NEW MECHANICAL TEST DATA HANDLING CONCEPT AT IABG

A. Grillenbeck, S. Dillinger, S. Prause
grillenbeck@iabg.de, dillinger@iabg.de, prause@iabg.de
IABG mbH, Einsteinstrasse 20, 85521 Ottobrunn, Germany

OVERVIEW

The current market for space testing requires more and more efficient and accurate data handling facilities for mechanical testing, and in particular for specific applications, even high channel counts.

Facing this challenge, IABG has initiated and already has partially implemented a new test data handling concept.

In this paper, an overview on this concept will be presented and details on the already realized achievements for the modal test facilities will be given. First experience already has been made in real tests such that the achieved benefit may be demonstrated.

Finally, the remaining future work will be addressed with respect to the implementation of this concept to the vibration, shock and the acoustic test facilities.

1. INTRODUCTION

The ESA coordinated space test centre at IABG in Ottobrunn provides all relevant kinds of mechanical testing facilities as needed for spaceflight hardware dynamic qualification and characterization. These facilities provide:

- Vibration testing
- Acoustic testing
- Shock characterization
- Modal characterization

Each of these facilities has different requirements to the mechanical test data handling with respect to sampling rates, dynamic range, data quantity and data processing on the one hand, but also various requirements with respect to maximum channel numbers, on test site availability or mobility, and user interfaces and specific software for various measurement applications in the frequency or the time domain. Further requirements may be added to this list.

Nevertheless, there are also a number of communalities which have to be used to find an efficient approach in defining the data acquisition and handling system for the mechanical test facilities and to implement its use in the daily work without producing excess cost with respect to hardware and software procurement, follow-on maintenance and licensing, as well as costs related to operator training and common or specific user interface design. Tab. 1 summarizes some of the typical requirements to the mechanical test data handling as seen today and the near future at IABG.

Facility	Sample Rate (kHz)	Average Quantity of Channels	Maximum Quantity of Channels	Sensors
Vibration 320 kN 200 kN 80 kN	 6.5	 50 - 200 50 - 200 20	 600 250 ---	Acceleration Force Strain
Acoustic Reverber. PWT	 6.5- 25	 50 - 100 10	 350 ---	
Shock	30 - 200	20 - 50	250	Acceleration Strain
Modal MST other	 1 - 10 up to 200	 50 - 500 10 - 30	 1,000 ---	Acceleration Force Strain Pressure Displacement

Tab. 1: Requirements to the Mechanical Data Handling at IABG

According to Tab. 1, it becomes evident that three vibration facilities and two acoustic facilities - the reverberation chamber and the progressive wave tube (PWT) are run at IABG. Additionally, the modal test facility is used for classical modal survey testing (MST) as well as for other applications like the in-operation vibration analysis and the micro-vibration characterization. While the data acquisition systems for vibration and acoustic are allocated close to the respective facility, the mobility, i.e. the capability to work at any suitable test site is fundamental to shock and modal testing.

In Tab. 2, the typical operation modes and data output of the IABG mechanical test data handling are presented. For all mechanical tests, with the exception of the MST, time domain data are acquired first which subsequently are processed and transformed into the respective frequency domain formats and plots. This two steps approach may appear not time efficient, but always keeping the time domain data is valuable for any additional post processing which may be required for further detailed inspection of the test article dynamic behaviour. Therefore, it was not intended to change this approach for the new data handling concept taking into account that nowadays, the data post processing is not too much time consuming and a limited number of on-line FFT processing is sufficient for almost all test applications, if required at all.

