Advanced Tools for Efficient On-line Support of Test Campaigns

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Two new tools have been developed for processing vibration test data: one for comparing responses from different tests, and one for predicting the notches in an intended excitation profile. The 'Test Comparison' tool allows the automatic comparison of responses in two or more tests, such as pre- and post-test low-level runs. The quality of the match is given in terms of numerical indices and a flexible, user-friendly interface permits an efficient assessment of the results. The 'Notching Prediction' tool computes the notches required for a given excitation profile, knowing the responses to a previous excitation profile and the maximum accelerations allowed for each sensor. The new excitation profile incorporating the possible notches is computed automatically based on all the responses selected by the user. Various options are available to customise the processing. These new tools have been used to support the recent qualification testing of the Polar Platform and XMM.

Introduction

Vibration test campaigns for the qualification and acceptance of spacecraft structures are usually expensive to run. Test duration is one major driver of the total cost and solutions for performing the various tasks more quickly have to be applied wherever possible. One area in which time-savings are possible is the processing of the test results. Indeed, once the spacecraft has been instrumented and installed on the shaker, most of the time spent is related to assessment of the results from the latest run and definition of the strategy for the next one. These activities usually take several hours, and sometimes days, while the vibration run itself lasts only a few minutes. This is even more critical for tests using a multi-axis vibration facility, where tests in all axes can be performed sequentially without down time for spacecraft orientation changes.

To minimise the duration of a test campaign, it is therefore essential to speed up the evaluation of test results as much as possible by employing efficient tools. In fact, such tools are becoming indispensable as the spacecraft become more and more complex and the amount of data to be examined is growing enormously as a consequence.

The two new tools, which have been developed in DynaWorks 4.0, form an additional optional module of the DynaWorks package called the 'Sine Vibration Tool Box'. The development effort was conducted by Intespace in Toulouse, under the technical supervision of ESTEC's Structures Division.

Test comparison

To verify that a spacecraft or its subsystems have not been adversely affected by a full-level vibration test, a low-level run is again performed and the responses obtained compared with those of the initial low-level run. The most common method of comparing responses is to superimpose the printouts of the two runs for each measurement point, which is time-consuming and cumbersome, particularly for heavily instrumented spacecraft, and sometimes not appropriate if the plotting scales are different. In addition, this procedure is prone to human error and significant differences in responses can easily be overlooked. The new automated tools that have been developed in Dynaworks 4.0 make the comparison more reliable, as well as simplifying and speeding up the overall comparison process.

The 'Test Comparison' module is a user-friendly tool enabling the user to automatically compare the responses from tests on one or more specimens and to detect any deviations. The latter could be due, for instance, to structural damage resulting in frequency shifts and/or different response spectra. Two or more tests can be compared simultaneously, and they can be of the same or different excitation levels, e.g. two low-level tests and a qualification test.

The test comparison consists of four main steps :
- preparation
- comparison
- display, and
- diagnosis.

Preparation
This is an interactive step to define the tests, the responses to be compared and the options to be used in the comparison. The preparation window is presented in Figure 1. The selection of tests and responses is extremely easy due to the archiving and retrieval capabilities of the DynaWorks database system. Just a cut and paste on a single database element is necessary to select all the responses of a test. A pairing table to establish correspondence of the sensors from different tests can be created automatically when the second or subsequent tests are specified. Manual updating of this pairing table is also possible for customised applications. An option to apply a function to the responses before performing the comparison is also available.

Comparison
This step prompts the user for the selection of an indicator and runs the comparison. Indicators compute index values which are a measure of the correspondence between responses*. There are four categories of indicator: 2D, 3D, Peak and MinMax.
- The 2D indicators provide one index value per sensor and per test pair for the whole frequency range of comparison.
- The 3D indicators provide one index value per sensor, per test pair and per frequency point.
- The Peak indicator computes an index value for a given number of response peaks selected by the user.
- The MinMax indicator is identical to the peak indicator, but is applied to maximum and minimum peaks.

