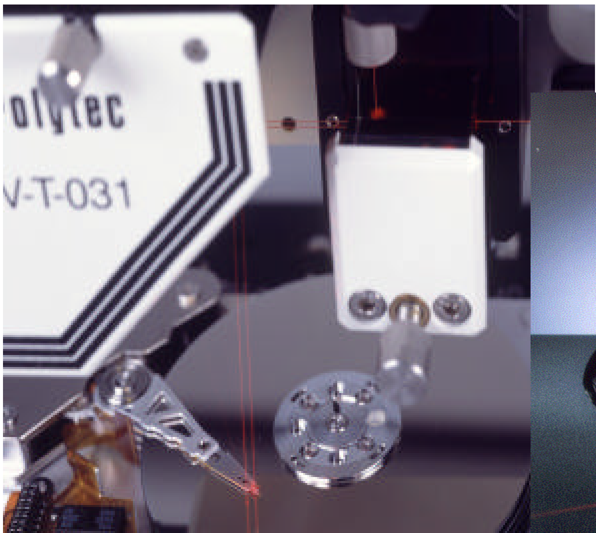
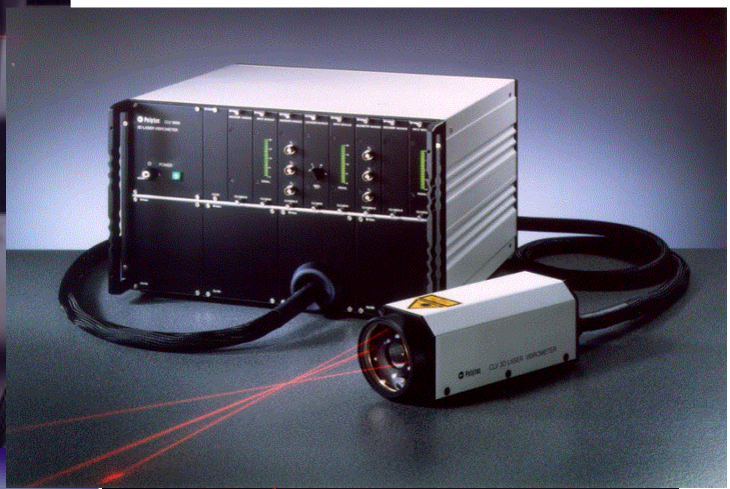
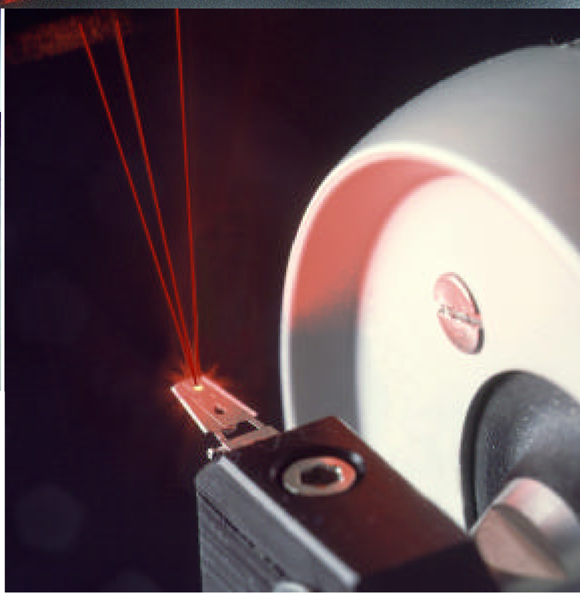
LDV
Laser Doppler Vibrometer

Applications to Data Storage Dynamics







The standard for high performance dynamic testing, vibration imaging and analysis for R&D, engineering & quality control

Introduction

Laser Doppler Vibrometers (LDVs) are the workhorses for non-contact, high-end R&D, continuation engineering, mechanical troubleshooting and quality control testing of data storage devices at the component and system levels. The technical literature is full of published reports in how LDVs have helped data storage industry during the last 15 years. These efforts continue today, helping mechanical system to respond with requirements for higher data densities and faster access times reducing misregistration & improving data transfer. LDVs are used in design of all mechanical data storage devices, hard disk drives (HDD), removable media devices, optical storage, DVDs and tape drives. Among these different applications are:

Applications:

- Component resonance testing,
- Drive level resonance testing
- Component & system modal analysis
- Media testing
- Head-media interface dynamics
- Head load-unload dynamics
- Track-seek & track dynamics stability
- Crash & drop testing
- Spindle testing
- Optical drives
- Tape drives

Component Level Testing using Fiber Optic, Digital and Scanning LDVs

Suspension Resonance:

The suspension assembly (also known as the HGA) is a vital part of the disk drive, providing the mechanical mounting for the read/write head embedded at end on the slider. Therefore, it is important to determine mechanical resonance of the suspension that might cause instability of the read/head and contribute to off-track errors. Frequency response measurements on the suspension reveal numerous resonant frequencies and mode shapes that correspond with bending, torsion and sway modes of the suspension structure. These relate directly to mechanical properties of the suspension such as geometry, stiffness, head moment of inertia, etc.. Suspension design validation requires experimental analysis of these parameters.

