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VIBRATION LIMITS - the present codes & future changes

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Vibration signals derived from machinery may be detected, measured and adequately related to their sources as a result of pioneering work carried out in the U.K. and elsewhere. Signatures from new and freshly commissioned machines may be used as base data against which deviations resulting from service life may be compared. The characteristics of different deterioration modes have been established such that the techniques for their identification and monitoring may be suitably selected(1,2). But scant attention has yet been giving to the limiting conditions - the amount of vibration that is permissible and if exceeded can lead to disastrous consequences.

Vibration codes and standards do exist. There origin is somewhat obscure with evidence that they relate to qualitative assessments based on the operation of plant and machinery 40 or more years ago; at a time when there was a large measure of over-design and understressing, not at all comparable with modern operating conditions. Reliance on such codes is all that is available to the uninitiated operating engineer so that shut-down decisions may be reached on the basis of codes which are somewhat questionable.

Cash can be lost, businesses ruined, persons maimed and killed if the wrong decisions are taken.

Shut-downs on the slightest pretext and production, profits and cash lost. Ruin faces businesses which lose too much profit; ruin faces those which have horrific explosions as a consequence of delayed action. Safety is at risk if the right action is not taken in good time. But what fine judgment defines 'the right time'?

For the pilot of a multi-million pound aircraft with vibration alarms set at irresponsible levels there is little freedom of action - but the wrong alarm setting may mean falsity or disaster. For the manager of a pumping station it may merely mean the starting up of another pump if vibration levels seem high. But for the process manager who has a major machine with high vibration levels the decision of whether and when to shut-down can be very critical.

But who cares?

Certainly the study of limiting vibration levels is not likely to interest the manufacturers of monitoring equipment or alarm systems. It is most unlikely to appeal to plant manufacturers who are not even interested in the incorporation of monitoring systems in their basic designs.

The evaluation of good and proper vibration limits is a scientific study of the failure characteristics singular to each type of machine. It is of value to plant operators and their insurers. From such organisations some measure of guidance should be forthcoming. Is it?

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Vibration Threshold Levels.

Credit for the first systematic attempt to determine limiting permissible vibration levels is generally attributed to T.C.Rathbone (3) when in 1939 as Chief Engineer, Turbine and Machinery Division, Fidelity & Casualty Co. New York he used the subjective opinions of various engineers to grade machines according to whether they were rough or smooth-running. Not only was this appraisal subjective and related to relatively slow-running land-based machinery with sturdy foundations but by comparison with modern instrumentation the measurements were somewhat crude.

Ten years later, H.G.Yates produced criteria in a similar manner from a series of measurements on marine geared turbine installations (4). Comparison of these limits against those recommended by Rathbone were obscured by the differences in overall flexibility, mountings for the marine units in-situ and en-voyage being very different from those for land-based installations.

Downham and Woods (5) undertook a study of the operational limits associated with periodic checks for machinery at Shell Chemicals(UK) Limited and compared this with other criteria such as that of Rathbone and Yates. The results were in effect to modify the Rathbone criteria extended to the higher speeds of modern machinery but as later indicated by Downham (6) such charts are capable of demonstrable correlation to human discomfort thresholds and are not truly indicative of component failure limits (7)(8)(9).

Vibration Codes.

Standards and codes which have been issued as providing an indication of the acceptability of the quality of vibrations include:

VDI 2056 ; BS 4675.1971 ; ISO 2372 ; ISO 2373 : ISO 3945

That such criteria are suspect is inferred by the range of 'individual' standards which - in addition to those mentioned by Downham for Shell - include a wide range of diagnostic engineers and plant operators. It would be interesting to know what evidence was used as the basis for the current standards.

Thus in the preparation of the IRD 'general machinery vibration severity chart' it is understood that Nicholls (10) employed the influence of machine tools on the quality of finish in the manufactured parts as a basis for the severity threshold. Yet these are good and practical charts most suitable for the prudent plant operator.

Rationalisation of the Rathbone criteria by Maten (11) led to the limits recommended in Table 1.

In Australia, Ray Beebe (12) recommends the use of slightly different values as set out in Table 2.

Engine malfunction vibration levels for GMC Allison 501 Diesel engines (1) indicate a maximum of almost 1in/s vibrational velocity at all speeds which is rather higher than that considered acceptable for industrial machinery. But again, there is an absence of information for a definitive basis.

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TABLE 1 VELOCITY STANDARDS

Directly measured maximum velocity (in/s)	(mm/s)	Classification	Severity rating
>0·5	>12·7	AA	Extremely rough; dangerous; shut down
0·3–0·5	7·6–12·7	A	Very rough; correct within few weeks; check monitor frequently
0·2–0·3	5·1–7·6	B	Rough; correct to save wear as soon as possible
0,1–0·2	2·5–5·1	C	Fair; minor fault; uneconomical to correct
<0·1	<2·5	D	Smooth; well-balanced; well-aligned

TABLE 2 VIBRATION LIMITS, TURBINES (STIFF FOUNDATIONS)

	Good	Allowable	Just tolerable	Unsatisfactory
RMS velocity (mm/s)	<1·8	<4·5	<11·2	>11·2
50 Hz only displacement peak-to-peak (μm)	<16	>40	>100	>100
<10 Hz max. displacement (μm)	<80	<200	<500	≤500

Trends.

