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An Electrodynamic Method of Exciting Servo-Tabs for Flight Flutter Testing

by

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ROYAL AIRCRAFT ESTABLISHMENT

AN ELECTRODYNAMIC METHOD OF EXCITING SERVO-TABS FOR FLIGHT FLUTTER TESTING

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SUMMARY

A detailed description is given of an electrodynamic method of exciting servo-tabs for flight flutter testing. Tests made to develop and establish the feasibility of the technique on a large aircraft with pure servo-tab controls are described. Some specimen flight records are shown.

It is considered that the system is useful for investigating tab flutter characteristics up to about 30 cycles per second, but that its main value lies in the excitation of aircraft structure modes at very low frequencies (below 3 c.p.s.) where it possesses a marked superiority over the mechanical inertia exciter.

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1 INTRODUCTION

During the past few years flight flutter testing has become established as an essential adjunct to theoretical calculations as a means of checking the flutter stability of new aircraft types during prototype flying. The two well known techniques of flight flutter testing are the "Amplitude Response" and the "Decaying Oscillation" technique[1]. Briefly, the former consists of the measurement at incremental airspeeds of the response of the aircraft structure to an artificial sinusoidal excitation force of varying frequency, and the latter consists of the measurement, again at incremental airspeeds, of the free rates of decay of the aircraft structure in its various natural modes, following the application of a transient exciting force (or the sudden removal of a sinusoidal exciting force). In both methods the results of the tests are extrapolated to higher airspeeds to predict flutter or excessively low damping conditions.

One of the chief problems associated with all present flight flutter testing techniques is that of obtaining sufficient excitation to produce structural amplitudes large compared with the normal aircraft vibrations arising from aerodynamic and engine exciting forces. For sinusoidal excitation the inertia exciter has been used with success on many flight flutter tests, but for very large aircraft with low flutter frequencies the out-of-balance moment required to produce adequate forces becomes excessive. For example, on a large bomber aircraft, an exciter weighing 280 lb with its drive motor etc., and having an out of balance moment of 365 lb in., failed to excite adequately a 2 cycles per second mode of oscillation of the tail unit. It is also difficult to produce a rapid stop on such large exciters when using the decaying oscillation technique.

The present paper describes fully an electrodynamic excitation system which was developed to excite low frequency modes on aircraft with pure servo tab controls. The exciter was used with success to apply relatively small oscillatory forces direct to the servo tabs, thereby inducing large aerodynamic forces on the aircraft main surfaces. Records obtained during the tests are shown in Figs.8 and 9.

2 DESCRIPTION OF AIRCRAFT

The aircraft on which the exciter was used was an Avro Lancaster Mk.7 N.X.676 with a modified control circuit. The relevant features of the modified aircraft are described in the following paragraphs.

Lancaster N.X.676, shown in Fig.1, was basically a standard Mk.7 aircraft, but the control rods were arranged to operate pure servo-tabs, instead of being connected directly to the main control surfaces. The main rudder control surfaces on the port and starboard sides were coupled together, as were the two elevator halves, but the ailerons could rotate independently of one another. Stops were fitted to limit the angular movement of each main control surface, and cockpit lights to give warning if the surfaces hit the stops. Because of the high sensitivity of this system to control rod forces, it was necessary to provide the pilot with spring "feel" and to reduce backlash and friction in the tab-control system to a minimum. In the case of the rudder circuit to which the exciter was attached, it became particularly necessary to reduce friction to a minimum to avoid wastage of exciter force and this was done by ensuring good bearing tolerances and by lubricating with thin anti-freeze oil. A fuller description of an identical control system is contained in Ref.2.

To cater for the electrical power supply requirements of the excitation system an additional Type 02 generator was fitted to the port outer engine.

3 DESCRIPTION OF EXCITER

The exciter was an electrodynamic moving coil device working on the "loudspeaker principle" i.e. it consisted of an armature whose coil was supplied with alternating current and which moved in a magnetic field produced by direct current field coils. It was therefore, fundamentally a force producing machine, the force being proportional to the D.C. field strength and to the armature current. Control of the force and frequency could therefore be obtained by varying the armature current and frequency only, the D.C. field being left at some pre-determined value.

Fig.2 shows a photograph of the main parts of the exciter.

The armature consists of a steel tube (A) approximately 2 ft long which is suitable for direct linking into the control rod system of the Lancaster. A soft iron sleeve (B) is mounted on to the tube to form part of the magnetic circuit, and the two armature coils (C) are wound on this sleeve.

The field coil (D) fits in the soft iron carcase (E) followed by the soft iron flanges (F) and the bearing housings (G).

The steel tube of the armature runs axially on the three ball bearing races (H) in each of the bearing housings and the armature is therefore placed in position during assembly of the other components. When completely assembled, air gaps exist between the inside diameters of the flanges (F) and the outside diameter of the sleeve (B). The complete magnetic circuit is axially through the carcase, radially through the flanges, and thence across the air gaps on to the armature sleeve. Consequently the complete field flux is concentrated in each of the air gaps and, in the working position, the armature coils are moving in this flux.

Fig.3 shows a photograph of the exciter installed in the aircraft. The function of the handwheel is that of moving the exciter body axially. This feature was necessary since the mean position-to-trim of the aircraft control circuit varied with the flight condition and it was necessary to adjust the exciter body in order to reposition the magnetic field air gaps over the armature coils after a change of trim.

Cooling air was fed to the exciter from ducts in the sides of the aircraft fuselage, and this made possible a considerable increase in armature current beyond the value permissible for the uncooled condition.

