Minutes of the Technical Advisory Board for Mechanical Environments of the Confederation for European Environmental Engineering Societies Held on 19th September 2002 at Bruges, Belgium

Present at the Meeting of the Technical Advisory Board for Mechanical Environments (TABME) were;

Dr U. Braunmiller	GUS
Mr M. Dumelin	SSEE
Mr E. Furrer	GUS
Mr T. Geise	PLOT
Mr M. Juntunen	SEEF
Mr. D. Richards	SEE (Chairman)
Mr T. Trost	SEES
Dr K Zieghan	GUS

Matters Arising

Prior to the meeting Dr P. Dehombreux had written saying he could no longer attend the meeting. Apologies were received from Jouni Sirén.

A list of TABME members, including corresponding members, was circulated. As usual this list is attached to the minutes as Attachment No 1.

Systematisation of Measurement Methodologies

CEN TC 261 SC5 W14 – Test Methods & Test Schedules . It was reported that no meetings of this group had occurred since the last meeting of the TABME. In fact it was stated that it was currently "sleeping".

STANAG 4370. Marcus reported that issue 2 was close to final ratification by the NATO countries, issue 3 was close to issue.

Mil Std 810F It was stated that change note 2 was now on the web. [Chairmans note: in order to downloaded, in PDF format, the US military environmental test standard Mil Std 810F go to the ASSIST option at http://www.dodssp.daps.mil/dodssp.htm.]

UN Orange Book. Karl updated a report on the proposed vibration / bounce test for the UN "orange" book. This had been proposed by the US several times (an rejected), it was recently also proposed by Spain. Karl has proposed a more up to date test, however, some countries required basic test. A discussion followed on failure modes.

DIN 30787. It was stated that electronic (PDF) copies of the English version were also circulated at the IEC TC 104 meeting by the German DNV organisation.

IEC TC104. David Richards reported a meeting had occurred in April 2002 in Frankfurt. Also a meeting of several working groups and maintenance teams had occurred in Seattle in August. Markku reported on the maintenance team activity and on some of the difficulties they were having including package testing in the existing vibration test. Markku also reported on a new working group on test tailoring. [Chairmans note: following the meeting an e-mail discussion occurred which indicated some confusion on the scope of the working group. This seemed to have resulted from comments from the IEC TC 104 chairman.]

CEN Workshop Agreement. At the last CEEES workshop we had a presentation on the new CEN Workshop Agreement (CWA). Karl reported that he had attended a meeting of the Defence Procurement CWA. Following the meeting Sonja Holatka, on behalf of Karl, had circulated information on this CWA. In consequence it is not reproduced here. Further information is available on the CEN website www.cenorm.be.

Overview At a previous meeting the group had generated an overview of European and International work currently underway relating to transportation stresses. That overview was included as an attachment in the minutes of the last meeting. This meeting reviewed and updated the chart. The updated version is include here as attachment No 2. [Chairmans note: It is intended to review this chart on a regular basis.]

Technical Papers - Working Practices

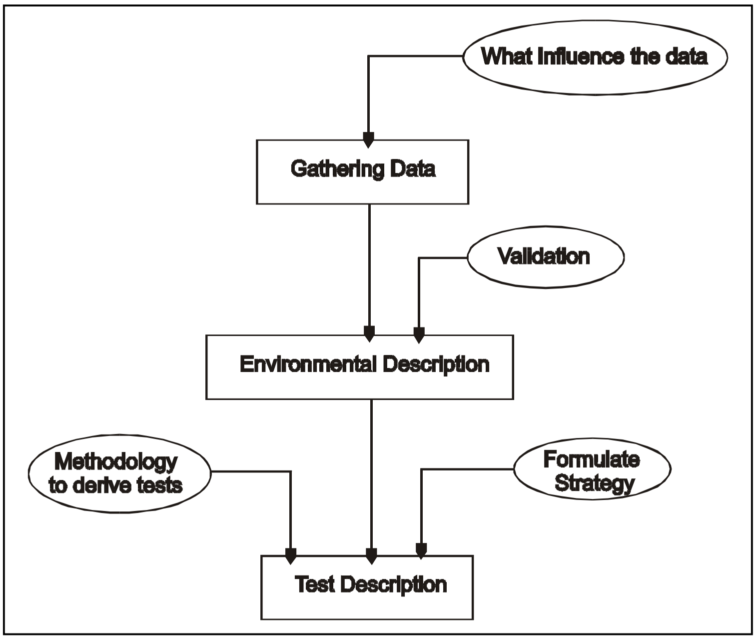
A significant amount of discussions occurred at the last meeting on the possibility of the group generating a "working practices" document on the subject of deriving environmental and test severities from measured data. Following the previous discussions the Chairman had prepared an circulated a draft paper for comment prior to the current meeting.

