Picture credits:
NASA/Arpington

FLY HIGH WITH POLYTEC TEST INSTRUMENTATION

Non-contact Vibrometry Helps Ensure Performance, Quality, Safety and Reliability of Aircraft, Missiles and Spacecraft.

Aerospace engineers, designers, manufacturers and operators face many test and measurement challenges as today's aircraft performance and sophistication is pushed to new levels. Extensive vibration testing is needed to produce data for modal analysis and FE model correlation, for verifying design specifications have been met, and for non-destructive material testing.

In this issue, learn how Polytec's vibrometers increase performance, improve time-to-market and lower costs in aerospace development. Vibration testing for experimental modal analysis is performed on wings and airframe structures, aircraft wheels (see article on page 8), engine components, and even on space structures like the solar sails developed by NASA (page 4). When designing innovative jet engines, the correct interpretation of life-time relevant vibration phenomena is one of the most challenging and important tasks (page 12). Next-generation aircraft require enhanced and reliable structural health monitoring to assure their long term performance; laser vibrometry is there to assist (page 9). All this and more is included in this edition.

Find more information on
www.polytec.com/usa/aerospace

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EDITORIAL



Eric Winkler

Dear Reader,

The best ideas for our products come from you – our customers. To turn these ideas into real products requires extraordinary innovation by our employees of which nearly 20 % are working on product development.

Your ideas and Polytec's product development team are two of the reasons why we are a world leader in optical measurement systems.



Dr. Helmut Selbach

The PSV-400 Scanning Laser Vibrometer is a success story that has revolutionized 1-D and 3-D vibration measurements.

This paradigm shift away from contact transducers allows aerospace engineers to quickly measure complex vibration phenomena on aircraft components, even utilizing multiple input/multiple output (MIMO) acquisition, to rapidly calculate deflection shapes and frequency response functions.

The PSV hardware is only part of the story. The rest of the story centers on our user-friendly PSV software. Besides simplifying setup and operation, the software provides intuitive 3-D animation, powerful post processing and import/export interfaces to CAE and FEM packages. Your measurement needs, our PSV software, both are regularly updated.

Our customers are our best resource – proof is seen in their excellent articles about aerospace applications of scanning vibrometry in this issue. We are proud to say "thank you" for your valuable feedback, and continued support!

Eric Winkler
Vice President
Optical Measurement Systems

Dr. Helmut Selbach
Managing Director Polytec GmbH

News from the Global Polytec Network

Polytec continuously improves and refines its sales force, serving its customers globally with direct sales and service facilities in the United States, Germany, England, Japan and France and a worldwide network of specialized distributors for all main regions and markets.



Michael Frech, who successfully led Polytec's laser measurement systems business unit in Germany, has accepted a new position as president of Polytec, Inc., the North American subsidiary of Polytec Germany. Working from the headquarters office in Tustin, CA, Mr. Frech adds his technical, sales and management expertise to an experienced North American team.

His successor at Polytec Headquarters is Eric Winkler (see editorial), who previously headed Polytec's European sales force.



We welcome **Mr. Toshihiko Takahashi** as our new president of Polytec KK in Yokohama, Japan. He has worked with the Japanese automotive and aerospace industries for 19 years specializing in NVH and modal testing. At Polytec KK he will lead an experienced team of service, application and sales engineers.



Arend von der Lieth is now responsible for worldwide customer service which offers technical advice, repair and calibration, measurement services, system rentals and training classes to support our customers in solving their specific measurement challenges.



HYSEN Corp., our Korean distributor, was the 2006 Hysen Representative of the Year. **Clark Lee**, president of Hysen, received this award in recognition of their excellent sales and marketing performance.

Adding to our growing list of local representatives, we welcome GROM Acústica & Automação in Brazil, A. O. Ezra Electronics in Israel and Vibewise CC in South Africa.

You will find complete and up-to-date contact information at www.polytec.com.

Products & Solutions

Our new DVD contains comprehensive information about our entire selection of measurement solutions including product data sheets, brochures, application notes, videos and demo software. Order your DVD at info@polytec.com (USA, Mexico, Canada) or LM@polytec.de (all other countries).



Product News



New CLV-2534 Compact Laser Vibrometer

The new two-part CLV-2534 Compact Laser Vibrometer integrates the laser into the Vibrometer Controller and uses a fiber-optic cable to provide laser power to the small Sensor Head. The innovative design increases mounting and positioning options without sacrificing precision. Vibration measurements can be made in a bandwidth of 1.5 MHz at 10 m/s maximum velocity. Options such as an integrated video camera, a displacement integrator and various microscope objectives enable the CLV-2534 to solve many applica-

tions ranging from microstructure R&D to industrial inspection of large structures. With a minimum 1.5 μm laser spot size and integrated video camera, small parts can be measured without a special microscope. On the other hand, its high optical sensitivity and IP 50 protection make the Compact Sensor Head well suited for both industrial and R&D applications in the automotive, aerospace and electronics industry.

Further information:
www.polytec.com/usa/vibrometers

New PSVSoft Release 8.4

Polytec's PSVSoft Scanning Vibrometer Software has significantly expanded and improved the data acquisition, analysis and presentation modes with the release of version 8.4. Numerous requests and suggestions from the user community have been incorporated. Along with other improvements, the following new features have been implemented.

Individual Geometry Components (see image below)

The measurement geometry can be divided into a hierarchical set of geometry components enabling a mapping of point sets to the corresponding components' name.

Enhanced Functionality of the Signal Processor

The signal processor has become an even stronger data processing tool. New functions allow 1-D data sets to be combined with a 3-D data set, extract single directions from 3-D data sets, and to compare points with different indices directly. Many of the mathematical functions can now operate also on complete spectra or time domain data sets. A parameter

input wizard assists in providing the correct parameters for multi-parameter functions.

New Cursor Functions in Analyzer Window

Two new cursors have been added to the standard analyzer window for an extensively enhanced peak analysis capability. First, a band cursor providing statistical parameters and harmonic oscillator curve fitting including peak position and damping. Second, a harmonic cursor that plots up to 12 cursor lines at the 2nd, 3rd, ... order of the base frequency.

Enhanced Import and Export Options

In addition to extended ASCII import and export options that allow the ex-

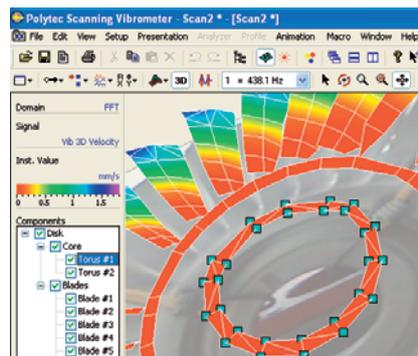
change of PSV data with almost any system, user defined data sets can now be exported in universal file format (UFF) or in ME'scope binary format to make pre-processed Polytec data available for post processing in external packages. Frequency spectra and time domain data can be imported from UFF and ME'scope data files. For example, modal fits from ME'scope can be imported and compared to the original data of PSV, or measurement data from other systems (e.g. accelerometer data) can be included in PSV data visualization. A great step towards acquiring additional data from hidden points.

Further information:
www.polytec.com/usa/psv400

New VibSoft Release 4.4

The new VibSoft Release 4.4 for Single-Point Vibrometers supports now the OFV-2500 series Vibrometer Controllers and the OFV-534 Compact Sensor Head providing a screen window for the video image which can be saved together with the data. It has all improvements listed for PSVSoft except scanning and 3-D features. For detailed information about VibSoft, please visit:

www.polytec.com/usa/vibrometers.



Polytec Partners: *SPEKTRA*



Primary calibration of an OFV-505 Vibrometer (left) using a CS18P-HF Primary Calibration System

Certified Quality by Traceable Calibration of Laser Vibrometers

Laser vibrometers are precision instruments for non-contact vibration measurements. Vibrometer data quality is important for many applications in industry, science and medicine. Obvious examples are quality control data for mass produced sensors and measurement devices and patient health care data. Another important data quality application is primary calibration of vibration transducers, calibrators and measurement instruments

Since the laser vibrometer is very precise, it can serve as a reference standard under well defined conditions. Certification of future vibration data quality is getting closer to reality as SPEKTRA moves forward with developing a traceable calibration based on an ISO standard.

Calibration Requirements

Due to data sensitivity and the wide range of vibrometer applications, the requirements for calibrating laser vibrometers are continuously increasing. On one hand, manufacturers target quality control of critical functions and specifications of their products. On the other hand, there is a growth of individual calibrations which are derived from the conditions of the actual application.

For example:

- Frequency range and amplitude of the item being measured
- Calibration of the system with regard to a defined signal output and a certain measurand
- Calibration at defined settings of the system, e.g. amplification range or filter settings
- Specification of the uncertainty of the measurement

Traceability to International Standards

A critical requirement for vibrometer quality assurance is the traceability of the calibration with regard to acceleration as the measurement variable, or variables that are derived from

acceleration like vibration velocity and displacement. Such calibrations must be performed by national laboratories like the German PTB (National Metrology Institute) or laboratories that are certified by the accreditation body of Deutscher Kalibrierdienst (DKD) or respective national associations.

In order to achieve worldwide acceptance and comparability of vibrometer calibrations, the PTB is leading the effort to define an ISO Standard (ISO 16063-41 First Working Draft July 2005: "Methods for the calibration of vibration and shock transducers – Part 41: Calibration of Laser Vibrometers"). The ISO standard is based on a national DKD guideline prepared by the PTB in close collaboration with Polytec, a leading manufacturer of laser vibrometers, and SPEKTRA, a leading manufacturer of primary calibration systems.

In 2004, SPEKTRA was accredited as a primary acceleration laboratory offering a traceable calibration of laser vibrometers. Based on international mutual agreements, SPEKTRA's range of calibration services is already accepted worldwide. Please visit www.spektra-dresden.de/edkd.html for a list of accredited items and ranges.

