A Force – Intensifying Gripper For Concentric Gripping

M. Akyurt, H.A. Bogis, A.A.N. Aljawi, A.A.A. Alghamdi and F.A. Dehlawi
King Abdulaziz University, College of Engineering
P.O. Box 80204, Jeddah 21589, Saudi Arabia
Email:akyurt99@yahoo.com, hbogis@hotmail.com, a_aljawi@hotmail.com,, aljinaidi@hotmail.com
and fdehlawi@hotmail.com

Abstract

Two versions of a rugged gripper are discussed. Both grippers enable concentric gripping. The grippers comprise two centric slider-crank mechanisms that are driven by a common crank. The sliders, to which the twin fingers are rigidly attached, run on the same axis. One version of the gripper features force-intensification at the grip over a wide range of operation. The second version (gripper-i), which is applicable for internal gripping, features a wide gripping range. Gripper-i is relatively more compact, and it exerts a nearly constant gripping force within much of its range of operation.

Keywords: concentric gripping, force intensification, gripper, gripping force, jaw displacement, ruggedness, transmission angle

1 Introduction

An industrial robot consists basically of a body or base, an arm, and a wrist. The gripper is attached to the wrist, and it enables the robot to pick up work pieces and hold, manipulate, transfer, place and release them accurately in a discrete position. Thus the gripper is an important interface between the robot and its environment without which the robot cannot function effectively. Custom-designed grippers can be quite costly. Surveys on grippers are available [1-6].

The gripper for industrial robots is generally used to handle only one or a few objects of similar shape, size, and weight in a repetitive operation which requires minimum gripping dexterity, and is limited in its versatility. Where the robot is required to manipulate a tool rather than a work piece, the gripper is designed to grasp and handle the tool while at the same time supplying it with the required power to perform its function. This permits the robot to handle more than one tool during one cycle, often in conjunction with a quick-change device. In many applications, such as in spot and arc welding, spray painting, rotating spindles for metal cutting operations, heat torches, and water jet cutting, the tool is directly attached to the wrist of the robotic arm, and effectively becomes the gripper.

Grippers can be classified as a) mechanical finger type, b) vacuum and magnetic type, and c) universal grippers. The most common grippers today, in the order of use, are pneumatically actuated finger type, vacuum type, electrically actuated finger type, and hydraulically actuated finger type grippers [7]. Pneumatic systems are popular especially because they are easy to use, install, and service.

When used as a hand, the gripper is used to grasp by fingers, which generally are two non-jointed tongs. The fingers (jaws) are the appendages that make actual contact with the object. The grip in this case will be at a point [8]. In grasping, the part is held (constrained) by the gripper by either shaping the fingers so as to enclose the part, or by friction. The latter case yields simpler finger geometry but requires higher grasping forces. Grippers with jointed fingers are relatively uncommon in industrial robotics.

Actuation of fingers can be by pneumatic or hydraulic actuators, by rope, or by rack-and-pinion arrangements, where the rack may be actuated by a solenoid. Wire-and-pulley mechanisms are used for master-slave type of manipulators [9]. Electric grippers generally use AC/DC motors or solenoids to activate the jaws; their use, however, is limited due to the weight penalty that they impose. Hydraulic grippers can exert large forces, and yet generally carry an excessive weight penalty also [7].

If the objective of the gripper is to pick up and move an object of known shape and size, it is possible to design a gripper with a single-degree of freedom that will meet specific requirements. The versatility of a given gripper can be improved if various designs of *finger*(s) can be incorporated to meet mission constraints. Certain applications may necessitate the changing of the gripper as a whole. The mechanism of grasping, the stability of the grip (grab), the safety and integrity of the gripped object, and planning and control of the grasp forces have been the subject of considerable theoretical and experimental investigations.

