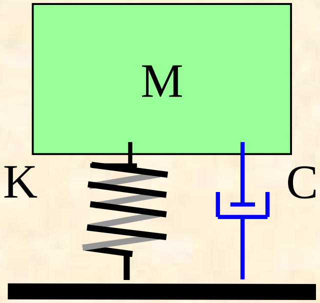
S&V measurements

Notes 4: Sensors for vibration measurements

Luis San Andres
Mast-Childs Chair Professor
Texas A&M University



Lsanandres@tamu.edu

http://rotorlab.tamu.edu/me459/default.htm

S&V modern systems

included with permission

See notes on

Digital Image Correlation (provided by Trilion)

&

Optical Vibrometry (provided by Polytec)

Other

National Instruments –
Resources (web cats on instrumentation)

http://us.ni.com/webcasts/sensor-measurement-fundamentals?espuid=CNATL000003505620

APPLICATIONS OF VIBRATION TRANSDUCERS

1) Measurements on Structures or Machinery Casings: Accelerometers and Velocity Sensors

Used in gas turbines, axial compressors, small and mid-size pumps.

These sensors detect high frequency vibration signals related to bearing supports, casing and foundation resonances, vibration in turbine/compressor vanes, defective roller or ball bearings, noise in gears, etc.

2) Displacement measurements relative to rotating shafts: Proximity Probes (capacitance or eddy-current)

Used in turbomachinery supported on fluid film bearings, centrifugal compressors, gears and transmissions, electric motors, large pumps (>300HP), some turbines and fans.

These sensors detect shaft static displacements, unbalance response, misalignment, shaft bending, excessive loads in bearings, dynamic instabilities, etc.

ACCELEROMETERS

Advantages	Disadvantages
Simple to install	Sensitive to high frequency noise
Good response at high frequencies	Require external power
Stand high Temperature	Require electronic integration for velocity and displacement
Small size	

VELOCITY SENSORS

Advantages	Disadvantages
Simple to install	Low resonant frequency & phase shift
Good response in middle range frequencies	Cross noise
Stand high temperature	Big and heavy
Do not require external power	Require electronic integration for displacement
Lowest cost	

PROXIMITY SENSORS

Advantages	*Disadvantages*
Measure static and dynamic displacements	Electrical and mechanical noise
Exact response at low frequencies	Bounded by high frequencies
No wear	Not calibrated for unknown metal materials
Small and low cost	Require external power
	Difficult to install

Novel types: **OPTICAL FIBERS and LASER BEAMS**.

Digital Image Correlation and Optical (Laser) Vibrometers

plenty of commercial products including sensors, signal processing and analysis

From ***Reference:*** Harry N. Norton, Handbook of transducers, Prentice Hall, Chap:5,6,7

VELOCITY SENSORS

Electromagnetic linear velocity transducers: Typically used to measure oscillatory velocity. A permanent magnet moving back and forth within a coil winding induces an *emf* in the winding. This *emf* is proportional to the velocity of oscillation of the magnet. This permanent magnet may be attached to the vibrating object to measure its velocity.

Electromagnetic tachometer generators: Used to measure the angular velocity of vibrating objects. They provide an output voltage/frequency that is proportional to the angular velocity. *DC tachometers* use a permanent magnet or magneto, while the *AC tachometers* operate as a variable coupling transformer, with the coupling coefficient proportional to the rotary speed.

ACCELERATION SENSORS

Capacitive accelerometers: Used generally in those that have diaphragm supported seismic mass as a moving electrode and one/two fixed electrodes. The signal generated due to change in capacitance is post-processed using LC circuits etc., to output a measurable entity.

Piezoelectric accelerometers: Acceleration acting on a seismic mass exerts a force on the piezoelectric crystals, which then produce a proportional electric charge. The piezoelectric crystals are usually preloaded so that either an increase or decrease in acceleration causes a change in the charge produced by them. But they are not reliable at very low frequencies.

