robot loading procedure. In the future, robots may be equipped with sufficient intelligence to figure out how to load the different cartons onto the pallet. At the time of this writing, it is a systems problem of significant proportions.

13-3 MACHINE LOADING AND UNLOADING

These applications are material-handling operations in which the robot is used to service a production machine by transferring parts to and/or from the machine. There are three cases that fit into this application category:

Machine load/unload. The robot loads a raw workpart into the process and unloads a finished part. A machining operation is an example of this case.

Machine loading. The robot must load the raw workpart or materials into the machine but the part is ejected from the machine by some other means. In a pressworking operation, the robot may be programmed to load sheet metal blanks into the press, but the finished parts are allowed to drop out of the press by gravity.

Machine unloading. The machine produces finished parts from raw materials that are loaded directly into the machine without robot assistance. The robot unloads the part from the machine. Examples in this category include die casting and plastic modeling applications.

The application is best typified by a robot-centered workcell which consists of the production machine, the robot, and some form of parts delivery system. To increase the productivity of the cell and the utilization of the robot, the cell may include more than a single production machine. This is desirable when the automatic machine cycle is relatively long, hence causing the robot to be idle a high proportion of the time. Some cells are designed so that each machine performs the same identical operation. Other cells are designed as flexible automated systems in which different parts follow a different sequence of operations at different machines in the cell. In either case, the robot is used to perform the parts handling function for the machines in the cell.

Robots have been successfully applied to accomplish the loading and/or unloading function in the following production operations:

Die casting
Plastic molding
Forging and related operations
Machining operations
Stamping press operations.

We will discuss these applications in the following subsections. For each application, a brief description of the manufacturing process will be given. More detailed descriptions of the processes are to be found in other references.[1,2,7,8]

Die Casting

Die casting is a manufacturing process in which molten metal is forced into the cavity of a mold under high pressure. The mold is called a die (hence the name, die casting). The process is used to cast metal parts with sufficient accuracy so that subsequent finishing operations are usually not required. Common metals used for die-casted parts include alloys of zinc, tin, lead, aluminum, magnesium, and copper.

The die consists of two halves that are opened and closed by a die casting machine. During operation the die is closed and molten metal is injected into the cavity by a pump. To ensure that the cavity is filled, enough molten metal is forced into the die that it overflows the cavity and creates "flash" in the space between the die halves. When the metal has solidified, the die is opened and the cast part is ejected, usually by pins which push the part away from the mold cavity. When the part is removed from the machine, it is often quenched (to cool the part) in a water bath. The flash that is created during the casting process must be removed subsequently by a trimming operation which cuts around the periphery of the part. Thus, the typical die-casting production cycle consists of casting, removing the part from the machine, quenching, and trimming.

The production rates in the die-casting process range from about 100 up to 700 openings of the die per hour, depending on type of machine, the metal being cast, and the design of the part. For small parts, the die can be designed with more than one cavity, thus multiplying the number of parts made for each casting cycle. The die-casting machines have traditionally been tended by human operators. The work tends to be hot, repetitive, dirty, and generally unpleasant for humans.

Perhaps because of these conditions, die casting was one of the very first processes to which robots were applied. The first use of a robot in die casting was around 1961. Engelberger cites one instance in which a Unimate robot had been used in a die casting application for over 90,000 hours.[2]

The die-casting process represents a relatively straightforward application for industrial robots. The alterations required of the die-casting machine are minimal, and the interlocking of the robot cycle with the machine cycle can be accomplished by simple limit switches. Few problems are encountered in either the programming of the robot or the design of the gripper to remove the part from the machine when the die is opened. The process requires only that the robot unload the die-casting machine, since the metal is in the molten state before the part is formed. On some die-casting machines (called cold-chamber die-casting machines), the molten metal must be ladled from the melting container into the injection system. This part of the process is more difficult for robots to accomplish.

