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POSITIONING AND HANDLING IN WEIGHTLESS ENVIRONMENT

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ABSTRACT

After experimental verification on the first and second orbital workshops, manufacturing processes suitable for industrial application will emerge. The flight facility environment for this use will contain functional elements similar to those employed in manufacturing on earth.

Several electro-mechanical devices to transfer, position and retrieve space manufacturing equipment are discussed. Application to an orbital manufacturing facility is described.

INTRODUCTION

Previous speakers have dealt with manufacturing processes which employ weightless environment of space flight to create new and unique products. Following experimental verification of such processes, pilot plant operations in space will emerge. Eventually, a complex of space stations devoted entirely to creation of useful products may evolve from ideas similar to those described today.

Writing in the January 23, 1967 issue of Technology Week, Isaac Asimov stated: "Mankind is now faced with the practical need for working under low gravity conditions and technologists will have to develop "low gravity engineering", in consequence. The day for that is coming; it is clearly ahead, and the problems it brings will be like nothing experienced in the past."

Unique products from space will be available in quantity only when low gravity engineering provides the tools and facilities to support the emerging low gravity materials processing technology.

Like its counterpart on earth, the space manufacturing plant will have to accommodate supporting tooling to the process requirements within a suitable facility.

Gravity dependent tooling techniques used on earth to move and position objects cannot be used in space. Frictional forces between objects disappear with the absence of the uni-directional force gravity or dead weight. Well known proposals for positioning and handling objects in the neutral stability conditions of space include remotely controlled jet propelled tugs, extendable booms and truss-like structures. A new approach to space handling systems is to mechanically connect objects with a linkage which provides the means to propel, guide, stabilize, rendezvous and dock. (Reference 1, 4)

This type of device consists of a number of powered links which may be actuated relative to each other. Controls at the fixed or free end will be operated to extend the device in a straight or serpentine configuration as required to transport, rendezvous, and dock objects at tip. This serpentine actuator is called a serpentuator.

The serpentuator will be designed to impart approximately 1/100 g to objects at the tip. Between two and four pounds force is estimated to be adequate to move an object with 200 to 400 pound mass in space.

The serpentuator replaces the earth floor which serves to position and locate objects and assists in translation of men and materials. Thus the space plant can be as large as its space floor, which is equal to the volume reached by a serpentuator system.

Figure 1 illustrates how a space manufacturing plant may consist of a number of tools and processing units positioned outside but near the actual manned quarters. These modules would be brought inside or docked with the parent space station for loading and service. Captive or free flying modules would be deployed to proper orientation for gravity gradient for particular processes as well as to assist in dissipation of heat generated during a manufacturing process. In addition, a serpentuator could also serve as a remote inspection and repair system for the entire space station and serve to transfer men and materials between adjacent spacecraft.

The serpentuator system could be used to locate and position a vacuum refinement module adjacent to the parent space station. (Reference 5)

Calculations indicate vacuum of the order of 10^{-15} torr exists in the wake of objects orbiting at about 500 kilometers. While earth vacuum systems can equal or approach space vacuum of 10^{-9} torr, none have been able to achieve that available in the wake of an orbiting object. Figure 2 shows how experimental verification of calculations could be done using a serpentuator system. (Reference 8)

In addition to conducting parametric studies on roles and missions for serpentuators in Apollo program (Reference 12), the Marshall Space Flight Center Manufacturing Engineering Laboratory has fabricated and tested feasibility and engineering models of several designs of serpentuators.

The first model was built to verify control and positioning accuracy in a single plane. Test hardware of a hand powered hydraulic model to be used in the first Saturn workshop was built and evaluated. A full size, eight link, forty foot length serpentuator to assist in ATM film retrieval was built for evaluation in underwater simulation. The latest engineering model uses a hermetically sealed electromechanical hinge to prevent outgassing of lubricants and permit sterilization. A short description of each of the model serpentuator follows.

FIVE-LINK FEASIBILITY AND DEMONSTRATION MODEL

The model serpentuator was built several years ago to demonstrate in a single plane how objects in space might be relocated without expending mass.

Each link of this electro-mechanical model employs surplus DC electro motors and ball screws to provide hinge motion. See Figure 3. Figure 4 shows the fixed base link and four movable links. It may be operated from the base control console or the tip link using the same control box.