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Dr. Georg Siegmund, Polytec GmbH

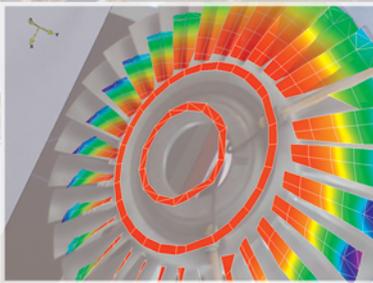
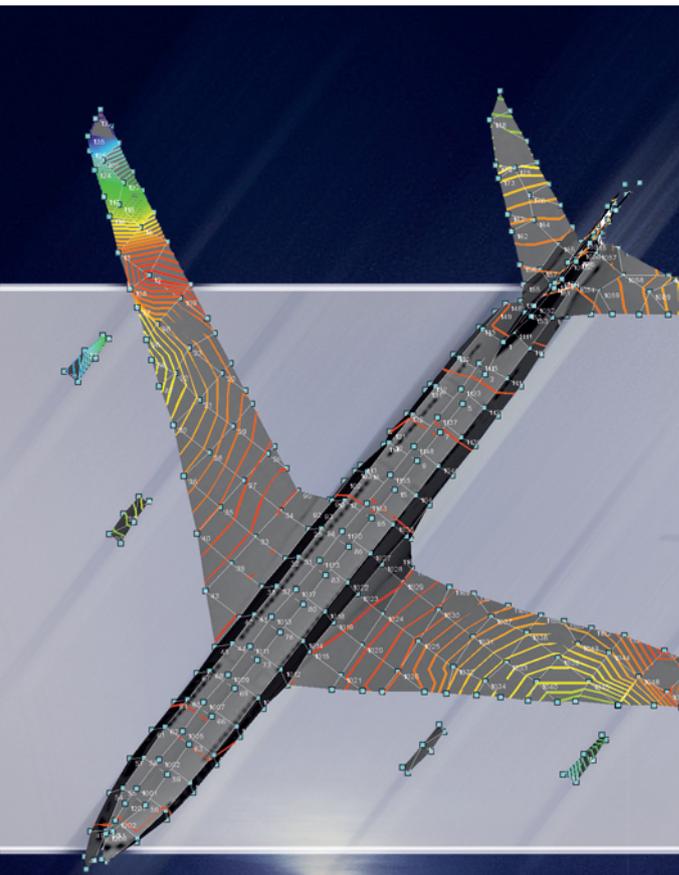
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Aerospace Vibration Testing



Laser-based Vibration Measurement Technology Helps to Increase Performance, Improve Time-to-market and Lower Costs in Aerospace Development

- Ground Vibration Testing
- Noise, Vibration and Harshness
- Experimental Modal Analysis
- Material and Fatigue Testing
- Engine Testing

Vibration Measurements in Aerospace Development

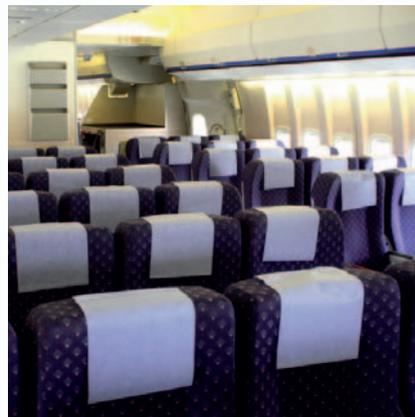
Structural testing is an integrated part of aerospace product design, development and manufacture. It is an essential step to ensure performance, quality, safety and reliability in the final product.



Today's market pressure for new, affordable high performance aerospace products is increasing the number of product variants and the complexity of tested structures. Product development and design refinement teams are requesting more efficient modal testing to increase throughput, while maintaining accuracy adequate to correlate with FE analysis models (i.e. load analysis, acoustic radiation, etc.). In addition, these new structures require a substantial number of spatial data points. The combination of more structures and more measurement points is rapidly increasing the costs of doing a traditional modal test with its labor intensive approach of instrumenting structures with accelerometers and multi-channel data acquisition systems.

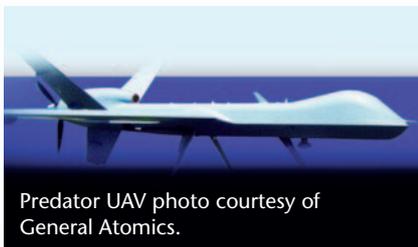
Noise, Vibration and Harshness

The fight for commercial aircraft orders has lead aerospace manufacturers to seek competitive advantages in two significant areas: fuel economy and increased passenger comfort. Consequently, today's aerospace engineers are more concerned with noise mea-



surements than their predecessors were. By improving interior sound quality, aircraft engineers increase passenger comfort and desire to fly in a next generation commercial jet. In addition, by reducing exterior noise, the designer can improve the aircraft's acceptance in urban settings where air traffic is growing rapidly.

Polytec Vibrometers are a requirement for leading aerospace companies eager to make NVH measurements on their newest aircraft.



Predator UAV photo courtesy of General Atomics.

Flutter Certification

At the Air Force Institute of Technology (AFIT), Polytec's PSV-400-3D Scanning Vibrometer technology is used to measure vibration characteristics of Unmanned Aerial Vehicles (UAV) and other intricate aerospace and vehicular structures. Its use has improved the results of flutter analysis for airplane FE and reduced significantly test time and post processing analysis.

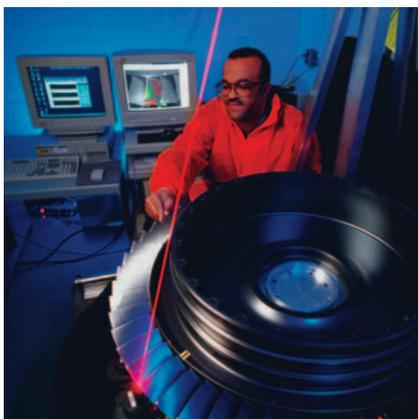


Engine Testing

The demand for environmentally friendly and more powerful jet engines is pushing engine design to new limits.

The correct interpretation of lifetime-relevant vibration phenomena is one of the most challenging and important tasks which can be successfully solved by laser vibrometry. Read the article on page 12.

Measurement of turbine blade vibrations. Photo courtesy: Greg Roberts, Pratt & Whitney.



Ground Vibration Testing

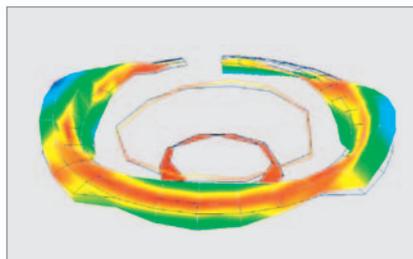
Ground Vibration Testing (GVT) is a costly requirement for new aircraft and aerospace structures. Data taken can be used for modal analysis and finite element (FE) model correlation, for loads analysis to prevent structural failure and flutter certification.

Component Testing

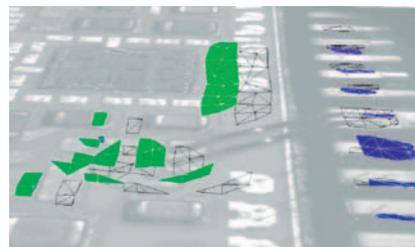
A vibration analysis of an aircraft component can characterize the structural dynamics, determine the fundamental frequencies and define a complete modal model of the component.

For instance, aircraft tires are critical components that must meet very high quality standards. Read more about experimental 3-D scanning vibrometer measurements on an A320 aircraft wheel (page 7).

Operational deflection shape of an aircraft wheel.



Find a comprehensive article about ground-based, dynamic testing of solar sails at NASA on page 4.



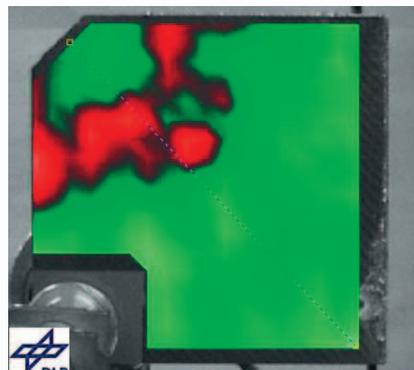
MEMS and PCB Testing

Laser vibrometry is the first choice for vibration testing printed circuit boards and micro-electro-mechanical sensors and actuators (www.mems-analysis.com).

Material Testing

Material delamination and cracking are common defects that can significantly degrade the performance of aerospace products. To find localized defects, both nonlinear laser vibrometry (www.polytec.com/usa/aerospace) and lamb wave detection (article on page 9) are successfully used as a means of non-destructive testing (NDT).

Material delamination detected by non-linear laser vibrometry. Photo courtesy: IKP-ZFP, University of Stuttgart.



Flying the Best

Scanning laser vibrometry features rapid, full-field, non-contact (no mass loading) vibration measurement with high spatial and frequency resolution. By using Polytec's Scanning Vibrometers, aerospace development engineers and scientists can reduce both the time and complexity of vibration testing. Polytec vibrometers are the gold standard for non contact vibration measurement for aerospace development, quality control and aircraft health monitoring. Find more detailed information on page 15 or visit www.polytec.com/usa/aerospace.

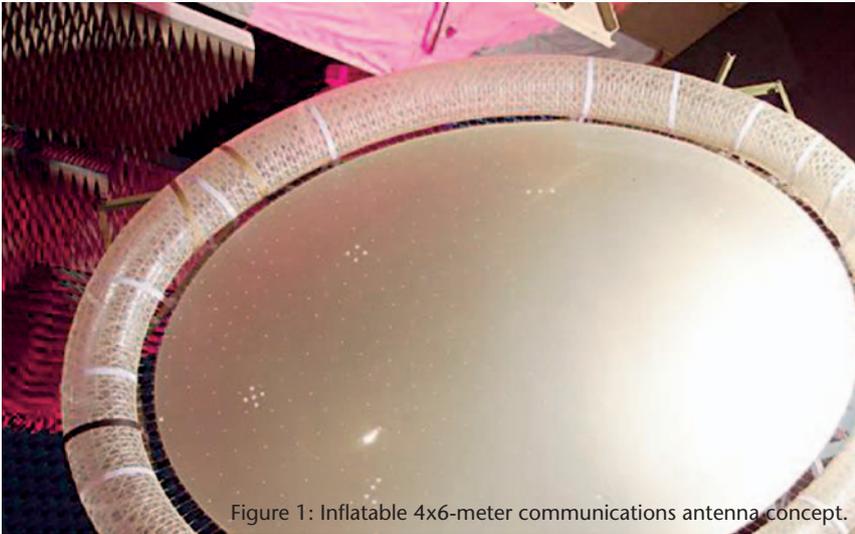


Figure 1: Inflatable 4x6-meter communications antenna concept.

Introduction

NASA has been developing Gossamer space structures for many years to reduce launch costs and to exploit the unique capabilities of particular concepts.

For instance, dish antennas (Figure 1) are currently being pursued because they can be inflated in space to sizes as large as 30 meters and then rigidized to enable high data rate communications. Another example of a Gossamer structure is a solar sail that provides a cost effective source of propellantless propulsion. Solar sails span very large areas to capture momentum energy from photons and to use it to propel a spacecraft. The thrust of a solar sail, though small, is continuous and acts for the life of the mission without the need for propellant. Recent advances in materials and ultra-lightweight Gossamer structures have enabled a host of useful space exploration missions utilizing solar sail propulsion.

