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by

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A Note on Derivative Apparatus for the N.P.L. 9½-inch High Speed Tunnel

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SUMMARY

A brief description is given of new equipment for measuring derivatives on finite aspect ratio models with trailing-edge flaps in the N.P.L. 9½ inch high speed tunnel. Some account is also given of considerations leading to the choice of method.

1. Introduction

A brief description is given in this note of new derivative apparatus recently fitted to the N.P.L. 9½ in. square high speed tunnel. A self-excitation technique is used, and the design has benefited largely from experience gained with earlier equipment in the same tunnel. The earlier apparatus was limited to the measurement of direct pitching moment derivatives for finite aspect ratio and two-dimensional models, with a frequency parameter ranging up to 0.07 at $M = 1$, whereas the new equipment has been designed to measure complete sets of derivatives relating to pitching, vertical translation and flap rotation for finite aspect ratio models only, with frequency parameter ranging up to 0.25 at $M = 1$. Consideration has been given to the possibility of adapting the equipment at a later date for the measurement of flap derivatives with two-dimensional models and at the same time photographing the oscillatory flow pattern.

The design of derivative apparatus for measurement at high speeds is made difficult by the large aerodynamic forces involved and the high frequencies required to obtain a frequency parameter approaching full scale. In the following section some account is given of the influence of these factors in the choice of a self-excitation method for the new equipment.

2. Design Considerations

A general principle relating to the measurement of wing derivatives for pitching and vertical translation states that complete sets of derivatives can be obtained from measurements of pitching moment and lift for pitching oscillations about two axis positions. A design was adopted based on this principle since it led to a much simpler mechanical construction than one in which provision was made for a vertical translation of the model and pitching about one axis only. Additional requirements for the determination of the flap derivatives were (a) measurement of the flap hinge moment and the total lift and moment on the model for flap oscillations with the wing fixed, and

(b)/

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(b) measurement of the flap hinge moment with the flap locked to wing and the model performing pitching oscillations for each axis position in turn.

A further consideration largely affecting the mechanical design lay in the choice between an arrangement in which a model of a complete planform is supported by a sting at the centre of the working section, and the half-model technique in which a model of half the planform is supported at the wall of the tunnel. The choice of the latter arrangement was determined mainly by the need for the maximum rigidity in the model support in order to maintain a high stiffness in roll or vertical translation and a corresponding high natural frequency compared with the maximum driving frequency of 100 c.p.s. aimed at in the design. It was felt that a sufficiently rigid sting would have introduced considerable aerodynamic interference. A disadvantage of the half-model technique is the presence of the tunnel boundary layer at the root of the model, and it is hoped later to remove this by suction in order to investigate its effect.

The models for use with this apparatus are regarded as rigid, which implies in practice that they are very stiff and have natural frequencies large compared with the maximum driving frequency. A high natural frequency alone is not sufficient, a point which is illustrated by the calculation, based on constant derivatives, of the errors due to flexure in the measured derivatives for a rectangular wing. This leads to the result that for a mass-balanced model and a given frequency parameter the errors in the non-dimensional derivatives are approximately proportional to the expression

$$\frac{\rho V^2}{\sigma\left(1 - \frac{f^2}{f_o^2}\right)}$$

where σ is the flexural stiffness, f_o the flexural frequency and f the frequency of the imposed pitching oscillation. If f/f_o is small the errors are inversely proportional to flexural stiffness. When the model is not mass-balanced about the axis an additional error term due to the product of inertia is introduced which is proportional to the above expression with ρ omitted.

It follows from these considerations that in order to maintain a given level of accuracy a model stiffness proportional to V^2 is required, and with an efficient form of model construction this implies a similar proportionality for mass and inertia. Roughly the same argument applies to moving parts connected with the support and drive of the model, since these partly determine the stiffness for roll and vertical translation.

Mechanical inertia was the main factor influencing the choice of method in this apparatus. If an inexorable forcing technique is considered, it follows from the preceding argument that for a given frequency parameter inertial reactions roughly proportional to V^4 will be present. For any practical design allowing easy interchange of models it was found that at high speeds the inertial reactions were very large compared with the aerodynamic reactions, and the possibility of successfully balancing them out with a mass driven in anti-phase seemed doubtful.