During the discussions it became apparent that the paper needed an overview. It was agreed and the working practices would need an overview of the larger process. It was further suggested that this could follow the same process as that of a paper by Markku viz.

Environmental Test Tailoring Management plan
Life Cycle
Environmental Conditions
Derivation of Test Specification

Markku undertook to prepare an overview for the paper

Discussion occurred on the likely content of the working practices with regard each method. It was indicated that a diagram of different approaches was required and recommendations / conclusions should be included. The diagram set out at the meeting is shown below.



The chairman undertook to prepare a modified version of the existing paper and circulate for additional input. However, the action for the group to review the exist draft remained. **Action – All Members**

A comment was made that a comparison of the various methods may be required. In such a case some thought would be needed to create a number of suitable "test cases". This was discussed but no decision was needed at this meeting.

The possibility of a workshop on the process of test tailoring was discussed and suggested it could be undertaken in the near future.

The Possibility of Initiating a CEN Workshop Agreement.

It had been observed that work on both DIN 30786 and the work of IEC TC 104 WG 15 had resulted in the collation of transportation vibration and shock data. Previously PLOT had attempted to set up a group of agencies to collect and collate vibration and shock transportation data. A CEN Workshop Agreement (CWA) could permit much of the current and future data to be deposited in a manner which would allow ready access by a variety of end-users. The purpose of three agenda topics was to review the work that had already been undertaken and discuss the possibility of the TABME initiating a CWA.

Ed Furrer explained the background to the DIN 30786 database and the Chairman the collection process used by IEC TC 104 WG 15 for determining the validity of data. Copies of two documents (one on data validation and the other an assessment of road transportation data – electronic copies can be obtained from the Chairman) were circulated at the meeting. Karl indicated he had found a US web site (www.isthg.com) selling transportation data.

It was agreed that initiating a CWA would require a business case and also self supporting financially. A CWA would need a workshop to initiate a suitable business case. It was agreed to pursue the idea.

Future Methods of Transportation Testing. This was left open for the next meeting.

Round Robin Exercise & Monograph. This was left open for the next meeting.

Any Other Business

Karl reminded the group that the last CEEES main meeting had agreed to set up an improved web site. To this end the METAB needs to set out a mission statement (Action on Chairman) and include information on members (Photo & short CV – **Action all members**).

Following discussions between the various working group chairmen it seems likely that the subject of the workshop following the next meeting would be on the use of digital recorders to acquire information (temperature, humidity, vibration & shock) on transportation.

Thomas Trost gave a brief presentation on the a new Eureka project E2606 “Handling Stresses due to Terminal Handling and Transport. Further information can be obtained from Thomas.

Next Meeting

The date of the next meeting of the TABME is planned for 13th February 2003 in London, UK.

Attachments

1 Names and Addresses of TABME Members
2 An Overview of European and International work
3 A Review of Methodologies for Deriving Vibration and Shock Test Severities

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An Overview of European and International work

Group / Standard	Connection with CEEES Working Group	Other Connections
ISO – TC 108 wg 26 &27		Kjell Ahlin
ISO – TC 122	Thomas Trost	
ISO - Railway		
IEC TC 104	David Aad Markus Markku	Trygve Hell
CEN TC 261	Ulrich Thomas	
CEN TC 320 Transportation Services		Soren Ostergaard
DIN 30787	Ulrich Karl	Ed Furrer
BSI	David	
UN Orange Book		
Mil Std 810		Skip Connon
Nato Standard - AC310	David	
Nato Standard - AC301	David Markus	Peter van Harmelen
Nato Standard - ITOPS		
CEN Workshop Agreement	Karl	
IEC Railways		

A Review of Methodologies for Deriving Vibration and Shock Test Severities.