As a rule, grippers of industrial robots comprise rigid links, and are linkage-actuated. Fingers may undergo rotation, as in scissors-type grippers, or translation, as in the case of rack-and-pinon drives, or curvilinear translation (CT), as in the case of using a parallelogram mechanism. Transformation of the linear input from a

pneumatic or hydraulic actuator into rotary finger motion is generally carried out by means of lever-type mechanisms, and by rack-and-pinion arrangements.

1.1 Concentric Gripping

As for the workpieces that robotic grippers handle, cylindrical workpieces have been identified [16] as the predominant ones in the manufacturing industry, followed by those with prismatic shapes. About 98% of all parts involved in machinery can he handled by a two-fingered gripper [9].
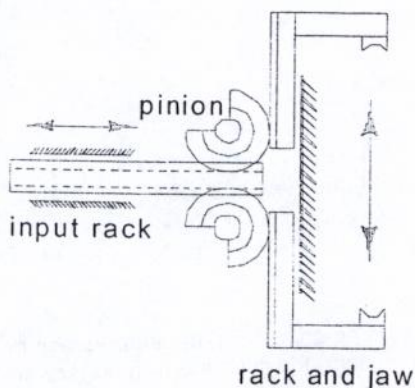

Figure 1: The rack-and-pinion gripper.

The prevailing state of the art of gripper technology as regards the handling of cylindrical workpieces is essentially represented by the rack-and-pinion type gripper (Fig. 1[1]), which comprises two rigid fingers that are translated by means of rack-and-pinion arrangements. Due to the inherently fragile and bulky nature of the rack-and-pinion type gripper, it is judged [16] that this gripper is mechanically unfit for harsh industrial environments. Researchers are at work currently, trying to come up with suitable substitutes [4,5,10,16-17]. The idea is to succeed the line contact rack-and-pinion arrangement by sturdier surface-contact designs that employ prismatic joints and / or pin joints.
During this replacement process it would be desirable, naturally, not to compromise on the main strength of the rack-and-pinion gripper, i.e., its ability to grip cylindrical objects concentrically. Concentric handling of cylindrical objects is a vital gripper requirement, and is related to the avoiding of the perturbation of workpieces of different diameters during the grasping process by, say, V-notched fingers.
An alternative gripper is the curvilinear translation (CT) gripper (Fig.2[2]). This device maintains the parallelity of its jaws during closure, and therefore can handle work-pieces of prismatic shapes. Because of the curvilinear nature of the jaw-closing action, however, concentric gripping of cylinders of various diameters is normally not possible.
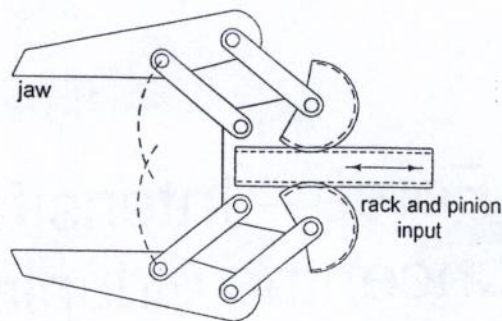

Figure 2: The curvilinear translation gripper.

Perhaps the simplest of all grippers are the tilting-jaw type of grippers (Fig. 3[3]), which are also referred to as tong grippers and rotational finger grippers. Being all pin-jointed, tilting-jaw grippers are more rugged than most of the existing rack-and-pinion type parallel-closure grippers. It was shown [16] that tilting-jaw and CT grippers can achieve very similar concentric gripping effects when provided with special jaws. Although the scissors and tongs-type grippers are simpler than the CT gripper, they are not as versatile, since they cannot easily handle prismatic workpieces.
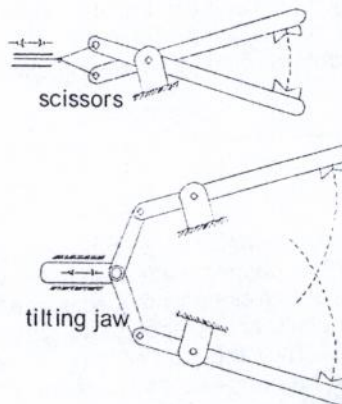

Figure 3: Tilting-jaw type of grippers.