The use of a spring to form a tuned system seemed more promising since this would balance out the inertial forces if the forcing frequency were equal to the still-air resonance frequency. The influence of

inertia/

inertia in this case is through the effect of a departure from still-air resonance and for a given percentage error in frequency is approximately proportional to V^2. A practical example indicated that, in the worst case, in order to attain 1% accuracy in a stiffness derivative measurement the forcing frequency should not depart by more than 0.01% from the still-air resonance frequency.

A logical development of the method of balancing an inertia with a spring is a self-excitation technique, which avoids completely the need to set frequency to a very close tolerance. In this method the tuned system is driven by an electromagnetic exciter which is part of a feedback loop deriving its input from a displacement pickup oscillating with the model. The phase of the current in the exciter coils is adjusted to bring the exciting force into quadrature with the model displacement and thus to balance the damping forces. As a result the system oscillates at its natural frequency, which in still air is governed by the elastic stiffness, and in the wind by the elastic plus a direct aerodynamic stiffness. The latter is proportional to the frequency difference, and although this may be very small (down to 1% of the mean), the individual frequencies can easily be measured to 1 part in 10^6, which gives more than adequate accuracy on the difference. The direct damping derivative may be determined from a knowledge of the forces exerted by the exciter coils, but in practice it is simpler to measure the electrical power input and relate this directly to the damping. Electrical losses in the exciter can be determined by clamping the coils and measuring the power with the same current flowing as when the system was oscillating.

4. Mechanical System

The general arrangement is shown in Figs.1 and 2. Two vibrating systems are provided one for the wing and the other for the flap, and both are mounted in a rigid rectangular frame which is tied down to an earthed structure by three force pickups. Each system consists of two rigid steel cylinders supported by crossed-spring bearings which permit axial rotation but are very stiff for lateral displacements. A torsion bar is connected between the cylinders one of which may be clamped to the model and the other linked to the exciter as shown in Fig.2. A free-free oscillation is excited with a node between the cylinders.

Experience with earlier equipment had suggested this arrangement for two reasons. In the first place, if one end of the torsion bar is clamped to earth and the excitation is applied at the model end, very large reactions are transmitted to the earthed structure when using the stiff torsion bars required to obtain high frequencies, and this gives rise to heavy apparatus damping. Secondly, attachment of the exciter at the model end increases inertia and thus reduces frequency for a given elastic stiffness. It may be remarked that at the highest frequencies the torsion bars are working fairly close to the fatigue limit at the maximum working amplitude of 2°.

The object in providing separate vibratory systems for wing and flap is to keep down the inertia and elastic stiffness in the flap system in view of the small aerodynamic stiffness forces to be measured. Since the flap is supported by the wing at the hinge, rigidity requirements in the drive are not so stringent.

A relatively weak C-spring is connected between each cylinder at the model end and the earthed structure in order to prevent divergence of the system, and provision is made for displacing the earthed end of this spring for the purpose of balancing out mean aerodynamic moments when working at incidence.

Measurement/

Measurement of the cross-derivatives is effected by the three frame pickups, which, in the case where the wing is oscillating with the flap locked to it, give lift and incidentally rolling moment. When the flap is oscillated the wing is clamped to the frame, and the pickups then give lift, pitching moment and rolling moment.

The frame and vibratory systems are enclosed in an air-tight box to prevent flow into the tunnel, and the rods linking up with the exciter coils pass through seals formed by flexible metal bellows.

A range of frequency from 25 to 100 c.p.s. is provided by sets of torsion bars.

3. Electrical Equipment

(i) Pickups

The whole of the pickup system is based on the F.M. equipment supplied by Southern Instruments. Displacement pickups are fitted to both wing and flap cylinders, and consist of a brass slug moving in the field of a small coil enclosed in a dust core shell. The coil is shunted across the F.M. oscillator inductance. A sensitivity of 2 volts per degree displacement is obtained.

A capacity type force pickup has been developed for the frame (Fig.3). It consists essentially of two annular diaphragms placed in tandem to give a parallel motion to the centre boss to which the load is applied. The boss forms the moving electrode of a condenser which is included in the F.M. oscillator circuit. An output of 0.4 volt per microinch displacement is obtained. A diaphragm stiffness giving one microinch per lb load is sufficient to give the frame system an adequate frequency response.

