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RESEARCH MEMORANDUM

INVESTIGATION OF EFFECT OF REDUCTION OF VALVE FRICTION IN A POWER CONTROL SYSTEM BY USE OF A VIBRATOR

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WASHINGTON

July 28, 1955

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INVESTIGATION OF EFFECT OF REDUCTION OF VALVE FRICTION IN A POWER CONTROL SYSTEM BY USE OF A VIBRATOR

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SUMMARY

Brief ground tests were made to determine the effect of reduction of valve friction in a power control system of a fighter airplane by use of a vibrator. The airplane response to stabilizer deflection was simulated by the movement of a spring-mass-dashpot system, the motion of which was made visible to the pilot by means of a spot of light projected on a screen. In the tests the pilot attempted to move the light spot rapidly and accurately from one horizontal line to another horizontal line marked on the screen.

The response characteristics of the original system were considered relatively good, though some variations in behavior in different runs were recorded that were attributed to variations in valve friction. In order to obtain a consistently adverse condition to determine the effects of the vibrator, friction was added to the control valve. A vibrator, consisting of a pair of contra-rotating eccentric weights, was then attached to the valve push rod and tests were made with the vibrator running at various speeds.

The results indicate that the vibrator was an effective means of overcoming the adverse effects of valve friction on the control characteristics. The use of a vibrator may allow relaxation of required tolerances in manufacture of valves.

INTRODUCTION

Flight tests of airplanes with hydraulic power control systems have shown that friction in the control valve causes extremely undesirable effects on the handling qualities (ref. 1). Attempts have been made to establish a criterion for the maximum allowable value of valve friction, but these attempts have not yielded conclusive results. In general, any amount of valve friction, no matter how small, appears to have more or less adverse effects. Serious efforts have been made by designers of power control systems to reduce valve friction by ingenious arrangements of seals and very precise machining. In spite of these efforts, however, reduction of friction of the control valve to an acceptable value while still maintaining a high pressure hydraulic system free of leakage has proved extremely difficult.

In the application of hydraulic servomechanisms to the control of gun turrets, a vibrator has sometimes been employed to reduce the adverse effects of friction in the control valve. So far as is known, however, such a device has not been employed in power control systems used in airplanes. For this reason, a brief ground investigation was made to determine what improvements might result from the use of a vibrator on the power control system in an airplane.

METHODS OF REDUCING CONTROL VALVE FRICTION

The type of control valve used in many power control systems for airplanes consists of a cylindrical spool which incorporates the necessary lands and operates in a sleeve. In earlier designs the spool was equipped with rubber "O" ring seals. These rubber "O" ring seals, though effective in preventing leakage, proved objectionable from the standpoint of friction. Usually the force required at the valve spool to move the valve was of the order of several pounds and the friction had the further objectionable characteristic of requiring greater force to start the motion than to continue it. Some later designs of power control systems have avoided the rubber "O" rings and have employed an accurately lapped spool to reduce leakage as much as possible. Such leakage as still occurs may be collected in a labyrinth and returned to the reservoir through the return line. While valves of this type may have very low friction under ideal conditions, tests have shown that sticking may occur because of various factors. As shown in reference 2, hydraulic forces on the valve spool may cause it to seek a position in which it rubs against one side of the cylinder. In this condition, sticking of the highly polished spool surface to the valve may occur. This tendency for the valve to stick may be further aggravated by the presence of dirt in the hydraulic fluid (ref. 3). Further refinement in the design of the valve spool such as the machining of a very slight taper on the lands or the use of grooves to equalize the pressure around the spool may be employed in an effort to offset the sticking tendencies. While these methods are possibly effective, they increase the difficulty of manufacture and the valve still may show erratic variations of friction in service.

The use of a vibrator consisting, for example, of a small eccentric weight driven by an electric motor might be used to keep the valve spool in continuous motion so that no problem of static friction would exist.

