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THE COMPACTION OF POWDERS BY VIBRATIONS - PRELIMINARY RESULTS

by

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SUMMARY

The compaction of dry powders by vibrations likely to be encountered by dry powder extinguishers in service (peak accelerations up to 2.0 g n, frequencies in the range 10 Hz to 100 Hz) has been studied. Preliminary results indicate that higher levels of compaction than can be achieved by these vibrations result from impacting the container of powder onto a rigid surface, at a frequency of 1 Hz, from a height of 1.5 cm. Further study of the problem is recommended.

KEY WORDS Dry powders; compaction; vibration.

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DEPARTMENT OF THE ENVIRONMENT AND FIRE OFFICES' COMMITTEE
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1. INTRODUCTION

Dry powders are often stored where they may be subjected to vibrations, such as in buildings where there is heavy machinery, and on vehicles or ships. These vibrations, if of appropriate amplitude and frequency can cause consolidation or "packing" of the powder which in turn will have an adverse effect on the performance of the extinguisher when it comes to be discharged. Even if an extinguisher is not normally subjected to vibration, normal handling and maintenance work can result in the extinguisher being set down heavily on the floor or other surface. If this is repeated a number of times consolidation of the powder can result.

An international standards co-ordinating committee, the Comité European de Normalisation has set up a Tripartite Sub-committee ("CENTRI 2") to study the problems associated with European standards for portable fire extinguishers. One of the features under discussion is the possibility of specifying a compaction test for dry powder extinguishers which will take into account the suitability of such extinguishers for use in the conditions outlined above. This note reports some preliminary studies which provide background information for the further development and specification of such a compaction.

2. EXTINGUISHING INFORMATION

A review[1] of vibrations likely to be encountered in practice showed that the lowest levels of vibrations are met with in buildings (accelerations (G) up to 1.0g_n at 8-35 Hz) and ships (accelerations (G) up to 1.5g_n at 50-80 Hz). Vibrations found in road vehicles vary with the type of vehicle, road surface and location on the vehicle. Vibrations likely to be encountered by items attached to bodywork or located in storage spaces are at frequencies in the range 10 Hz to 100 Hz and accelerations up to 2.0g_n.

Vibration tests currently included in various national standards for dry powder extinguishers are summarized below:

(a) French standard vibration test[2]

In this test, the charged extinguisher is submitted to vibrations at 20 Hz and 'amplitude' 0.8 mm for 15 minutes before being subjected to a discharge test. It is understood that the 'amplitude' is here defined as the 'peak to peak' displacement. If this is so, then the peak acceleration in this test is 0.64 gn.

(b) USA Navy vibration test[3]

In this test, the charged extinguisher is subjected to vibration at 20 Hz and an 'excursion' of 1.27 mm (0.05 in) for 10 minutes before being subjected to a discharge test. If 'excursion' is synonymous with 'peak to peak' displacement then the peak acceleration in the Test is 1.02 g n.

(c) Canadian Impaction Test[4]

In this test the extinguisher is impacted by dropping from a height of 15.9 ± 0.254 mm (0.625 ± 0.01 in) at 0.42 Hz for 10 minutes before being subjected to a discharge Test.

Evans and Millman[5], amongst others, have investigated the effect of vibrations on the packing of powders, mainly with the object of increasing the packing density for specific purposes, e.g. powder metallurgy. The powders used have been largely artificial blends of different coarse sizes. Evans and Millman noticed that maximum compaction often occurred within a few minutes and reported that the greatest increase in packing density occurred at or around certain fixed frequencies which they assumed to be resonant frequencies of the systems used, and therefore to be dependent upon the apparatus and powder used.

Suzuki, Takahashi and Tanata[6] present a theoretical relationship between the amount of packing and the peak acceleration of the vibrations, based on a consideration of the motion of a single 'ideal' particle on a vibrating plate. Their equation is:

$$(1-e) = (1-e_o) + 0.073 \left[\frac{\phi\ (G)}{G^2-1} \right]$$

where $\phi\ (G) = \sqrt{G^2 + 1 - 2G \sin 2\pi n_1} + G \cos 2\pi n_1$

e = voidage of compacted bed, i.e. $(1-e)$ = solids fraction.

e_o = voidage of uncompacted bed.

