Assembly Processes
Finishing, Packaging, and Automation

EDITED BY
Richard Crowson
Preface

Handbooks are generally considered to be concise references for specific subjects. Today’s fast-paced manufacturing culture demands that such reference books provide the reader with how-to information with no frills. Some use handbooks to impart buzzwords on a particular technical subject that will allow the uninitiated to gain credibility when discussing a technical situation with more experienced practitioners.

The second edition of *Handbook of Manufacturing Engineering* was written to equip executives, manufacturing professionals, and shop personnel with enough information to function at a certain level on a variety of subjects. This level is determined by the reader.

The final book, Volume IV, deals with the finishing of the product. Packaging and automation are also discussed. The selection of the assembly process and the influence of production rate and quality of the product must be considered by the manufacturing engineer as the productivity of the facility and workers is balanced.

Jack M. Walker, who was unable to participate in the editing of this book, but who contributed greatly in the last few months of his life, was a pioneer in new ways of solving old problems.

Jack loved the advent of rapid prototyping. He spent many hours sharing how rapid prototyping had applications in choosing methods of manufacture or in selecting materials that could not be selected by mathematics alone. Jack as the manufacturing engineer loved to place prototypes before the persons responsible for making the final decision in new products. He often called this “touchy, feely” time the point at which a person would love or hate the design.

Some products lend themselves to hands-on evaluation, and the finish, appearance, and feel are very important in the final choice of a material in this case. But, as nanometer-level technology develops, the issues of finish and assembly become much more critical. An engineering science called tribology deals with the interactivity of miniscule particles of materials as they come in contact with each other.

Manufacturing engineers must think in terms of this area of assembly and finishing and ways to relate experience with larger components to the micron- and nanometer-sized components used in newer technologies today. Thus, this book was edited to provide the background and working knowledge for the manufacturing professionals of the next decade.

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Richard Crowson is currently a mechanical engineer at Controlled Semiconductor, Inc., in Orlando, Florida. He has worked in the field of engineering, especially in the area of lasers and in the development of semiconductor manufacturing equipment, for over 25 years. He has experience leading multidisciplinary engineering product development groups for several Fortune 500 companies as well as small and start-up companies specializing in laser integration and semiconductor equipment manufacture.

Crowson’s formal engineering training includes academic undergraduate and graduate studies at major universities including the University of Alabama at Birmingham, University of Alabama in Huntsville, and Florida Institute of Technology. He presented and published technical papers at Display Works and SemiCon in San Jose, California.

He has served on numerous SEMI task forces and committees as a voting member. His past achievements include participating in writing the SEMI S2 specification, consulting for the 9th Circuit Court as an expert in laser welding, and sitting on the ANSI Z136 main committee that regulates laser safety in the United States.
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1 Manual Assembly

John P. Tanner

and

Jack M. Walker

1.0 INTRODUCTION TO MANUAL ASSEMBLY

In today’s complex manufacturing world, it is sometimes difficult to remember what the real purpose of manufacturing a product is—and what the total elements of the process consist of. If we assume that whatever we manufacture, we will insist on good quality products, on-time delivery, and complete customer satisfaction, then we should concentrate on the most economical method to achieve these results. We should make our manufacturing decisions based on cost. Of course, cost is not a simple thing to determine. There are a lot of different ways of looking at cost.

For a method of arriving at the lowest cost while maintaining quality, delivery, and happy customers, perhaps we should examine a one-person business operation. A few hundred years ago, there were a lot of them—and even today, there are more than most of us realize. The nation’s small businesses, those with one to ten employees, grew in numbers during recession-plagued 1991, resisting the downturn experienced by medium and larger companies, according to a U.S. Census Bureau report. The number of small businesses increased up to 1% per year between 1987 and 1991. Larger businesses increased up to 3% per year through 1990, then declined in 1991; those with 10 to 100 employees were down 0.2% in 1991, while those with more than 100 fell 1.7%. Businesses with more than 100 employees are generally concentrated in the manufacturing sector, which as recently as 1970 accounted for 35% of the workforce. By 1991, manufacturing workers made up less than 20% of the workforce.

In 1991 there were more than 4 million establishments in the United States with fewer than 10 employees, about 1.5 million with 10–99 employees, and 134,000 companies with more than 100 employees (a total of 6,199,339 establishments). See Figure 1.1 for a breakdown of the manufacturing industries.

Now let’s get back to our one-person factory. Upon receipt of an order, the owner makes each of the parts, assembles them, and does the finish painting, packing, and delivery. The difference between his total income and the amount of money he spent during the month is his salary, or profit. Of course, he may be paying rent on the building, buying raw materials and supplies, and even making payments on his equipment.
and machines. Let’s deduct these, and now we have his profit. Whoops—he probably pays for heating, lighting, insurance of some type—and taxes—and the remainder was his profit. We can see that even in the one-person factory, real cost is not so easy to determine.

