Streamlined Test Setup with TEDS Technology

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1. ABSTRACT

TEDS (Transducer Electronic Data Sheet) Technology packages manufacturer and user-defined information within the traditional analog ICP® transducer. Using the same simple two-wire electrical connection, these smart sensors are now able to identify themselves over a network, allowing completely self-configurable transducer setup. This paper describes how to efficiently use TEDS technology on large multi-channel structural tests, such as modal analysis. An update on the developing smart sensor IEEE P1451.4 standard that describes TEDS is provided. Also, practical equipment additions (from Pocket PCs and PDAs to a 3D sonic coordinate digitizer) are integrated within the system setup solution.

2. INTRODUCTION

Structural test professionals stand to reap great cost savings in test set-up time from technologies introduced and commercialized in the past several years. Two of the most significant commercializations have been in the form of standardized TEDS (Transducer Electronic Data Sheet) transducers and 3 dimensional coordinate digitization (3DD). Although certain advantages have been realized from these products, even greater gains are to be had by the seamless integration of them together into an integrated system of acquiring test set-up data. A third aspect of integration is provided by technology driven by the consumer marketplace – the Personal Digital Assistant (PDA). The increasing popularity of these devices, along with fierce competition among their manufacturers, has resulted in increasing power/performance ratios, and low cost developer toolkits which make customized solutions for structural testing a reality.

2.1. TEDS Standardization

Through the efforts of the P1451.4 Standards Working Group commissioned by IEEE, the most popular structural test transducers have been modified to include on board memory for the purpose of self-identification. The draft IEEE P1451.4 standard proposes the mixed mode transducer interface and the encoding method for the TEDS. In addition to the proposal of this standard, the structural test market has driven the de facto standardization of this interface for IEPE (Integrated Electronic Piezo Electric) transducers. With thousands of channels installed worldwide by multiple manufacturers, the physical layer of what will be the IEEE P1451.4 interface is firmly entrenched in the market. In addition, the members of the working group also encode the TEDS data using a common method. This collaboration has resulted in a level of Plug and Play functionality for TEDS systems that is similar to the level of PnP enjoyed by IEPE sensors.

Although immediate market demands have dictated the rather inflexible implementation of TEDS. The P1451.4 working group is also charged with generalizing the physical interface for use with transducers of any design (rather than just IEPE), and also with developing a generalized method by which manufacturers, developers, and even end users may encode the TEDS as they see fit. It is in this flexibility that the working group apparently proposes a paradox: How may one encode the TEDS however he chooses, yet still provide for PnP capabilities by letting anyone decode the data?

The answer to this question lies in both compromising encoding flexibility, and the use of a common method by which one may declare the data format. The working group is developing what is known as ‘IEEE P1451.4 Description Language’ (DL). The intent of the DL is to provide a common method to express how the data in the TEDS is encoded. Given the task of decoding or encoding a TEDS, a host process (as shown in Figure 1) accepts the raw data and a collection of data templates (published in the DL), and processes them. The result of this process is a collection of transducer field/data pairs, which are exposed to the data acquisition application.

The P1451.4 working group has named this “encoding/decoding engine” process “P1451.4 T-Block”, or T-Block. The T-Block is targeted as the object oriented software interface to TEDS transducers. The T-Block exposes various methods and properties to higher level applications, which are used to identify and/or manipulate transducers on P1451.4 interface. The T-Block also relies upon a set of TEDS templates that are presumed to be available in the same environment.

