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Design and Use of Counting Accelerometers

By

J. Taylor

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Summary.—The fundamental principles underlying acceleration recording by means of a counting accelerometer are analysed. The essential design requirements for a counting accelerometer are presented. A design that has been specially made to meet these requirements is described. Both mechanical and electrical counting are considered, but mechanical counting is found to be superior.

1. *Introduction.*—In order to design the structure of an aircraft it is desirable to know the loads which may be imposed in flight and the number of repetitions in a given time. The overall loads to which the wings are subjected are nearly proportional to the acceleration of the c.g. of the aircraft. Measurement of acceleration, therefore, provides a means of estimating loads, but in order to obtain reliable estimates records must be taken on representative aircraft over a large number of flying hours and analysed statistically.

It is impractical to analyse by direct methods long continuous records of acceleration. The task, however, can be greatly simplified by use of an instrument which counts the number of times given thresholds of acceleration are crossed, *i.e.*, the counting accelerometer.

The subsequent interpretation of the counts requires a knowledge of the general pattern of acceleration changes which correspond to the counts. It is possible to acquire this knowledge by means of additional equipment used for a short time and then removed.

The requirements for counting accelerometers are discussed in this report, and also the general features of a practical instrument which has flown satisfactorily for over 50 hours.

2. *Requirements for a Counting Accelerometer.*—2.1. *Accelerometers in General.*—A counting accelerometer is used in an aircraft primarily to gain an indication of the applied forces. It has been shown[1] that there are two main requirements for any type of accelerometer used for this purpose. The first is that it should record accurately the overall accelerations of the aircraft. The second is that it should reject local accelerations caused by vibrations. For any type of accelerometer this corresponds to an exact response to sinusoidally varying accelerations at a relatively low frequency with a negligible response to accelerations at a relatively high frequency.

It was proposed[1] that the dividing line between what are regarded as low and high frequency for this purpose should be at about $2\frac{1}{2}$ times the natural frequency of the wing of the aircraft on which the accelerometer is being used. A standard accelerometer was postulated with the following properties:—

* R.A.E. Report Structures 78, received 15th December, 1950.

(*a*) It should consist of a main mass and spring, with a secondary spring coupling a rotary inertia to the main mass (a particular arrangement is shown in Fig. 4).

(*b*) The rotary inertia should have an equivalent mass of $0 \cdot 35$ times the main mass.

(*c*) The secondary spring should have an equivalent stiffness $1 \cdot 25$ times that of the main spring.

(*d*) The damping should be such that the rate of change of amplitude response ratio* is zero at zero frequency.

The change in time lag with frequency of such an accelerometer is shown in Fig. 1 and the amplitude response ratio with frequency is shown in Fig. 2. For comparison the behaviour of a single spring mass system is also shown. In Fig. 3 are given the apparent accelerations shown on a standard accelerometer under vibration ; the particular accelerometer considered is intended for use in aircraft of wing natural frequency up to 4 cycles per second.

2.2. *Principles of Counting.*—In principle, a counting accelerometer counts the number of times a given set of thresholds of acceleration are crossed. The primary object in counting these crossings, however, is to determine the ranges of acceleration. Minute fluctuations about a given level therefore should not be recorded as actual crossings. A decision has to be made as to what amplitudes of fluctuation can be regarded as minute from this standpoint. It is proposed that any particular threshold of acceleration should, for counting purposes, be given a small though finite width, so that for a rising or falling acceleration no count is made until the band has been completely crossed. The width of this band has been tentatively chosen as $0 \cdot 1g$.

In considering the way in which the counting mechanism shall be restrained in its response to minor fluctuations, it is necessary to bear in mind that there must be no risk of a miscount for any other reasons. Whilst this is an obvious requirement for a counting accelerometer, it has to be mentioned as one which is not easily met owing to inertia effects and possibly other causes. It is conceivable that when a threshold is crossed with great rapidity no count will be registered or, alternatively, if registered, the count may be more than one. In the instrument described the criterion set is that no miscount shall take place for a virtually instantaneous change of acceleration of magnitude $2g$ or less.

