A Comparison of Laser and Capacitive Probe RVA Testing.

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Background

RVA is an acronym for **R**unout, **V**elocity and **A**cceleration. It is used to describe the motion of a rotating body as it deviates from an ideal plane of reference. In rigid disk and drive manufacturing, the two important reference directions are the axial (parallel to the long axis of the spindle motor and perpendicular to the plane of rotation of the disk) and the radial (perpendicular to the long axis of the motor and in the plane of rotation of the disk) directions.

The use of Doppler lasers to measure disk flatness offers significant advantages over the more conventional capacitance probe systems. These advantages are superior signal to noise ratios, smaller measurement area, improved acceleration repeatability and the ability to show short wavelength disk distortions that affect the flying and terrain following ability of smaller footprint heads. In addition there are practical considerations such as much greater stand-off distances (6" for laser compared with 0.004" for capacitive probe) and the ability to measure a wide variety of material types without correction factors, that make the use of Doppler laser attractive for accurate disk flatness measurements without the risk of accidental disk/probe contact and resulting probe damage.

Signal-to-Noise (S/N) Ratio and Dynamic Range.

As capacitive probes decrease in size the effective S/N falls rapidly since capacitance is proportional to area, as the active probe diameter decreases so the sensitivity drops as the square of the probe diameter.

The Doppler laser works on similar principles to a high quality, phase locked FM tuner. Provided the return beam (signal) exceeds the limiting threshold, the FM signal is captured and "locked" and, regardless of the carrier amplitude, an accurate measurement is assured. Doppler laser systems have a dynamic range greater than 140dB and typical S/N ratios are 54dB with respect to a 1µm (40µ") measurement using a 1.5MHz bandwidth and a 10µm beam diameter. A 1.67mm diameter capacitance probe using a 5kHz bandwidth will have a S/N ratio of 30 dB under ideal conditions. Assuming that the signal is above the noise floor, a similar diameter capacitance probe will have a sensitivity of 0.8µV/µm. The resulting measurement signal will be ≈60dB **BELOW** the noise floor.[1]

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[1] With a nominal standoff of 100µm (0.004") the capacitance probe has a capacitance of about 0.2pF. Given that the capacitance change is linear with distance, it follows that a 1µm change in runout requires a system sensitivity of 0.002pF/µm (0.00005pF/µ").

Measurement range for a Doppler laser RVA system exceeds ±300µm with 0.002µm resolution (±0.012" with 0.1µ" resolution) compared with ±50µm with (at best) 0.12µm resolution (±0.002" with 5µ" resolution) for the conventional 1.67mm capacitive probe. This gives the user a 6x improvement in measurement range and a 50x improvement in measurement resolution.

Differentiation Noise Errors and Integration Errors.

In any system that has random measurement uncertainties, such as electronic noise, the dominant source of error for numeric (and analog) differentiation comes from the input errors themselves. Accuracy diminishes with increasing order of derivatives.

Input errors are critical because, even when small, differentiation algorithms (and circuits) magnify them enormously. Since an analogous situation is present when using analog techniques for signal differentiation, both systems will suffer the same data input errors (noise) and similar differentiation error exaggerations.

The crucial factor here is the sample interval (***h***) or, in the case of an analog circuit, the bandwidth. Since truncation error (or S/N ratio for analog circuits) is proportional to sample interval (or bandwidth for analog circuits) and input error is inversely proportional to sample interval (or bandwidth), an optimum choice of sample interval can sometimes reduce these differentiation errors.

The opposite occurs for integration techniques in both cases and results in smoothing of the data thereby effectively reducing input errors (after integration).

The contention here is that a single differentiation will intensify any uncertainty (random error) of any measured signal, while a single integration of that same signal will smooth out and thus reduce any random errors. Double differentiation of this same signal will greatly exaggerate the random errors by the square of the sample interval (h^2 or bandwidth^2),compared with the single differentiation case (***h*** or bandwidth).[2]

With capacitive probe techniques, the direct measurement is one of displacement which requires two levels of differentiation to get acceleration figures. For a well designed analog differentiator, the effective input noise is doubled which results in a 6dB decrease in S/N for velocity and therefore a 12dB decrease in S/N for acceleration measurements. This coupled with, at best, a 30dB S/N ratio for displacement with respect to 1µm, will yield acceleration measurements with a S/N ratio of 18dB (>12% measurement uncertainty). Compare this with Doppler laser systems which use velocity as the direct measurement. These systems require only one differentiation step to get acceleration and one integration step for displacement. For the same measurements, the displacement S/N is ***improved*** by 6dB resulting in a 60dB S/N ratio(with respect to 1µm) and for acceleration a 48dB (or <0.4%) uncertainty in measurement.