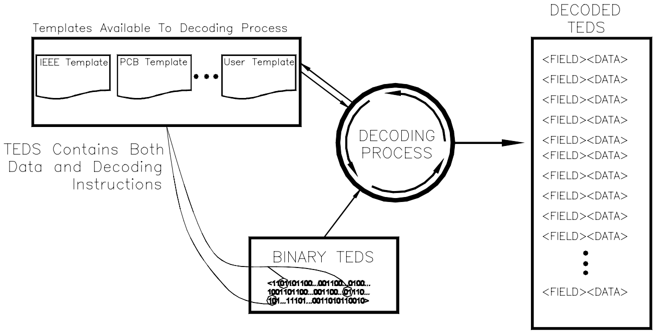

Figure 1 – T-Block Encoding / Decoding Engine

The T-Block is directed to the appropriate template by some of the data held in the TEDS itself. This template then presents the rules for decoding the rest of the TEDS. By providing for the publication of different templates, P1451.4 gives transducer manufacturers, 3rd party developers, and end users the ability to store their choice of information in the TEDS, while publishing how that data is encoded in a standard language (the DL). It has also allowed the P1451.4 Working Group to publish a set of 'IEEE Templates' prior to the finalization of the standard. It is this set of 'IEEE Templates' that have allowed the implementation of Plug and Play compatibility in today's market. Future Plug and Play compatibility will be ensured by a robust T-Block that is able to decode TEDS data in any well published template; and conversely, encode property/value data in any well published template.

This flexibility allowed by the DL allows applications such as the ones presented in this paper to develop independently, while still projecting future compatibility with the finalized standard.

2.2. Structural Test TEDS Implementation

The implementation of TEDS into structural test applications begins with a fundamental view of the information required to completely describe mechanical measurements being made. The underlying complication of using transducers is that the measured output is a voltage. Very seldom is the transducer output voltage of interest in structural testing. Rather, it is the vibration of a particular point on the structure that is truly of interest. Implementing self-identifying transducers with TEDS automates the process of defining the mechanical meaning of a particular voltage signal. From an overall test perspective, the physical measurement channel must be correctly mapped to three different information sets: transducer information, geometric information relevant to that transducer, and any other signal conditioning effects. These are tabulated in Table 1.

Examples of data from these information sets would include manufacturer, model number, serial number, and calibration information for the transducer information. Geometric information commonly includes a measurement point number, component identification, structure identification, and 6 degree-of-freedom coordinates (X, Y, Z position, along with orientation angles). Signal conditioning effects often include any external filtering, gain, or multiplexed (bank switched) output settings.

Measurement Channel	***Transducer Info***	***Geometry Info***	***Signal Conditioning***
1	*trans_data*	*geo_data*	*sc_data*
2	*trans_data*	*geo_data*	*sc_data*
.	*---*	*---*	*---*
.	*---*	*---*	*---*
n	*trans_data*	*geo_data*	*sc_data*

Table 1. Database of Test Information

The complete database of test information outlined above typically resides on a host processor capable of controlling the data acquisition hardware, reviewing raw data, and processing test results.

With both the content and the location of the test database defined, the tasks of obtaining the information and transferring it to its final destination remain.

2.3. Transducer Information

The storage and distribution of the transducer information is the designed intent of TEDS transducer. As mentioned previously, a pre-defined set of 'IEEE templates' exists which actually include all of the information which is considered in this category of Transducer Information. It is this set of data which ultimately identifies the transducer. Some of this information (Model Number, Serial Number) is stored in the TEDS at the time of manufacture. Other data (sensitivity, calibration date) can be updated during periodic calibrations.

2.4. Geometry Information

Collection of geometry data is the designed intent of the 3D Sonic Digitizer. The automated collection of the 3D coordinates, as well as recent developments in using it to determine additional DOF (orientation)[1], have proven this method to be an effective method for increasing the accuracy of the collected data and decreasing the resources required to collect it.

At first, the TEDS transducer presents itself as a likely candidate as the method of transporting this geometry information back to the host database. That is, we could measure the coordinates of the test point using the sonic digitizer, writing that information directly into the TEDS. Effectively, we are telling the transducer where it is, and then having the transducer repeat that information back to the host database when queried. However, this choice to utilize the TEDS to store and transmit 6 DOF geometry data may not be the optimal solution. Two interests drive this choice: maximizing the use of a finite TEDS storage capacity and maximizing the confidence in the TEDS data.

