DOUBLE LEAD SPIRAL PLATEN PARALLEL JAW END EFFECTOR

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INTRODUCTION

Space Station Freedom currently is planned to be constructed by astronauts and highly sophisticated robots. The S.S. Freedom will require a large number of complicated Extra Vehicular Activity (EVA) tasks such as assembly of the structural truss, connection of fluid, gas, and electrical lines, and manipulation of large payloads in the hostile environment of space. NASA Langley Research Center's Automation and Technology Branch is conducting research in the development and use of robots in performing these EVA tasks. Since many EVA tasks require the dexterous hand manipulation which currently only an astronaut can provide, a robotic "hand" or "end effector" must be developed to meet these requirements. An end effector, the Double Lead Spiral Platen Parallel Jaw End Effector (Spiral), was developed as a response to problems in the design of the current LaRC Puma (LP) end effector, and to meet the needs of S.S. Freedom assembly tasks (see Fig. 1). It is highly controllable and compact, and has a very high gripping force for its size and weight.

This paper will discuss the design problems associated with the LP end effector and how the Spiral end effector addresses these problems, and will give results of test data for three end effectors: the Spiral end effector, the LP end effector, and the TRI (Telerobotics Model #EP75/30) end effector (see Fig. 2). The Spiral and LP end effectors use the same electric motor to power the jaws so direct comparisons can be made between the two designs. The TRI end effector was included in this series of tests as a benchmark of commercially available lightweight end effectors.

There are a number of general design guidelines used in the development of end effectors. Gripping strength and the knowledge of the absolute position of the end effector's jaws (fingers) are two of the most important design criteria. In addition, finger speed should neither be so slow as to be laborious nor so fast as to be uncontrollable. Also, it is desirable that the gripping force not diminish after the power to the end effector has been turned off. Parallel jaw motion, where the fingers are constrained to move transversely in one plane, is preferred over the four-bar mechanism motion which moves the fingers in two planes (see Fig. 3). The LP and TRI end effectors use four-bar mechanisms to keep the fingers parallel. This motion creates difficulties in grasping an object by a remote operator who must compensate for the fingers moving in two orthogonal axes. This motion is a problem in both the teleoperated (man-in-the-loop) mode and the robotic mode.

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If the fingers could be made to move in-plane while remaining parallel, considerable programming difficulty would be avoided. The most significant design problem involves converting the rotary motion of the motor shaft into linear motion of the fingers, while utilizing the motor torque in an efficient way to maximize the gripping strength and maintain a high degree of controllability. There are no firm requirements associated with these guidelines. Therefore, end effectors must either be designed for a specific task or designed for versatility, which will include compromises.

LaRC PUMA END EFFECTOR

The LP end effector was developed for research in the manipulation and assembly of S.S. Freedom hardware. The assembly evaluations involve struts with metal fittings on the ends which attach to the space station's truss nodes. The end effector must be capable of being accurately positioned over the fittings. Then the end effector must grip and turn the fittings in order to simulate the construction of the S.S. Freedom truss. The researchers were able to position the end effector over the fittings, and grasp and manipulate them. But when it came time to release the fitting, the end effector would seize and not release.

The problem is in the LP end effector drive system. An electric motor (rated for 13 W, 60 oz-in. peak torque) is used to turn a worm gear which reacts against a bevel gear. This bevel gear is secured to a four-bar mechanism which allows the fingers to remain parallel while moving in an arc (see Fig. 3). In order to gain enough mechanical advantage to firmly grip an object, the worm gear has a very low lead angle. This low lead angle makes the end effector self-locking. Once the worm has stopped, it cannot be reversed to release an object. The worm/bevel gear arrangement is subject to wear, which makes the fingers loose and adds to the positional uncertainty of the fingers.

DOUBLE LEAD SPIRAL PLATEN PARALLEL JAW END EFFECTOR

The Spiral was developed as a solution to the problems of the LP end effector. The result is an end effector which is more efficient, has a greater gripping strength, and is highly controllable.

The problem of keeping the fingers parallel while moving in plane was solved by using a rail system to hold the fingers. Linear bearings mounted on hardened steel rails react the loads without excessive deformation.

To efficiently use the small torques of the compact motor, a very efficient means of doing work is needed. One of the more efficient and basic ways of lifting objects is to utilize a roller on an inclined plane (see Fig. 4). The roller reduces friction, and a low angle inclined plane makes it possible for small amounts of "pushing" force to raise large weights. The penalty one pays is that a long incline may be needed to lift an object up a short distance.

The principle of the inclined plane was used in the Spiral end effector design. By wrapping the inclined plane in a spiral, a considerable length can be incorporated in a small disk. A roller, placed in a spiral channel and constrained to move in one plane by rails, would be able to move back and forth and take advantage of the inclined plane's work efficiency. A spiral has the further advantage that each complete rotation is a constant lead pitch. This means that once the angle of the spiral is known, the position of a constrained roller is also accurately known. Two spirals, one the mirror image of the other and with a common center point, allow two constrained rollers to move in a back-and-forth motion. The distance between the rollers is a linear function of the spiral's rotation angle.