If business improves, one person may not be able to do everything by working at a faster pace, or working longer hours—and at some point the owner will have take some action in order to continue on-time delivery, et cetera. He might decide to buy the parts and just perform the assembly operation (or vice versa). Another option might be to add helpers and continue to perform all the operations in-house. In most cases, a growing company will probably elect to continue to perform the assembly function in order to have better control of quality, finish, delivery time, and so forth. It will still be “their” product as far as the company’s customers are concerned, which will keep the customers satisfied and give the company the opportunity to add additional sales. As the company continues to grow, the owner might reconsider his make-or-buy decisions and perhaps add equipment to fabricate critical parts in-house. In the assembly area, the first step might be to add automated screwdrivers, nut runners, riveters, spot-welding heads, and perhaps pick-and-place mechanisms. To move parts from the fabrication or receiving department to the assembly stations, some type of transfer device might be a logical improvement. The same applies for the transfer of parts and assemblies down the assembly line. There are an infinite number of options, including redesigning the

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FIGURE 1.1 Statistical breakdown of U.S. manufacturing industry.
product to reduce the number of parts required to be fabricated and thereby simplifying the assembly process.

In the end, the assembly process may well become the key to the owner’s continuing success. The small firm that started with a one-person assembly operation has now grown to a multiemployee company, probably using many of the same techniques that were successful in the beginning of the one-person shop. With more orders, and probably more diverse products, it is decision time again. This is the subject of this chapter.

There are as many factors influencing the assembly process decisions as there are products, customers, and factory managers. Geoffrey Boothroyd, in *Assembly Automation and Product Design*, quotes Henry Ford’s principles of assembly as follows:

First, place the tools and then the men in the sequence of the operations so that each part shall travel the least distance whilst in the process of finishing. Second, use work slides or some other form of carrier so that when a workman completes his operation he drops the part always in the same place which must always be the most convenient place to his hand and if possible have gravity carry the part to the next workman. Third, use sliding assembly lines by which parts to be assembled are delivered at convenient intervals, spaced to make it easier to work on them.

Assembly operations can be performed manually, automatically, or integrated in some manner using a combination of systems. If manual assembly is employed, an operator can adapt to changing conditions such as those brought about by part variation, mislocation, and product model mix. An operator can compensate for these changing conditions and, as a result, may not require elaborate tools and fixtures to perform the assembly tasks. However, operator error and fatigue can result in quality problems.

When production volumes are high enough, some assembly operations can be performed automatically with special-purpose machines. These automatic assembly machines consist of workstations grouped along some type of transfer system for part conveyance. Each station performs one task with the aid of dedicated station equipment, jigs, and fixtures. Part variation, misalignment, and product mix are not readily adapted to, because sensors cannot always be employed efficiently or economically to guide or monitor the assembly process. Therefore, part variations and slight misalignments can result in jamming, incomplete operations, and excessive machine downtime. However, automation can still be justified when the production volumes are high, product life is long, and assembly tasks are simple. For an assembly operation to be performed successfully on a repetitive basis, it is absolutely essential that part variation and location be minimized and consistency in dimensions and location be maximized. To achieve this in a mass production environment requires elaborate and costly tooling, fixtures, and the employment of expensive production controls. Therefore, many assembly operations are performed manually to resolve some of the problems in mating parts with variations or mislocations, which may result in increased assembly costs and lower productivity.
1.1 ASSEMBLY WORK INSTRUCTIONS

“Assembly processing” is another way of saying “assembly methods.” Assembly methods sheets, or work instructions, must describe clearly what is to be done, in what sequence, and with what tools and materials. Assembly methods sheets should minimize operator learning time and must be economical to prepare, reproduce, distribute, and change. Assembly process planning should include an assembly process summary or process routing, detailed work instructions for each operation called out in the summary, an operations parts list for each operation, process sketches or visual aids, and a workplace layout for each operation. The work instructions should call out all tools necessary to perform the operation, and there should be a standard time on the process summary for each operation called out, broken down to the level of setup and run times.

In process planning for fabrication, whether for machining or forming, the skilled machinist or sheet metal mechanic could work to what amounts to an outline process routing supplemented by the engineering drawing of the piece part. As a skilled worker, he can set up the machine and perform the work with a minimum of written work instructions. Such is not the case with assembly operations. The work must be totally and carefully planned by the manufacturing engineer, and complete work instructions prepared. These are the two extremes. In most manufacturing plants today, process planning will fall somewhere in between.

If the plant is a high-volume producer of a single product line, then detailed assembly work instructions may be unnecessary. Once operators are trained to perform a short-cycle assembly operation, little else is needed except possibly some clear, concise visual aids showing the critical details of the operation in pictorial, or exploded view, form. However, the manufacturing engineer must plan such production down to the most detailed level. He or she must prepare a layout of the assembly lines, show each and every workstation in plan view, plan the assembly tools required, and write a complete description of the work performed at each station on the line. The manufacturing engineer must establish standard times and decide where visual aids are needed and prepare them, and then fine tune or balance the line, assist in training the operators, and finally shake down or debug the line.