The single point fiber optic LDV provides the necessary tool for measuring dynamic response of small parts like the suspension. The fiber optic probe can be micro-positioned for precise targeting of the measurement laser spot. The analog velocity and/or displacement output can be plugged into a dynamic signal analyzer to determine the frequency response function (FRF). This will yield the resonant frequencies that correlate to the various modes of vibration. Collecting FRF data at various points on the suspension are used to generate mode shapes using modal analysis software.

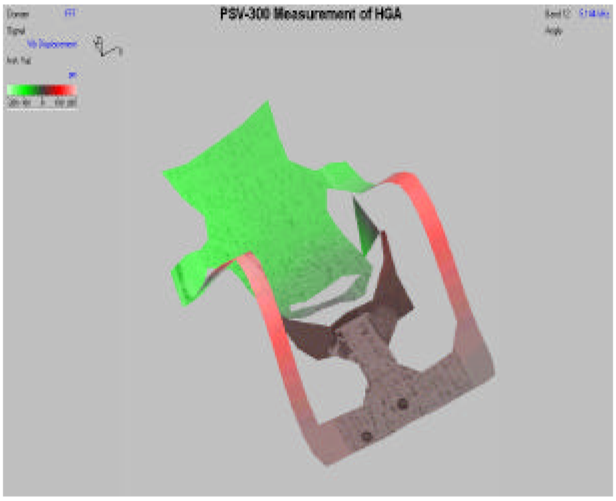


Figure 1 Bending mode of HGA at 5114 Hz.

Alternatively, the PSV-300 Scanning Laser Vibrometer can automatically scan a selected point grid to collect and display mode shapes of the HGA, with great timesavings. A single scan of the HGA, excited through the voice-coil or shaker, can yield animations of each out-of-plane mode of vibration. Figures 1 & 2 shows PSV measurements of two dominant gimbal modes.

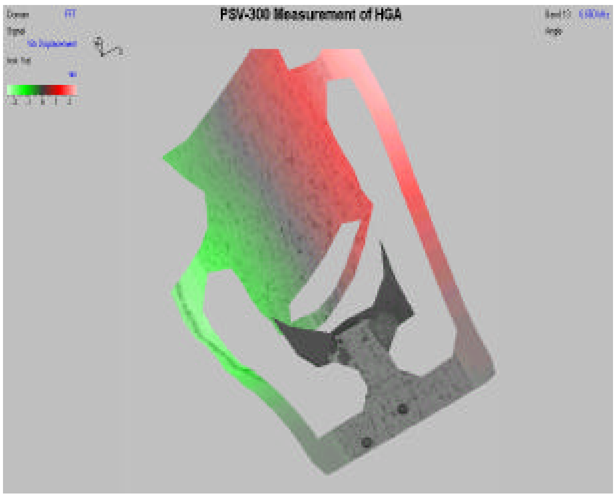


Figure 2. Torsion mode of HGA at 6650 Hz.

E-block resonances:

Lateral motions of disk drive suspensions can be measured by targeting the laser beam on the HGA from the side. Disk Drives using multiple disk platters stacked together on the same spindle hub have an array of heads and suspensions connected together on the same E-block. The sway modes of assembled arms and suspensions are measured on multiple data points along the thin edges of each suspension. .

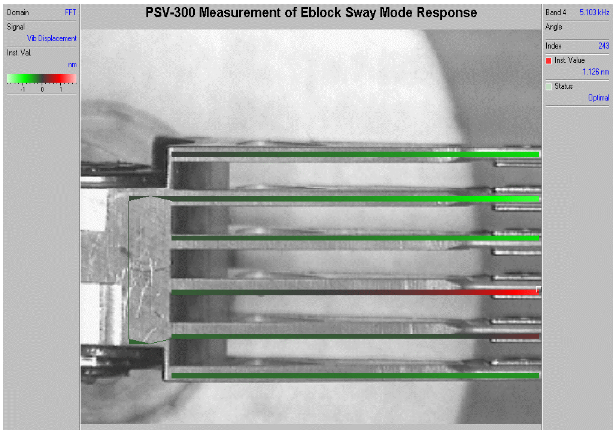


Figure 3. Color Map, PSV-300 measurement of sway mode response on 6 HSA arms at 5.10 kHz frequency and 1.6 nm peak displacement..