The current trend towards the tailoring of test seventies has resulted in many new vibration test severities being proposed. As a number of these are derived for quite specific conditions and applications, it may not be surprising to find that they can exhibit considerable variability. Inspection of the various test seventies would suggest that much of this variation may be due to differing derivation methods, rather than the original measured data.

The problem is typified in US military standard Mil Std 810, where test seventies are derived from two different methodologies. A survey (Reference 1) undertaken under the auspices of the Confederation of European Environmental Engineering Societies (CEEES) appears to confirm that no single method, for assessing road transportation vibration data, has general acceptability.

The disparity between the various methods used for deriving test severities from measured environmental data appears to arise as a result of differing opinions as to the most appropriate approach for addressing both time variant and transitory aspects of the dynamic responses. This paper specifically considers the methodologies for deriving test severities for the road transportation dynamic environment.

The Problem

A significant proportion of the dynamic environment experienced by material carried as cargo on vehicles transported over made up roads, originates from the interaction of the vehicle road wheels with the road surface. The severity of these motions are dependent upon a number of factors which include the irregularities of the road surface, vehicle geometry as well as wheel and suspension characteristics. However, one of the most significant factors appears to be vehicle velocity. Clearly during normal transportation operations the velocity of the vehicle will be varying throughout the journey, and results in time variant dynamic responses. Such responses are often termed non-stationary.

Figure 1 illustrates typical vibration responses acquired during a forty minute journey. The figure indicates a clear relationship exists between vehicle velocity and response severity, described in terms of root mean square acceleration values derived at five second intervals. It also indicates the degree of variability of responses that occurs during a typical journey due to other effects.

In addition to variability with time, the dynamic responses also contain both continuous and transient components. Experience indicates that the transient components can be difficult to separate from the continuous, in that the transients occur at irregular intervals and exhibit a wide variation of amplitudes (References 2 to 6). Traditionally, for testing purposes, the continuous responses have been considered as vibrations, whilst the transient responses have been considered as shocks. Although these groupings are convenient for establishing test requirements, in reality the separation of the continuous and transient components is often quite arbitrary and, almost always, difficult to quantify. Clearly, the use of an inappropriate method for separating continuous and transient dynamic responses may particularly influence the vibration test severity.

Due to the difficulties of establishing 'worst case' road conditions, use is sometimes made of standard test tracks. The use of such tracks may have advantage in certain circumstances, as they permit standard road surfaces to be traversed at constant speed, hence significantly reducing the non-stationary component of the dynamic responses. Test tracks may also reduce the occurrence of transients within the responses, although, this may not always be the case.

For smaller payloads the major dynamic responses may arise from the payload 'bouncing' on the cargo deck of the vehicle or jostling' with other cargo. Whilst, such effects are not specifically considered by the remainder of the paper, the separation of these so called "loose cargo" effects from those arising more directly from the carriage vehicle is yet another problem facing the environmental engineer.

The Differing Test Generation Approaches

A number of approaches are in current use to derive vibration test seventies from measured data. A number of methods are described here and the advantages and disadvantages of each discussed. However, the different approaches considered are far from an exhaustive list and, even of those considered, a number of derivatives are known to exist. The actual methods selected, for discussion here, are those which appear in a number of current or proposed national standard test requirements.

Conventional PSD Enveloping Approach

This is probably the most common, the oldest and simplest method in current use to derive test severities which are invariably in the form of Power Spectral Density (PSD). Although in use before the advent of digital analysis equipment, the availability of such equipment has meant this method is readily viable for almost most analysts.