Display
Once the comparison has been performed, the results are displayed in several windows as:
- a plot of the repartition and cumulative distribution of indices as a function of the index value (Fig. 2), providing an overview of the quality of the agreement between the responses used in the comparison
- 3D plot of 2D index values as a function of the tests and sensors (Fig. 3)
- 3D plots of 3D index values as a function of tests, sensors and frequency, the magnitude of the index being given as a fringe plot.

Selection criteria are available to display only indices in a given range, for instance indices greater than a specified threshold. This is particularly useful in combination with the

*A low index indicates a good correspondence.

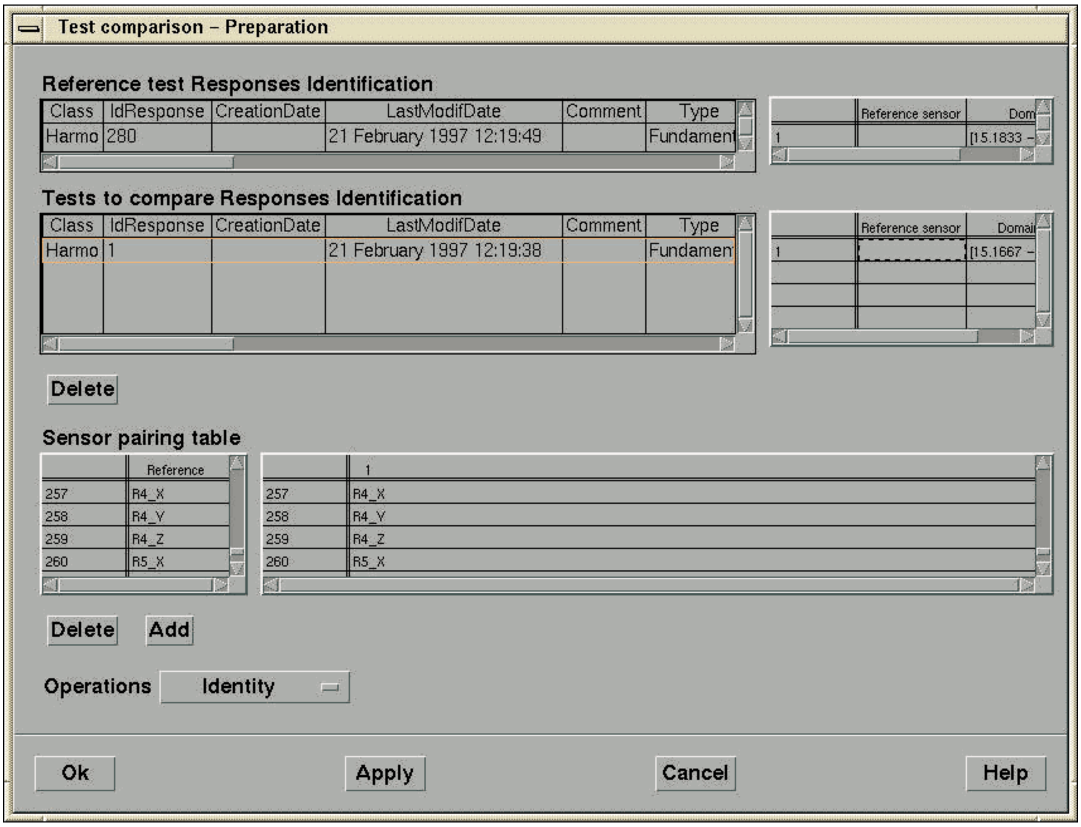


Figure 1. The Test Comparison preparation window

Diagnosis feature to identify sensors exhibiting larger deviations than a pre-defined maximum limit.

A Status window can be displayed informing the user in which registers of the analysis window the data being displayed are located.

Diagnosis
The diagnosis step is designed for the graphical examination of responses having generated an index that meet the selection criterion. A database view of the Response class opens automatically (Fig. 4). It contains only the curves satisfying the criterion defined in the display step. Simultaneously, a 'graphic' window (Fig. 5) is opened displaying the selected curve in the 'view on database' window superimposed on the response of the reference test to which it was compared (according to the pairing table).

