Fakulteta za strojništvo
Aškerčeva 6
1000 Ljubljana

Seminar pri predmetu angleški jezik

Guidelines for the design of robotic gripping systems

Jernej Prešeren
Dejan Avguštin
Tadej Mravlje

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1. 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, guidelines are presented which can be applied to a wide variety of grippers. Guidelines are divided into three major categories: those that improve system throughput, those that increase system reliability, and those that decrease cost. 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.

2. INTRODUCTION

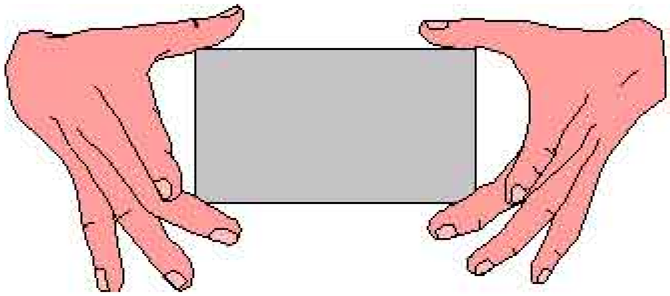
The design of the end-of-arm tooling for a robotic assembly system is very important for reducing errors and decreasing cycle times. This is the piece of the robotic parts handler or assembler that physically interacts with the environment. While many factors may be blamed for the common failures of 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.

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.

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.

3. GRIPPERS



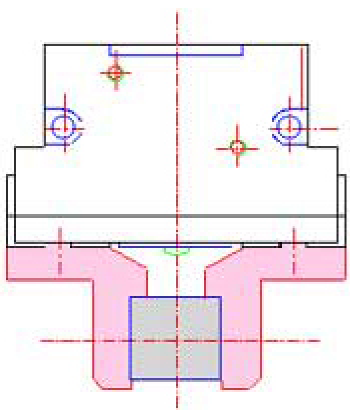
What is a gripper? Why use one?

A gripper is a device which enables the holding of an object to be manipulated.

The easier way to describe a gripper is to think of the human hand. Just like a hand, a gripper enables holding, tightening, handling and releasing of an object.

A gripper is just one component of an automated system. A gripper can be attached to a robot or it can be part of a fixed automation system.

Many styles and sizes of grippers exist so that the correct model can be selected for the application.



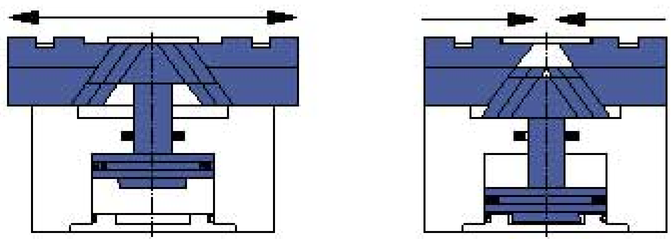
What is the basic operating principal of a gripper?

Compressed air is supplied to the cylinder of the gripper body forcing the piston up and down, which through a mechanical linkage, forces the gripper jaws open and closed.

There are 3 primary motions of the gripper jaws; parallel, angular and toggle. These operating principals refer to the motion of the gripper jaws in relation to the gripper body

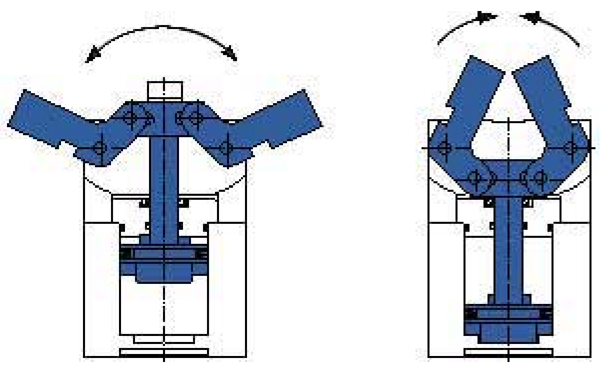
Parallel Gripper

The gripper jaws move in a parallel motion in relation to the gripper body. Used in a majority of applications, parallel grippers are typically more accurate than other style grippers.