It must be pointed out in summary, that the rotational finger type as well as CT type grippers that have been proposed as substitutes for the rack-and-pinion gripper do not strictly and sufficiently meet the requirement of concentric gripping. More specifically, the requirement that rotational-finger type and CT grippers be able to handle cylindrical objects concentrically is tantamount to compelling the designer to custom-design fingers with complicated curvilinear finger contours.

1.2 Force Considerations

The reliability of clamping is a significant criterion in gripper design, i.e., the workpiece must not fall out of the jaws, and it must be stable in its orientation relative to the jaw not only in transit but also while the robot undertakes job-related operations. The intensification of the clamping force is, for most products, the only practical way to improve the reliability of clamping [10]. This is especially true for strong and stiff parts, such as steel forgings, large castings, bar stock, and thick-walled tubes. Strong grips are also required where the

gripper is to perform technological operations, such as assembly operations, where insertion of parts into seats may require considerable axial forces.

The clamping force may be increased by increasing the capacity of the drive, or alternatively, a means may be used to intensify the available force. Because most grippers have pneumatic drives, an increase in power normally involves an increase in dimensions, and hence in weight, both of which are considered as penalties.
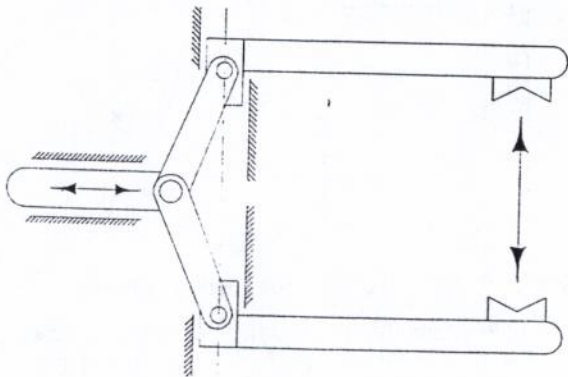

Figure 4: A centric KAU gripper.

A major priority in contemporary gripper development is hence to evolve improved designs that are rugged and compact, and which are able to apply large grasping forces, in addition to satisfying the basic requirement of concentric gripping of cylindrical objects. Gvozdev [10] and Bicchi and Balkema [11] discussed grippers that are equipped with means of intensifying the clamping force. Still other researchers [5, 12-14] proposed various design alternatives for grippers that feature not only concentric gripping but also force intensification. One such design [13] is shown in Fig.4[4]. In this regard Mannaa and associates [5] proposed a set of design criteria for grippers. Their conditions imply, in part, that (a) the work-piece, irrespective of its diameter, will not be disturbed during the gripping process and, that (b) the fingers will not be required to possess special jaw profiles other than a V-notch. They further stressed the desirability of evolving new gripper designs that embody force-intensification techniques for the purpose of securing reliable grips.

In what follows, we study the characteristics of a novel concentrically grasping gripper which also allows force intensification. Two versions of the same design are discussed, one for external gripping and the other for internal gripping.

