Vibration and Acoustics Laboratory

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I. Introduction

Mechanical vibration is an important issue for mechanical fatigue failure, machinery precision, and manufacturing process. The mechanical design in domestic industry is still in structural static analysis or even just for simple mechanics calculation and neglecting the importance of dynamic analysis. On the other hand, the industrial noise problem becomes important for environmental concerns. The industry in Taiwan just notices the noise issue and yet lack of complete study in noise generation and propagation analysis so as to carry out proper action in noise protection. In fact, noise and vibration are strongly related to each other and important issues to deal with. The diagnosis and control of mechanical vibration and noise are urgent and crucial for industry.

Vibration and Acoustics Laboratory (VAL) in the Department of Mechanical Engineering, NPUST is founded in 1993 and plans the development objectives as follows:

1. Dedicate to the education of sound and vibration technology for specialization, popularization and generalization.
2. Dedicate to the training of students to enhance the professional skills in sound and vibration and enable to perform practical applications and lifelong learning
3. Dedicate to the technology development in the field of sound and vibration for the application in industry and academic research

The technical services of VAL include:

1. Structural vibration modal testing and finite element analysis for products and machineries
2. Noise and Vibration measurement, analysis and improvement for products and machineries
3. Finite element analysis (FEA) in structural static, heat transfer and vibration analysis
4. Training program in Computer Aided Engineering (CAE)
5. Training programs in vibration, noise and Experimental Modal Analysis (EMA)

This article introduces the VAL team about the research projects in recent years, the integration of technology in noise and vibration, and the performance for industrial service.

II.Research Activity and Performance in VAL

The core technology in VAL includes:

1. Vibration analysis: fundamental principle of vibration, vibration characteristics of structures, vibration standards and regulations, analytical procedure in solving vibration problem, mathematical modeling techniques, four types of vibration analyses (modal, harmonic, transient and spectrum response analyses), and application to engineering problems.
2. Noise measurement analysis: fundamental principle of sound, sound wave theory, sound spectrum and 1/3 octave band analysis, sound evaluation indices, measurement standards, sound level meter and FFT analyzer, and applications to engineering structural sound measurement.
3. Experimental Modal Analysis (EMA): experimental measurement of vibration, instrument implementation (FFT analyzer, accelerometer, and impact hammer), signal processing techniques, procedure in performing EMA, and engineering applications.
4. Computer Aided Engineering (CAE) : applications of FEA software (ANSYS, LS-DYNA, VL-ACOUSTICS) in practical engineering problems, fundamentals of FEA, procedures in FEA application, various types of structural FEA (truss, beam, plane, solid, shell and contact elements), topics in statics, heat transfer and vibration.

The research ability and integration technology development in the VAL contain two main themes:

1. Integration of CAE and EMA for Engineering Design and Applications

2. Development and Application of Low -Cost and Customized Vibration and Noise Measurement and Automated Analysis System

2-1 Integration of CAE and EMA for Engineering Design and Applications

The idea and technology for the integration of CAE and EMA in virtual testing have been widely adopted in practical engineering problems. This technology in Taiwan is still in the infant stage and for future development.

CAE can be interpreted as the use of computer programs developed by oneself or commercial software to conduct engineering analysis. The most popular numerical tools should be the finite element method (FEM). The use of FEM in performing analysis for engineering problems is called FEA. Since most practical engineering structures are complex, the industry generally uses the general purpose FEA software. The VAL mainly adopts the ANSYS software in teaching and research.

EMA in simple words is just the experimental methods for vibration measurement. The purpose of EMA is to obtain structural modal parameters, including natural frequencies, mode shapes, and modal damping ratios. The applications of EMA include: (1) model verification, (2) response prediction, (3) model modification (4) force determination, (5) sub-structuring and coupled analysis, and (6) health monitoring or damage detection. Figure 1 shows the flow chart for model verification via the integration of EMA and FEA. The objective in performing model verification is to obtain validated analytical model. Figure 2 reveals the flow chart in structural design modification. The first step is to conduct model verification to validate the analytical model. The next step is to perform response prediction via the validated model. Finally, if the structural modification is required in order to meet the design specification, the model modification will be carried out and repeated to achieve the design goal.