4 DESCRIPTION OF EXCITER POWER SUPPLY AND CONTROL SYSTEM

The complete exciter power supply and control circuit is shown in Fig.4. The left hand side of the circuit shows the specially installed Type 02, 24 volt generator on the port outer engine. In series with this generator is a 24 volt lead acid accumulator, and the nominal 48 volts total is applied to the two ends of a large fixed resistor capable of carrying the full exciter armature current (Fig.5). Twelve tappings from this resistor are taken to the fixed commutator as shown. Rotating brushes driven by a D.C. motor run on this fixed commutator, and the tappings are of such values that a stepped sine wave voltage appears at the brushes if they are rotated at a constant angular velocity. The D.C. motor driving the brushes has a speed control in the form of an armature resistance, and the frequency of the stepped sine wave can thus be varied by varying the speed of this motor. The stepped sine wave voltage is applied through an ammeter and a further series variable resistance to the exciter armature. The exciter force can thus be controlled by variation of the series resistor, and the ammeter can be calibrated in terms of exciter force provided that the exciter field (supplied direct from the aircraft 24 volt system) remains constant.

The nominal 48 volts supply to the tapped resistor passes through a manually operated circuit breaker. This breaker can be released, thus switching off the exciter armature current, by the operation of either of two push buttons, one controlled by the observer and one controlled by the pilot. The exciter force can thus be cut off instantaneously when using the decaying oscillation technique, or in an emergency. The precaution was taken of locating the pilot's push button adjacent to the throttle quadrant rather than on the control column, otherwise the operation of the button might be prevented in an emergency case if large amplitude control column oscillations were to occur.

The exciter control panel for the observer is shown in Fig.6, and contains all controls except the ammeter and switch. The sequence of operations was to switch on first the field and then the armature of the D.C. motor used to drive the rotating brushes. The brushes would then be rotating before any power was supplied to the exciter. Finally the exciter field and armature supplies were switched on with the armature variable resistance in the position corresponding to minimum force. The force was then adjusted to the desired value.

5 PERFORMANCE AND PHYSICAL DIMENSIONS OF COMPLETE EXCITATION SYSTEM

The maximum force obtained from the exciter (measured statically in the laboratory) was approximately ±80 lb. This figure was obtained with the armature coils connected in parallel and with full cooling. The force was measured by a spring balance, being the peak force required to pull the armature steadily from one side of its working position to the other with 28.5 volts D.C. across the field coils and 52.5 volts D.C. across the armature coils. (52.5 volts was a near approximation to the actual aircraft condition, being made up of a 28.5 volt aircraft supply plus the added 24 volt accumulator.) In the static case these voltages produced a field current of 5.4 amps and an armature current of 18 amps (i.e. 9 amps per coil). In the oscillating case, the exciter back e.m.f. increased the apparent resistance of the exciter so that the full 18 amps armature current was not attainable. At the peak current position a further 12 amps was taken by the large tapped resistor.

Summarising, the maximum power requirements and weights for exciter and control gear were:-

52.5 volts, 30 amps for armature circuit
27 volts, 5.4 amps for field circuit
Weight of exciter = 48 lb
Weight of control gear = 72 lb.

6 VIBRATION RECORDING EQUIPMENT

Conventional vibration recording equipment was used in order to measure the response of the aircraft to the exciter force, the test aircraft being comprehensively instrumented with some 35 Lanelec inductance acceleration transducers feeding into McMichael carrier wave amplifiers with double integration. The signals from the amplifiers were recorded on Films and Equipment 12-channel galvanometer recorders. In addition to the above vibration recording apparatus a separate check on the fin tip lateral vibration amplitudes was obtained by the installation of Sperry low frequency electromagnetic velocity transducers feeding directly into the recorders: alternatively the signals from these transducers could be monitored visually by the observers. This latter apparatus provided a reliable and completely independent check on the aircraft response at these points.

7 RESULTS

It was originally intended to investigate thoroughly the response of the aircraft to the rudder tab excitation over the frequency range of 0-30 cycles per second and preliminary tests showed that the excitation system would produce substantial tab amplitudes over this frequency range. However, because of a series of aircraft serviceability troubles not associated with the experimental installation the tests were eventually confined to the investigation, over a very limited airspeed range, of the 3 cycles per second fuselage torsion - tailplane antisymmetric bending mode shown in Fig.7. Figs.8 and 9 show records of the excitation of this mode in flight at two different airspeeds. On these recordings the exciter current trace shows the point at which the excitation was cut off, and the resulting decay of the aircraft oscillations is clearly seen. The damping values deduced from the rates of decay of these oscillations at the two airspeeds are given on the respective Figures.

8 CONCLUSIONS

An electrodynamic exciter applying an oscillating force to a tab control circuit appears to be a practical means of excitation for the indication of the aircraft flutter characteristics in which appreciable tab motions are present. The method has been demonstrated to be effective over the range 0 to 30 cycles per second in the case of a Lancaster with pure servo-tab controls, and there is every reason to suppose that such a method could be used successfully on many spring tab control systems.

To ensure satisfactory behaviour of the type of excitation system described in this paper it is necessary to reduce the friction losses in the control system to negligibly small proportions. The exciter is also more difficult to install than the simple mechanical inertia type. It is however, potentially much more effective than the latter for a given installation weight, at frequencies below about 3 cycles per second. It also possesses, in common with all electrodynamic excitation systems, much greater controllability than the inertia exciter. Particularly advantageous features are the force/frequency relationship which can be controlled at will in flight, and the very rapid force cut-off which can be achieved when using the decaying oscillation technique.