G = peak acceleration (gn)

n_1 = the dimensionless time (ft_1) at which the particle falls on the vibrating plate.

Using this, they predicted a maximum value of (1-e) at a peak acceleration of $G = 2.5 g_n$. Experiments with coarse sand and calcite particle sizes 0.4 mm to 1.5 mm) in containers 12 cm diameter 19 cm high largely confirm this prediction. At $1 < G < 2.5$ compaction was greater at 20 Hz and 30 Hz than at 50 Hz. For $G > 2.5$, (1-e) assumed a constant value, independent of frequency.

3. EXPERIMENTAL PROGRAMME

The experimental programme, of which some preliminary results are reported here, includes an investigation of the following factors.

(1) Container (extinguisher) dimensions. (Diameters in the range 60 mm to 180 mm).
(2) Powder, characterized by chemical composition and size distribution.
(3) Frequency of vibration. Range 10 Hz to 100 Hz.
(4) Peak acceleration. Range $0.8 g_n$ to $2.0 g_n$.

The experiments are intended to indicate the conditions of vibration under which maximum compaction can occur for particular powders. Full scale model extinguishers constructed from transparent materials can then be charged and subjected to these vibrations. The behaviour of the powder when discharged from the model extinguisher will then be studied.

Concurrently with the vibration programme, the compaction of similar samples of powder when subjected to impaction by dropping the container vertically onto a solid surface, is being studied.

4. APPARATUS AND PROCEDURE

The powders used are described in Table 1. They were contained in a graduated transparent 'Perspex' tube 63 mm inside diameter, 75 mm outside diameter, 220 mm high attached to an aluminium base plate. This assembly was rigidly fixed in the vertical position to the centre of a horizontal electromagnetic vibrating table. A given weight of powder was carefully poured into the container and lightly compacted to a predetermined level by gently tapping the side of the container. This level was chosen to be lower than that resulting from the pouring of the powder yet not low enough to intrude substantially into subsequent packing by the vibrations. Having established this initial constant level, the container was sealed and vibrated under the appropriate conditions. Packing was substantially complete after five to ten minutes but most samples were vibrated for 15 minutes, and a few for 20 minutes, before constant levels were established. The final level was read after the vibrations had been stopped. The experiments were divided into short series, each at a given frequency and consisting of experiments made at 0.8, 1.0, 1.5 and $2.0 g_n$. Fresh powder was used for each series. Between each experiment in a series, the powder was loosened by shaking and re-distributed by inverting the container a number of times before re-establishing the initial level.

Experiments were also made in which identical samples of powder were compacted by impaction. The container, held in the upright vertical position, was arranged to fall onto a rigid steel plate from a height of 1.5 cm at frequencies of 0.2 Hz and 1.0 Hz for a time of 8 min 20 s, the total number of impactions being 100 at 0.2 Hz and 500 at 1.0 Hz.

5. RESULTS

The results are reported in terms of frequency (Hz) and peak acceleration (g_n). These qualities are related to the amplitude of vibration by the following equation.

$$G = \frac{0.4\pi^2 \, af^2}{981} = 4.02 \times 10^{-3} \, af^2$$

where G = peak acceleration (g_n)
a = amplitude, i.e. ½ peak to peak displacement (mm)
f = frequency (Hz)

The degree of compaction is expressed as the ratio (R)

$$R = \frac{\text{bulk density after vibration}}{\text{bulk density before vibration}}$$

Values of 'bulk density before vibration' are shown in Table 1.

The results of the vibration experiments with the three powders investigated so far are shown in figs 1, 2 and 3 in which R is plotted against frequency and peak acceleration. The results of the impaction experiments are shown in fig. 4. The values of maximum compaction achieved are summoned together with the conditions under which they occurred, in Table 2.

It was observed, during the vibration tests, that under certain conditions 'fluidization' of the powder appeared to occur. This was most pronounced with powders 1 and 3 and occurred most frequently at 40 Hz with a few instances at 30 Hz. The conditions under which this 'fluidization' was observed are summarized in Table 3.

