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YO-YO DESPIN MECHANISMS

By Kenneth S. Bush

NASA Langley Research Center
Langley Station, Hampton, Va.

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I. INTRODUCTION

Spin stabilization has proven very reliable in maintaining angular orientation of the last stages of vehicles used for injection of spacecraft into orbit or for maintaining acceptable payload trim angles of ballistic probes. Mission or experiment criteria, however, often require a reduction in the initial spin rate to a value lower than that required for stabilization.

Spin reduction has been accomplished by such devices as "retro" jets utilizing an active sensing system, fixed impulse despin motors, or a yo-yo despin system. The yo-yo despin system, first proposed by the Jet Propulsion Laboratory of the California Institute of Technology, reference 1, consists of two pieces of cables with weight on the ends. The release of the weights and cables from the spinning spacecraft discards sufficient momentum to reduce the spin to the desired value. This so-called conventional yo-yo despin system has been utilized in many space applications. Modified versions of the simple yo-yo, such as a two-stage despin system, provide advantages such as increased accuracy over the single-stage system but not without added complexity. The latest version utilized at the Langley Research Center is a "stretch" yo-yo which employs tension springs, cables, and weights to partially compensate for errors in initial spin rate and physical constants existing at the time of initiation of the despin system. The stretch yo-yo system was conceived by Mr. Henry J. Cornille of Goddard Space Flight Center, reference 2, with analytical theory reported by Dr. Joseph V. Fedor, reference 3.

II. FUNDAMENTAL PRINCIPLE OF YO-YO DESPIN

The principle of yo-yo despin is illustrated in figure 1 and shows the various phases of operation. Phase I takes place while the weight and cable are tangent to the cylindrical drum. In general, it is during this phase that the major portion of energy is transferred. Phase II takes place while the weight and cable rotate on an arc about the point of attachment. Weight release is usually at a point approximating a position radially in line with an element of radius. Figure 2 shows a stretch yo-yo with the same basic features of the conventional system except a spring is used as a portion of the cable.

The kinetic energy of the rotating body is transferred to the weight and cable during transition of the weight from its initial position to the release point of the cable from the body. At the time of release the required amount of momentum has been transferred to the yo weight and cable which is discarded at time of release. On initiation of the initial event (yo-weight movement) the operation is self-sustaining and progresses until the despin operation is completed.

The yo-yo system is a very simple means of accomplishing spacecraft despin, is mechanically simple, and uses only basic scientific principles in its operation.

The basic theory of the yo-yo system is that of the conservation of energy and momentum and is illustrated by the following equation:

$$T = \frac{1}{2} I\dot{\phi}^2 + \frac{1}{2} M\left(\dot{x}^2 + \dot{y}^2\right)$$

where

T	total kinetic energy
$\dot{\phi}$	spin rate
I	moment of inertia of spinning body about the spin axis
M	total mass of both weights
$\dot{x}$	velocity of yo weight in x-direction
$\dot{y}$	velocity of yo weight in y-direction

III. SYSTEM SELECTION

The selection of the type of despin system must be considered with regard to the specific requirements of each application. The three systems discussed in this paper are listed below with salient characteristics indicated.

A. Single-Stage (Rigid) Yo-Yo System:

Simplicity of the single-stage system and associated reliability dictate use when spacecraft final spin rate is to be zero and accurate prediction of moment of inertia about the spin axis is possible. If despin requirements are not exacting, this system should also be considered for despin to intermediate spin rates.

B. Two-Stage Yo-Yo Despin System:

The two-stage system has application in meeting more exacting final despin rates. The despin may be zero or an intermediate rate. Reduction in spin rate per stage results in a large decrease in percentage of error in the final spin rate.

C. Stretch Yo-Yo Despin System:

The stretch yo-yo is an adaptive system which partially compensates for errors in both initial spin and moment of inertia. This system is capable of yielding the most precise despun conditions; however, design complexity and system calibration dictate close examination of the capabilities of the other despin systems.

IV. TYPICAL DESPIN SYSTEMS

A. Single-Stage Yo-Yo Despin System:

A system representative of a single-stage yo-yo despin was designed, qualified, and flight tested on a sounding rocket program.

1. Design criteria -

The system was required to reduce the spin rate of the payload - expended solid rocket motor combination from approximately 270 rpm to zero ±6 rpm. The angular deceleration was to be minimized.

2. System description -

The single-stage yo-yo shown in figure 3 was incorporated in the adapter section between the payload and the last stage of the rocket vehicle. The experiment requirement for low angular deceleration was achieved by the use of three complete wraps of the yo-yo cables. The time of despin can be related directly to initial spin rate and cable length, that is, the longer the cable the greater the despin time for a given initial spin rate. The system as initially designed used separate pyrotechnic release mechanisms to free the yo weights. During the first spacecraft mission one yo weight failed to release and prevented proper functioning of the system. The system was modified to incorporate a cable to connect the two yo weights. The connecting cable passed through a tubular guide and passed over the anvils of two pyrotechnic cable cutters. The yo weights were retained against hollow conical seats and had provisions for preloading the connecting cable. Preload was applied to the connecting cable by jack screws bearing against swage fittings which were applied after passing the connecting cable through the weights. Functioning of either cutter severed the cable and provided simultaneous freeing of the weights. The cable, weight, and one-half of the cut cable are shown in figure 4.

3. Design parameters -

a. Roll inertia, 3.83 slug-foot^2

b. Yo weight (each), 84 grams (includes cable fittings)

c. Drum radius, 10 inches

d. Cable length, 15.71 feet

4. Results -

a. Development tests were conducted at the Langley Research Center in the 60-foot-diameter vacuum sphere at reduced pressure to negate aerodynamic effects. The results of five tests are tabulated below.