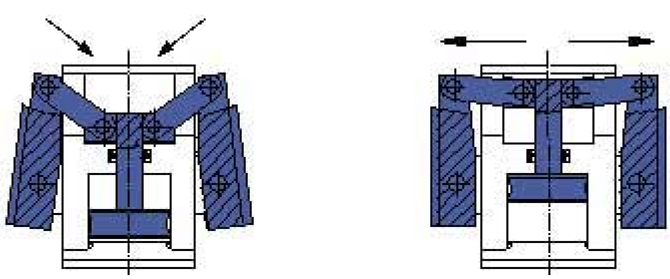
Angular Gripper

The gripper jaws are opened and closed around a central pivot point, moving in a sweeping or arcing motion. Angular grippers are often used when limited space is available or when the jaws need to move up and out of the way.



Toggle Gripper

The pivot point jaw movement acts as an over-center toggle lock, providing a high grip force to weight ratio. This mechanism will remain locked even if air pressure is lost.



Differences between a 2-Jaw and 3-Jaw gripper

2 Jaw

3 Jaw

2-Jaw Gripper:

The most popular style of gripper, all 2 Jaw grippers (angular, parallel and toggle) provide 2 mounting locations for the fingers that come in contact with the part to be grasped. The jaws move in a synchronous motion opening and closing toward the central axis of the gripper body

3-Jaw Gripper:

A more specialized style of gripper, all 3 Jaw grippers (parallel and toggle) provide 3 mounting locations for the fingers that come in contact with the part to be grasped. The jaws move in a synchronous motion opening and closing toward the central axis of the gripper body. 3 Jaws provide more contact with the part to be grasped and more accurate centering than 2 jaw models.

Internal vs External Gripping

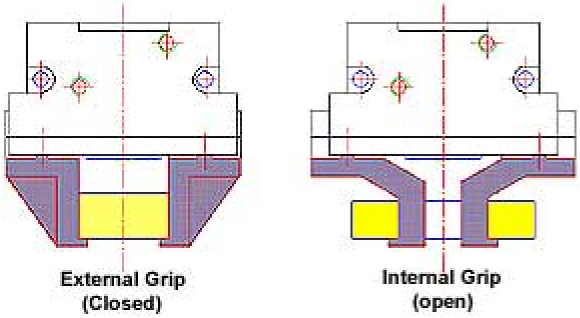
Grippers are used in two different holding options, External and Internal. The option used is determined by the geometry of the part to be grasped, the process to be performed, orientation of the parts to be grasped and the physical space available.

External:

External gripping is the most common way to hold parts. The closing force of the gripper is used to hold the part.

Internal:

Internal gripping is used when the part geometry will allow and when the process to be performed need access to the outside surface of the part grasped. The opening force of the gripper is used to hold the part.

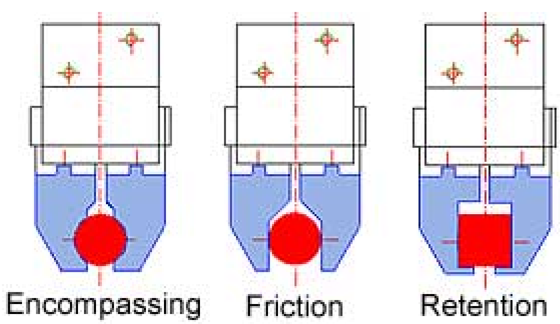


Tooling/Finger design considerations

Custom gripper tooling/fingers are needed for each application. Fingers are used to actually make contact with the part to be grasped.

Careful consideration when designing these fingers can greatly reduced the size and grip force of the gripper needed for the application.

The encompassing or retention finger shape is preferred because it increases stability and also reduces the necessary grip force. However, the additional jaw travel required to encompass or retain the part must be taken into consideration.



3.1. More about grippers

Grippers and rotary actuators are two of the key components used on pick and place robotic machines, duplicating the action of the human hand and wrist.

Grippers are available in two basic types based on the motion of their jaws. Angular jaw grippers provide motion similar to that of a lobster's claw, the jaws moving in angular rotation. Parallel jaw grippers have jaws that move toward or away from each other, remaining parallel to each other through the range of motion. Both gripper designs are available in two, three, and four jaw configurations.