6. DISCUSSION

It can be seen from figs 1, 2 and 3 and from Tables 2 and 3 that the highest levels of compaction are associated with the incidence of 'fluidization' during part or the whole of the vibration period. It is probable, as suggested by Evans and Millman[5] that the powder is 'excited' by a resonance phenomenon at frequencies peculiar to the particular equipment and powders used. Under these conditions the powder particles may become momentarily separated, thereby reducing interparticle friction and enabling the particles to re-orient themselves into a closer packing geometry.

When the powders were compacted by impaction this phenomenon did not appear to occur. The higher levels of compaction that occurred, therefore, could be regarded as being the result of a different packing mechanism. When the container comes to rest on the rigid steel plate, the powder is subjected to high deceleration forces, sufficient to overcome the interparticle friction forces, thus forcing particles one past the other into closer packing geometries. Figure 4 and Table 2 showed that even though maximum compaction has not reached in some cases, the levels of compaction achieved at 1.0 Hz were always higher than those for vibrated powder.

The prediction of Suzuki et al[6] cannot be tested with the present results since the maximum acceleration investigated was 2.0 g_n. Examination of figs. 1 to 3 reveals that there is a tendency for the curves to flatten and possibly maximize at 1.5 to 2.0 g_n. Further experiments at 2.5 and 3.0 g_n, although not within the range of conditions thought to be of immediate interest would be valuable since levels of compaction even higher than those achieved by impaction may be encountered. The frequency at which these experiments should be made is clearly in the range 30 to 50 Hz.

It can also be seen that as a general rule, the finest powders are compacted the most by both vibrations and impactions. The fine powders, 1 and 3, (see Table 1) have the lowest initial bulk density. Interparticle forces (gravitational and electrostatic) are more significant with very fine powders and result in low bulk densities. These forces are, however, overcome by vibrations, thus enabling the powders to compact.

7. CONCLUSIONS

For the three powders investigated, using the equipment described, the maximum compaction effected by vibrations occurs at a frequency of 40 Hz and peak accelerations of 1.5 to 2.0 g_n. Further experiments at 40 Hz, 2.5 and 3.0 g_n are recommended.

Higher levels of compaction than were achieved by the vibrations used in these experiments occurred when the powder was impacted by dropping the container onto a rigid surface. This technique should be investigated further since it offers a relatively simple method, which is likely to be as effective as vibration, for compacting powders.

It is possible that powders compact in different ways depending on whether the compaction is by vibration or impaction. This should be borne in mind when developing a compaction test. Discharge tests, using model extinguishers, should be made as powders compacted by both vibration and impaction before any compaction test is finally specified.

8. ACKNOWLEDGEMENTS

Mr. M. O'Hara and Miss S. P. Benson performed the experimental work reported in this Note.

9. REFERENCES

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Table 1

Weights and size distributions of powders used

	Powder		
	1	2	3
Weight used (gms)	460	800	555
Initial height (cm)	17	17.6	17.2
Initial bulk density (gm/cm^3)	0.87	1.46	1.035
Per cent by weight less than stated size			
125 µm	97.1	97.8	94.5
105 µm	95.2	94.5	91.7
90 µm	92.2	87.6	86.6
75 µm	86.4	73.5	81.0
53 µm	76.3	48.1	70.5
45 µm	74.4	44.8	68.8
30 µm	54.3	19.9	45.5
20 µm	40.4	9.4	30.3
10 µm	12	2	14.3

Size analysis by sieving

45-125 µm : BS 410 (1962) sieves
10-30 µm : Allen Bradley Sonic Sifter

Chemical composition of powders

Powder 1: Commercially available synthetic powder based on potassium bicarbonate

Powder 2: Commercially available standard sodium bicarbonate powder

Powder 3: Commercially available general purpose (ABC) powder based on ammonium phosphates

Table 2

Summary of maximum compactions achieved in vibration and impact tests

Powder	Maximum compaction achieved by vibration	Maximum compaction achieved by impaction
1	R = 1.25 at 40 Hz, 1.5 gn	R = 1.36 at 1 Hz
2	R = 1.09 at 30 Hz, 2.0 gn	R = 1.12 at 1 Hz
3	R = 1.23 at (40 Hz, 1.0 gn (80 Hz, 2.0 gn	R = 1.25 at 1 Hz

