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COMPTE RENDU DE REUNION

Commission MECA-CLIM du 16/01/2019

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Agenda

1 – dernières évolutions de la série des normes 50144 – 1 à 6
2 – STANAG
3 – DEF STAN 0035
4 – ASTELAB mécanique
5 – Round Robin mécanique
6- agenda du 16 janvier 2019

Ce compte rendu est basé sur le précédent (de la séance du 18 septembre 2018). Les ajouts et corrections apportés par rapport au CR précédent et apparaissent en caractères bleus.

1 – dernières évolutions de la série des normes de la série XP X 50144 –   1 à 6

RAS .

2 – STANAG 4370- leaflet 2410

La commission s'est consacrée lors de la présente réunion à proposer des corrections à la DEF STAN 00-035 Part 5 Issue 5 Chapter 12-01 , car celle ci sera reprise comme base dans l'évolution du leaflet 2410 « Development of laboratory vibration test schedules » . Donc les § à modifier sont :

- le §3.5 MRS & FDS approach: cf. annexe 1 du présent CR . Les corrections proposées apparaissent en caractères rouges et les propositions de suppressions sont surlignées en jaune.
- le §4 Recommendations : cf. tableau proposé en annexe 2 du présent CR.

Le tableau proposé au §4 a fait l'objet , après la présente réunion, d'un développement ayant conduit à le terminer , et ceci en langue anglaise.
Christian Lalanne a relu ce tableau et a proposé quelques modifications qui ont été prises en compte. Lors de la rédaction de l'alinea pour la méthode SDF SRE concernant le point 9 sur la relation bi univoque de l'approche, la rédaction de l'alinea a été reprise . En relation avec ce point, Christian a fourni un extrait d'un de ses ouvrages montrant la relation bi univoque entre DSP et SDF ou SRE ; on trouvera cet extrait en annexe 5.

Une partie des articles mis en référence dans le tableau de l'annexe 2 sont téléchargeables

par ftp à l'adresse suivante :
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dans le dossier : DEF STAN 0035/FDS MRS

3 – DEF STAN 0035 issue 5
Voir ci dessus pour les §3 et §4 du Ch. 12-01 part 5 issue 5.

4 – Round Robin mécanique
Activité en suspens. .

5- agenda du vendredi 22 mars 2019 :

1- approbation du présent compte rendu de la séance du 16 janvier 2019
2 - présentation d'une étude interne par Max Bourcart
3 – poursuite de la rédaction du §4 de la DEF STAN 00-035 Part 5 Issue 5 Chapter 12-01 .
4- divers

ANNEXE 1 change proposals to § 3.5 of DEF STAN 00-035 Part 5 Issue 5 Chapter 12-01

3.5 Maximum Response Spectrum and Fatigue Damage Spectrum Approach

3.5.1 The vibration analysis tools known as Maximum Response Spectrum (MRS) or Extreme Response Spectrum (ERS) and Fatigue Damage Spectrum (FDS) were originally developed within the French Atomic Energy Authority. The original purpose was as a means of comparing the effects of different vibration environments on materiel and to develop test specifications. The different vibration environments were compared in terms of their damage potential effects on notional (single degree of freedom) components within the materiel. The damage effects addressed were peak pseudo-acceleration response relating to acceleration loadings (by means of Maximum Response Spectrum) and fatigue (by means of Fatigue Damage Spectrum). In addition to peak acceleration loadings, peak velocity and displacement can also be considered.

3.5.2 The basic process behind the Maximum Response Spectrum and Fatigue Damage Spectrum methods is similar to that that of Shock Response Spectrum (SRS). Essentially the relative responses of a range of Single Degree of Freedom (SDOF) oscillators are computed. The Maximum Response Spectrum is the highest value of response achieved by each Single Degree of Freedom when its base is excited by the waveform under investigation. The Fatigue Damage Spectrum comprises of the fatigue damage computed from the cycle amplitudes and the Palmgren Miner hypothesis. Several specific methods can be used to compute Maximum Response Spectrum and Fatigue Damage Spectrum. Some of these permettent de calculer ces spectres pour differents types of waveform (mostly sine, sine sweep or random Gaussian stationnary or non stationnary) and permit significant savings in the computing times required. ~~However, in recent years it has become practical to compute the Maximum Response Spectrum and Fatigue Damage Spectrum of non-stationary waveforms.~~

3.5.3 The main assumption made when using Shock Response Spectrum, Maximum Response Spectrum and Fatigue Damage Spectrum, is that the real materiel responses can be represented by the response of a base excited Single Degree of Freedom system. Whilst this is not always the case, it can be a reasonable assumption. Furthermore, when computing Maximum Response Spectrum and Shock Response Spectrum, an assumption of the Single Degree of Freedom oscillator damping value needs to be made. ~~The outcome of the calculations is more dependent upon the damping value selected for Maximum Response Spectrum than is usually the case for Shock Response Spectrum~~. For Fatigue Damage Spectrum calculations a further three constant factors need to be used. Normally two of these factors are set to unity, so play little part in the calculations. The third factor is the constant used in the Basquin relation representing the SN curve where the results are sensitive to this factor.

3.5.4 In theory Maximum Response Spectrum and Fatigue Damage Spectrum can compute the loadings and fatigue life respectively of a single degree of freedom system ~~in absolute terms~~. ~~However, they are almost never used in this role, as the necessary assumptions prohibit such absolute predictions~~. The real advantage of Maximum Response Spectrum and Fatigue Damage Spectrum is as a tool to compare the maximum response and fatigue effects of different excitations and environments and in particular to compare the real environment to the specified one. In such cases parameter variability has little real effect provided reasonable values of damping and fatigue constant are selected (and the same values are used in all the calculations). The Fatigue Damage Spectrum method has the advantage of accommodating non-stationary data. ~~In other circumstances other methods are more appropriate for vibration test specification development.~~ *(This last sentence is of a general nature and should apply if it is considered relevant to all methods) .*

3.5.5 the MRS & FDS method has incorporated the consideration of environmental variability and of the product resistance to this environment by a stress/strength approach. This is done by implementing the uncertainty coefficient and the test factor in the process .