Vibrators of this type have frequently been used in instrument applications and also, as noted previously, in hydraulic control systems. For example, the advantages of a vibrator in increasing the static accuracy of a gun turret hydraulic control system are described in reference 4. In this case, the vibration (described as "dither") was applied to the pilot valve of a two-stage servomechanism. The report states "the addition of dither . . . to the oil gear is responsible for a tremendous increase in the static accuracy . . . . Dither reduces the force required to drive the pilot valve by approximately ten times and undoubtedly reduces friction in the differential synchro bearings.

"The use of dither allows standard running fits to be used for all pins and levers in the stroke control and also permits the use of a 0.006 in. nominal overlap in the pilot valve with corresponding tolerances on the pilot land widths, spacing between lands, sleeve port diameters, and sleeve port spacing."

The use of a vibrator to reduce valve friction in an airplane control system is also suggested in reference 5, though no data are presented to show its effect.

Another method to remove the static friction of the valve would be to continually rotate the valve spool while the system is in operation (ref. 6). The use of a vibrator was most convenient for the investigation described herein.

APPARATUS AND TESTS

Ground tests were made on the power control system which operates the longitudinal control (all-moving stabilizer) of a fighter airplane. For these tests the stabilizer was linked to a spring-mass-dashpot system in the manner described in reference 1 and shown in figure 1. The motion of this system was made visible to the pilot by means of a spot of light projected on a screen beside the cockpit such that the motion of this light spot in response to longitudinal control deflection approximated the normal acceleration response of the airplane. In the tests the pilot attempted to rapidly and accurately move the light spot from one horizontal line to another higher horizontal line marked on the screen. The tests described in reference 1 have shown that difficulty in accurately moving the spot of light in this manner is indicative that difficulty will be encountered in flight, particularly in precision flight tasks such as tracking or formation flying.

A diagram showing the essential parts of the power control system is shown in figure 2. The valve of the system tested had a single "O" ring seal at each end of the valve push rod. These seals were not subjected to full system pressure, however. A chamber vented to the return line was located inside each seal to collect leakage flow past the lapped valve rod. The "O" rings therefore acted mainly as wipers to prevent residual leakage and to exclude dirt. The small piston attached directly to the valve was provided to add damping to the valve motion for prevention of chatter. The ratio between deflection of the stick grip and deflection of the valve, stabilizer fixed, was 4.6:1. The ratio between deflection of the stick grip and stabilizer angle, valve fixed, was 0.84 inch per degree. For the vibrator tests, a vibrator consisting of a pair of contra-rotating eccentric weights driven through a flexible cable by a variable speed motor was attached directly to the valve push rod. The mass unbalance of the vibrator was 0.208 inch-pound. The method of mounting the vibrator is indicated in figure 2. For some tests additional valve friction was introduced by means of a flat spring bearing on the side of the valve push rod. During the tests, instrument records were obtained of the stabilizer position and the position of the mass-spring system which simulated the airplane response.

The investigation was conducted by having several pilots record a series of simulated pull-ups to various values of normal acceleration and with various conditions of valve friction and vibrator speed. All the pilots were experienced in flying high-speed fighter airplanes and had previously conducted research on power control systems.

RESULTS AND DISCUSSION

The results of the investigation are based on the records of simulated pull-ups and on the pilots opinions of the precision of control. In general, differences noted between the conditions tested were quite noticeable to the pilots, and their opinions were in good agreement with the conclusions drawn from the recorded time histories. Some differences were observed, of course, between various runs made with a given control configuration, but the runs shown in the report were selected as typical of the results obtained in each condition.