2 The Gripper

The six-link gripper being presented here is a rugged mechanism with linear input. Shown schematically in Fig. 5,[5] it comprises two identical centric slider-crank mechanisms that are driven by a common crank. Crank A_oAC is pivoted at Ao, and the crank angle is denoted by Θ_7. Sliders B and D, to which the twin fingers are rigidly attached, run on the same (fixed) axis. The fingers may be straight-faced, as shown in Fig. 5, or they may be provided with V-notched faces, depending on the application. The shaded block represents the work piece. A pneumatic actuator, not shown in Fig. 5, would be attached at point A of the mechanism to drive the gripper. The configuration shown in Fig. 5 is for external gripping of workpieces.
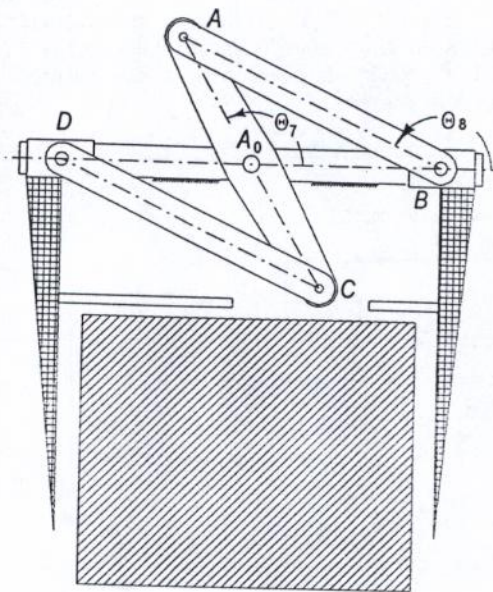

Figure 5: The six-link gripper for external gripping.

Let l be the jaw opening (distance between points B and D), l_7 the length of crank $A_oA=A_oC$, and l_8 the length of the connecting rod AB=CD. Figure 6 illustrates the variation of non-dimensional jaw opening, l / l_7, with crank angle Θ_7. The column at right lists several values for the parameter, l_8 / l_7. It follows from Fig. 6 that jaw opening decreases with increasing crank angle until Θ_7 reaches 180 degrees. This observation is true for all values of l_8 / l_7. The change in jaw opening becomes increasingly less with increases in crank angle, until it becomes insignificant after about 160 degrees. It is interesting to note that increasing the l_8 / l_7 ratio causes an essentially *linear* increase in the dimensionless jaw opening at any crank angle.
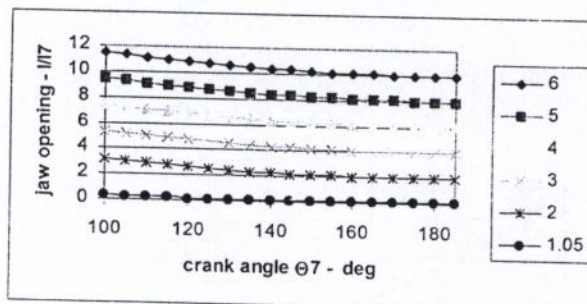

Figure 6: Variation of jaw opening with crank angle for ratios of l8/l7.

The transmission angle is a reliable measure of the smoothness of operation of a mechanism. For a slider-crank mechanism that is driven by its crank, as it is in the present case, the transmission angle is defined as the angle between the normal to the axis of the slider and the connecting rod. By definition the transmission angle will be . 90□, the 90□ being the best possible value.

Figure 7 shows the variation of the transmission angle in the mechanism of Fig. 5 with crank angle and with the ratio of lengths l_8 / l_7. The smallest values of the transmission angle are observed to occur at the starting crank angle of 100□ for all l_8 / l_7 ratios, as would be

expected. Although this observation is very vivid for values of $l_8 / l_7 < 3$, the reduction in transmission angles is not so noticeable for larger values of l_8 / l_7, when the transmission angles remain above 70° for all crank angles of interest.
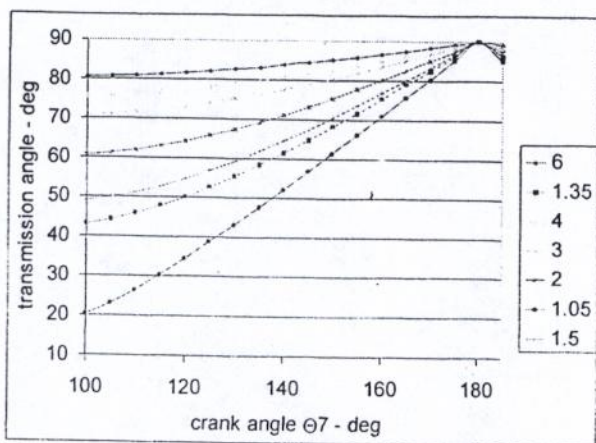

Figure 7: Change in transmission angle within the range of operation for several l8/l7 ratios.