Links are activated sequentially by limit switches sensing maximum angular travel of adjacent links. Link motion started either at tip or base will continue until stopped by end limit switches or at some point by the operator. Multi-link devices in general require a feedback system and rate control of the angular motion between links in order to be controllable. The need for such a complicated control system can be avoided by sequencing so that only one link moves at a time. Restriction of freedom between links to single plane motion and with only one rotary joint at the attachment base allows the free end to reach each point in a spherical motion volume. Two steering modes provide sufficient flexibility by either starting the link motion from the base gimbal end or from the free end.

The force available to move the links is proportional to the deflection of the control stick. Links can move 20 degrees and return. These links were considered typical for 100 foot serpentuator to be stored and launched in the unpressurized area of a 33 foot diameter booster. (Reference 9)

DESCRIPTION OF DEMONSTRATION MODEL OF HAND POWERED HYDRAULICALLY OPERATED SERPENTUATOR

This serpentuator was designed for possible use within an early Orbital Workshop to assist the astronauts in transferring various items from their launched position in the MDA to the walls of the empty S-IVB booster. The astronauts would move the folded serpentuator through the forty inch diameter removable hatch in the forward bulkhead, clamp it to internal structure, then by controlled deployment, transfer objects from the hatch entrance to predetermined locations on the tank walls. Figure 5.

This demonstration model was hand powered, hydraulically operated and could be controlled from either fixed or free end.

General specifications for this serpentuator were:

1. Total Length - 18 feet.
2. Number of links (including base link) - 5.
3. Length of each link - 3.6 feet.
4. Total End Force - 6 pounds.
5. Fold into maximum envelope not to exceed 39.75 inches in one dimension.
6. The base link would contain a "roll" actuator.
7. Incorporate quick-disconnect base attachment.
8. Control system would consist of on-off valves controlling flow from hand pump to hydraulic rotary actuators.

One tip link and one link actuator separated by a fifteen foot tabular spacer was built to evaluate the design and human factors. Evaluation and testing was conducted on air bearings and in water (Figure 6) by suited operators.

Test results included:

1. Folded serpentuator could be handled and attached in low gravity by one man.

2. Directed movement could be accomplished by operator at tip.

3. Operator fatigue could be reduced by a hydraulic system requiring a small number of relative high force pump strokes rather than numerous low force, high frequency strokes. Operators in astronaut suits reported the effort to overcome suit restraint more fatiguing than operating the pump. Unsuited subjects in air and water found movement and control easy and not fatiguing.

4. Off the shelf rotary hydraulic seals have unacceptable leakage for space operations.

5. The need for a hermetically sealed powered hinge joint moving $\pm$ 180° movement established.

This design was not pursued further when the Orbital Workshop concept filled the S-IVB tank volume with multiple floors. (Reference 10)

DESCRIPTION OF FULL SCALE ENGINEERING MODEL OF SERPENTUATOR TO TRANSFER FILM CASSETTES ON ATM

Past experience has shown that extra vehicular activity makes large demands on astronaut time and energy. This serpentuator was proposed to assist the astronaut in extravehicular activity which cannot be avoided. Retrieval and replenishment of film of the multiple cameras in the Apollo Telescope Mount is an example of unavoidable astronaut EVA. An astronaut will move himself and film cassettes about exterior of the AAP cluster using a combination of hand rails and foot holds.

Responsibility for moving the bulky film cassettes while preventing inadvertent collisions with ATM structure will require constant attention and effort. The astronauts task would be reduced if transfer of the film cassettes were separated from the effort of moving himself.

A remotely operated serpentuator could provide this assistance. To study the operational problems and rewards of this proposal, a full scale engineering model serpentuator will be evaluated in a neutral buoyancy facility on full scale ATM mock-ups.

The proposed serpentuator would be supported between the solar panels and sun shield on the Apollo Telescope Mount. Figure 7 illustrates how the eight link serpentuator would be deployed from launch position on the octagonal shaped ATM.

Figure 8 shows the serpentuator positioned near the MDA EVA hatch to receive film cassettes. The serpentuator tip is remotely controlled to intercept the astronaut at the work station and solar end. Figure 9 shows one configuration assumed by the serpentuator enroute to the solar end of the ATM.

Changes in the AAP program have altered some details of the 1/20 scale model configuration but the illustrations are still realistic because the position of the MDA and film service locations are unchanged.

Figure 10 shows the 40 foot serpentuator being evaluated on air bearings. The base actuators are attached to the octagonal mount which will simulate the ATM attachment during underwater testing. Individual rubber bellows cover each hinge joint to permit pressurizing the interior of the serpentuator. The tip control box is also pressurized. The astronaut support and film cassette holders for underwater testing are not shown.