3. *Description of a Practical Counting Accelerometer.*—The counting accelerometer that has been made to meet the points mentioned above (section 2) is intended for use in aircraft with a wing natural frequency up to 4 cycles per second. The main construction is shown diagrammatically in Fig. 4. The accelerometer consists of a single cantilever spring, 10 in. long and 2 in. wide, on the end of which is a brass mass of about 2 lb. Such a heavy main mass is used so that applied accelerations develop sufficient force to operate mechanical counters without appreciable alteration to the readings. The end of the cantilever spring is attached to two subsidiary spiral springs which are held in tension by a continuous tape passing over two rollers. The tape is fastened to the upper roller which carries a recording pointer and is also connected through a 9:1 step-up gearing to a hollow aluminium cylinder which rotates in the field of a permanent magnet with a central iron core. Eddy currents in the aluminium cylinder produce a resistance proportional (to within 1 per cent) to the angular velocity. It has been established, moreover, that the damping produced in this way remains appreciably constant with time and operational use.

Two methods of counting have been developed, a mechanical method and an electrical one. The mechanical counters are arranged with a series of ratchet wheels in the path of the pointer.

* Amplitude response ratio is the ratio of the amplitude of the measured acceleration to the amplitude of the applied sinusoidally varying acceleration.

When the acceleration first crosses any particular threshold the pointer passes over a tooth, and this is the first stage of the counting operation. The second stage takes place later when the threshold is crossed the reverse way (as it must be) and the count indicator then moves one digit. The action is symmetrical with respect to the $1 \cdot 0g$ corresponding to level flight.

The effective inertia of the counter itself is reduced by having a light flexible connection between it and the ratchet wheel. Without such connection the counter is liable to register two or more counts for the single crossing, a danger already mentioned (section 2.2) for mechanical systems. The travel corresponding to one tooth of the ratchet wheel combined with the flexibility of the pointer gives the required small but finite width of the threshold band, namely $0 \cdot 1g$ approximately.

The electrical method of counting has been developed and used satisfactorily as part of a prototype instrument for over 50 hours flying. The electrical method is convenient for a prototype accelerometer which is undergoing development but it is not thought desirable that it should be used on counting accelerometers generally. The electrical system used is such that high-speed relays with an electro-magnetic counter in parallel with each relay are energised on the pointer passing a given threshold and remain energised until released by a second high-speed relay when the pointer recrosses the threshold in the reverse direction.

In the first few instruments counts will be made at intervals of $0 \cdot 1g$ for accelerations up to $1g$ above and below level flight and at intervals of $0 \cdot 2g$ for further departures up to $2g$ above and below.

The estimated weights and overall dimensions of the accelerometers are given in the following table.

	Mechanical Counting	Electrical Counting (Two containers)	
Weight	12 lb	10 lb Total	40 lb 50 lb
Height	13 in	11 in.	8 in.
Length	18 in.	17 in.	11 in.
Breadth	$5\frac{1}{2}$ in.	5 in.	11 in.

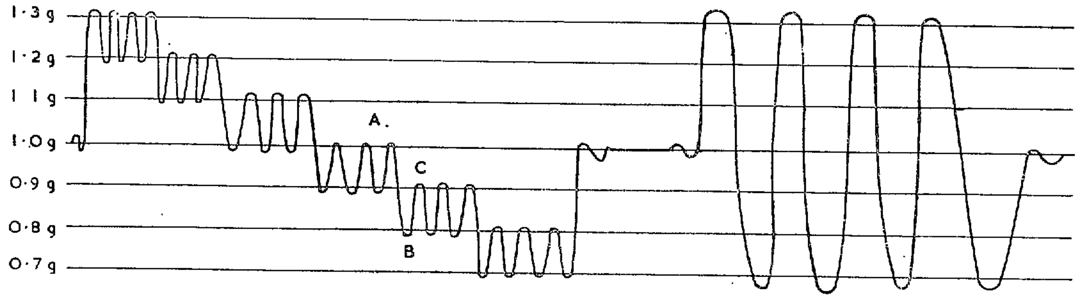
Photographs of the mechanical counting accelerometer are given in Figs. 5, 6 and 7.