The Spiral end effector's design is based on two mirrored spirals machined into a rotating platen. The platen is attached to a gear reduction unit which increases the motor's output torque while reducing the angular velocity. The angular velocity of the platen determines the fingers' speed. The fingers, constrained by the rails, are attached to rolling pins which ride in the spiral channels. As the platen rotates, the pins roll in the channel moving the fingers either forward or backward, depending on the platen's direction of rotation. The gripping force of the fingers is a function of the spiral's inclined plane efficiency and the torque increase through the gear reducer. The platen makes only three-and-a-half revolutions to move the fingers their full travel distance. Therefore, a decrease in the motor's output speed, along with the concommitant increase in torque, is advantageous (see Fig. 5).

TEST RESULTS

The Spiral, LP, and TRI end effectors were tested for gripping strength, positioning accuracy, finger speed, and gripping force relaxation. The Spiral and LP end effectors use the same electric motor for their input power, so a comparison of the performance between the two will show directly the advantages or disadvantages of each design.

GRIPPING STRENGTH

In order to measure the gripping strength, a force sensor was placed between the jaws of the end effectors, and the stalling force at a number of different input power levels was recorded (see Fig. 6). A second degree least-squares curve fit was generated for each data range. The Spiral end effector was the most powerful end effector of the group, showing a maximum gripping force of nearly 80 lb. Using the same motor for input power, the Spiral end effector has a 250 percent increase in gripping strength over the LP unit.

POSITIONING ACCURACY

The three end effectors were fitted with digital shaft encoders which were used to record the number of encoder counts per unit length of jaw movement (see Fig. 7). A least-squares fit line was developed for the data to determine the degree of linearity in the positioning system. The Spiral end effector showed the greatest degree of linearity. The data points on both the opening and closing sides of the chart fall on the line. The LP and TRI end effectors are fairly linear. However, both showed a degree of hysteresis when the jaw movements changed directions. These hysteresis effects could build at every movement reversal, and eventually cause confusion as to the absolute jaw position.

FINGER SPEED

The opening and closing finger speed of the three end effectors was measured for a high and low range of no load power levels (see Fig. 8). The LP end effector was the fastest, the TRI was moderate, and the Spiral was the slowest of the group. The Spiral's speed is not a disadvantage for most applications, and can be an advantage in a teleoperated mode where there are reaction control time considerations and the slower speed allows time for fine corrections.

GRIPPING FORCE RELAXATION

A force sensor was placed between the jaws of the end effectors which were loaded at 36.5 lb (the maximum for the LP). The input power was then turned off, and the relaxation force was monitored over a period of an hour and a half (see Fig. 9). All of the end effectors performed well in this test, with the TRI showing less relaxation than the other two.

CONCLUSIONS

The Double Lead Spiral Platen Parallel Jaw End Effector is an extremely powerful, compact, and highly controllable end effector that represents a significant improvement in gripping force and efficiency over the LP end effector. The Spiral end effector is very simple in its design and has relatively few parts. The jaw openings are highly predictable and linear, making it an ideal candidate for remote control. The finger speed is within acceptable working limits and can be modified to meet the user's needs; for instance, greater finger speed could be obtained by increasing the spiral's pitch. The force relaxation is comparable to the other tested units. Optimization of the end effector design would involve a compromise of force and speed for a given application.

