This Paper submitted to theProceedings of the *1998 IEEE International Conference on Robotics and Automation*
CAISR Tech Report #TR97-109

Gripper Design Guidelines for Modular Manufacturing

Greg C. Causey and Roger D. Quinn
Department of Mechanical and Aerospace Engineering

Case Western Reserve University (CWRU)
Cleveland, Ohio 44106-7222

Abstract

This paper describes guidelines for the design of grippers for use in modular manufacturing workcells. Gripper design is an important and often overlooked aspect of the design of a complete assembly system. Here we present guidelines which can be applied to a wide variety of grippers and are divided into two major categories: Those that improve system throughput and those that increase system reliability. Designs of several grippers, currently being used in a modular manufacturing workcell, are presented as examples of the application of the guidelines to real world problems.

1. Introduction

The design of the end-of-arm tooling for a robotic assembly system is very important for reducing errors and decreasing cycle times. This is the piece of the robotic parts handler or assembler that physically interacts with the environment. While many factors may be blamed for the common failures of workcells, the culprit is very often the grippers. Well designed grippers can increase throughput, improve system reliability, compensate for robot inaccuracy, and perform value added functions to the assembly.

The design of the gripper systems is not a trivial task. Unfortunately, the finalized parts and assembly sequence are often given to the designer, who must then devise grippers to handle the parts and perform the assembly. It is much more desirable for the design of the grippers to occur concurrently with the design of the rest of the system. Often a small feature added to a part can greatly increase the reliability of the gripper. Other times, a proper gripper design can simplify the overall assembly, increase the overall system reliability, as well as decrease the cost of implementing the system.

Recently, the manufacturing community has begun to use readily available, off-the-shelf components to build up automation systems in a modular way. This catalog based approach to machine design has many benefits including:

- ease of replacement of defective and worn-out parts
- cost savings
- shorter design times
- more rapid implementation of the machine
- leveraging the expertise of component builders

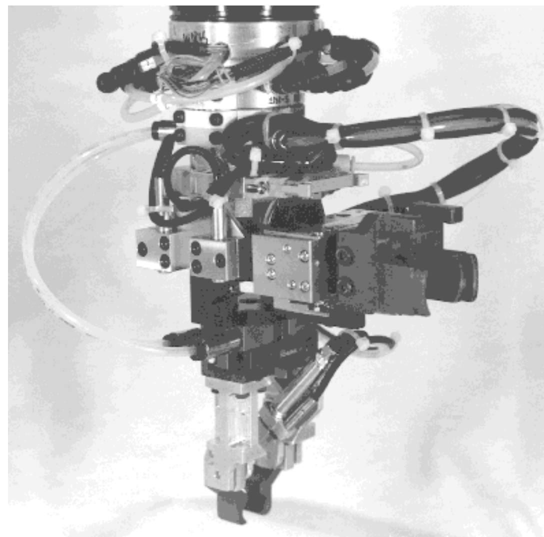


Figure 1: Water Valve Assembly Gripping System

Many gripper manufacturers have also taken this approach. It is easy to buy a quick connect, a remote centering compliance device, a rotary wrist mechanism, and two pneumatic actuators from the same vendor, bolt them together, and have a fairly complex and sophisticated gripping system. While this is a wise approach to building a gripping system, it is important to recognize that gripper fingers must interact reliably with the specific part(s) to be grasped. For a positive, nimble, self-centering grasp, the gripper fingers themselves must conform to the shape of the part they are holding. While it is adequate in some cases (and, unfortunately, necessary in others) to use simple flat plates or ‘‘V’’ grooves, much better designs are usually realizable.

As discussed above, it is evident that the design of the gripping system is very important for the successful operation of the workcell. However, little has been accomplished in the area of design parameters and guidelines for end effectors. While many text books on robotics discuss grippers, they mostly deal with types of grippers. Some work has been done in the design of grippers[1,2,3], but it is still in its infancy. Boothroyd and Dewhurst have introduced guidelines for part design[4], but have not addressed the design of grippers. The CWRU Agile Manufacturing team has discussed gripper design in past publications[5,6,7], but only superficially. This work builds on the past lessons and attempts to present a cohesive set of guidelines.