Currently, TEDS transducers offer memory storage capacity of just dozens of bytes. With a limited amount of storage available, it is preferred to minimize the number of different data fields stored in the TEDS, while maximizing the resolution of the data that is stored. Also, by limiting the number of fields in the TEDS to those that simply define the transducer itself, the original intent of the TEDS is preserved. That is, to provide a transducer with the capability of identifying itself. By storing geometry information in the TEDS, the TEDS is then more likely to be incorrect. For example, should the transducer be removed and used on another test structure, the TEDS could very well not be updated. The transducer would then identify itself as being in a particular point in space, when in fact it is not.

2.5. Signal Conditioning Information

The third class of information in the test database is the effects imposed on the analog transducer signal by any external signal conditioning. These effects commonly include signal gain, low pass filtering, and bank-switched outputs.

The inclusion of these factors by the host processor in the measurement is somewhat inherent to the design of most signal conditioners. In the case of the modular multi-channel signal conditioning system presented here, the same serial communication interface which is required to control these features is used to report back their status. Coincidentally, this same communication interface is used to communicate the TEDS data back to the host processor.

3. Experimental System

There are several enabling technologies that have contributed significantly to the current state of large multi-channel test systems[2]. Continual improvements in instrument quality with reduction in system costs have increased the feasibility for test laboratories to assemble large channel count systems. From lower cost analog-to-digital converters (ADCs) to the automated fabrication of piezoelectric accelerometers, the trend for more, high resolution channels at a lower cost continues to grow.

A large multi-channel test system for such applications as experimental modal analysis includes accelerometers and force transducers, sensor cabling, signal conditioning, excitation source and actuators (if required), test accessories such as a coordinate digitizer, data acquisition hardware and software, and parameter estimation software. The following systems are just two typical examples of modal test systems recently integrated by The Modal Shop and PCB Piezotronics, for both the automotive and aerospace industries. Both utilize the new IEEE P1451.4 TEDS technology currently available in most ICP® sensors. The first system allows for simultaneous data acquisition, while the second utilizes an approach of bank-switching sensors into a smaller, more affordable data acquisition system.

Simultaneous data acquisition of all measurement DOFs provides the highest quality and most consistent data set[3,4]. By eliminating the need to rove a batch of sensors about a test structure, potentially significant errors related to time variance and variable mass loading are eliminated. Additionally, other test configurations (i.e. structural modifications, multiple boundary conditions, etc.) can easily and quickly be evaluated. The entire data set is acquired in just minutes, compared to hours or even days when roving sensors. If economically feasible, simultaneous data acquisition is the recommended configuration.

In the first case, eighty triaxial accelerometers (PCB model T356B08) allow for measurement of 240 response DOF, and four impedance heads (PCB model T288D01) measure the driving point force and acceleration for up to four reference input locations. The sensor signal conditioning (TMS model 442A126) interfaces directly to a 256 channel Agilent VXI acquisition system, enabling simultaneous acquisition of all experimental DOFs. Electromechanical modal shakers (MB Dynamics Modal 50) utilize through-hole armatures for easy stinger attachment, whether using traditional rod stingers, or piano wire type kits to eliminate all transverse inputs at the load cell. Shaker support stands (TMS model 2050A) conveniently allow for configurations requiring lateral excitation input.

If a complete, simultaneous data acquisition system is not economically feasible, then assembling a system which allows for as rapid data acquisition as possible provides the next most consistent data set. This requires eliminating (or at least minimizing) roving sensors about the test structure. Roving sensors significantly increases acquisition time due to the need to re-setup the batch of response sensors between each acquired data set. Since parameter estimation techniques assume time invariance, acquiring data over days or even just hours is potentially dangerous and can lead to data corruption. Additionally, roving sensors about the test structure varies the distributed mass load of the response sensors, resulting in data inconsistency. Therefore, fully instrumenting the test structure with a complete set of transducers, and bank-switching into a smaller, more affordable data acquisition system is an ideal compromise. This bank-switch can be manual, but is more effective and efficient when computer automated. The result is the ability to acquire multiple sets of data in just minutes, nominally longer than a true simultaneous acquisition.