Table 3

Incidence of 'fluidisation' during vibrations

Powder	Period over which 'fluidisation' occurred at stated vibration levels		
	Initially	10 minutes	20 minutes
1	30 Hz, 2.0 gn 40 Hz, 1.0	40 Hz, 1.5 gn	40 Hz, 2.0 gn
2	40 Hz, 1.5 gn	40 Hz, 2.0 gn	–
3	30 Hz, 2.0 gn 40 Hz, 0.8, 1.0 gn	40 Hz, 1.5 gn	40 Hz, 2.0 gn

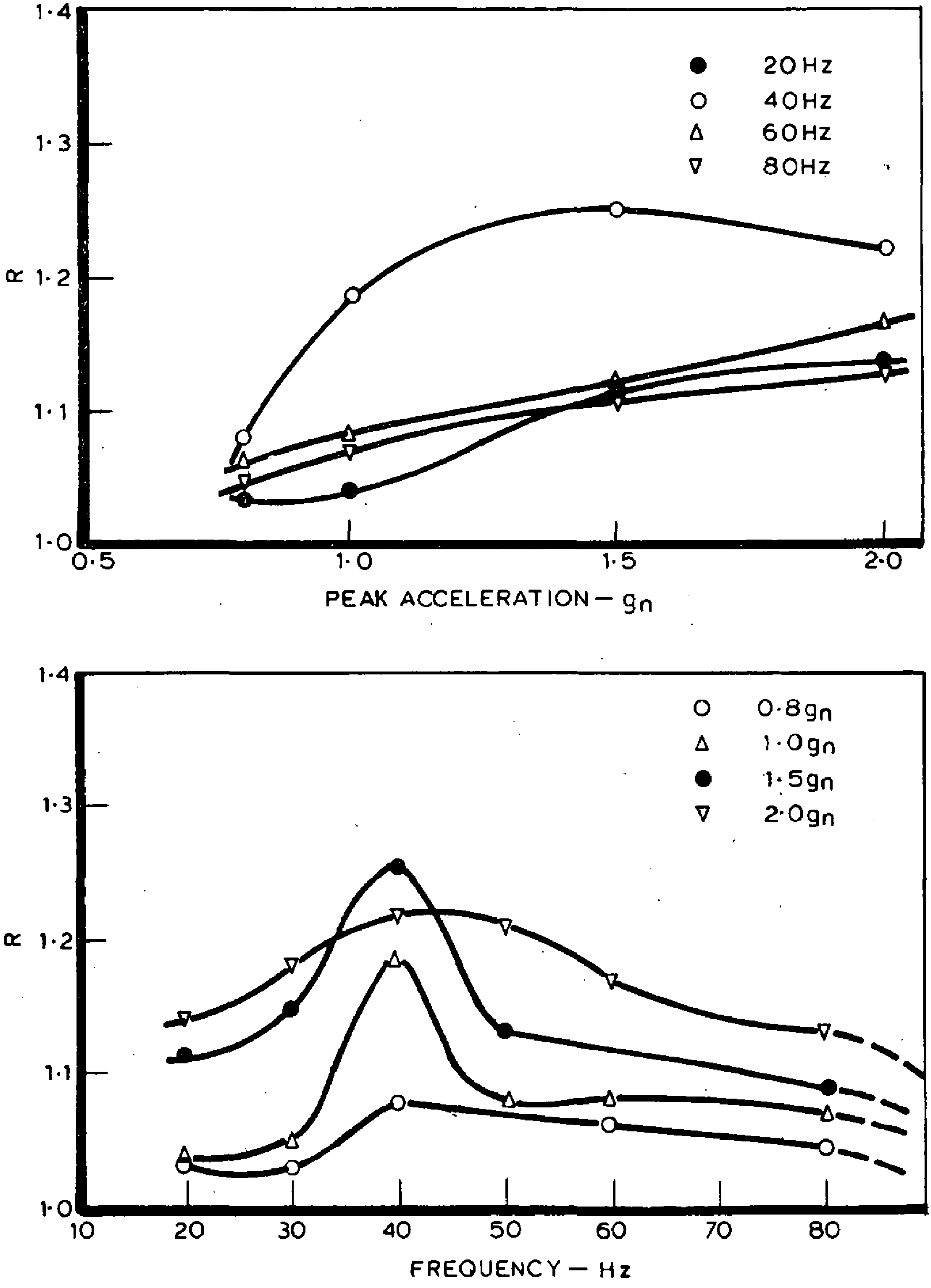

FIG.1 RESULTS OF VIBRATION TESTS – POWDER 1

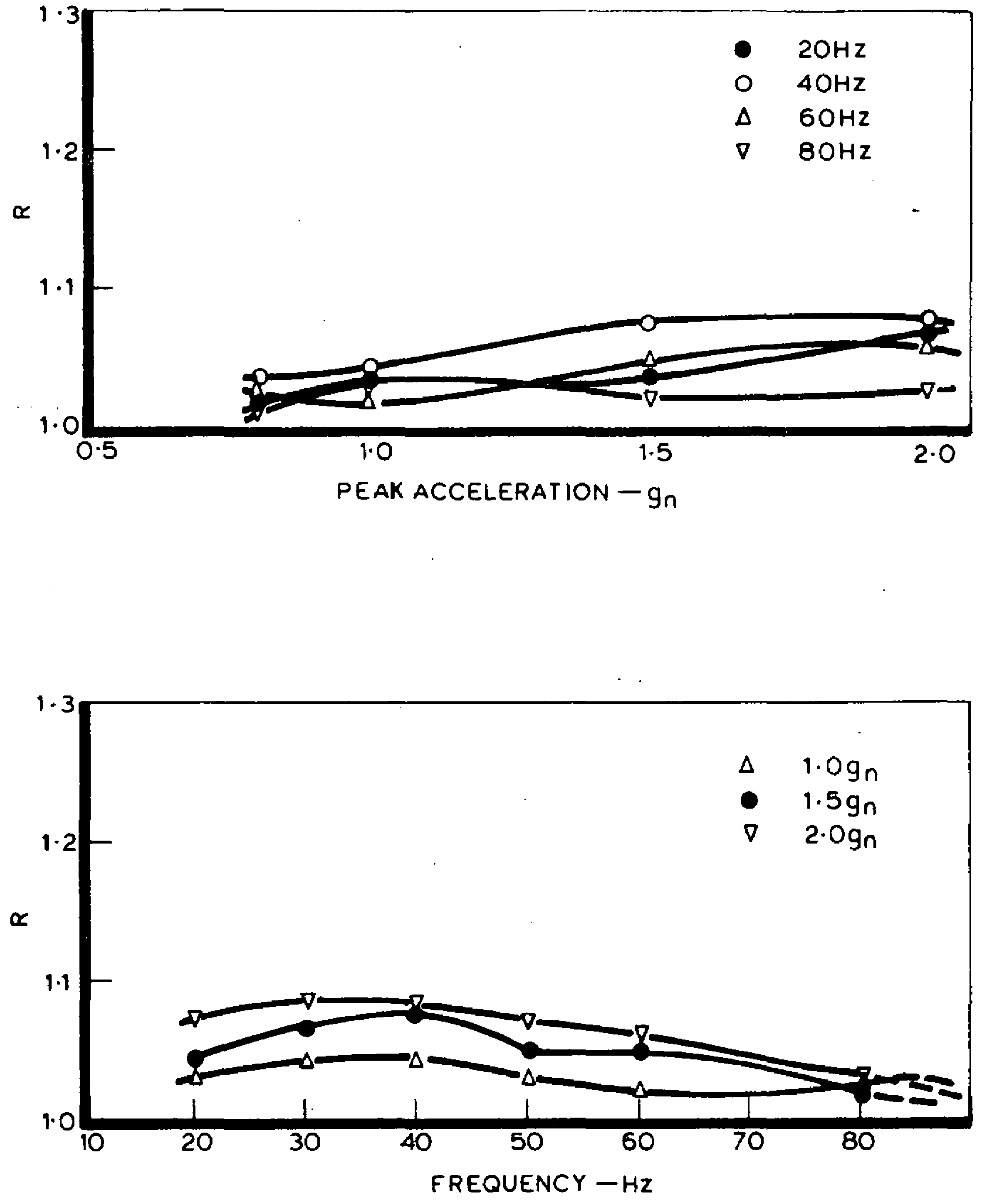

FIG. 2 RESULTS OF VIBRATION TESTS — POWDER 2