Using these guidelines, grippers can be designed more quickly and with a higher confidence level. The guidelines may also be used as performance criteria and allow a rapid evaluation of designs.

Grippers themselves, however, can be as unique and varied as the parts they handle. How then, can general guidelines be developed to address each unique design? Many grippers, while physically different, share the same general function. For example, most parallel jaw grippers approach from a single direction, and then close to grasp the part. Rotary action grippers, in contrast, move to a position above the part and then rotate their jaws to grasp the object. By developing guidelines which can be applied to a style of gripping rather than a specific gripper design, they may be applied to a wide variety of grippers.

The requirements and expectations placed on gripping systems have increased greatly because of the introduction and acceptance of modular manufacturing concepts and vision-based flexible parts feeding. In non-flexible automation systems, the grippers had but one purpose, pick a part from one location and place it at another. Usually grippers were mounted on pneumatic slides which created a pick and place motion. With the proliferation of industrial robots in recent years, however, many new problems and challenges have arisen. Robots themselves have limited payload capacity, limited accuracy, and fixed repeatability. In a hard automation system, the uncertainty comes from the machine stops in the bowl feeder and on the pneumatic slides. In the case of a flexible workcell, there are many more sources of error including: The accuracy and repeatability of the robot, the vision system, the robot-camera calibration, and the tool offsets. Properly designed grippers can help compensate for these unknowns.

2. Gripper Footprint

An important concept in the consideration of a gripper design is the footprint of the gripper. That is, how much additional area around the object being retrieved is required to physically situate the gripper such that it can retrieve the part without a collision. This parameter becomes very important in flexible feeding applications where the spacing between parts is random and unknown. The standard procedure for retrieving a part from a flexible feeder is to first locate the part using the vision system[6]. After a candidate part has been located, then a check must be preformed to ensure that there is enough clearance for the gripper to reach the part without colliding with other parts or the feeder itself. A larger footprint means more candidate parts will not be retrieved simply because the gripper it too big. Unnecessary system delays could occur because the gripper cannot reach most of the parts the vision system has identified and located.

An apparently obvious definition of footprint is *the vertical projection of the gripper's fingers when open*. However, it is easy to show this definition is overly simplified. An example in which the above definition fails is a gripper that approaches a part from the side. Another counter example (Figure 2) is a complicated wrist mechanism. One gripper approaches from an angle which could allow a second gripper to collide with parts. In this case, the footprint is not the gripper fingers, but part of the pneumatic actuator and the second gripper.

A more general and complete definition of the footprint of the gripper is as follows:

> *The three dimensional space which must be free of obstructions for a gripper to successfully grasp a part.*

There are many nuances and subtleties in the definition. The space doesn't necessarily have to be adjacent to the part. In the example in Figure 2, part of the space that needs to be vacant is displaced from the front of the part

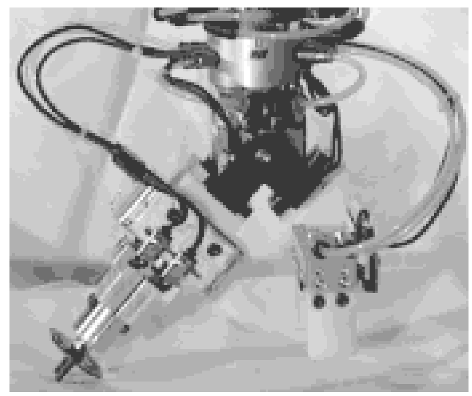


Figure 2: Complicated Gripper Footprint

being retrieved by several inches. Another example is a gripper with a large chamfer on the leading edge which would push neighboring parts out of the way as it approached its target part. In this case, the footprint of the gripper would be very small relative to the vertical projection of the gripper fingers.