Practice has shown that a minimum transmission angle of 40° or greater will ensure the smooth operation of a slider-crank mechanism when inertia effects can be disregarded [15]. On the other hand, the operation of the gripper can be considered to be quasi-static in most applications. It would be safe, therefore, to opt for a minimum transmission angle of 40°. It may be verified from Fig. 7 that a value for l_8 / l_7 that is equal to or greater than 1.22 will provide a transmission angle larger than 40° throughout the region of operation of the gripper. It is concluded therefore that, for design purposes, an l_8 / l_7 ratio of 1.35 may be safely utilized.
Referring to Fig. 5, let it be assumed that, for a safe grip, a gripping force of 100N must be applied by each finger on the workpiece. It may be shown, for a gripper with $l_8 / l_7 = 1.35$, that torque requirement on the crank will be as depicted in Fig. 8. The values in this figure are for a mammoth gripper with length of crank, A_0A, equal to 1m and connecting rod length, BC, equal to 1.35m.
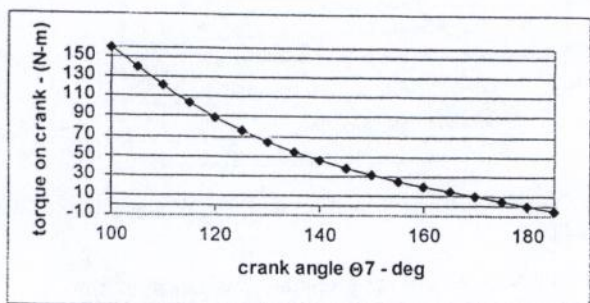

Figure 8: For selected dimensions, crank torque needed to produce a gripping force of 100N within range of operation.

It may be observed from Fig. 8 that the required crank torque rapidly decreases with crank angle. The crank torque is reduced to one tenth of its starting value by about 155°. This is an unmistakable sign of the force-intensification characteristic of this type of gripper. It is also evident from the figure that the torque actually

becomes negative when the toggle position is crossed at 180°.
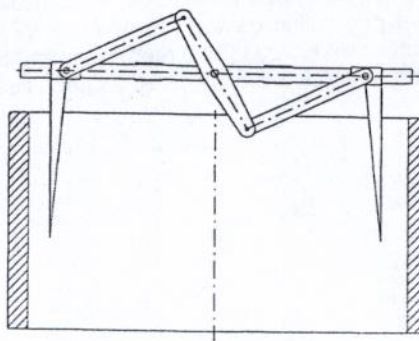

Figure 9: Six-link gripper for internal gripping.

It may be pointed out that the mechanism of Fig. 5 may be viewed at a different configuration to obtain another type of gripper, as shown in Fig. 9. This new gripper, to be referred to as gripper-i, would be suited for the internal gripping of tubular workpieces. It may be verified that, for the same l_8 / l_7 ratio, the grippers of Fig. 5 (gripper-e) and Fig. 9 (gripper-i) possess identical transmission angle characteristics. One important difference is that, the connecting rod of gripper-e would always be in tension during the working stroke, whereas that of gripper-i would always be in compression.
Figure 10 shows the variation of dimensionless jaw opening in the two mechanisms, for an l_8 / l_7 ratio of 1.35. It is clear that gripper-i (internal) exhibits a considerably larger range of jaw openings at all crank angles. This advantage in jaw openings approaches 5 to 1 at a crank angle of 140°, and becomes even larger, when transmission angles exceed 60° in both mechanisms (Fig. 7).
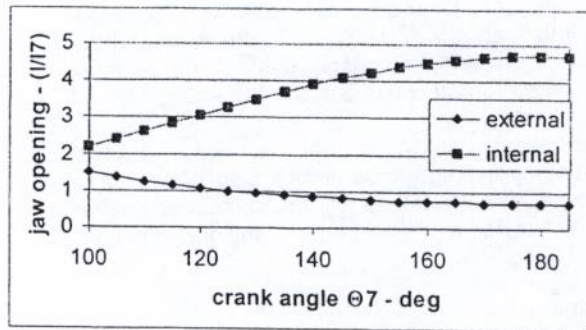