3.5.6 This Maximum Response Spectrum and Fatigue Damage Spectrum methods are described in greater detail in Annex C.

Method	Interest	Limitations	References
FDS & MRS	1- The MRS (or ERS) and FDS-based method takes into account the two most frequently observed failure modes in dynamic mechanics (fatigue damage limit and the extreme response limit) 2- the method of development of the specifications using the MRS and FDS does not introduce any additional assumption compared to the method by envelope of the PSD, The mechanical model used (one dof linear system) is the one already considered for shocks with the SRS. SRS is a spectrum widely used to characterize shocks, there is in practice little difference between the assumptions here retained with those of other methods, and in particular with the envelope method of PSD, knowing that, moreover, these methods rely on reducing the duration of the tests on an expression stemming from Basquin's relationship $(N \sigma^b = \text{Constant})$ The table below presents a comparison between assumptions used for the method based on envelope of PSDA and method of FDS and MRS. 3- all types of dynamic mechanical environments are treated the same spectra, which allows comparisons of severities with the same criteria of failure : - between two test specifications, - between any real environment and a test specification, between any two or several real environments for different durations, 4- the SDS takes into account the duration of application of the vibration, unlike the PSDs 5- Calculations are possible for stationary and non-stationary random vibrations (this is not the case for PSDs) 6- It is possible to combine the effects of several vibrations 7- the joint use of the SRM makes it possible to estimate the severity of the test related to the reduction of the duration starting from a criterion of mechanical stress (similar to the SRS for the shocks) 8- it is possible to define a specification by a test of nature different from that of the real environment (sine swept instead of a random vibration, random vibration instead of shocks repeated in great number,…). This transformation is in general	Other failure modes can occur in mechanical solicitations of all types, related for example to: - Oligocyclic fatigue - fretting corrosion - strong non-linearities, - etc. In these cases, specific approaches are to be implemented. This does not call into question the FDS MRS approach, because for the oligocyclic fatigue it is managed in structural fatigue tests occurring very early in the development and for the other phenomena they are in general treated on a case-by-case basis by specific approaches (for example fretting corrosion). In addition, the REX shows that even if the precipitated failure is of a type different from the two failure modes initially assumed, its highlighting remains relevant. It may be noted that for the cases mentioned above of the other possible modes of failure, the other methods do not respond better. Consider the impact of differences between real behavior and assumptions made: - on the number of dof: it is for the first mode that one generally observes the largest relative displacements answer, and thus the greatest constraints - this is the criterion for shocks	See annex 3 The articles can downloaded by FTP at the following link : ftp.grzeskowiak.fr meca-clim mot de passe : 433Che!a port : 21 open the folder DEF STAN 0035/FDS MRS/

	not very relevant, unless knowing the exact values of the parameter b and the Q-factor of the material concerned. Il faut que l'équivalence soit effectuée à la fois pour les FDS et pour les MRS, 9- for stationnary signals , calculation of MRS and FDS damage assumes more-over that the signal is gaussian. In such a case,: there is a bi-univocal relation between PSDA ans MRS or FDS (if no duration reduction). For non stationnary signals, there is no bi-univocal relation between the temporal signal and its SRS , or FDS calculated from the temporal. In this latter case, only the FFT and the temporal signal are in bi-univocal relation. 10- the number of points with which the PSD are calculated does not have an appreciable effect on the MRS and FDS which of it result, except for the first points of these spectra, the interval of frequency having to be smaller when the number of points is larger, 11- the value of Q-factor chosen to calculate the FDS and to deduce a specification from it does not affect any the result, even if the duration of test is reduced. One can also say that a specification established for Q=10 produces the same effects as the real vibrations even if Q factor of the specimen is different from 10, 12- the use of FDS and MRS with Q-factor variable does not affect any the specification obtained (and thus little interest presents), 13- in the absence of reduction of the duration of test, the specifications calculated by equivalence of the fatigue damage are far from sensitive to the value of the parameter b chosen for the calculation of the FDS, 14- the method by equivalence of the damage makes it possible to define a specification of stationary random vibrations of the same severity than a non-stationary real vibration, 15- it is possible to create a signal of acceleration directly having a given FDS, signal which could be used to control a test facility. As for the PSD. defined starting from a FDS., the result is not very sensitive to the choice of the parameters of calculation (Q-factor, parameter b, with the reduction of duration near for this last),		

	REX: 50 years of experience feedback in France; a dozen years at the international level (see list of 55 published articles identified in appendix 3); no application misfit related to this method has been reported.		
Enveloppe de DSPA	This method has the following advantages: - it is easy to implement, with few means of calculation, - it authorizes reductions of durations starting from a criterion of fatigue damage (on the condition of tailoring the value of the parameter b used) (critére s'appuyant sur la loi de Basquin), - it makes it possible to do the synthesis of several situations of which the vibratory environment of each one is characterized by one or more spectral concentrations in only one PSD. An investigation undertaken at the European level showed that this method by envelope of the power spectrum density is very much used (in its simplest form, without reduction of duration)	Nevertheless, it presents the following disadvantages for which it is necessary to have attention: -the manner of drawing the envelope using segments of right-hand side is very subjective, the results being able to be very different according to the operator, (except using a software defining the specification in same energy, à condition que l'on puisset considerer l'énergie comme un critère de défaillance) - the method is not appropriate for the non stationary situations, with the additional difficulty that the stationary in this case is likely to be appreciated in the totality of the waveband, - la méthode n'est pas utilisable pour des signaux non gaussiens, - this method is not inevitably suitable when the amplitudes of the vibrations of different situations are very disparate, different, etc For example situation out of compartment boat and situation out of compartment plane.	A review of Methodologies for Deriving Vibration and Shock Test Severities, CEEES/TABME/Paper/01, 2002. LALANNE C., Mechanical Vibration and Shock, Volume 1: Sinusoidal Vibration, ISTE-Wiley 2014. RICHARDS D.P., A review of analysis and assessment methodologies for road transportation vibration and shock data, Environmental Engineering, Vol. 3, n° 4, December 1990, pp.23/26.
Peak Hold	The so-called "Peak-Hold" approach differs from the PSDA envelope method only because instead of considering the PSDA calculated from the average of the PSDAs calculated over n segments of a signal, the envelope is considered of all these PSDAs. All that has been said for the PSDA envelope method therefore also applies	Same disadvantages as the PSD. In addition : - the use of peak-hold leads to a considerable overestimation of the environment - the statistical uncertainty of peak-hold spectra is very large	
Amplitude Probability Density Approach	Reflections have been carried out in the United Kingdom to try to take into account the distribution of the instantaneous values of the measured signal. This approach has been proposed by Darrel Charles in the article.	Caution is advocated when comparing measured data with data generated by test-house equipment or described in specification documents. For the future, the simulation in a test house of the effects of this environment could be more precise if it were possible to	CHARLES D., Derivation of environment descriptions and test severities from measured road transportation data, Part I, Environmental Engineering, Vol. 5, n° 4, December 1992, p. 30, Part II, Environmental Engineering, Vol. 6, n° 1, March 1993, pp. 25 / 26.