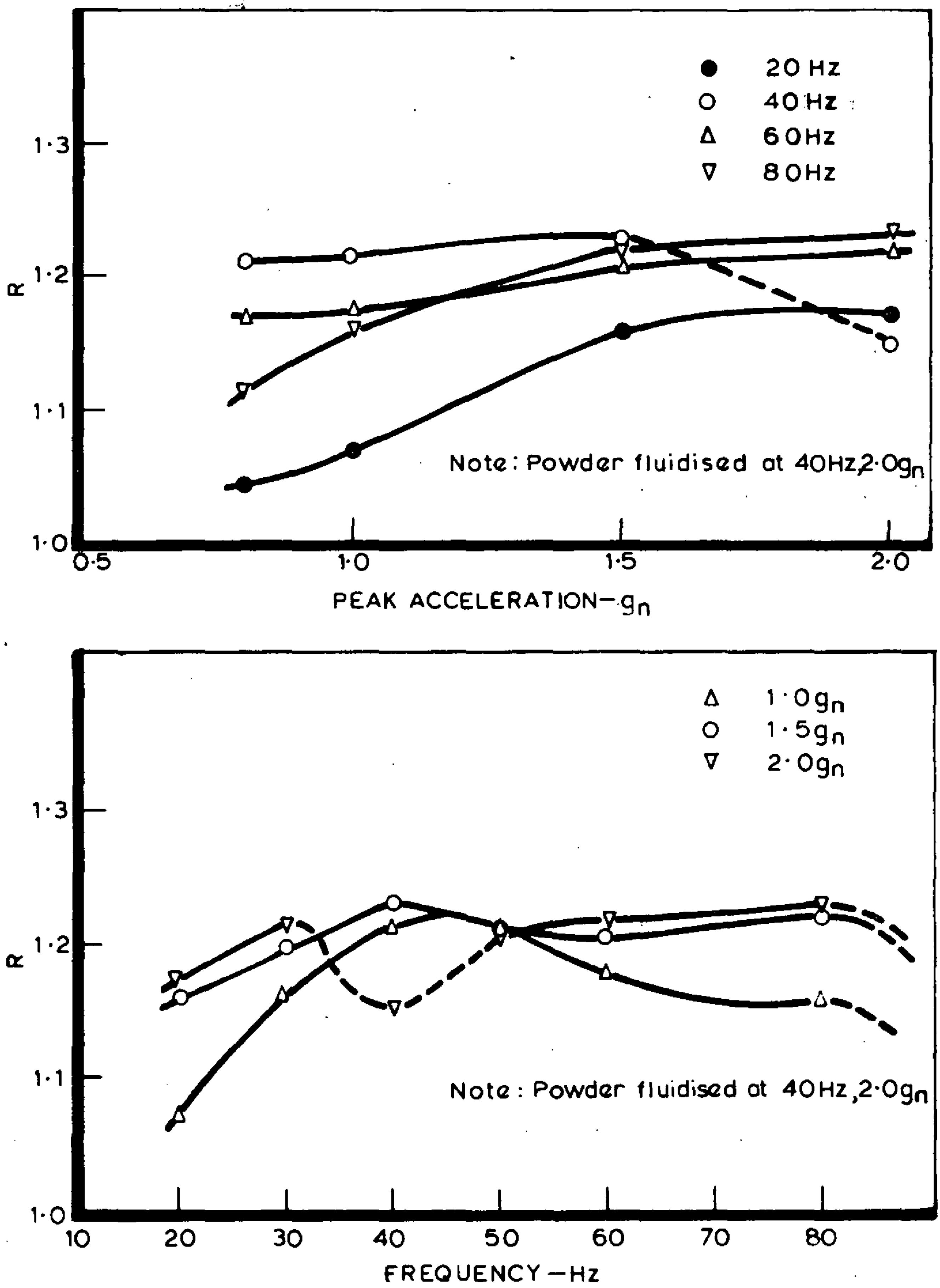

FIG.3 RESULTS OF VIBRATION TESTS– POWDER 3

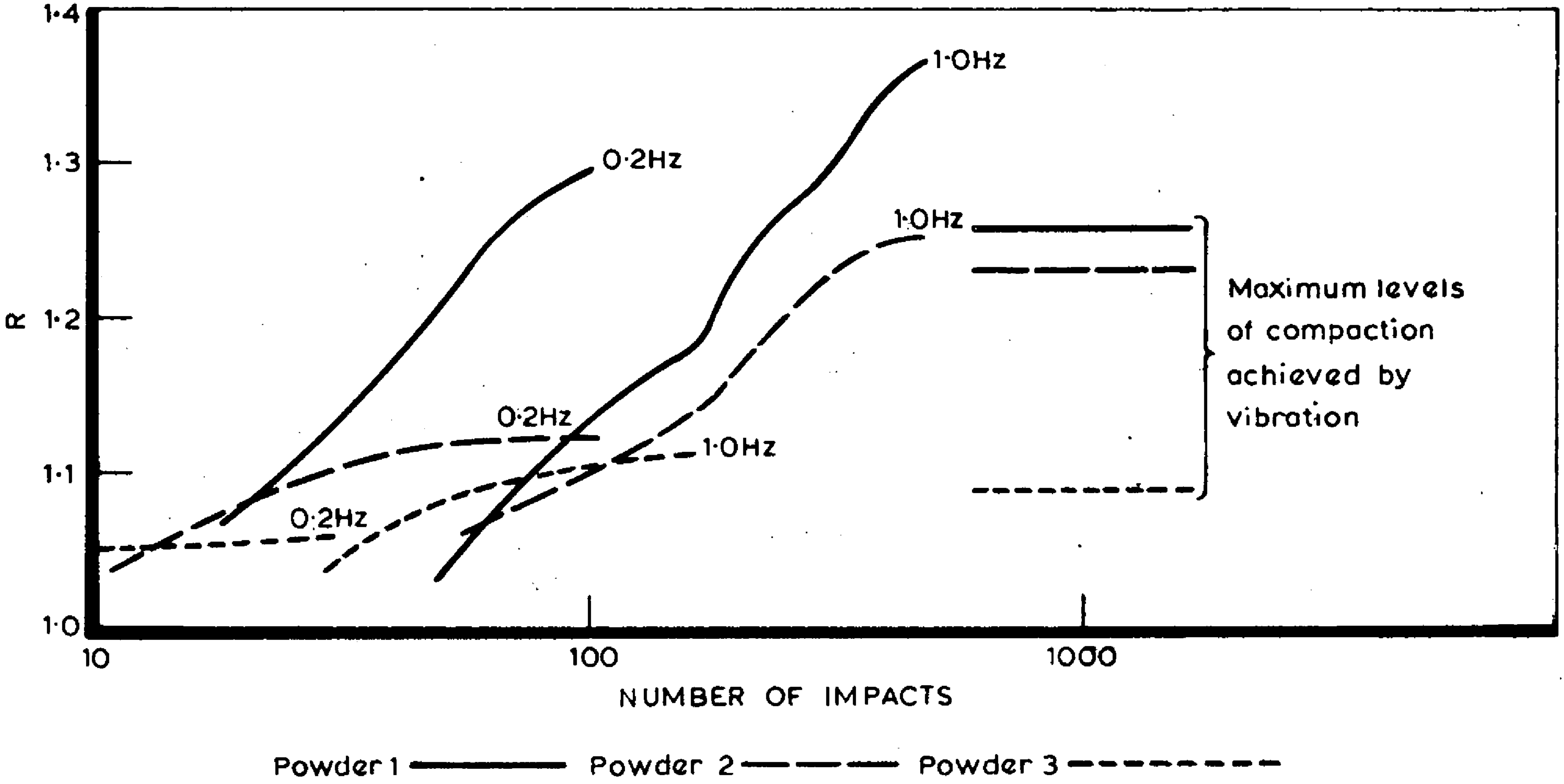

FIG. 4 RESULTS OF IMPACT TEST — ALL POWDERS