Unit Manufacturing and Assembly Processes

There are a bewildering number of manufacturing processes able to impart physical shape and structure to a workpiece. However, if these processes are broken down into their basic elements and then examined for commonality, only a few fundamental processes remain. These are the building blocks, or unit processes, from which even the most complicated manufacturing system is constructed. This section describes these unit processes in sufficient detail that a technically trained person, such as a design engineer serving as a member of an integrated product and process design team comprised of members from other specialties, could become generally knowledgeable regarding the essential aspects of manufacturing processes. Also, the information presented in this section will aid such an individual inpursuing further information from more specialized manufacturing handbooks, publications, and equipment/tool catalogs.

Considering the effect that a manufacturing process has on workpiece configuration and structure, the following five general types of unit manufacturing process can be identified.

Material removal processes—Geometry is generated by changing the mass of the incoming material in a controlled and well-defined manner, e.g., milling, turning, electrodischarge machining, and polishing.

Deformation processes — The shape of a solid workpiece is altered by plastic deformation without changing its mass or composition, e.g., rolling, forging, and stamping.

Primary shaping processes—A well-defined geometry is established by bulk forming material that initially had no shape, e.g., casting, injection molding, die casting, and consolidation of powders.

Structure-change processes— The microstructure, properties, or appearance of the workpiece araltered without changing the original shape of the workpiece, e.g., heat treatment and surface hardening.

Joining and assembly processes —Smaller objects are put together to achieve a desired geometry structure, and/or property. There are two general types: (1) consolidation processes which usemechanical, chemical, or thermal energy to bond the objects (e.g., welding and diffusion bonding) and (2) strictly mechanical joining (e.g., riveting, shrink fitting, and conventional assembly).

Unit Process Selection

Each component being manufactured has a well-defined geometry and a set of requirements that it must meet. These typically include:

- Shape and size
- Bill-of-material
- Accuracy and tolerances
- Appearance and surface finish
- Physical (including mechanical) properties
- Production quantity
- Cost of manufacture

In order to satisfy these criteria, more than one solution is usually possible and trade-off analyses should be conducted to compare the different approaches that could be used to produce a particular part.

Control and Automation of Unit Processes

Every unit process must be controlled or directed in some way. The need for improved accuracy, speed,and manufacturing productivity has spurred the incorporation of automation into unit processes regarding both the translation of part design details into machine instructions, and the operation of the unit process itself and as a subsystem of the overall production environment. The section of this chapter on computer-aided design/computer-aided manufacturing (CAD/CAM) discusses the technology involved in creating and storing CAD files and their use in CAM. The expectations of precision are continuing to change,as indicated in Figure 13.2.1. This drive for ever-tighter tolerances is helping spur interest in continual improvements in design and manufacturing processes.

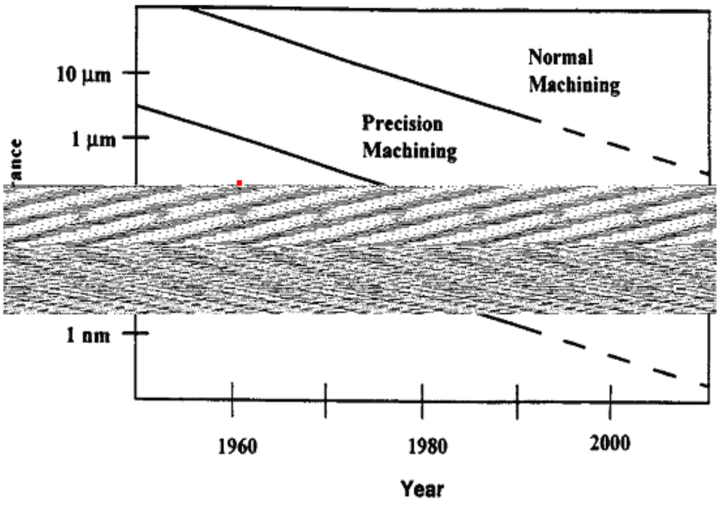

FIGURE 2.1 Precision machining domains.