As can be imagined, the possibilities of gripper footprints are as widely varied as the grippers themselves. The important concept is that the footprint of the gripper is not necessarily the vertical projection of the fingers and that it should to be minimized.

3. Design Guidelines

The design guidelines are separated into two different categories: Those that improve the throughput of the system and those that improve the reliability of the system. However, there is some overlap in these areas as well as some mutual exclusion. It may not, for example, be possible to apply all the guidelines to any one design. At times, one guideline may suggest one design direction while another may suggest the opposite. Each particular situation must be examined and a decision must be made to favor the more relevant guideline.

3.1. Guideline to Increase Throughput

Minimize the Gripper Footprint: As explained in Section 2, this can increase the throughput of the system.

Chamfer the Exterior of Gripper Fingers: This allows the gripper to displace neighboring parts as the target part is being approached. This effectively reduces the footprint.

Minimize the Gripper Weight: This allows the robot to accelerate more quickly. Each robot has a fixed payload capacity and heavier tooling causes larger overshooting. Often, gripper fingers for handling light plastic parts are made from aluminum or steel and are much stronger than necessary and, hence, overly heavy.

Grasp Parts Securely: This allows the robot to be run at higher speeds thereby reducing the cycle time. This may be accomplished by designing the shape of the gripper fingers to compliment the shape of the part being handled.

Avoid Tool Changes: This guideline is different from the previous ones in that it does not directly apply to the gripper fingers, but to the gripping system as a whole. While automatic, tool changes are time consuming compared to most robot moves since they involve straight line motion and because extra care must be taken to ensure the gripper is not mishandled during an exchange. This extra time decreases the throughput of the workcell.

Grip Multiple Parts with a Single Gripper: This helps to avoid tool changes and is normally possible when handling multiple parts of similar shape or size. It is also possible to design multiple gripping surfaces actuated by a single actuator. Figure 3 shows a single gripper with two gripping surfaces designed to handle three parts.

Install Multiple Grippers on a Single Wrist: This allows the robot to have more than one gripper ready for use and may decrease cycle time in two ways. First, as in the previous guideline, a tool change may be avoided. Second, multiple grippers allow multiple parts to be handled at the same time which can reduce total robot motions. Figure 1 and Figure 8 show two grippers on a single rotating wrist mechanism.

Include Functionality in Gripper Fingers: This can speed the system by allowing the gripper to perform a task that would usually be done by an additional piece of hardware.

3.2. Guidelines to Increase Reliability

Grasp Parts Securely: This is obviously very important to ensure system reliability. For example, it decreases the likelihood that the part will be dropped or will shift in the gripper during robot motion and subsequently be misaligned when placed. This is in strong supports for the following guideline.

Fully Encompass the Part with the Gripper: This has two benefits: to help hold the part securely and to help align the part in the gripper jaw in the presence of uncertainties in the pickup location.

Do Not Deform the Part During Grasping: Some lighter plastic parts are easily deformed and care should be taken when grasping the parts. If the part is deformed, problems will occur when trying to insert the part into a fixture because its shape has been changed.

Minimize Finger Length: This is also related to the secureness of the grasp. Obviously, the longer the fingers of the gripper the more they are going to deflect when grasping a part. When the fingers deflect, the face of the grippers are no longer properly aligned with the part and the quality of the grasp suffers.

Provide an Ample Approach Clearance. When designing a more complicated gripping system, it is difficult to fully visualize all the necessary clearances. Consider multiple grippers on a rotary wrist, each grasping multiple objects, as an example. It is important

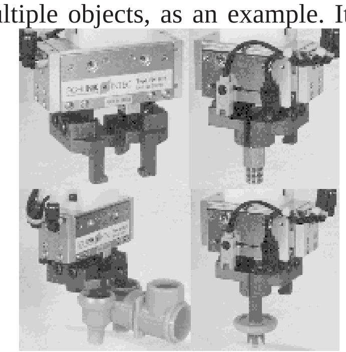


Figure 3: Single Gripper Handling Multiple Parts

to ensure that there is ample clearance to approach the pickup location so that if there is some uncertainty in the location of the part, a collision will not occur.