A dynamic link between the 'view on database' window and the 'graphic' window allows the automatic updating of the latter when another record is selected in the 'view on database' window. Selection only requires a mouse click or the pressing of an arrow key to move to another record. This feature provides a very efficient means of going through all responses satisfying the selection criterion.

Application
The module was applied in the framework of the Envisat/Polar Platform and XMM qualification testing at ESTEC. The results of the comparisons were available shortly after the tests, allowing the project engineers to hold their post-test assessment meeting without delay. Most of sensors exhibited indices lower than the agreed maximum threshold and did not require additional work. The few sensors that did exhibit higher than threshold values required further inspection and so plots with superimposed responses generated for these sensors were examined for acceptance on a case-by-case basis.

This represented the first application of the new tool in a real tests and the efficiency of the on-line support was much appreciated by the projects. Some potential improvements to the software that were identified during the Polar Platform tests were already implemented by Intespace for the XMM tests.

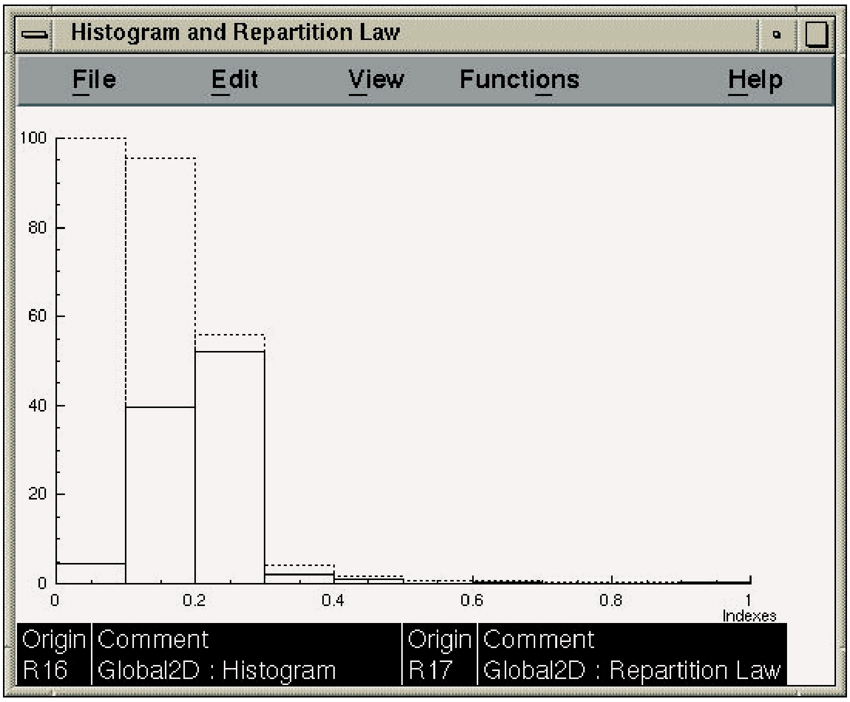


Figure 2. Distribution and repartition-law window

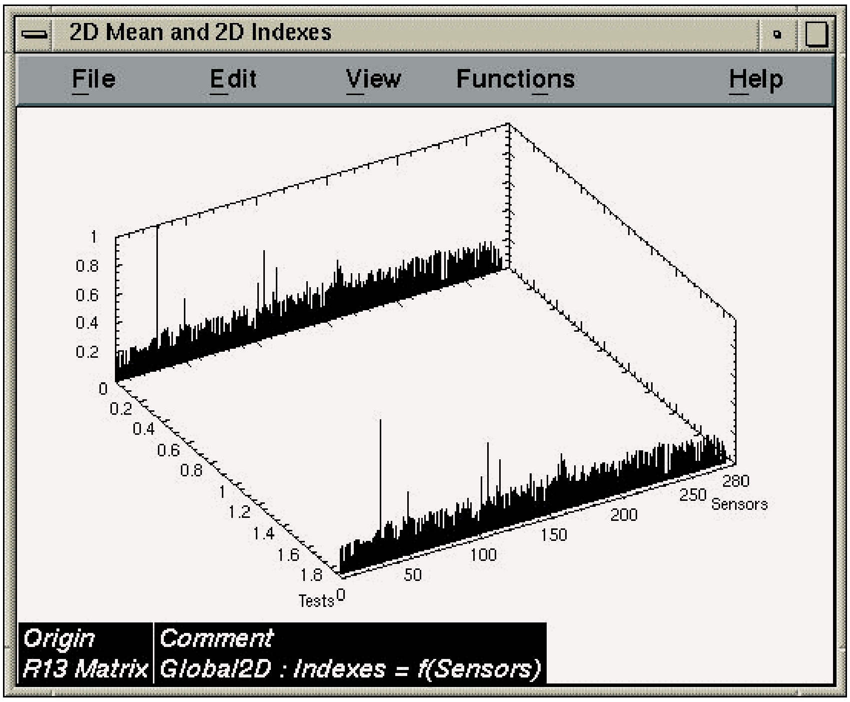


Figure 3. 2D mean and indices window

Notching prediction
In order not to damage a specimen/instrument, it is usually necessary to notch the shaker excitation in the frequency ranges of specimen resonance. The final notched profile is ultimately determined by extrapolation of the responses obtained during the low- or intermediate-level runs. The purpose of the 'Notching Prediction' tool recently implemented in DynaWorks is to automate this activity in order to speed up and increase the reliability of the derivation of the notched excitation profile.