Modern machine tool controls are emphasizing two areas: adaptive control and communication. For adaptive control the controller must adapt its control gains so that the overall system remains at or near communication links the data the optimal condition in spite of varying process dynamics. Expanded collected by a unit process controller to other segments of the manufacturing operation. Data regarding production time and quantity of parts produced can be stored in an accessible database for use by inventory control and quality monitoring. This same database can then be used by production schedulers to avoid problems and costs associated with redundant databases.

At the factory level, machining operations employing two or more numerically controlled (NC)machine tools may use a separate mainframe computer that controls several machine tools or an entire shop. The system is often referred to as distributed numerical control (DNC).

Today many factories are implementing fiexible manufacturing systems (FMS), an evolution of DNC.An FMS consists of several NC unit processes (not necessarily only machine tools) which are interconnected by an automated materials handling system and which employ industrial robots for a variety of tasks requiring fiexibility, such as loading/unloading the unit process queues. A single computer serves as master controller for the system, and each process may utilize a computer to direct the lower-order tasks. Advantages of FMS include:

- A wide range of parts can be produced with a high degree of automation
- Overall production lead times are shortened and inventory levels reduced
- Productivity of production employees is increased
- Production cost is reduced
- The system can easily adapt to changes in products and production levels

Unit Processes

In the following discussion, a number of unit processes are discussed, organized by the effect that they have on workpiece configuration and structure. Many of the examples deal with processing of metals since that is the most likely material which users of this handbook will encounter. However, other materials are readily processed with the unit processes described in this chapter, albeit with suitable modifications or variations.

Mechanical assembly and material handling are also discussed in this section. On average, mechanical assembly accounts for half of the manufacturing time, and processes have been developed to improve the automation and fiexibility of this very difficult task. Material handling provides the integrating link between the different processes —material-handling systems ensure that the required material arrive at the proper place at the right time for the various unit processes and assembly operations.

The section ends with a case study that demonstrates how understanding of the different unit processes can be used to make engineering decisions.

- Material removal (machining) processes
  - Traditional machining
    - Drill and reaming
    - Turning and boring
    - Planing and shaping
    - Milling
    - Broaching
    - Grinding
    - Mortality
- Nontraditional machining
  - Electrical discharge machining
  - Electrical chemical machining
  - Laser beam machining
  - Jet machining (water and abrasive)
  - Ultrasonic machining
- Phase-change processes
  - Green sand casting
  - Investment casting
- Structure-change processes
  - Normalizing steel
  - Laser surface hardening
- Deformation processes
  - Die forging
  - Press-brake forming
- Consolidation processes
  - Polymer composite consolidation
  - Shielded metal-arc welding
- Mechanical assembly
- Material handling
- Case study: Manufacturing and inspection of precision recirculating ballscrews

Material Removal Processes

These processes, also known as machining, remove material by mechanical, electrical, laser, or chemical means to generate the desired shape and/or surface characteristic. Workpiece materials span the spectrum of metals, ceramics, polymers, and composites, but metals, and particularly iron and steel alloys, are by far the most common. Machining can also improve the tolerances and finish of workpieces previously shaped by other processes, such as forging. Machining is an essential element of many manufacturing systems.

Machining is important in manufacturing because

·It is precise. Machining is capable of creating geometric configurations, tolerances, and surface finishes that are often unobtainable by other methods. For example, generally achievable surfaceroughness for sand casting is 400 to 800 μin. (10 to 20μm), for forging 200 to 400 μin. (5 to 10 μm), and for die casting 80 to 200 μin. (2 to 5 μm). Ultraprecision machining (i.e., super-finishing, lapping, diamond turning) can produce a surface finish of 0.4μin (0.01 μm) or better. The achievable dimensional accuracy in casting is 1 to 3% (ratio of tolerance to dimension) depending on the thermal expansion coefficient and in metal forming it is 0.05 to 0.30% depending on the elastic stiffness, but in machining the achievable tolerance can be 0.001%

·It is flexible. The shape of the final machined product is programmed and therefore many different parts can be made on the same machine tool and just about any arbitrary shape can be machined.In machining, the product contour is created by the path, rather than the shape, of the cutter. By contrast, casting, molding, and forming processes require dedicated tools for each product geometry, thus restricting their flexibility.

·It can be economical. Small lots and large quantities of parts can be relatively inexpensively produced if matched to the proper machining process.