Plastic Molding

Plastic molding is a batch-volume or high-volume manufacturing process used to make plastic parts to final shape and size. The term plastic molding covers a number of processes, including compression molding, injection molding, thermoforming, blow molding, and extrusion. Injection molding is the most important commercially, and is the process in this group for which robots are most often used. The injection-molding operation is quite similar to die casting except for the differences in materials being processed. A thermoplastic material is introduced into the process in the form of small pellets or granules from a storage hopper. It is heated in a heating chamber to 200 to 300°C to transform it into semifluid (plastic) state and injected into the mold cavity under high pressure. The plastic travels from the heating chamber into the part cavity through a sprue-and-runner network that is designed into the mold. If too much plastic is injected into the mold, flash is created where the two halves of the mold come together. If too little material is injected into the cavity, sink holes and other defects are created in the part, rendering it unacceptable. When the plastic material has hardened sufficiently, the mold opens and the part(s) are removed from the mold.

Injection molding is accomplished using an injection-molding machine, a highly sophisticated production machine capable of maintaining close control over the important process parameters such as temperature, pressure, and the amount of material injected into the mold cavity. Traditionally, injection-molding machines have been operated on a semiautomatic cycle, with human operators used to remove the parts from the mold. Many injection-molding operations can be fully automated so long as a method can be developed for removing the parts from the mold at the end of the molding cycle. If a part sticks in the mold, considerable damage to the mold can occur when it closes at the beginning of the next cycle. Methods of removing the parts from the mold include: gravity to cause the parts to drop out of the mold, directing an air stream to force the parts out of the mold, and the use of robots to reach into the mold and remove the parts. The selection of the method depends largely on the characteristics of the molding job (part size, weight, how many parts to be molded per shot).

Industrial robots are sometimes employed to unload injection-molding machines when other less expensive automatic methods are deemed to be insufficiently reliable. One of the robot application problems in injection molding is that the production times are considerably longer than in die casting, hence causing the robot to be idle for a significant portion of the cycle. When humans tend the molding machines, this time can be utilized to perform such tasks as cutting the parts from the sprue-and-runner system, inspecting the parts, and removing the flash from the parts if that is necessary. However, some of these tasks are difficult for a robot to perform, and methods must be devised to accomplish these activities that do not rely on a human operator performing the unloading function. Cutting the parts from the sprue-and-runner system can be readily accomplished by the robot using a trimming apparatus similar to the setup used in die casting for trimming the flash from the casting. Part inspection and flash removal are not as easily accomplished by the robot.

Another issue arising when long molding cycle times are involved is whether the robot should be used to tend one machine or two. If two molding machines are tended by the robot, there is a significant likelihood that the two molding cycles will be different. This creates machine interference problems, in which one machine must wait for the robot because it is presently engaged in unloading the other machine. This waiting can lead to problems in overheating of the plastic and upsetting of the delicate balance between the various process parameters in injection molding.

Forging and Related Operations

Forging is a metalworking process in which metal is pressed or hammered into the desired shape. It is one of the oldest processes and derived from the kinds of metalworking operations performed by blacksmiths in ancient times. It is most commonly performed as a hot working process in which the metal is heated to a high temperature prior to forging. It can also be done as a cold working process. Cold forging adds considerable strength to the metal and is used for high-quality products requiring this property such as hand tools (e.g., hammers and wrenches). Even in hot forging, the metal flow induced by the hammering process adds strength to the formed part.

The term forging includes a variety of metalworking operations, some of which are candidates for automation using robots. These operations include die forging and upset forging. Other processes in the forging category include press forging and roll die forging. Generally these processes do not lend themselves to the use of robots for parts loading and unloading of the machines.