Test	1	2	3	4	5
Initial spin rate, rpm	287.0	265	250	277.8	271.2
Final spin rate, rpm	0.09	0.20	2.61	1.14	0.84
Time to despin (time to second cable release)	0.733	0.789	0.750	0.742	0.771
Time between release of cables	-----	+0.0009	-0.0096	-0.005	+0.028

b. Flight tests were conducted utilizing the above despin system on a Shotput Rounding rocket and a Scout Vehicle-San Marco Payload. The Shotput final despin rate was 0.1 rpm and the Scout Payload was despun to within the design criteria of ±6 rpm.

5. Summary -

The adequacy of the single-stage yo-yo system for the application cited can be attributed to two major factors.

a. The system is insensitive to initial spin rate if the final despin rate is zero. Systems designed for final spin rates other than zero would reflect a percentage of error in the final spin equal to the percentage of error in the initial spin.

b. The predicted moment of inertia of the burned-out rocket motor and payload combination was determined by experimental measurement utilizing a rocket motor available from a ground firing test. The close simulation of the moment of inertia with the expended flight rocket motors was extremely fortuitous.

B. Two-Stage Yo-Yo Despin System:

A system representative of this type of despin was designed for a NASA Langley Research Center flight project by the Fairchild Stratos Corporation.

1. Design criteria -

The system was required to despin the payload, expended last rocket stage, and the vehicle shroud combination from an initial spin of 600 rpm to effectively zero rpm.

2. System description -

The two-stage despin system is shown in figure 5 and was designed to despin the spacecraft from 600 to 60 rpm during the functioning of the first set of yo-yo weights. The second yo-yo system reduced the spin rate from 60 to effectively zero rpm. Accurate prediction of the roll inertia of the spinning bodies was not possible due to mass uncertainties in the burned-out rocket motor, the staging of despin permits closer control of the final spin rate. The percent error in moment of inertia is reflected as a percent error in the spin rate after each yo-yo stage functions. By using the two-stage system the error in final spin rate can be greatly reduced. The system as shown is recessed into the shroud with the heat shield not shown. The yo weights of each system are retained in position by means of a circumferential cable passing through redundant cable cutters diametrically opposite one another. A fitting to permit preloading is part of each restraining cable assembly. The first-stage yo-yo is sequenced through an onboard programer. The cable cutters are fired thereby cutting the restraining cable releasing the first-stage weights. The yo-yo cable attach fittings incorporate a boss that actuates a microswitch at time of cable release. This switch closure fires a second set of cable cutters thus releasing the weights of the yo-yo second stage to complete the despin sequence. The release of energy stored in the preloaded restraining cables assures freedom from fouling and provides simultaneous release of the yo weights.

3. Design parameters -

   a. Roll inertia (first-stage despin), 7.17 slug-foot^2

   b. Roll inertia (second-stage despin), 7.01 slug-foot^2

   c. Yo weight (each)(first stage), 2.15 pounds

   d. Yo weight (each)(second stage), 2.91 pounds

   e. Drum radius, 0.937 foot

4. Results -

   a. The first-stage despin was tested at Fairchild Stratos on a spin table giving a reduction from 597 to 60.26 rpm. The second-stage despin was tested in the LRC 60-foot vacuum sphere at a simulated altitude of

150,000 feet. This test was performed in free fall reducing the spin from 70 to 1.4 rpm.

b. A subsequent rocket launch was conducted using this yo-yo despin system resulting in a residual spin rate of approximately 1/6 rpm.

5. Summary -

The adequacy of the two-stage yo-yo despin system was verified for the application cited. Sufficient insensitivity to errors in predicted initial spin rate and moment of inertia was demonstrated in meeting the required final spin rate.

C. Stretch Yo-Yo Despin System:

A system representative of this type of despin was designed for a flight program for the NASA Langley Research Center by Honeywell Incorporated.

1. Design criteria -

The system was required to despin the payload and the expended last-stage rocket motor from an initial spin rate of 312 rpm ± 66 rpm to a final spin rate of 45 rpm ± 6 rpm. The system was to accommodate ±5-percent variation in roll inertia and ±21-percent variation in initial spin rate.

2. Description of systems -

The stretch despin system is shown in figure 6. One yo weight, spring, cable, and end fitting are shown in figure 7. The selection of the stretch despin concept was dictated by the requirement that the system produces the desired final spin rate with significant variations in initial spin rate (±15 percent) and in roll inertia (±5 percent). During normal operation the spring is expected to stretch a predicted amount. If the initial spin rate is greater or lesser than nominal, the spring will elongate more or less than normal during yo-yo operation and produce a final spin rate near the design value. The stretch yo-yo system is also relatively insensitive to departure from the predicted or design moment of inertia. The weight retention and release system utilized dual cable cutters to sever a cable to free both weights simultaneously. As shown in figure 7, the weight has a retaining lip about which the weight rotates on release. The release system consists of an interconnecting cable with attached levers at both ends. Applying tension in the connecting cable rotates the levers against release pins that retain the weight in position. The release pins are spring loaded and upon severing the connecting cable the pins are withdrawn from the weights. The yo-yo system is free to function. Release of the yo weights, springs, and cables from the despun spacecraft occurs when the cable is radially in line with an element of radius.