9 ACKNOWLEDGMENTS

The author is indebted to Messrs. C.E. Tammadge and D.F. Wright, who carried out the flight tests referred to in this paper.

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Ref. No.	Author	Title, etc.
1	Kirkby, W.T., Luscombe, P.D.R.	Comparative flight flutter tests using the "Decaying Oscillation" and "Amplitude Response" techniques. R.A.E. Report No. Structures 248. April, 1959.
2	Walker, J.G., Lyons, D.J., Townsend, B.R.	Preliminary note on flight tests of servo-tab controls on a Lancaster aircraft. R.A.E. Report No. Aero.2395. November, 1950.

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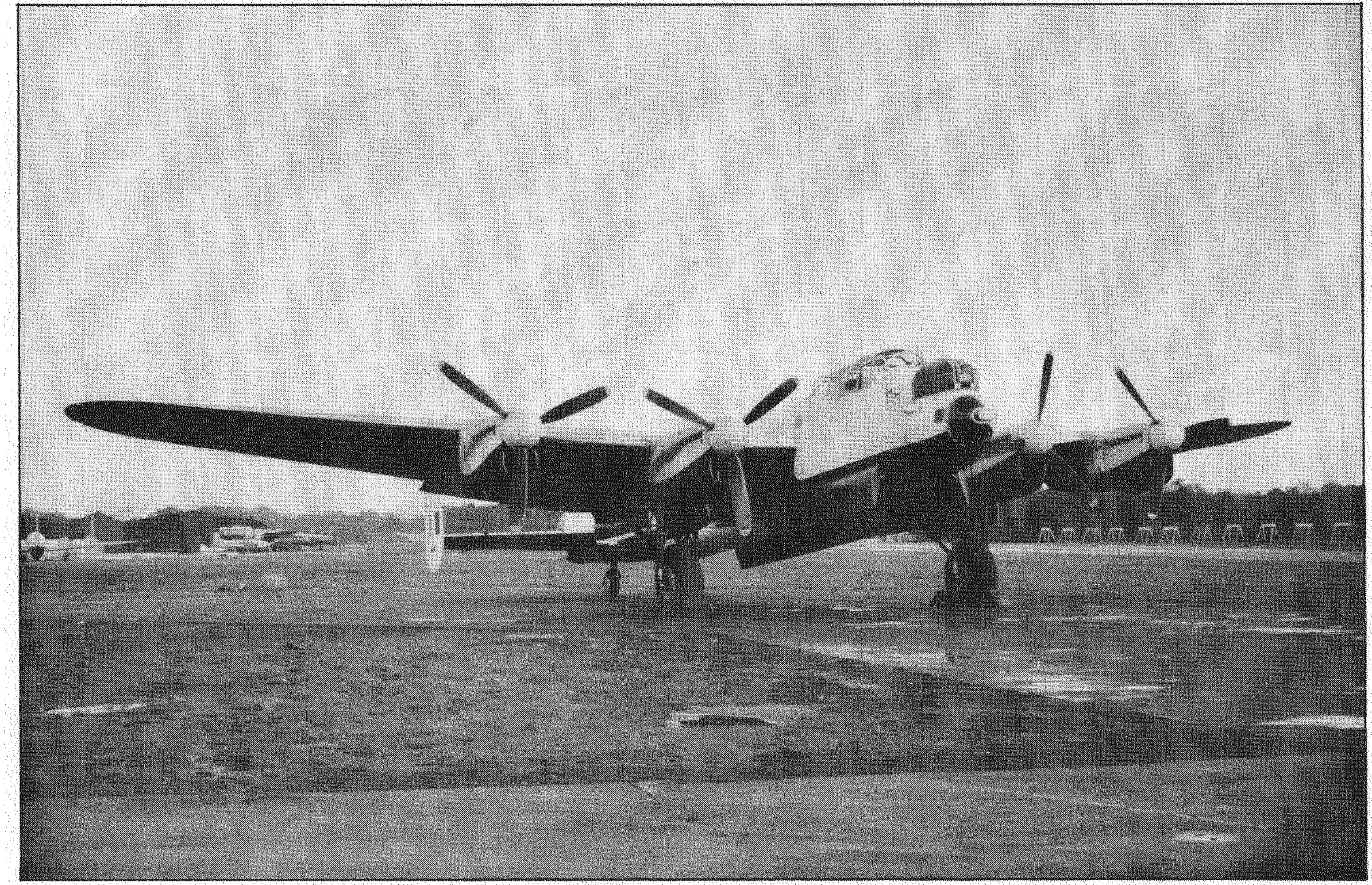