The seven powered hinges move 0 - 45° and all links move in a common plane. Each hinge is actuated by a linear ball screw driven by an electric mechanical gear train. The angular actuation is 1 RPM maximum, to assure low tip velocity. Actuator torques are made larger than required for space operations to assure adequate power for underwater simulation. The three outboard link actuators produce 40% smaller torques than the inboard link actuators.

Yaw and roll actuators are provided at the base to allow tip to reach any point in the water volume. Figure 11 shows the base roll and yaw actuators. Each actuator can produce 450 foot pounds of torque with a maximum angular rate of 1 RPM.

Both actuators are direct current electro-mechanical, employing harmonic drive units. The roll actuators rotate $\pm$ 200° while interference with the mounting frame restricts the base yaw actuator to $\pm$ 120°.

Roll, pitch and yaw actuators are mounted outboard the tip link to provide final positional adjustments similar to wrist movements in conjunction with the relatively gross movements of the upper arm.

The eight-link 40 foot serpentuator will be manually controlled from either fixed or free end. TV scanning and angular readouts on each link will permit operator at fixed end to develop a repeatable sequence of motions required to move the cassettes between required points on the cluster. (Reference 11)

ENGINEERING MODEL OF SERPENTUATOR HAVING HERMETICALLY SEALED ACTUATORS.

Greater reliability of components operating in space can be expected if the components are operating in an earth like environment than in the space environment. Existing technology with proven performance can be used if earth temperatures and pressures can be created in space. Metal bellows are a potential solution to enclose the pressurized hinge linkage. However the reliability of bellows flexing more than a few degrees while under small internal pressure is not well established since bellows typically are used without pressure and with modest linear motion.

This program sought to develop a reliable electromechanical hinge which could operate $\pm 180^{\circ}$, be packaged in a cylindrical container less than five inches in diameter, be hermetically sealed and produce about 50 foot pounds of torque.

Figure 12 shows the power train and linkage which meets the above specification. A DC motor driven ball screw operates the linkage which can move $\pm 180^{\circ}$.

Figure 13 shows the two hinged model built for testing. Serpentuator actuators are controlled remotely from a separate control box or from switches in the base link. Links are operated separately and motion is the same direction as switch is operated.

Figure 14 shows how a serpentuator made from 8 links could be folded into a 13 1/2 cubic feet volume. The serpentuator would be 38' long. The sketch also shows how pitch and roll motions could be achieved without use of actuators employing rotary seals. (Reference 6, 13)

CONCLUSIONS

The serpentuators described constitute the preliminary system analysis and design of alternate approaches to one concept for positioning and locating objects in a space manufacturing plant.

Current and future in-house efforts will refine component and system performance to provide design specifications for flight hardware.

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(10) Contract NAS 8-20707, Astro-Space Laboratories, Inc., Huntsville, Alabama, 1967.

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(12) Contract NAS 8-21279, Martin-Marietta Corp., Denver, Colorado, 1969.

(13) Contract NAS 8-30166, Astro-Space Laboratories, Inc., Huntsville, Alabama, 1969.

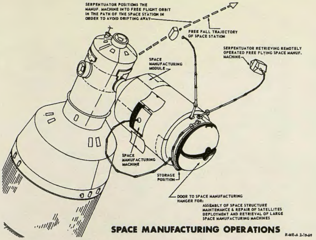


Figure 1. Space Manufacturing Tools and Modules Positioned and Handled by Serpentuator.

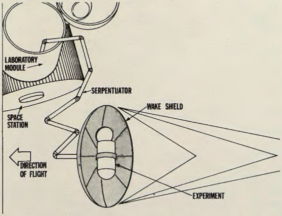


Figure 2. High Vacuum Refining Module Positioned and Handled by a Serpentuator.

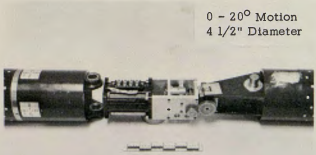


Figure 3. Typical Hinge Actuator of Five Link Model Serpentuator.

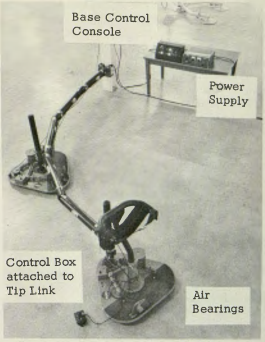


Figure 4. Five Link Serpentuator Control and Positioning Accuracy Evaluation on Air Bearings.

