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PASSIVE SUN SEEKER/TRACKER AND A THERMALLY ACTIVATED POWER MODULE

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ABSTRACT

This paper describes the development and testing of two mechanisms using a shape memory alloy metal (NITINOL) as the power source. The two mechanisms developed are a passive Sun Seeker/Tracker and a generic type power module. These mechanisms use NITINOL wire initially strained in pure torsion which provides the greatest mechanical work capacity upon recovery, as compared to other deformation modes (i.e., tension, helical springs, and bending). (See Figure 1.)

INTRODUCTION

The term Shape Memory Effect (SME) is used to describe a group of alloys, that upon heating, exhibit a new mechanical property known as shape memory or shape recovery (Figure 2). These alloys possess the ability to remember a shape imparted to them while in the high temperature or austenitic phase. At lower temperatures they are in the martensitic phase and may be strained or deformed to some intermediate shape. All or some of that plastic strain may be recovered by subsequent heating through the transition temperature from martensitic to austenitic states. The transition temperature is quite low (i.e., 80°C (176°F), and the recovery force is approximately 758 MPa (110 KSI).

SUN SEEKER/TRACKER

The Sun seeker/tracker senses any misalignment of the impinging solar radiation and uses this radiation energy to drive the mechanism until it is centered on the Sun. Neither external energy nor signals are required to drive and position the unit.

Present state-of-the-art trackers use optical detectors to first seek the Sun and then preprogrammed algorithms are used to determine and follow the position of the Sun. The drive mechanisms consist of primary and back-up motors, gear trains, and complex feedback control systems.

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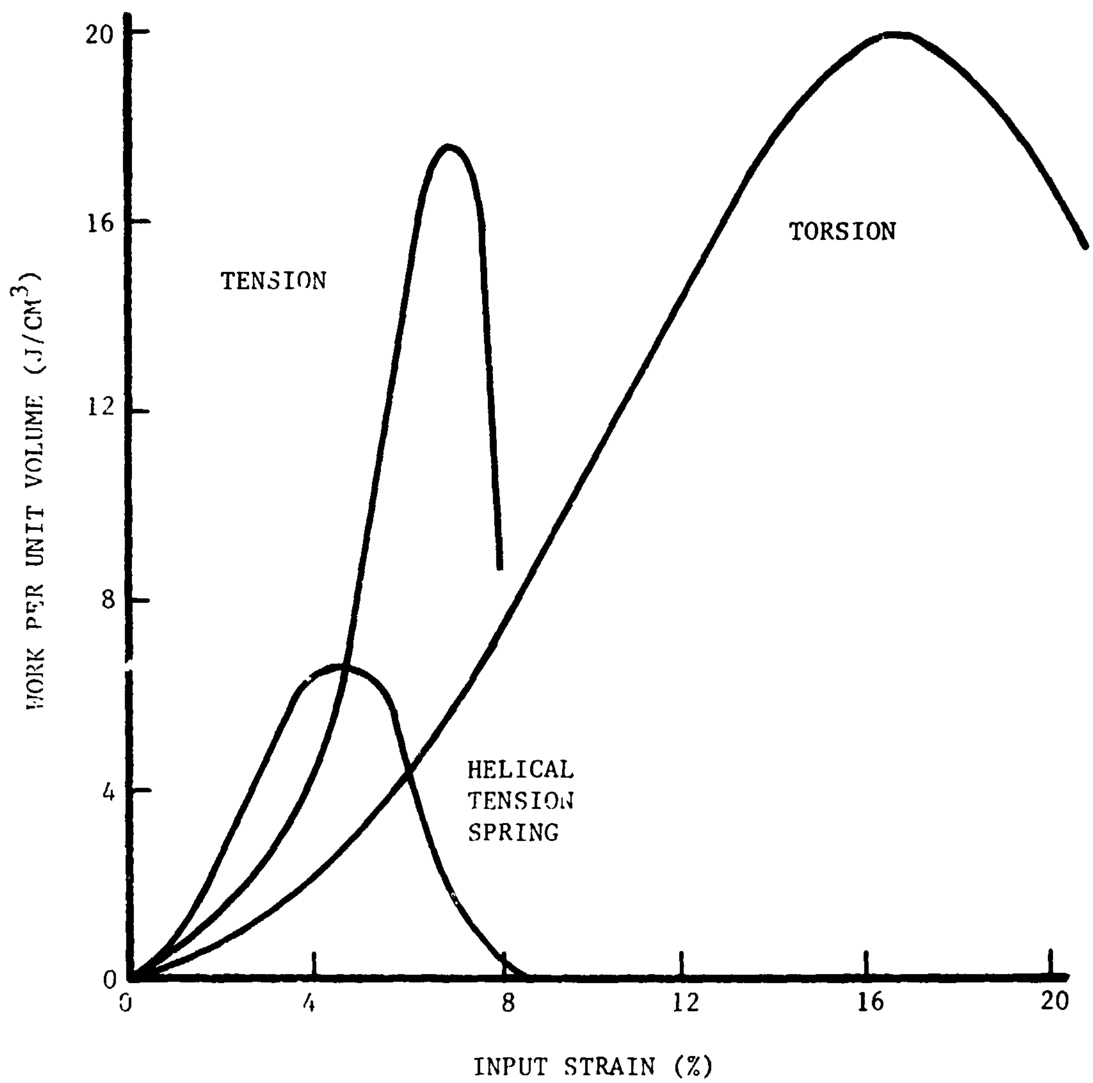

Figure 1. Performance for Three Different Configurations Using 0.14 cm Diameter Wire