A small capacity pickup based on the bending of a short beam has been constructed for measuring flap hinge moments with the wing oscillating. This requires the flap to be mass-balanced.

The calibration of the F.M. electronics for all these pickups can be rapidly checked by switching into the F.M. oscillator circuit a small capacity which is known to be equivalent to a certain displacement or force.

(ii) Amplitude Measurement

The signals from the displacement pickups provide a measure of amplitude as well as forming the input to the feedback loop. They are measured with a very stable feedback amplifier (intrinsic gain 3500, gain with feedback 11) followed by a crystal diode bridge and D.C. microammeter.

(iii) Wattmeter Measurements

Both driving power and current, and the components of pickup outputs, are measured with a dynamometer wattmeter preceded by buffer amplifiers. These amplifiers have been developed specially for this purpose and are based on circuits employing a large amount of negative feedback of the same order as in the amplitude amplifier but with a much greater current output. Although these amplifiers are A.C. coupled, the phase-shift through each over the frequency range of the tests is not more than 1/20 degree.

The wattmeter is also used for setting the driving current in quadrature with the displacement by taking signals from the displacement pickup and from a resistance in series with the exciter coils and adjusting the phase of the current to give a null reading.

In measuring the in- and out-of-phase components of force pickup outputs, the displacement pickups provide in-phase reference signals, whilst quadrature reference signals are obtained from these with the aid of a phase shifter previously adjusted with the aid of the wattmeter.

(iv) Frequency Measurement

Frequency is measured with two Dekatron counters and an arrangement of electronic gates made by Labgear. The signal from a displacement pickup is amplified and pulsed at a certain voltage level. When the operation commences a signal pulse opens gates to the counters, one of which counts signal pulses and the other 1000 cycle pulses from the N.P.L. standard frequency. When 10^n signal pulses have been counted a pulse is produced which closes the gate to the standard frequency counter to leave a reading which represents the time in milliseconds for 10^n signal cycles. Integral values of n may be set up to a maximum of 5.

(v) Drive and Control (Fig.4)

The current to the exciter coils is provided by a straightforward push-pull amplifier with a moderate amount of feedback and a maximum output of 17 watts. A tunable twin-T filter is incorporated for removing signals which might excite the lower frequency mode of the vibratory systems, i.e., with both cylinders oscillating in phase under the constraint of the C-spring and bearing springs.

To maintain a constant stable amplitude a control device is provided which automatically adjusts the driving power to changes in damping. Its action is illustrated in Fig.5. The signal from the displacement pickup is amplified and then squared by a trigger circuit to give a constant amplitude square wave of the same frequency and phase as the input. A controllable fraction of the input is subtracted from the square wave and harmonics are removed with a tunable low-pass filter to leave a signal which is fed into the driving amplifier. With this arrangement a very small increase in amplitude can be made to give a large decrease in driving power, and thus to stabilize the motion. The device is much more rapid in action than conventional automatic gain controls which involve relatively large time constants for smoothing the D.C. voltage applied to the grid of the variable-mu valve.

