automatic wing spar assembly tooling, new methods of tooling will challenge the industrial and manufacturing engineer (Boeing).

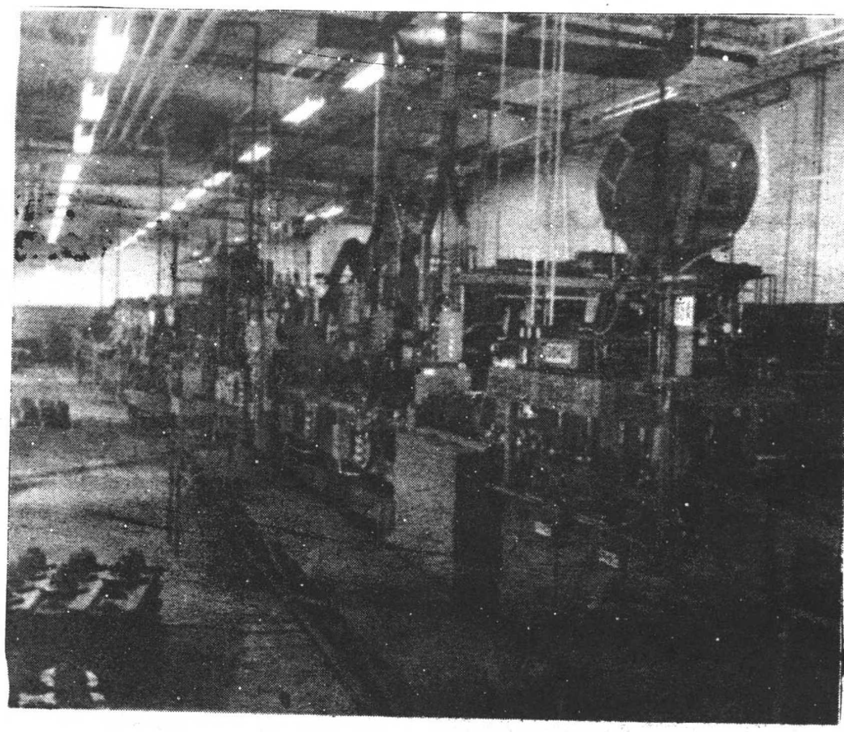

Figure 6
Integrated automation, machining, assembly, and testing in sequential automation (Giddings and Lewis).

puters, and manufacturing processes. Such individuals will also be heavily involved with all aspects of quality control and assurance as the manufacture of higher technology products becomes more commonplace.

Design Engineering

Creative **product designers** will always be needed as the capacity of high technology manufacturing makes possible production of a vast array of incredible new products, many of which have not even been designed as of the present. Tomorrow's designer will need to be thoroughly informed of the modern manufacturing methods and their capabilities. The designer of the future using the computer in a **Computer Aided Design (CAD)** system, will smoothly integrate new design ideas with new material and new processes as they become available. Preparation for jobs in this area will require college level education and on-the-job industrial training.

ON-GOING MANUFACTURING TECHNOLOGY

It is certain that modern manufacturing technology will always be in a continuing state of development. As new materials, methods, and computer aids come into play, the manufacturing engineer will apply these to solve production problems.

Materials

The product designer will continually seek new materials that are lighter, easier, and, especially, cheaper to process, while meeting design requirements for strength and durability. **Plastic** and **composite materials** will play a more important role in future products, thus permitting additional energy savings both in manufacturing processes and in powering road, air, and space vehicles (Figure 7).