	A rnethodology has heen presented for deriving environment descriptions from measured data. The derivation of test severities from measured data has been discussed. With respect to test amplitudes, two methodologies have been presented. Each method attempts to accommodate the characteristics of measured data, particularly its peak-to-rms ratio, and therefore its damage potential. A procedure for deriving test durations relating to in service use has also been explained.	customize the amplitude distribution and peak-to-rms ratio of the applied vibration.	
Foley / Sandia Approach	This study is summarized in the following sources: '(FSA 1 à FSA 4) Environmental descriptions of road transport are based on measured data acquired during actual road transport. These data represent a wide variety of vehicles, load configurations, locations and speeds. The vehicles were all American with air and spring suspensions. For a specific vehicle / location, the rms values in each of several frequency bands (bands of different widths) were measured. The most important values for the different vehicles and locations in each band are those used as the environmental description. In general, only the worst 10% of all cases were used in this process. The vibration test severity is performed by converting the rms value into PSD and then from an envelope of these values. This latter process is neither fully documented nor particularly well defined and appears to have a reasonable degree of judgment. This approach is useful when vehicles with similar (but not identical) characteristics need to be considered. Conversion of RMS values to "equivalent" power spectral density seems to be the prime opportunity to include factors for unquantified variables The method differs significantly from other commonly used approaches.	There is no mention to any approach associated to the name « Foley ». The column « References » mentionned that the listed studies and others resulted in two guidance documents for package designers (FSA 5 et FSA 6) None of these 2 documents can be considered as a general approach for deriving the test severities from the field environment. Unlike other approaches, the method recognizes the problems associated with non-stationary and transient conditions. Unfortunately, it largely tolerates these effects by creating bandwidths large enough not to be sensitive to these variations. As a result, the method can produce much lower test levels than most other methods. Foley's method is quite difficult to reproduce because it requires a data analysis approach intrinsically different from that used elsewhere. Discretion must also be used to configure the different frequency bands and select the prerequisite data. The process does not easily facilitate data verification because many features are lost. In addition, the methodology requires pre-selection of bandwidths, if these were inappropriate (ie if the dynamic characteristics of the vehicle differ from those assumed), nothing can be done to correct the situation. As a result, the result may be unduly influenced by limited or abnormal	MIL STD 810 G CN1 only mentionned the following reference relative to « FOLEY » FSA0: Random Data: Analysis and Measurement Procedures, Chapter 10, J.S. Bendat and A.G. Piersol, Wiley-Interscience, 1971 « Foley, J.T., M. B. Gens, C. G. Magnuson, and R. A. Harley; "Transportation Dynamic Environment Summary," Sandia Laboratories, EDB 1354, January 1973b. » • FSA 1: "Preliminary Analysis of Data Obtained in the Joint Army/AEC/Sandia Test of Truck Transport Environment" (Foley 1966a) • FSA 2: *The Environment Experienced by Cargo on a Flatbed Tractor-Trailer Combination* (Foley 1966b) • FSA 3: *Transportability Study Covering Highway Movement of Atomic Energy Commission 15-ton Nuclear Cask from Wilmington, Delaware to Albuquerque, New Mexico (Bryan 1965)* • *FSA 4: Force-Controlled Vibration Testing (Otts 1965a) Used Fuel Disposition Campaign Storage and Transportation Transportation Shock and Vibration Literature Review June 6, 2013* *Impedance Measurement of a Flatbed Truck* (Otts 1965b) *Joint Army/AEC/Sandia Test of Truck Transport Environment, December 7-17, 1964 (Test No. T-10767)* (Mortley 1965) A second study evaluated the shock and vibration transportation environment associated with shipping a Beech liquid helium Dewar flask on a Ford F600 flatbed truck (Foley 1968,Foley 1969).

		portions of the data. This can be of particular concern when using actual road data, as the worst conditions can be generated by a very limited range of occurrence and specific vehicles. As a result, it is almost impossible to verify the severity of Foley road vehicles with the vehicles of the day. The main limitations here are that the existing methodology does not seem to be based on a quantifiable process. As such, the user is unable to quantify the factors already included in the analysis. The other uncertainty is related to the choice of the most unfavorable conditions. The method also seems to produce lower test amplitudes than most others and with a relatively simplistic spectral shape. The method does not treat variability in a way that quantifies it. In addition, when you include different vehicles and locations, the result is particularly sensitive to the choice of different scan bandwidths and the bandwidth conversion.description of the environment to a test severity. Unfortunately, it largely tolerates the effects of non-stationary and transient phenomena by creating bandwidths large enough not to be sensitive to these variations. As a result, the method can produce much lower test levels than most other methods. Since the Foley approach does not produce an output that can be used directly as a vibration test specification, it must be converted to a PSD. The conversion process used by Foley was not well documented. Attempts to "reverse" his conversion suggest that it was not based on a quantitative method. It seems to have included a test margin, but it does not seem to be consistent over the entire frequency range.	In a third study, Foley and Gens evaluated the shock and vibration transportation environment for shipping a 15-ton used nuclear fuel cask that traveled by truck from Oak Ridge, Tennessee to Paducah, Kentucky, and by rail from Paducah, Kentucky to Oak Ridge, Tennessee. This study is summarized in the following reports: • "The Rail Transport Environment" (Gens 1970) • "Shock and Vibration Measurements During Normal Rail and Truck Transport" (Foley and Gens 1971a) • *Environment Experienced by Cargo During Normal Rail and Truck Transport–Complete Data* (Foley and Gens 1971b) The listed studies and others resulted in two guidance documents for package designers: • *I. Techniques for Measuring Transportation and Handling Environments; II. Available Literature and How It May Help Package Designers* (Foley 1970) • *Transportation Shock and Vibration Descriptions for Package Designers* (Foley 1972) •FSA 5 : *I. Techniques for Measuring Transportation and Handling Environments; II. Available Literature and How It May Help Package Designers* (Foley 1970) •FSA 6 : *Transportation Shock and Vibration Descriptions for Package Designers* (Foley 1972)
Connon /Aberdeen Proving Ground Approach	This alternative approach was developed in the late 1980s specifically to determine the severity of Mil Std 810D tests for wheeled and tracked vehicles. The method was developed by the US Army Aberdeen Proving Ground, using its test track surfaces, and was largely automated. The method has been used for other applications, but not always successfully. This method uses the measured acceleration power spectral density values, which must be calculated for consistency using a	1. As the method necessitates the use of specific test surfaces and vehicle speeds, it is not particularly suitable for data acquired on normal road conditions. The inclusion of a wide range of life cycle conditions can mean that the test severity is significantly lower than the worst case. 2. Even the repeated use of mean plus one	Only a few attempts to use the method with real field data appear to have been documented . A research in MIL STD 810G CN1 on the word « Aberdeen » gives the following : ***4.1.3 Procedure III - Large assembly transport.*** *The test facility for this Method is a test surface(s) and vehicle(s) representative of transportation and/or service*