The jaws of most grippers are synchronized to one another, though grippers with unsynchronized jaws are available in a few sizes from several manufacturers.

The range of motion of angular jaw grippers run~~s~~ from small displacement angles, such as 6˚ per finger, up to 90˚ of rotation, which gives 180˚ of total rotation. Miniature parallel jaw grippers may have a total range of jaw displacement of around 1/4 inch while larger grippers may have a range of 8 inches. Wider ranges are sometimes available as a special order option from some manufacturers.

Forces developed by grippers range from several pounds to as much as 3000 pounds with input air pressure ranging from 20 psig to 100 psig, depending on the manufacturer. This is force measured at the gripper jaws. The fingers fitted to most angular jaw grippers are effectively first class levers, with the bearings of the jaws being the fulcrum and the input force from the actuator mechanism working against the load at the part contact points of the fingers. Since no one standard design is used for either angular or parallel jaw grippers, the design mechanics and load ratings of the gripper being used should be considered when designing the fingers.

The machine builder designs fingers that attach to the jaws of the gripper. Finger design is dependent upon the part or parts being grasped. Fingers should be configured to securely grip the part. In some applications, the part may be fragile and subject to damage if the grip force is too great. Creative finger design can overcome many of these problems. The contour of the fingers may be part of the solution. Another solution might be to line the contact surfaces of the gripper with a resilient material such as urethane.

Miniature rack and pinion
rotary actuator

Three jaw
parallel gripper

Another factor to consider when selecting the gripper, as well as all of the other related machine parts, is the actual mass of the object being manipulated. Though the grip force requirement may be low, the part might still be heavy in comparison to the needed grip force. The bearings of the gripper and the rest of the components must be able to handle the load.

Grippers are available in both double-acting and single acting configurations. Single acting grippers can be either spring assisted to open or spring assisted to close. Generally, since spring forces are low, the gripper is pressurized when grasping an object.

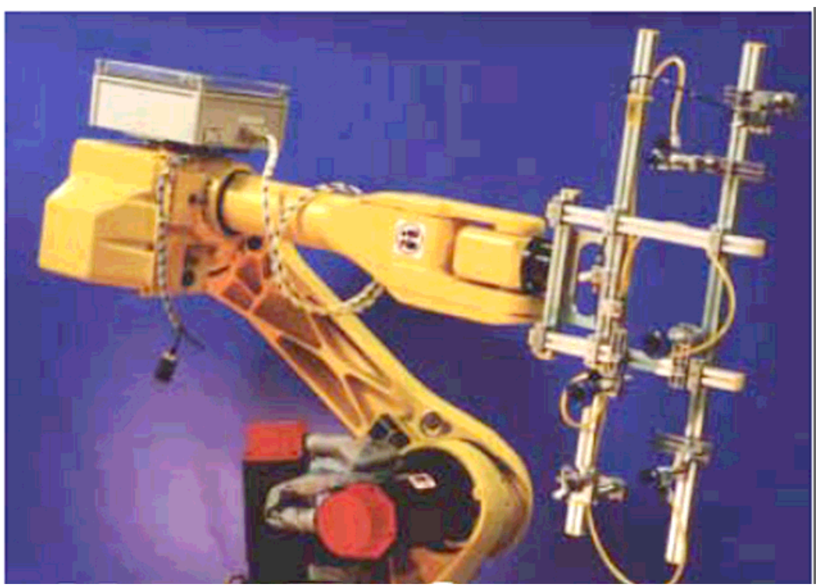
Some double acting grippers are available with a spring assist feature. In case air pressure is lost, the gripper will continue to exert gripping force on the object being held by the fingers. This feature may prevent the object being dropped if air pressure is lost, but if that is a necessary requirement, the machine designer should allow for acceleration, as well as deceleration, forces when running grip force calculations.

A variation on the spring assist feature discussed in the last paragraph is to use an angular gripper with an overcenter feature. The linkage goes overcenter; air pressure must be applied in order to release the grip.

Grippers may be oriented in any position. However, care should be taken to ensure debris does not fall onto the gripper, especially in applications where the gripper is mounted "jaws up," as

debris could obstruct the operation of the gripper. Protective covers, with openings for jaws to protrude though, are available from some manufacturers.
Many grippers allow the installation of Hall Effect or proximity sensors to provide a signal that the jaws are in a specified position. The sensor type usually depends on the construction geometry of the gripper.