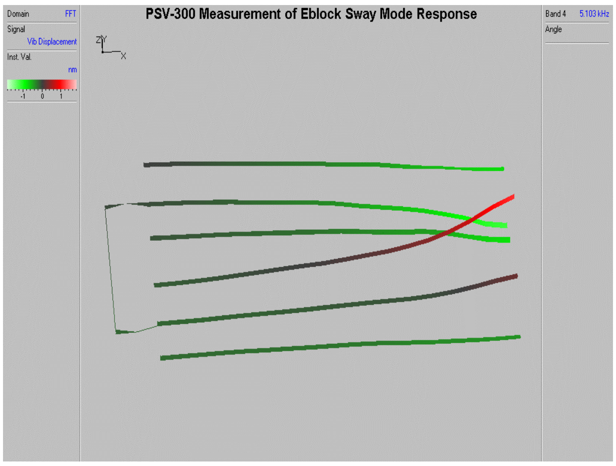


Figure 4. 3-D Animation frame of same sway mode response shown in figure XX. Shows phase relationship between individual HGAs

The laser spot can be focused down to a 5 um spot to target even the smallest of features. While single point LDV measurements on the slider are enough to determine resonant frequencies, characterization of the entire e-block assembly can be measured with the PSV-300 Scanning Laser Vibrometer from a single scan. Individual resonant frequencies from each suspension can be determined and displayed as animations of lateral deflection. The resonant frequencies of individual suspensions differ due to slight differences in manufacturing tolerances. Energy transferred through the mounting block provides coupled excitations of adjacent suspensions at each resonant frequency. The coupling of resonant modes between suspensions can also be determined with the PSV-300

Slider resonances:

LDV measurements can be scaled down to even the small features of nano and pico sliders to measure their dynamic responses. On the component level, micron level spatial resolution is needed for micro-positioning the laser spot on a given site of the slider, especially if measurements need to be made near the reading or write element. The fiber optic LDV can focus the laser spot down to 20um using standard 10 mm lens, or alternatively, 3 um using the OFV-120-3 micro-spot lens. Also, microscope based measurements are possible using the OFV-075 Microscope Adapter for the clearest resolution video image of laser spots that can focus down to less than 1 um.

Because of their small sizes, low mass and stiff materials, the natural frequencies of sliders start in at 100’s of kHz and extend all the way into the MHz range. The OFV-3001 Controller with OVD-02 high frequency velocity decoder has a bandwidth of 1.5 MHz. For resonant frequencies in this range and beyond 1.5 MHz, there are several options. Digital LDV systems allow measurements up to 2MHz and the OFV-2700 Ultrasonic controller offers 10MHz and 30MHz analog output options. This controller comes equipped with either the OVD-30 displacement decoder or the OVD-05 Velocity Decoder, which can also be installed in the OFV-3001 controller series.

Quality Control Measurements, resonance testing

Pivot Bearings:

Resonance measurements using the LDV can be an indicator of defects inside mechanical parts such as pivot bearings that would not be apparent during visual inspection. In the case of pivot bearings supplied directly from manufacturers, the fundamental resonant frequency is an indication of bearing pre-load. This useful measurement can be used for quality assurance purposes before the pivot bearing is build into the disk drive. The Compact Laser Vibrometer (CLV) provides features for production measurements on small parts that not require the high bandwidth, or dynamic range for R & D measurements using the fiber optic LDV. Drive manufacturers can therefore characterize and maintain certain quality levels from the component suppliers.

Slider Resonance –KLA-Tencor HRT-300 HGA Resonance Tester

Today's high-bandwidth disk drive servos are more susceptible to HGA vibration than ever before. 1st bending & torsion resonance modes are directly related to off-track performance in the drive. The industry-standard KLA-Tencor (formerly Phase Metrics) HRT300 HGA Resonance Tester makes it possible to measure the resonance characteristics of HGAs in production line testing, incoming inspection and QA testing using non-technical personnel.

The HRT300 examines HGA resonance characteristics. A precision vibration source excites the HGA over a frequency range of 1 kHz to 30 kHz, while an LDV measures the response of the slider. FFT analysis is performed on the excitation and response data to calculate the mechanical transfer function of the HGA under test

Windage can be measured to evaluate HGA performance due to the head/media interface. Head displacement is measured only in the presence of the spinning disk. An optional manual setup/load station can be added with a spinning top disk and complementary head to more closely match drive conditions.