Facility	Operation Mode Recording / Processing	Post Processing	Output Formats
Vibration	Time Domain off-line	Spectra PSD	Universal Files DynaWorks Neutral Files
Acoustic	Time Domain off-line	PSD	
Shock	Time Domain off-line	SRS	
Modal MST	Frequency Domain on-line	Spectra, FRF Mode Tuning	
Other	Time Domain	Any processing	

Tab. 2: Mechanical Data Handling Operation Modes and Output

One specific feature of the mechanical data handling at IABG is its decentralized concept, i.e. each facility mentioned in Tab. 1 has its own data handling capacity. This concept is a logical and mandatory consequence of the various tests which usually have to be performed independently and in parallel on the IABG mechanical test facilities on equipment, subsystem and element level for spaceflight, as well as for other industrial applications.

Up to now, the data acquisition for vibration, acoustic and shock was based on RACAL digital tapes and Heim A480 recorders with dedicated signal conditioning units for IEPE and piezoelectric sensors, strain gauges etc., as well as on an LMS CADA-X based user programmed application (UPA) stack to perform off-line processing of the recorded time domain data into spectra, power spectral density (PSD) or shock response spectra (SRS).

For the modal tests, always different and specific hardware and software had to be used to provide the specific excitation and data acquisition means based on sine dwell and on-line co-quad analysis, as well as to perform MIMO modal identification using time domain methods. The measurement facility for modal tests was operated either to directly acquire spectra or frequency response functions (FRF), or to tune modes and to measure mode shapes. For the phase separation technique as used in MST, since mid of the 1980's, in particular, IABG's large modal test system was used providing up to 886 channels. This facility was accommodated in a 9 m container (see Fig. 2).

Driven by the need to replace the modal test system by state-of-the-art solutions both for the hardware and for the software in order to ensure future competitiveness and the fulfilment of test requirements, IABG has derived a new data handling concept which deems to be the most suitable to the way of our testing business.

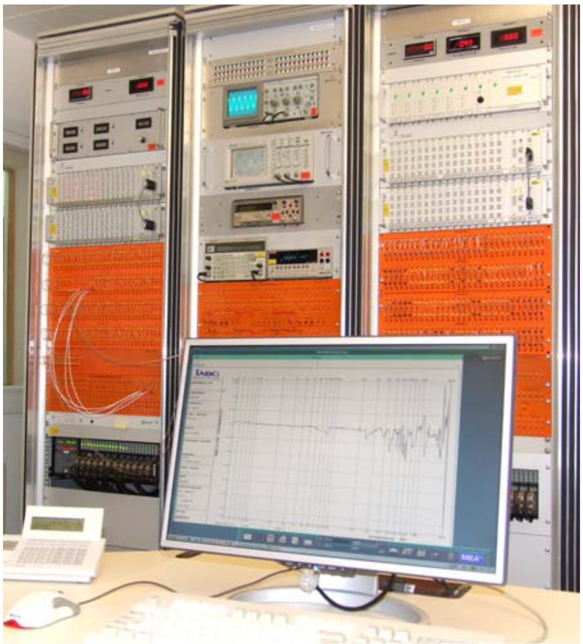

Fig. 1: Current Data Acquisition for the 320 kN Vibration Facility

Fig. 2: Already History: IABG's Modal Test Container as used for many ARIANE 5 modal tests

2. BASIC REQUIREMENTS

As it can be seen in Tab. 1, modal testing of large structures usually presents the highest demand on the amount of channels. In addition, modal testing also presents the most demanding requirements to the on-line data processing. In our old modal facility the amount of 886 channels was achieved by automated block switching of 126 signal conditioners and amplifiers during a measurement. Today such a concept is considered no longer favourable when considering the demand to reduce testing and dynamic loading times, however, a maximum of 1000 channels or even more are considered mandatory for any future complex spaceflight structure like main launcher constituents or complex payloads.