Figure 10: Variation of jaw opening with crank angle in gripper-e and gripper-i.

Figure 11 shows the variations of torque requirements on the crank shaft in the two grippers for a gripping force of 100N. The ratio of lengths, l_8 / l_7 is 1.35, and the length of the crank is assumed to be 1 m in each gripper. It is observed that torque requirement on gripper-i remains nearly constant until a crank angle of about 130°, after which it decreases rapidly due to the toggle effect. Both curves converge at 180°, and become negative thence.
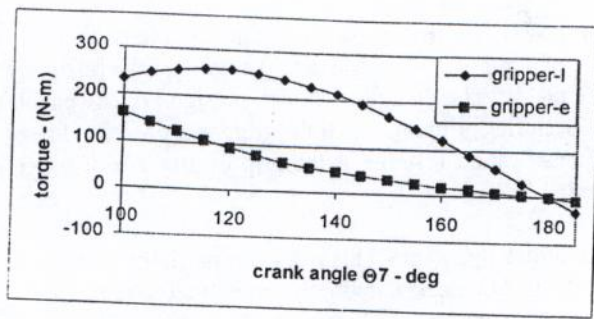
Figure 11: The change of crank torque with crank angle in the two grippers.

Figure 13: A side view of gripper-i.

3 Gripper Assemblies

Figure 12[6] shows two views of a possible assembly drawing for gripper-e at its fully open position. The gripper is actuated by a pneumatic actuator, denoted by 1 in the figure. The actuator is anchored on the frame of the gripper by a trunnion (14), while the tip of its plunger (13) is pin-jointed to the rigid extension of common crank (2) of the twin slider-crank mechanisms. A specially contoured connecting rod (3) is pinned to one of the sliders, while the other connecting rod (4) is not contoured. On each of the sliders, the fingers (6) are located by dowel pins and secured by screws. The common guide of the two sliders is specially machined so as to prevent rotation while allowing sliding. The guide is fixed at the common crank shaft. The connecting rods are fashioned in pairs to ensure smoothness of operation. The crank arms (2) are specially contoured to avoid obstructions, and they are provided with bushes and bosses at several joints to allow rotation only about desired axes. Connections at joints are made by the use of C-clips (snap rings) for compactness. A keyed bush complete with a set screw is provided on the extension of the crank shaft (9) to facilitate assembly on a robotic wrist.
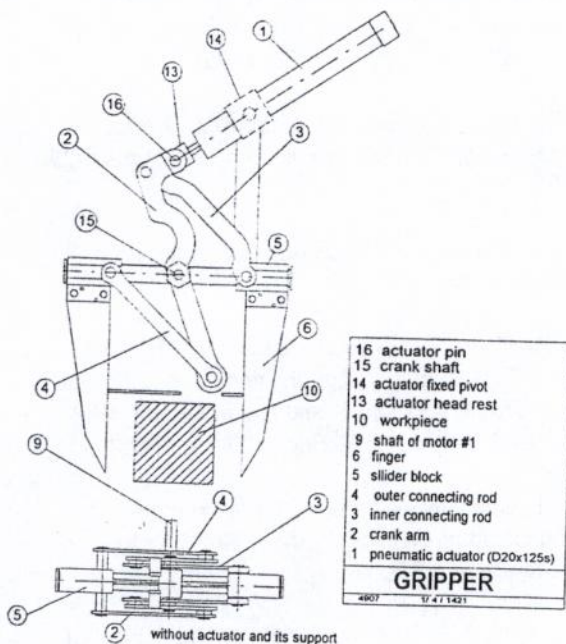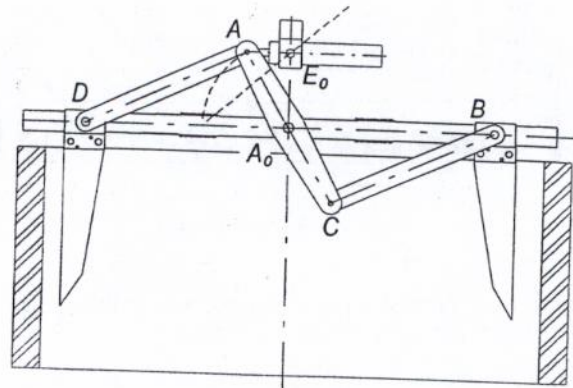
Figure 13[7] shows a side view of a proposed assembly drawing for gripper-i. This gripper is also actuated by a pneumatic actuator, which is pivoted at E_0. The tip of the plunger of the actuator is pin-jointed at A to the common crank of the twin slider-crank mechanisms. Figure 13 shows the gripper at the fully open position ($\theta_7 = 100$). The dotted line passing through E_0 indicates the final inclination of the actuator at the toggle position. No contouring is needed on this mechanism. Like in gripper-e, one finger is fixed to each slider. The common guide of the two sliders is specially machined so as to prevent rotation while allowing sliding. The guide is again fixed at the crank shaft. The connecting rods are likewise fashioned in pairs to ensure smoothness of operation. A keyed bush and set screw is provided on the extension of the crank shaft to facilitate the assembly of gripper-i on a robot.