Figure 5

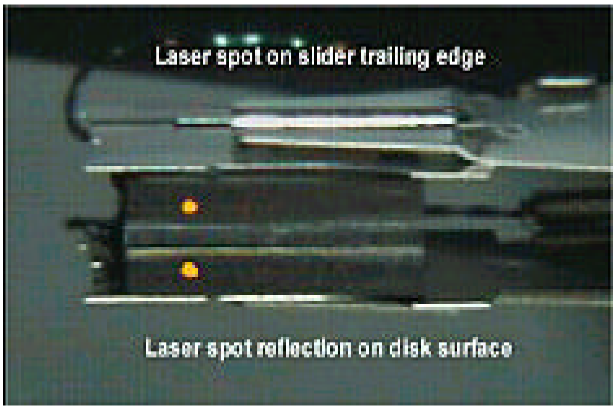


Figure 6

New Actuated Suspension Stroke Test: The HRT300 also provides an actuated suspension test, which measures displacement of the head versus the voltage / current applied to the secondary actuator. The test can be conducted with or without shaker excitation. Call (858) 646-4883 for more HRT300 information.

Resonance Drive Level Measurements Using the PSV-300 Scanning Laser Vibrometer:

Testing of the complete disk drive arm-suspension assembly is required to experimentally verify mechanical performance under operating conditions. Until an accurate FEA model is made for the complete arm-suspension, behavior at the drive level cannot be predicted from measurements made at the component level. Heavier components will transmit or force their own resonances onto lighter, less massive components. For example, forced responses of the more massive actuator arm will force their resonance responses onto suspensions. Figure 7 below shows an example of the arm resonating at 5.78 kHz imposing the suspension into its second torsion mode.

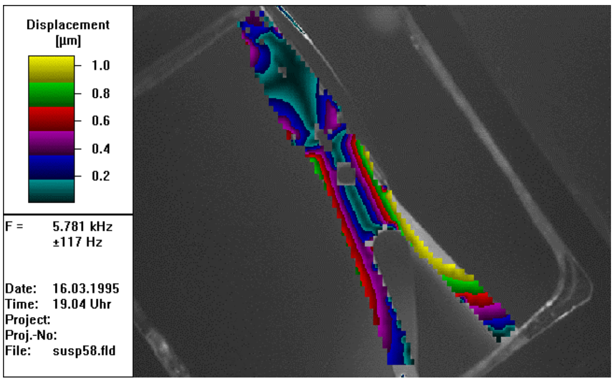
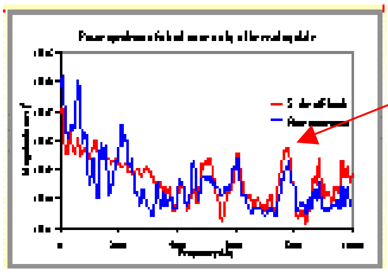


Figure 7

With the PSV-300 the user can quickly discover what is actually happening to the entire arm-suspension assembly by performing a single test in a matter of minutes. A detailed modal analysis study of discrete measurement points on an arm-suspension assembly can take days for capturing, acquiring and transferring data to modal analysis programs, to do that the user needs to add time for curve fitting and report editing. The PSV-300 can automatically scan and acquire data at a user-selected array of up to thousands of measurement points over the complete assembly. The software automatically displays the vibration patterns and operation deflection modes corresponding to given resonances. The PSV-300 also provides the tools for the user to evaluate how coupled the different modes are so he can decide if there is an actual need for separating the modes via modal analysis.

Many a times that is not necessary. This accelerates testing of assembled drive designs before they are tooled up for manufacturing with improved product-to-market times.

Figure 8 below illustrates a scan measurement made on an arm-suspension assembly at the second sway mode (8838 Hz).



Response shape of the second sway mode of Arm-Suspension

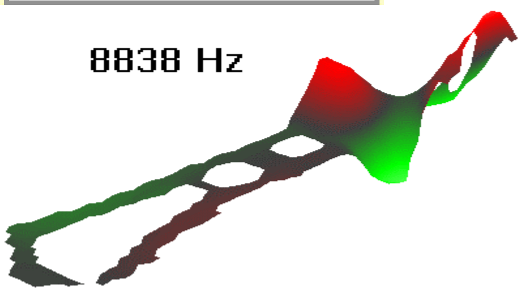


Figure 8

The PSV-300 helps to quickly discover what is actually happening to the entire arm-suspension assembly by performing a single test in a matter of minutes. A detailed modal analysis study of discrete measurement points on an arm-suspension assembly can take days for capturing , acquiring and transferring data to modal analysis programs. The PSV-300 can automatically scan and acquire data at a user-selected array of up to thousands of measurement points over the complete assembly.
The software automatically displays the vibration patterns from measurement. This accelerates testing of assembled drive designs before they are tooled up for manufacturing..