4. *Interpretation of Results*.—In using counting accelerometers it is primarily hoped to find the variations of acceleration and the corresponding structural strain.

The structural strain will depend largely on the physical properties of the aircraft and also on whether it is flying or taxying on the ground. It is essential to differentiate between accelerations counted on the ground and in the air. The value of the results would moreover, be increased still further if the recorded accelerations were linked with height and speed of the aircraft. As height and speed change only comparatively slowly on civil airliners it would be satisfactory to record these together with the counter readings at moderate time intervals. It is proposed that in the early models a camera should be installed to take photographs of height, speed, time and counter readings at 10-minute intervals. This installation would approximately double the volume and weight of the accelerometer with mechanical counters. The maintenance required with such instruments would be changing of films at suitable intervals (30 hours recording time with a magazine of 180 exposures).

A typical record taken during a number of flights on Viking VW217 is shown in Table 1.

The final interpretation of the counts must depend on an estimate of the probable ranges of acceleration associated with the threshold counts. The diagram below shows two graphs of acceleration changes.



With the counting requirements given in section 2.2 both these graphs would correspond to 4 counts at each of the thresholds 0·7 to 0·8, 0·8 to 0·9, 0·9 to 1·0, 1·0 to 1·1, 1·1 to 1·2, 1·2 to 1·3*g*, but the one on the left has approximately four times the number and about a sixth the amplitude of those on the right. These may have completely different structural fatigue effects and the estimation of these effects is one of the most important reasons for counting accelerations.

It should be sufficient to determine the ranges of acceleration over a small fraction of the total recording time and use this as representative of the whole. It is proposed that ranges of acceleration are counted by noting the maximum and minimum of each range ; A, B in the diagram above would have a maximum between 1·0*g* and 1·1*g* with an adjacent minimum between 0·8*g* and 0·7*g* and B, C would have a maximum between 0·9*g* and 1·0*g* with an adjacent minimum between 0·8*g* and 0·7*g*. The accelerometer with electrical counting can be adapted to make this fuller investigation and it has been so adapted for the first 50 hours flying. The corresponding ranges of acceleration and thresholds crossed in 26½ hours flying from Farnborough to Fayid and back is given in Table 2 and a similar table of ground records given in Table 3. These tables are included as an indication of the type of correlation required. The actual number of the counts per hour on such a few hours must be regarded as a preliminary value.

5. *Conclusions.*—5.1. The purpose of a counting accelerometer is to record the number of times various levels or thresholds of acceleration are crossed. This marks an essential distinction between a counting accelerometer and a continuous recording accelerometer the records of which are too laborious to analyse for any long period of time. The continuous recording accelerometer, however, is still regarded as an aid to interpretation of the counting accelerometer, for which purpose it is required for short initial period only.

5.2. The essential requirements for a counting accelerometer are as follows:—

(*a*) It must record accurately overall accelerations and reject local acceleration produced by vibration. This requirement may be expressed in the terms of response to sinusoidally varying acceleration. The critical figure is assessed at 2½ times the wing natural frequency, and accelerations below this have to be recorded accurately and above this have not to be recorded at all.

(*b*) The threshold which is recorded as having been crossed must have a small but finite width so that a slight unsteadiness of acceleration is not recorded as a major change. The required width of the threshold is assessed tentatively at 0·1*g*.

(*c*) There must be no risk of any crossing of the threshold being, on the one hand, not recorded or, on the other hand, being registered as two or more crossings.

5.3. A design of accelerometer is described which has been established as meeting the above requirements. It has two forms, mechanical and electrical. The mechanical is recommended as the better for routine statistical work. Its principles are described in detail and it is illustrated in Figs. 4 to 7. The electrical is of value for checking the mechanical and has also the advantage that it can be easily converted for continuous recording. The weight of the mechanical one is 12 lb, but the corresponding electrical one is 50 lb.

REFERENCE

No.	*Author*	*Title, etc.*
1	J. Taylor	Characteristics required for accelerometers for measuring low frequency accelerations in flight. A.R.C. 13,156. May, 1950.
2	J. Taylor	Accelerometers for determining aircraft flight loads. *Engineering*. April 11th and 18th, 1952.