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

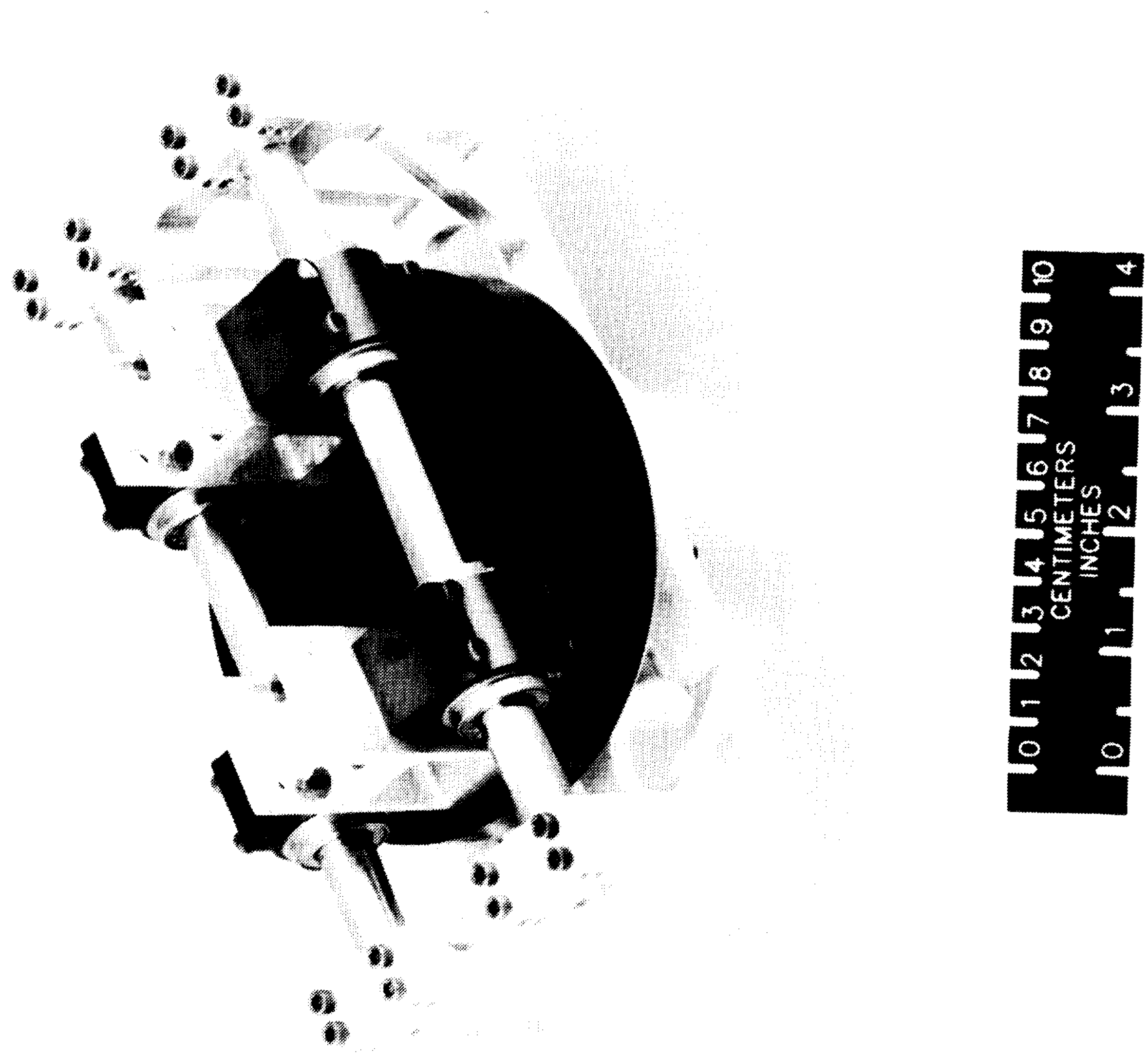
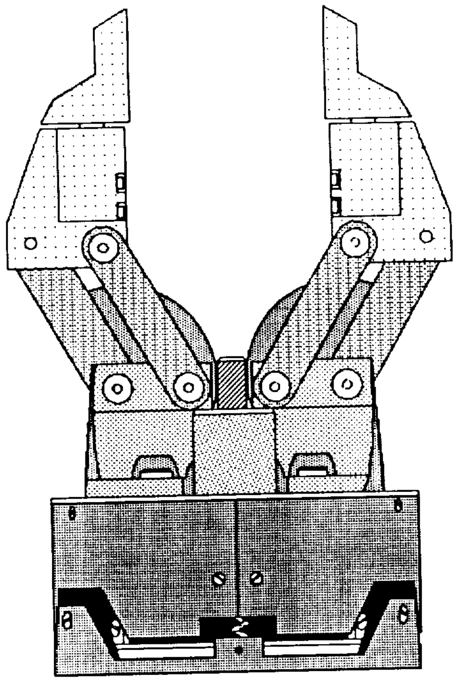
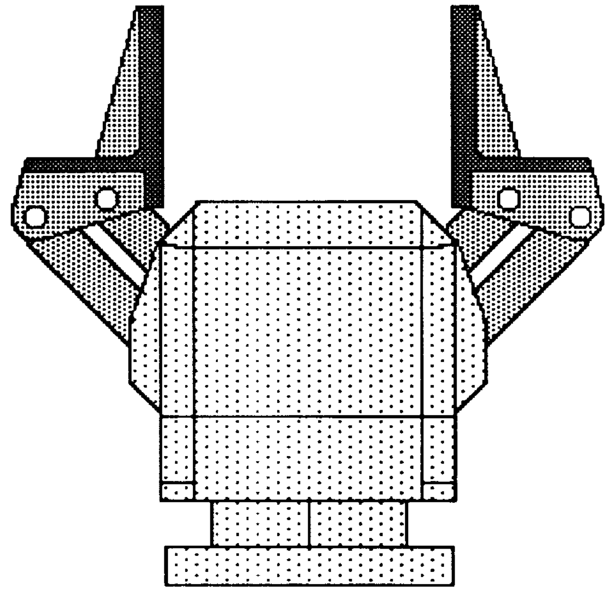