Process. The derived vibration test seventies are based upon PSD measurements from different measurement locations and conditions. Essentially these are all overlaid and a spectra formed over the top of the overlays to envelope all the PSD values. This enveloping spectra may used directly as the test spectra or it may be factored to encompass possible variabilities. Commonly it is also further enveloped to produce a spectra with fewer points required to define it.

Assumptions / Limitations. The main limitations of this approach are essentially the limitations in the use of the PSD as a data reduction procedure. Specifically the temporal averaging process inherent in the computation of a PSD, means it has no real ability to accurately describe time variant data. Moreover, it does not allow the effect of transient responses to be separated from the continuous responses. As such, this approach cannot readily be used as a means of quantifying these transients. For the approach to produce meaningful results, considerable control over the data gathering must be imposed.

Advantages / Disadvantages. The approach, without doubt, represents the most convenient data analysis method and produces an environment measurement from which vibration test seventies can easily be derived. However, it does not readily lend itself to the description of the general transportation environment and appears particularly unsuitable when dealing with actual road conditions.

Repeatability. Good statistical accuracy can achieved for each individual spectra by use of a record of sufficiently duration. However, the enveloping process does not constitute a statistical improvement and frequently a few spectra can supplant all others. Additionally each of the spectra enveloped may be of different statistical quality. Another limitation on repeatability occurs when the shape of the various spectra differ. As a consequence the resultant enveloping spectra may not represent a condition that can realistically occur.

Applicability. The approach is at its most useful when the data are stationary. To achieve this practically the vehicle under investigation must be traversing test tracks at constant speed.

Traceability. The PSD generated by this approach is statistically sound provided that the “rule” of stationarity is followed. If non-stationary data is used, the outcome still has a statistical basis but not that arising from the entire record.

Relationship with Other Methods. A number of other methods are based upon the PSD enveloping approach but intended to rectify various limitations of the basic approach.

The Peak Hold Spectra Approach

A sometimes adopted derivative of the PSD method, utilising "peak hold" values allows the non-stationary effects to be, at least partly, evaluated. In this context the "peak hold" values are essentially the largest PSD values that occur, in each, spectral band, over the analysis record length. Peak hold spectral density values may be used instead of the conventional (average) PSD although they are more generally used to augment it.

Process. The process is the same as the PSD enveloping approach excepting that peak hold spectra are used. If the resultant spectra are used to create a test definition a correction is need to establish a conventional PSD which would produce the required peak hold spectra. Typically this would involve reducing the spectral values equally across the entire test frequency range to produce a root mean square value of one third the rms computed from the peak hold spectra.

Assumptions / Limitations. The use of the combined peak hold values and conventional PSD data can give a useful indication between peak and mean spectral values, the detailed interpretation of the variation can be difficult. For transportation data, the spread between the conventional PSD values (i.e. the mean values) and the peak hold values may be quite considerable. Of course, a conventional Gaussian random signal will exhibit a variation between its peak and mean spectral values, whilst a further variation will occur if the data contains any time variance (i.e. non-stationary) effects or embedded transients. The situation is further complicated by the fact that the statistical confidence in the peak envelope values is not consistent with the confidence in the conventional PSD values.

Advantages / Disadvantages. The use of only the peak hold spectral density values as a basis for setting test seventies can result in notable conservative test levels. This is particularly germane when the data contains non-stationary and transitory conditions. In these cases the spectra are almost certain to represent a condition which would have a very low probability of occurrence. In conjunction with the PSD, the peak hold spectra can be a useful indicator of the effects of non-stationary and transient conditions.

Repeatability. No real statistical confidence can be placed in the peak hold spectral values unless it comes from a lengthy record from a known distribution. The resultant peak hold spectra may comprise a very low probability occurrence of the original waveform appearing for only a transitory periods. As such repeatability can be extremely poor.

Applicability. The peak hold spectra is not a PSD and should not be applied directly as vibration test severity. To do so would incorrectly implement the peak hold spectra as a conventional PSD, effectively incorporating a huge factor for test conservatism. The usual method of implementation is to derive a PSD would produce, in the test, a similar peak hold spectra.