The bank-switching technique is illustrated by the second case, 276 modal array accelerometers (PCB model T333B) can be configured in uniaxial, biaxial or triaxial configurations about the test structure. These modal array sensors utilize an innovative and proven press-fit mounting socket and cabling system[5] specifically designed for efficient and economical large channel count applications. Six impedance heads and shakers are used for the reference input measurements. The modular signal conditioning system includes ICP power modules with computer controlled bank-switch output modules (TMS models 442A126 and 441A175, respectively), interfacing directly into a 112 channel VXI acquisition system. Figure 2 (found after the references) illustrates how these 288 sensor channels are routed to just 112 acquisition channels. Using computer control, the six banks of sensors (A-F) are automatically switched to acquire three sets of data, without any manual interference or interruption. The banks containing only response sensors (A, B, C, D and F) consist of 48 channels each of the modal array accelerometers, output in banks of 16 from the bank-switch output modules, as indicated graphically. Note that the first module of bank E contains the driving point sensors. The reference data from these six impedance heads is directly connected to the VXI acquisition system, as these measurements must be acquired with each of the three data sets.

As with simultaneous data acquisition systems, when utilizing automated bank-switching systems additional test configurations can be efficiently evaluated. This is clearly evident in the data presented in Table 2. First, several assumptions should be clarified regarding the data table. Cost estimates are expressed as a percentage of overall system cost. Consistent components were selected for each configuration to ensure an "apples-to-apples" comparison. Some system components were not included in the system cost estimates (i.e. PC workstation, modal exciters, etc.) as they were exactly the same in each case, with a resulting net effect of zero. Pre-setup time was measured based upon actual experimental setup for two cases, fully instrumented (which includes simultaneous and both bank-switching examples) and roving sensors. In this particular experiment, data was not acquired in all cases. With a Δf of ½ Hz, and 32 averages, autoranging, acquisition, scanning the data for quality and storing the data required approximately 5 minutes. Using automated switching, preparing additional measurements took just a minute with the fully instrumented test cases. However, when roving sensors, six hours of the nine hours required to setup the entire test are spent roving 100 sensors in between acquisition sets, rather than all up front. The effects of these types of roving test systems not only reduce data consistency and quality, but also significantly reduce overall test efficiency, magnified with each additional required test configuration. This is clearly indicated by the total time allotted for each case, where an extra 15 to 20 hours can easily be spent each time a structure is tested.

Simultaneous, 288 ch			
No. of Test Configurations	*PreSetup Time*	*Acquisition Time*	*Cost Estimate*
1	9 hrs	5 min	100%
2		5 min	
3		5 min	
4		5 min	
Total Time Allotted			9 hrs 20 min

Bank-switch, 288 to 112 ch			
No. of Test Configurations	*PreSetup Time*	*Acquisition Time*	*Cost Estimate*
1	9 hrs	17 min	60%
2		17 min	
3		17 min	
4		17 min	
Total Time Allotted			10 hrs 8 min

Roving, 112 ch			
No. of Test Configurations	*PreSetup Time*	*Acquisition Time*	*Cost Estimate*
1	3 hrs	6 hrs 17 min	40%
2		6 hrs 17 min	
3		6 hrs 17 min	
4		6 hrs 17 min	
Total Time Allotted			28 hrs 8 min

Bank-switch, 288 to 64 ch			
No. of Test Configurations	*PreSetup Time*	*Acquisition Time*	*Cost Estimate*
1	9 hrs	35 min	48%
2		35 min	
3		35 min	
4		35 min	
Total Time Allotted			11 hrs 20 min

Table 2. Test System Models

Even with instrumentation to optimize data acquisition efficiency, large multi-channel systems can utilize other tools to improve test setup efficiency. An ultrasonic 3D coordinate digitizing system (TMS model 5230XL series) automates the measurement of the Cartesian coordinates of each sensor location, greatly reducing test setup time[6]. Typical time savings of 80% or more can be achieved dedicated to geometry definition. Additionally, techniques such as array calibration, bar coding, automatic sensor identification and intelligent computer control can be incorporated to efficiently handle hundreds or even thousands of parallel sensor channels[7]. For even greater automation, all these tools are being meshed together with the new TEDS technology, providing for a smart and seamless integration.