The team of ATK Space Systems, SRS Technologies, and NASA Langley Research Center, under the direction of the NASA In-Space Propulsion Office (ISP), has developed and evaluated a scalable solar sail configuration (Figure 2) to address NASA's future space propulsion needs. Testing of solar sails on the ground presented engineers with three major challenges:

- Measurements on large area surfaces thinner than paper

- Air mass loading under ambient conditions was significant thus requiring in-vacuum tests
- High modal density required partitioning of the surface into manageable areas.

This article will focus on the unique challenges with vacuum chamber, dynamic testing of a 20-meter solar sail concept at the NASA Glenn Plum Brook Facility (Figure 3).

In-Vacuum Setup

A Polytec Scanning Laser Vibrometer system (PSV-400) was the main instrument used to measure the vibration modes. The laser scan head was placed inside a pressurized canister to protect it from the vacuum environment (Figure 4). The canister had a window port from which the laser exited, and a forced air cooling system prevented overheating. A Scanning Mirror System (SMS) was developed and implemented, that allowed full-field measurements of the sail from distances in excess of 60 meters within the vacuum chamber.

The SMS (Figure 5) was mounted near the top of the vacuum chamber facility and centered over the test article, while the vibrometer head was mounted above the door frame of one of the large chamber doors. The SMS contained a stationary mirror that reflected the Polytec laser beam to a system of two orthogonal active mirrors.

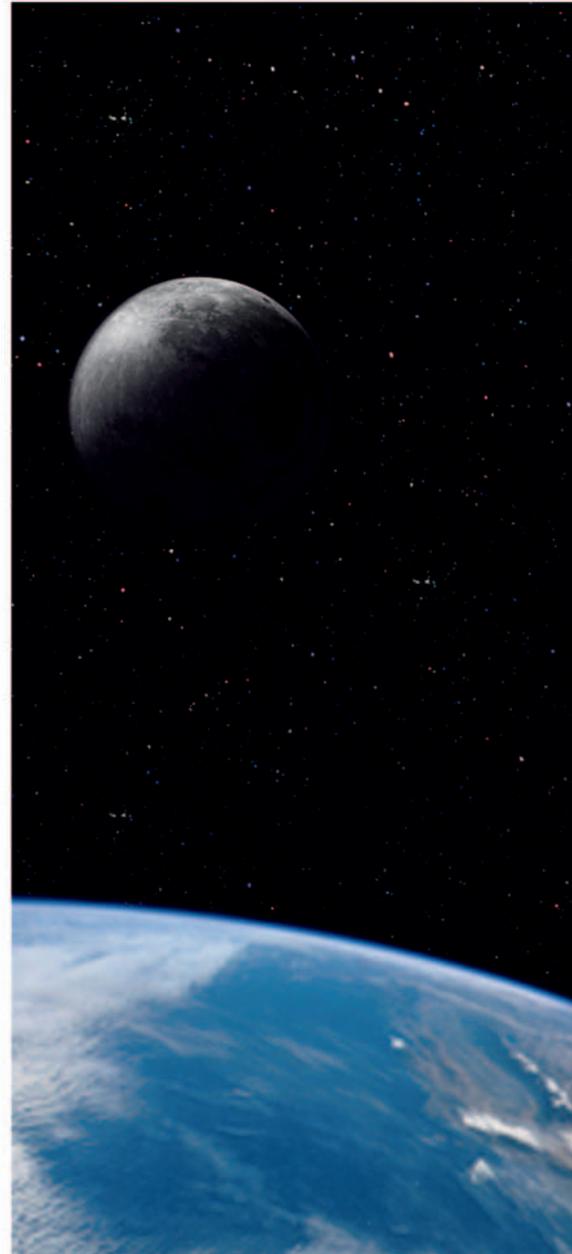


Figure 2: Deployed 20-meter solar sail on vacuum chamber floor.



Sail Away...

Laser Vibrometry Helps to Validate Gossamer Space Structures

NASA is pursuing the development of large ultra-lightweight structures commonly referred to as Gossamer space structures. These structures have large areas and small aerial densities, which complicates ground testing significantly as the ground operations interfaces and gravity loading can become cumbersome. Laser vibrometry has proven to be a critical sensing technology for validating the dynamical characteristics of these Gossamer structures, due to its precision, range, and non-contacting (zero-mass loading) nature.

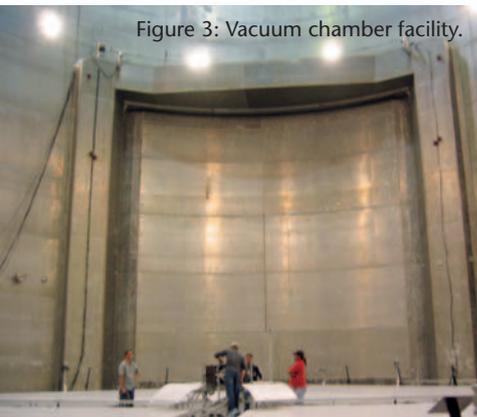
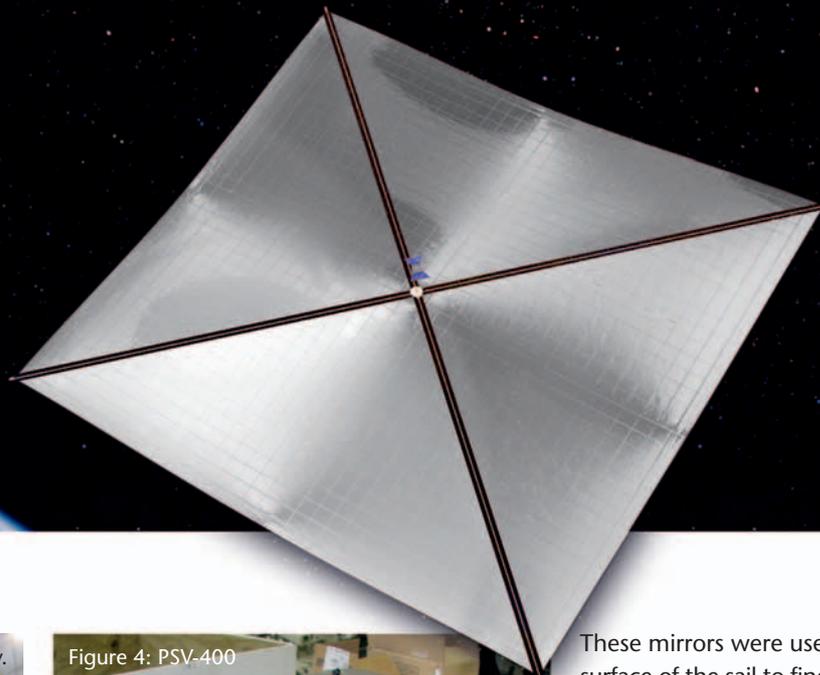


Figure 3: Vacuum chamber facility.

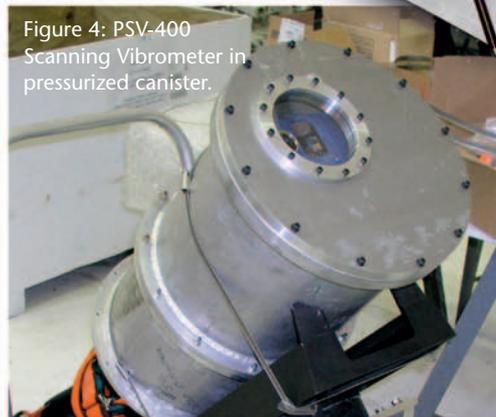


Figure 4: PSV-400 Scanning Vibrometer in pressurized canister.

These mirrors were used to scan the surface of the sail to find retro-reflective targets previously attached to the sail surface. These targets were essential to getting a good return signal and overcoming the specular nature of the reflective sail surface.

Fully Automated Test Procedure

A specially developed target tracking algorithm enabled automatic centering of the laser beam on each retro-reflective target. The initial laser system alignment,

target tracking process, and entire data acquisition procedure was automated using the Microsoft Visual Basic (VB) programming language. Polytec's VB Engine and PolyFileAccess allowed the program to control all the functional capability of the Polytec system. The alignment of the vibrometer laser to the SMS steering mirrors was accomplished by software that used the vibrometer scan mirrors to trace out a square grid across a retro-reflective target ring on the SMS. The strength of the laser return signal was measured during the scan. The software finds the angular location of the center of the target by calculating the centroid of this array of signal strength values and the corresponding mirror angles.

Once the laser was aligned to the SMS, a second program aligned the laser to the targets on the solar sail using the SMS steering mirrors. When all the targets were aligned and identified, then a third program incrementally read the target locations from a file and ran the entire data acquisition and storage process.

For each target, the program would re-scan and center the laser prior to acquisition to ensure the highest quality dataset. This fully automated test procedure was considered critical, since many tests could take over 5 hours to run. Prior to the test, the vibrometer and SMS were certified for an 85-meter standoff distance (although larger distances are possible), well beyond the required distance of 60 meters for this test configuration.