Traceability. The peak hold spectra produced by this approach is at best be statistically poor and in the worst case unsound. Additionally the user of the peak hold approach alone is unlikely to be able to identify and verify the applicability of the data generating the peak hold spectra.

Relationship with Other Methods. A better statistical description of worst case conditions can be established from the Amplitude Probability Density approach described hereinafter. The Maximum Response Spectra also allows consideration of the effects of worst case conditions. With that said compiling Peak Hold Spectra requires very little effort beyond a conventional PSD. As such the approach can be a useful first indicator as to whether further consideration of worst case conditions is necessary.

The Foley Approach

The road transportation test severities presented in Mil Std 810D for "composite" wheeled vehicles are based upon a set of environments descriptions, derived in the early 1970's by Sandia National Laboratories at Albuquerque (Reference 7).

Process. The road transportation environmental descriptions are based upon measured data acquired during actual road transportation. These data represent a variety of vehicles, loading configurations, locations and speeds. For a specific vehicle/location the root mean square values in each of several frequency bands (of different bandwidth) were measured. The most severe value for the different vehicles and locations, in each band, are those used as the environmental description. In general, only the most severe 10% of any record was utilised in this process. The creation of a vibration test severity appears to involve converting the rms values of the environmental description to "equivalent" Power Spectral Density values and then forming an envelope over these values.

Assumptions / Limitations. The SANDIA approach, in part, addresses the problems associated with non-stationary effects, transient conditions as well as the variation in dynamic characteristics between different vehicles and locations. Unfortunately the method does not appear to consider any of these aspects in a quantifiable manner. The approach appears to be particularly sensitive to the selection of analysis bandwidth, and in the conversion of the environmental description to a test severity. In fact, the latter aspects appears to be far from a precise or readily definable process.

Advantages / Disadvantages. The SANDIA analysis approach can be undertaken with relatively simple equipment (filters and true rms meters) and is very tolerant of variations between vehicle characteristics (as a consequence of the use of rms values along with a large analysis bandwidth). Moreover, unlike some other approaches, the method does at least acknowledge the problems associated with non-stationary and transients conditions. Unfortunately as a consequence of the manner it which it tolerates these effects the method can produce test levels markedly lower than most other methods.

Repeatability. As the Foley approach does not produce an output that can be used directly as a vibration test specifications it has to be converted in to a PSD. The conversion process that Foley appears to have used was not based upon a particularly quantitative process. It seems to have included a test margin but it does not seem to be consistent across the full frequency range.

Applicability. The approach is useful when vehicles of very similar (but not identical) characteristics need to be addressed.

Traceability. The process does not readily facilitate data verification as much of the data characteristics are lost. As a consequence the result can be unduly influenced by limited or anomalous portions of the data.

Relationship with Other Methods. The method differs from other commonly used approaches.

The Aberdeen Proving Ground Approach

A more recent vehicle transportation test seventies presented (originally) in other parts of Mil Std 8I0D were derived using a procedure significantly different from the preceding method. This alternative approach was developed, specifically to derive test severities for Mil Std 810D, by the US Army Aberdeen Proving Ground.

Process. . This method uses the measured acceleration power spectral density values (calculated using a 1 Hz bandwidth) along with the standard deviation in each band. The measured data are acquired from a selected range of vehicle locations, road surfaces and speeds. A vibration description for each measurement condition is computed as the mean plus one standard deviation value, in each of the 1 Hz bands. These are combined for each surface / speed from the individual measurement conditions again by computing the mean plus one standard deviation value. These are further combined for each location within the vehicle from the combined surface / speed conditions again by computing the mean plus one standard deviation value. When several vehicles are to be considered, the computation of mean plus one standard deviation is repeated yet again. The test spectra is derived by enveloping the final description.