Another consideration for measurements at the drive level are the windage and air bearing forces present on the slider when the disk is spun up. The common method for exciting the arm-suspension assembly is under forced excitation from the voice coil. Though the arm is dominated by force from the voice coil, air flow from the spinning disk creates windage forces on the air foil of the suspension. Furthermore, an air bearing is created as the slider is loaded against the spinning disk by the flexure. At sub-micron flying heights, air pressure from the spinning disk effects the motion of the slider and is easily disturbed by surface irregularities in the disk. The vibration on the slider is dominated more by the runout of the spinning disk than other external forces.

For this reason, modal testing of the disk drive HGA/slider under operational excitation requires a second fiber optic LDV channel to measure disk runout/velocity. Scanned measurement from channel A are measured relative to excitation from windage and air bearing forces from the disk measured by the second reference channel B and correlated by mechanical transfer function (A/B). For this measurement we also recommend the fiber optic LDV using OFV-3001 with either single fiber OFV-511 or dual-fiber OFV-512 (see section “Head /Media” for differential measurement).

Flex cables & voice coils: The LDV has sufficiently small spot size to target tiny elements like flexure cables leading down the suspension to the read-rite head. The result of knowing the wire resonances and coupling to the structure are important for HGA reliability. Though designed for axial rotation, voice coil assemblies can exhibit vertical translation when asymmetries or defects exist in the design. When these resonances coupled to the arm and suspension, this can cause significant mechanical instability of the whole disk drive. Measurements of voice coil resonance and vertical translation are important for determining the structural reliability.

Component and System Modal Analysis:
The task of performing a full modal test of disk drive suspensions has historically presented a number of obstacles. Mainly, the lack of three-dimensional

information and the resulting amount of time required to test, has made this a cost intensive procedure. One that is indispensable as well in an industry with ever increasing pressure to improve performance while slashing costs. By using the innovative 3D-LV vibrometer from Polytec PI, the response of a suspension or actuator arm can be measured and the results obtained provide three-dimensional characterization over the entire structure. Further test time reduction is achieved with an integrated 3D-LV scanning system employing Polytec PI's positioning products and expertise. The result is a system with unparalleled capability. Furthermore, the scanning portion of the system can easily adapted for use with the large number of fiber LDV sensors so prevalent in the disk drive test field.

Figure 9 3D-Scan

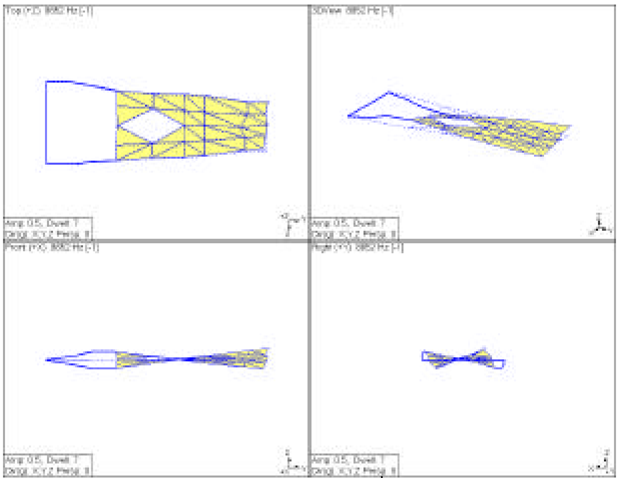


Figure 10 Suspension 2nd torsion mode

Head Media Measurements: Air Bearing & Slider Resonances:
Measurements of slider air bearing resonances are also made during operating. Air bearing resonances are very stiff compared to suspension resonances. Resonant frequencies usually occur at frequencies in excess of 1 MHz. Placement of the laser beam at the outer trailing edge of the suspension is usually necessary to detect all modes and requires special fixturing for positioning the spot.

As nano and pico sliders become the standard in the industry, dynamic transient events become more relevant for mechanical and tribology engineers. They are interested in the influence of scratch impact of the air bearing stiffness; influences of lubricant thickness on slider dynamics, for single bump contacts, dynamics of take-off and landing. They are also interested on the linear time frequency analysis to the impact response of the air bearing and the slider torsional and bending modes at different flying heights. As scales become smaller non-linearities arise in the slider / lubricant interaction.