On the other hand, large channel quantities which only are used from time to time for large test articles are not a very interesting investment when considering economic aspects. Therefore, the flexible use of any new data handling system by all mechanical test facilities was - and is - the most important requirement to any upgrade of our mechanical test data handling systems. Besides of this basic requirement, the following technical, operational and economic requirements were considered for the new data handling concept:

- The data acquisition and handling consists of small modules of about 100 - 150 channels which easily may be combined to a fully synchronized array of 1000 channels or even more.
- Any amount of channels is controllable by one single PC-based console. In particular, the channel setting is based on one single list, applicable to all mechanical test facilities and which has a direct link to our sensor data base.
- The signal conditioning and digitizing uses the latest technology of 24 bit (at least 16 bit) A/D conversion and sampling rates up to 200 kHz, and provides an excellent signal-to-noise ratio as well.
- The recording of time data is performed by each unit's local hard disks, but the on-line access to the data is feasible for any operation mode of the data acquisition systems. This in particular is required for the MST when the primary data output is in the frequency domain.
- The data records, as well as all relevant software interfaces, are fully transparent enabling the development and adaptation of suitable graphical user interfaces as well as analysis applications. This requirement was most important for the new modal test facility since any commercially available software package did not satisfy our advanced test concepts and requirements. Consequently, this resulted in the need to write the application by ourselves.
- A fully programmable signal generator is available providing all relevant signal types and a programmable frequency increment of 0.1 mHz.
- Other frontends like the existing Heim A480 and strain gauge conditioning units may be integrated into the new test data handling concept in order to protect the existing hardware investments. This feature also shall enable the step-by-step conversion to the new test data handling facility.
- The hardware fulfils stringent EMC requirements such that even non-standard laboratory conditions as encountered in mobile applications will not disturb the measurements.
- The hardware is easy to maintain and spare parts are available for a considerable future period.
- Calibration or facility checks shall be fully accessible to the user and easy to perform before any test to prove facility test readiness.
- Software licensing is flexible and affordable.

3. SELECTED CONCEPT

The selection process indeed was driven by the modal test facility, but the envisaged solution always was checked against the needs for the other mechanical test applications. It turned out that a number of vendors were able to provide hardware compliant to our requirements and a large variance of standard software was offered which, however, often was driven by typical application markets and applications. Finally, the key to the order placement was the availability of a really convincing signal generator and the ability to provide an open software platform and accessible data structures. In addition, the capability of an on-line co-quad analysis was only fulfilled by the minority of vendors, as well as the flexibility to accept software adaptation to our needs.

Finally, the contract was awarded to Dewetron in Austria. The hardware consists of three packages which may be combined via network: Frontend Packages, Complementary Control Package and Modal Package.

The Frontend Packages (FEP) of this facility consist of:

- A PC with integrated monitor to run up to 256 channels, i.e. providing frontend setting, baseline time data recording, data storage with built-in RAID for instantaneous data backup, versatile data display and fundamental analysis.
- Signal conditioners and amplifiers with up to 2 x 126 channels IEPE, voltage or strain. Their baseline characteristics are 24 bit A/D, 200 ksample/s per channel and a SNR better than 105 dB.

Each of this Frontend Packages already may be run standalone for time domain data acquisition. For the facility extension to channel counts higher than 256, as well as for the facility customization to our needs, the following package, the Complementary Control Package (CCP) is added:

- A PC based control console with a 1 GB network connection to the above mentioned elements.
- A visual.net software platform.
- Dedicated GUI and application software.

Finally, for completing the modal test facility the signal generator and safety mechanisms, the Complementary Modal Package (CMP) is added:

- Signal generator with its own PC and integrated self checking capability, i.e. a watchdog which compares the definition of the output signal and the actual output signal; such that any deviation will cause safe generator shutdown.

- Two further independent safety mechanisms based on structural response observation and instantaneous comparison to limit values for alarm or abort.
- Two reference lines and one synchronization line between all FEPs and the CMP.

The components of the facility are shown in Fig. 3.

Frontend Package | Complenentary Control Package | Complementary Modal Package

Fig. 3: Elements of the New Test Data Handling Facility

With these components, the minimum equipment forseen for each mechanical test facility as indicated in Tab. 3. The maximum quantity of channels to be provided to each facility is based on further Frontend Packages or the temporary use of the baseline capacity of another facility.