3. Design parameters -

   a. Roll inertia, 8.12 slug-foot^2

   b. Total yo weight, 7.95 lb (includes 60 percent of spring weight)

   c. Spring constant, 522 lb per ft

   d. Spring stretch, 0.5 foot

   e. Spring preload, 15 lb

4. Results -

   a. Development tests of the stretch yo-yo system were conducted at Honeywell, Incorporated. Three tests were conducted to establish the adaptiveness of the stretch yo-yo to variations in initial spin. Figure 8 shows the results of these tests which verified the performance of the system within the design criteria.

   b. Two flight missions of the Scanner spacecraft were flown, and in both cases the despin system operated within the design tolerances.

5. Summary -

It has been demonstrated that a stretch yo-yo despin system is adaptive to spacecraft despin applications which require a system to be self-corrective in providing a low percentage error in the final despin rate with a high percentage error in the initial spin rate. The capability of the systems to afford a low error final spin rate is not affected drastically by in-flight variations in the predicted spacecraft roll moment of inertia.

V. CONCLUSION

This paper has presented some of the fundamental principles and performances of three yo-yo type despin systems. Flight tests of each type have demonstrated that the equations set forth in the reference documents are sound and will permit design of a simple mechanism for despinning rotating bodies in a space environment. These systems can be constructed of basic materials and fabricated by state-of-the-art techniques. The designer is afforded great latitude in the selection of the type of despin system and flexibility in the detailed design of the system and components. Straightforward engineering computations complemented by good design practices should provide a successful despin system.

REFERENCES

1. Eide, Donald G.; and Vaughan, Chester A.: "Equations of Motion and Design Criteria for the Despin of a Vehicle by the Radial Release of Weights and Cables of Finite Mass." NASA TN D-1012, 1962, p. 49.

2. Carnille, H. J., Jr.: "A Method of Accurately Reducing the Spin Rate of Rotating Spacecraft." NASA TN D-1420, 1962.

3. Fedor, J. V.: "Analytical Theory of the Stretch Yo-Yo For Despin of Satellites." NASA TN D-1676, 1963.

4. Fedor, J. V.: "Theory and Design Curves for a Yo-Yo Despin Mechanism for Satellites." NASA TN D-708, 1961.

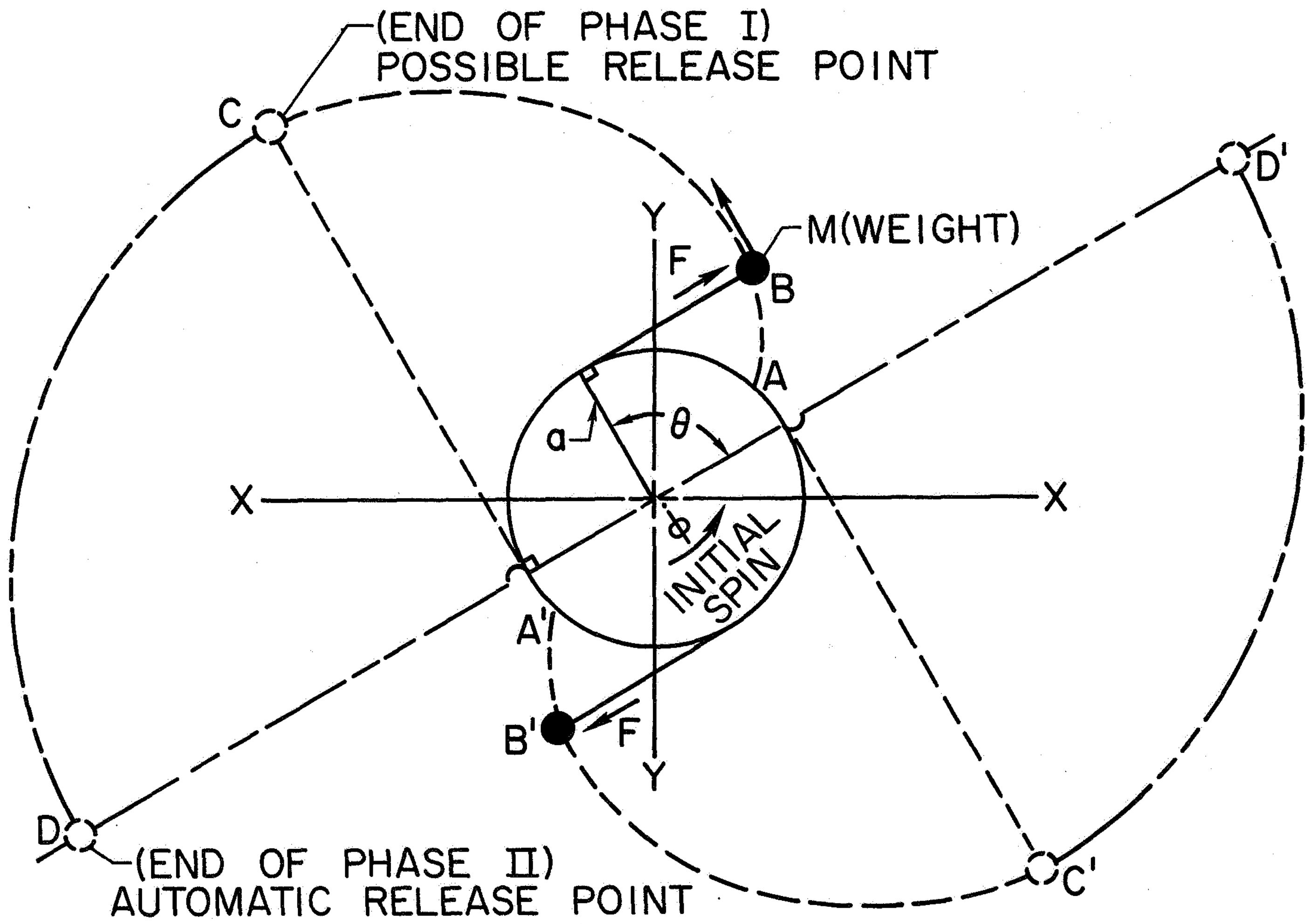

Figure 1.- Yo-yo operation.