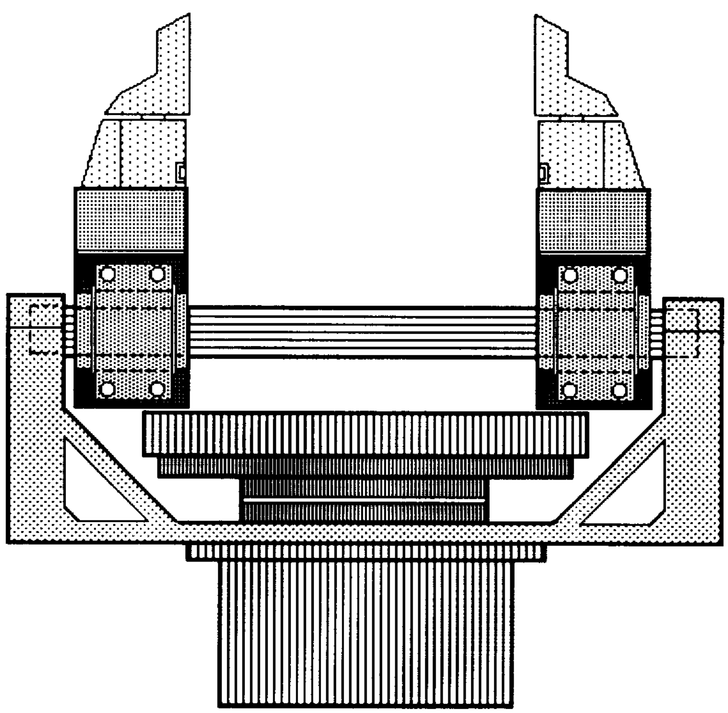
Figure 1. Double Lead Spiral Platen Parallel Jaw End Effector.



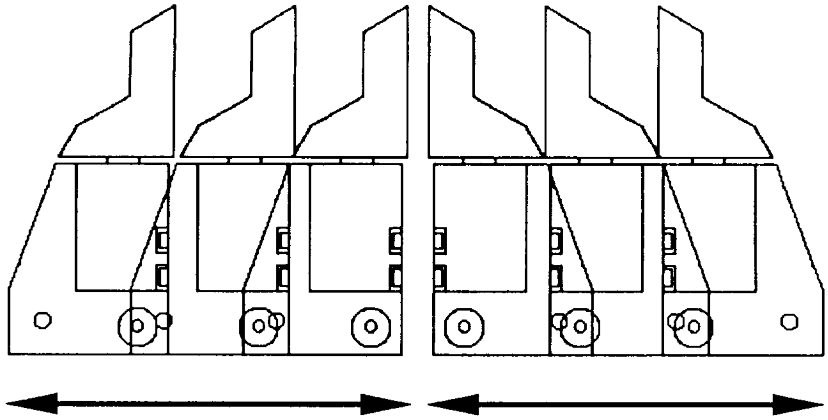
LP End Effector



TRI End Effector

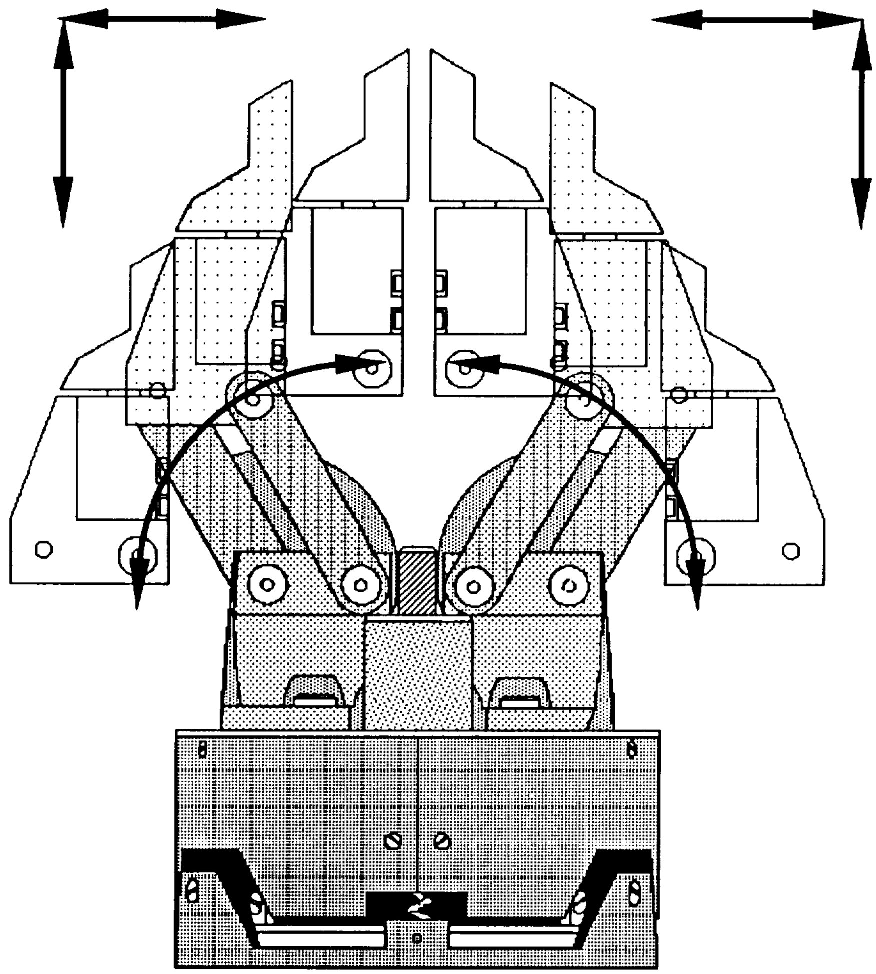


Double Lead Spiral Platen Parallel Jaw End Effector
Figure 2.