	common bandwidth (1 Hz was used by Aberdeen). In addition to calculating the usual average value, the standard deviation of the variation in each band is also calculated. The measured data is acquired from a selected range of vehicle locations, surfaces, and test track speeds. A vibration spectrum for each individual measurement condition is calculated as the average value plus a standard deviation, in each frequency band. Surface and velocity spectra are combined by calculating the average spectrum plus a standard deviation of the individual measurement conditions. These are then combined for each location in the vehicle by calculating the mean plus a standard deviation of the previously combined values. When several vehicles are to be taken into account, the calculation of the mean plus one standard deviation is repeated. The test spectrum is derived by wrapping the final description. Assumptions / Limitations In some ways, the method can be considered an improvement of the Peak-hold approach. However, unlike this method, a statistical estimate is used from the mean and the variance. An important advantage of the method is that it can be relatively easily automated on a digital analysis system. In addition, the method easily allows for the inclusion of a quantifiable and constant degree of test conservatism. The method is partly able to quantify the variations that occur during measurements. Four groups of variation are encompassed, namely. those due to random measurements, road surfaces, locations in a vehicle and different vehicles. The process does include four factors or margins to account for variability. The first margin (of a standard deviation) concerns the normal random measurement error. The margin will be minimized by a sufficiently long measurement record provided that the data is stationary. If the data are variable in time, 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 concerns the surface area and speed of the road and is generally controlled using test tracks designated to the US Army Aberdeen Proving Ground. The effect of using other surfaces is unknown, but it must be assumed that significant differences could occur. The third factor relates to locations in the vehicle and is controlled using only generic locations designated by the US Army Aberdeen Proving Ground. The effect of using again other locations must be assumed to be	standard deviation may not result in test levels which encompass the worst case conditions. The method does not intrinsically check for this, but it is strongly recommended that the user does so. 3. The method is not particularly resilient to the inclusion of non-stationary data and care needs to be taken with the distribution of data included (types of surface, location of transducer, vehicle speeds etc.). 4. As already indicated the process calculates factors to account for variations in location, surface and vehicle. However, this assumes an essentially Gaussian variation or at least a symmetric distribution. As this is not necessarily the case, care with the selection of data included is necessary. Even environment distribution are analyzed on a statistical way, there is no consideration of the product resistance to this environment and therefore no possibility of calculating a safety factor as the one resulting from a stress/strenght approach . Unfortunately, like the peak blocking method, the results of the Aberdeen Proving Ground approach can easily be distorted if nonstationary data is included. For this reason, the procedure dictates the use of specific test tracks traveled at a specified constant speed. The use of a relatively narrow bandwidth means that the method does not much tolerate variations in the content of the response spectrum between vehicles and locations. As a consequence, the higher the number of locations and vehicles included in the data set, the more likely the spectral peaks are to be "averaged". For this reason, a degree of selectivity is generally required (and exercised) on the incorporation of data into such a set. When only a small percentage of events give the highest levels, as is the case here, there is a risk that the severity of the derived test does not include the most adverse cases. At least one	*phases of the environmental life cycle. The test item is loaded on the vehicle and secured or mounted to represent the life cycle event. The vehicle is then driven over the test surface in a manner that reproduces the transportation or service conditions. The test surfaces may include designed test tracks (e.g., test surfaces at the US Army Aberdeen* *Test Center (paragraph 6.1, reference b), typical highways, or specific highways between given points (e.g., a specified route between a manufacturing facility and a military depot)). Potentially, such testing can include all environmental factors (vibration, shock, temperature, humidity, pressure, etc.) related to wheeled vehicle transport.* - page 54-7-F-C2 , is presented an « *EXAMPLE APPLICATION OF FATIGUE DAMAGE SPECTRUM. Historically, four specific test courses at Aberdeen Test Center (ATC) have been used to generate data for vibration specifications for wheeled vehicles*. »

	significant. The fourth factor, due to different vehicles, is also controlled by a judicious selection of the US Army Aberdeen Proving Ground. Without this level of control of the US military, one could expect little repeatability. applicability The US Army Aberdeen Proving Ground approach attempts to quantify the effects of 4 significant variations that affect the vibration conditions induced by vehicles. However, it is questionable whether this can be achieved by a common factor and a semi-automated process. The use of the mean plus one standard deviation seems to be nothing more than convenience, as it does not seem to rest on a solid 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. Once the process is complete (for a particular vehicle), it is no longer possible to trace the individual variations due to the surface or location. Nor is it possible to derive the original conditions producing the resulting severities. This inherent inability to verify the quality of data (or more specifically the traceability of unreliable data) is offset by the use of a rigorous verification process during data acquisition and processing. Aberdeen has widely published the basics of this process, which is essentially fully automated. As previously indicated, the process attempts to create a reproducible base including factors to account for location, area and vehicle variations. However, this assumes essentially Gaussian variation or at least a symmetric distribution. In addition, the method raises the question of whether repeated use of the mean plus one standard deviation is a sufficient factor. Experience with real field data suggests that this assumption is not a priori. Relationship with other methods As shown in Figure 13, the method can, with minimal additional effort, be used in conjunction with a conventional PSD method or even the peak hold method. The methods have a limited similarity with an approach published by NASA (Dynamic Environmental Criteria, NASA-Hdbk-7005, 13 March 2001).	documented use of this method indicates that this has occurred. Unfortunately, as it requires the use of specific test surfaces and vehicle speeds, the method is not particularly suited to data acquired under normal road conditions. Few attempts to use the method with actual field data are documented and some of these do not appear to be particularly satisfactory. The inclusion of a wide range of life cycle conditions may mean that the severity of the test is significantly lower than the worst case. Even repeated use of the mean plus one standard deviation may not lead to test levels encompassing the most adverse conditions. The method does not verify it intrinsically, but it is strongly recommended to the user to do it.	
NASA Handbook 7005 Approach	This uses a factorized standard deviation to create a test spectrum for the launch / flight of a rocket from a set of separate flight measurements. NASA's approach is specifically designed to allow information from just a few launches to create a test severity that, with a high degree of confidence, will likely	1. Although the NASA method was originally intended to accommodate non-stationary data (booster flight) in reality it forced the data to be stationary by averaging over each measured flight. For most other	1- Potter, R. C., and Crocker, M. J., “Acoustic Prediction Methods for Rocket Engines, Including the Effects of Clustered Engines and Deflected Exhaust Flow,” NASA CR-566, Oct. 1966. 2 Sutherland, L. C., “Sonic and Vibration Environments for