Facility	Baseline Channel Quantity	Maximum Channel Quantity	Facility Packages
Vibration 320 kN 200 kN 80 kN	 240 120 20	 600 250 125	 A480 1 – 2 FEP + CCP
Acoustic Reverber. PWT	240	360 ---	1 – 1.5 FEP + CCP
Shock	120	360	1 – 1.5 FEP + CCP
Modal MST	500	1,000	up to 4 FEP + CCP + CMP

Tab. 3: New Mechanical Data Handling at IABG

According to this concept, the actual advantage of the new system is focused in the Complementary Control Package which provides the following features:

- Central control console for all attached FEPs
- Adapted GUI for vibration, shock and acoustic testing on the one hand and for modal testing on the other hand
- Standardized facility consistency and functionality checks
- Standardized set-up list for all channels and all applications which is directly linked the sensor database.
- Further off-line data processing capability for standard output in plots, lists and data formats, as well as test reporting and archiving.

4. REALIZATION FOR THE MODAL TEST

The modal test facility is the first realized step towards the new test data handling at IABG. Up to four FEPs, one CCP and one CMP make up the complete modal test system. Alternatively, all four FEPs may be used independently and in parallel for different test campaigns, since the CCP component simply consists of a PC, the network and the respective software modules. The block diagram of the new versatile modal test facility (VMT) is shown in Fig. 4.

The main features and functionality of the VMT facility are as follows:

- Each FEP of the VMT can handle up to 250 measurement channels (IEPE or voltage).
- The standard sampling rate for modal testing is 10 kHz per channel, higher sampling rates per channel are possible.
- The PC of each of the FEPs performs the on-line co-quad analysis of the time signals by using overlapping data segments and determines the real and imaginary parts as well as distortion factors for each individual channel.
- The co-quad analysis rate depends on the actual channel count and data segment length, 3 data sets per second for 250 measurement channels is standard, up to 5 data sets per second are practically possible.
- All FEPs are connected to the VMT server (CCP) via local network. In the VMT facility, the FEPs are fully remote controlled by the VMT test control software.
- The data packages containing the results of the on-line co-quad analysis are transferred to the CCP and may be displayed instantaneously.

The signal generator is a decisive element in a modal test facility. This instrument has to

- generate the control signals for several modal vibration exciters in parallel at a precisely defined common frequency,
- control the amplitude and phase angle of each output channel individually,
- prevent signal interruptions or voltage steps that would generate shock excitation with uncontrolled high frequency components due to changes of any signal parameter,
- exclude any uncontrollable signal generator status.

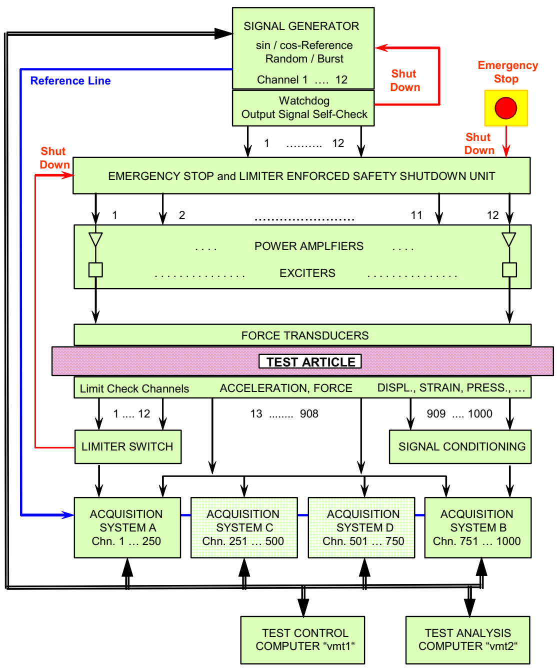

Fig. 4: Block Diagram of the Versatile Modal Test Facility (VMT)

The VMT signal generator (the CMP) basically is a standard computer equipped with 16 high speed output channels:

- 12 modal vibration exciters may be controlled simultaneously. The remaining 4 channels are used internally.
- The standard output sample rate is 100 kHz, and up to 1 MHz is possible.
- The frequency resolution is 0.1 mHz. This resolution is necessary for the precise tuning of test article modes with small damping values in the low frequency range.
- All signal parameter changes are performed as smooth transitions.
- The processor of the signal generator is constantly checked by an independent watchdog unit. This watchdog also blocks the output signals if the processor does not respond.
- In the VMT facility, the signal generator is connected to the CCP via local network and it is fully remote controlled by the VMT test control software. For other applications, the signal generator can work as stand-alone generator controlled by its own operator software.

The VMT facility can be configured as standard configuration with 1 to 4 FEPs, providing up to 1000 measurement channels and 12 vibration exciters. However, the hard- and software concept is designed for up to 8 FEPs. The frequency range for modal testing by using tuned sine excitation is between 0.5 and 10,000 Hz.

The most important element on the VMT server is the test control software and its Graphical User Interface. This software consists of several modules that provide

- the generation of the test setup files,
- the test control,
- and the modal test data processing and analysis

in one common environment.

The in-house development of this software ensures the possibility to adapt the data handling, display and processing to specific test requirements and, of course, implements the possibility to check and fix any software bug immediately.

The CCP uses a high resolution monitor screen displaying the full graphical user interface for the test control (see Fig. 5).

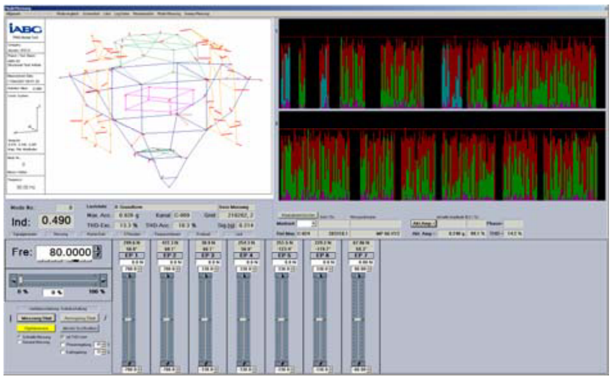

Fig. 5: Central Control Monitor of the VMT

This display includes:

- The exciter controls, i.e. setting of the excitation frequency as well as of the forces and relative phases of each active individual vibration exciter.
- A fully 3-dimensional accessible display of the test article structure with the presently measured amplitude vectors.
- The most important parameters of the present vibration status of the test article, i.e. in particular the mode indicator value and the maximum response acceleration.
- During sweep measurements, the indicator function is displayed on-line, additionally the structure representation may be replaced by the display of selected response functions,
- The display of all presently measured amplitude values (up to 1000), referenced to an individual amplitude limit for each channel.

This display of the relative amplitudes of all measurement channels (right upper section of the screen) is a decisive feature of the test control software with respect to test article safety as well as to data quality:

- This display shows instantaneously the present vibration status of the test article, the trend of growing or diminishing amplitudes is visible.
- During a sweep measurement for example, the excitation level can be adjusted, if too high vibration amplitudes are to be expected. (The software, of course, reduces or shuts down the excitation forces automatically as soon as one of the individual amplitude limits is exceeded).
- This amplitude display shows also the distortion factors for each channel. These distortion factors indicate possibly disturbed test article vibrations as well as faulty individual sensors. The detection of distorted test article vibrations or malfunctioning sensors during the measurement enables the immediate correction of the problem and thus avoids later difficulties in the off-line analysis of the data.