Chamfer the Approach Surfaces of the gripper fingers: This can increase system reliability by decreasing the likelihood of a part-gripper crash. The chamfer allows the gripper to self-center parts in the gripper jaw as the robot approaches the part for pickup.

Fingers should Align Grasped Parts: This can also help center parts in the gripper jaw, but in contrast to the previous guideline, by aligning a part in the gripper as the jaws are being *closed*. A misaligned part can cause problems later in the assembly by causing the *place* operation to fail. Insuring that the part is properly aligned in the gripper can help remove this uncertainty. This is usually accomplished by including generous chamfers at the parting lines of the gripper fingers.

Design for Proper Gripper-Part Interaction: The interaction of the surface material of the gripper jaws and the part is important for alignment. When the shape of the gripper matches the shape of the part, it is desirable to have a low friction interface so parts may slide relative to the gripper jaw for alignment purposes. If, however, a flat surface is being used, then a high friction interface is desired since the part would not be aligned anyway and the higher friction increases the secureness of the grasp.

Encompass Actuator Mounting Points: This is often overlooked in gripper design. By designing the fingers to encompass the mounting points, they will be properly aligned. Improper alignment of the gripper fingers can reduce the secureness of the grasp.

Do Not Rely on Added Parts for Location: Often errors can occur when a component, added to a subassembly in an earlier operation, is used for location in the current operation. If the part was misplaced or is not present, then the current operation could fail. It is best to use permanent features so that if there was an error in a previous step, the current picking operation will not be affected.

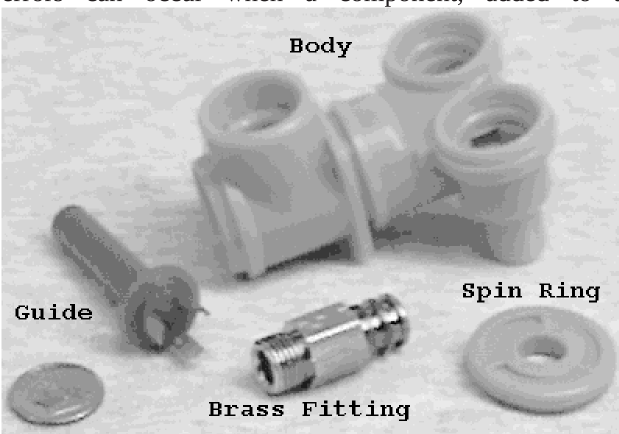


Figure 4: Water Valve Assembly Parts

Assembly Grippers should Align Parts: In contrast to grippers used only for pick and place, assembly grippers need to have features added which align parts before the assembly operation takes place. Consider, for example, an operation which inserts a cap into a cylinder (see section 4.2). Rather than designing a gripper to hold the cap and relying on the robot to properly align the parts, a better design would align the parts before the insertion operation.

Incorporate Functionality into Gripper Fingers: Each time a gripper must pick or place a part, there is the possibility of an error. By designing gripper fingers to do an extra task, dedicated assembly hardware is avoided. Because the part is never released from the gripper, there is less chance of it being mishandled.

4. Example Gripper Designs

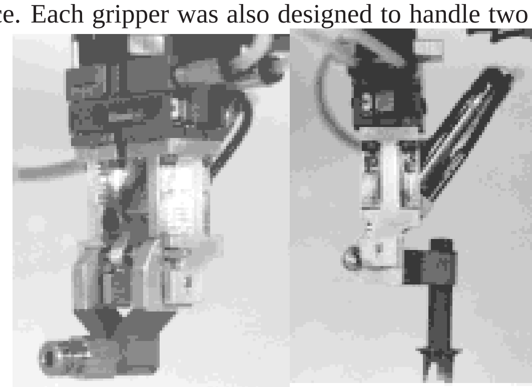
The following section examines two gripping systems that embody many of the guidelines listed above. The first system is used to do an assembly of a refrigerator water valve while the second is used to assemble and package tire valve stem covers. Both grippers are being used in a demonstration workcell constructed by a corporate sponsor.