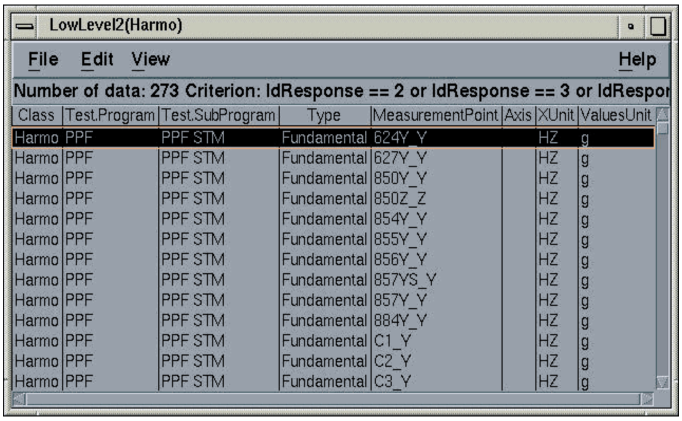


Figure 4. Database view of selected responses

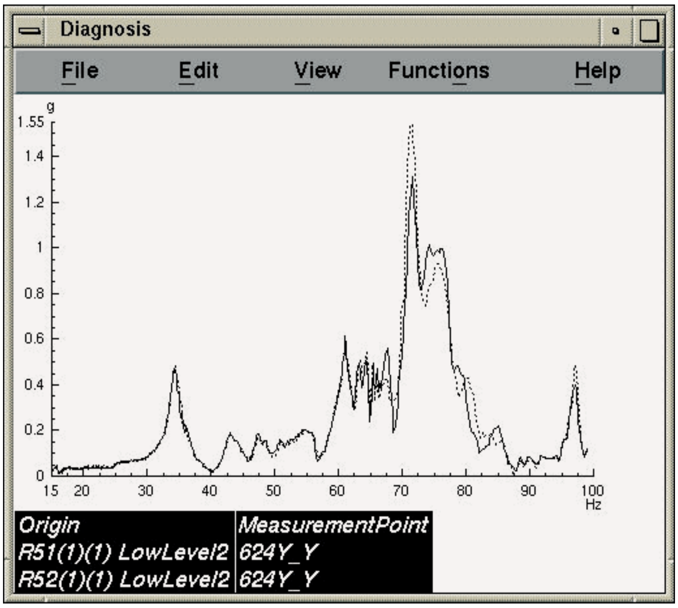
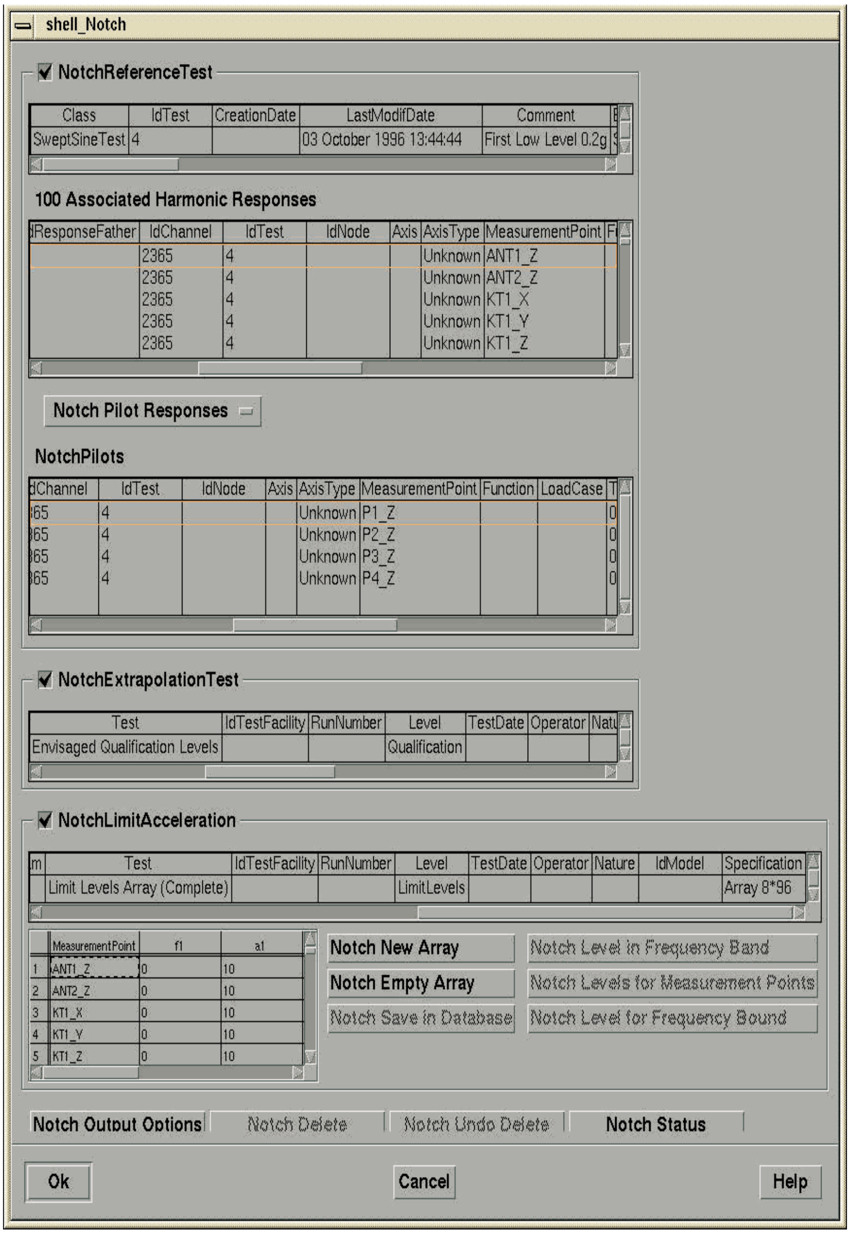


Figure 5. Diagnosis window

Figure 6. Data definition window



The ‘Notching Prediction’ tool computes the notches required to a given excitation profile knowing the responses to another excitation profile and the maximum accelerations allowed for a selected set of sensors. It consists of two main inter-active steps:
- definition of input data for the automatic prediction
- updating of the proposed notched profile with a graphics tool.

The process starts with the definition of the input data in the window presented in Figure 6, by cutting and pasting database items into the various areas on the screen. The items to be defined are:
- the reference test from the test class
- the associated harmonic responses from the response class
- the reference excitation from the response class if the pilot response option is selected
- the extrapolation test from the test class
- the limit acceleration table from the test class.

All responses of the reference test – for example a low-level test for which responses are already available – can be specified, or only a subset, according to the user’s wishes.

There are two options for defining the reference excitation:
- *test specification*: the test specification stored with the test definition in the DynaWorks database is used
- *pilot average*: the average of a list of responses, usually the pilot responses, is used, and a new sub-window allows the definition of these responses for this option.