Table 3 represents a detailed expansion of Table 1 presented previously. The specifics of Transducer Information and Geometry Information are listed here along with the initial storage location of each piece of data. Since all of the data is required for processing on the host, the link by which each is transmitted is shaded in the table.

Parameter	*Stored In TEDS*	*Stored In PDA*	*Stored On Host (PC)*
Calibration	***X***		
Model / Serial No.	***X***	***X***	
Direction		***X***	
Node No.		***X***	***X***
Meas. Ch.			***X***
Geometry			***X***

Table 3. Channel Identification Parameters

Initially, one must identify which information and parameters are required or important to retain. Generally for modal analysis, the parameters listed are considered necessary, while others (i.e. component name, etc.) may or may not be recorded. It is important to note that the developing IEEE standard is attempting to put together an open architecture that permits adapting this technology to all applications. Additionally, the technology allows anyone to implement in a proprietary or custom format if best suited for a given application. Effectively, this prevents limiting the scope of this technology's capability.

In the past, the collection of all of these different parameters has been individually automated. Now, the seamless integration of this information into an efficient relational database effectively eliminates the potential for human error and again drastically improves efficiency. With these technologies, one can install hundreds of sensors onto a test structure and not be required to maintain any bookkeeping by hand.

During installation, the link between sensor (measurement DOF) and location (physical DOF) needs to be established. That link, as indicated in Table 3, is primarily through the sensor serial number. A Personal Digital Assistant (PDA) with integrated bar code scanner is used to acquire model number, serial number, node number and direction[8]. Each sensor is marked with a bar code identifying itself, and each physical DOF of the test structure is labeled as well. A reference card has the six potential directions coded as well. When installing the sensor, the serial number is scanned, along with the node number and direction, storing this information in a database on the PDA.

After all the accelerometers are installed, they communicate model number, serial number and calibration to the smart signal conditioning system using TEDS technology. The smart signal conditioning system, communicating over RS232 with the host PC, records the sensor identification information with the appropriate measurement channel information in a table within software on the host PC. With a single request, the system identifies which sensor is connected on which channel, tabulating up to 2048 sensor channels in less than two minutes.

The remaining information needed is the structure's geometry data. The aforementioned sonic digitizer acquires a table of Cartesian coordinates by node number on the system's host PC. The three databases are all linked by serial number and node number, integrated through software to create the necessary universal files used by commercial parameter estimation software packages.

4. Conclusion

Streamlined Modal Test Setup has been made possible by the emergence and commercialization of 3 separate and distinct technologies: TEDS transducers, 3D Sonic Digitizing, and the Personal Digital Assistant. Commercial support for each facilitated the development of each of these. In the case of TEDS, a commitment by transducer manufacturers for open standards has allowed users to adopt technology today while being assured of future compatibility with greater flexibility. In the case of the PDA, consumer electronics have been customized for an application that would not otherwise support such powerful processing capability and convenience at such a low cost.

Even though each component of a Streamlined Modal Test Setup System is capable of justifying itself, the value added by each is amplified by their seamless integration.

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[1] Lazor, et al, "Automated Measurement of Direction Cosines for Transducer Systems", Proceedings of 19th International Modal Analysis Conference

[2] Bono, et al, "New Developments in Multichannel Test Systems", Sound and Vibration Magazine, August 1999

[3] Larkin, et al, "Structural Development of the TOPEX/POSEIDON Satellite, Sound and Vibration Magazine, August 1992

[4] Forrest, et al "Up To Date Structural Dynamic Test Capability Speeds Modal Analysis", TEST Engineering and Management, April/May 1991

[5] Lally, et al, "Structcel – A New Instrumentation System", Proceedings of the 14th Transducer Workshop

[6] Bono, et al, "Automated 3D Coordinate Digitizing for Modal / NVH Testing, Sound & Vibration January, 1996

[7] Lally, et al, "Multichannel Management Concepts For Modal Analysis and Testing", TEST Engineering & Management, January 1996