FIG. 1. SERVO-TAB LANCASTER NX676

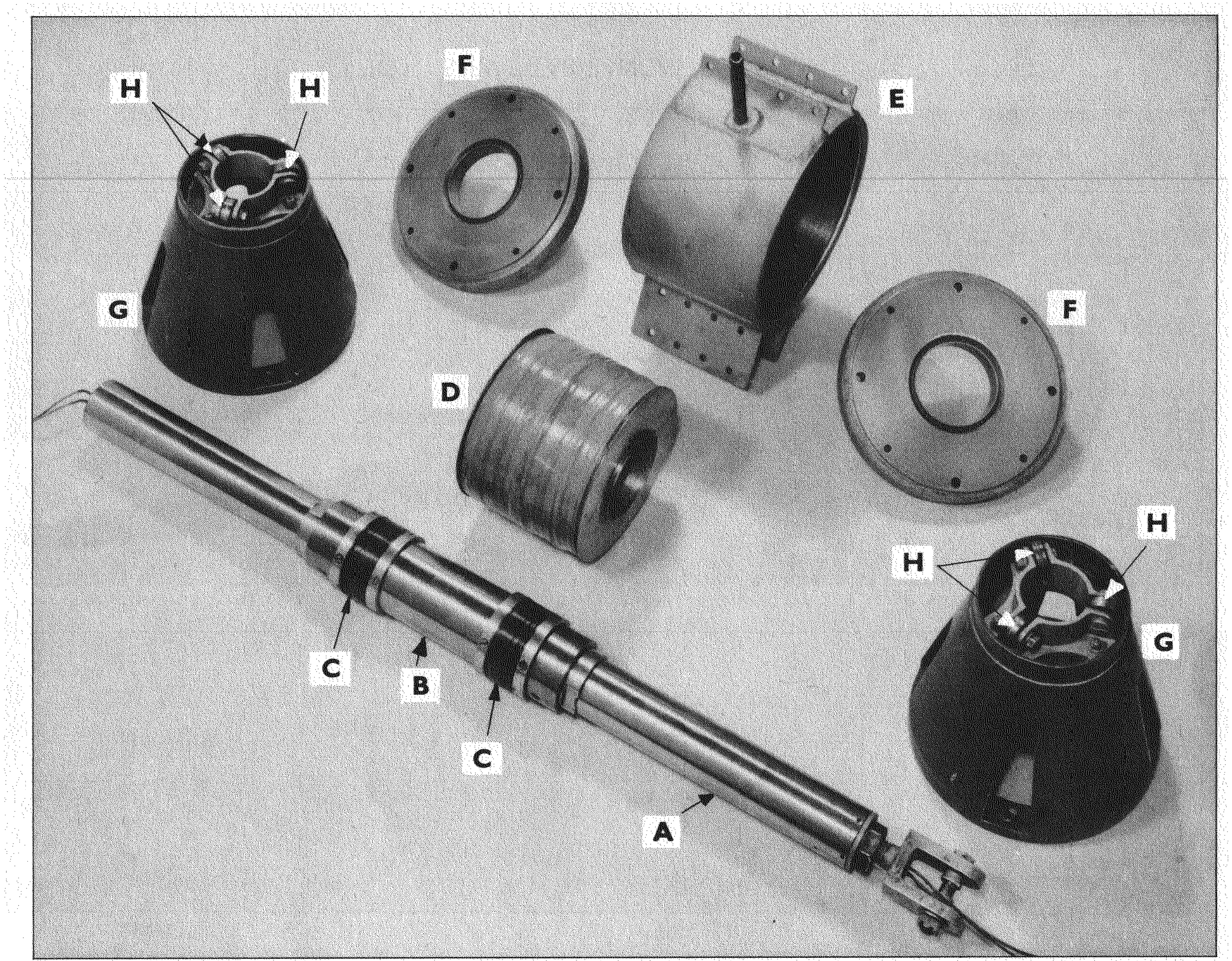

FIG.2. THE COMPONENT PARTS OF THE ELECTRODYNAMIC EXCITER

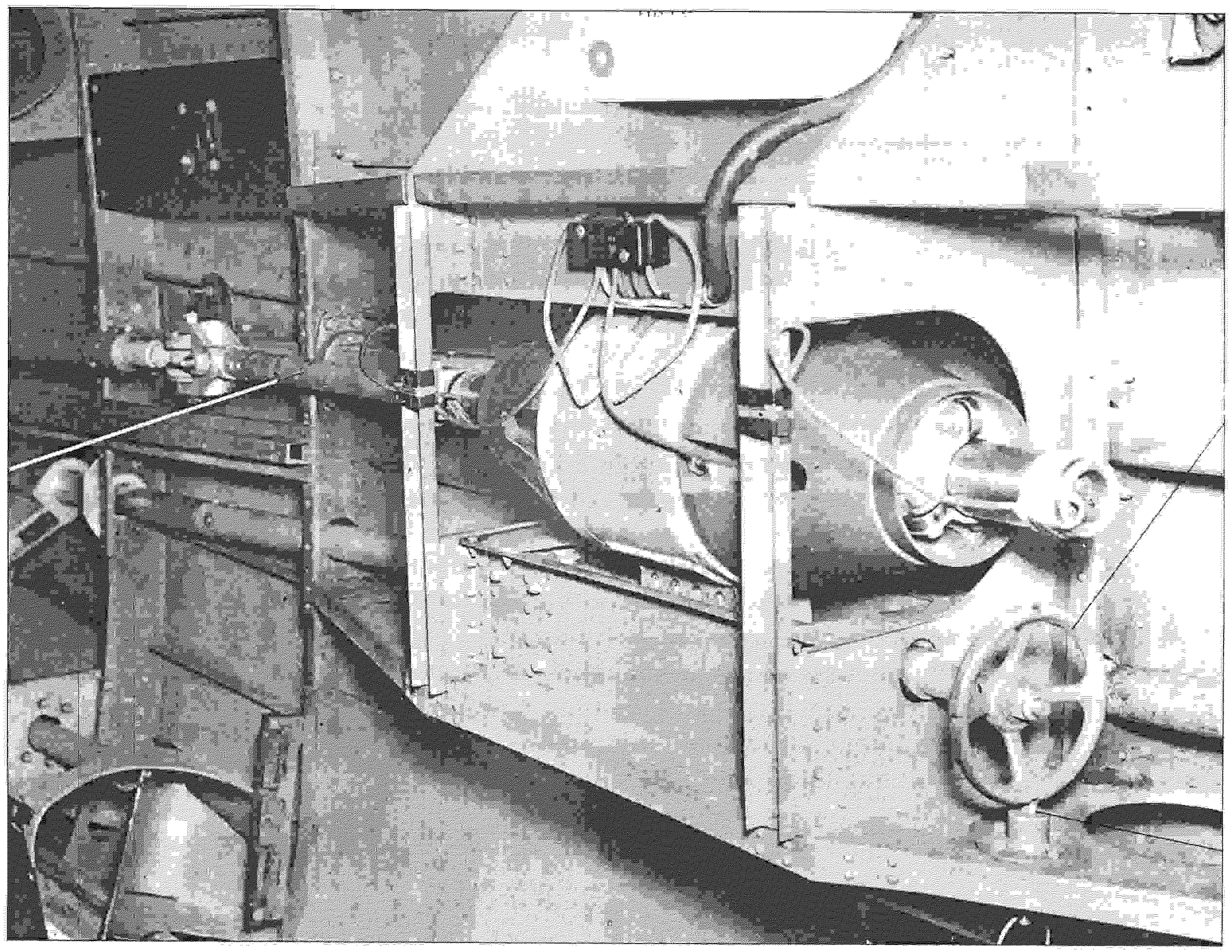