TABLE 1

Part of Counting Accelerometer Record taken on Viking VW217

Recorded time in minutes	Average Speed in tens of knots	Average Height in thousands of ft	Number of times thresholds of accleration crossed* 0·5g to 0·6g	0·6g to 0·7g	0·7g to 0·8g	0·8g to 0·9g	0·9g to 1·0g	1·0g to 1·1g	1·1g to 1·2g	1·2g to 1·3g	1·3g to 1·4g	1·4g to 1·5g	Remarks
1280–1290	00	00			13	132	491	447	105	11			On ground
1290–1291	00	00				4	29	18	4	1			
1291–1300	13	06				5	22	35	19	4	2		
1300–1310	14	08					0	2	1				
1310–1320	14	08					1	0					
1320–1330	15	08					1	1					
1330–1340	14	08					0	1					
1340–1350	15	08					9	12					
1350–1360	14	08	1	1	5	13	68	56	6	3	2		
1360–1370	14	08		1	8	48	145	140	31	2	1		
1370–1380	15	08	1	1	3	17	77	72	11	1			
1380–1390	15	08					12	7					
1390–1400	15	08				1	18	14					
1400–1410	15	08				2	49	42	3				
1410–1420	16	08				4	60	56	3				
1420–1430	15	06					0	0					
1430–1440	15	03					10	18					
1440–1450	15	01			1	3	23	36	0				
1450–1460	00	00	4	21	89	248	523	442	206	79	30	10	Also 3 crossings of the 1·5 to 1·6g threshold On ground
1460–1470	13	01			6	36	118	127	37	7			
1470–1476	13	01		1	3	13	46	77	29	5			
1476–1480	00	00	3	11	29	83	175	163	74	35	12	1	On ground

* One count is made when a threshold has been crossed once in each direction.

TABLE 2

Ranges of Acceleration in Flight

Approximate Conditions

Viking VW217 with take-off weight of 32,000 lb.
$26\frac{1}{2}$ hr recorded flying time from Farnborough to Fayid and return.
140 knots at 8,000 ft.

Number of Thresholds of Acceleration Crossed

Accel. in *g*'s	0·4 to 0·5	0·5 to 0·6	0·6 to 0·7	0·7 to 0·8	0·8 to 0·9	0·9 to 1·0		1·0 to 1·1	1·1 to 1·2	1·2 to 1·3	1·3 to 1·4	1·4 to 1·5
Counter readings	1	5	15	81	476	2821		2855	475	89	18	4

Corresponding Number of Ranges of Acceleration

Min. in *g*'s \ Max. in *g*'s	0·4 to 0·5	0·5 to 0·6	0·6 to 0·7	0·7 to 0·8	0·8 to 0·9	0·9 to 1·0	1·0 to 1·1	1·1 to 1·2	1·2 to 1·3	1·3 to 1·4	1·4 to 1·5	1·5 to 1·6
0·3 to 0·4								1	1			
0·4 to 0·5							1	4	2		1	
0·5 to 0·6						1	2	4	8	5		
0·6 to 0·7					6	4	22	66	23	7	4	
0·7 to 0·8						27	205	396	122	36	9	1
0·8 to 0·9							1976	2379	319	45	9	2
0·9 to 1·0								1956	267	37	3	2
1·0 to 1·1									39	6	2	1
1·1 to 1·2										6	2	
1·2 to 1·3												
1·3 to 1·4												2

TABLE 3

Ranges of Acceleration on Ground

85 min recorded time on Viking VW217 during journey from Farnborough to Fayid and return.