[8] Hunt, et al, "Dynamic Validation of the X-34 Reusable Launch Vehicle", Sound and Vibration Magazine, March 2000

< Figure 2 may be found on the following page >

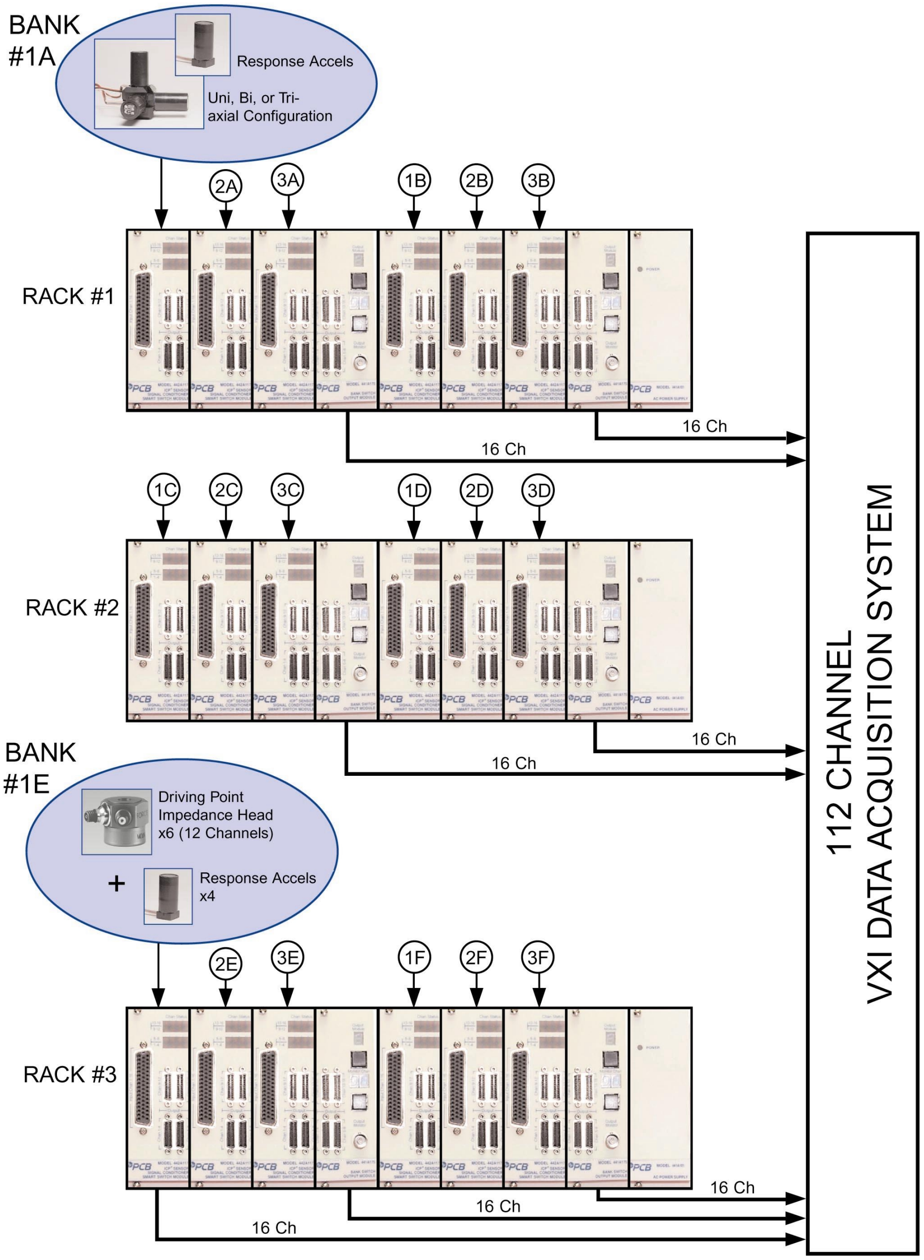

Figure 2 – Typical Bank-Switched Modal Test System