Assumptions / Limitations. In some ways the method can be considered as an enhancement of the peak hold approach. However, unlike that method, statistical confidence exists in the two values computed (the mean and variance). Unfortunately, like the peak hold method, the results from the Aberdeen Proving Ground approach can easily be distorted if non-stationary data are included. For this reason the procedure dictates the use of specific test tracks traversed at constant speed. The use of relatively narrow bandwidth means that the method is not very tolerant of variations in response spectra content between vehicles and locations. The consequence of this is that the more locations and vehicles included in the data ensemble, the more likely are the spectral peaks to be 'averaged out". For this reason a degree of selectivity is usually exercised over the incorporation of data into such an ensemble.

Advantages / Disadvantages. An important advantage of the method is that it can be relatively easily automated on a digital computer analysis system. Moreover, the method readily permits the inclusion of a quantifiable and consistent degree of test conservatism. Unfortunately, because it necessitates the use of specific test surfaces and vehicle speeds, the method is not particularly suitable for data acquired on normal road conditions.

Repeatability. The method is intended to part quantify the variations that occur during the measurements. Four groups of variation are encompassed viz. random measurement variation, road surface, location within vehicle and different vehicles. The process is effectively including four factors or margins to account for variability. The first margin (of one standard deviation) is on the normal random measurement error. The margin will be minimised by a sufficiently long measurement record provided the data are stationary. If the data are time variant the margin will be influenced by the amount of non-stationarity. The variation due to non-stationarity will be greater with this method than for a normal PSD approach. The second margin is for road surface/ speed and is usually controlled by using designated test tracks at the US Army Aberdeen Proving Ground. The effect of using other surfaces is unknown but it must be assumed that significant differences would occur. The third factor is locations within the vehicle and is controlled by only using locations designated by the US Army Aberdeen Proving Ground. The effect of using other locations again must be assumed to be significant. The fourth factor is due to different vehicles is also controlled by judicious selection by the US Army Aberdeen Proving Ground.

Applicability. The US Army Aberdeen Proving Ground approach makes some effort to quantify the effects of 4 significant variations that influence the vibration conditions induced by vehicles. However, whether this can be achievable by such a semi “automated” process is questionable. The basis for using a the mean plus one standard deviation seems no more than convenience as it appears to have no firm technical or statistical basis. The method has been used for environments other than vehicles but with only limited success. The main difficulty is the necessary control over the measurement conditions. The use of this method has also been known to produce tests which do not encompass the worst measured cases.

Traceability. Once the process is completed (for a particular vehicle) it is not possible to trace any individual variations due to surface or location. Nor is it possible to derive the original conditions producing the resultant severities.

Relationship with Other Methods. The method is **a** derivative of the basic PSD method.

The APD Approach

A fairly recent method, used by the Cranfield University and proposed for inclusion in UK Def Stan 00-35, utilises both acceleration PSD values and amplitude probability densities (APD). The PSD is utilised to give the spectral shape to the test severity but the overall amplitude is modified to allow the measured probabilities densities to be encompassed. This can be achieved, in practice, by several strategies but the simplest involves using several levels of vibration amplitude, each used for a different test duration.

Process. The general principles behind this procedure are described in Reference 8 and the actual implementation in Reference 9. These amplitudes and relative durations are derived from the probability density values allowing the measured APD to be replicated.

Assumptions / Limitations. The method assumes that the spectral content of the dynamic responses remains similar at all amplitude levels. Current measurements indicate this assumption is generally valid, although its verification for each vehicle type may be prudent. By including low occurrence events the method allows the effects of transients events to be quantified not only in terms of amplitude but also in terms of relative rates of occurrence. Essentially the method replicates the transient events by means of a period of short duration high amplitude random vibration. In the real environment both continuous and transient responses occur concurrently, unfortunately, current vibration test equipment necessitate the different test amplitudes to being applied simultaneously.

Advantages / Disadvantages. The approach has the advantage that it allows both non-stationary and transient data to be accommodated. The APD’s together with the associated PSD’s can be used directly to create a good environmental description for a particular vehicle. In particular it allows test durations to be established on a sound technical basis. The main disadvantages are that the method assumes that the spectral content of the dynamic responses remains similar at all amplitude levels and requires long measurement durations.