FIG.3. ELECTRODYNAMIC EXCITER INSTALLATION

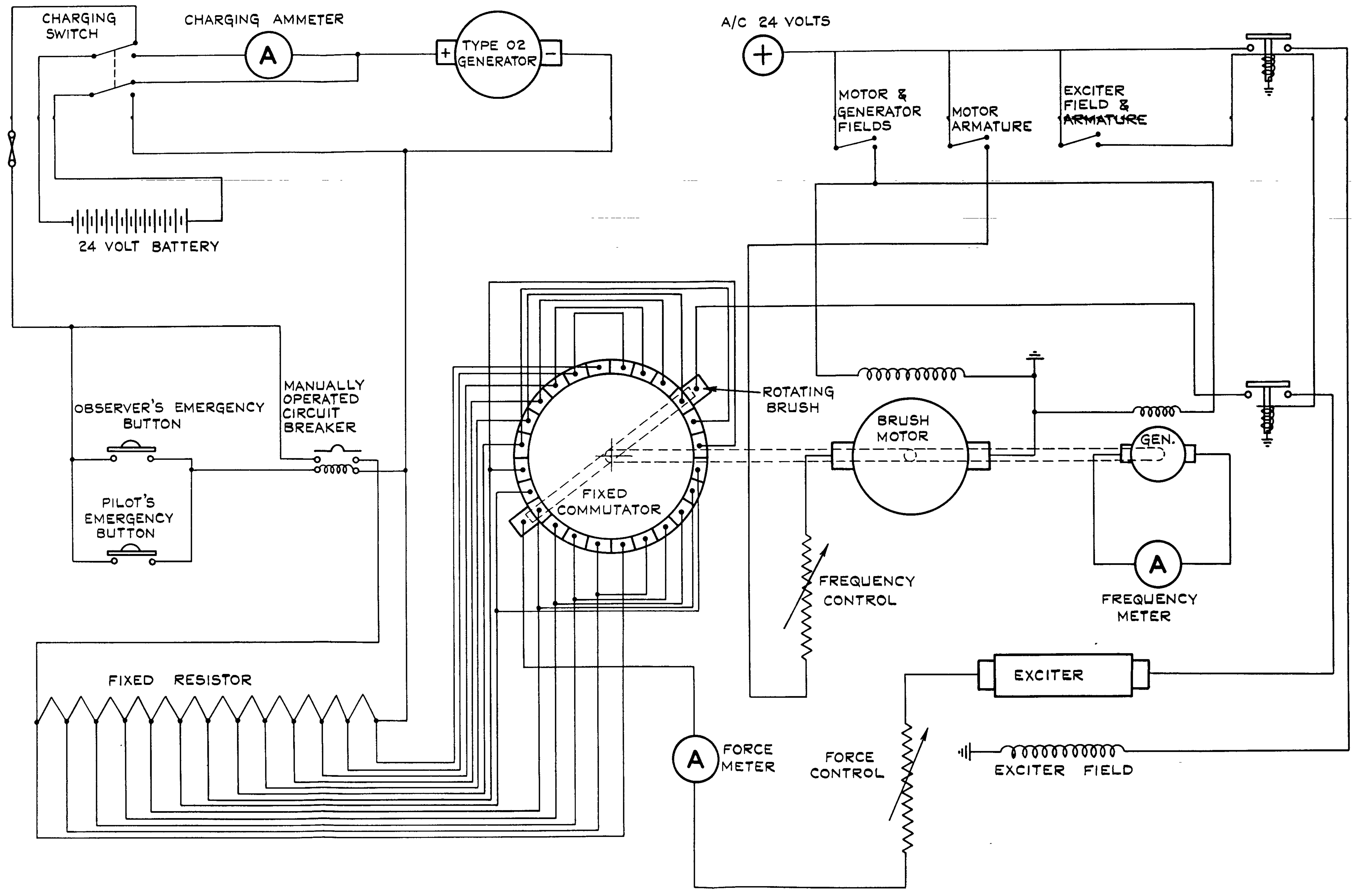

FIG. 4. EXCITER POWER SUPPLY AND CONTROL CIRCUIT.