For the physical dimensions of the grippers shown in Figs. 12 and 13 ($l_7 = 1$, $l_8 = 1.35$m), Fig. 14 presents a plot of actuator forces required to generate a gripping force of 100N within the range of operation of the grippers. It is thus clearer in Fig. 14 than it was in Fig. 11 that the same pneumatic actuator can be used to drive both grippers. The working strokes of the actuators would also be roughly equal, i.e., for a crank length of 1.0 unit, actuator strokes would be 1.41 and 1.29 units for gripper-e and gripper-i, respectively.

16 actuator pin
15 crank shaft
14 actuator fixed pivot
13 actuator head rest
10 workpiece
9 shaft of motor #1
6 finger
5 slider block
4 outer connecting rod
3 inner connecting rod
2 crank arm
1 pneumatic actuator (D20x125s)

GRIPPER

without actuator and its support

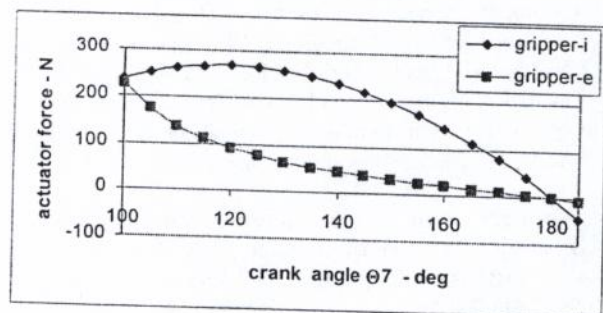Figure 12: Two views of gripper-e.

Figure 14: The required actuator force in the two grippers to generate a gripping force of 100N.
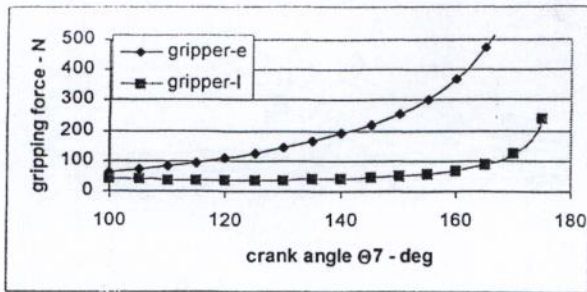
Figure 15: The resulting gripping force over the range of operation for an actuator force of 100N.