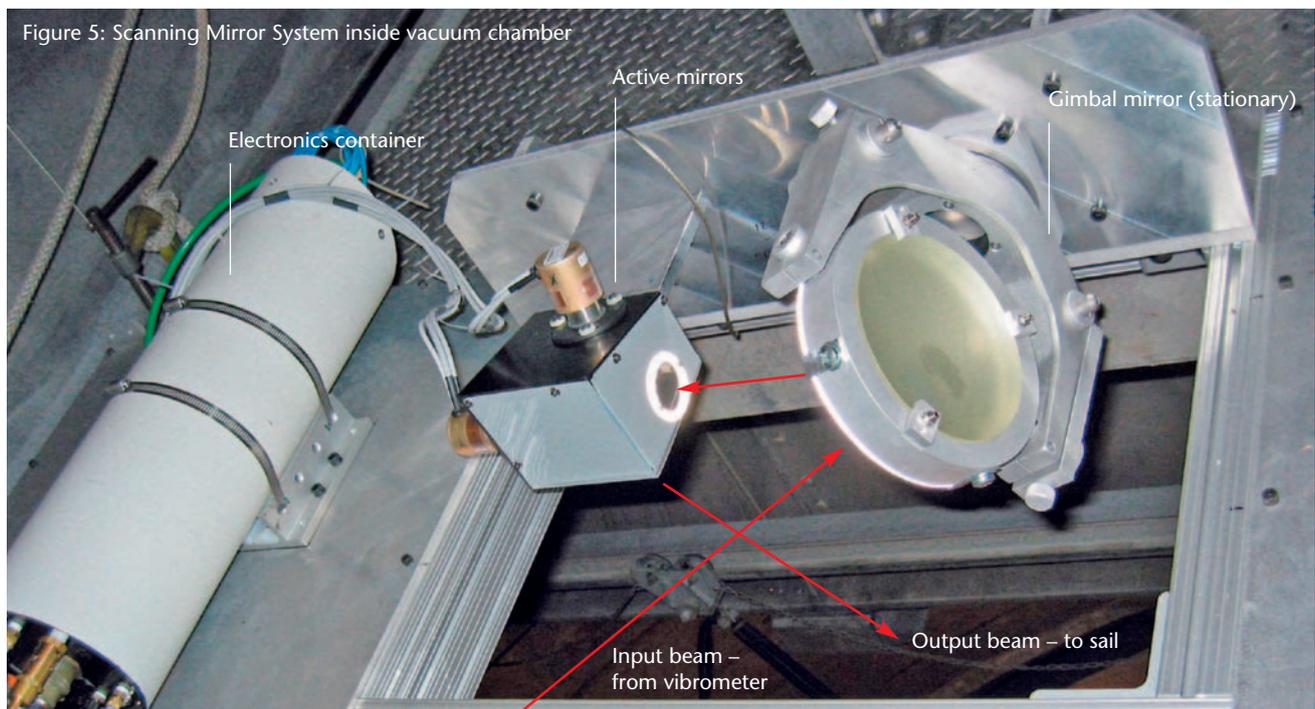
Excitation of Sail Motion

The baseline excitation method for the solar sail dynamics test used an electro-magnet mounted at each sail membrane quadrant corner near the-mast tip (2 magnets per sail quadrant), for a total of 8 magnets. A side view of the mounting fixture is shown in Figure 6. The magnet is mounted on a vertical translation stage with a linear actuator for precise, remote in-vacuum positioning of the magnet.

The magnet needs to be positioned within 5 mm of the sail to work properly, so small cameras were positioned next to each magnet and carefully

aligned to ensure that the proper gap size was achieved. To reduce sail motion during vacuum pump down, the mast tips were secured with an electro-magnet that prevented vertical and lateral motion. Once at vacuum the voltage to the electro-magnet was removed, allowing a spring to pull the magnet away from the test article. The mast tips were then free to move with a soft suspension system gravity off-loader.

Most of the dynamics testing effort was focused on getting the best quality data possible on a single quadrant in-vacuum. The quadrant that had the most pristine sail membrane surface with few flaws was selected. The quadrant test used only the magnets on the quadrant of interest for stimulating the dynamics. The quadrant test was followed by a full sail system test, in which one corner magnet on each quadrant is driven simultaneously. This technique allowed for adequate excitation of the entire sail system and for the identification of major system level vibration modes. To reduce test time, the full sail system test only



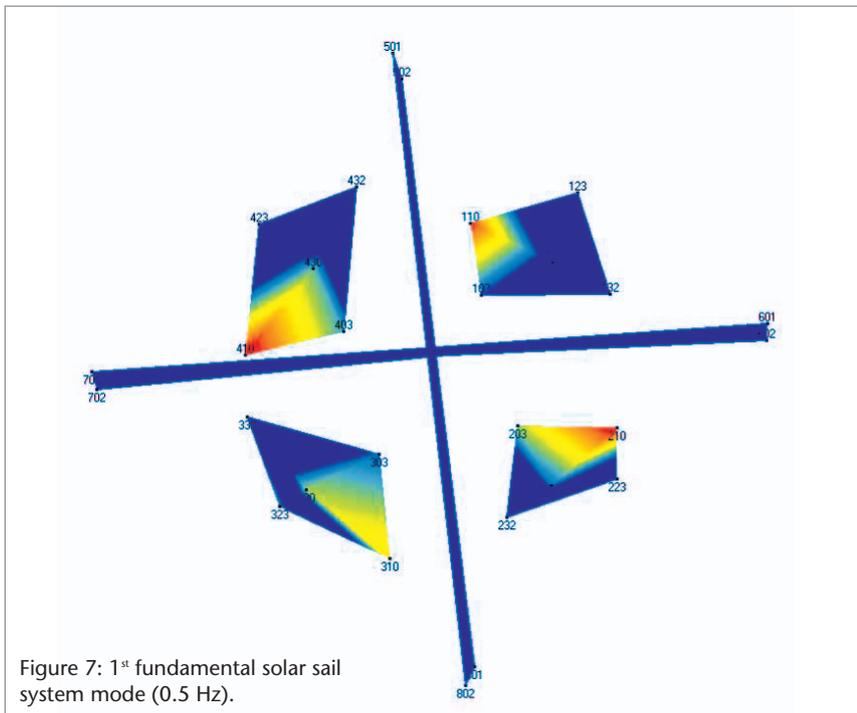


Figure 7: 1st fundamental solar sail system mode (0.5 Hz).

measured 5 sail membrane locations per quadrant and two mast tip measurements per mast. Since the test article configuration did not change from the quadrant tests to full sail system tests, the high spatial resolution quadrant test results with 44 measurements per quadrant could be compared with the lower spatial resolution system test results with only 5 measurements per quadrant.

Solar Sail Dynamics

The 1st fundamental system mode of the solar sail identified was a “Pin Wheel Mode” with all quadrants rocking in-phase (Figure 7) at a frequency of 0.5 Hz. In this mode all the mast

tips are twisting in-phase and the quadrants follow the motion by rocking and pivoting about the quadrant centerline. The 1st sail membrane mode, that has low mast participation, is a breathing mode (Figure 8) at 0.69 Hz. In this mode, the sail quadrant undergoes 1st bending through its centerline. Other higher order sail dominant modes were also found in which the long edge of the quadrant is in 1st bending, but the centerline undergoes either 2nd or 3rd order bending. These test results are important for updating structural analytical models that can be used to predict the on-orbit performance of the solar sail, free of gravity, to aid in further design iterations.

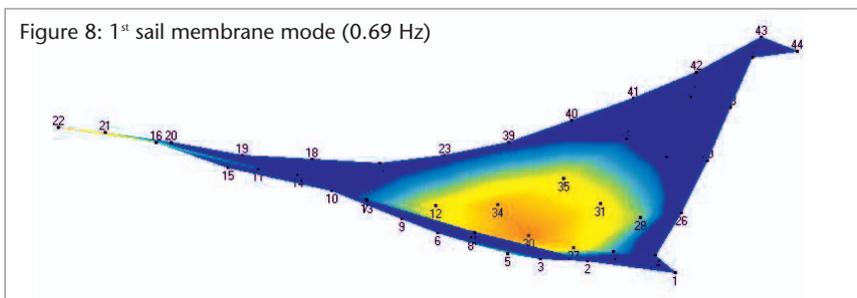


Figure 8: 1st sail membrane mode (0.69 Hz)

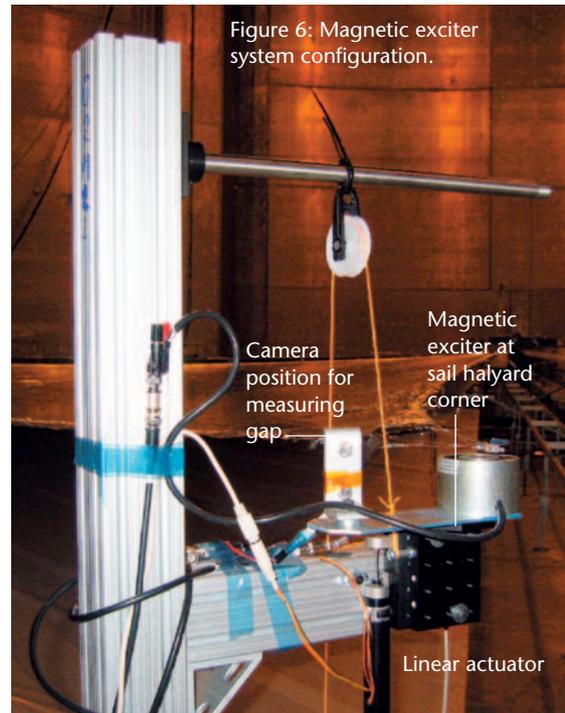


Figure 6: Magnetic exciter system configuration.

Conclusions

Laser vibrometry was successfully used to identify the fundamental solar sail system modes for structural model correlation. Also, higher order sail membrane modes were identified through a combination of many tests on each quadrant. The methodology described in this article is being further utilized for other Gossamer test programs, such as the antenna technology development program to validate large space based communication antennas.

We would like to thank NASA for granting permission to publish this article.

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Where the Rubber Hits the Runway

Experimental 3-D Scanning Vibrometer Measurements on a Complete A320 Aircraft Wheel

Aircraft tires are critical components that must meet very high quality standards. Low frequency tire vibrations can affect aircraft handling while moving on the airport tarmac and may induce undesired fatigue-inducing vibrations (shimmy) in the landing gear. Vibration analysis can characterize the tire dynamics, determine the fundamental frequencies and define a complete modal model of the tire. From this model, engineers can objectively evaluate their concerns about the impact of vibrations on adjacent aircraft components. These concerns have very real consequences since excessive vibrations can lead to premature component fatigue and failure.

Experimental Setup

A complete A320 aircraft wheel was prepared with reflective spray and mounted on a shaker that was driven by a white noise excitation signal. The vibration response was measured in the radial, tangential and axial directions by a 3-D Scanning Vibrometer located 2.5 m from the wheel.

A high measurement point density was used with over 100 points on the tire and hub (Figure 1). Because of the non-periodic nature of white-noise excitation, a Hanning window with 66% overlap was used. Operational deflection shapes (ODS), frequency response functions (FRF) and coherence were measured from 30 to 400 Hz. Operational deflection shapes (ODS) were then constructed from the data. For more complete analysis and model verification, this experimental data can be passed to modal analysis software.

Results

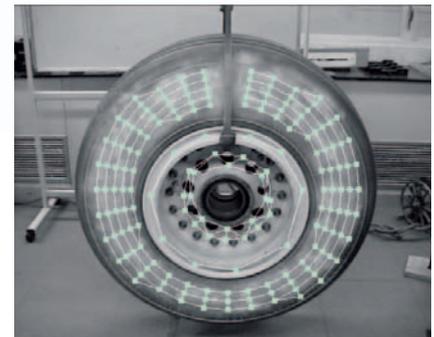
Main resonances occurred at 37, 69 and 353 Hz. The ODS at 37 Hz shows a pure tire bending (Figure 2 a). At 353 Hz, a hub bending oscillation is combined with a higher tire bending shape (Figure 2 b). The FRFs (Figure 3) were clean and the deflection shapes were spatially well resolved. The coherence was reduced at frequencies between resonances, but in the regions around the peaks it was sufficient for operational modal analysis verification.