All of the above documentation is necessary when assembly lines are initially established or set up, and to train the operators. Once the line is flowing smoothly and the operators are trained, there will be less and less reliance on written work instructions and even visual aids. This initial planning documentation should always be available for ready reference and should be kept up to date by the manufacturing engineer.

If the company manufactures a variety of different product lines in medium to high volumes, or sets up and produces to a job-order-type system, or does both, assembly process documentation that is complete and to the greatest level of detail is especially important. It is a proven fact that good assembly process planning and documentation significantly reduce operator learning (and relearning) time. This is especially important when the production run is relatively short. It also teaches the correct methods to operators and thereby reduces costs of assembly labor.
The assembly process documentation package is essential to the operation of an ongoing production-control and time-keeping system. The assembly process routing provides the steps or sequences that materials, parts, assemblies, and work in process must follow to build the product. It provides the time standards for each operation, and the assembly parts list for each operation provides the information needed by production control to pull and kit material for production.

In a small plant, where production runs may be small to nonexistent, assembly process planning with only minimum documentation is required and can be justified for the reasons mentioned earlier. Even in the case where no formal production control system exists and the production supervisor draws material from the stockroom in one batch issue for the entire job, pictorial visual aids, workstation layouts, a tool list, and an assembly process routing should be provided.

1.2 ASSEMBLY OPERATION SEQUENCES

In assembly process planning, operation sequences usually parallel the indented parts list or engineering tree chart, because it should represent how the product goes together or is assembled. This initial assembly process sequence plan should define an assembly operation for each major and minor subassembly and for the final assembly (Figure 1.2). It should be emphasized that this is an initial breakdown and normally will be followed by a more thorough analysis of the steps required to assemble the various subassemblies and the final assembly. This detailed analysis is normally done in the preproduction planning phase in the form of an operation
process chart. Figure 1.3 shows an example of an operation process chart for a Coast Guard radio receiver.

The assembly process may include soldering, wiring, press fitting, brazing, shrink fitting, welding, adhesive bonding, riveting, and mechanical fastening. Within each of these assembly processes a series of sequences is required to accomplish the

FIGURE 1.3  Operation process chart for a radio guard receiver.
Manual Assembly

process, without regard to the product configuration, material, or quantity to be produced, or the rate of production. For example, many of the steps in creating a circuit card assembly, a wire harness, the frame of a truck, or in the installation of fittings on a sailboat are essentially the same. The detailed instructions for the sequence should spell out the differences peculiar to the product at hand.

Often in assembly work, standard sequences or operations are possible for any product where these processes of assembly are used. The result is a considerable saving in manufacturing engineering time and in the elapsed time required to prepare and release an assembly process plan to the shop. Such standard processes enable preprinted process planning documentation, which may only require a part number and quantity to be entered before it is ready for release. A good example of this is in the manufacture of cables for electrical or electronic equipment, where diagrams are preprinted of the various electrical connector pin configurations, requiring only that the manufacturing engineer sketch in the wires terminated to the pins for the specific cable application. Computer-aided process planning (CAPP), covers the use of a database to accomplish this task.

1.2.1 Routings, Work Instructions, and Visual Aids

Assembly process routings, such as the one shown in Figure 1.4, list the operations in the sequence in which they must occur to assemble the item or product called out in the heading. In addition to listing the operations in their proper sequence, it lists the standard times for each operation, the performing department, and the latest revision level of the process instruction sheets. The issue or revision level of the process information establishes configuration control of the product on the shop floor, because normally the assembly department does not work to engineering drawings. The importance of this cannot be emphasized enough. It is the responsibility of the manufacturing engineer always to have the latest revisions to the engineering drawings incorporated into the assembly process documentation, especially when the job is active on the production floor. In many companies the inspection department uses the process documentation to perform in-process inspections of the product. This is especially true where detailed process work instructions are used, and the process documentation is also used for shop configuration control.

As indicated earlier, the assembly process summary or routing is used by production control to move material or work in process to the next operation or sequence. A copy of the assembly process summary travels with each batch of parts and material and in effect becomes a routing sheet or shop traveler. For this to happen, the sequences must be stamped off, either by inspection or by the operator, as they are completed. If line production is involved, such a routing or traveler is unnecessary, as the progression on the assembly line is the routing followed by the assemblies. The process routing is an especially valuable tool in the job shop, where the shop is laid out by function or process, and does not follow the product flow.

Assembly work instructions are the heart of the manufacturing engineering documentation package, and explain how the product is to be assembled in production. The assembly work instructions should be available at the operator workstation,