Number of thresholds of acceleration crossed

Accel. in g's	0·4 to 0·5	0·5 to 0·6	0·6 to 0·7	0·7 to 0·8	0·8 to 0·9	0·9 to 1·0		1·0 to 1·1	1·1 to 1·2	1·2 to 1·3	1·3 to 1·4	1·4 to 1·5	1·5 to 1·6	1·6 to 1·7	1·7 to 1·8	1·8 to 1·9	1·9 to 2·0	2·0 to 2·1	2·1 to 2·2
Counter readings	1	25	155	745	2382	5872		4826	1890	538	178	45	13	2	2	2	2	1	1

Corresponding Number of Ranges of Acceleration

Min. in g's / Max. in g's	0·4 to 0·5	0·5 to 0·6	0·6 to 0·7	0·7 to 0·8	0·8 to 0·9	0·9 to 1·0	1·0 to 1·1	1·1 to 1·2	1·2 to 1·3	1·3 to 1·4	1·4 to 1·5	1·5 to 1·6	1·6 to 1·7	1·7 to 1·8	1·8 to 1·9	1·9 to 2·0	2·0 to 2·2	2·2 to 2·4
0·3 to 0·4													2					
0·4 to 0·5									3	10	22	10	3					
0·5 to 0·6									47	104	87	20	2					
0·6 to 0·7							4	75	548	415	115	20	2					
0·7 to 0·8						2	103	1396	1517	207	28	8	12				1	
0·8 to 0·9							2295	4114	524	33	10	4	1				1	2
0·9 to 1·0								288	16	3	2							
1·0 to 1·1																		
1·1 to 1·2																		
1·2 to 1·3											1	1						

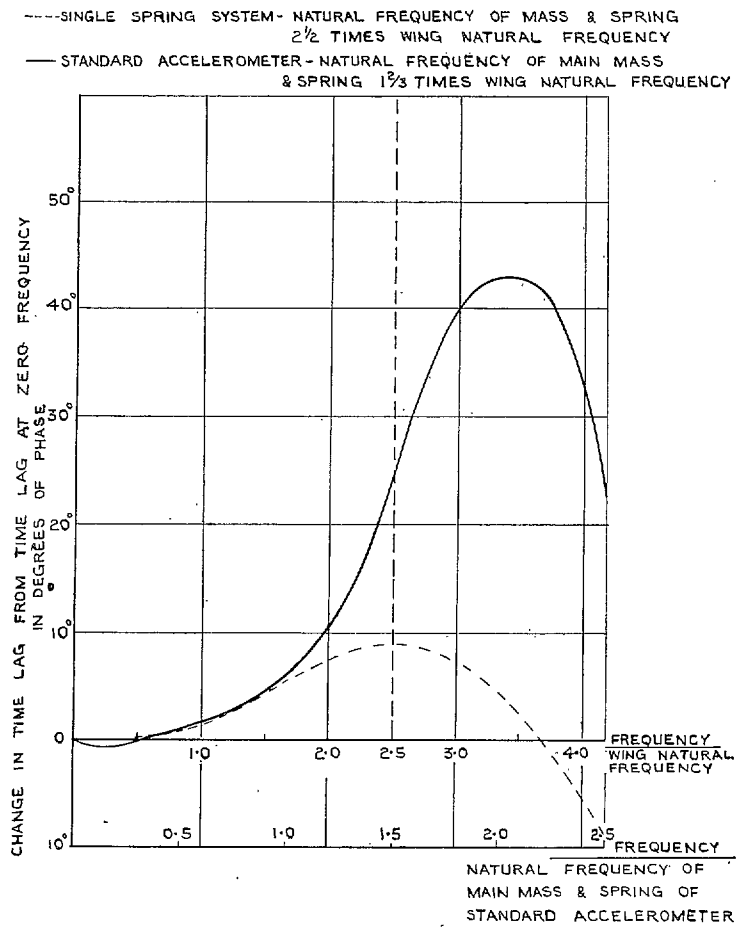


FIG. 1. Standard accelerometer change in time lag.