4. CHOSING GRIPPING HANDS



4.1 Configure the Gripper Footprint

From your chosen form of interface, you'll need to construct the framework or footprint for the grippers, allowing them to reach various securing points of a blank or part. First, determine stability and flexibility of the workpiece, what obstructions are present during pick-up, what secondary operations are needed and method of drop-off. Critical is the part weight, cell layout, robot payload capacity and reach. Recommended is a lightweight, modular, aluminum framework easily adjustable to accommodate changes required during trial runs. Construct the framework with various brackets and connectors configured to the outside dimension of your part to allow for securing all sides of the part.

4.2 Mount Clamps, Brackets and Extensions

With your framework complete, choose adjustable clamps and brackets for mounting to all sides of the partframe profile. This provides maximum flexibility. Then choose tubular arms or extensions that allow for height and angle adjustments to reach every possible area of the part for optimal gripping. Whatever type of gripper you choose, incorporate the proper types of mounting mechanisms—mechanical adapters, brackets or manifolds—for that gripper.

4.3 Select the Part-Securing Method—Grippers or Fingers

This describes the actual mechanical means—pneumatic grippers, pliers or fingers—by which your newly constructed part handler contacts the part. Grippers normally are required for heavy and very flexible parts or when a large pulling force is necessary. Grippers also find use on parts or sheet with holes or porosity, making vacuum-cup usage impractical. For most applications, however, vacuum-cup securing is most cost-effective. Most surfaces, even textured, can be secured by specifying the proper type and size of vacuum cup. At times, vacuum cups are the initial and primary means of part pick-up, then gripper fingers flip behind the part for added support while moving parts overhead or at high speeds.

4.4 Select the Right Vacuum Cup

Some common vacuum-cup shapes include oval, flat. Oval cups are useful when the workpiece is long and narrow or if the workpiece has raised ribs or edges. Flat vacuum cups (Fig. 1) are used for flat workpieces with smooth to slightly textured surfaces. They hold up best to shear when a horizontal load is applied and offer a faster response time than bellows-styled cups. The 11⁄2-bellows vacuum cups (Fig. 2) provide a flexible sealing lip for workpieces with irregular, smooth or contoured surfaces. In addition, they work well with slightly flexible surfaces. The bellows provide dampening and help protect sensitive workpieces. The 21⁄2-bellows vacuum cup (Fig. 3) is used for maximum part compliance and dampening. Vacuum cups are made from a variety of materials, each with specific properties. (See table for characteristics of each.) For high abrasion and wear resistance, choose polyurethane. For higherheat applications, choose silicone or Viton. Nitrile provides good overall performance in a variety of conditions. Once you’ve chosen the style and material based on environmental and workpiece conditions, you can size your vacuum cups and determine the lift capacity using the following basic formulas. An irregularly shaped workpiece or one subjected to high accelerations can adversely affect lift capacity.

Figure 1

Figure 2

Figure 3

Vacuum-Cup Material Characteristics

Material	Nitrile	Silicone	Polyurethane	Viton
Shore hardness [°Sh]	55 ± 5	55 ± 5	55 ± 5	70 ± 5
Temperature range [°F]	-77 to +248	-86 to +392	-68 to +167	-50 to +428
Abrasion strength	••	••	••••••	••
Wear resistance	•••••	••	••••••	•••
Tear strength	••••	•	••••••	•
Oil resistance	••••••	••••••	•••••	••••••
Acid resistance	•••	•••	•	••••••
Hot-water resistance	••••	•••	•	•••••

•••••• = excellent; ••••• = very good; •••• = good; ••• = medium; •• = poor; • = not recommended