	encompass the most adverse case. The weighted standard deviation is based on a Student's T distribution that relates the small sample size to the degree of confidence required.	applications this approach is unlikely to be applicable and some control over the measurement methodology will be required to ensure data stationarity. 2. Essentially the distribution of measurements included within the ensemble should be Gaussian. Since the computed standard deviation is multiplied by a factor, typically in the 1.2 to 1.4 range, any errors associated with the computation of the standard deviation will be exaggerated. 3. The method also has the potential to create a test severity that does not encompass the worst measured case, resulting in an under-test. In the original application this was circumvented by the use of an additional factor of typically between +3 dB and +6 dB. Even environment distribution are analyzed on a statistical way, there is no consideration of the product resistance to this environment and therefore no possibility of calculating a safety factor as the one resulting from a stress/strenght approach .	Ground Facilities - A Design Manual," NASA CR-61636, 644 pp, Mar. 1968 (NASA Acc. N76-71920). 3 Archer, J. S., "Natural Vibration Modal Analysis," NASA SP-8012, Sept. 1968. 4 Barnoski, R. L., Piersol, A. G., Van Der Laan, W. F., White, P. H., and Winter, E. F., "Summary of Random Vibration Prediction Procedures," NASA CR-1302, Apr. 1969. 5 Himelblau, H., Fuller, C. M., and Scharton, T. D., "Assessment of Space Vehicle Aeroacoustic Noise-Induced Vibration Prediction, Design, Analysis and Testing," NASA CR-1596, July l970. .6 Rubin, S., "Prevention of Coupled Structure-Propulsion Instability (Pogo)," NASA SP-8055, Oct. 1970. 7 Kacena, W. J., McGrath, M. B., Engelsgjerd, I. K., and Rader, W. P., "Aerospace Systems Pyrotechnic Shock Data," Vol. I through VII, NASA CR-116437,-116450,-116401,-116402,-116403,-116406,-116019, Mar. 1970 (NASA Acc. N71-17900 through 5-19250), 8 Robertson, J. E., "Prediction of In-Flight Fluctuating Pressure Environments Including Protuberance Induced Flow," NASA CR-119947, Mar. 1971 (NASA Acc. N71-36677). 9 Eldred, K. M., "Acoustic Loads Generated by the Propulsion System," NASA SP-8072, June 1971.
AECTP 240 Leaflet 2410 Vibration Specification Development Procedure.	AECTP-240 LEAFLET 2410/1 Development of Laboratory Vibration Test Schedules (VST) The method presented in §1 « General » of the leaflet 2410 is based on ITOP 1 1 050. We have referred to the document entitled « ITOP 1-1-050 - Development of Laboratory Vibration Test Schedules » 46 pages and dated 6/10/2006 . ITOP states that "there is no single best approach for VSD. The methods utilized will depend on several factors, including the vibration environment, the system goals, the value of the hardware, system fragility, test schedule constraints, test lab capabilities, and other considerations. Independent of the methods utilized the results must define the vibration in laboratory testable terms and include a definition of the vibration	**Limitations with Statistically Based Combination of Spectra** It is thus this method is a priori close to that by envelope of the PSDA (with its qualities and defects), completed to be able to synthesize several environments and to "treat" the case of the random + narrow band or sinus. As indicated, nothing comes to validate this procedure, very structured, but without experience feedback known and especially without theoretical support. How is the equivalence of actual environmental severity / specification demonstrated? in particular for the truncation of the peaks and the subsequent addition of components ... The method only concerns stationary signals for which a DSP can	- articles related to ITOP 1-1-50 : ? - articles related to Piersol FDS : see annex 4 The articles can downloaded by FTP at the following link : ftp.grzeskowiak.fr meca-clim mot de passe : 433Che!a

	levels and test exposure times. Several methods are presented in this ITOP for consideration, as outlined below: - Maximum Response and Fatigue Damage Spectra Technique (described in annex C) - Statistically Based Combination of Spectra , described in the core of the document. For the Statistically Based Combination of Spectra there are the following steps : - Definition of the life profile according to the type of carrier (percentages of time spent in each configuration) (page 17). - Calculation of the PSDA (p.25). - Calculation of the average DSP + N standard deviations, with standard value N = 1. - Truncation of the peaks of the DSP with a defined procedure (p.26). - Combination of DSPs of different events with a rather complicated procedure - Reduction of the duration with Miner (in passing, it is noted that one assumes the constraint defined in terms of acceleration (page 12), with a factor n to take account of nonlinearity; if one considers parameter b "equivalent" integrating this factor n, this leads to consider a linear relationship between these two parameters. - Possible treatment of sinusoidal or narrow-band components (p.35) suppressed during peak truncation. Note that if the signal is non-stationary or non-Gaussian, the ITOP simply advises to reproduce what has been measured (no synthesis, no statistics, and therefore weakness compared to our method) (p.25). The ITOP method is a list of operations that can appear, from a distance, very elaborate, but which in fact do not rely on any theory to show that the result is a representative specification with reasonable numerical margins. Annex C FDS & MRS method This method, developed from Piersol / Henderson's expression of damage, is fundamentally very similar to the FDS / MRS method cited above. It has a priori all the advantages of classical FDS. For the Piersol method, the expression of the damage involves the speed DSP (Gaberson influence). But we	be calculated. The limitations are already those of the use of the DSP. **Limitations with Annex C** The usage is to calculate PSDA's obtained from acceleration rather than speed; it is easy to show that the damage obtained is the same in both cases. This complication brings nothing. Because of the simplified formulation of Miles, the FDS can be calculated only at natural frequencies equal to the frequencies defining the PSDA, and therefore with the same number of points. One then can not calculate the FDS from the range of frequencies of the PSD's to the problem of truck vibration and aircraft (different ranges). - That is particularly an issue in the case of a synthesis between PSD which is not defined in the same frequency range and with the same resolution in frequency - Initially, calculation to be only started from a PSD (and therefore a stationary vibration). The method has however been completed for a vibration defined as a function of time The Piersol damage expression also neglects a factor that is a function of the natural frequency and the parameter b (the use is rather to use PSDs obtained from the acceleration and it is easy to show that the damage obtained is the same in both cases : $\frac{\Gamma\left(1+b/2\right)}{\left[8\,\pi\left(2\,\pi\,f_0\right)^2\right]^{b/2}}$ complicating the formulation for comparisons with FDS of non-stationary or sinusoidal vibrations - Criterion of MRS not utilized in this approach: • No validation of vibration specification duration reduction • no equivalence based on the extreme response damage because equivalence based on SDF coming from a synthesis of	port : 21 - open the folder DEF STAN 0035/FDS MRS

	have seen that this leads to the same value of the damage that one would get with a DSP of acceleration (of course modifying the expression to account for the DSP speed - DSP acceleration relationship, namely $G(f)\ \text{accélération} = G(f)\ \text{vitesse} \times (2\pi f)^2$. The result is the same, but it is still less common to calculate DSP speed ... - with very simplifying assumptions compared to the previous FDS / MRS method (distribution of Rayleigh peaks, effective value of the response obtained from the Miles relationship)	several environments of different durations inevitably does not imply an equivalence in extreme response damage - no uncertainty coefficient nor test factor with probabilistic approach based on variabilities	