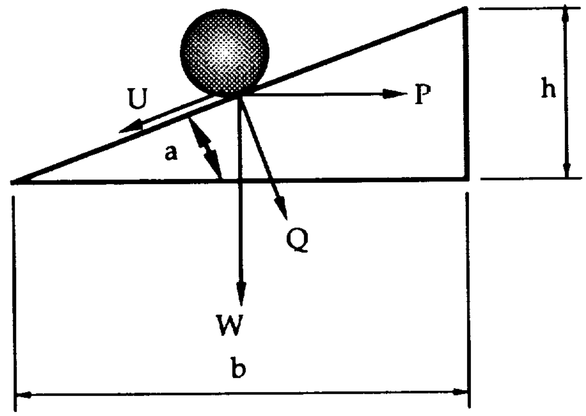


PARALLEL JAW MOTION

FOUR BAR MECHANISM MOTION. THE FINGERS REMAIN PARALLEL AS THEY DESCRIBE AN ARC, MOVING TRANVERSLY IN THE X AND Y DIRECTION



LaRC Puma End Effector
Figure 3.



W = Weight (or Force), Gripping force for the end effector.
P = Force Required to move W, the motor torque for the end effector.
Q = The normal force on the inclined plane.
U = Force of friction, u * W * cos(a)
a = angle of incline
b = run
h = rise

Neglecting Friction:
P = W * (h/b) = W * tan(a)
W = P * (b/h) = P * cot(a)
Q = W/cos(a) = W * sec(a)

Figure 4. Inclined plane mechanics.

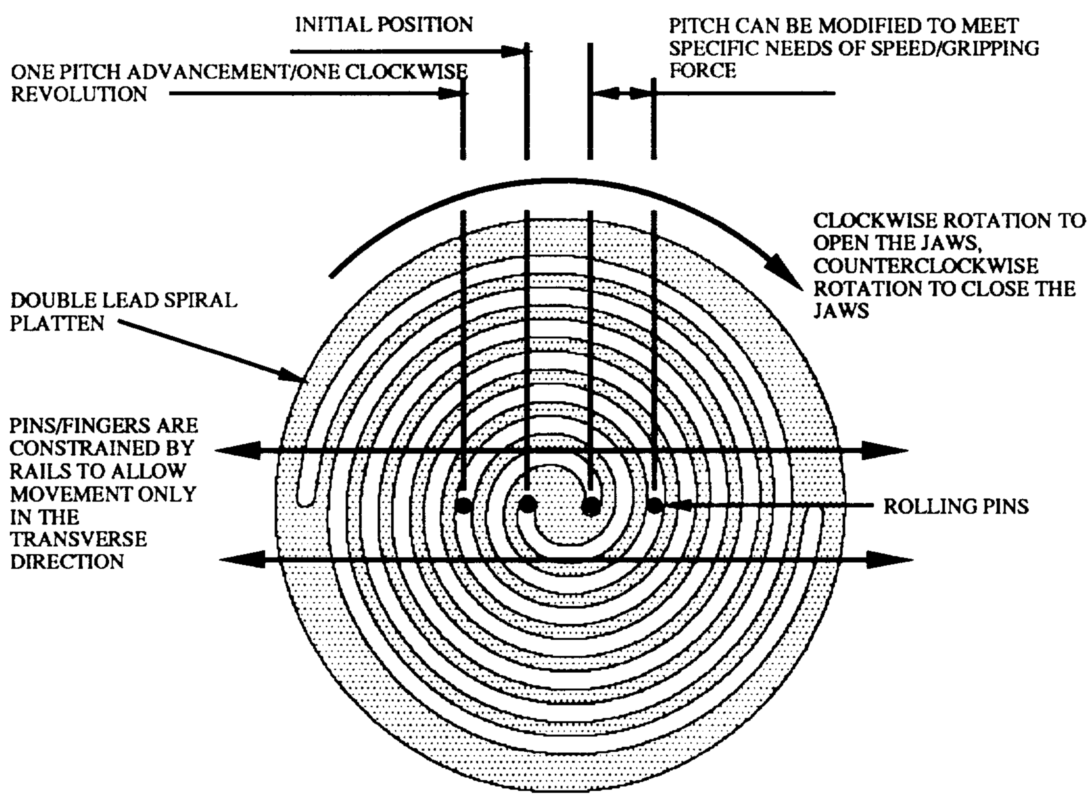


Figure 5. Inclined plane mechanics.