4.5 The grasping structural layout

The previous analysis equivalently applies to all the four types objects to be handled, since, further to the slotted pipes, also the related fixtures are suitably shaped to be grasped by the same device. Moreover, for safe grasping, a two degrees-of-freedom architecture, Fig. 4, already satisfies the cinematic specifications, and, for leanness, duty-driven command leads to the work-cycle accomplishment by an under-actuated set-up. Figure 5 shows a longitudinal section of the hand for explanatory purposes. The mechanism presents the outer frame, the sliding gripper unit and the hydraulic jack for the actuation. The gripper unit slides inside and outside the frame, and is supported by pegs moving along suitable grooves, realised in the lateral walls of the frame. The individual pipe/fixture is grasped by two fingers, hinged to the slider, solid to the back palm. Once grasped, the pipe/fixture leans against the palm and is hold by the fingers. These fingers are actuated by a 4-bars linkage, whose central link, named bridge link, is pushed by the actuation shaft of the hydraulic jack through a set of actuation springs. Another set of springs, the sequencing springs, keeps "open" the gripper unit, unless the "retracted" condition is turned off. Suitable couplings allow the initial tuning of the gripper, in order to pre-set the diameter of the grasped pipe/fixture. Figure 4. Ensemble view of the hand architecture. Figure 5. Detailed view of the hand architecture. A single hydraulic ram actuates both the gripper degrees-of-freedom: - the hand translational path, to recover or extract it in and out of the guiding frame; - the fingers rotational path, to grasp or release the singled-out pipe/fixture.

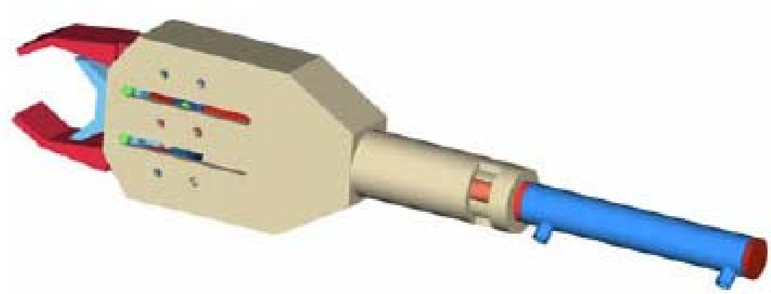


Figure 4. Ensemble view of the hand architecture.

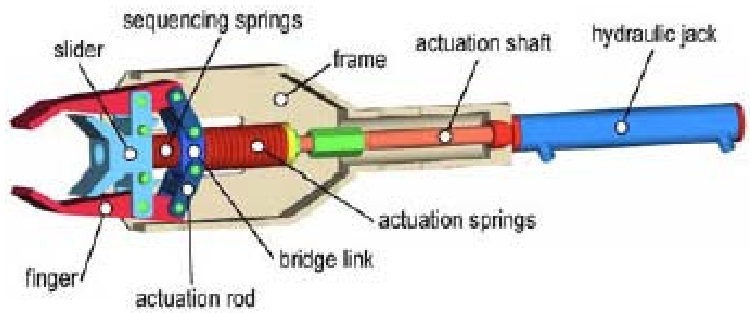


Figure 5. Detailed view of the hand architecture.

A single hydraulic ram actuates both the gripper degrees-of-freedom:

- the hand translational path, to recover or extract it in and out of the guiding frame;
- the fingers rotational path, to grasp or release the singled-out pipe/fixture.

The device is under-actuated, and the task agenda needs proper sequencing to enable the scheduled grasp mobility. This is done by the two sets of springs: the actuation springs and the sequencing springs. Consider the four pictures, given by the Fig. 6: the contrivance is sectioned, in order to show the internal mechanical design details.. The four states of the gripper to complete a grasping cycle are shown: hand drawing back and pulling out, object engagement and force locking.

Once the jack is actuated, it pushes the carrying shaft, until the pegs supporting the gripper unit have slid against the ends of the grooves; this defines precisely the position of the palm with respect to the frame of the gripper and later on the position of the pipe which, once grasped, leans against the v-shaped palm. Then the fingers close until reaching the surface of the pipe; further displacement of the fingers is no more possible due to the geometry of the system composed of the gripper unit and the pipe. The following translation of the jack shaft results in a compression of the actuation springs until the preset retaining force level at the interface between the fingers and the pipe is reached. The value of this retaining force can be tuned by screwing up and down a suitable control screw on the actuation shaft. This screw shorts or lengthens the length of the actuation shaft such to change the compression of the actuation springs corresponding to the stop extension of the hydraulic jack.