The research topics in coop with industry by applying the integrated technology of CAE and EMA conducted by the VAL in recent years include the following:

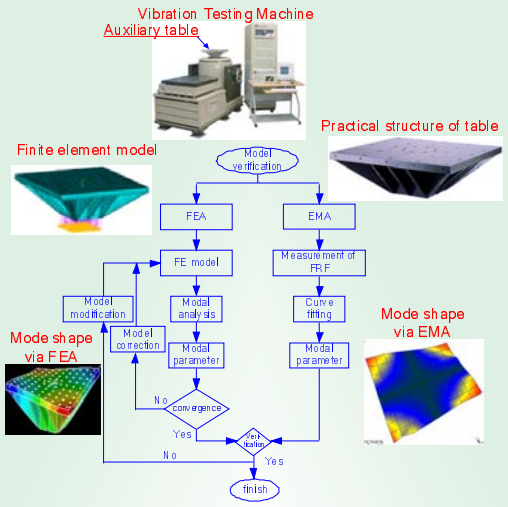


Figure 1 Model verification flow chart by integrating EMA and CAE techniques

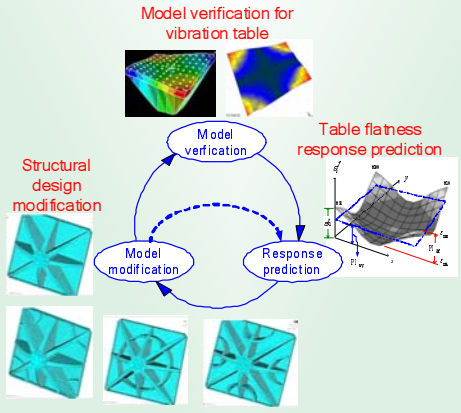


Figure 2 Structural design modification flow chart for CAE and EMA

1. The integration of design and development of golf clubs (OTA Co.)
2. The Design analysis of vertical auxiliary table of vibration testing machine (King Design Co.)
3. The integration of design and development of sliding table of shock testing machine (King Design Co.)
4. The analysis and experimental verification of environmental vibration testing of printed circuit board (ASE Group)
5. The design and development of components in vehicle industry (MIRDC)
6. The development and application of intelligent material structural system (NSC)
7. The design analysis of percussion musical instruments (NSC)

The VAL has started the coop work with OTA Co. since 1999 and dedicated to the design analysis technology development and procedures for over 10 years. The major achievement includes 6 funded research projects, 27 academic papers, and 8 graduate and 19 undergraduate students involved in the research activities. The established technology contains: (1) the application of CAE to vibration and impact analysis of golf clubs, (2) the inter-connection between CAD (Pro Engineer) and CAE (ANSYS) software for analysis, (3) the application of EMA to experimental verification for golf clubs, (4) the integration of CAE and EMA for model verification to obtain the validated analytical model, (5) introducing the virtual testing design concept for golf club design modification with particular purposes of performance specification, and (6) the prediction of hitting sound of golf club and the structural design of golf club head.

King Design Co. is a manufacturer for the vibration and shock testing machines and coop with the VAL since 2003. The King Design Co. Reliability Lab is working with the VAL. There are 7 funded research projects from NSC and 28 academic conference and journal papers. 7 gradate and 6 undergraduate students participated in research work. The well established technology in the design analysis and development is mainly for the vertical auxiliary table (vibration table) and sliding table (shock table) including: (1) introducing the CAE and EMA techniques to the structural vibration characteristic study for the design of vibration and shock tables, (2) establishing the model verification and virtual testing technique to integrated design, (3) developing the standard design verification procedures for the tables to fit the need of different vibration and shock testing specification required by the customers.With the use of CAE and EMA techniques and the professional analytical abilities in shock and vibration, the integrated design concept and procedure can also be adopted to the development of other precision machineries.

ASE Group is a known IC packing company. The VAL applies the special skills of EMA as well as the model verification procedure as shown in Figure 1 to enhance the design analysis with the verification of experimental works. The coop work has lasted for 5 years since 2005. The company provides the scholarship for a graduate student annually. There are 17 academic papers published. Figure 3 reveals the vibration testing and analysis verification of PCB. So, the stress distributions of package, IC and solder balls can be predicted as shown in Figure 4. The VAL leads the industry in this field for coupling effect evaluation including thermal and random vibration loading simultaneously.

