SYMPOSIUM ON VIBRATIONS IN HELICOPTERS*

(AFTERNOON SESSION)

On Saturday, January 27th, 1951, the Association held a symposium on the practical approach to vibrations in helicopters, in the Library of the Royal Aeronautical Society, at 4 Hamilton Place, London, W 1

Opening the afternoon session, Mr N E Rowe, who presided, said We were to have had a paper on " The Measurement of Vibration " by Mr M O W Wolfe, of the Royal Aircraft Establishment, but unfortunately he is suffering from influenza Dr G E Bennett, however, has kindly come forward to give us more or less an impromptu talk on the measurement of vibration

We shall then have a paper by Mr R H Warde, of the Air Registration Board , and to complete the picture from the airworthiness point of view, Mr J K Williams, also of the Air Registration Board, will present a short paper on the question of fatigue So that the airworthiness considerations which arise will be covered adequately

The Measurement of Vibration.

By Dr G E BENNETT (Instrumentation Dept , R A E)

I wish to make a few general and rather basic remarks on the present-day knowledge of the instrumentation of vibration, in order to get an appreciation of the problem of the measurement of vibration in helicopters I take my cue from the emphasis which has been laid by earlier speakers on the importance of very low frequencies, and I shall emphasise the instrumentation for these very low frequencies

When thinking of frequencies of the order of 2-3 c/s, one very naturally has in mind practices in civil engineering and ship engineering and the type of instrument which has been used in those fields for the measurement of low frequency vibration In particular one thinks of the type of vibrograph made by the Cambridge Instrument Company which gives a direct record of vibration on celluloid In connection with vibration measurement in helicopters, however, one must have regard to the weight and size of the instrument The order of size of the Cambridge vibrograph is about 1 cu ft , and it will be appreciated immediately that this cannot be applied to measurement in helicopters The same objection in respect of weight and size applies, although to a very much less degree, to the R A E vibrograph, which gives a record on photographic film The other limitation of that instrument is that it is not suitable for frequencies below about 10 c p s

One is therefore forced, possibly very reluctantly, to consider for this work the use of a vibration pick-up in conjunction with an amplifier and a galvanometer or cathode ray tube recorder This may appear very regrettable to many of you, but there is no other alternative, and in any case, with the present state of the art, an instrument of this type is not as formidable as one might think

* The first half of " Symposium on Vibrations in Helicopters was published in No 4, Vol 4 (Jan Feb March, 1951) issue of this Journal

For ground resonance tests on helicopters the pick-up presents very little difficulty It consists of a cylindrical permanent magnet and pole piece, which may be heavy and bulky, fixed securely to the ground, and a light coil attached to the vibrating member and arranged to move freely in the gap of the magnet The relative movement of the coil and magnetic field is then equal to the movement of the point of attachment, and a voltage is generated across the coil proportional to the vibration velocity

For flight tests there is a problem in arriving at a suitable type of pick-up There are two possibilities, both of which, of course, must consist basically of a mass suspended on a spring The first possibility is a pick-up which has a natural frequency lower than the lowest frequency it is required to measure—commonly called a vibration pick-up The second possibility is a pick-up having a natural frequency higher than the highest frequency to be measured, an acceleration pick-up In the one having the low natural frequency the amplitude of the suspended mass is, ideally, equal to the amplitude of the vibration On the other hand, in the accelerometer the amplitude of the mass is proportional to the applied acceleration The usable frequency ranges of both the vibration pick-up and the accelerometer are determined by the value of the natural frequency, by the damping present and by the accuracy required for the amplitude and possibly for the phase measurement

There are two cases when the measurement of phase may be relevant The first case, and the obvious one, is when it is necessary to phase two or more vibrations or one vibration with respect to something else Secondly, phase is important when measuring a complex vibration with various harmonics There, if the phase error in the instrument varies with frequency, the various components of the vibration will be subjected to different time lags, and their summation will be quite different from the actual vibration being measured

For the vibration pick-up and when dealing with frequencies, say, below 1,000 c/s, the error lies at the low frequency end The extent of this error can be seen from the familiar family of response curves for a system of 1 degree of freedom consisting of a mass spring and velocity damping The best degree of damping for amplitude measurement is about 0 65 critical To take an example, if one wished to record down to 3 c p s with an error of $\pm$ 5 per cent , one would require an undamped natural frequency of about 2 4 c p s and a damping of 0 65 critical So that, to measure these low frequencies, the natural frequency of the measuring device must be very low indeed

On the other hand, with the accelerometer the error lies at the high frequency end, and one can again determine its extent from the familiar family of response curves for various degrees of damping In this case also the optimum damping for accurate amplitude response is about 0 65 critical, and if one wanted the error to be within $\pm$ 5 per cent with this damping the upper limit of frequency measurement would be about 0 8 times the undamped natural frequency of the pick-up For example, for measuring 20 c p s a natural frequency of 25 c p s would be needed, and that is very easy to obtain in a compact instrument