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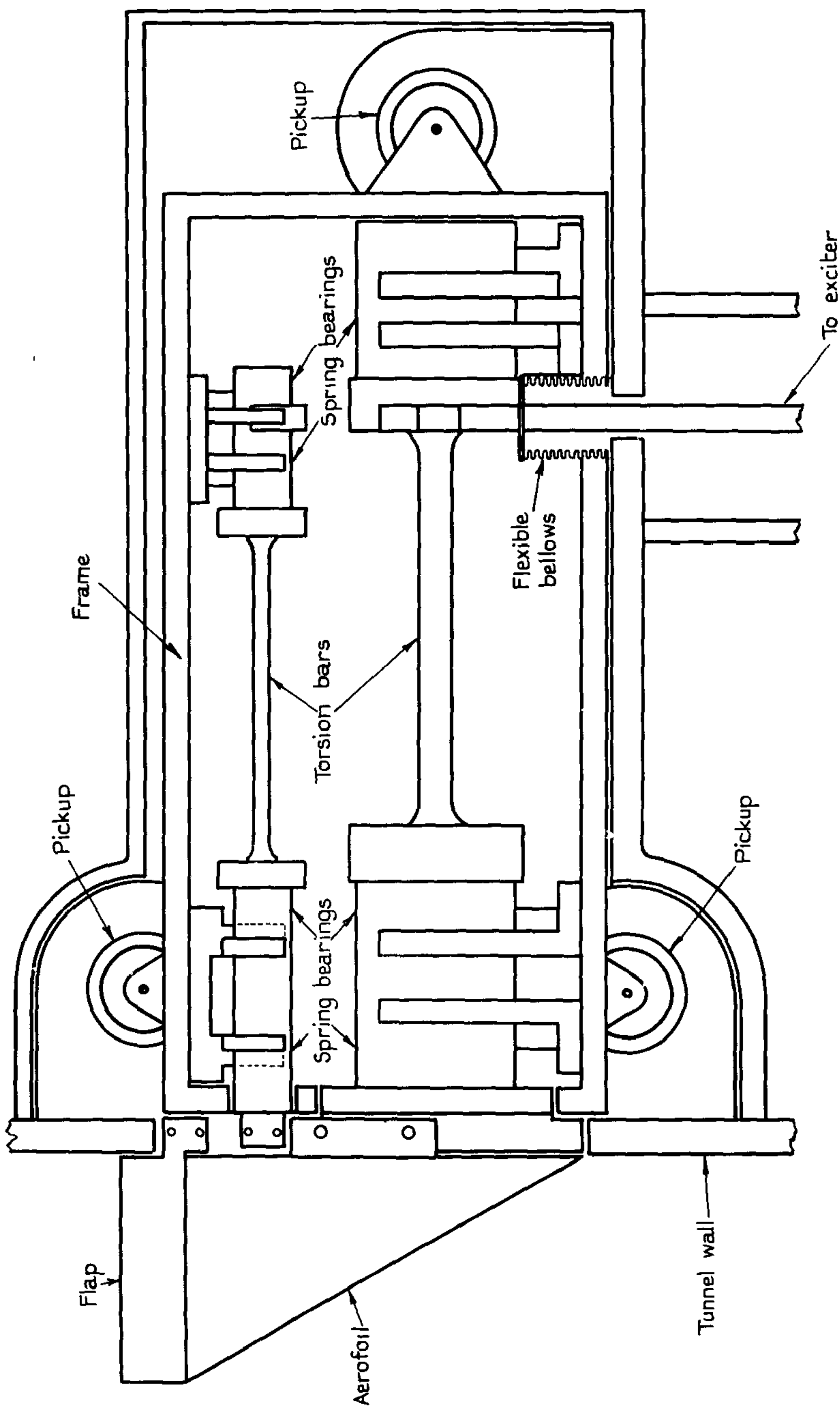
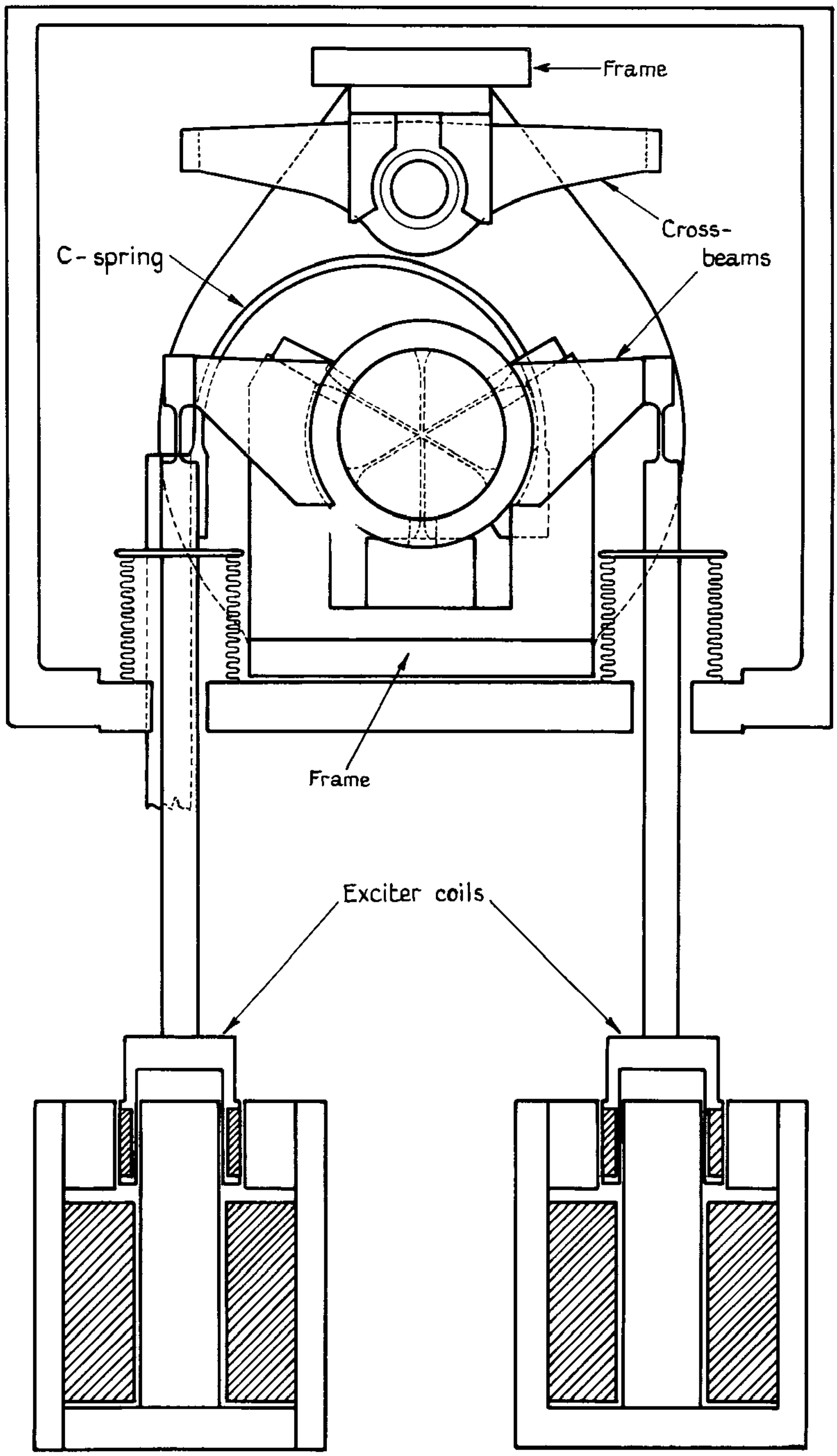
Fig. 1.