Another important element in the quality concept of the VMT system is the integrated facility self check. This software module simulates a full scale measurement by feeding all available measurement channels via a specific signal line with a common calibration signal. The obtained results are, in the same way as during measuring sensor signals, transferred from the FEPs to the CCP server and are analysed there. As a standard, this measurement is performed in an automatic, but fully user customizable, sequence at different predefined frequencies and input amplifier settings. This process checks and verifies within a few minutes:

- The functionality of all FEPs and of the CMP computers in the actual VMT configuration.
- The functionality of the VMT software as well as of the FEP and CMP signal generator software.
- The functionality of all software interfaces, on each computer as well as between the individual computers, including all command and data communication.
- The functionality and calculation rate of the on-line co-quad analysis.
- The correct amplitude, phase, offset and sine quality of the reference sine and cosine signals (by an absolute co-quad analysis).
- The correct amplitude, phase, offset and sine quality of all individual measurement channels (by a comparative co-quad analysis).
- The correct function of all input amplifiers using all internal signal paths.

Thus, at any time before or during a test, the correct functionality of the complete test facility as well as the quality of each individual measurement channel can be checked, verified and documented.

The safety concept of the VMT facility includes the following features:

- The software compares each measured amplitude value (by default 3 times per second) to an individually predefined limit value for each measurement channel. If one of the limit values is exceeded, the excitation signals are reduced or shut down, depending on the individual system setup.
- Additionally, an external and independent control instrument compares the time signals of up to 12 selected channels on hardware basis to predefined limit values. If one of these limit values is exceeded, the excitation signals are switched off smoothly.
- A manual emergency stop is available.
- Distortion factors are calculated within the on-line co-quad analysis and displayed on-line on the screen. Thus, distorted test article vibrations as well as defective sensors can be detected immediately.
- The output signals of the signal generator are limited by software to a specific maximum voltage as well as to maximum exciter forces for each individual vibration exciter.
- All changes in the output signals are performed with smooth transitions.
- The signal generator is controlled by an internal watchdog unit.
- If the test control software detects a communication problem or that a timeout occurs, the excitation signals are shut down.
- The test control software includes the possibility to count and record the loading times respectively the vibration cycle numbers for selected channels.
- The correct function of IEPE sensors is indicated by a LED for each individual channel.
- All measurement channels are checked with respect to signal overload, an overload is indicated on the screen.
- In the test control software, excitation is not possible without active measurement process, i.e. there is no excitation without active limit control.
- All relevant actions in the test control software are automatically recorded in a log file, such that any events may be analyzed later.

The analysis modules of the VMT software provide for the processing of mode shape data

- static and animated mode shape display (regular and 3-dimensional-stereoscopic),
- mode shape listings,
- eigenvector normalization,
- orthogonality and MAC checks,
- generalized and effective masses,
- rigid body motion calculations,
- linearity checks,

and for the processing of sweep data

- display of spectra and FRFs,
- data listings,
- response mode shapes,

- calculation of force patterns,
- visualization of the mode shape contents,
- curve fitting,
- rigid body analysis,
- synthesis of response functions from a modal model.

Spectra as well as mode shapes are stored in the Universal file format and are hence ready for the transfer to the customer without additional work.

Additionally, small data viewer software is available and may be handed out to the customer to visualize the measured mode shapes respectively response functions.

5. NEXT STEPS

The migration of the new concept to the vibration, shock and the acoustic test facility still lies ahead. The currently used UNIX based MEAn software package for these test applications was developed 12 years ago at IABG and since then, it has been continuously updated to reduce the analysis time and to increase the accuracy of the analysis results. Also, new measurement amplifiers, A/D converters, and computers were introduced step-by-step to replace older, less powerful ones. However, now it is mandatory to face the upgrade of the UNIX environment to the PC environment and to take this opportunity to integrate the previously defined FEP and CCP elements of the new test data handling.

By doing so, the existing investments in terms of signal conditioning units and acquisition channels which are still considered useful have to be protected. This basically concerns 154 strain gauge bridge amplifiers, 432 acquisition channels on the Heim A480 recorders, as well as the related conditioners for IEPE or passive accelerometers. Indeed, this results in an inhomogeneous design as shown in Fig. 6, but by experience, this may be well handled and it is open for the future replacement of older systems by FEPs. The Racal tape recorders, however, no longer will be used.