Assumption	Method by envelope of the PSDs, including SRS	Method of equivalence of fatigue damage	The assumption is needed for
Proportionality relative displacement response / acceleration	X	X	SRS Test Duration reduction
Proportionality relative displacement response / stress	X	X	SRS Test Duration reduction
Linear one dof system	X	X	SRS
Wöhler curve modeled by the Basquin rule	X	X	Test Duration reduction
Linear assumption of fatigue damage cumulation (Miner)	X	X	Test Duration reduction (Basquin's rule)

Table 1 - presents a comparison between assumptions used for the method based on envelope of PSDA and method of FDS and MRS.

ANNEX 3 List of international articles related to FDS & MRS approach

A Method of Accelerating Durability Tests by Pseudo Damage Editing
Mahesh Software Systems, Pvt, Ltd, ***Inde***

Analysis of Nonstationary Vibroacoustic Flight Data Using a Damage-Potential Basis
The Aerospace Corporation - Rubin Engineering Company, ***USA***

CBM for vibrating equipment on rotorcraft
And Helicopter Vibration Shock and Vibration Qualification of Equipment
nCode + AgustaWestland, ***UK***

Characterization and Synthesis of Random Acceleration Vibration Specifications
*University Twente, **Pays-Bas***

Comparison of Multi-Axis and Single Axis Testing on Plate S
*Sandia National Laboratories, **USA***

Comparaison of Test Specifications and Measured Field Data
*Blekinge Institute of Technology, Karlskrona, **Suède***

Comparing different vibration tests proposed for li-ion batteries with vibration measurement in an electric vehicle, G. Kjell, J.F. Lang, EVS27 International Battery, Hybrid and Fuel Cell Electric Vehicle Symposium, Barcelona, Spain, Nov. 17-20, 2013. Espagne

Correlation of Sinusoidal Sweep Test to Field Random Vibrations, L. Jayahari, G. Praveen, Master's Degree Thesis, ISRN: BTH-AMT-EX—2005/D-13—SE, Department of Mechanical Engineering, Blekinge Institute of Technology, Karlskrona, 2005, Sweden.

Defining a Representative Vibration Durability Test for Electric Vehicle (EV) Rechargeable Energy Storage Systems RESS), *EVS29 Symposium Montréal, Québec, June 19-22, 2016, Canada*

Deriving Gaussian Fatigue Test Spectra from Measured non Gaussian Service Spectra
*Munich University of Applied Sciences + Knorr-Bremse SfS GmbH, **Allemagne***

Desenvolvimento de Testes Acelerados de Fadiga Aplicados a Atuadores Electrônicos de Turbocompressores
*Universadade Federal de Uberlândia, Faculdade de Engenharia Mecânica, **Brésil***

Development of a Computer-*Aided Accelerated Durability Testing Method for Ground Vehicle Components, Thesis, University of Manitoba, Canada.

Development of Shock and Vibration Test Specifications for Telecommunication Equipment in Automotive Environments
*VTT Manufacturing technology and Nokia Research Center, **Finlande***

Development of Vibration Specifications for LRUs on Fighter Aircraft from Flight Data
*National Aerospace Laboratories, Bangalore, **Inde***

Evaluating Fatigue Equivalence Using Measured Vibration Data, 2003 Launch Vehicle and Spacecraft Dynamic Environments Workshop, June 17-19, 2003, El Segundo, CA, USA

Evaluation of Vibration Test Severity by FDS and ERS

*D.H.Cho, Korea Aerospace Industries, **Corée***

Evaluation of Vibration References with Equivalent Kurtosis and Dissimilar Amplitude Probability Densities
Redstone

Experimental evaluation of the FDS-based equivalence approach for the mission synthesis in accelerated life tests
*Dept. of Engineering for Industry, University of Bologna, **Italie***

Extreme Response and Fatigue Damage for FPSO Structural Analysis
*American Bureau of Shipping, Houston, TX, **USA***

Fatigue Damage for Sweep-Sine and Random Accelerated Vibration Testing
*Institute for Electric Rotary Systems, **Slovenie***

Fatigue Damage Import - How to use the fatigue damage spectrum for accelerated tests, V-Note #0010, VIBRATION RESEARCH CORPORATION, USA

Fatigue Damage Spectrum at Ford Motor Compagny, J.V. Van Baren
*Vibration Research Corporation, **USA***

Fatigue Damage Spectrum Calculation Based on Vibration Specifications
*Chrysler Group + Oakland University, **USA***

Fatigue Damage Spectrum calculation in a Mission Synthesis procedure for Sine-on-Random excitations, Journal of Physics: Conference Series, Volume 744, Number 1, Dept. of Engineering for Industry of the University of Bologna (***Italy***) and Siemens Industry Software NV Leuven, ***Belgium***

Fatigue Damage Spectrum – A New Tool to Accelerate Vibration Testing, Sound & Vibration/March 2015, ***USA***

Fatigue Margins Established by Unit and Spacecraft Protoqualification Tests
*The Aerospace Corporation, El Segundo, **California***

Generating Accelerated Loading Profiles from Measured Time Series Data
*University of Manitoba, **Canada***

How do I Measure the Life of my Product
*Calvin College, Grand Rapids, **Michigan***

Implementing the Fatigue Damage Spectrum and Fatigue Damage Equivalent Vibration Testing
*Stress Engineering Services, Inc., **Houston***

Interest of equivalent damage methods for railway equipment qualification to vibrations

Vibratec, ***France***

Test Center, Army Test and Evaluation Command, ***USA***

Investigation of the Durability Transfer Concept for Vehicle Prognostic Applications
nCode with US Army TARDEC, ***USA***

Methods for Accelerating Dynamic Durability Tests
nCode, ***UK***

Mission Synthesis of Sine-on-Random excitations for accelerated vibration qualification testing
Thèse, Bologne, ***Italie***