Head/Media Interface Studies;
The high-resolution feature of the digital LDV permits highly accurate measurements for head/media interface dynamics during different experimental conditions. For example, it is of great importance to know what happens to the slider at different flying heights when using media with certain specifications for a given file product. With current media products, the average surface roughness and micro-waviness of the media shipped today are around 5nm to 10nm in height and λ in the order of 100 microns (roughness average).

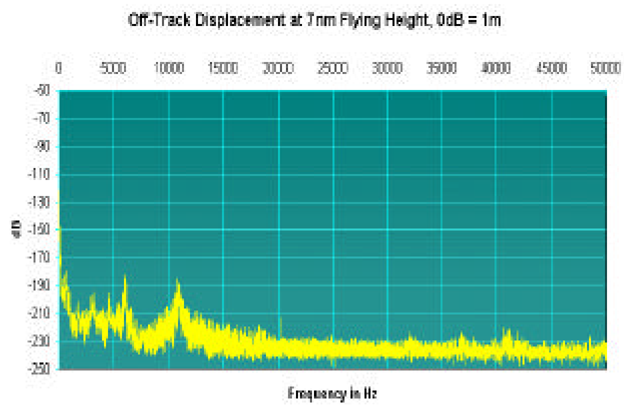


Figure 11

If we fly the head at flying heights of 4nm and 7nm; the dynamics of the slider in track-follow state will be quite different. The graphs displayed above (figures 11 & 12) show those measurements in the off-track direction with remarkable differences.

Even though we would like to fly the slider around 4nm for better magnetic pick-up, the resonances at such flying height are so dominant in comparison with the ones with the 7nm flying height that this is best, from the dynamics point of view, for that particular product. Engineers thus can characterize a given HGA and slider configuration with a particular media product. If this is not satisfactory, engineers could measure other product combinations and evaluate them with the digital LDV. This documentation will support choosing a given HGA, slider and media combination for a given file product which in the end would minimize misregistration errors

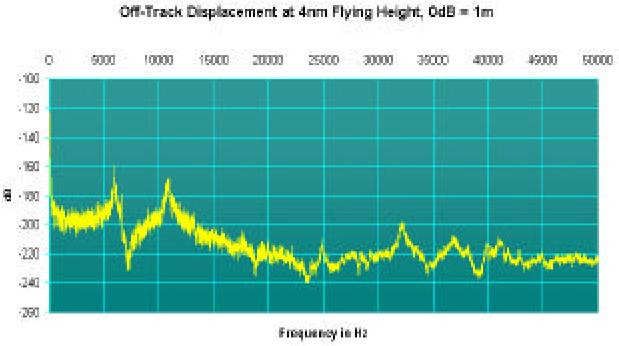


Figure 12

Head/Disk Interaction and TTI TR1000L Research and Development Ramp-load System

The mechanics of ramp-load is completely different than that of the traditional CSS; with head-disk contact being the primary concern as compared to stiction in the case of CSS. The researcher will discover very quickly that traditional CSS test tools are not adequate to fully understand the ramp-load process.

In terms of motion control, the critical parameters for ramp-load testing include: disk velocity at load and unload, actuator (head) acceleration, velocity and deceleration, and head synchronization to load/unload at specific sector on disk. Polytec offers fixtures for dual beam differential measurements by using the OFV-T-031 test stand or by using a dual beam delivery device that mounts unto the OFV-075 microscope adapter. For quality control and assurance applications where a large number of drives need be tested Tommy Trang Industries or **TTi** (San Jose, CA) implements motion control for the ramp as well. The travel of the ramp is in the same relative motion to and from the head (dynamic ramp.)

Figure 13

This method allows the use of sensors such as the Laser Doppler Vibrometer (LDV) to study the head dynamics during load/unload. Strain-gauge (SG) sensors can still be used but to measure frictional forces between head and ramp (instead of head and disk.

Acoustic emission (AE) sensors are used to detect head disk contact by analyzing the slider response at the bending mode frequencies. Since the energies involved at the slider bending modes are extremely small, sharp band-pass filters must be employed. The use of digital filtering and frequency analysis (hence full bandwidth acquisition of the sensor involved) is also recommended for critical studies.