Vibration limits determined by definitive quantities tend to ignore the fact that changes have occurred in both the geometry and dynamics of the machine system during the course of its life, involving redistribution of energies and accordingly progressive changing trends in the various vibration levels of each component.

For the Canadian Navy, Glew and Watson (13) reported as far back as 1968 that the mean level of a signature component was a straight line with a positive slope for 75% of its life ; at the onset of critical failure the slope increased exponentially. How useful it would be if component manufacturers when carrying out life tests were to offer vibration monitoring measurements to provide a further basis for life monitoring (14).

Trends should not necessarily be measured only for the fundamental frequency, experiments by the author (15) to identify the onset of fatigue failure indicated that the second overtone (3 x fundamental) was the most sensitive failure indicator.

Specifications and Litigation.

It is an interesting reflection of the author's pioneer work and the increasing awareness of quality control/consumer entitlement that vibration limits are being specified in contracts - and enforced.

A situation was presented to the author in which an enterprising engineer obtained permission to establish a vibration monitoring unit in a new plant which incorporated a 25 MW gas turbine installation. While taking base-line signatures he found the rotors to have vibration levels of 0.45 in/s against specified values of 0.25 in/s. Despite considerable pressure to accept this rotor the variation from contractual stipulations was enforced and at least one rotor of value £ 0.25M was dismantled, returned to the manufacturer and a new (and acceptable) replacement supplied - all at considerable cost to the manufacturer by way of dismantling, transport, new rotor building and delay penalties. The purchaser lost by not having the facility available on time.

The defined vibration limits may have been proper. Or they may not. At any rate there is now one major manufacturer to whom vibration limits has a hard meaning.

Limit Setting - A Proposed Technological Approach.

The foregoing information has been submitted to demonstrate the argument that such limits as do exist are fixed on somewhat arbitrary - but practical - grounds which it is suggested can be more properly appraised by existing technical methods. It is submitted that:

1) the limits differ according to the identity of the critical component which is subject to failure

2) the limits depend upon the failure mode for that component or system of components

3) existing techniques of stress analysis and fracture mechanics can be satisfactorily adapted to perform these calculations and establish these limits.

Thus there is a difference between the criterion for a rotor shaft wiping plain bearings and one which causing fatigue in rolling element bearings (indeed the designers of the SPM monitoring systems have established their own special criteria for such bearings - although, again, the basis of these criteria are not revealled). There is a difference between the criteria for a cracked rotor and a cracked structural support - both have crack growths related to the cyclic stressing but one has greater consequential effects than the other.

Conclusion

With increasing use being made of vibration monitoring techniques the time is now opportune for an improvement in decision data. This will be needed as new machinery shews signs of failure; in many instances enlightened managements have only recently introduced monitoring to new machines, hence the urgency for such improved data has not become apparent; however, for specification purposes at least, for purposes of litigation also, definite technically-determined information is already a matter of prime importance.

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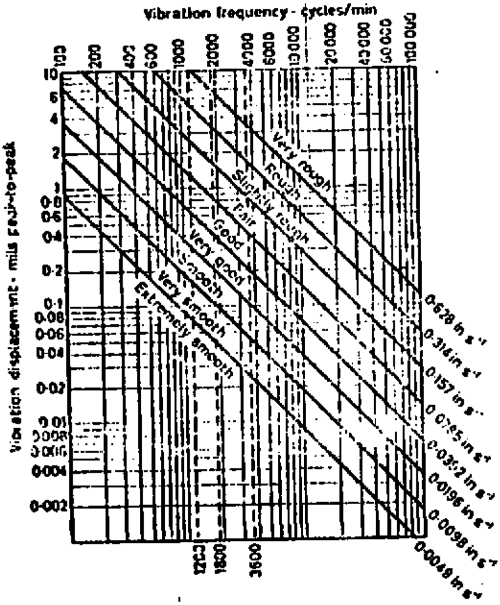

Figure 1. General machinery vibration severity chart

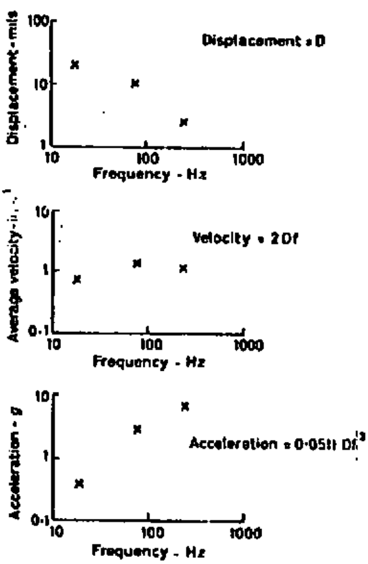

Figure 2.

GMC Allison 501 vibration criteria based on destruction tests.