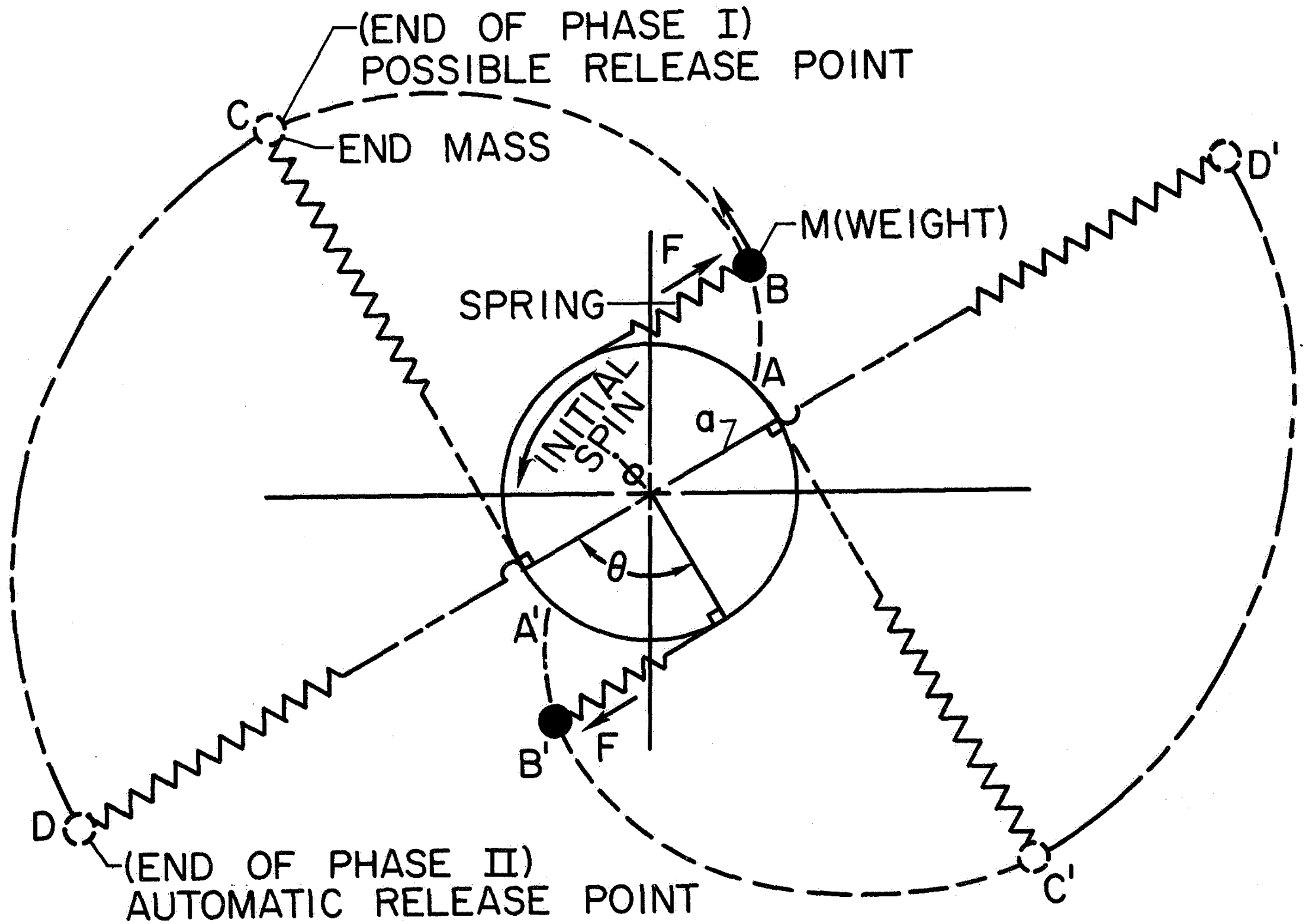

Figure 2.- Stretch yo-yo operation.