Summary

The 3-D Scanning Vibrometry improves the quality of experimental modal analysis of aircraft wheels by combining a

simple setup procedure with a high measurement point density. Good deflection shapes are quickly and easily obtained without perturbing the structure. While only one example, this measurement represents a growing trend within the aerospace industry to perform 3-D tests on aircraft components.

Figure 1: Experimental setup and scan grid on the A320 wheel (courtesy Groupe SOPEMEA, Vélizy, France).



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guilbault@sopemea.fr

The complete measurement setup (including shaker and shaker controller) was provided by SOPEMEA. The aircraft wheel was supplied by Messier-Bugatti.

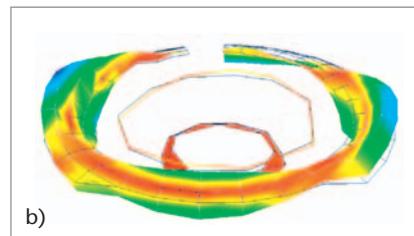
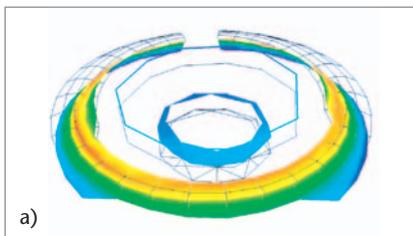


Figure 2: Operational deflection shapes at 37 Hz (a) and 353 Hz (b).

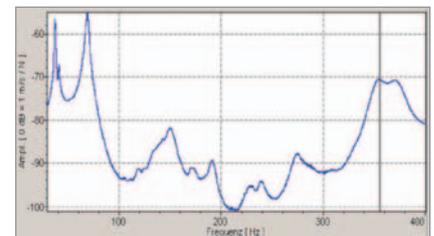


Figure 3: Average frequency response function



Healthy Airplanes

*Health Monitoring of Aerospace Structures:
Laser Vibrometry for Damage Detection Using Lamb Waves*

Lamb wave inspection uses guided ultrasonic waves to detect damage in structures. Its commercial exploitation has been limited by drawbacks in current detection techniques. Using a new detection technology known as 3-D Scanning Laser Vibrometry, structural damage is clearly identified by locally increased in-plane and out-of-plane vibrations. The method is simple, fast and reliable, eliminating complex Lamb wave propagation studies, baseline measurements and signal post-processing.

Introduction

Aircraft designers, manufacturers and operators face many test and measurement challenges in the near future.

New, large capacity civil airframes that make greater use of composite materials are being developed and will be more widely used. At the same time, new military structures exhibit improved performance by relying on greater structural complexity.

End-users of these new aerospace structures demand reduced life-cycle costs and high operational availability. These goals can be achieved with the application of new materials and wider use of damage-tolerant design concepts that result in lighter structures and better performance.

While these new aircraft are being developed, the existing fleet is ageing and must be maintained.

A number of life extension programs have been considered and performed in recent years; civil structures are being converted from passenger aircraft to freighters and military aircraft are redesigned to add new weapon capabilities. These developments are a major challenge to existing aircraft structure inspection and maintenance methods.





Figure 1: Experimental arrangements for Lamb-wave damage detection using 3-D laser vibrometry as a receiver.

Ageing aircraft structures require a significant maintenance effort. The application of new materials and damage-tolerant concepts in next-generation aircraft also requires enhanced and reliable structural health monitoring, with regular periodic inspections, to assure a safe and an extended operational life.

Damage Detection with Lamb Waves

A number of new technologies have been developed with the potential for automatic damage detection in aerospace structures. One promising technology is Lamb wave inspection, the most widely used damage detection technique based on guided ultrasonic waves, i.e. ultrasonic wave packets propagating in bounded media. While several Lamb-wave applications have been tried over the last 20 years, to date, the practical commercial exploitation of ultrasonic guided waves has been very limited.

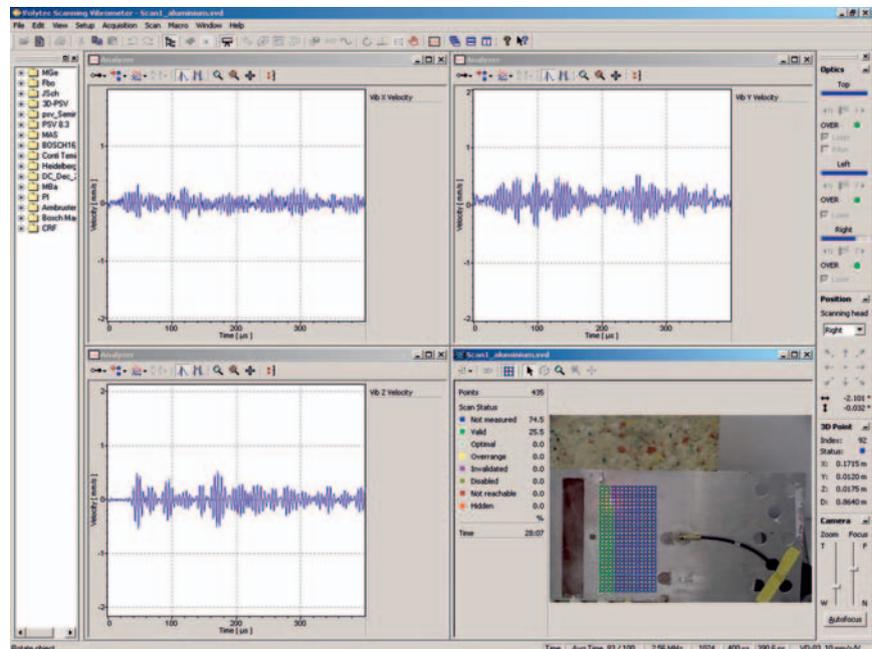
There are three major drawbacks associated with current Lamb-wave damage detection techniques:

1. A significant number of actuator/sensor transducers are required for monitoring large structures. This is labor intensive, slow and costly. From the logistic point of view, it is not practical to cover an aircraft

with many thousands of bonded or embedded transducers.
 2. Lamb-wave monitoring strategies, often associated with complex data interpretation, require highly qualified NDT technicians for point-by-point field measurements. Consequently, broad deployment is restricted by higher costs and lack of properly trained technicians.

3. Current signal processing and interpretation techniques used for damage detection utilize signal parameters that reference baseline data representing the “no damage” condition. These parameters can be affected by effects other than structural damage such as changes in temperature or bad coupling between the transducer and the structure.

Figure 2: In-plane and out-of-plane Lamb-wave responses plotted using Polytec’s PSV Software.



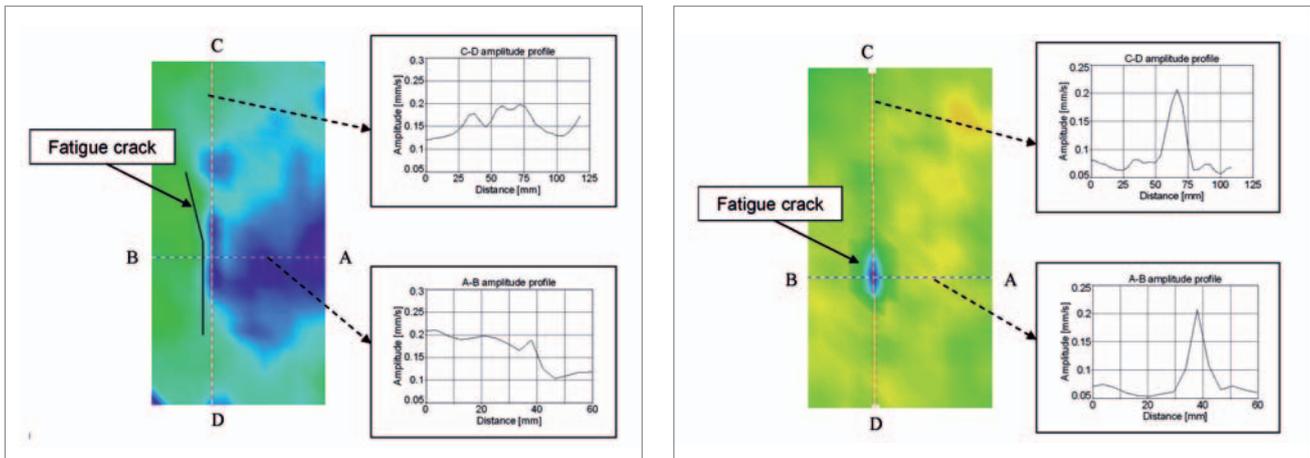


Figure 3: Fatigue crack detection in metallic structures using Lamb waves. RMS amplitude contour maps show amplitude profiles across fatigue cracks for: 75 kHz in-plane vibration (left) and 325 kHz out-of-plane vibration (right).

3-D Scanning Laser Vibrometry

Laser vibrometers can overcome many difficulties associated with Lamb-wave damage detection techniques. In Figure 1, the application of a non-contact, multi-point scanning laser vibrometer to structural damage detection is illustrated. Lamb-waves from a piezo-ceramic transducer are sensed using the Polytec PSV-400-3D Scanning Vibrometer (Figure 2). The 3-D scanning vibrometer covers the complete optically accessible surface with a high density of sample points. At each sample point, the vibration vector is measured including both in-plane and out-of-plane components. These measurements are assembled into an intuitive 3-D animated deflection shape.

Examples of damage detected in aerospace specimens using Lamb-wave monitoring are shown in Figures 3 and 4. These results show that structural damage can be identified clearly by locally increased in-plane vibration amplitude (e.g. fatigue crack in Figure 3, left, and delamination in Figure 4) and by attenuation of out-of-plane vibration amplitude (e.g. fatigue crack in Figure 3, right).

Conclusion

Scanning Laser Vibrometry can reveal structural damage and its severity such

as crack length and delamination area. Simple contour maps and profiles of Lamb-wave amplitude across the structure are sufficient to see the damaged areas and do not involve studies of complex Lamb-wave propagation in the structures, baseline reference measurements in undamaged structures, or signal post-processing to extract damage-related features. The method is straight forward, fast, reliable and immune to environmental effects.