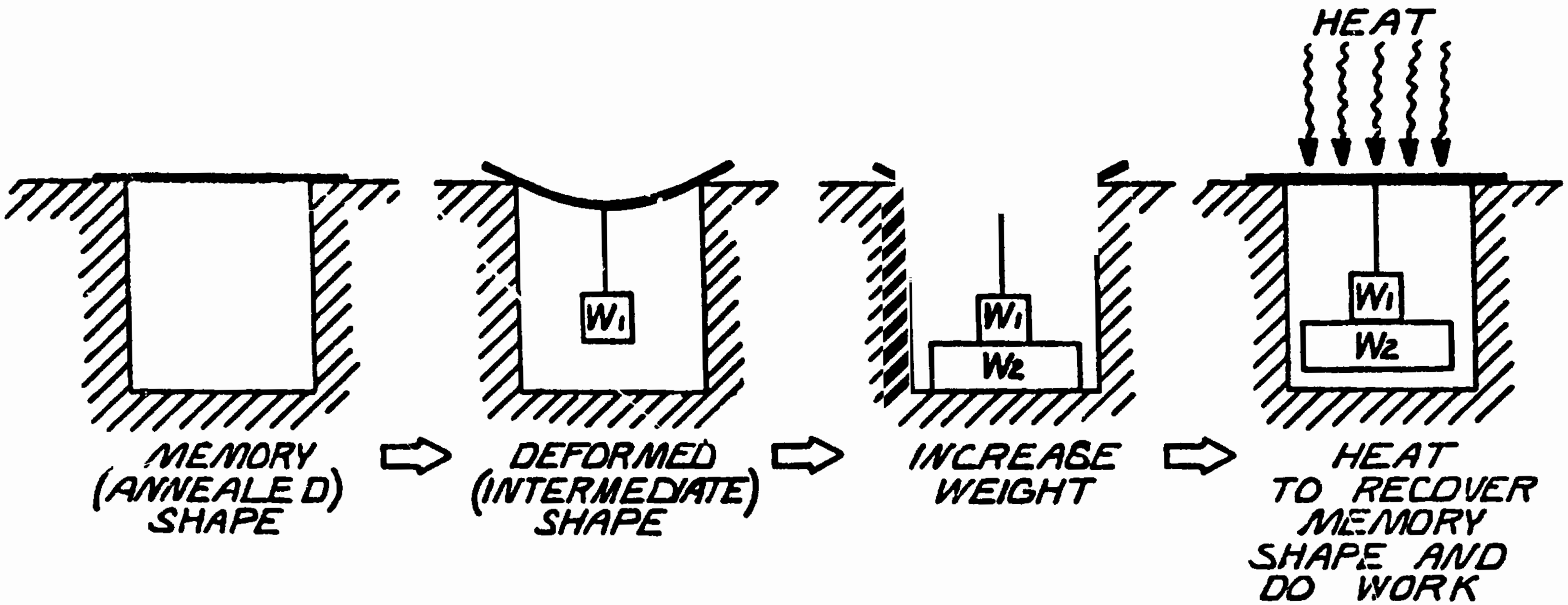

Figure 2. Principle of Shape Memory Recovery and Work

The Sun seeker/tracker (Figures 3 and 4) consists of two major sections: the outer drum and the inner drum, which houses the 33 drive nits. These sections are mounted on concentric shafts that rotate independently. The inner drum is divided into 10° sections around the periphery, in which indexing Nitinol drive units are housed (Figures 5 and 6).

The purpose of the drive units is to sequentially index the inner drum around the fixed outer drum until a neutral point is reached; at this time the unit is centered on the Sun. A locking mechanism may be activated to hold the unit in place until the Sun moves far enough to activate one of the positioning Nitinol drives.

Each of the 33 drive units are identical, consisting of only three parts: a lever arm, a torsion bias spring, and a twisted Nitinol wire (Figure 7). The only moving parts are the lever arm and its pivoting head, both of which have bias springs to stow the mechanism after activation. The Nitinol wire is fixed into the rotating lever arm and clamped to the inner drum on the other end. Overall, the whole assembly is very simple and reliable, and its cost could be reduced by investment casting the lever arms and heads since all 33 drive units are identical.

For several reasons the 0.14 cm (0.055 in) wire diameter was selected over the available 0.08 cm (0.031 in) and 0.25 cm (0.098 in) wire diameters to drive the unit. First the work per unit volume ratio was higher for this wire than the others tested in torsion as (Figure 8) and the calculated output torque and overall mechanism size was well suited for a prototype model using the 0.14 cm diameter wire.

When the drive unit is in the stowed position, the cool martensite Nitinol wire, initially twisted approximately 500°, is restrained in a twisted configuration by a torsion bias spring. The overall angular movement is 50° upon heating and is limited in either direction by roll pin stops. Activation occurs when the Sun rays heat the Nitinol wire above transformation temperature and elastic austenitic recovery tends to untwist the wire to the untwisted memory annealed configuration. In the process, the torsion bias spring is wound and the lever arm drives the inner drum with respect to the outer drum 10°, (Figure 3). Now the adjacent wire is exposed and heated, this sequence continues until the mechanism is centered on the Sun and locked into position. As the Nitinol cools, the modulus of elasticity of the wire decreases allowing the torsion bias spring to wind the Nitinol wire and stow the drive unit, totally disengaging it from the outer drum. As it is stowed, the lever arm must clear the next indexing peg on the outer drum. As shown in Figure 9, the spring loaded head of the lever arm pivots to clear the indexing pin of the outer drum.