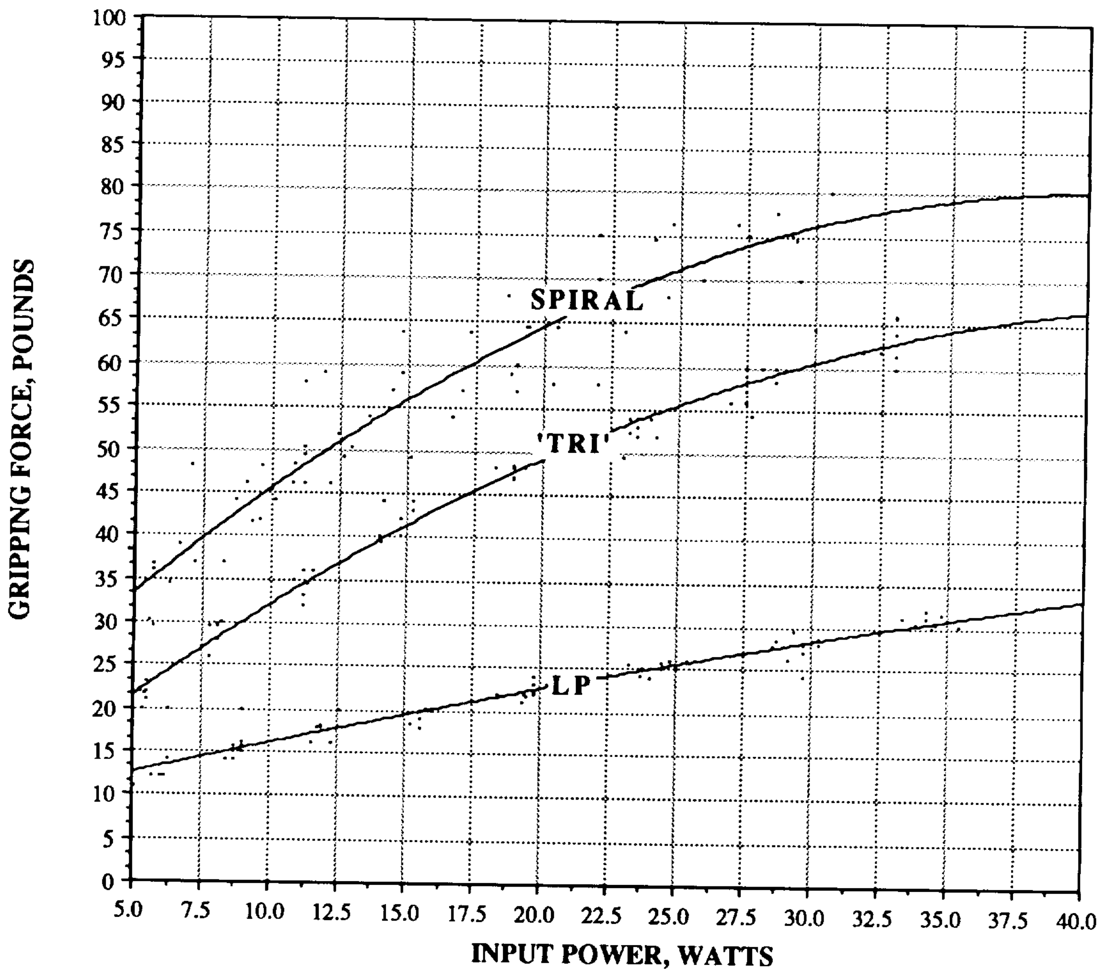


Figure 6. Gripping force versus power.