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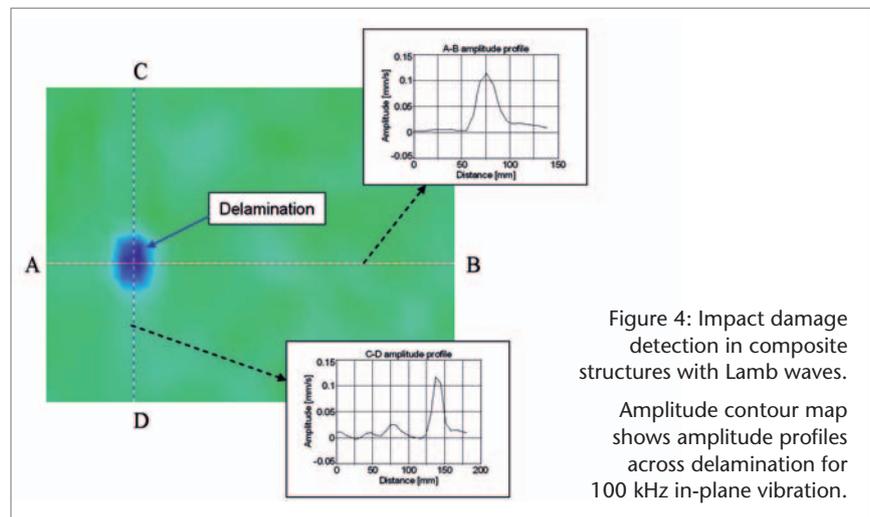


Figure 4: Impact damage detection in composite structures with Lamb waves.

Amplitude contour map shows amplitude profiles across delamination for 100 kHz in-plane vibration.

More information can be found in: W.J. Staszewski, C. Boller and G.R. Tomlinson, Health Monitoring of Aerospace Structures, John Wiley & Sons, Chichester, 2003. The full text of this article (including references) is available on the Internet and can be downloaded on www.polytec.com/usa/aerospace.



Secure Power for Jet Engines

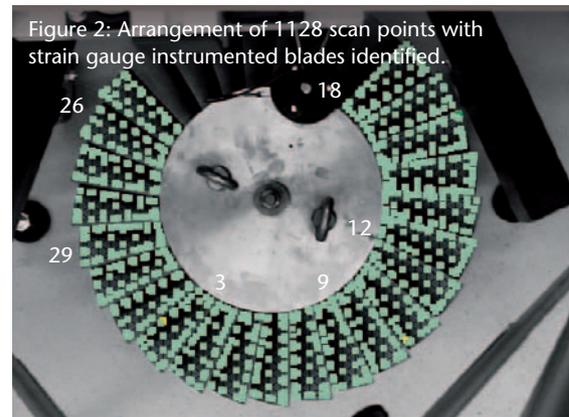
Using Scanning Vibrometry to Visualize Localization Effects of a Jet Engine Compressor Blisk

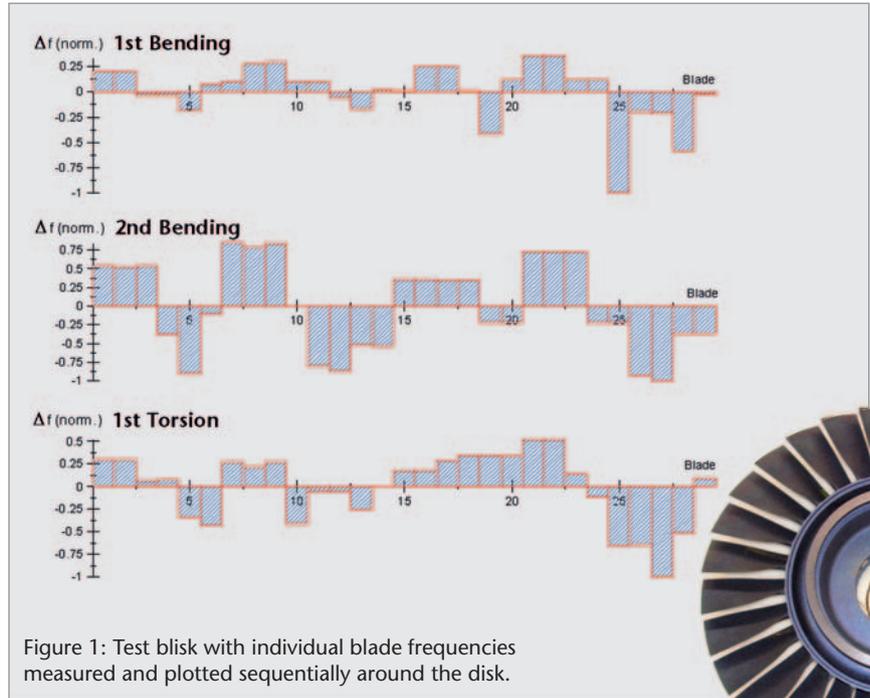
Blade integrated disk (blisk) technology is an innovation increasingly used in the design of jet engines. To be commercially effective, blisks must be designed and manufactured to specifications that insure long lifetimes. The dynamic properties of blisks can be used as an important quality check on the manufacturing and the design process. With this type of inspection, the correct interpretation of lifetime relevant vibration phenomena is one of the most challenging and important

tasks. The non-contact measurements taken by the PSV-400 Scanning Vibrometer are essential for precise vibration mode visualization and discrimination between acceptable and unacceptable localized vibration amplitudes.

Introduction

The demand for environmentally friendly and more powerful jet engines is pushing the integral design of blade integrated disk to new limits.





The manufacturing of these structures is either realized as one piece or based on friction welding so that weight-intensive blade foot constructions are not necessary. Consequentially, a stress optimized design is achieved allowing for higher rotation speeds. However, there are a number of important questions with regard to the structural dynamics of the blisk. The primary concern relates to the creation of individually different vibration behaviors for each blade (Figure 1) due to influences from manufacture imperfections (mistuning). These departures are not negligible in new jet engine designs. They can lead to localized vibration modes which produce high stresses in blades due to aerodynamic excitation.

Effect of Localization

If a localized vibration mode is excited during operation, maximum displacements can be more than twice as high compared to the perfect design (tuned). The strain level of blades affected by localization is particularly high negatively impacting the expected lifetime of the blisk. This tendency is intensified by an extremely low pure material damping value as a result of the integral construction.

Aiming at a visualization of vibration modes, and thus localization phenomena, laser scanning vibrometry can be regarded as powerful tool.

Experimental Setup

The blisk under test (Figure 2) contains 29 blades, of which the blades # 3, 9, 12, 18, 26 and 29 are instrumented with different types of strain gauges. Due to the additional mass, damping and stiffness resulting from each strain gauge an additional and non-negligible mistuning is generated. Before testing, a strain gauge calibration has been performed to define allowable limits.

The excitation is realized by applying an electro-dynamic shaker connected to the clamping device (Figure 3), using a periodic chirp signal in the range of the fundamental blade frequencies.

In order to determine the frequency response functions (FRF), a reference force cell is mounted on the shaker. Due to shadowing effects, the PSV- 400 scan initially includes just 22 blades. To complete the vibration mode information in circumferential direction, an additional ring-shaped scan close to the blade tips is carried out.

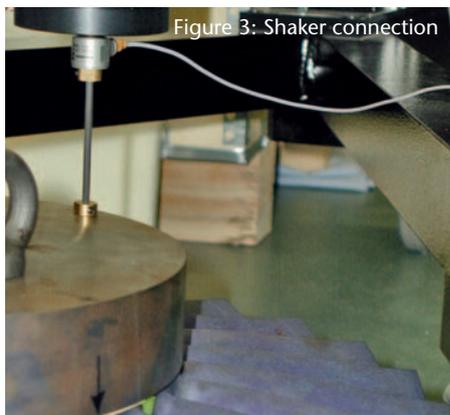
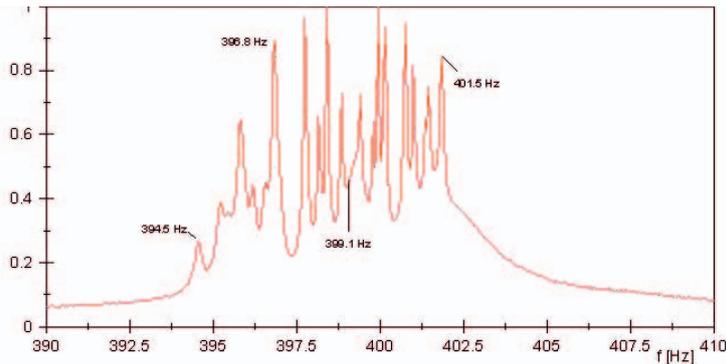


Figure 3: Shaker connection

Figure 4: Averaged Frequency Response Function.



Results

By plotting the average value of the frequency response functions (FRFs) for all scan points (Figure 4), it can be seen that a number of peaks appear inside the investigated frequency range. Some of the peaks result from blade mistuning, whereas others are assigned to modes dominated by a strongly coupled movement between disk and blade.

In Figures 5 and 6, a representative selection of modes is visualized. The cases a) – c) are characterized by strong couplings of disk and blade vibration, which is documented by the appearance of nodal diameter lines. Case a) corresponds to a mode with two nodal diameters known as “cyclic symmetry mode 2” (CSM 2), which appears distorted to a certain

degree due to mistuning. For this reason, the pure sine shape of the unwound mode (traveling around the circumference of the disk at each blade), as expected for a tuned system, gets lost (Figure 5a).

The mode shapes b) and c) correspond to CSM 5 and CSM 1 whereas a corresponding assignment in d) is not possible. From the visualization a strongly localized mode shape appears in the vicinity of blade #3 presumably caused by mistuning. Such a mode is characterized by a largely isolated vibration of a single blade or of a group of adjacent blades. Blade #3 is instrumented with a strain gauge causing additional mass and stiffness and with that additional mistuning. Preliminary experiments show that the frequency assigned to this mode corresponds to

the so called blade-alone frequency of the instrumented blade #3.

Conclusions

Based on data taken with the PSV-400 Scanning Vibrometer, localization effects at mistuned compressor blades could be verified. The knowledge of such phenomena is of essential significance with regard to the evaluation of lifetime.

Acknowledgement

This work has been supported by the Rolls-Royce Company. The authors are grateful for this commitment. The investigations are part of the project DeSK Blisk Validation (FKZ: 80121978) which is funded by the Federal State Brandenburg and the European program for regional development.

A German version of this article is available on the Internet and can be downloaded on www.polytec.de/aerospace.

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Figure 5: Selected vibration modes.