Figure 15 depicts the force-intensification characteristics of the two grippers for the configurations shown in Figs. 12 and 13. The ordinate shows the gripping force that would be generated when a constant actuator force of 100N is applied. It may be verified that gripper-e displays force intensification during about 65□ of crank rotation, starting with a crank angle of 115□. Gripper-i has more modest force intensification characteristics that are essentially confined to the region 168□ to 180□ of crank rotation. Both grippers clearly display toggle behaviour in the vicinity of 180□. A remarkable feature of gripper-i that is clearly visible in Fig. 15 is that the grip force remains essentially constant over a considerable region of crank movement. This aspect, which may have technological ramifications, occurs while the jaws travel to cover a dimensionless jaw displacement l / l_7 of about 2.19.

4 Concluding Remarks

It must be emphasized that the joints that are utilized on the two grippers are confined to pin joints and prismatic joints. There are no gears involved. Consequently both grippers are inherently rugged. Gripper-i is relatively more compact. The latter gripper is also simpler in construction since it does not involve contoured elements.

From Fig. 15 it follows that gripper-e features considerable force-intensification qualities. For an assumed actuator force of 100 N acting on the gripper, the corresponding gripping force applied on the workpiece exceeds 100N at a crank angle of about 115E, and keeps rising until the toggle position. Thus the crank of gripper-e is in the force-intensifying mode for about 65E of rotation. This region corresponds to a finger displacement of 0.37 units (Fig. 10) for a crank length of unity. The region of force intensification is considerably less for gripper-i, being from a crank angle of about 168E until 180E, which corresponds to a finger displacement of 0.09 units.

Gripper-i exhibits several unique properties. It features a relatively large jaw displacement within its range of operation. The total jaw displacement of gripper-i is 2.5 units as opposed to 0.8 units exhibited by gripper-e when both grippers have a crank of length 1.0 units. This would enable gripper-i to handle a wide range of workpiece sizes. A further unique property of this gripper is that the grip force remains essentially constant during 88% of its gripping range. This property may be interpreted to mean that fragile or weak workpieces of various internal diameters / sizes also can be safely handled by this gripper, without the danger of their being crushed.

In conclusion it may be stated that the construction of the two grippers is rugged, and the designs are relatively simple. The unique six-bar design does enable concentric gripping. Both grippers possess force-intensification features at the grip by the use of toggle action.
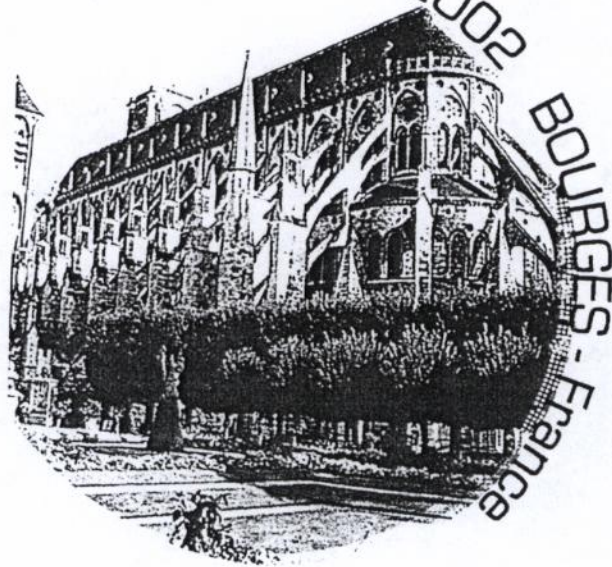
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