The extrapolation test is the test for which the notching prediction is to be made. The database item pasted into this area must contain the excitation specifications of the test. The table of limit accelerations contains the maximum allowable acceleration values per sensor and is unique for each test specimen, i.e. it does not depend of the excitation level for which the notching prediction is foreseen. Maximum limits can be defined for each sensor in multiple frequency bands. Built-in function-alities are available to help define this table easily.

Once all of the input data has been defined, the computation of the prediction can be started. After a few seconds, a graphics window appears with the profile of the new test with the derived notches. A table is also created providing, for each sensor, the maximum value in each frequency band and the ratio to limit the allowable acceleration defined for that sensor in that frequency band. A value greater than one indicates that a notch will result from that response.

Updating of computed specification

Two options are available in the graphics window for updating the computed notched specification. The first option is automatic. A notched excitation profile with constant levels which best fits the computed profile is computed based on the definition of a minimum frequency bandwidth and a tolerance on the level. The second option is to construct manually a minimum envelope either graphically with the mouse or by typing-in numerical data (Fig. 7).

The user has the option of storing the updated notched specification and some intermediate results in the database for later use.

Application

This module was also exploited within the framework of the Envisat/Polar Platform (PPF) qualification testing at ESTEC. The notched profiles generated have been compared with those derived by the contractor with a tool specifically developed for these qualification tests. In all cases, there was excellent agreement between the two sets of predictions.

The limitation of the DynaWorks tool available at the time of the PPF test has been removed in the version used for XMM. It relates to the definition of the excitation profiles and maximum allowable acceleration curves which could only be represented with constant values in each frequency range. It is now possible to have ramps in the definition of these items. Similarly, the notched specification updated manually can now incorporate ramps.

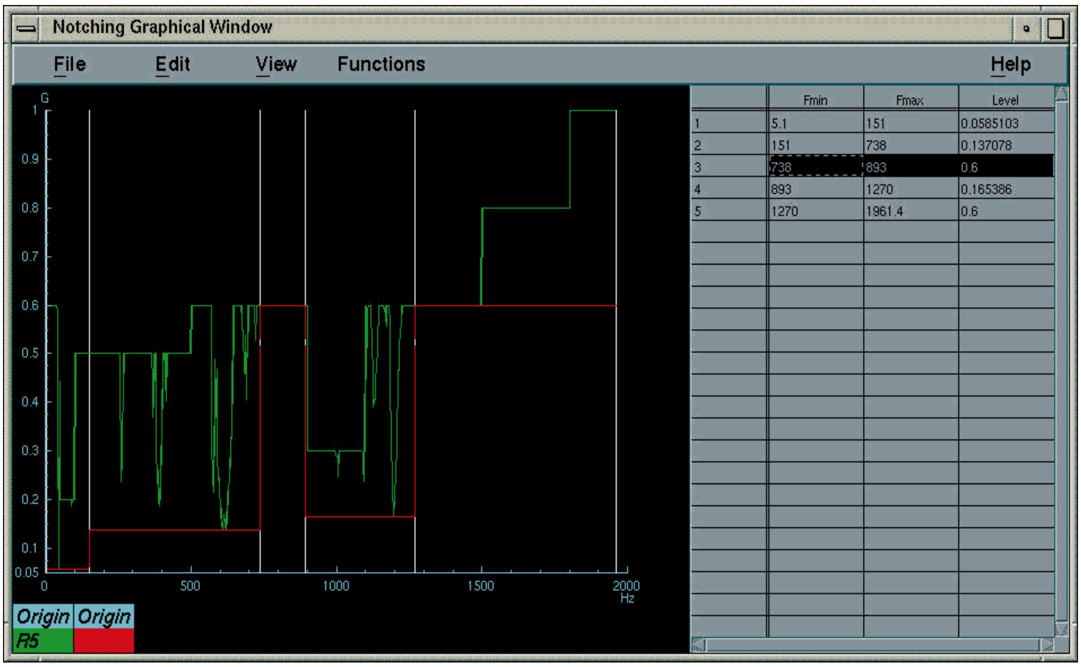


Figure 7. Graphical window