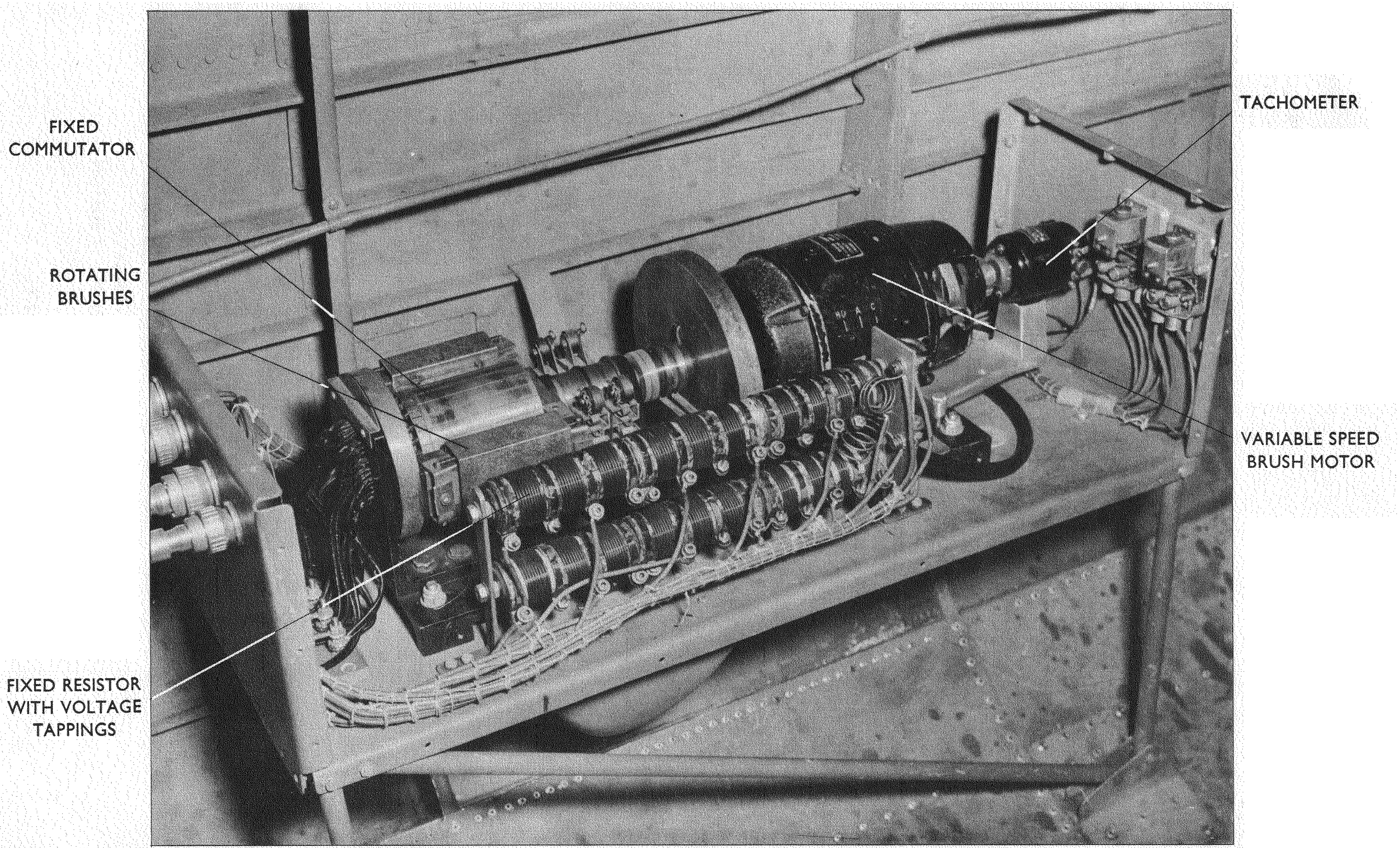

FIG.5. CONVERTER FOR EXCITER, A.C. POWER SUPPLY

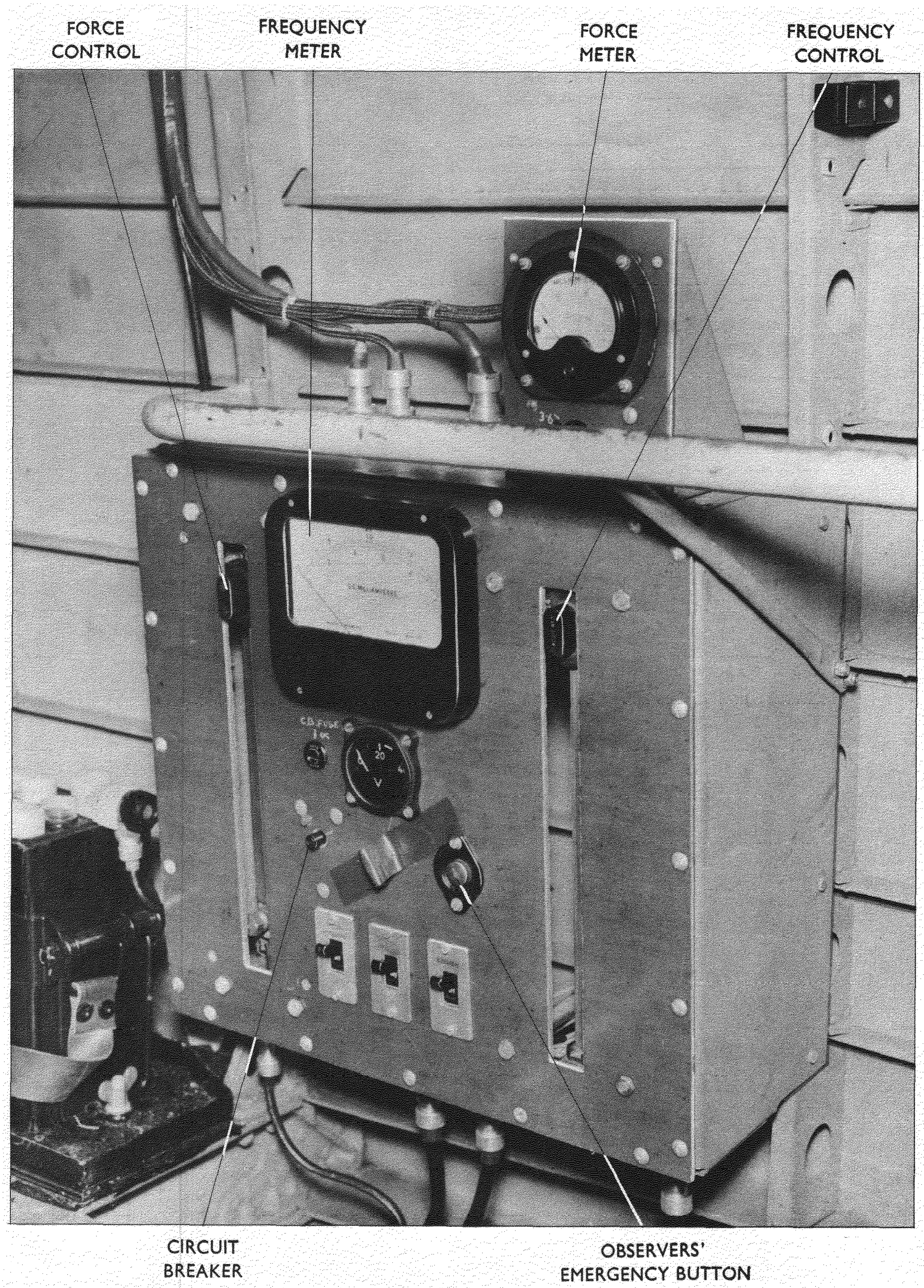

FIG.6. EXCITER CONTROL PANEL