The results of the investigation are shown as time histories of simulated abrupt pull-ups in figures 3 and 4. Time histories of pull-ups with the original airplane system are shown in figure 3. The characteristics of the power control system in the original airplane varied in an unexplained manner from time to time during the course of the tests, which extended over a period of four days. When the system was operating at its best, very little effect of valve friction was apparent as shown by the ability to make a very smooth and rapid pull-up such as is shown in figure 3(a). At other times, however, an appreciable amount of valve friction was apparent which interfered with the pilot's ability to make the desired control motions. A record taken in this condition is shown in figure 3(b). For the conditions of speed and altitude simulated in these tests the stick motion per g of the test airplane was relatively large. This large stick motion was obtained by the use of a linkage-ratio changer in the control system which in normal airplane operation doubles the stick motion for a given stabilizer deflection when the landing gear is raised. In addition, the airplane possessed a relatively large amount of static longitudinal stability. The large stick motion required in maneuvers alleviated the adverse effects of valve friction and prevented any unstable response of the combination of pilot and simulated airplane. Furthermore, throughout the tests, the control system was equipped with a feel device consisting of a centering spring and viscous damper, which had been developed previously by the manufacturer to improve, as much as possible, the controllability of the airplane during precise maneuvers.

In general, it was felt that the characteristics of the power control system tested were relatively good. Nevertheless, in cases where friction was present in the valve, the pilots felt that difficulty would be experienced in accurately tracking a target. In order to obtain a consistently adverse condition to determine the effects of the vibrator, friction was added to the control valve by means of a flat spring bearing on the valve push rod and the results obtained in this condition are shown in figure 4(a). Typical results obtained with this added friction in conjunction with the vibrator are shown in figure 4. Though the magnitude of the friction added was not measured, its value may be inferred to be about 5 pounds from the value of vibrator speed which was required to produce appreciable response of the control valve. The records shown in figure 4(b) correspond to a vibrator speed of 500 rpm or an alternating force on the valve of ±1.4 pounds. No vibration could be felt in the control system; nevertheless, some improvement in the characteristics of the response was observed as compared to the case of figure 4(a). This improvement is shown mainly by the shorter time required to reach the desired steady value of the response. At a vibrator speed of 1,000 rpm (fig. 4(c)) corresponding to an alternating force of ±5.6 pounds on the valve push rod, a very slight vibration was apparent at the control stick. This condition was considered to be optimum by the pilots. With a vibrator speed of 1,500 rpm (fig. 4(d)), corresponding to an alternating force of ±12.7 pounds, noticeable vibration was transmitted to the control stick. This vibration appeared to remove not only valve friction but also control friction throughout the control system linkage. The pilots felt that the system now behaved as a very frictionless control system, a condition which has been shown previously to be more undesirable than the one with a small amount of static friction on the control stick (ref. 1). In this condition, considerable attention was required to prevent making inadvertent small stick movement. This result is shown by the irregular character of the response in figure 4(d). This and other runs obtained in this condition showed, in general, that the irregularities had a shorter period than in the cases without the vibrator.

The characteristics of the control system with the vibrator but without added friction were investigated but records were not obtained because of instrument failure. The pilots comments indicated, however, that when the vibrator was operating the characteristics were the same whether or not friction was added to the valve. This result appears to indicate that the control characteristics would be relatively insensitive to changes in valve friction if a vibrator were used.

CONCLUDING REMARKS

The use of a vibrator on the control valve of a power control system has been shown to be an effective means of overcoming the adverse effects of valve friction on the control characteristics. In addition, the vibrator appears to make the system insensitive to reasonable variations in control valve friction. Since the action of the vibrator is to keep the valve in continual motion in order to eliminate the effects of static friction, other means of accomplishing this result such as the use of a continually rotating valve would very likely have similar effect. While valves of sufficiently low friction may, perhaps, be obtained by suitable design and the maintenance of sufficiently high standards of precision in manufacture and assembly, the use of a vibrator such as that tested would, perhaps, allow relaxing the required tolerances and thereby make the valves easier to manufacture. Failure of a vibrator of the type tested would not result in serious adverse effects on the controllability in normal flight but would merely cause the airplane to revert to a condition similar to that normally present in many existing high-speed fighter airplanes. On the other hand, provision of the vibrator might considerably improve the precision of flight during tactical maneuvers such as tracking.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., April 28, 1955.