Die forging is a process accomplished on a machine tool called a drop hammer in which the raw billet is hit one or more times between the upper and lower portions of a forging die. The die often has several cavities of different shapes which allow the billet to be gradually transformed from its elementary form into the desired final shape. The drop hammer supplies mechanical energy to the operation by means of a heavy ram to which the upper portion of the forging die is attached. The ram is dropped onto the part, sometimes being accelerated by steam or air pressure. Die forging can be carried out either hot or cold.

Upset forging, also called upsetting, is a process in which the size of a portion of the workpart (usually a cylindrical part) is increased by squeezing the material into the shape of a die. The formation of the head on a bolt is usually made by means of an upsetting operation. The process is performed by an upsetting machine, also called a header. The blank (unformed raw workpart) is clamped by the two halves of a die possessing the desired shape of the product. The die is open on one end, and a plunger is forced by the upsetting machine into the blank causing it to take the shape of the die. Upsetting is often used in high-volume production of hardware items such as bolts, nails, and similar items. In these cases, the economics permit the use of fixed automation to produce the parts. In other cases, where the production of parts is in medium-sized batches, automation can sometimes be accomplished using industrial robots.

Forging, especially hot forge operations, is one of the worst industrial jobs for humans. The environment is noisy and hot, with temperatures at the workplace well above 100°F for hot forging. The air in the forge shop is generally filled with dirt, furnace fumes, and lubricant mist. The operation itself is repetitive, often requiring considerable physical strength to move and manipulate the heavy parts during the operation. The human operator experiences the blows from the drop hammer directly through the grasping tongs used to hold the part and in the form of vibration through the floor.

Unfortunately, the process is not easily adapted for robots. Some of the technical and economic problems include:

- The forging hammers and upsetting machines used for low- and medium-production runs are typically older machines, designed for manual operation, and do not lend themselves to the interfacing required for robotics automation.
- Short production runs are typical in many forge shops, thus making it difficult to justify the robot setup and programming effort for any single part.
- The parts occasionally stick in the dies. This can be readily detected by a human operator but poses problems for the robot. To minimize the frequency of sticking, the human operator periodically sprays lubricant into the die openings. The robot would have to be equipped and programmed to do this also.
- The design of a gripper for forging is a significant engineering problem for several reasons. First, the parts are hot, perhaps 2000°F, and the gripper must be protected against these temperatures. Second, the gripper must be designed to withstand the shock from the hammer blows because the parts must typically be held in position by the robot during the process. Third, the gripper must be designed to accommodate substantial changes in the shape of the parts during successive hits in the forging cycle. Some aspects of the forging process require operator judgment. The part must be heated to a sufficient temperature in order to successfully perform the hot working operation and the human operator often makes this judgment. A cold part would probably ruin the die. The raw workparts are generally placed in the heating furnace at random, and selecting the parts that are ready to be formed is an operator decision. Another problem is that different parts can require a different number of hammer strokes to form the final shape, a judgment that is made by the operator.

Each of these problem areas must be addressed in order for the robot forging application to be a success. Many of the problems are solved by making considerable use of interlocks and sensors. These devices permit the determination of such process variables as part temperature before processing, the presence of the workpart in the gripper, whether the part is stuck in the die, whether the robot arm is clear of the ram before operation of the drop hammer, and other factors.

Machining Operations

Machining is a metalworking process in which the shape of the part is changed by removing excess material with a cutting tool. It is considered to be a secondary process in which the final form and dimensions are given to the part after a process such as casting or forging has provided the basic shape of the part. There are a number of different categories of machining operations. The principal types include turning, drilling, milling, shaping, planing, and grinding. Commercially, machining is an important metalworking process and is widely used in many different products, ranging from those that are made in low quantities to those produced in very high numbers. In mid-volume and high-volume production, the operation is very repetitive with the same machining sequence being repeated on part after part.

The machine tools that perform machining operations have achieved a relatively high level of automation after many years of development. In particular, the use of computer control (e.g., computer numerical control and direct numerical control) permits this type of equipment to be interfaced with relative ease to similarly controlled equipment such as robots.