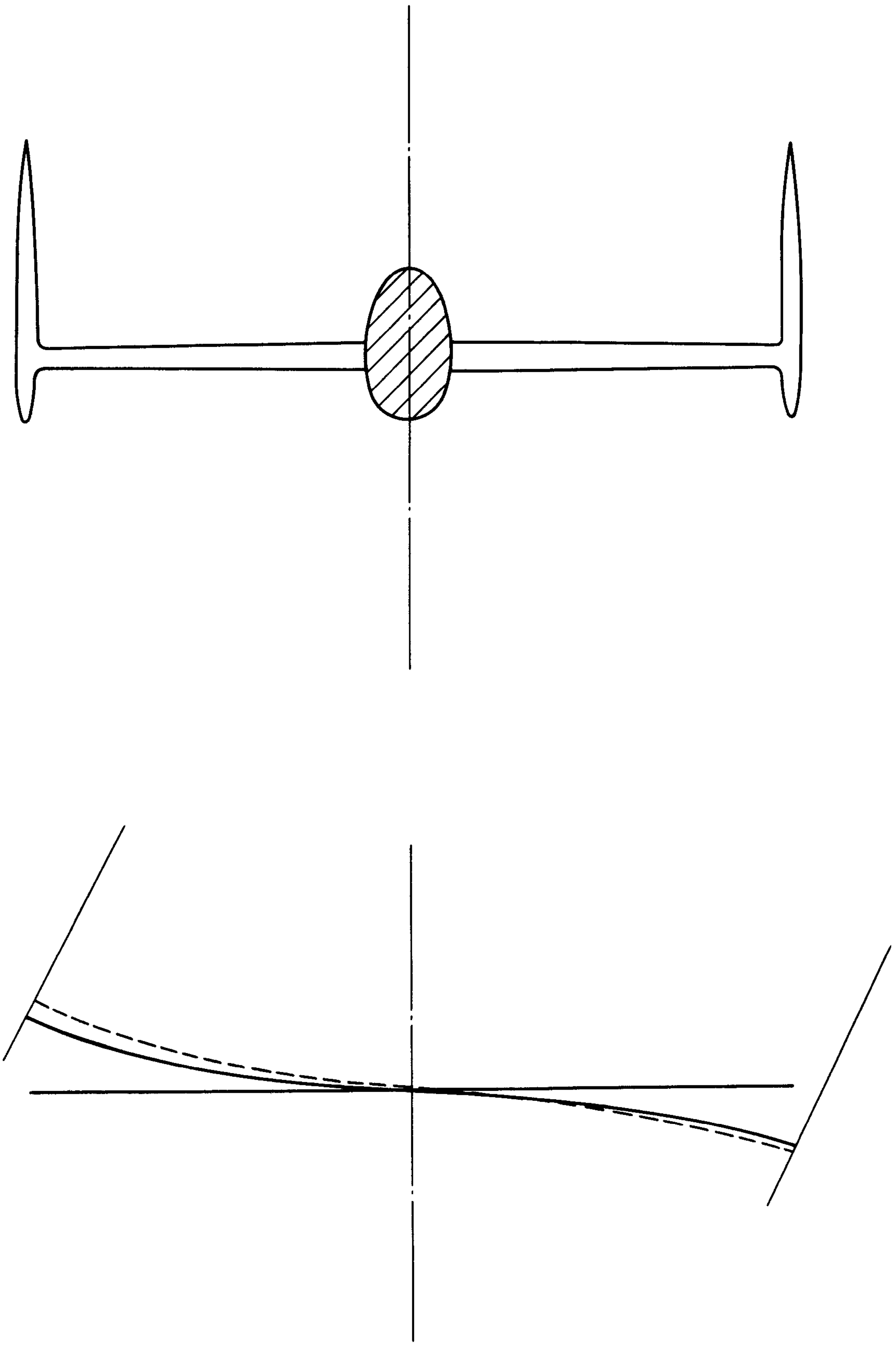

FIG. 7. 3·65 c/s FUSELAGE TORSION - TAILPLANE ANTISYMMETRIC BENDING MODE MEASURED DURING GROUND RESONANCE TESTS ON LANCASTER NX 676.