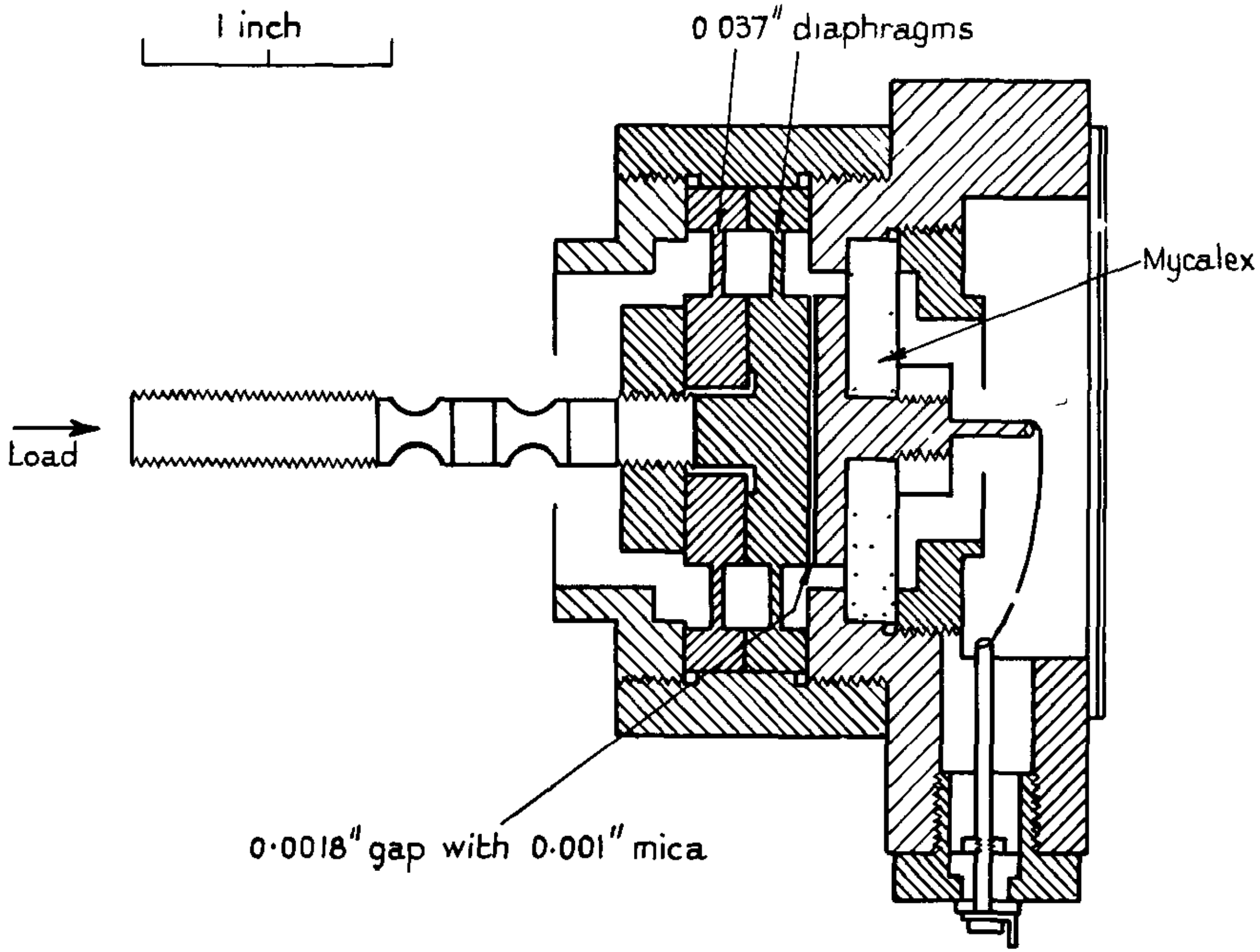


General arrangement _ side view

FIG 2.