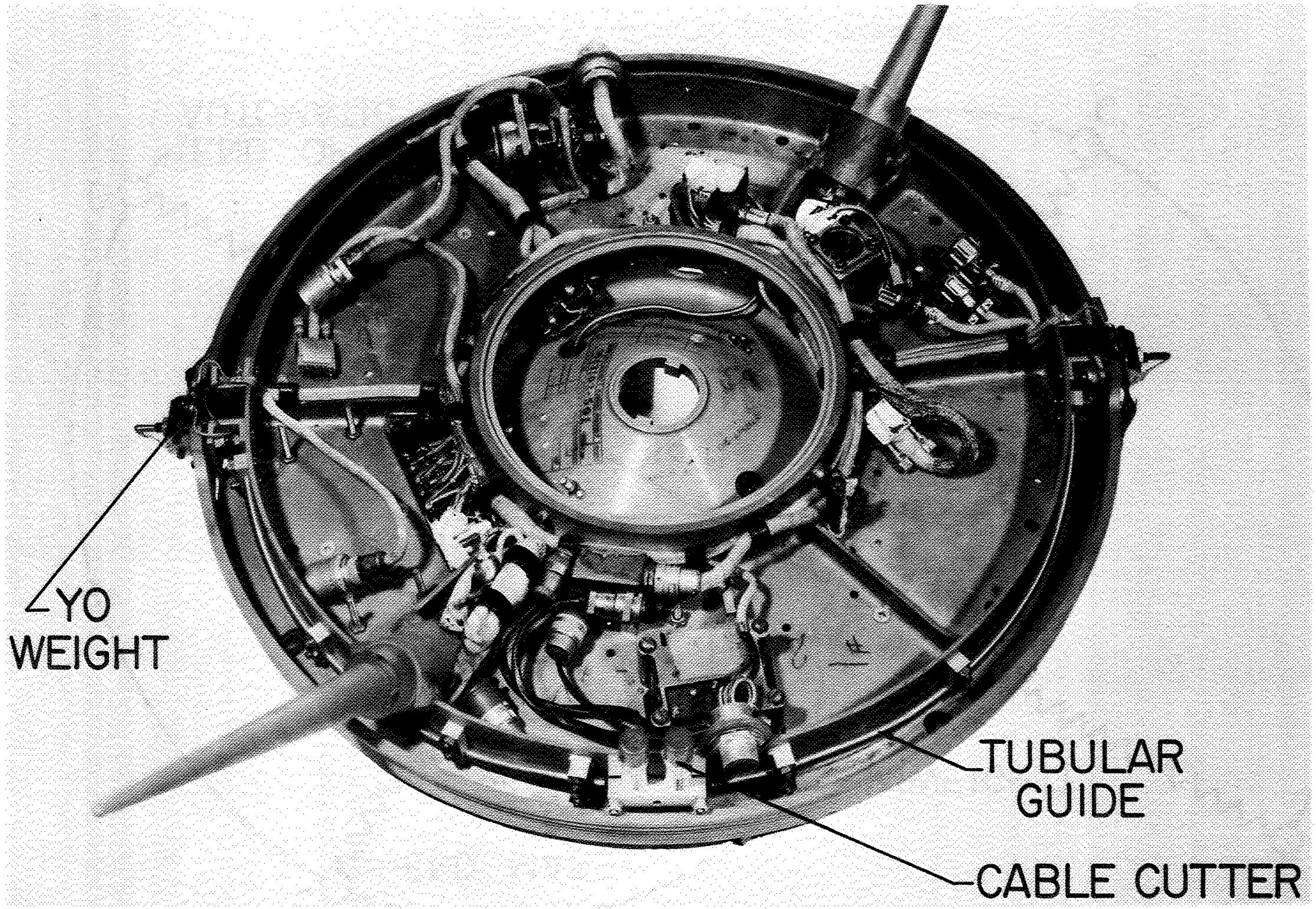

Figure 3.- Single-stage yo-yo despin.