Time Transient Measurements: Track-seek dynamics, track-stability, crash and drop testing

Time domain testing with simultaneous velocity and displacement measurements is absolutely required for a number of applications. In track-seek dynamics engineers want to know how fast they can move the HGA from a given track to another one on the platter, which determines in great measure the seeking time restrictions. Simultaneous velocity and actual displacement measurements are required to understand the velocity ramps, g-level accelerations, the total slider displacement as well as damping. Servo electronics can be tested only after the mechanics are completed and the PES can't be used for it. LDV measurements provide the information necessary for servo engineers to design the servo to compensate for "ringing" of the HGA. The same goes for high g levels that tend to dropout from the PES. There are extensive references in the literature to LDV measurements for track dynamics and crash-stop testing.

The Computer Mechanics Laboratory (UC Berkeley) & the Center for Magnetic recording (UC San Diego) have conducted numerous studies on dynamic track stability, with analog and digital LDVs. On those studies a wide variety of effects (component resonances, windage, media contributions) have been considered.

Media Testing, Thot Technologies

Thot Technologies has developed a wide variety of instrumentation to test many parameters related to media topography flutter and dynamic response. An LDV is the sensor at the heart of these machines; an automated stage scans the LDV radially over the media and acquires the out-of-plane signal of the surface passing underneath. This rough output carries, the runout, profile, flutter, waviness, scratch, surface finish and micro-waviness time signal to sophisticated electronics and software that analyze, present and displays the data in a number of formats. Since media measurements are technical subject fields by themselves, the reader can refer to http://www.thot-tech.com/techpapr/here.html for a full description of these techniques. Thot Technologies is an established supplier for all media manufacturers

Spindle Runout Measurements using the LDV and Thot Technologies Model 4238 Spindle Tester

Synchronous error motion, sometimes referred to as runout or repeatable runout, is important in the evaluation of rotational motion especially in machine tools, turbines, high speed drills and other precision applications. It is also a vital factor when examining balance of large rotating masses. Measurements can be made with high accuracy of any polished or finely finished rotating spindle,

Asynchronous error motion, sometimes referred to as non-repeatable runout, is critical to the application of extreme precision devices such as hard disk drives where the errors can be as small as 10 nm (0.5 micro-inch).

LDV systems allow the Thot Technologies' Model 4238 spindle tester to measure axial and radial surfaces of rotating bodies down to less than 2.5 nm (0.10 micro-inch).

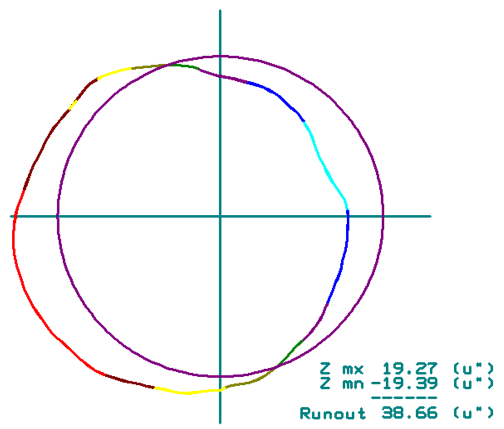


Figure 14

Non-repeatability of spindle motion in the radial direction is a key cause of track misregistration.

The spindle tester is capable of making both repeatable and non-repeatable measurements of axial and radial runout, velocity and acceleration (RVA). Measurements can be made as stand-alone spindle, shaft, ball or race. The Thot Spindle Tester has complete software analysis tools for displaying a variety of formats.

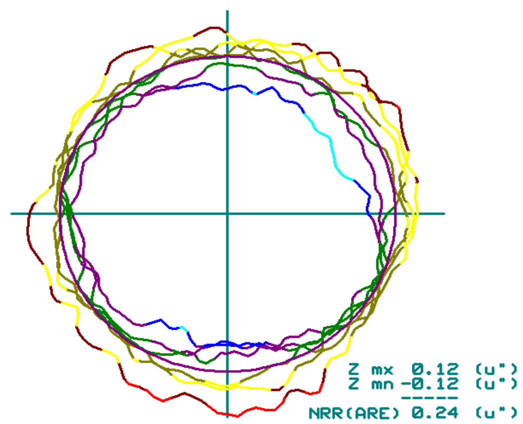
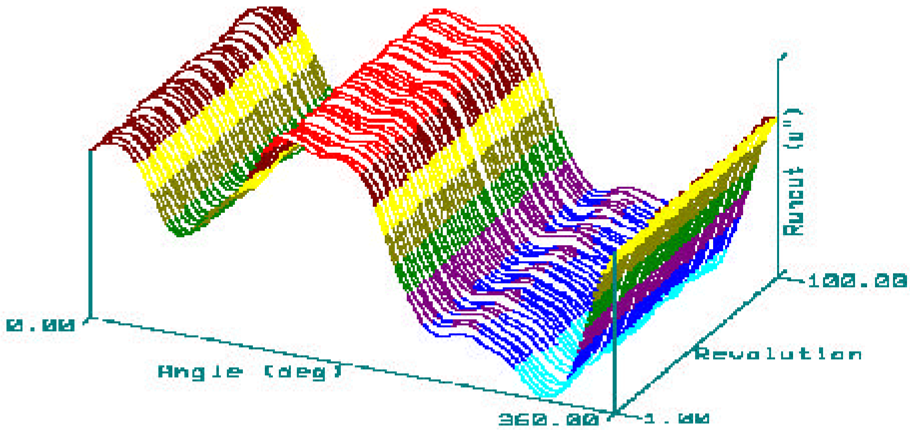