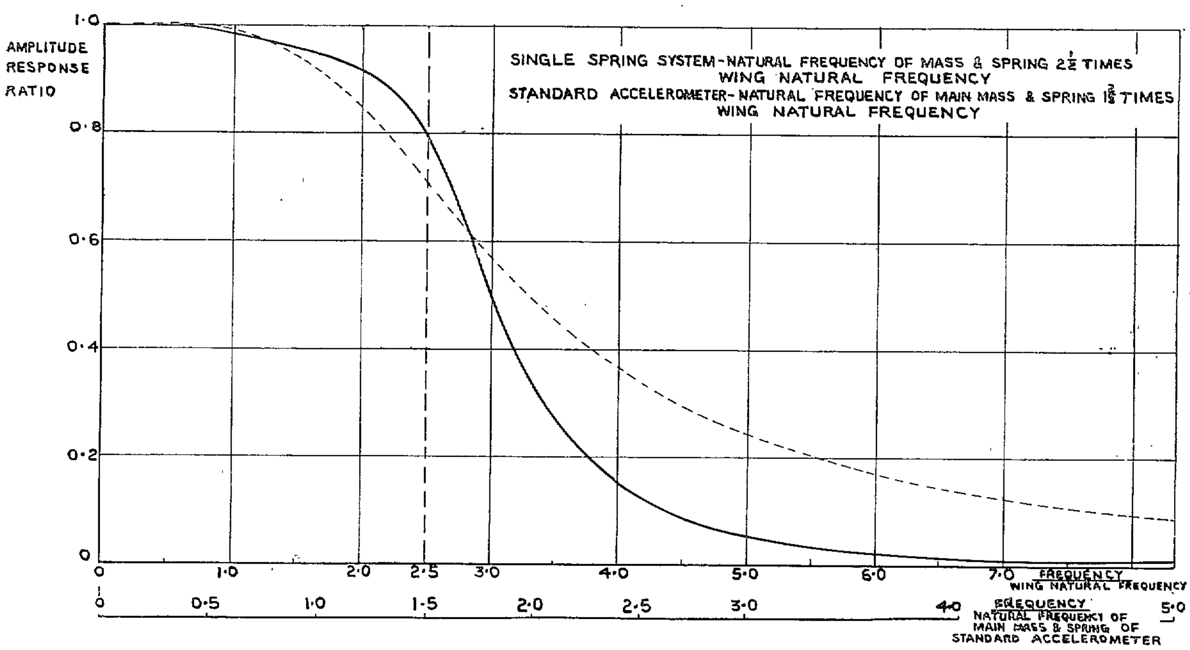


FIG. 2. Standard accelerometer. Amplitude response ratio.