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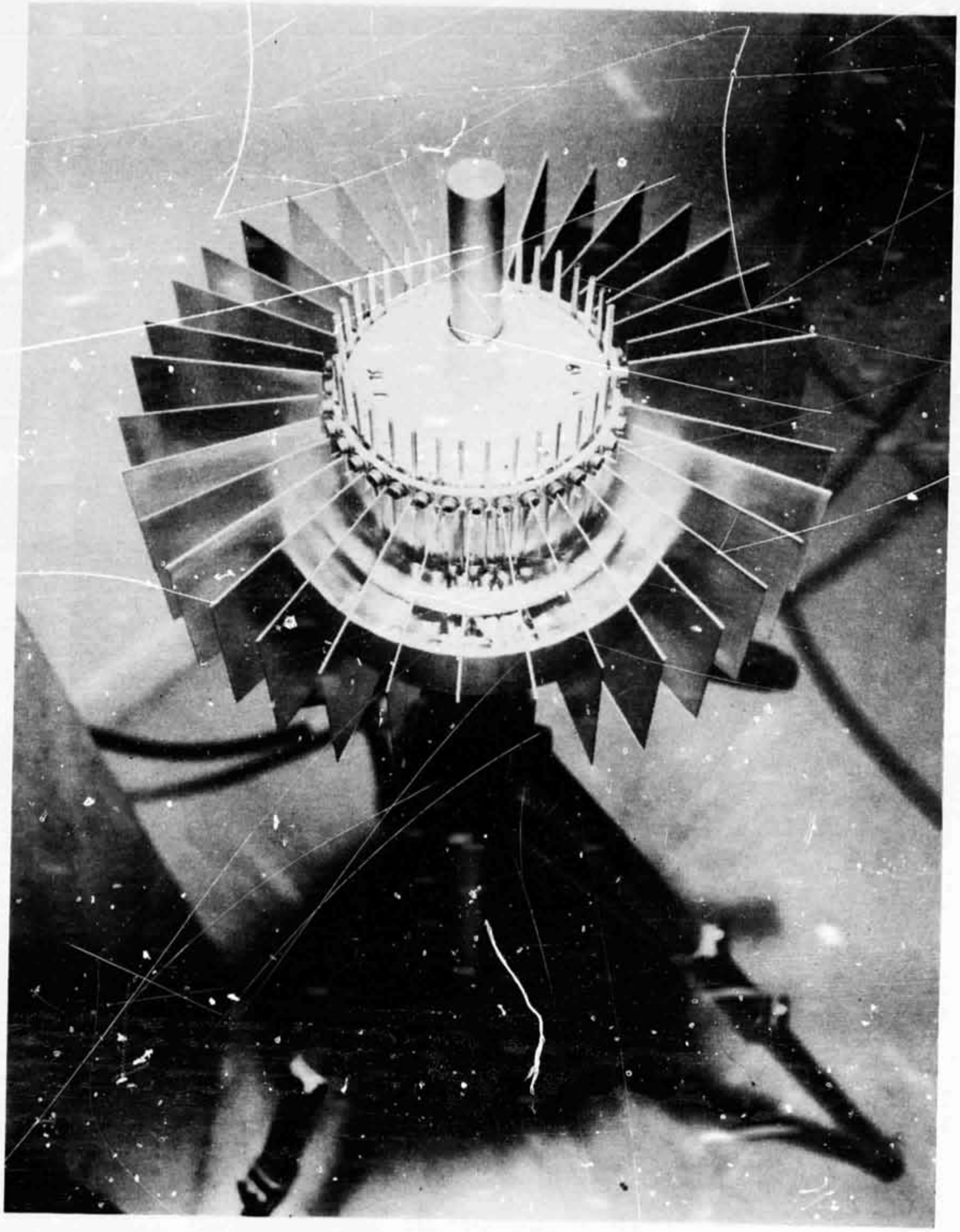

Figure 3. Plan View of Sun Seeker/Tracker

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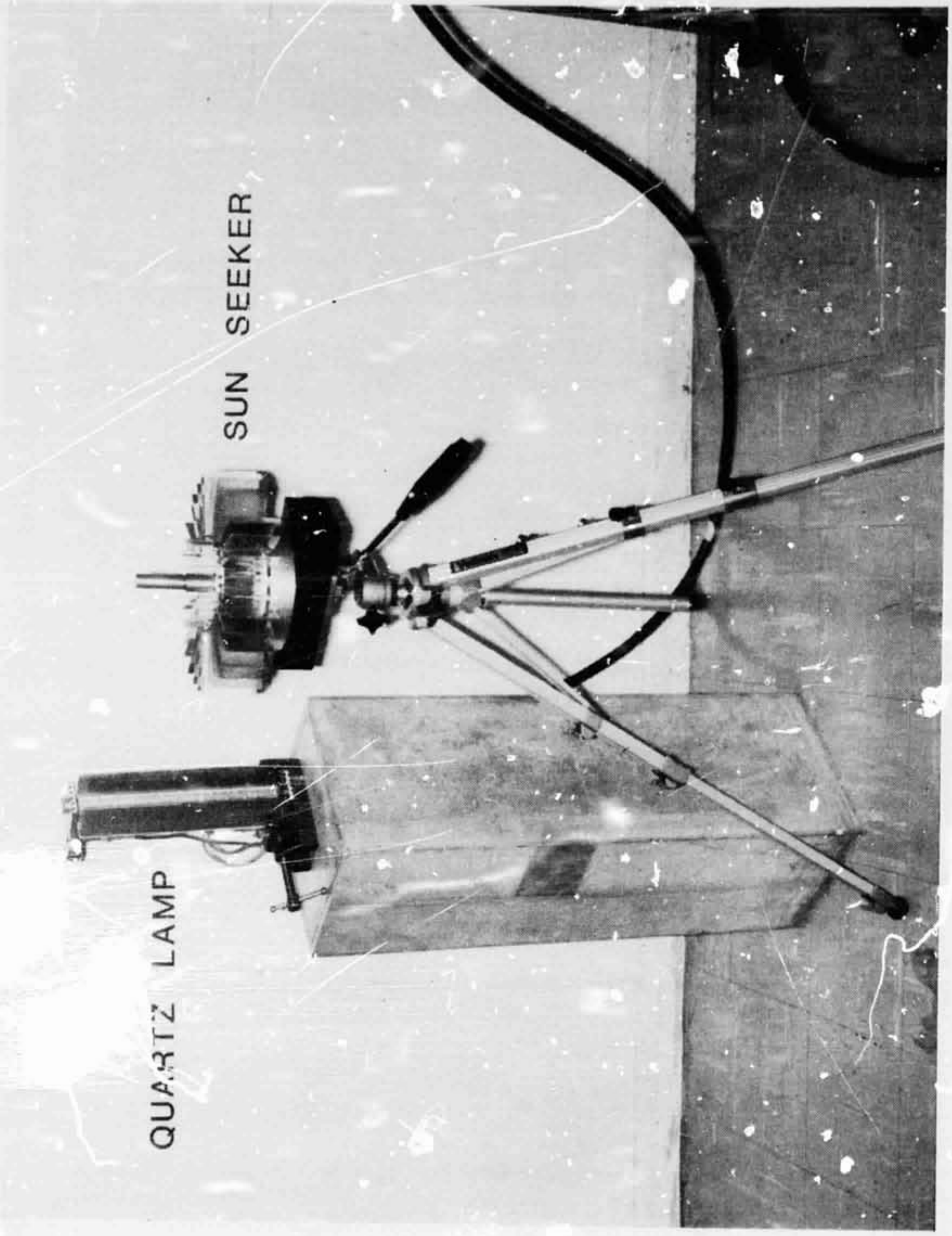