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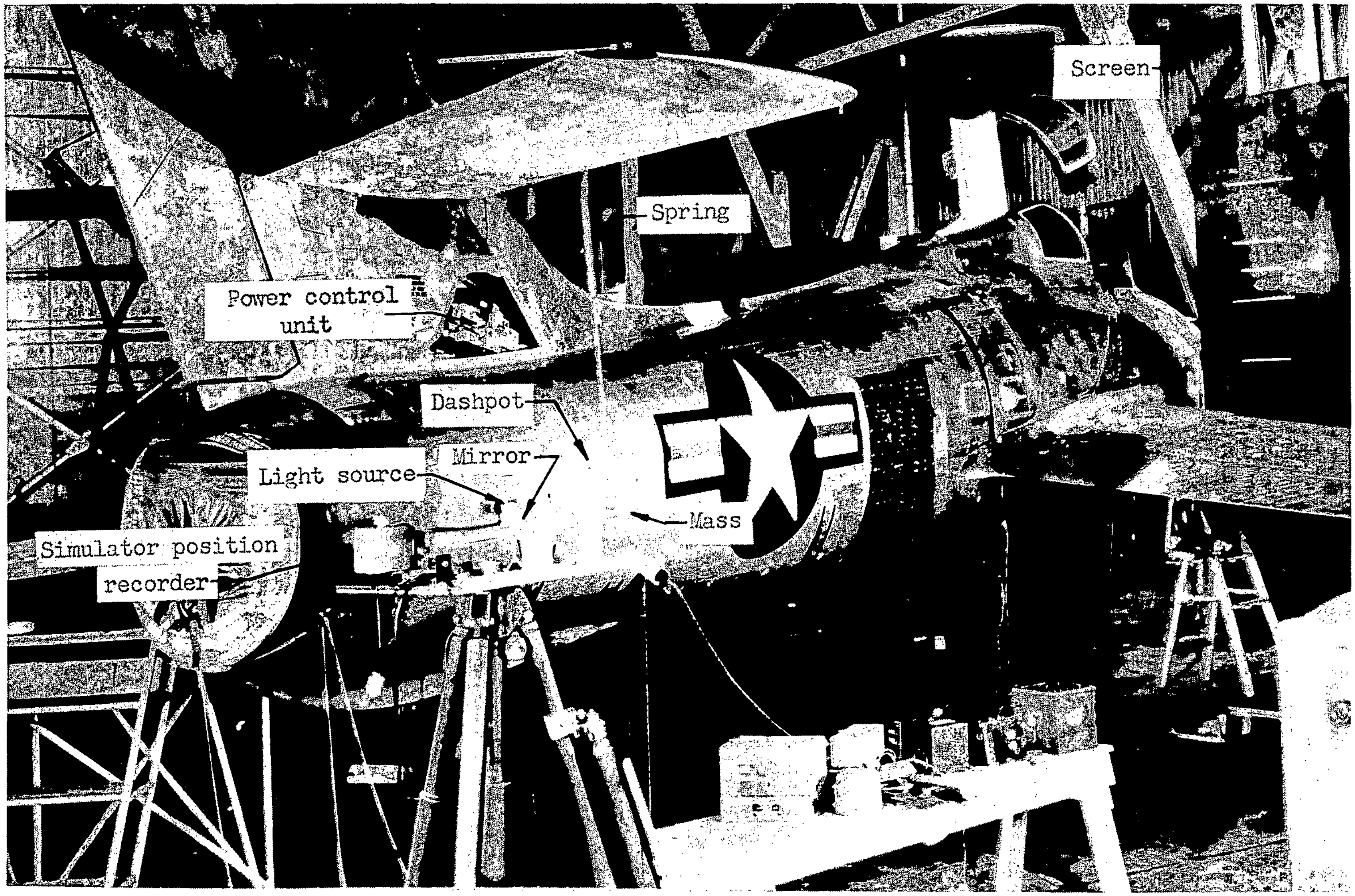

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Figure 1.- Photograph of airplane with equipment for tests of power control system.