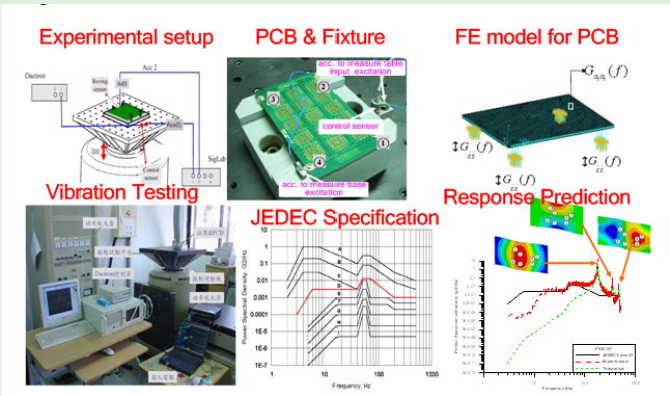


Figure 3 Vibration testing and analysis verification for PCB

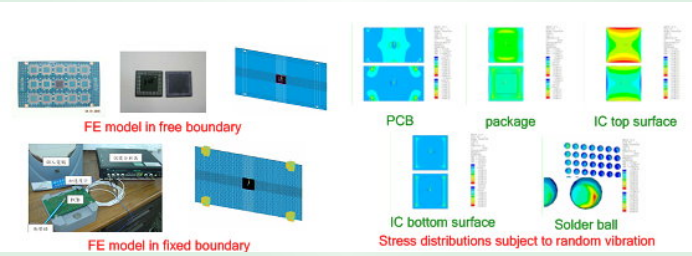


Figure 4 Vibration testing and stress analysis for PCB, package, IC and solder ball

The integrated CAE and EMA techniques have been widely adopted for practical application. Beside the aforementioned about the golf club design,other sport equipments such as tennis rockets are also investigated. The technique has been used for 3C products and testing machine design for environmental shock and vibration tests. Other industries such as precision machineries for machine tools or automobiles can be well related to the CAE and EMA integrated technology. The VAL has carried out many engineering projects associated with industries..

The VAL plays the role in supporting the industrial needs and academic contribution. The objective of VAL will continue to train students with the integrated technology of CAE and EMA as well as the applications to engineering problems and educate students with positive working attitude for the industry.

2-2 Development and Application of Low-Cost and Customized Vibration and Noise Measurement and Automated Analysis System

Vibration is an important issue in industry. Machineries become higher speed and more precision and thus require more abilities to reduce vibration effect. However, the vibration analysis technique in domestic industry is not so common. One of the reasons is that the observation and analysis of vibration phenomenon are not easy for the cost of testing equipment as well as the lack of analysis tools. To enhance the development in the field of vibration, the domestic language instruction media in teaching vibration is demanded and can be used for industrial applications.

The experimental measurement and analysis of sound and vibration generally rely on the general purpose FFT analyzer or Sound Lever Meter to obtain the acceleration and sound pressure level, and so forth the corresponding frequency domain analysis can be conducted to get sound and vibration spectra and to study the structural sound and vibration characteristics for machineries and products. For general applications, the experiments can be easily carried out. However, there are potential disadvantages, such as the high price for the well-equipped functional analyzer. For simple purpose applications such as the on-line inspection base on sound and vibration signals or for other post-processing applications, the analyzer may not be economic. Also, the data requiring necessary post processing is not always available or easy to transfer to other analysis programs.

For the industrial needs on the further applications of noise and vibration measurement and analysis, the VAL dedicates to develop noise and vibration analysis programs. The software will be developed base on the concept of copyleft for freeware deployment so as to promote the professional fields in sound and vibration and become popular. The low cost and customized measurement and analysis system will be established for different purposes and different industrial requirements. The recent coop works regarding to the development of analysis modules and measurement application modules by the VAL are illustrated as follows:

1. Development and verification of fan noise measurement system (Yen Sun Co.)
2. Development of fan sound quality inspection and automated quality control module (Yen Sun Co.)
3. Development of tool FRF measurement system and tool chatter stability diagram prediction module (Precision Machinery Center)
4. Development of vibration analysis soft -ware (NSC/AnCAD Co.)
5. Module for Modal analysis by free vibration response only (NSC)
6. Development of structural damage detection base vibration mode shape (NSC)
7. Sound simulation generator and spectrum analysis module (NSC)
8. Measurement and evaluation of bus interior sound and vibration (Master Co.)
9. Golf club vibration quality index analysis module (OTA Co.)
10. Sound and vibration correlation analysis module for golf club and club

head (OTA Co.)

11. Golf club hitting sound prediction module (OTA Co.)
12. Pad design analysis module for shock testing machine (King Design Co.)