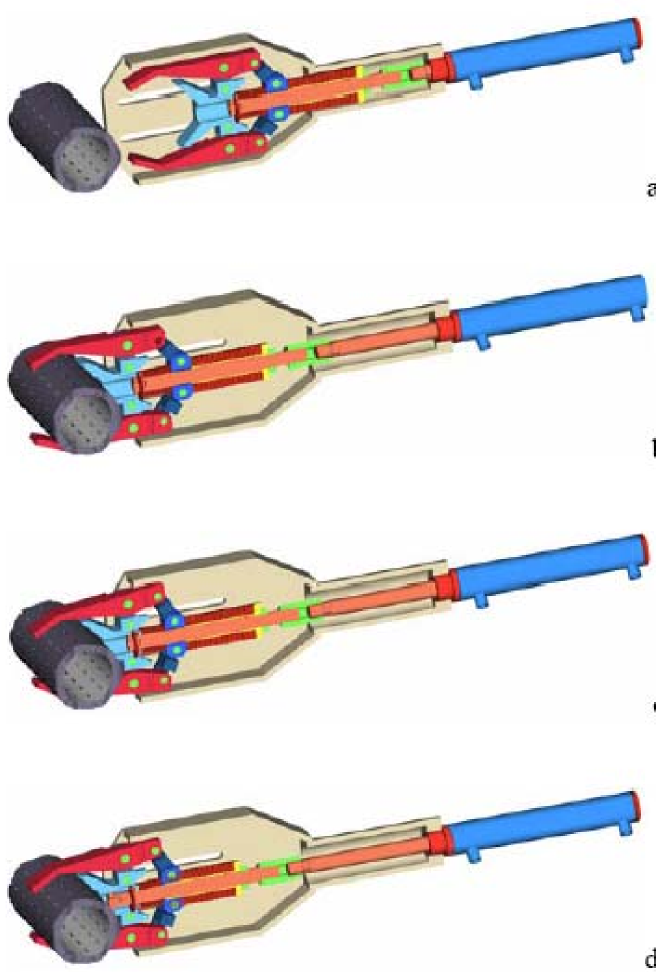

a)
b)
c)
d)

Figure 6. The grasping cycle: drawing back (a), pulling out (b), jaws grasping (c), palm locking (d).

The release cycle runs along the same sequence in the backward order; the palm locking situation keeps the pre-set safe grasping, which combines form- to force-closure, according to the above out-lined design specifications. Actually, the item loading and screwing on spindle of the multifunctional head is the critical step for the individual gripper work-cycle. Thereafter, the safe holding is sought by doubling the effectors carried by the pick-and-place arm; each cylindrical item is, accordingly, clamped at two locations, close to the extremities, so that it is carried and held parallel to the drilling track, easily allowing the screwing task, given in charge to a suitably shaped rotating spindle.
To simplify the system and improve its reliability, the arm is commanded in open loop, without any feedback on the position of the hands. Each actuator can be switched between two states, on and off. Suitable stops assure the correct positioning for the different working phases; these stops can be set up to tune the arm.
The combined form- and force-closure enhances the grasping process reliability, also, in terms of external disturbances. The object surface can be wet and traces of oil could be present, so the

friction factor at the rod-fingers interface cannot be easily estimated (it might be supposed to be around 0.2); the form-closure is worthy shrewdness: the axial degree-of-freedom is fully blocked by any residual friction; the redundancy in the radial direction provide safety margin against geometrical tolerance. The force-closure is properly fixed at the lowest threshold to grant the screwing task. This operation, indeed, is fulfilled, once the items are disposed coaxial to the spindle; then, the multifunctional head is operated to engage the screwed extremity of the pipe/fixture and during this phase the grippers have to prevent, without damage, any turning.

5. EXAMPLE GRIPPER DESIGN

5.1. 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 7 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.