The challenging point of this design is the PC version of the MEAn software package, now called MEAn-XP. As many MEAn software modules as possible shall be migrated from UNIX platform to the PC platform (i.e. the CCP) to reduce development costs and risks. Today, the concept phase for the development of the software modules and the migration of the MEAn-XP software package is concluded. The following work packages are defined and are now in he make:

- Development of a new module to create the measurement channel table – MEAedit.
- Development of a new module to set up the measurement amplifiers – MEAset.
- Migration of the module to control the recording – MEArecord.
- Migration of the modules for data analysis – MEAn-Analysis.
- Migration of the modules for presentation of the analysis results – MEAn-Presentation.

In the following chapters, the characteristics of the MEAn-XP modules are described and new features are explained.

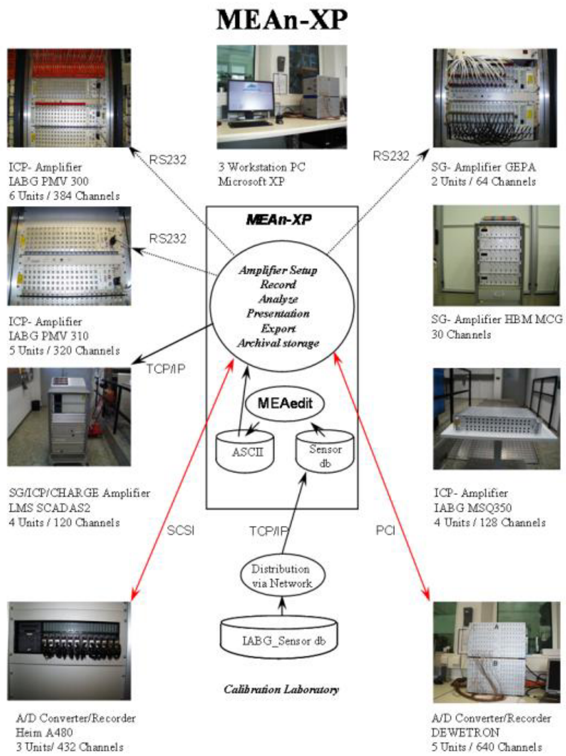

Fig. 6: Layout of the MEAn-XP

<u>MEAedit</u>

Provides the GUI to easily prepare the measurement list and the set-up for the frontend upload. Its output is the global table and the channel table. The latter directly may be used to set the different frontend devices.

The content of the global table consists of:

- Information about the project and test item
- Scheduled end of test campaign (due date for the next earliest sensor calibration)
- Operator identification
- Sensor database ID and measurement configuration

The channel table comprises (see also Fig. 7):

- Virtual channel number
- Frontend type and frontend channel
- Measurement ID including axis and direction
- Sensor serial number (high lighted when out of calibration)

- Sensor sensitivity (automatically extracted from sensor data base)
- Measurement range request of operator
- Full scale setting of the amplifier (computer calculated to meet the operator's request)
- Channel transfer factor
- Error flag

The automatic indication of the sensor calibration validity is a new feature of this software module.

<u>MEAset</u>

This software module uses the output file of MEAedit for initialization, setup and check of the measurement amplifiers. These checks depend on the features of the individual amplifiers:

- System - in - use check (is measurement system occupied by another user?)
- Setup check (do all demanded channels meet the operator requirements?)
- Channel calibration (full scale calibration, strain gauge bridge zeroing)

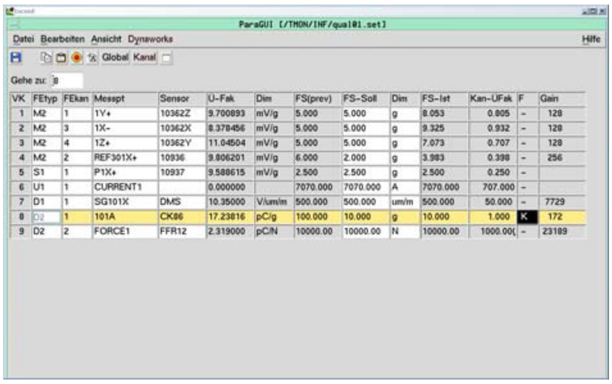

Fig. 7: MEAedit GUI

<u>MEArecord</u>

This module is similar to MEAset, but it is used during the acquisition run time to check and to record the A/D converters, the AC/DC coupling as well as the full scale voltage. These checks depend on the features of the A/D converters.