4.1. Water Valve Assembly Gripper

The water valve assembly consists of four distinct parts: the body, the brass fitting, the guide, and the spin ring, shown in Figure 4 with a dime for size reference. The assembly sequence proceeds as follows: First, a body is retrieved from a tray feeder and placed in a fixture. Next, a brass fitting is retrieved and inserted into the top front of the body. The brass fittings are fed using a Genex flexible feeder (Adept FlexFeeder 250). Next a guide is grasped and a spin ring is picked up (using two grippers on a single wrist), both are fed using flexible feeders. The guide is inserted into one of the two pockets near the back of the body. The spin ring is then dropped over the top of the guide. Finally, another guide and spin ring are retrieved and placed in the other pocket.

This assembly held some unique challenges for the design of a gripping system. First, it was desired to perform the assembly without tool changes, so all the parts had to be handled by one gripping system. Second, the brass fittings and guides were being fed on their sides from flexible feeders and needed to be rotated through 90° before assembly. Third, since flexible feeders were being used, a gripper with too large a footprint could adversely effect system throughput. Last, a small tabletop robot was being used for the assembly so the total weight of the gripping system was a concern.

The final design of the gripping system included two actuators mounted on a rotary wrist, shown in Figure 1. Using multiple grippers on a single wrist made it possible to handle both the guides and spin rings at once. Each gripper was also designed to handle two parts so that a tool change was avoided. The first gripper was designed to manipulate the brass fittings and guides and rotate the parts through 90° without setting them down. The second gripper was used to handle the bodies and the spin rings.



Grasping a Fitting (unrotated) Grasping a Guide (rotated)

Figure 5: Brass Fitting/Guide Gripper

The brass fitting/guide gripper (Figure 5) is a good example of the application of several of the design guidelines. The length of the gripper fingers was designed to minimize the footprint of the gripper. Even though the rotary jaw mechanism is rather large, the long fingers can retrieve parts without the mechanism colliding with other parts or the feeder. The exterior of the fingers was chamfered to allow the gripper to displace nearby parts, thereby further reducing its footprint. The rotary motion designed into the jaws of the gripper allows the brass fitting and guides to go directly from the feeder (horizontal orientation) to the assembly (vertical orientation) without intermediate intervention. The gripping surface was designed to compliment the shapes of both the fitting and the guide so that a more secure grasp of each part was obtained. This was necessary since the rotary motion is rapid to decrease the cycle time. The grippers were also designed to help center the parts as they are grasped. This is especially needed when picking

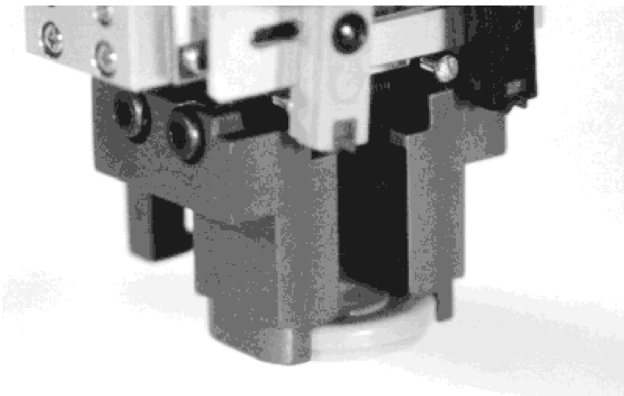


Figure 6: Spin Ring Gripper

the guides since they do not lay perfectly horizontal but at a slight angle relative to the angle of the gripper jaws. The fingers themselves were notched to fit the actuator keys so that they would be properly aligned.

The gripper used to handle the spin ring and body (Figure 6) also exemplified many of the design guidelines. It differs from the previous approach to grasping multiple parts in that a different protrusion is used to pick each part. This was necessary because the parts are very dissimilar. In this case, the footprint was minimized by shortening the body gripping fingers so that they would not interfere with neighboring spin rings on the flexible feeder as a spin ring was grasped. Because the bodies are retrieved from a tray, their gripper footprint was not a concern. The exterior surface of the spin ring jaws is circular to make the jaws thinner and decrease the footprint.