Figure 4. Testing Sun Seeker/Tracker Using a Quartz Lamp

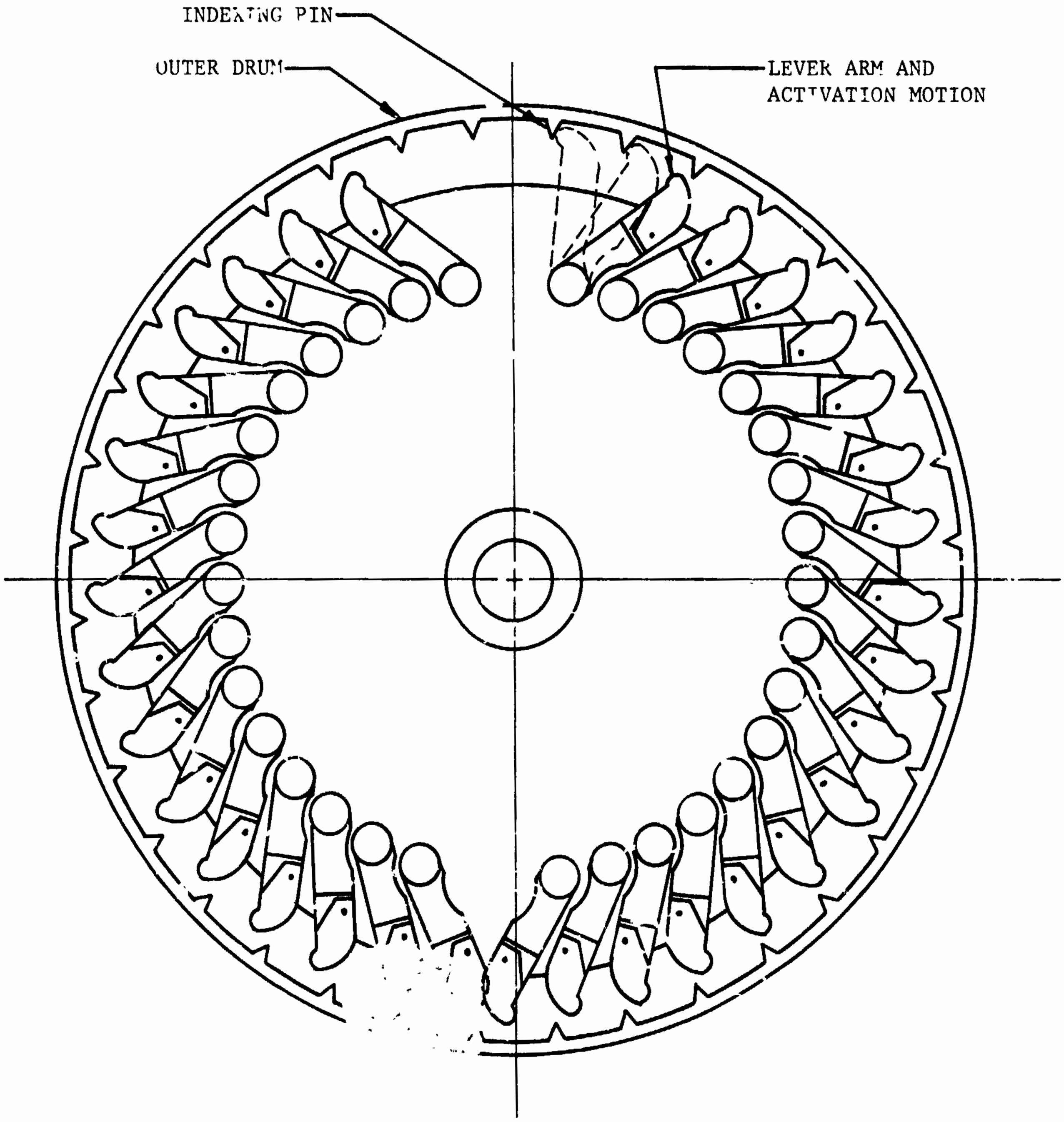

Figure 5. View of Lever Arm Arrangement

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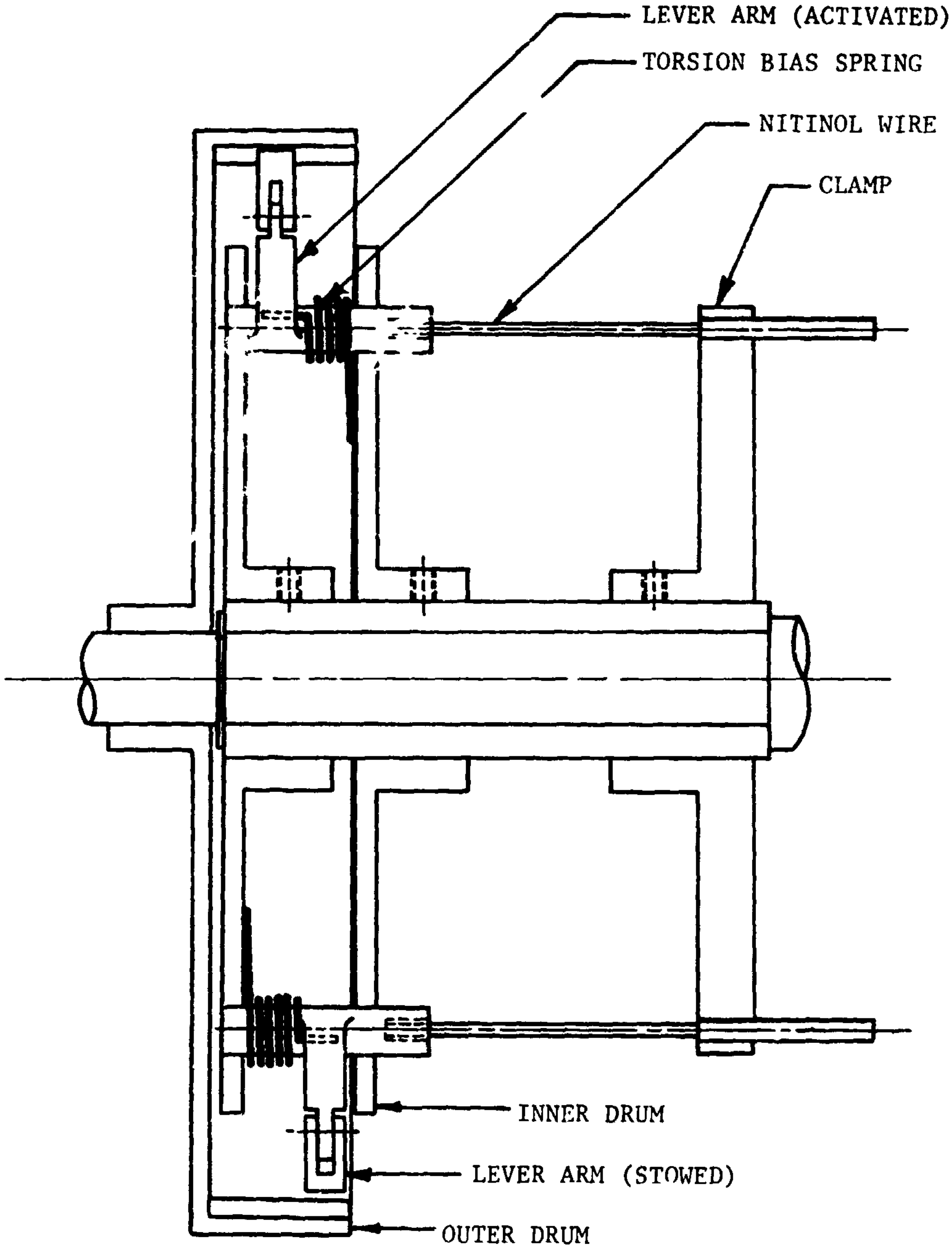