Repeatability. To quantify the high amplitude / low occurrence events with a reasonable degree of confidence, a very long measurement record is required. With that said the practical use of this methods has shown that repeatable APD’s can be achieved even with modest record lengths. Also because a amplitude distribution is formed its extrapolation can be possible (although vehicle non-linearities cannot be ignored).

Applicability. The approach is usable with measurements containing both non-stationary and transient data. The approach also alleviates the need to undertake separate "vibration" and "shock" analysis (and testing). However, probably the most notable aspect of the method is that it expands the concept of "tailoring" vibration test seventies beyond those of using power spectral density based measurements alone.

Traceability. The APD generated by this approach is statistically sound and frequently comprises a useful data validity check. The APD can be misinterpreted when the data are non-stationary. Specifically the distribution is distorted by the data non-stationarity. As such a separate (simple) check on data stationarity is prudent.

Relationship with Other Methods. The method differs from the approaches set out here. However, it is a akin of the old level crossing process often adopted before the ready availability of digital computers.

The MDS / FDS Approach

The vibration analysis tools known as Maximum Response Spectra (MRS) and Fatigue Damage Spectra (FDS) were originally developed within the French Atomic Energy Authority. The original purpose was as a means of comparing the affects of different vibration environments on equipment. The different vibration environments were compared in terms of their damage potential effects on notional (single degree of freedom) components within the equipment. The normal damage effects addressed were peak acceleration response relating to acceleration loadings, (by means of Maximum Response Spectra) and fatigue (by means of Fatigue Damage Spectra).

Process. The basic process behind MDS and FDS is very similar to that that Shock Response Spectra (SRS). Shock Response Spectra were developed in the US in the early 1940's to compare the effects of nuclear tests on structures. These early SRS's were obtained by setting a "comb" made of reeds onto a rigid block. Each of the reeds had a different natural frequency and the tip of each touched a smoked glass plate. The shock from the explosion was transmitted to the reeds via the rigid block. As a result of the shock each reed vibrated and its maximum displacement was witnessed by the smoked glass plate. The reeds vibrated differently, depending upon the characteristic of the shock and gave a "response spectra" which could be used to characterise the shock. The main technical differences between these early SRS measurements and todays MRS/FDS is that the latter address the peak acceleration response of the "reeds" vibrations (rather than shock) and establish the fatigue damage that would have accrued on the "reed" during its vibration response motions. Today of course the responses are all established numerically.

Assumptions / Limitations. The main assumption made when using SRS, MRS & FDS is that the real equipment responses can be represented by the response of a base excited single degree of freedom (SDOF) system. Whilst, this is not always the case, it frequently is. Further when computing MRS & SRS an assumption on the SDOF damping value needs to be made. However, the outcome of the calculations are more dependant upon the value selected for MRS than is usually the case for SRS. For FDS calculations a further three constant factors need to be set. Normally two of these factors are set to unity so play little part in the calculations. The fourth factor is the constant used in the Palmgren-Miner fatigue hypothesis. The results are very sensitive to this latter factor, although work has shown FDS values can be easily modified for other values.

Advantages / Disadvantages. In theory MRS and FDS can compute the loadings and fatigue life of an SDOF in absolute terms. However, they are not usually used in that role mostly because of the limitations set out above. The real advantage of MRS & FDS is as a tool to compare the maximum response and fatigue effects of different excitations and environments. In such cases parameter variability has little real effect provided reasonable values of damping and fatigue constant are selected (and the same values used in all the calculations). The main disadvantage of FDS is the very long computation times necessary.

Repeatability. The repeatability of MRS is arguably as good as that for SRS. Theoretically if MRS calculations of random vibration measurements are been made then statistically quite a long record would be required to ensure maximum values are observed. Practically an estimate of likely errors is easily derived. A number of different numerical approaches are available to compute MDS & FDS. Moreover, some of these are simplifications of the basic approach and are limited to specific excitation types (broad band random or sine sweep). These different approaches have little real effect on the computed MRS values but can have significant effect on the FDS values. When used for comparison purposes (using the same method) this is of no consequence. However, this would not be the case if the comparison was from FDS computed using several methods.