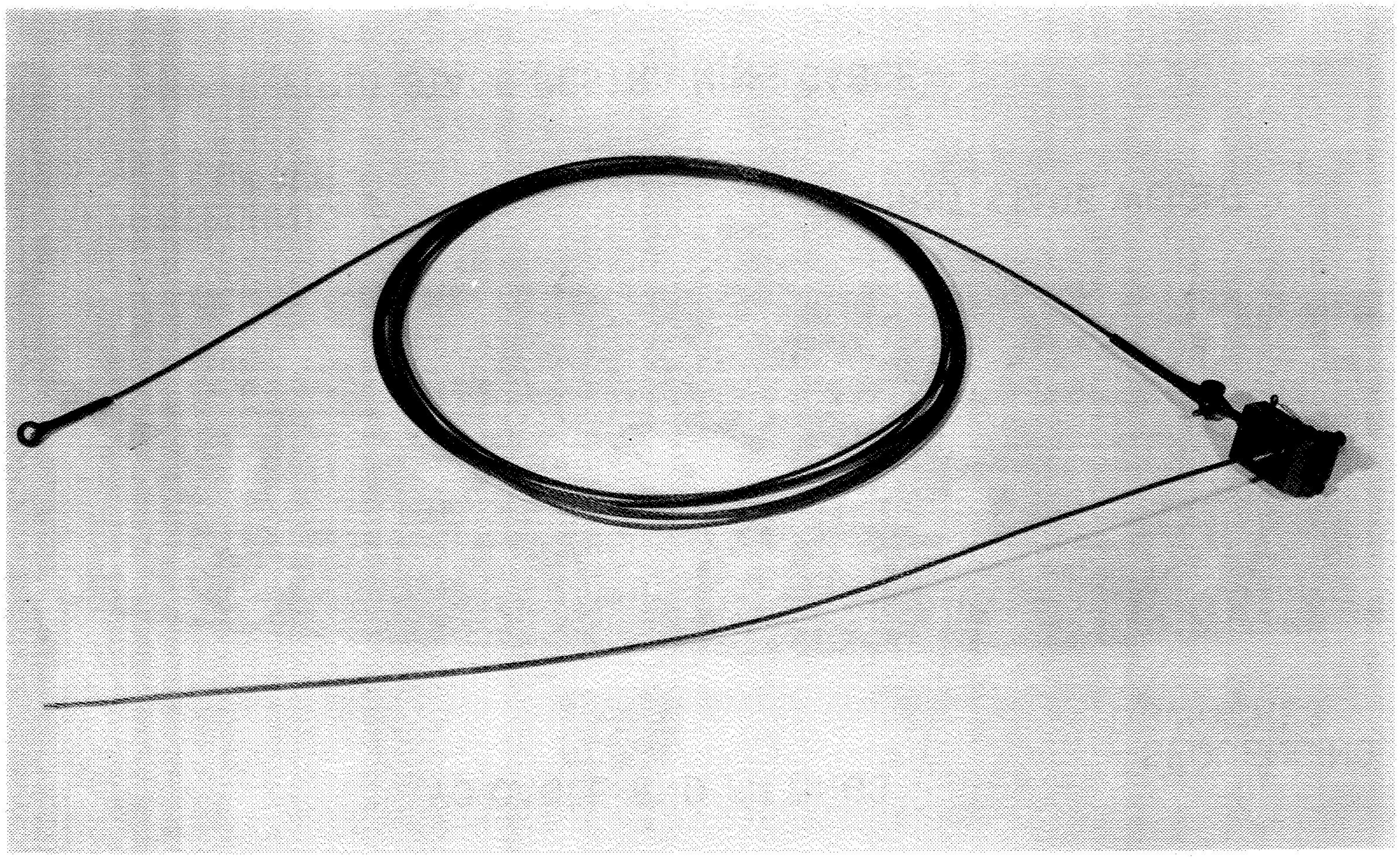

Figure 4.- Single-stage weight and cables.

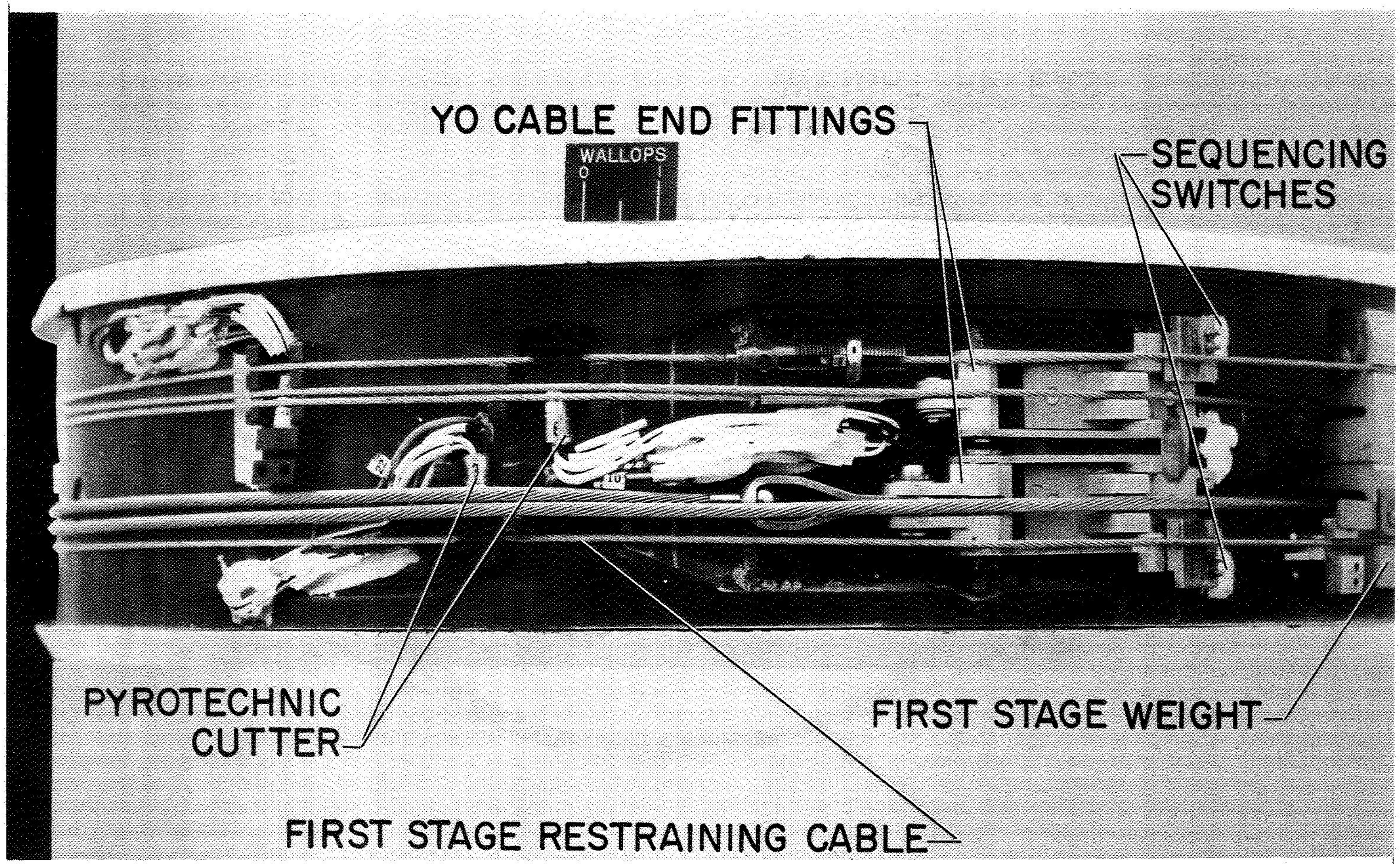

Figure 5.- Two-stage yo-yo despin system.