Figure 6. Cross-section of Sun Seeker/Tracker

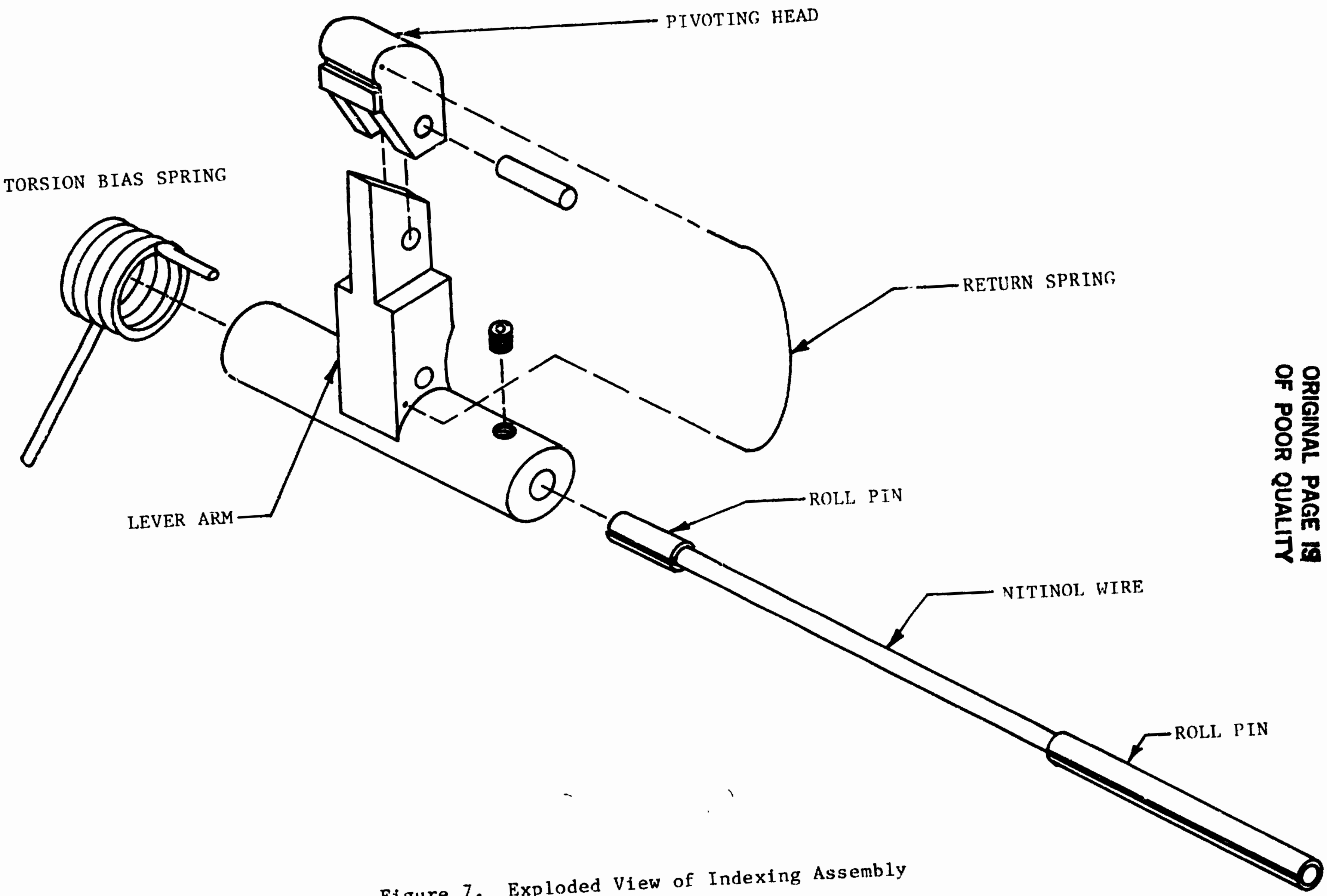

Figure 7. Exploded View of Indexing Assembly