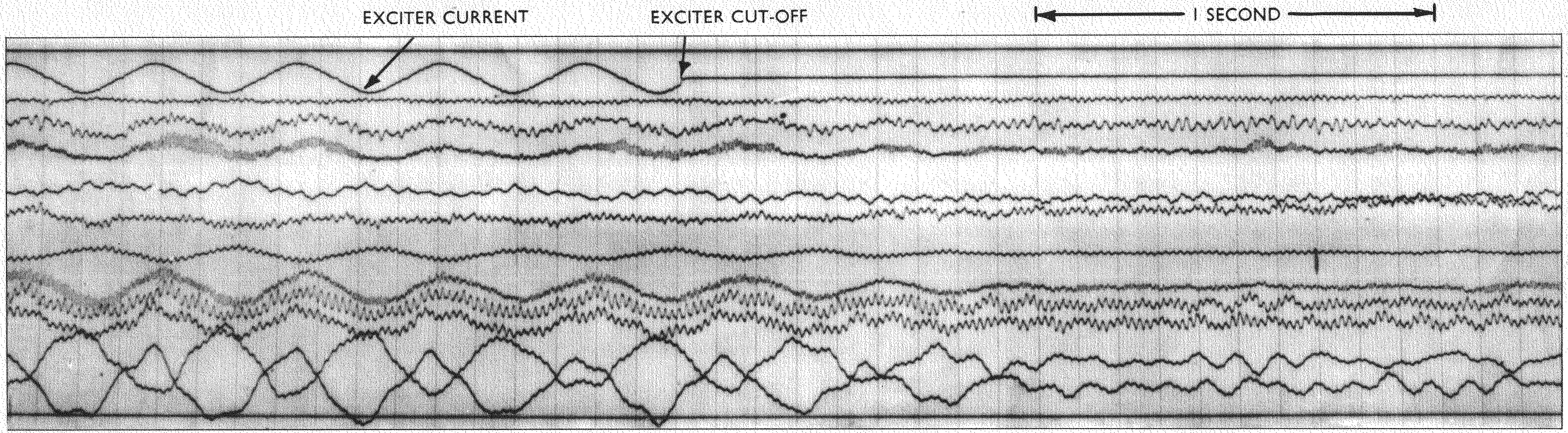

FIG.8

I.A.S. = 130 knots. FREQUENCY = 2.9 C.P.S. $C/C_C = 0.056$

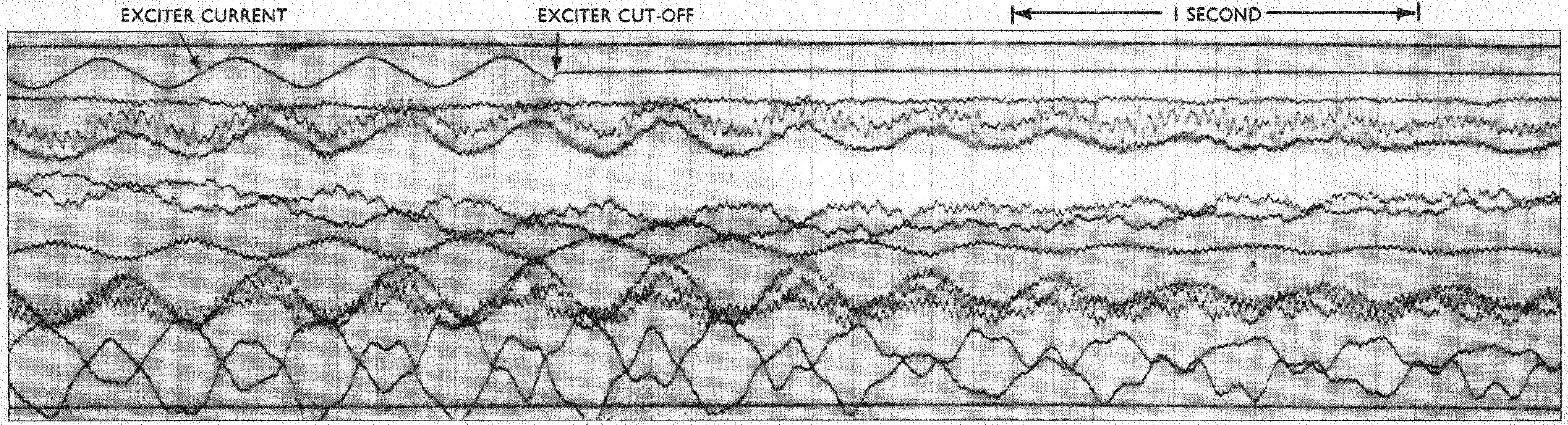

FIG.9

I.A.S. = 150 knots. FREQUENCY = 3.1 C.P.S. $C/C_C = 0.032$

FIG.8 & 9. RECORDS OF THE TAILPLANE ANTISYMMETRIC MOTION DURING EXCITATION FOLLOWED BY CUT-OFF AT APPROXIMATELY 3 CYCLES PER SECOND

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