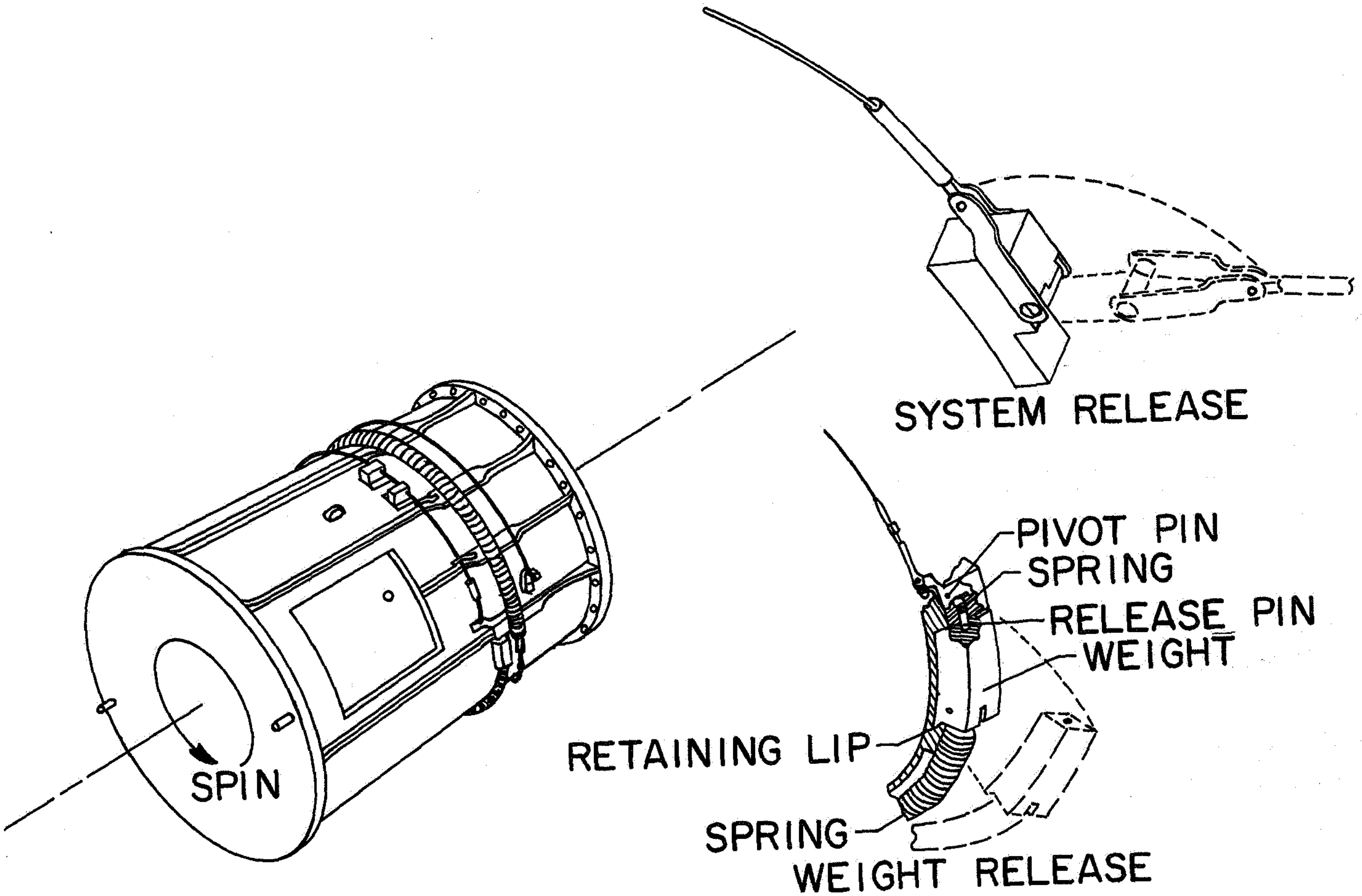

Figure 6.- Stretch yo-yo despin system.