New Techniques for Vibration Qualification of Vibrating Equipment on Aircraft, *Aircraft Airworthiness & Sustainment 2010, U*SA

On field durability tests of mechanical systems - The use of the Fatigue Damage Spectrum,
XXIV Italian Group of Fracture Conference, 1-3 March 2017, Urbino, Italy

On the Shaker Simulation of Wind-Induced Non-Gaussian Random Vibration
Hindawi Publishing Corporation, Shock and Vibration, Volume 2016, Article ID 5450865
School of Reliability and System Engineering, Beihang, China +
Mechanical Engineering, Blekinge Tekniska Högskola, Karlskrona, ***Suède***

Ottimizzazione delle prove su pista dei veicoli usando Spettri di Danno a Fatica
nCode + CNH – Modena , ***Italie***

Qualifica a Vibrazioni di Componenti Meccanici: Studio e Verifica di una Procedura di Test Tailoring, Thesis, Università di Bologna, Italie

Qualification testing of racecar equipment subject to engine-induced vibrations - How to derive a test profile using a mission synthesis procedure
Siemens Industry Software NV, Leuven, ***Belgique***

Random Vibration Testing Development for Engine Mounted Products Considering Customer Usage
Chrysler Group, ***USA***

Reliability Fatigue Design Synthesis and Experimental Validation of Accelerated Vibration Durability Test
Valeo, ***France***

Research on the Random Vibration Cumulative Fatigue Damage Life Based on the Finite Element Analysis, W. Chengcheng, L. Chuanri and M. Tian, *Applied Mechanics and Materials Vols. 300-301 (2013) pp 992-996, China.*

Response Spectrum Methods in Tank-vehicle Design
*Blekinge Institute of Technology, Karlskrona, **Suède***

Shaker Testing Simulation of Non-Gaussian Random Excitations with the Fatigue Damage Spectrum as a Criterion of Mission Signal Synthesis, International Conference on Engineering Vibration, Ljubljana, Slovenia, 7-10 September 2015 Slovenia

Tailoring of Vibration Test Specifications for a Flight Vehicle
*Research Centre Zmarat, Hyderabad, **Inde***

The Effect of Kurtosis on Fatigue Life, J. Korean Soc. Mech. Technol., 17(4):675-681, 2015, Corée

The Equivalent Response Method for Test Specification Development, *SCLV Dynamics Environment Workshop, 25 June, 2016, USA*

The Fatigue Damage Spectrum and Kurtosis Control, SOUND & VIBRATION/OCTOBER 2012, USA

Understanding how Kurtosis is transferred from input Acceleration to Stress Response and its Influence on Fatigue Life
*nCode UK and NASA Langley Research Center, Virginia, **USA***

Using the Fatigue Damage Spectrum to determine flight qualification of vibrating components on helicopters, ASTELAB2009, France

Using fatigue damage spectrum for accelerated testing with correlation to end-use environment
*General Motors Company and Vibration Research Corporation, **USA***

Verification and Correlation of Fatigue Calculations for a Test Structure and Shaker Table, A. M. Daving, Thesis, NTNU – Trondheim, Norvegian University of Science and Technology, June 10, 2015. Norvège.

Vibration Durability Testing and Design Validation Based on Narrow Frequency Band
*Blekinge Institute of Technology, Karlskrona, **Suède***

Vibration provning - skräddarsydd efter analys av fältmätdata
*Volvo Lastvagnar, **Suède***

Vibration Test Specification Design and Reliability Analysis
*Automotive Research & Testing Center, Lukang, **Taïwan***

Vibration Durability Testing and Design Validation Based on Narrow Frequency Band, Master's Degree Thesis, Department of Mechanical Engineering, Blekinge Institute of Technology, Karlskrona, 2011, Sweden.

Books

Guide to load analysis for durability in vehicle engineering, P. Johannesson, M. Speckert, John Wiley & Sons, 2014

Metal Fatigue Analysis Handbook – Practical Problem-Solving Techniques for Computer-Aided Engineering, Y.L. Lee , M.E. Barkey, H.T. Kang, Elsevier Inc., 2012.

Lalanne C., Mechanical Vibration and Shock Analysis, 3rd Edition, Volume 5: Specification Development, ISTE – Wiley, 2014.

Standards :

— NF X 50-144-1, Demonstration of resistance to environmental factors — Design and execution of environmental tests — Part 1: Basis of the general environmental management process

— XP X 50-144-2, Demonstration of resistance to environmental factors — Design and execution of environmental tests — Part 2: Guidelines for the tailoring approach to general environment

— XP X 50-144-3, Demonstration of resistance to environmental factors — Design and execution of environmental tests — Part 3: Implementation of the tailoring approach for the mechanical environment

— XP X 50-144-4, Demonstration of resistance to environmental factors — Design and Execution of Environmental Tests — Part 4: Implementation of the tailoring approach for the climatic environment

— XP X 50-144-5, Demonstration of resistance to environmental factors — Design and Execution of Environmental Tests — Part 5 : Guarantee Coefficient

— XP X 50-144-6, Demonstration of resistance to environmental factors — Design and Execution of Environmental Tests — Part 5 : Test Factor

ANNEX 4 List of « international » articles related to PIERSOL FDS approach

In fact , these articles with no exception , have been written by authors from the USA .
And many of them come either from Vibration Research Corporation , private company which is commercializing a software havinbg implemented Piersol FDS approach or from GHI Systems (same group that QUALMARK which is commercializing HALT repetitive shock machines with pneumatic hammers) whose articles essentially refer to PSD comparisons or MRS comparisons on signals not having the same distributions , that isn't correct.

METHODS OF COMBINATION OF SPECTRA Assessment of Hydraulic Surge Brake Effects On Fatigue Failures Of A Light Trailer

\Villiam (Skip) Connon, U.S. Army Aberdeen Test Center

A Study of the Conservatism of Maxi-Max ASDs in the Analysis of Transient Random Environments Using Rainflow Fatigue Analysis*
Jerome S. Cap Sandia National Laboratories

Damage Potential Spectrum DP(fn) Software A Descriptor for the degree of potential fatigue damage precipitated in products, due to variability of tables ,fixtures and product response.