Robots have been successfully utilized to perform the loading and unloading functions in machining operations. The robot is typically used to load a raw workpart (a casting, forging, or other basic form) into the machine tool and to unload the finished part at the completion of the machining cycle. Figure 13-5 illustrates a machine tool loading and unloading operation in which the finished parts are palletized (lower left corner of the figure) after the machining cycle.

The following robot features generally contribute to the success of the machine tool load/unload application[2]:

Dual gripper. The use of a dual gripper permits the robot to handle the raw workpart and the finished part at the same time. This permits the production cycle time to be reduced.

Up to six joint motions. A large number of degrees of freedom of the arm and wrist are required to manipulate and position the part in the machine tool.

Good repeatability. A relatively high level of precision is required to properly position the part into the chuck or other workholding fixture in the machine tool.

Palletizing and depalletizing capability. In midvolume production, the raw parts are sometimes most conveniently presented to the workcell and delivered away from the workcell on pallets. The robot's controller and programming capabilities must be sufficient to accommodate this requirement.

Programming features. There are several desirable programming features that facilitate the use of robots in machining applications. In machine cells used for batch production of different parts, there is the need to perform some sort of changeover of the setup between batches. Part of this changeover procedure involves replacing the robot program for the previous batch

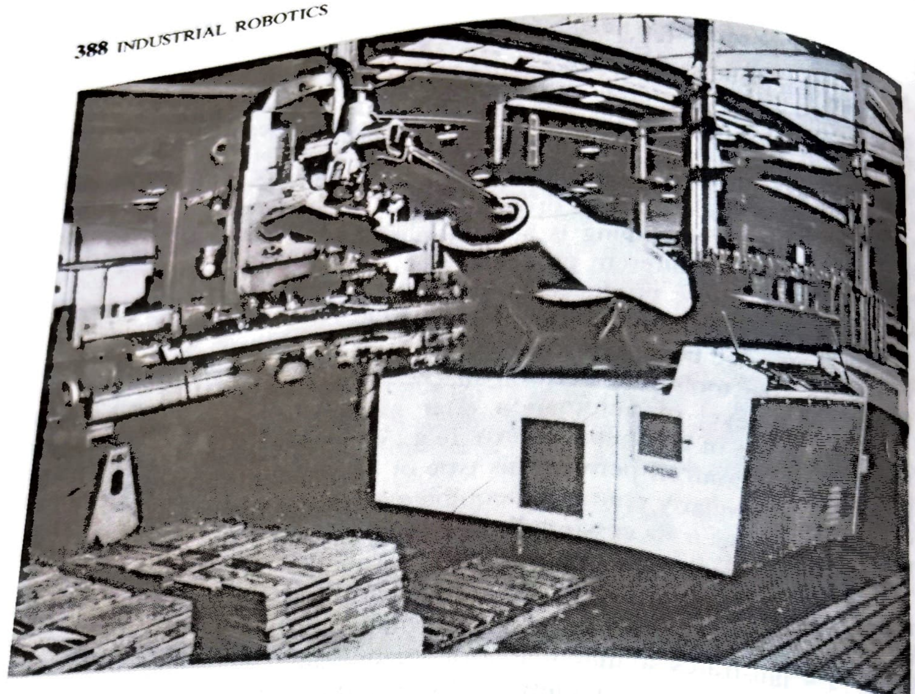

Figure 13-5 Unimate 2000 robot used to load and unload parts in a machine tool operation. (Photo courtesy of Unimation Inc)

with the program for the next batch. The robot should be able to accept disk, tape, or other storage medium for ease in changing programs. Another programming feature needed for machining is the capability to handle irregular elements, such as tool changes or pallet changes, in the program.