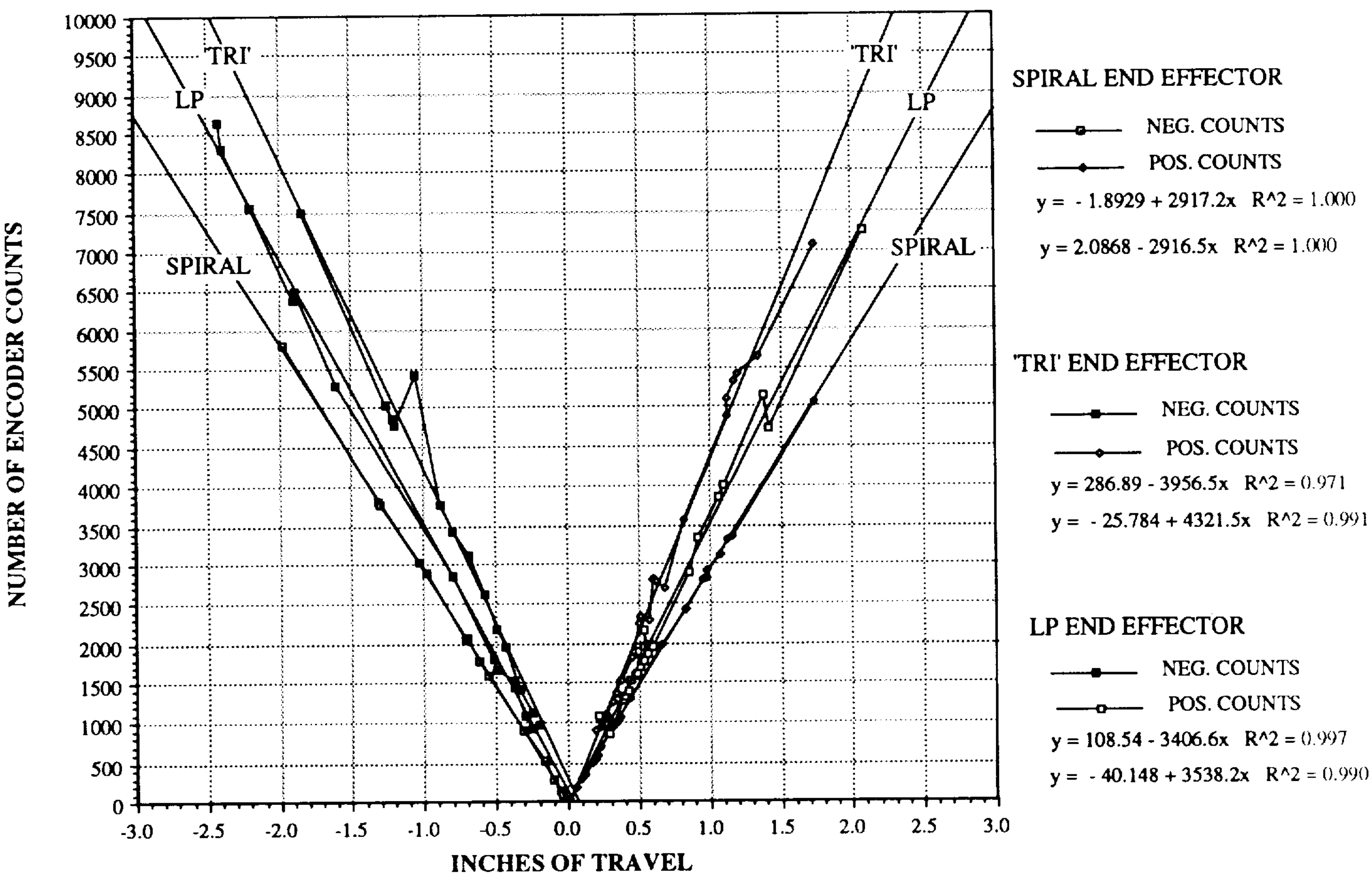


Figure 7. Linearity of jaw positioning.