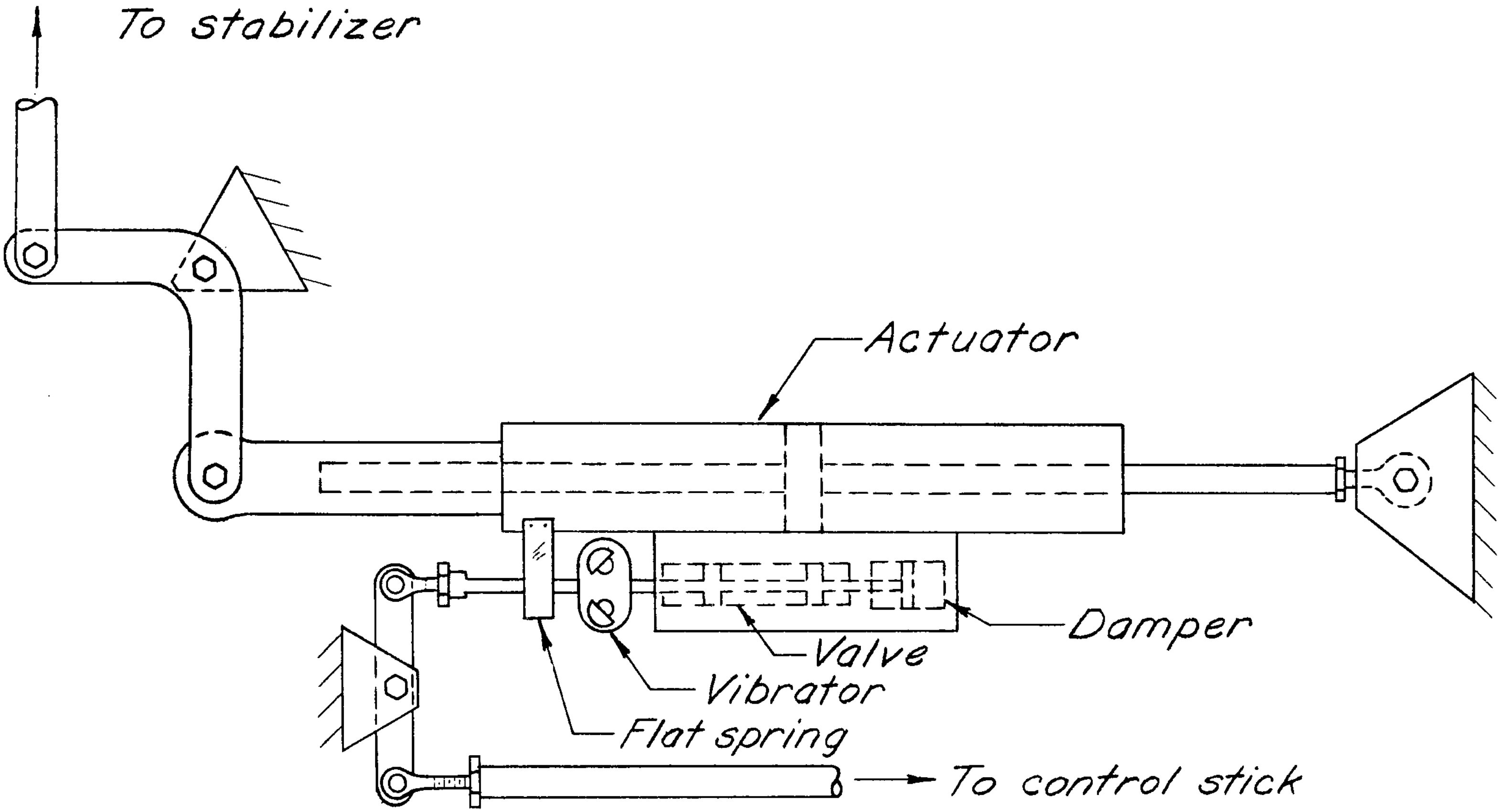
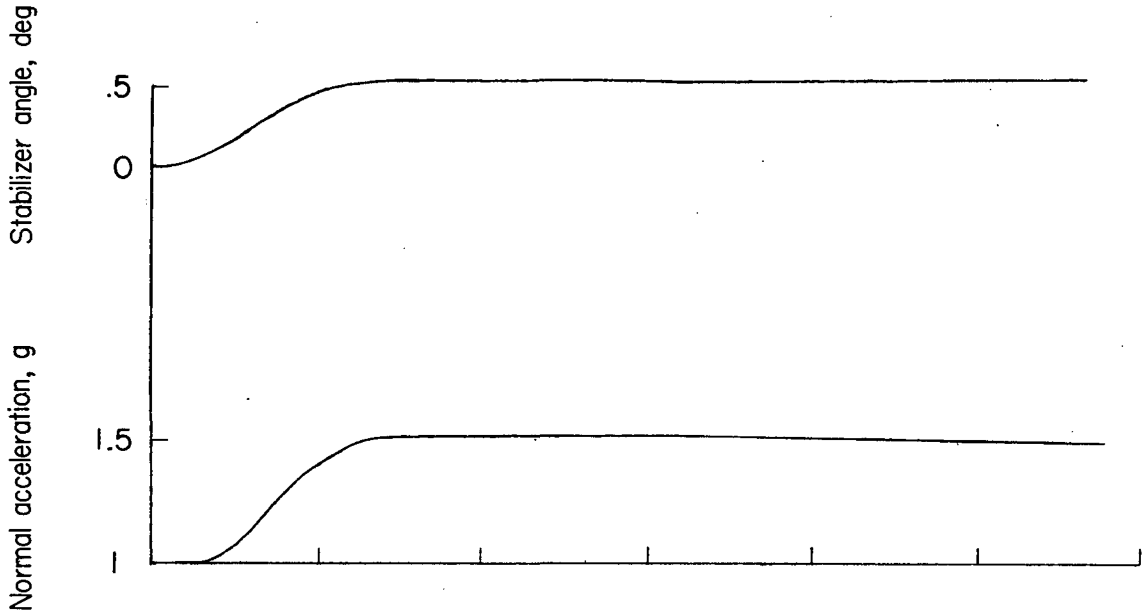