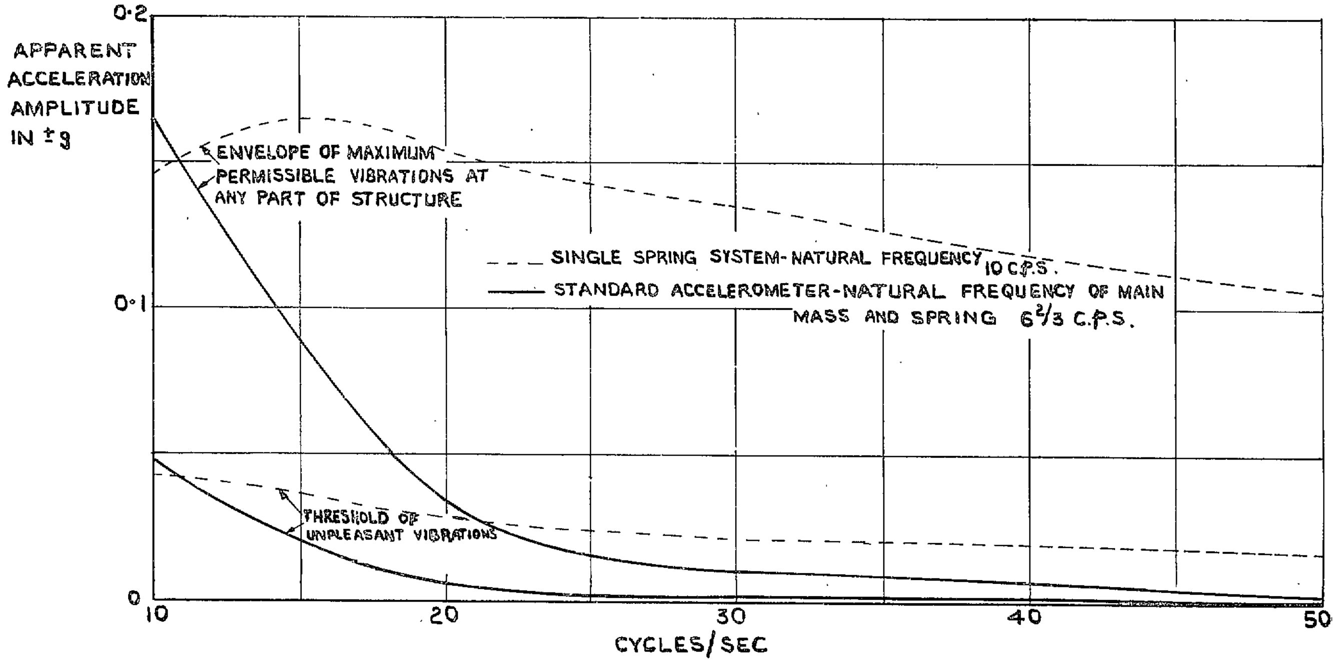


Fig. 3. Standard accelerometer. Apparent acceleration under vibration. (Accelerometer for use on wings with natural frequency 4 cycles per second.)

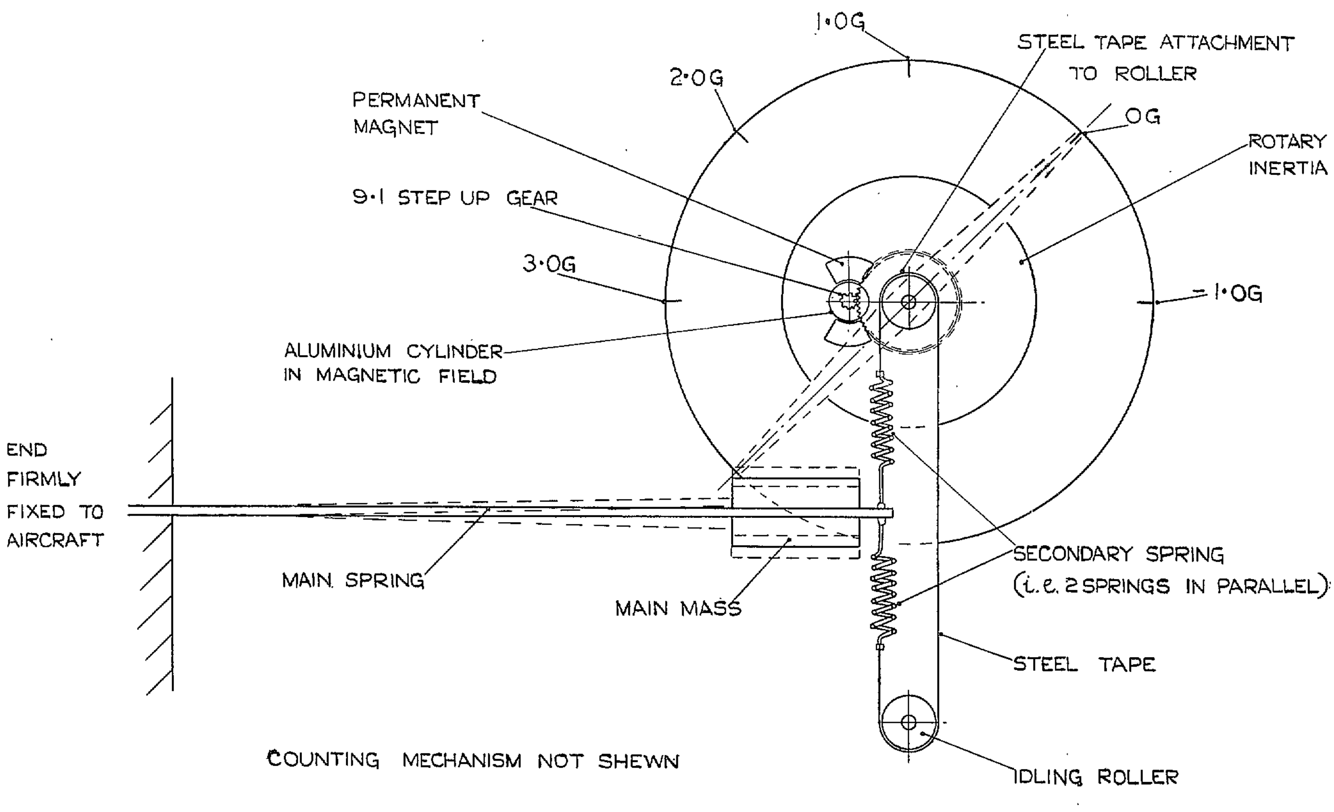


Fig. 4. Diagrammatic sketch of a counting accelerometer.