Figure 15

Figure 16 shows a 3D Wire-frame Graph of spindle runout data. Each line represents a revolution of data and 2000 data points. 100 revolutions of data were taken.



MEMS Microactuators

A proposed secondary head based microactuator is intended as a possible solution to improve track-seeking processes on smaller track densities

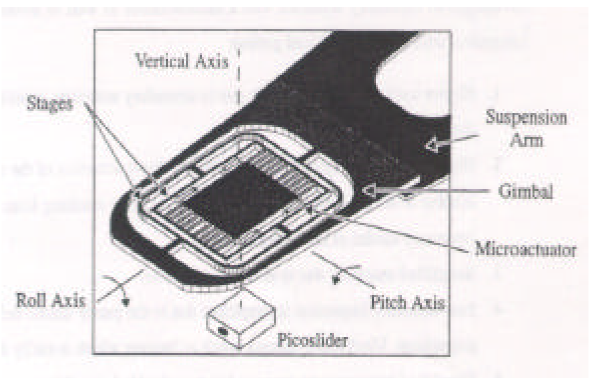


Figure 17. A schematic of a HGA with a gimballed MEMS based microactuator embedded.

. This approach increases the bandwidth of the system and allows for faster seek times. Head based microactuators can be fabricated using MEMS technology and placed on the head without modification to arm or suspension

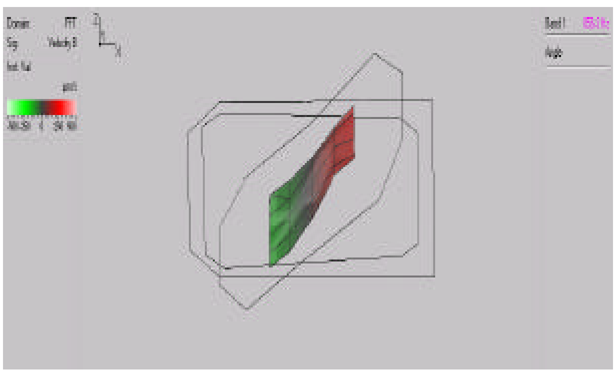


Figure 18. Pitch Mode of MEMS based microactuator at 856 Hz showing relative rotation of slider, inner, intermediate and external gimbal frame

Novel MEMS will require outstanding dynamic characterization for use in disk drive applications. LDVs are used for dynamic measurements on MEMS microactuators, even down to 1 um-level feature sizes. Coupling of the fiber optic probe into a microscope using the OFV-075 Microscope adapter allows high-resolution measurements of velocity and/ or displacement on tiny elements of MEMS actuators. Out-of-plane resonance modes of MEMS devices can also be measured using the Micro Scanning Vibrometer (MSV) system.

Tape Drive:

LDVs can be applied to studies of tape flutter, tape tension (via tape resonant frequency), helical-scanner dynamics and resonance testing of servo tape heads. Response measurements are limited to the out-of-plane direction. Alternatively, the In-plane Vibrometer can be used to measure tape drive dynamics in the plane of tape travel on measure transverse or longitudinal vibration where flutter or slippage may occur. For servo heads engineers study resonances as well as displacement measurements for servo-track position and stability. CLV systems are used for quality control and production assurance. PSV-300 systems are used to reduce product time-to-market.

Optical Drives:

The move towards narrower track-widths, increase the need for accurate characterization of mechanical resonances and require a sensor of wide bandwidth and sensitivity. LDVs are very effective at measuring the mechanical behavior of the focusing and tracking servo actuators for optical drives. Of special importance is measuring rocking modes of the focusing actuator. CLV systems are extensively used for QC for production-line components.