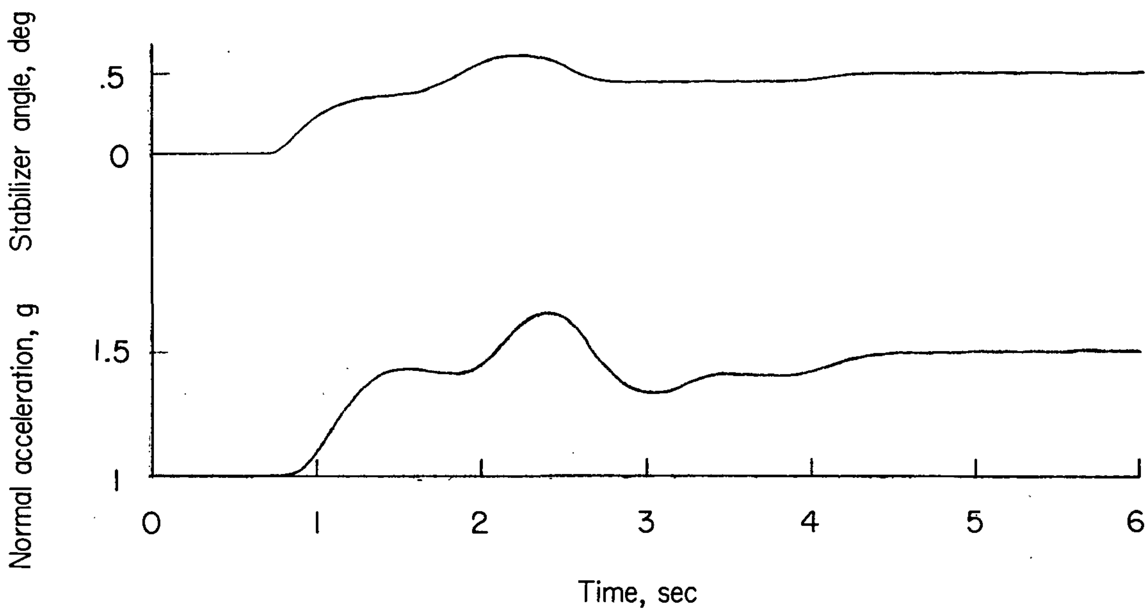