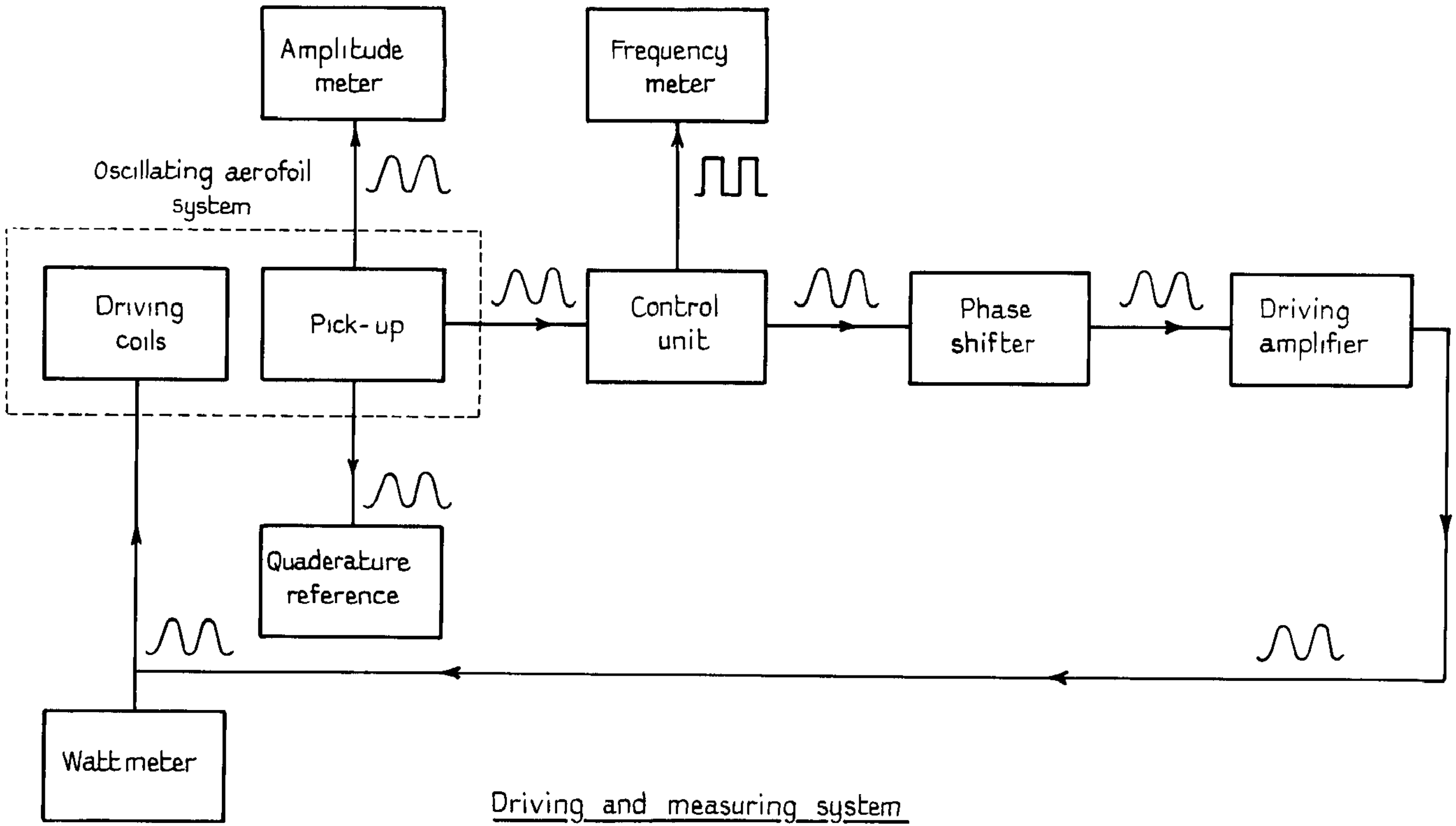


General arrangement – End view



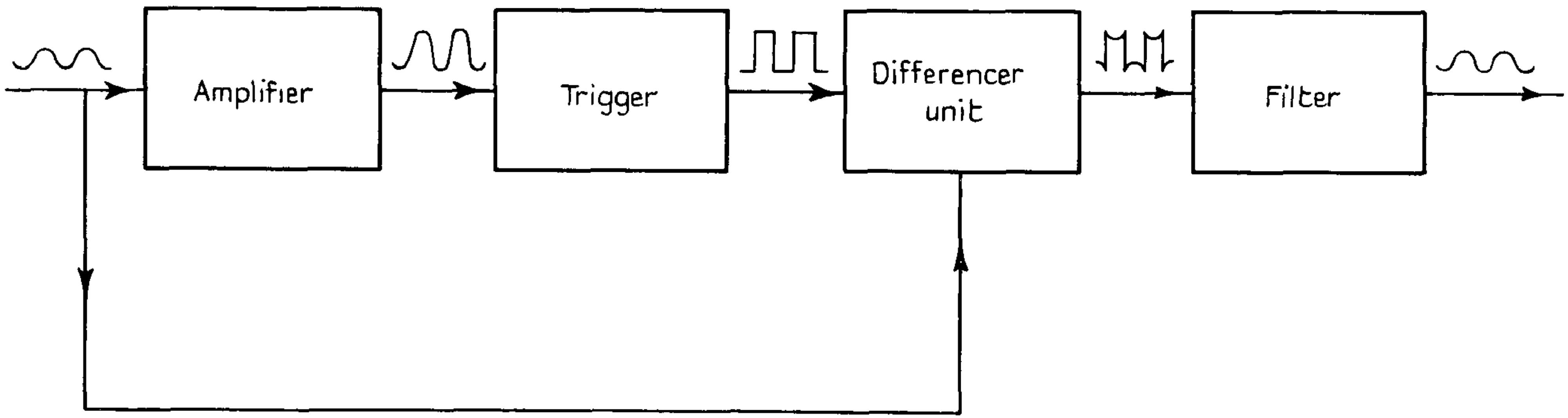
Capacity force pickup.

FIG. 3.



Driving and measuring system

FIG. 4.



Control system

FIG 5.

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