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[2] See books on Numerical Mathematics, e.g. Schaums Outline Series "Numerical Analysis 2/ed". McGraw-Hill.

Measurement Area

According to the capacitance probe manufacturers, the appropriate probe diameter should not exceed 60% of the shortest dimension to be measured. If measurement area is considered then this value becomes 36% of the desired measurement area. In disk drives, if one considers the total area of the slider (not the ABS area) then a 1.67mm diameter probe may be appropriate for disk measurements but, if one wishes to consider the head/disk interaction, then it is only appropriate for full sized sliders and marginal for 70% sliders. If one wishes to determine the suitability of the disk surface for "local head flight" and now considers the ABS area for a nominal 0.05µm (2µ") flying head, then it is readily apparent that the capacitance probe should NEVER be used to determine the suitability of the disks surface for head flight. (see table below)

Head Size	Total Slider Area (mm^2)	Total ABS Area (mm^2)	Capacitance Probe Area (mm^2)	Laser Probe Area (mm^2)
100%	13.0	2.0	2.2	$80x10^{-6}$
70%	6.4	1.4	2.2	$80x10^{-6}$
50%	3.3	1.0	2.2	$80x10^{-6}$
30%	1.3	0.6	2.2	$80x10^{-6}$
12%	0.2	0.25	2.2	$80x10^{-6}$

Practical considerations

1). Standoff Distance

Capacitive probe techniques require close proximity to the measurement surface in order to be able to make an RVA measurement. Typical stand-off distances are ≈100µm (0.004") which can cause the probe to come into contact with the disk if the disk is not properly clamped or has poor runout. By comparison the standoff distance for a Doppler laser system is ≈150mm (6") which completely eliminates the possibility of disk/probe interference.

2). Spindle Grounding Requirements

Capacitance probes require electrical continuity to make measurements. Air bearings and some heavily lubricated ball races do not have electrical continuity unless some form of conductive brush or Mercotac grounding device is used. These devices do not provide low impedance ground at high spindle speeds. By comparison, the Doppler laser requires no grounding to make a measurement. The Doppler laser only requires a "pseudo-specular" surface to reflect between 2-5% of the incident light back along the light path to be able to make accurate measurements. This is readily provided by a lightly buffed, matte surface finish even on black carbon materials.

3). Measurement of dielectrics such as glass, canasite and polycarbonate.

The Doppler laser system directly measures the surface and requires no material dielectric correction factors or ground plane to measure flatness. This ensures that different material types are readily measurable with no calibration or operator intervention. Therefore, in a production environment, disk types can be interchanged, batched or even sequenced at random without the need stop runs for setup or re-calibration.

In order to make RVA measurements on non-conductive materials such as carbon, glass and canasite, the capacitance probe requires the use of capacitive guard bands and dielectric correction factors. The method described below for thickness measurements on dielectrics is similar to the method used to make capacitance probe measurements on alternate substrates.

> *...A typical approach is to rigidly fixture a guarded probe over a grounded metallic backplane, which establishes a classic parallel electric field in the gap. When a uniform dielectric material is inserted into the gap, the capacitance changes according to material thickness and dielectric constant. After scaling for the dielectric constant of the material, this capacitance change can be converted into a thickness signal...*[3]

By comparison the Doppler laser system directly measures the surface and requires no such correction factors, additional hardware or ground plane.

4). Measurement uncertainty for acceleration readings

The accurate determination of acceleration depends primarily on the measurement area and system bandwidth. If the bandwidth is too low, then a high acceleration event will be severely attenuated by the bandpass electronics. Similarly, if the measurement area is large, then a small area acceleration event will not be detected by the probe. In the "Measurement Area" section, we discussed how the standard capacitive probe is large compared with smaller footprint heads and is therefore, not an appropriate technique for evaluating the disk surface "flyability" with respect to acceleration spikes. Because of the difference in measurement area, laser techniques will naturally yield higher values of acceleration than capacitive probes simply because they can resolve the fine surface details, and can detect and measure these high acceleration events that are artificially "smeared" by the large area capacitive probes.