Figure 2.- Diagram of power control unit showing method of attaching vibrator.

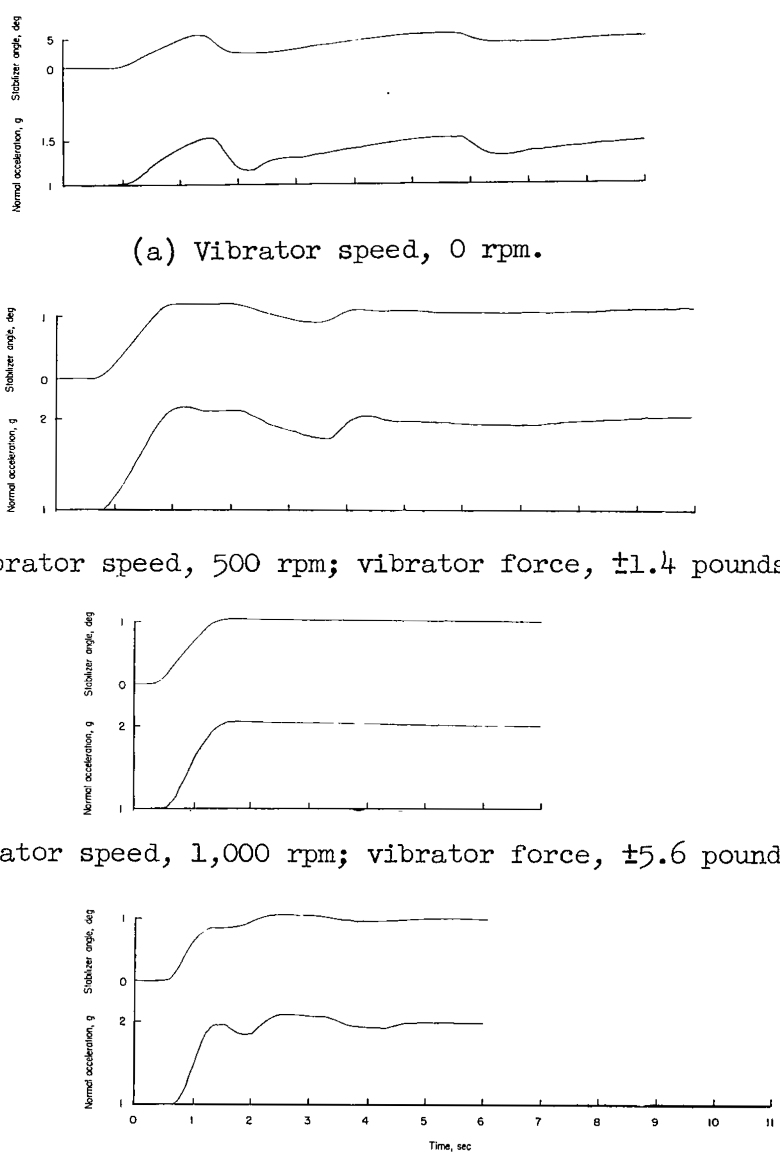


(a) System operating without apparent valve friction.



(b) System operating with appreciable valve friction.

Figure 3.- Time history of simulated pull-up maneuver with original control system.



(a) Vibrator speed, 0 rpm.

(b) Vibrator speed, 500 rpm; vibrator force, ±1.4 pounds.

(c) Vibrator speed, 1,000 rpm; vibrator force, ±5.6 pounds.

(d) Vibrator speed, 1,500 rpm; vibrator force, ±12.7 pounds.

Figure 4.- Time histories of simulated pull-up maneuvers with added friction and various vibrator speeds.