UNDERWATER DEMONSTRATION OF MATERIAL HANDLING WITH SERPENTUATOR

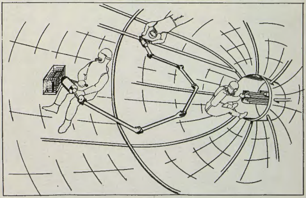


Figure 5. Concept of Portable, Hand Powered, Foldable Serpentuator.

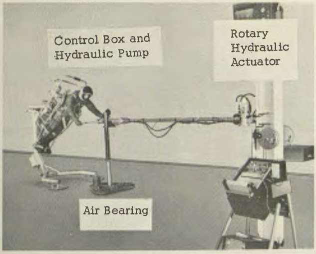


Figure 6. Human Factors and Design Evaluation of Hand Powered Serpentuator.

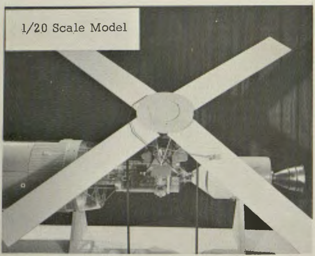


Figure 7. Initial Deployment from Launch Position of Forty Foot, Eight Link Serpentuator.

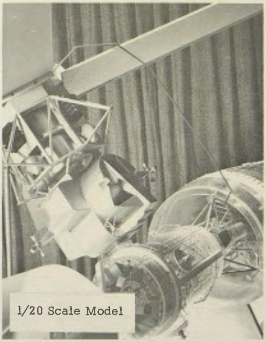


Figure 8. Forty Foot Serpentuator Tip located near MDA Egress Hatch.

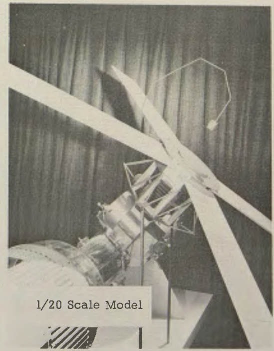


Figure 9. Tip of Forty Foot Serpentuator near Camera Hatches on Solar End of Apollo Telescope Mount.

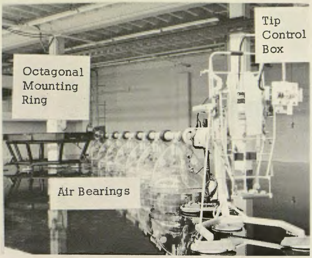


Figure 10. Forty Foot Serpentuator Control and Design Evaluation on Air Bearings.

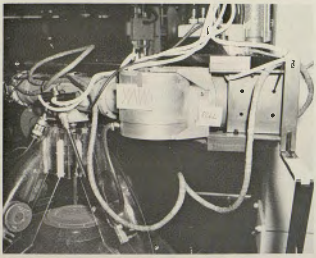
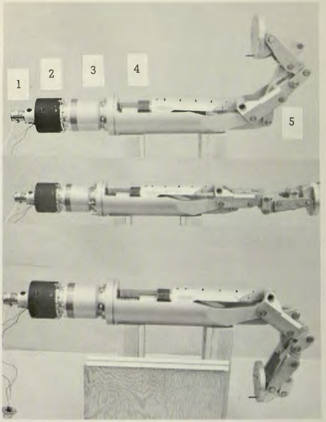


Figure 11. Base Roll and Yaw Actuators on Forty Foot, Eight Link Serpentuator.



1. Magnetic Brake
2. DC Motor
3. Harmonic Drive Unit
4. Ball Screw Operated Bell Crank
5. $\pm 180^{\circ}$ Travel Linkage

Figure 12. Mechanism of Hermetically Sealed Serpentuator Hinge.

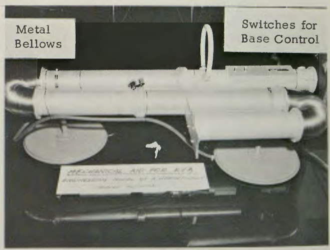


Figure 13. Two Link Test Hardware of Hermetically Sealed Serpentuator.

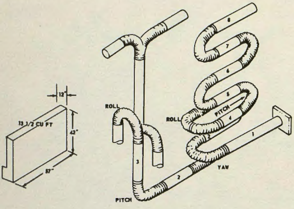


Figure 14. Hermetically Sealed Serpentuator with Three Degrees of Motion.