Process Selection

Machine tools can be grouped into two broad categories:

·Those that generate surfaces of rotation
·Those that generate flat or contoured surfaces by linear motion

Selection of equipment and machining procedures depends largely on these considerations:

· Size of workpiece
·Configuration of workpiece
· Equipment capacity (speed, feed, horsepower range)
· Dimensional accuracy
·Number of operations
· Required surface condition and product quality

For example, Figure 13.2.2 graphically indicates the various tolerance levels that can be typically achieved for common machining unit processes as a function of the size of the workpiece. Such data can help in identifying candidate unit processes that are capable of meeting product requirements.

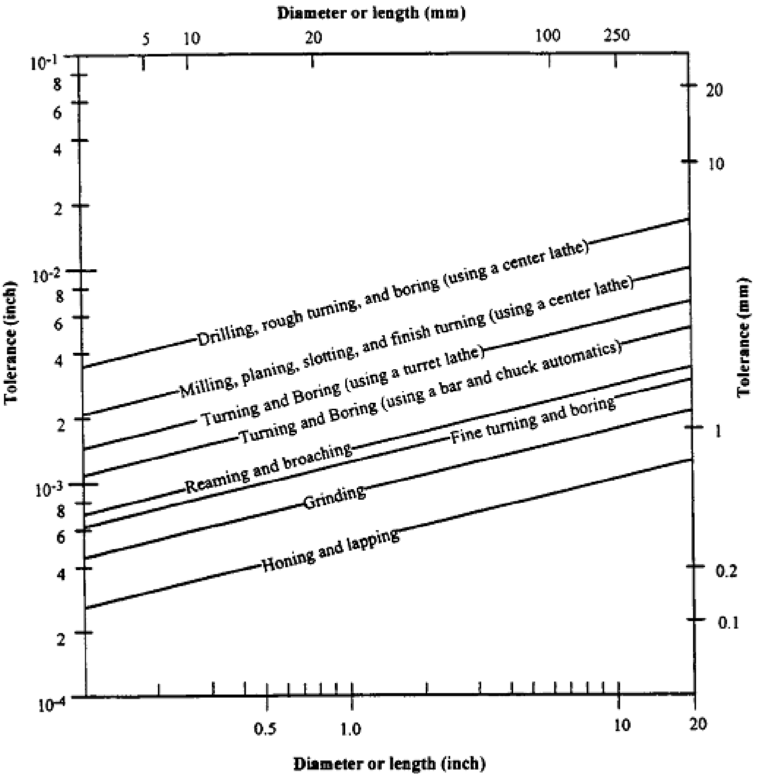

FIGURE 4.1Tolerance vs. dimensional data for machining processes.

Traditional Machining

Traditional machining processes remove material from a workpiece through plastic deformation. The process requires direct mechanical contact between the tool and workpiece and uses relative motion between the tool and the workpiece to develop the shear forces necessary to form machining chips. The tool must be harder than the workpiece to avoid excessive tool wear. The unit processes described here are a representative sample of the types most likely to be encountered. The reference list at the end of the section should be consulted for more detailed information on the unit processes discussed below, plus those that are not included here.

Process Kinematics in Traditional Machining. In all traditional machining processes, the surface is created by providing suitable relative motion between the cutting tool and the workpiece. There are two basic components of relative motion: primary motion and feed motion. Primary motion is the main motion provided by a machine tool to cause relative motion between the tool and workpiece. The feed motion, or the secondary motion, is a motion that, when added to the primary motion, leads to a repeated or continuous chip removal. It usually absorbs a small proportion of the total power required to perform a machining operation. The two motion components often take place simultaneously inorthogonal directions.

The functional definitions of turning, milling, drilling, and grinding are not distinctively different, but machining process specialists have developed terminology peculiar to a given combination of functions or machine configurations. Commonly used metal-cutting machine tools, however, can be divided into three groups depending upon the basic type of cutter used: single-point tools, multipoint tools, or abrasive grits.

Dynamic Stability and Chatter. One of the important considerations in selecting a machine tool is its vibrational stability. In metal cutting, there is a possibility for the cutter to move in and out of the workpiece at frequency and amplitude that cause excessive variations of the cutting force, resulting in poor surface quality and reduced life of the cutting tool.