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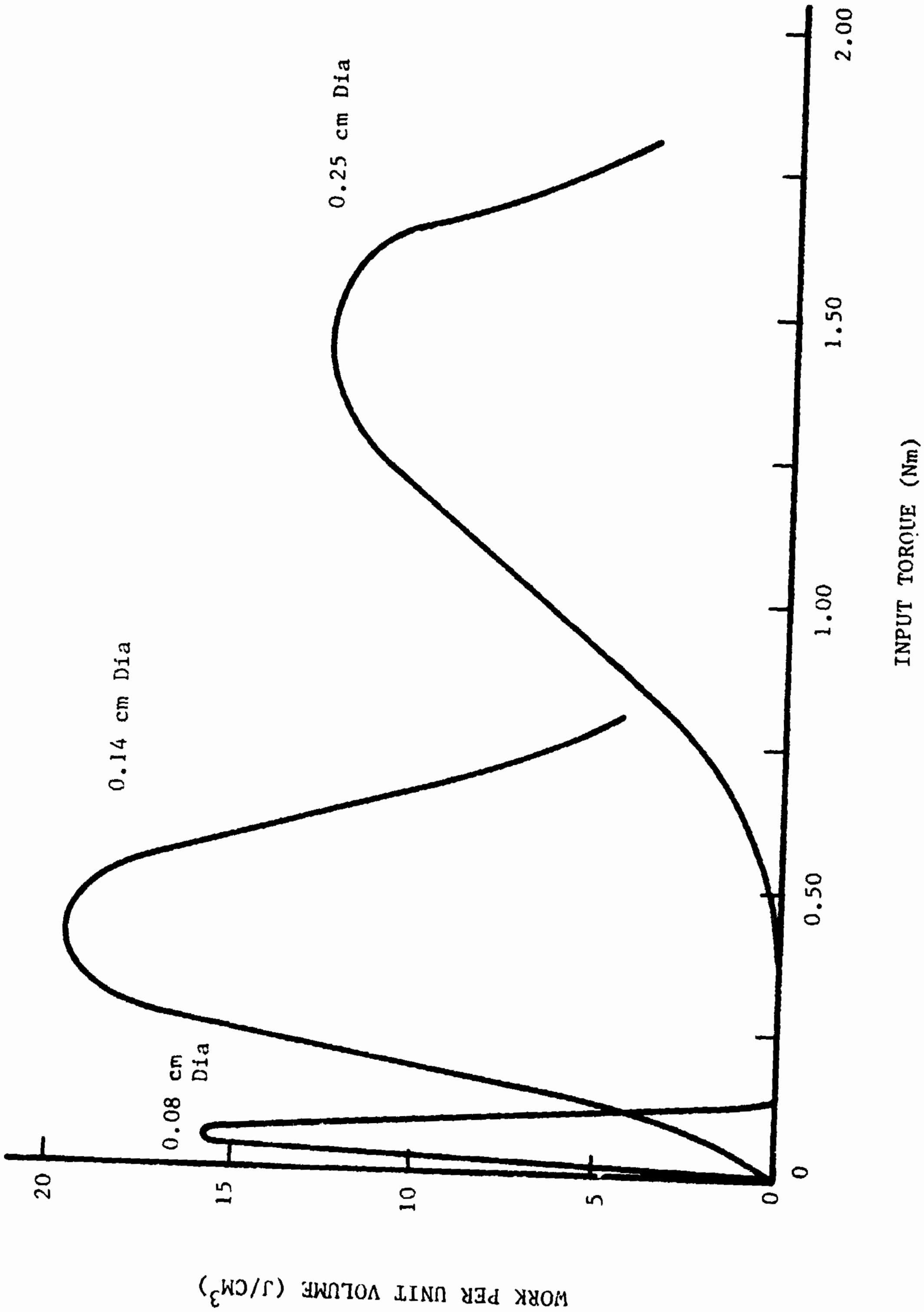
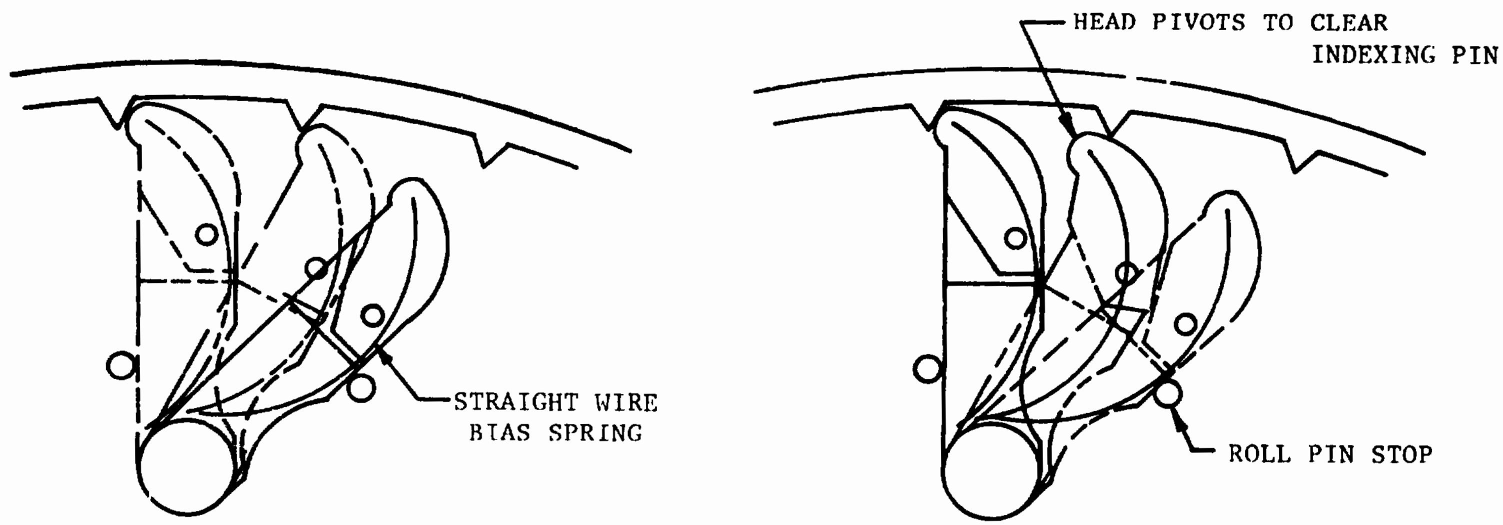