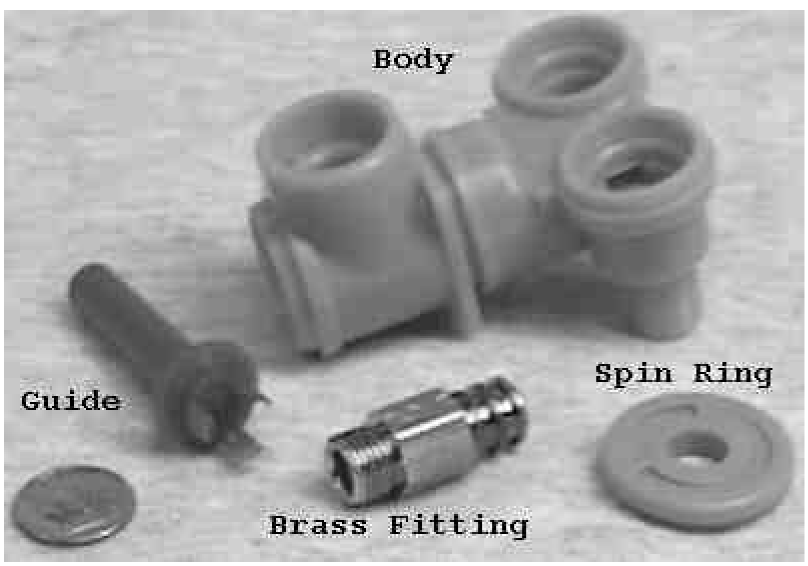
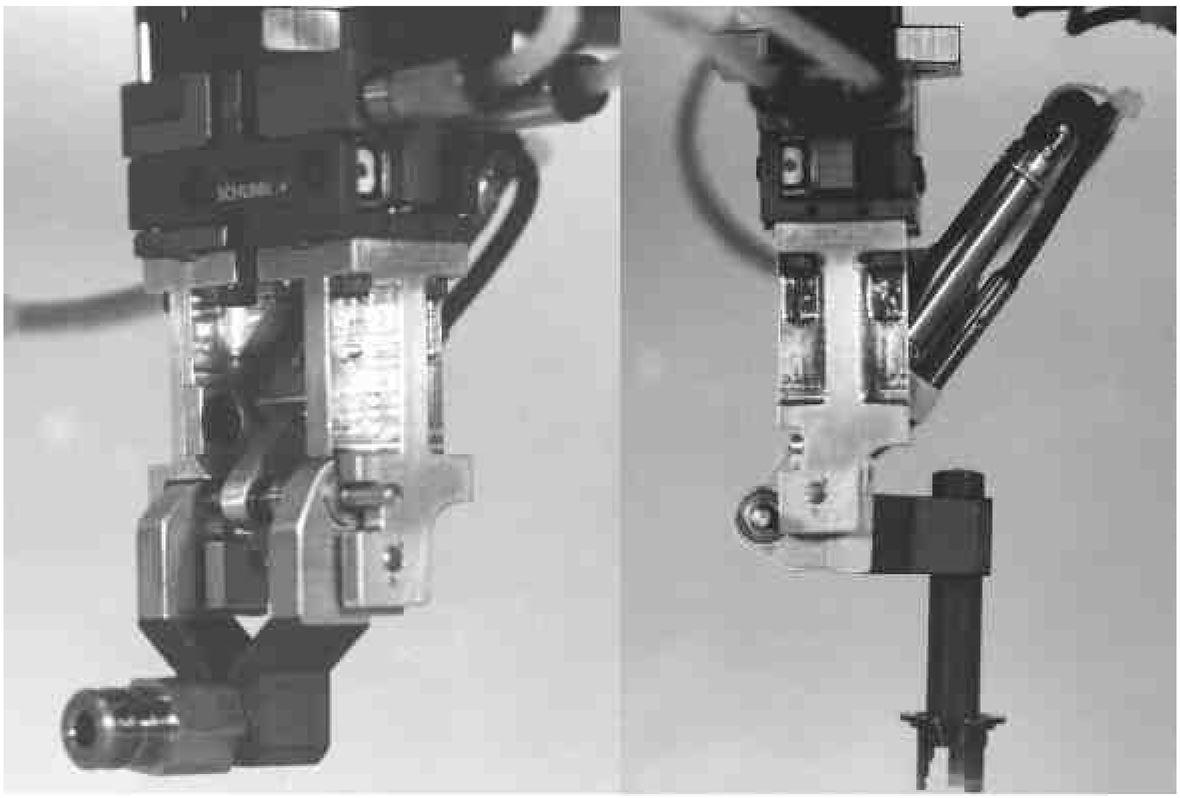


Figure 7: Water Valve Assembly Parts

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 8: Brass Fitting/Guide Gripper

The brass fitting/guide gripper (Figure 8) 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 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.