Applicability. Fatigue Damage Spectra is only one of two tools (along with APD) that permits test durations to be established, for complicated environments such as road transportation, on any quantitative basis. Additionally FDS and MRS permit comparison of the effects of significantly different types of excitations which cannot be done reliably with any other current method.

Traceability. In most cases the computed MRS and FDS can be adjusted for different damping and fatigue parameters. Moreover, the parameters used are generally quoted. However, the effect of different computation method on FDS is not readily accounted for and the method used is frequently not indicated. As MRS and FDS require significant computing effort they are not usually undertaken until other methods have been used to establish data validity.

Relationship with Other Methods. The FDS method differs markedly from any other commonly used approach. The MRS method is essentially the SRS method.

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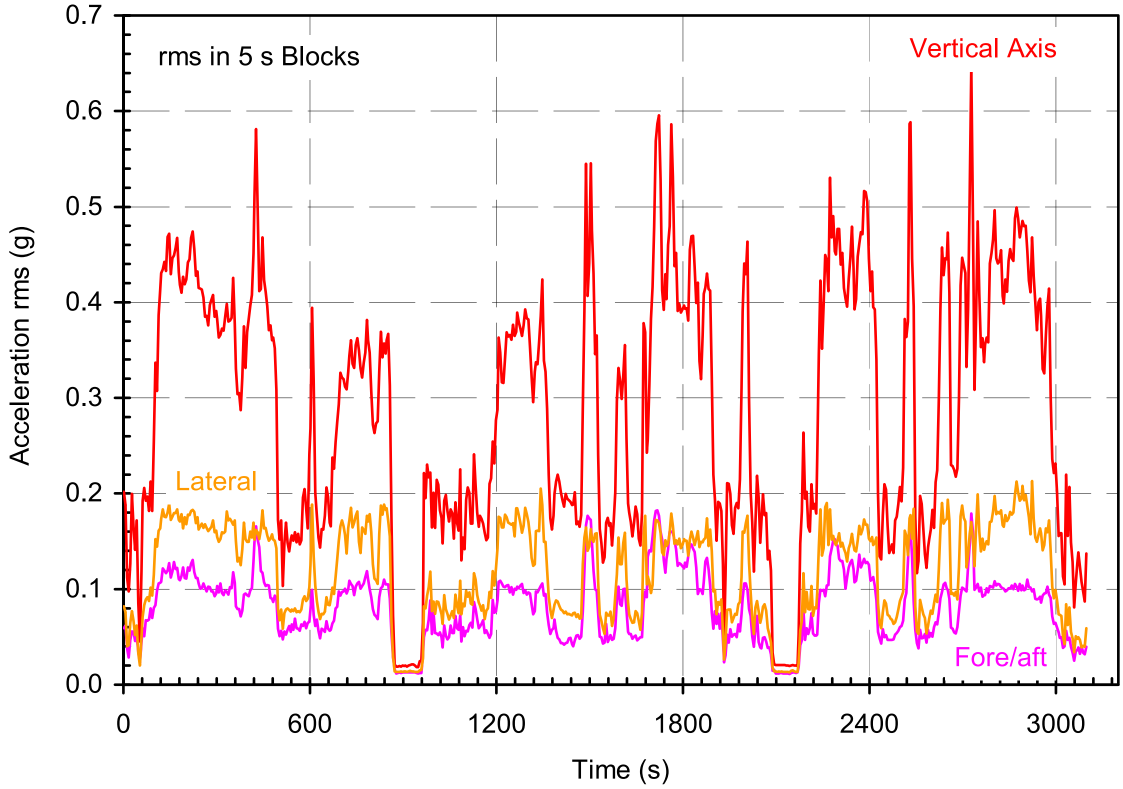

Figure 1 Typical Variations in Vibration Severity in a Typical Journey