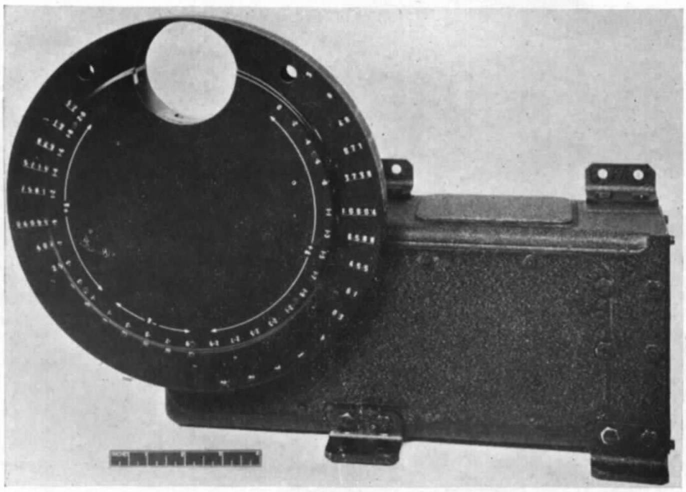


Fig. 5. Counting accelerometer.

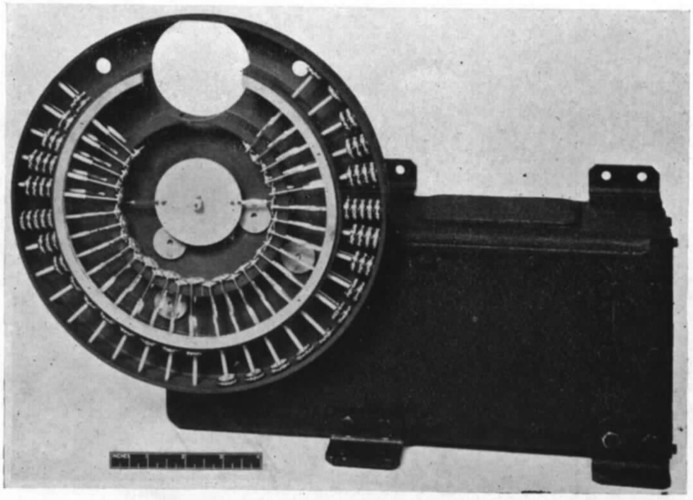


Fig. 6. Counting accelerometer with front cover removed.

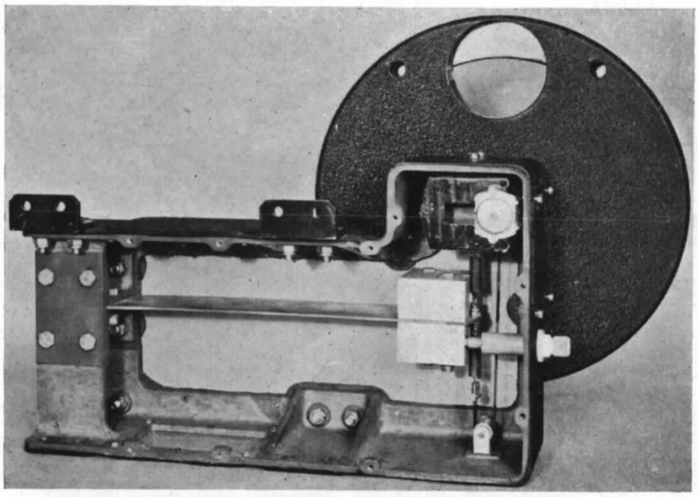


Fig. 7. Counting acclerometer with back cover removed.

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