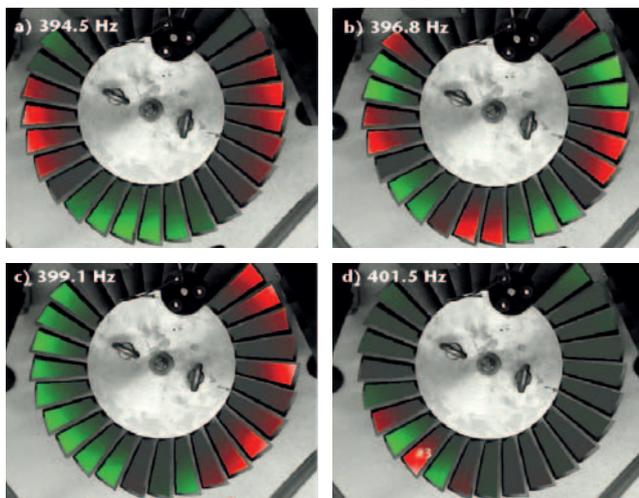
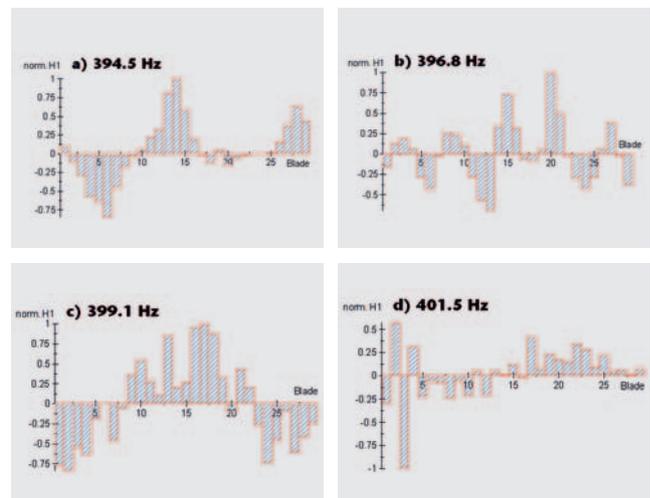


Figure 6: Selected modes corresponding to Fig. 4.



Polytec Scanning Vibrometers

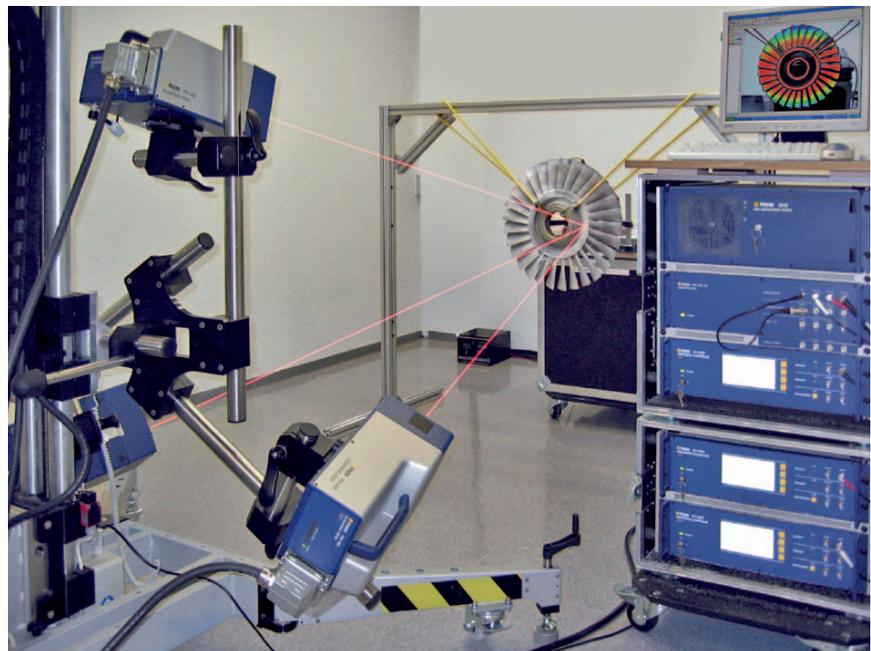
The PSV-400 and PSV-400-3D Scanning Vibrometers provide cutting edge measurement technology for the analysis and visualization of structural vibrations up to 20 MHz. Entire surfaces can be rapidly scanned and automatically probed with flexible and interactively created measurement grids, with no mass loading or added stiffness and no time.

Vibrations Made Visible

At the heart of every Polytec Scanning Vibrometer system is the laser Doppler vibrometer – a very precise laser-based, single-point transducer used for determining the vibration velocity and displacement by sensing the frequency shift of back scattered light from a moving surface.

Traditional multi-point vibration measurement methods use many fixed contact transducers making experimental modal and deflection shape analysis difficult and time consuming. However, through the use of dual-axis galvo scanners, the positioning of the laser vibrometer transducer spot can be automated. This is a great simplification for deflection shape, modal analysis and frequency response function measurements.

Now the geometry of the object and the location of the measurement points can be programmed through a computer's user interface greatly simplifying the measurement process and improving accuracy. To measure a deflection shape, just define the geometry and scan grid, and initiate a measurement. When the automatic scan is complete, display and animate the deflection shape in several convenient 2-D and 3-D presentation modes. These on-screen displays are extremely effective, intuitive tools for understanding the details of the structural vibration. Find more information on www.polytec.com/usa/psv400.



A Powerful Development Tool

The PSV-400 is a powerful data acquisition platform that can seamlessly integrate into the engineering workflow and the IT environment. The system can import geometry data directly from CAE and FEM packages or experimentally measure the geometry using the convenient Geometry Scan Unit (scanning laser range finder). All measurement results are available to third party applications through various export filters and PolyFileAccess, an open data interface. A powerful post processor is integrated in the software to apply various mathematical operations to the measured data.

Get the Complete 3-D Vibration Vector Information

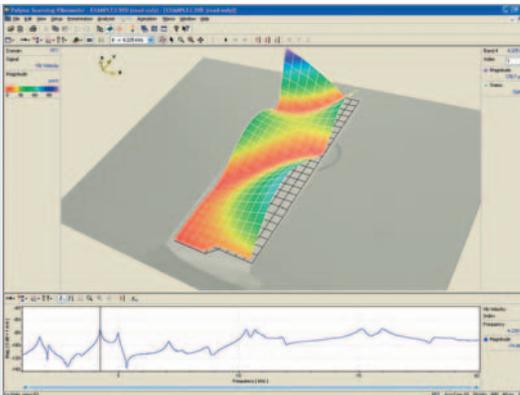
The PSV-400-3D Scanning Vibrometer has three independent sensor heads that extend scanning vibrometry to three dimensions. It enables intuitive 3-D animation of operational deflection shapes with clear separation of out-of-plane and in-plane vector components. The PSV-400-3D has 8 simultaneous measurement channels and the integral Geometry Scan Unit for quick and easy acquisition of 3-D geometry data directly from the structure under test.

www.polytec.com/usa/psv3d

Polytec Scanning Vibrometers:

Benefits for Aerospace Testing

- Dramatically increases throughput while lowering measurement costs
 - Simplifies frequency response measurements, calculation of deflection shapes and modal analysis
 - Efficient large-scale vibration data acquisition and management
 - Large stand-off distance for vibrometer and Geometry Scan Unit, up to 50 m for measuring typical surfaces of large objects
 - High spatial and frequency resolution (0.001 Hz) e.g. for modal analysis on turbine blades
- Test data can be measured directly at FE nodes
 - Fatigue testing at very high vibration levels up to 20 m/s
 - Measurement of rigid body modes (including in-plane motions)
 - Smooth transfer of measured data to modal analysis software and processing of multiple references for MIMO measurements
 - Partial measurements on large structures can be grouped together (stitched) to form a global data set of 3-D geometry and 3-D vibration data



Proud to Be Number One

Polytec is a global enterprise with corporate facilities in Europe, North America and Asia. A strong Polytec team of sales managers, application engineers and skilled representatives delivers Polytec technology to all parts of the world.

Founded in 1967, Polytec GmbH is an ISO-9000 certified manufacturer supplying customers with the gold-standard in laser Doppler measurement solutions. All of our vibrometer systems are developed, engineered and manufactured to the highest standards and specifications. Engineering such a sophisticated product requires a truly multi-disciplined company. Polytec's long-standing reputation and undisputed performance advantages are well known. We are very proud of the Polytec Scanning Vibrometer. Its design and construction demonstrate our expertise in opto-mechanics, electronics, computer hardware & software, as well as applications knowledge in the field of mechanical engineering.

Polytec At Your Service

Our market-leading position is built on innovative technology, high-quality products, engineering excellence, expert technical advice and thousands of satisfied customers worldwide. Polytec offers world-class products, technical support, measurement services, system rentals and training classes to support customers at every level in solving their measurement challenges.

Contact Us

If you would like any further information, please contact your local sales/application engineer or e-mail to info@polytec.com (for North America) or LM@polytec.de (all other regions).

Visit our website www.polytec.com for up-to-date technical information and future events, seminars and training classes.

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MEMS-Testing *in Step*



Semiautomatic, Wafer-Level Measurements of MEMS Dynamics

Micro Electro-Mechanical Systems (MEMS) find numerous applications in the automotive, aeronautic and consumer electronics industries. Wafer-level MEMS testing prior to packaging is an increasingly important measurement for achieving high yield and reliability at low production cost. The dynamic response of MEMS can now be measured using a semiautomatic probe station equipped with a scanning laser-Doppler vibrometer.

Dynamic testing of a MEMS wafer covered with an array of microstructures is time consuming and tedious when it is done manually, one device at a time. To improve the throughput, a semiautomatic probe station positions the wafer then a laser Doppler vibrometer performs the dynamic test on each device. The entire characterization process is controlled by software that steps the wafer and then initiates a measurement. The complete system (title image) consists of the Polytec MSA-400 Micro System Analyzer hardware running the Scanning Vibrometer Software, a SUSS PA200 Probe Station equipped with the MSA-400 Measurement Microscope Head, the probe

station controller hardware, and the SUSS ProberBench™ Operating System. The first step is to align the wafer, which programs the locations of the structures on the wafer. With this information, the software generates a wafer map. The next step is to define the measurement parameters for the vibration characterization of the MEMS. For the membrane array MEMS device, a grid consisting of 6 to 9 measurement points (Figure 1, top) is fitted to a single MEMS structure. After these two steps, the software is ready to initiate the step-and-repeat measurements on the MEMS device. Beginning at the first MEMS, the system steps to each device on the

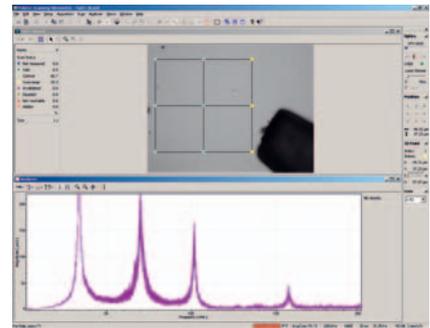


Figure 1: Measurement grid (top) and frequency spectrum (bottom) of the device displayed in the Polytec Scanning Vibrometer Software

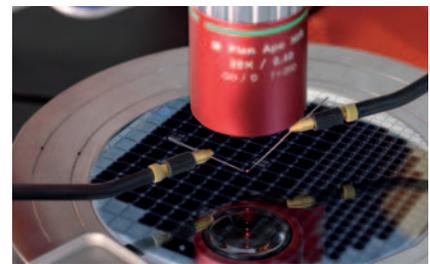


Figure 2: Scanning laser-Doppler vibrometer measurement of a single MEMS device on the wafer

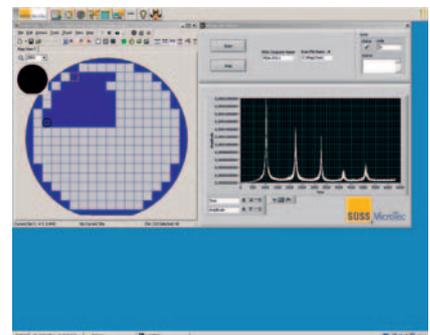


Figure 3: Wafer testing process and vibration signal displayed in the SUSS ProberBench™ Software

wafer as originally programmed. On each MEMS, a scanning vibrometer measurement is performed within 2 to 3 seconds (Figures 1 and 2), and saved together with the device ID. As a result, the full wafer map is measured and frequency spectra as well as deflection shapes of all devices are available (Figure 3).