<u>MEAn – Analysis</u>

Most of this module's functions will provide improved performance. It uses the global and the channel information in the output file of MEAedit for documentation and calibration of the time domain data.

- Negation of the actual 2 GByte limit for raw data files
- Dewetron database input in order to integrate the FEP systems
- Speedup of the swept sine analysis process
  Swept sine fundamental analysis 5 – 150 Hz, 2 Oct/min, resolution 1000 lines, 140 channels, sampling rate 6.5 kHz, scheduled time for analysis: 10 min
- Speedup of the random analysis process
  Random PSD 20 – 2,000 Hz, 20 sec., resolution 4 Hz, 120 DOF, 140 channels, sampling rate 6.5 kHz, scheduled time for analysis: 1:20 min
- Speedup of the SRS analysis process
  SRS MaxiMax 10 – 10,000 Hz, 0.5 sec., resolution 1/12 oct., Q = 10, 140 channels, sampling rate 30 kHz, scheduled time for analysis: 4:20 min
- Increased accuracy of the computed spectra by the use of the individual frequency response of each individual sensor instead of its sensitivity at 80 Hz (see Fig. 8 for an example)

<u>MEAn – Presentation</u>

Based on the previous generated information and data, this module provides the data output for the vibration, shock and the acoustic test facilities.

- Speedup of the plot process, scheduled run time for 140 plots is 5 min
- Plot layout in color
- Multiple plot (all X, Y and/or Z spectra in one plot)
- Interfaces to EXCEL, UFF58, DYNAWorks Neutral File
- PDF document output
- Data archive management

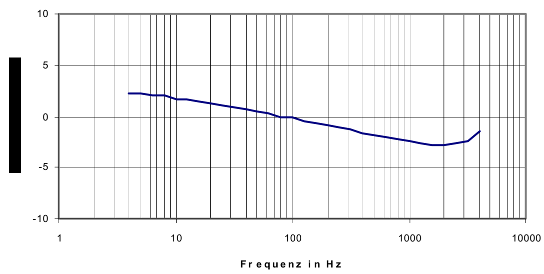

Fig. 8: Typical Frequency Response of an Accelerometer

CONCLUSION

The concepts of the new test data handling for the mechanical test facilities has achieved a maturate status, and for the modal test facility it is already fully implemented and operational.

This concept provides the latest hardware standards, as well it provides to highly flexible GUI for paving the way to a common standard for all mechanical test facilities. While retaining much of the software work in the hands of IABG, the high level of autonomy which we were used to have in the past also will be ensured in the future.

Finally, it is planned to have the new concept implemented to all mechanical test facilities in 2008.

ABBREVIATIONS

A/D	Analog to digital conversion
CCP	Complementary Control Package
CMP	Complementary Modal Package
DOF	Degree-of-Freedom
EMC	Electromagenetic Compatibility
FEP	Frontend Package
FFT	Fast Fourier Transform
FRF	Frequency Response Functions
GUI	Graphical User Interface
IEPE	Integrated Electronics Piezo-Electric
LED	Light Emitting Device
MAC	Modal Assurance Criterion
MIMO	Multiple Input Multiple Output
MST	Modal Survey Test
PSD	Power Spectral Density
PWT	Progressive Wave Tube
SRS	Shock Response Spectrum
UFF58	Universal File Format 58
UPA	User Programmable Application
VMT	Versatile Modal Test Facility