Figure 8. Performance of Three Diameter Nitinol Wires in Torsion



ACTIVATION:

INNER DRUM DRIVEN 10°
BY DRIVE UNIT. OUTER
DRUM FIXED

STOWAGE:

OUTER DRUM STATIONARY
AS DRIVE UNIT IS STOWED.
DRIVE UNIT'S HEAD PIVOTS
TO CLEAR INDEXING PINS

Figure 9. Kinematics of an Indexing Drive Unit

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Baffles are used to allow the sunlight to heat only one of the Nitinol drives at a time. Each drive unit is totally independent from the others. If a unit fails, operation of any other unit is not affected, as the other units will continue to operate accurately. If two of the drive units are actuated, one on the heating cycle and one cooling, the driving unit will still properly function because the lever arms act as a pawl and will not catch on the indexing pins unless they are driving. The lever arms are staggered in two levels to eliminate any possible interference.

To increase the radiation absorption of the wire, a parabolic reflector was placed directly behind the Nitinol with the wire at the parabolic focus point. The wire was also painted black to increase the amount of absorbed radiation; because bare metal reflects a large portion of the impinging radiation.

The number of drive units determines the accuracy of the tracker. This tracker is accurate to ±5° of centering on the Sun with 10° indexing steps. Drive units on either side of the center position are arranged to drive towards the centered position, thus the maximum angle the unit will have to rotate when seeking the Sun is 180°. See Figure 5.

The assembled unit is 15.25 cm (6 in) in diameter by 8.9-cm (3.5-in) long and is capable of operating with a restraining torque of 0.36 Nm (52 in-oz) and a stall torque of 0.65 Nm (92 in-oz). The output torque is a function of the size of Nitinol wire driving the unit; larger Nitinol wires could be used to greatly increase output torque.

The unit will track and seek in one axis. If two units were used, the Sun could be sought and tracked in two-axis or in three-dimensional space. At the present time, this prototype unit is undergoing cyclic life tests. To date the unit has been operating daily for 26 weeks using solar energy concentrated by fresnel lenses.

No mechanical problems have been experienced and no Nitinol fatigue or creep has been noted. The only adjustment required has been to manually correct for the ecliptic plane angle every few days.

TORSION DRIVE MODULE

The torsion drive module is a unit containing four Nitinol wires coupled with spur gears producing cyclic rotary motion of the output shaft when activated. This unit can be used in such applications as opening and closing valves and latches, rotating lenses and filter caps into position, window blind controls, or any application that needs a cyclic drive unit with restow capabilities.

The module is a 74 gram compact unit (2.5 cm by 2.5 cm by 8.3 cm) capable of producing output torque of 0.58 Nm (5.1 in lbs) in either direction with up to 200° of rotation. In specific situations where the output characteristics of the module are desired, the SME module would be superior to any conventional drive since because output torque to volume and weight ratios are several times higher.

The module uses four 0.14-cm diameters, 5-cm long Nitinol wires clamped down on one end and coupled with wind-up gears on the other. See Figure 10. Initially, two of the wires were twisted 400° and the others were free from strain. The annealed shape was a straight wire. Therefore, when the twisted wires are heated to transformation temperature, they will recover to their memory (i.e., untwisted configuration). Upon recovery they in turn will wind the two cool martensitic wires while producing an output torque on the shaft clamped to one of the wires. Now the other two wires are twisted and once heated above transformation temperature they will recover, twisting the two cool wires and driving the output shaft with a torque of 0.58 Nm. In this manner, repeatable power is produced in both directions. Output torque is a function of wire diameter, and the angle of twist is a function of wire length. The module could have been made shorter with the same output torque but reduced output angular rotation.

For demonstration purposed, the wires were heated electrically using a 2V rechargable, wet call, but any energy source could power the module if it could heat the wire above 80°C.

CONCLUSIONS

A wide range of applications for Nitinol materials appears to exist in a variety of structural and mechanical devices (Figure 11). For space systems applications, the potential of directly using environmental thermal energy to actuate required mechanical motions is attractive.

The material is basically metallic and should exhibit excellent resistance to hard vacuum, temperatures extremes, and radiation.

Further experimental work in characterizing and controlling the thermomechanical properties of Nitinol is required to permit the design and construction of reliable space hardware.