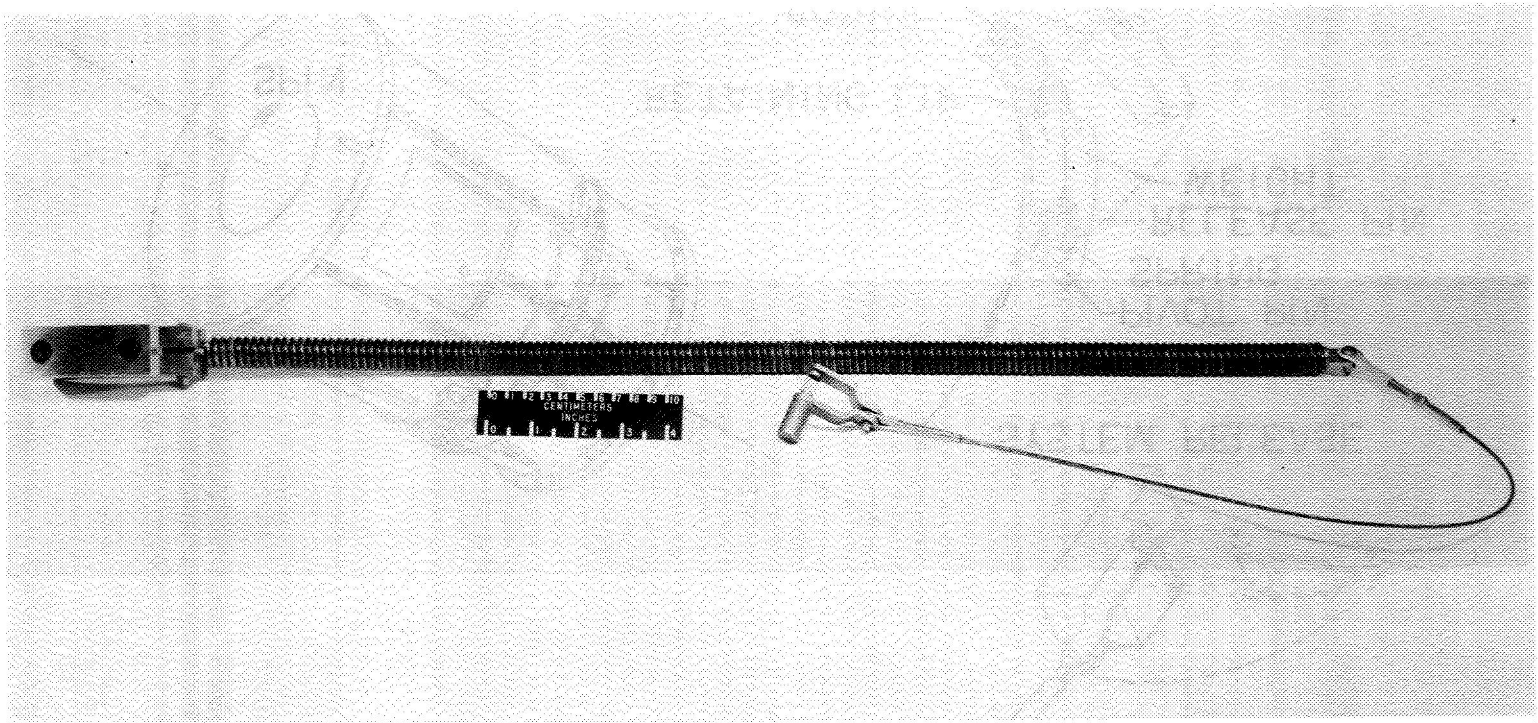

Figure 7.- Stretch yo-yo.

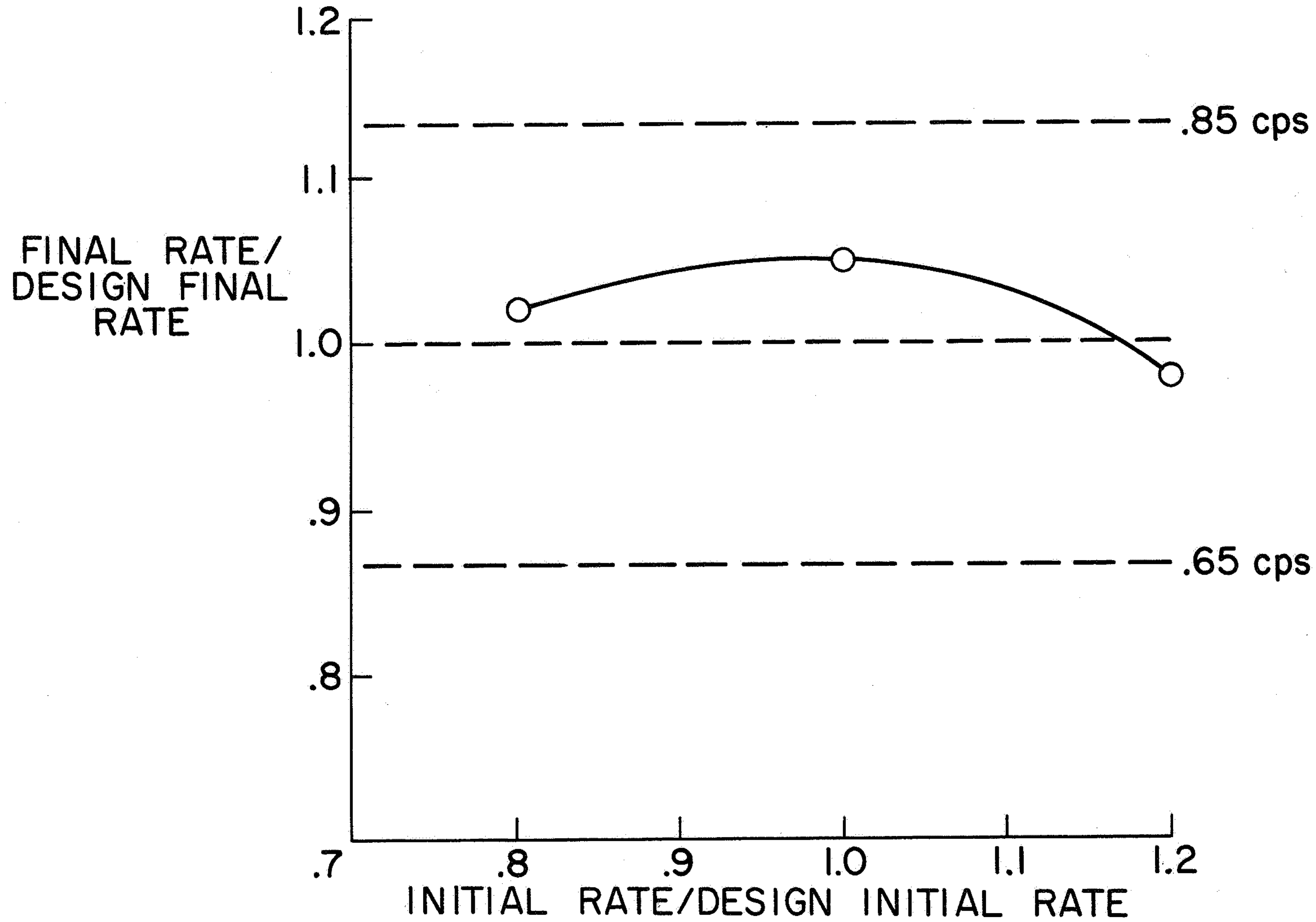

Figure 8.- Stretch yo-yo despin test results.

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