THE FATIGUE DAMAGE SPECTRUM AND KURTOSIS CONTROL
John Van Baren Philip Van Baren
Vibration Research Corporation Jenison, MI December 2009

A Primer on Fatigue Damage and Fatigue Damage Spectra By John Van Baren
– Vibration Research Corporation

A STUDY OF FATIGUE DAMAGE WITH APPLICATION TO VIBRATION TESTING
Jacob Maatman Vibration Research Corporation

Evaluation of Vibration References with Equivalent Kurtosis and Dissimilar Amplitude Probability Densities
Michael T. Hale & William A. Barber
Redstone Test Center
Army Test and Evaluation Command

Fatigue Damage Spectrum and Ford Motor Company
By John Van Baren Vibration Research

Fatigue Damage Import ***How to use the fatigue damage spectrum for accelerated tests*** David VandeBunte

THE FATIGUE DAMAGE SPECTRUM AND KURTOSIS CONTROL
John Van Baren Philip Van Baren Vibration Research Corporation
Jenison, MI December 2009

Fatigue Damage Spectrum – A New Tool to Accelerate Vibration Testing
John Van Baren, Vibration Research Corporation, Jenison, Michigan

How do I Measure the Life of my Product? Posted on June 9, 2016June 9, 2016 adminPosted in Experiments
(when it is subjected to a vibration environment)
Author: R.G. DeJong (3/20/15), Professor Emeritus, Calvin College, Grand Rapids, Michigan.

The Breaking Point: How Fatigue Damage Spectrum Can Help Predict a Product's Life Expectancy
Posted on Aug 13, 2015

Using Fatigue Damage Spectrum for Accelerated Testing with Correlation to End Use Environment
Tom Achatz, PE Global Technical Integration Engineer, General Motors Company
John VanBaren, PE President, Vibration Research Corporation

Some of these articles contain comparisons between PSDA or PSDV calculated from signals not having the same instantaneous values distributions. The conclusions could be therefore uncorrect. These articles are noted err1 ; …. ; err4.

Err1 - A Different Type of HALT Stimulus Case history By George Henderson GHI Systems, Inc., and Kim Kral SCI Corporation

Err2 - Fatigue Damage Descriptors for HALT and HASS George Henderson

Err3- EVALUATING FATIGUE PRODUCING VIBRATION ENVIRONMENTS USING THE SHOCK RESPONSE SPECTRUM
By George R. Henderson, GHI Systems, Inc., San Pedro, California Allan G. Piersol, Piersol Engineering Company, Woodland Hills, California

Correlating End-Use Environments and ESS Machine Excitation Using Fatigue Equality By George Henderson

Err4- Evaluating Vibration Environments Using the Shock Response Spectrum
George R. Henderson, GHI Systems, Inc., San Pedro, California Allan G. Piersol, Piersol Engineering Company, Woodland Hills, California

ANNEXE 5

SDF

Method by matrix inversion

Establishing the specification can be done in several ways:

– by searching for a PSD defined by line segments with any slope whatsoever. We consider the expression of the fatigue damage [4.38] (Volume 4) as:

$$\overline{D} = \frac{K^b}{C} \frac{T}{(4\,\xi)^{b/2}\,(2\,\pi)^{3b/2}} f_0^{1-\frac{3b}{2}} \left(\sum_j a_j\, G_j\right)^{\frac{b}{2}} \Gamma\left(1+\frac{b}{2}\right)$$

It is possible:

– either to take all the points (N) defining the fatigue damage spectrum. This option leads to a (specification) PSD characterized by N points;

– or to simplify the specification, choosing only a few points ($n < N$) of the fatigue damage spectrum, which will lead to a PSD itself defined by n points. In this case, the FDS of the PSD obtained may not be quite as close to the environment FDS (it is desirable that it remains an envelope).

On the basis of n couples, points f_{0_i}, D_i, n equations are obtained with the form:

$$\overline{D}_i = \frac{K^b}{C} \frac{T}{(4\,\xi)^{b/2}\,(2\,\pi)^{3b/2}} f_{0_i}^{1-\frac{3b}{2}} \left(\sum_j a_{i,j}\, G_j\right)^{\frac{b}{2}} \Gamma\left(1+\frac{b}{2}\right) \qquad [12.2]$$

where ([8.80] of Volume 3)

$$a_{i,j} = \frac{{}^{j-1,j}\Delta I_1 - h_{j-1}\;{}^{j-1,j}\Delta I_0}{h_j - h_{j-1}} - \frac{{}^{j,j+1}\Delta I_1 - h_{j+1}\;{}^{j,j+1}\Delta I_0}{h_{j+1} - h_j} \qquad [12.3]$$

$${}^{j,j+1}\Delta I_p = I_p\left(h_{i,j+1}\right) - I_p\left(h_{i,j}\right) \qquad [12.4]$$

and

$$h_{i,j} = \frac{f_j}{f_{0_i}} \qquad [12.5]$$

There is then a set of n linear equations between values G_j that can be expressed as follows in matrix form:

$$\overline{D} = A\;\; G_{b/2}$$

($G_{b/2}$ = a matrix column, each term of which is equal to $G_j^{b/2}$), yielding:

$$G_{b/2} = A^{-1}\;\overline{D} \qquad [12.6]$$

hence the amplitudes G_j. The PSD thereby obtained is defined by n points f_{0j}, G_j connected by straight line segments;

SRE

14.4.1. *Matrix inversion method*

14.4.1.1. *Search for a specification from an ERS*

The specification is then calculated from an ERS as follows [LAL 88]. Knowing that the extreme response can be expressed as follows in its simplified form (by supposing that $n_0^+ \approx f_0$):

$$ERS = \omega_0^2 \; z_{sup} \approx \omega_0^2 \; z_{rms} \sqrt{2 \ln(f_0 \; T)} \qquad [14.2]$$

where z_{rms} is the rms response displacement given by (Volume 3, [8.79])

$$z_{rms}^2 = \frac{\pi}{4\xi(2\pi)^4 f_0^3} \sum_{j=1}^{n} a_j G_j \qquad [14.3]$$

each line of the ERS satisfies the following equation

$$ERS_i \approx \sqrt{\frac{\omega_{0i} \ln(f_{0i} \; T)}{4\xi} \sum_{j=1}^{n} a_{i,j} G_j} \qquad [14.4]$$

For a PSD defined by horizontal straight line segments,

$$ERS_i \approx \sqrt{\frac{\omega_{0i} \ln(f_{0i} \; T)}{4\xi} \sum_{j} G_j \left[I_0(h_{i,j+1}) - I_0(h_{i,j}) \right]} \qquad [14.5]$$

In its matrix form, this equation is

$$ERS_2 = B \; G \qquad [14.6]$$

and therefore the values of $G(f)$.

If the PSD thereby determined is intended to be used as a specification to control a test, it must be kept in mind that the signal which will be delivered by the control unit, of a duration of about 30 s for a seismic shock, will not necessarily have the same ERS as that at origin. It can simply be confirmed that the mean of the ERSs of a great number of signals generated from the PSD would be close to the reference ERS.