Example 13-2 This example illustrates some of the features of an automated machining cell consisting of a T3 robot, two turning centers, and an automated gauging station. Figure 13-6 shows the robot tending one of the turning centers. The raw workparts are castings which enter the workcell on a pallet delivered by means of a conveyor. The raw parts can be seen in the figure in the lower right foreground. The robot picks up a raw workpart and exchanges the raw part in the first turning center for the finished part. The finished part is then loaded into the gauging station, checked for the proper dimensions, and if determined to be within tolerance, is ready for loading into the second machine. The robot then exchanges the gauged part for the finished part on the second turning center (shown in the figure). That part is gauged in the automatic gauging station, and loaded onto the outgoing pallet if within tolerance.

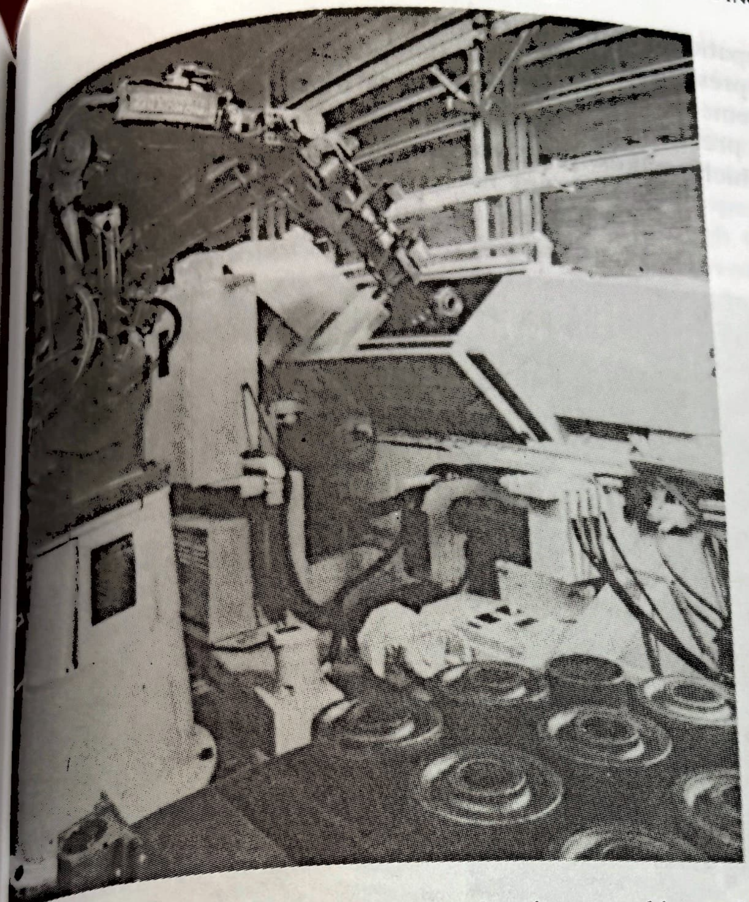

Figure 13-6 Cincinnati Milacron T3 robot performing a machine tool load/unload operation. See Example 13-2. (Photo courtesy of Cincinnati Milacron)

The loading and unloading operations are accomplished from the rear of each turning center rather than the front of the machines. This means that the front of each machine is clear for operator access, tool replacement, and observation.

Stamping Press Operations

Stamping press operations are used to cut and form sheet metal parts. The process is performed by means of a die set held in a machine tool called a press (or stamping press). The sheet metal stock used as the raw material in the process comes in several forms, including coils, sheets, and individual flat blanks. When coil stock is fed into the press, the process can be made to operate in a highly automated manner at very high cycle rates. When the starting material consists of large flat sheets or individual blanks, automation becomes more difficult. These operations have traditionally been performed by human workers, who must expose themselves to considerable jeopardy by placing their hands inside the press in order to load the blanks. During the last decade, the Occupational Safety and Health Act (OSHA) has required certain alterations in the press in order to make its operation safer. The economics of the OSHA requirements have persuaded many manufacturers to consider the use of robots for press loading as alternatives to human operators. Noise is another factor which makes pressworking an unfriendly environment for humans.