The other consideration is phase displacement in the instrument For the vibration pick-up the phase error is very large, except at zero damping, which cannot be used owing to the large amplitude magnification for this condition In the case of the accelerometer, however, if the damping is about 0 75 critical, the phase angle varies approximately with the frequency , *i e*, the time lag in the accelerometer is independent of frequency, and the signal, whatever its form, is merely displaced along the time axis and is not in any way distorted The position is therefore very much better in the case of the accelerometer With a damping of 0 65 to 0 75 critical, the errors in both amplitude and phase measurement are small for the frequency range zero to about 0 8 times the undamped natural frequency

It is thus seen that the accelerometer has some very important advantages for measurements at these very low frequencies It is difficult, if not impossible, to design a reasonably small vibration pick-up to have a natural frequency of the order of 1 or 2 c p s , as would be required There are a number of disadvantages in the use of such a very flexible spring mass system, and I will mention one or two of them With such a flexible system the static deflection of the spring is very large, and it would be difficult to get a spring which would deflect linearly to that extent Also, if the pick-up were required for the measurement of vibration in both the vertical and the horizontal directions, it would have to be designed to accommodate the static deflection of the spring, which at these very low frequencies may be of the order of 1 inch So that these very low frequencies do present problems which inevitably result in a pick-up which is very large and heavy

There are three possibilities for a spring of very low natural frequency One may use a circular diaphragm or spider spring with cut-outs to make it more flexible, and with the mass attached to the centre Such springs are very fragile and are liable to fail by fatigue , also, they tend to have a number of secondary resonances in the operating frequency range of the pick-up The second possibility is to use a helical spring In this case it is necessary to introduce a constraint so that the mass has one degree of freedom only

It is difficult, in a small design of pick-up, to give constraint without introducing friction into the system The third possibility is the use of a cantilever spring or a pendulum, but again this tends to increase very seriously the size of the pick-up This is the type of spring that is actually used in the kindred instrument, the vibrograph Further, with a very flexible spring it is very difficult to keep to a reasonable percentage of cross sensitivity of the pick-up, *i e*, the sensitivity of the pick-up to vibrations perpendicular to its operating axis

It therefore appears that for the measurement of low frequencies there is a strong case for the use of the accelerometer

In conclusion, I wish to mention one or two points about the electrical characteristics of these pick-ups The most popular type of vibration pick-up is the electro-magnetic generator, and there are two or three designs available in this country having a natural frequency in the region of 10 c p s The resistance, inductance and capacitance changes have not been used to any extent for vibration pick-ups because of the large static deflection The generator type is velocity responding, so that when the pick-up is at rest there is no output In the resistance, inductance and capacitance types, however, there will be a datum value of the parameter relating to the position of the pick-up when at rest This is not so serious in the case of the accelerometer, which is frequently of the resistance, inductance or capacitance type

For the frequency range of interest in helicopter vibration the popular acceleration pick-ups are the resistance and the inductance types

A typical design of inductance pick-up now available has ranges from 1G up to about 15G For a range of $\pm$ 12G it has a natural frequency of about 180 c p s Thus, it can be used at least up to 150 c p s The problems of design are comparatively easy, and the pick-up can be made very small

Of the types of resistance pick-ups I would refer to the unbonded fine wire type, which contains a complete Wheatstone bridge made up of very fine wires, the wires themselves forming the spring of the accelerometer The vibration produces strain in the four arms of the resistance bridge, which gives an output from the accelerometer proportional to the applied acceleration The main advantage of this type of pick-up is that at these low frequencies, it possesses sufficient sensitivity for use directly with a low frequency vibration galvanometer and a camera, without the use of an amplifier There is thus the possibility of making a very simple instrument using the unbonded resistance accelerometer to cover the range of (say) 1-50 c p s , for helicopter work

Finally, I should mention briefly the electrical circuits used with vibration and acceleration pick-ups The electromagnetic generator vibration pick-up gives a voltage output proportional to velocity, whilst the bridge circuit associated with a resistance or inductance acceleration pick-up gives a voltage output proportional to acceleration For a signal proportional to amplitude, therefore, a vibration pick-up requires one stage of electrical integration and an accelerometer two stages An electrical integrating circuit may consist of a straightforward resistance-capacitance network or a negative feedback amplifier in which the feedback is controlled by a resistance-capacitance differentiating circuit In the former case there are phase and amplitude errors at the low frequency end, and in the latter case errors exist at both the high and low frequency ends The required accuracy at the two extreme frequencies is attained by suitable choice of the electrical time constants and the degree of feedback For a limited frequency range, say 1 to 50 c/s, this choice presents very little difficulty, and is in general far more practical than attempting, in the design of the vibration pick-up, to overcome the phase and amplitude errors at frequencies in the region of one c/s

Airworthiness in the Presence of Vibrations

By R H Warde (Air Registration Board)

Introduction

Before dealing with the subject of airworthiness in the presence of vibrations, I would like to make it clear that all my remarks refer to civil type helicopters, for which a Certificate of Airworthiness is required

Turning now to the actual Requirements for the airworthiness of helicopters, the Air Registration Board, in December, 1949, made a provisional issue of Section G (Rotorcraft) of British Civil Airworthiness Requirements The following quotations indicate clearly their provisional nature

"This issue of Section G is to be regarded as provisional only, pending the accumulation of more knowledge on the behaviour of