The sound quality inspection for small fan in production line is of interest. The VAL uses the microphone to measure the sound pressure level of fans in conjunction with A/D card with the MATLAB platform. Figure 5 reveals the measurement module for fan noise inspection and will be extended to automatic quality control system for product on-line measurement. The customized measurement and analysis modules are useful for industrial applications.

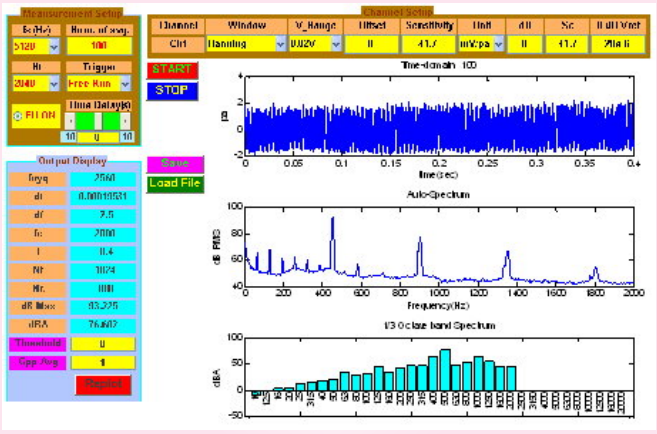
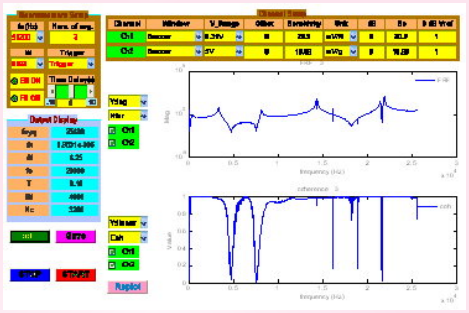
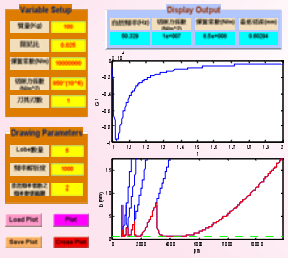


Figure 5 Fan noise measurement graphic user interface

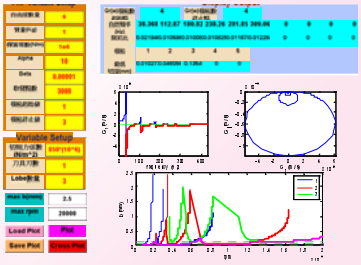
Chatter of machine tools is a kind of self-excited vibration and generally occurred in machining. The chatter is the major defect for cutting vibration to affect the machining quality and efficiency. Chatter will also cause bad effects on machining surface, surface roughness and noise as well as tool wears. The tool failures and the reduction of metal removal rate will increase the cost, time and material. The VAL use the MATLAB platform to develop the tool frequency response function measurement module as shown in Figure 6(a) and thus the tool chatter stability diagram can then be predicted as shown in Figures 6 (b) and (c) to provide a guided tool to determine the stability lobe diagram (SLD) so as to avoid chatter and increase the cutting efficiency.



6 (a) Dual channel FRF measurement module



6(b) SLD for SDOF model



6(c) SLD for MDOF model

Figure 6 Tool FRF measurement and chatter stability lobe diagram (SLD) prediction

For engineering problems related to sound and vibration either by experimental measurement or theoretical analysis, the post processing for the measured or analytical data is the crucial know-how and know-why issue. Different purposes of automatic analysis modules are generally required and can be provided for industrial uses.

The VAL develops the sound and vibration analysis and measurement system for particular purposes of applications. The features of the analysis tools are independent, interactive, user-friendly, graphic user interface (window), and with automatic data storage and retrieval functions. Besides, the low cost and customized sound and vibration analysis package can be useful for teaching and beneficial for industrial applications for different purpose needs.

III. Conclusions

The VAL has carried out many government and industrial funded research projects and established tight relationship with local industry to support high quality of engineering services. The VAL will continue to facilitate the equipment and fertilize students with sound and vibration professionals to meet the need for domestic industry and promote the extension education. The coop work with industries to create the professional values regarding to the fields in sound and vibration is always the goal. The VAL will certainly continue the works in (1) Integration of CAE and EMA for Engineering Design and Applications, and (2) Development and Application of Low-Cost and Customized Vibration and Noise Measurement and Automated Analysis System, and surely to promote and enhance the R&D and international competition abilities for industrial development in our country.