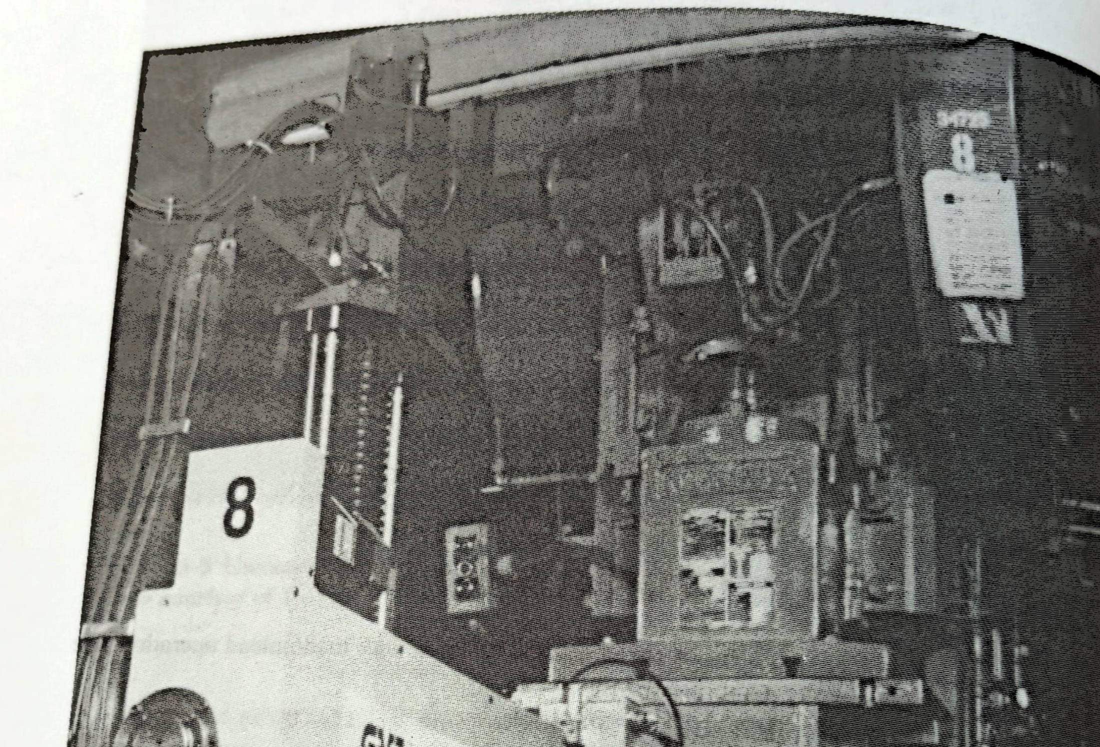

Figure 13-7 GMF robot performing machine loading/unloading task at a stamping press. (Photo courtesy of GMF Robotics)

Robots are being used for handling parts in pressworking operations, largely as a result of the safety issue. The typical task performed by the robot is to load the flat blanks into the press for the stamping operation. There are variations in the way this can be done. In forming operations, the robot can be used to hold the blank during the cycle so that the formed part is readily removed from the press. In the case of many cutting operations, the robot loads the blank into the press, and the parts fall through the die during the press cycle. Another robot application in pressworking involves the transfer of parts from one press to another to form an integrated pressworking cell. Figure 13-7 shows a *TLL* configuration robot working in conjunction with a pressworking operation.

One of the limiting factors in using industrial robots for press loading is the cycle time of the press. Cycle times of less than a second are not uncommon in pressworking. These cycle rates are too fast for currently available commercial robots. There is generally a direct relationship between the physical size of the part and the press cycle time required to make the part. Bigger presses are needed to stamp bigger parts and bigger presses are inherently slower. Accordingly, robots are typically used in pressworking for larger parts.

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