Figure 9: Spin Ring Gripper

The gripper used to handle the spin ring and body (Figure 9) 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.

6.GUIDLINES

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.

6.1. 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.

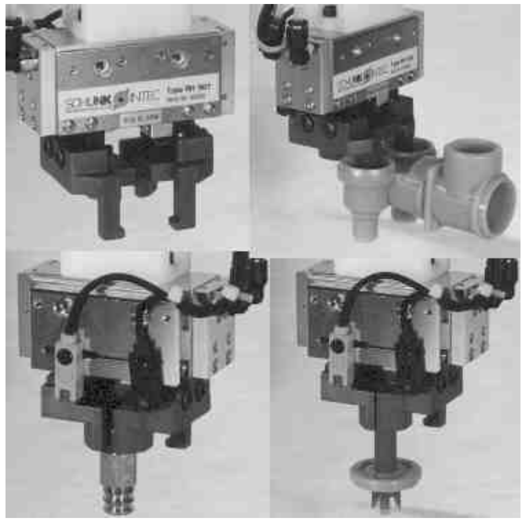


Figure 10: Single Gripper Handling Multiple Parts

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 10 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.

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.

6.2. 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 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.

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. 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.

6.3 Conclusion

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. One of the gripper assembly designs have been reviewed an example of the application of the guidelines. Although the grippers designed for these two operations are very different, the guidelines applied to both equally well.

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8. DICTIONARY

	English Technical term	explanation	Slovene translation
1	accurate	to be precise	natančen
2	adequate	to be suitable	primeren
3	align	to be arranged	uvrščen
4	angular	to be angled	kotni
5	application	something useful	aplikacija
6	approach	coming near	bližanje
7	assembly	setting up	montaža
8	attach	to add	pritrditi
9	bearing	two round cilynders for easier rotary motion	ležaj
10	bracket	carrier, holder	nosilec
11	chamfer	to cut away the edges	posneti
12	compensate	to level	poravnati
13	components	parts	deli
14	compress	to squeeze	stisniti
15	configurations	to appoint	nastavitve
16	consideration	attention	pozornost
17	contour	outline	obris
18	custom	common	običajno
19	cycle	specific time	ciklus
20	depend	counting on something	odvisen
21	device	apparatus	naprava
22	displacement	to shift	premestitev
23	drill	borrer	sveder
24	enable	to quality someone for something	usposobiti
25	encompass	to contain	vsebovati
26	error	mistake	napaka
27	exert	to use	uporabiti
28	external	outer	zunanji
29	flexibility	willingness	voljnost
30	footprint	outer shape of an object	odtis
31	fragile	somthing which likes to burn	vnetljiv
32	grasp	to seize	prijeti
33	grippers	things for grabbing	prijemala
34	guidelines	directions	smernice
35	hold	to possess	držati
36	inaccuracy	something that is not precise	nenatančnost

37	internal	inward	notranji
38	jaw	something for grabbing	čeljust
39	lengthen	to extend	podaljšati
40	manipulate	to direct something	upravljati
41	manufacture	production	produkcija
42	mount	to assemble	montirati
43	necessity	urgency	nujnost
44	parallel	two things that are alligned to same direction	vzporednost
45	porosity	thing with many small holes	poroznost
46	range	distance between two objects	razdalja
47	reduce	to lessen	zmanjšati
48	refer	to connect	nanašati
49	reliability	to be sure about something	zanesljivost
50	requirement	to demand	zahteva
51	resilient	something flexible	prožen
52	response	repliement	odgovor
53	rotary	something which is turning around the axis	vrtljivo
54	stability	something that is firm	stabilnost
55	synchronous	something that is done in the same time	sočasen
56	throughput	to product something	proizvodnja
57	uncertain	to be insecure about something	negotov
58	vendor	someone who is selling things	prodajalec
59	visualize	to imagine things	predstavljati si
60	wrist	a moving part of the robotic arm	zapestje