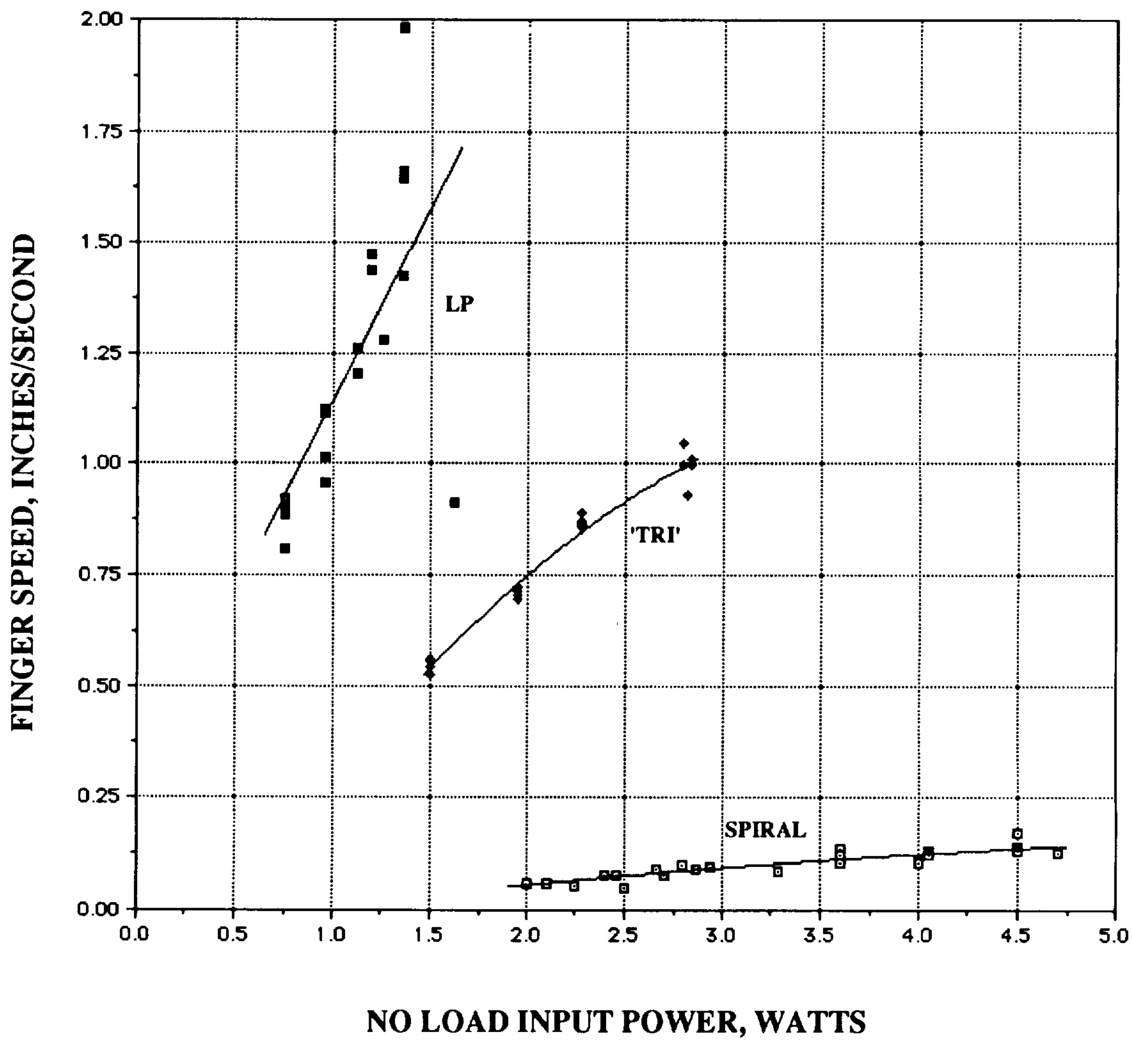


Figure 8. Finger speed versus input power.

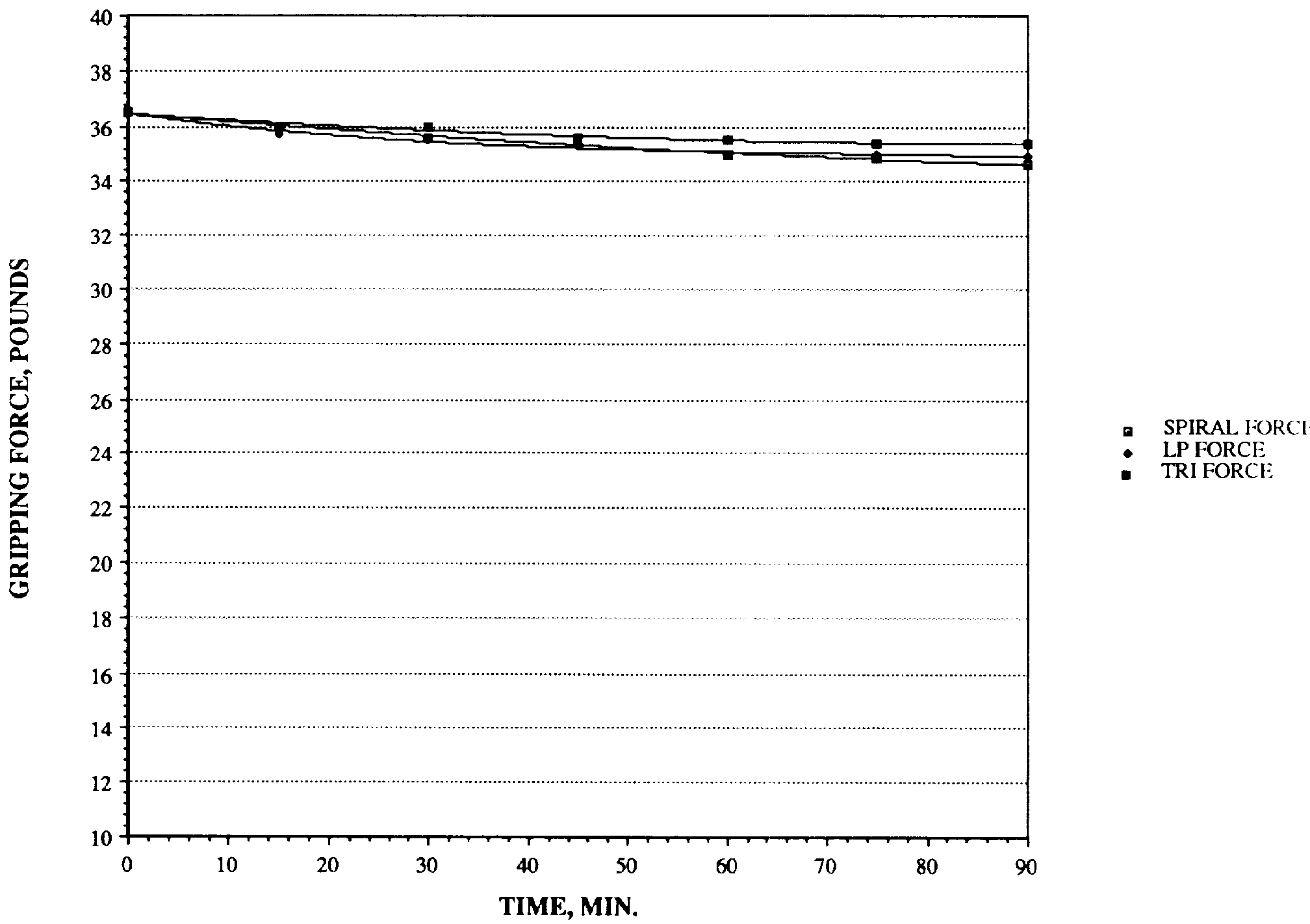


Figure 9. Gripping force relaxation.