Forced vibrations during cutting are associated with periodic forces resulting from the unbalance of rotating parts, from errors of accuracy in some driving components, or simply from the intermittent engagement of workpiece with multipoint cutters.Self-excited vibrations occur under conditions generally associated with an increase in machining rate. These vibrations are often referred to as chatter. All types of chatter are caused by feedback loop within the machine tool structure between the cutting a process and the machine frame and drive system. The transfer function of the machine tool, in terms of the stiffness and damping characteristics, plays a critical role in the stability of the overall feedback system. The static stiffness of most machine tools, as measured between the cutting tool and the workpiece tends to be around 10^5 lb-ft/in. A stiffness of 10^6 lb-ft/in. is exceptionally good, while stiffness of 10^4 lb-ft/in, is poor but perhaps acceptable for low-cost production utilizing small machine tools.

Basic Machine Tool Components. Advances in machine-tool design and fabrication philosophy are quickly eliminating the differences between machine types. Fifty years ago, most machine tools performed a single function such as drilling or turning, and operated strictly stand-alone. The addition of automatic turrets, tool-changers, and computerized numerical control (CNC) systems allowed lathes to become turning centers and milling machines to become machining centers. These multiprocess centers can perform a range of standard machining functions: turning, milling, boring, drilling, and grinding.

The machine tool frame supports all the active and passive components of the tool —spindles, table and controls. Factors governing the choice of frame materials are: resistance to deformation (hardness),resistance to impact and fracture (toughness), limited expansion under heat (coefficient of thermal expansion), high absorption of vibrations (damping), resistance to shop-floor environment (corrosion resistance), and low cost.

Guide ways carry the workpiece table or spindles. Each type of way consists of a slide moving along a track in the frame. The slide carries the workpiece table or a spindle. The oldest and simplest way is the box way. As a result of its large contact area, it has high stiffness, good damping characteristics, and high resistance to cutting forces and shock loads. Box slides can experience stick-slip motion as a result of the difference between dynamic and static friction coefficients in the ways. This condition introduces positioning and feed motion errors. A linear way also consists of a rail and a slide, but it uses a rolling- element bearing, eliminating stick-slip. Linear ways are lighter in weight and operate with less friction, so they can be positioned faster with less energy. However, they are less robust because of the limited surface contact area.

Slides are moved by hydraulics, rack-and-pinion systems, or screws. Hydraulic pistons are the least costly, most powerful, most difficult to maintain, and the least accurate option. Heat buildup often significantly reduces accuracy in these systems. Motor-driven rack-and-pinion actuators are easy to maintain and are used for large motion ranges, but they are not very accurate and require a lot of power to operate. Motor-driven screws are the most common actuation method. The screws can either be lead screws or ballscrews, with the former being less expensive and the latter more accurate. The recirculating ballscrew has very tight backlash; thus, it is ideal for CNC machine tools since their tool trajectories are essentially continuous. A disadvantage of the ballscrew systems is the effective stiffness due to limited contact area between the balls and the thread. (Note: a case study at the end of this section discusses the manufacture of precision ballscrews.)

Electric motors are the prime movers for most machine tool functions. They are made in a variety of types to serve three general machine tool needs: spindle power, slide drives, and auxiliary power. Most of them use three-phase AC power supplied at 220 or 440 V. The design challenge with machine tools and motors has been achieving high torque throughout a range of speed settings. In recent years, the operational speed of the spindle has risen significantly. For example, conventional speeds 5 years ago were approximately 1600 rpm. Today, electric motors can turn at 12,000 rpm and higher. Higher speeds cause vibration, which makes use of a mechanical transmission difficult. By virtue of improvement in motor design and control technology, it is now possible to quickly adjust motor speed and torque. Mechanical systems involving more than a three-speed transmission are becoming unnecessary for most high-speed and low-torque machines. Spindle motors are rated by horsepower, which generally ranges from 5 to 150 hp (3.7 to 112 kW) with the average approximately 50 hp (37 kW). Positioning motors are usually designated by torque, which generally ranges from 0.5 to 85 lb-ft (0.2 to 115 Nm).

The spindle delivers torque to the cutting tool, so its precision is essential to machine tool operation.The key factors influencing precision are bearing type and placement, lubrication, and cooling.