A secure grasp of the part was ensured in both cases. The spin ring jaws have a lip which reaches underneath the spin ring and fully encompasses the part to provide a solid grasp. The body fingers have protrusions that go into internal features in the body to provide a secure grasp. The fingers were designed as short as possible to stiffen them. Chamfers were added to the gripper to help center and align parts as they are being grasped. The gripper fingers fully encompass the mounting points of the actuator to provide a more secure and aligned interface between the actuator and fingers.

The application of the design guidelines resulted in a gripping system capable of reliably handling four parts at a single robot with no tool changes.

4.2. Tire Valve Assembly Gripper

The tire valve assembly consists of four parts: the cap, the seal, the container, and the lid, shown in Figure 7 with a dime for size reference. The assembly process is as follows: A pallet arrives at the workcell

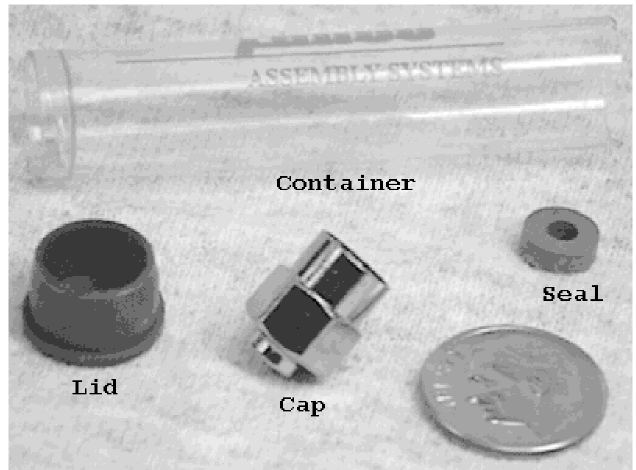


Figure 7: Tire Valve Assembly Parts

containing four tire valves, a container, and a lid. The robot first retrieves a seal from a bowl feeder and seats it into the first cap. Next, the cap/seal assembly is placed in the container. After four cap/seal assemblies have been made and placed into the container, the lid is placed on the container and the finished package (Figure 10) removed from the pallet. To meet desired throughput needs, four parts must be handled without a tool change.

Two different grippers, mounted on a rotary wrist, comprised the gripping system, shown in Figure 8.

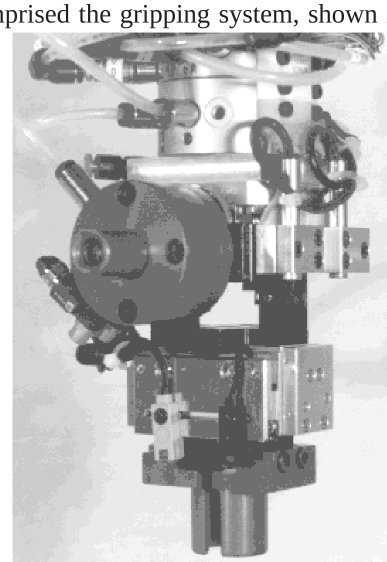


Figure 8: Tire Valve Assembly Gripping System

The first gripper was used to retrieve and seat the seal into the cap and then insert the cap/seal assembly into the container. The second gripper was used to place the lid on the container and then to remove the filled container from the pallet. By including multiple grippers on a single wrist and designing each gripper to handle multiple parts, a tool change was avoided. Gripper footprint was not a concern for these grippers as all the assembly locations were known and proper gripper clearance could be included in the design.