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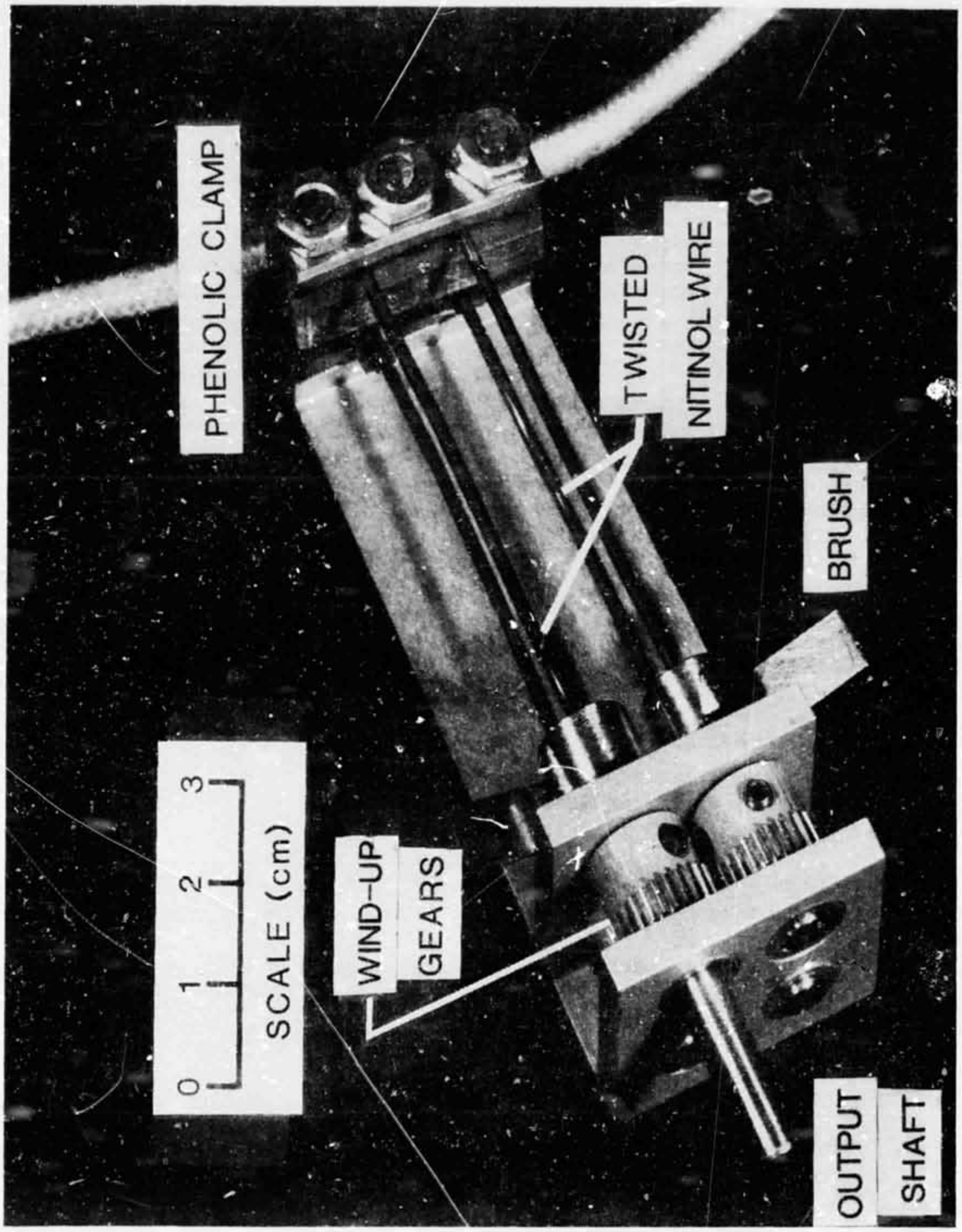

Figure 10. Thermally Activated Power Module

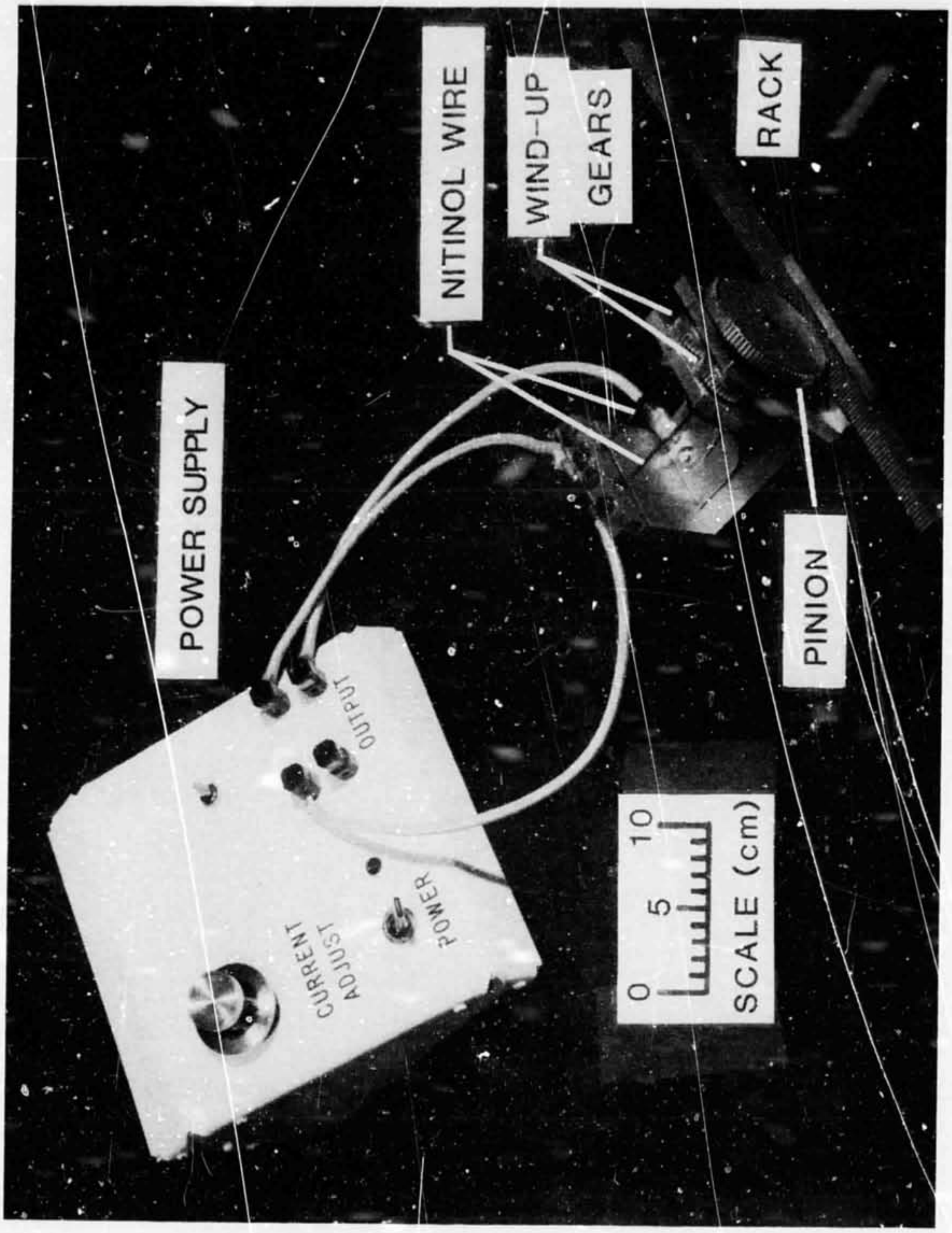

Figure 11. Linear Output Power Module