Find more information about the MSA-400 Micro System Analyzer on www.polytec.com/usa/microsystems and about the SUSS Probe Station on www.suss.com.

Precision Speed Measurement *by Light*



High-Precision Real Time Measurement of Car Speed Using Laser Surface Velocimetry

A novel application of Laser Surface Velocimeter (LSV) technology is being investigated at Renault for Driving Assistance System evaluation and test. While LSVs are traditionally used for precision measurement of surface speed and integrated length on moving materials used in manufacturing, Renault is incorporating the LSV as an on-board reference sensor to measure real-time vehicle ground speed with better than 0.1 km/h accuracy. This accuracy is found to be better than other methods commonly used for ground speed measurement including GPS.

Introduction

Driving Assistance Systems combine a variety of sensors with vehicle display, control and handling capabilities to improve driver performance and safety. As part of a project to evaluate new driving assistance systems using environmental sensors, engineers at Renault needed to measure the exact car speed in real time with better than 0.1 km/h accuracy. Common existing solutions are based on either GPS (Global Positioning System), the use of CAN (Controller Area Network) data, or optical sensors.

System Comparison

Differential GPS uses a network of fixed ground based reference stations to broadcast the difference between the positions indicated by satellite

systems and the known fixed positions. GPS based speed measurement systems have sampling frequencies below 100 Hz and the achievable accuracies no better than 0.1 km/h. Occasional signal dropouts are a significant disadvantage of this system.

Controller Area Network (CAN) is a shared serial bus standard for connecting electronic control units. When using CAN data for velocity measurements, the maximum sampling frequency is 40 Hz and the best available accuracy is only 0.2 km/h. Besides the lower sampling frequency and accuracy, CAN data filtering may cause a time delay of up to 60 ms. Another measurement approach is to use the Correvit optical velocity sensor. It is a non-contact solution similar to Polytec's Laser Surface Velocimeter;

but, it has a significant disadvantage in that it fails to work on wet ground.

Successful Tests

Desiring to find a better speed measurement solution, the LSV came to the attention of the Renault engineers at the end of 2004.

Figure 1:
Mounting of the LSV-065 Sensor Head

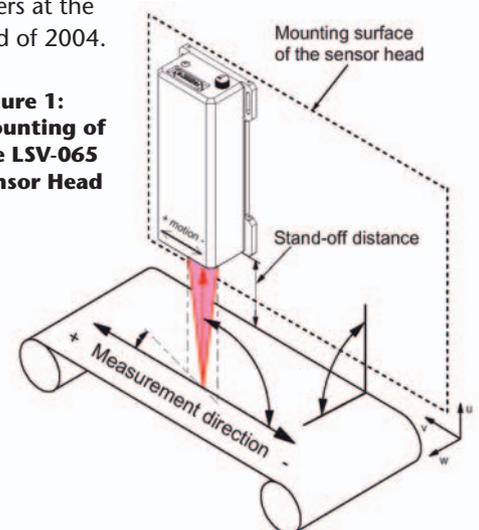




Figure 2: Position of the LSV Sensor Head inside the test car

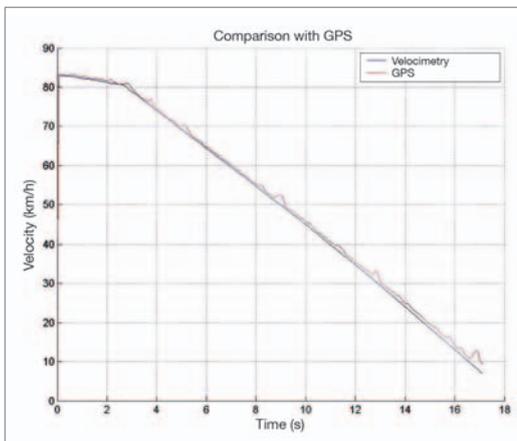


Figure 3: Comparison of velocity measured by GPS and LSV during a braking cycle

They took the opportunity to measure LSV accuracy and repeatability on a roller test bench with a velocity precision of 0.1 km/h. The results were very encouraging and a Series 6000 Velocimeter System was ordered at the beginning of 2005.

Polytec's LSV systems combine a sensor head, a controller and software into a rugged industrial package. These systems are very accurate, making measurements from standstill to speeds of more than 7200 m/min (430 km/h) in either direction. The Series 6000 Laser Surface Velocimeter consists of a compact, IP-65 protected LSV-065 Sensor Head and a 19" rack-mountable LSV-6200 Velocimeter Controller. The Sensor Head (Figure 1) is available with various stand-off distances up to 2.5 m (maximum depth-of-field of ± 0.1 m). The Controller powers the sensor head, manages signal demodulation and communicates the data to external process control systems.

To implement a field test with the LSV, a special challenge was to find the best place to mount the sensor on the car. If the sensor head were mounted outside the car, its function would be affected by vibrations and environmental conditions. The optimum position turned out to be inside the car, above the passenger front-seat (Figure 2). Once the test car had been equipped with the LSV, test runs were performed on a test track with various acceleration and braking cycles.

A GPS-based measurement system was used for comparison. From an analysis of the results, the LSV proved to be the superior measurement instrument, providing more stable and precise data. In Figure 3, velocity vs. time is plotted when braking from 80 km/h to nearly standstill. The GPS data were very noisy in comparison to the LSV data which showed a very smooth progression.

Conclusion

The LSV Laser Surface Velocimeter directly measures surface speed, thus providing an accurate, repeatable,

and reliable method of car velocity measurement. When mounted in test cars, it provides very stable and precise data, even when measuring on wet ground. Further investigations are necessary to clarify details of the test installation, portability to other types of vehicles, remote power supply and data processing.

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LSV-6000/LSV-300 Laser Surface Velocimeters

Laser Surface Velocimeters can measure surface speed and integrated length (start to stop) on all types of materials. They are used in a variety of industries including steel and metals, paper, plastics, high-grade films, glass, textile, and rubber. The sensors are typically used when contact devices such as encoder wheels or tachometers fail because

- Accuracy is lost due to slippage, poor contact or thermal expansion/contraction.

- Contact would damage the product.
- Extreme environmental parameters such as high temperature would quickly destroy the contact sensor.

Polytec's LSV systems combine a sensor head, a controller and software into a rugged industrial package that makes precision measurements from standstill to speeds of more than 7,200 m/min in either direction.

For more information:
www.polytec.com/usa/lsv

North America's Exciting Fall Exhibition Season

The fall is a busy time for Polytec with at least one important tradeshow each month. These shows are an excellent opportunity for engineers and scientists to see the current state-of-the-art in non-contact vibration measurement equipment.



Depending on the show, attendees will have the chance to see

- Scanning Vibrometers that measure 1-D or 3-D vibration vectors
- New, compact, low-noise vibrometers for single point measurements on large and small structures
- Micro System Analyzers where laser vibrometry, stroboscopic video microscopy and scanning white light interferometry are combined in one instrument to measure in-plane motion, out-of-plane motion and surface topography of MEMS devices.

In September, we will exhibit at Diskcon USA 2006. Located in the heart of Silicon Valley, this is the premiere show for hard disk drive development. Polytec will exhibit the new single point OFV-534 Compact Vibrometer and the PSV-400 Scanning Vibrometer in a vertical test stand configured to measure small parts.

In October, we will conduct a PSV training class in Ann Arbor, Michigan followed by a large exhibit at Automotive Testing Expo in Novi, Michigan featuring the PSV-3D Scanning Vibrometer and the HSV High Speed Vibrometer.

In November, we first attend the ASME annual meeting in Chicago where both the PSV-400 Scanning Vibrometer and the MSA-400 Micro System Analyzer will be presented. Next we attend the Aerospace Testing Expo in Anaheim, CA featuring the PSV-400-3D Scanning Vibrometer System.

Finally, we finish December, 2006 with Inter-Noise 2006 in Hawaii. A PSV-400 1-D Scanning Vibrometer System will be presented along side the OFV-534 Compact Vibrometer for single point measurements.

2006/2007 Trade Fairs and Events

Sept 13 – 14, 2006	Diskcon 2006	Santa Clara, CA, USA
Sept 18 – 20, 2006	ISMA 2006	Leuven, Belgium
Oct 04 – 05, 2006	PSV Training Class	Ann Arbor, MI, USA
Oct 17 – 18, 2006	9th Vibrometry Seminar	Waldbronn, Germany
Oct 17 – 19, 2006	MESUREXPO 2006	Paris, France
Oct 25 – 27, 2006	Automotive Testing Expo 2006	Detroit, MI, USA
Nov 06 – 08, 2006	International Mechanical Engineering Congress & Exposition (IMECE) 2006	Chicago, IL, USA
Nov 14 – 16, 2006	Aerospace Testing Expo 2006	Anaheim, CA, USA
Dec 04 – 06, 2006	InterNoise 2006	Honolulu, HI, USA
Jan 23 – 25, 2007	MOEMS-MEMS 2007 (Photonics West 2007)	San Jose, CA, USA
Feb 19 – 22, 2007	IMAC 2007	Orlando, FL, USA
Mar 20 – 21, 2007	Smart Structures and Materials 2007	San Diego, CA, USA
Mar 27 – 29, 2007	Aerospace Testing Expo 2007	Munich, Germany
May 01 – 04, 2007	North American Users Meeting	Ann Arbor, MI, USA

Reference our web site www.polytec.com/usa/events for the most up-to-date information and links on trade fairs and events!

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