The seal gripper uses a vacuum to lift a seal from a bowl feeder. A linear actuator, designed into the gripper,

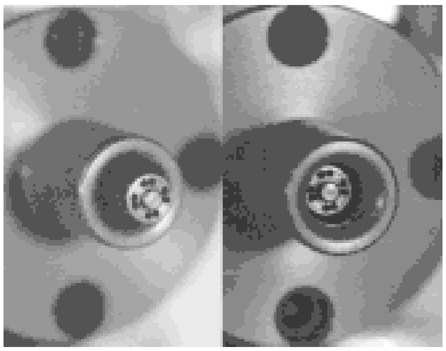


Figure 9: Linear Actuator at Extremes of Motion

provides the motion and force necessary to seat the seal. Figure 9 shows a close-up view of the actuator fully extended and fully retracted. After seating the seal, the gripper maintains the vacuum and picks the cap/seal assembly. The robot then positions the assembly over the container, the vacuum is turned off, and it is dropped into the container.

Including the functionality of seating the seal into the gripper increased the throughput and reliability of the system by avoiding extra operations and assembly hardware. A large chamfer was designed into the end of the gripper to properly center the cap as it was being approached. This also held the seal in alignment with the cap as it was inserted.

The lid/container gripper design reliably solved another potentially problematic operation. Figure 10 shows the gripper holding a finished tire valve package. A secure grasp of the lid was provided by a groove in the jaw into which the lip on the top of the lid fit. Chamfers were designed into the jaws to help center the lid as it was being retrieved. The circular internal cross section of the grippers match the shape of the lid and help improve the quality of the grasp. A long lead-in taper was designed on the inside surface of the gripper to align the container with the lid as the gripper inserts the lid. The gripper firmly presses the lid into the container and maintains its grasp on the lid as the robot lifts the completed package. The robot then drops the completed package into a bin.

As in the previous case, application of the guidelines aided in the design of a successful and reliable gripping system.

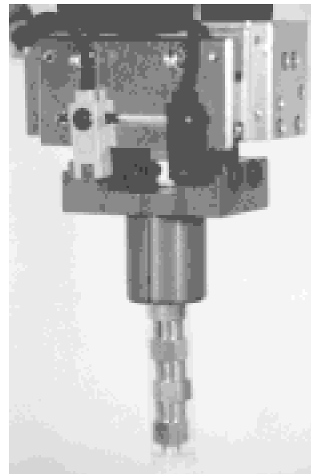


Figure 10: Finished Tire Valve Package

5. Conclusions

Guidelines for designing grippers for use in a modular manufacturing workcell have been developed. The guidelines have been divided into two categories: Those that help improve the throughput and those that increase the reliability.

Grippers designed using the stated guidelines have been constructed and are being successfully used in a modular workcell in an industrial setting. Two of these gripper assembly designs have been reviewed as examples of the application of the guidelines. Although the grippers designed for these two operations are very different, the guidelines applied to both equally well.

5.1. Acknowledgments

This work was funded through the Center for Automation and Intelligent Systems Research (CAISR) by the Cleveland Advanced Manufacturing Program (CAMP) and by corporate sponsors.

[1]Russel G. Brown and Randy C. Brost. A 3-d Modular Gripper Design Tool. *IEEE International Conference on Robotics and Automation Proceedings*, 2332-2339, 1997.

[2]Brain Carisle, et. al. A Pivoting Gripper for Feeding Industrial Parts. *IEEE International Conference on Robotics and Automation Proceedings*, 1650-1655, 1994.

[3]Steve Walsh. Gripper design: guidelines for effective results. *Manufacturing Engineering* v. 93, 53-55, November 1984.

[4]Geoffrey Boothroyd and Peter Dewhurst. *Product Design for Assembly*. Boothroyd Dewhurst Inc., 1989

[5]Frank L. Merat, et. al.. Advances in Agile Manufacturing *IEEE Incarnation Conference on Robotics and Automation Proceedings*, 1216-1222, 1997.

[6]Greg Causey, et. al.. Design of a Flexible Parts Feeding System. *IEEE International Conference on Robotics and Automation Proceedings*, 1235-1240, 1997.

[7]Wyatt Newman, et. al. Technologies for Robust Agile Manufacturing. *Submitted to the IEEE International Conference on Robotics and Automation Proceedings*, 1998.