For example, assume that we have a 1.67mm diameter, 2µ" (0.05µm) high asperity at a 25mm radius on a disk spinning at 3600RPM, that rises linearly to its full

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[3] "Using Capacitive Sensing for Noncontact Dimensional Gauging" ADE Corporation. **Sensors**, October 1988. Helmers Publishing, Inc. 174 Concord St., Peterborough, NH. 03458

height in 15% of its diameter. The asperity rises from zero to 2µ" in 27µsec which is equivalent to an acceleration of 137m/s^2. In order to accurately reflect this rise time, the electronics needs a bandwidth of 37kHz, which is ≈4x higher than current capacitive probe capabilities. Since capacitive probes used in disk measurements have a 10kHz maximum bandwidth and ≈5µ" height resolution they are clearly inadequate to deal with this condition both in height resolution and in bandwidth.

Typical acceleration events (defects) on disk are ≈25µm diameter and, under the same conditions as above, the asperity will rise to 2µ" in 0.4µsec, an acceleration of 630m/s^2 that requires a bandwidth of 2.5MHz to image accurately. These requirements are within the capabilities of Doppler laser technology but are totally outside the capabilities of capacitive probe technology.

As discussed earlier, with capacitive probe techniques, the direct measurement is one of displacement which requires two levels of differentiation to derive acceleration and results in a 12dB decrease in S/N for acceleration measurements. Doppler laser systems use velocity as the direct measurement and require only one differentiation step to get acceleration and one integration step for displacement, resulting in an effective "no-cost" 6dB head start for all measurements with respect to capacitive probes.

Couple this with 18dB better S/N ratios, (≈40dB for lasers compared with ≈22dB for capacitive probes ref. 10µm) and superior bandwidth, it is easy to see that, without special precautions such as capacitive guard rings and EMI shielding of the measurement system, the laser will give acceleration data that has >24dB (16x) better repeatability (<2% compared with >30% ref. 10µm displacement) and be capable of discriminating high acceleration asperities that affect head flyability.

5). Capacitance probe emulation

Because of the established base of older generation capacitive equipment and the associated RVA database, it is necessary to put in place the ability to correlate laser to capacitance probe measurements. This is accomplished at THôT Technologies by allowing the user total control to select the data collection sample interval, "software average" the region over which the measurement is made in order to correspond to the larger capacitive transducer, and then, further smooth the data to simulate the limited bandwidth used in the capacitive probe electronics. In this fashion excellent correlation can readily be established for runout. The correlation is acceptable for velocity measurements but suffers in the acceleration correlation due to the S/N limitations of the capacitance probe and the ≈2000x improvement in spatial resolution of the laser system.

Nonetheless, provided care is taken over the setup of the capacitive probe system and the corresponding "capacitance probe emulation" software parameters, satisfactory correlation can be, and has been, established between the two systems.

Conclusions

Doppler laser technology offers superior signal to noise ratios, faster response times and smaller measurement areas that are necessary for examining RVA characteristics of disks used in the current sub-2µ" flying capacity and can readily be extended to the sub-0.5µ" arena thereby ensuring the viability of future generations of disk drives.

The use of direct velocity measurements and a single differentiation step results in an immediate 6dB (2x) improvement in acceleration repeatability, with absolutely no penalty incurred, due simply to the decreased random noise from the single differentiation step for the laser as opposed to a double differentiation needed for capacitive probes. The situation is further improved by the superior (>18dB, or >8x) S/N ratio of the laser over the capacitive probe.

Smaller measurement areas ensure that disks can be characterized for suitability for low flying using the new generation of 30%, 12% and 7% sliders. Measurement areas can be easily reduced by at least 4x for the 4% and 2% sliders under investigation in laboratories for the 1GByte/in^2 programs.

For those users who are constrained to correlate with existing capacitive probe technologies, the Doppler laser systems come with an emulation mode that, with appropriate choice of emulation parameters, can be made to correlate with the older generation equipment.