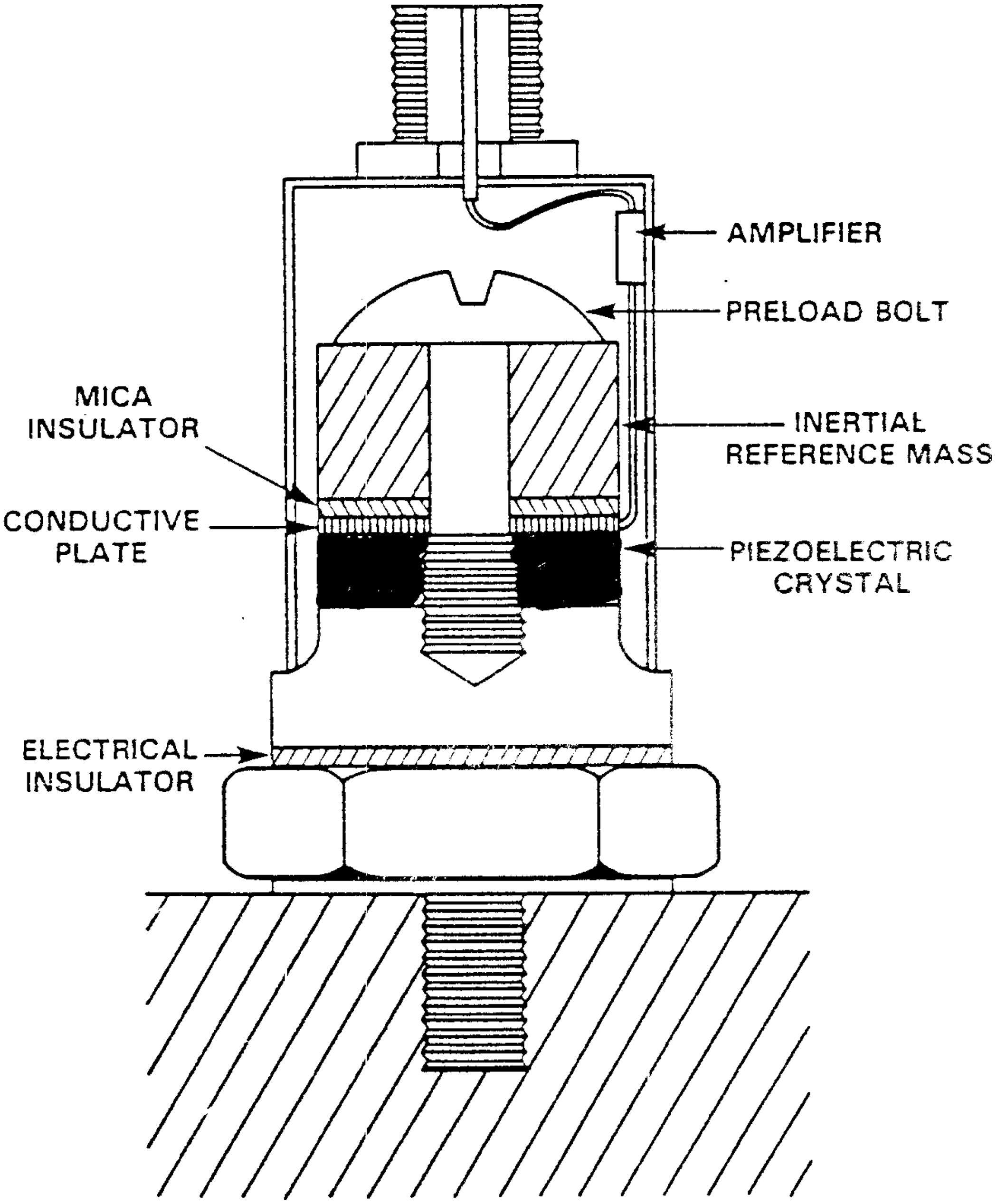
Potentiometric accelerometers: Relatively cheap and used where slowly varying acceleration is to be measured with a fair amount of accuracy. In these, the displacement of a spring mass system is mechanically linked to a viper arm, which moves along a potentiometric resistive element. Various designs may have either viscous, magnetic or gas damping.

Reluctive accelerometers: They compose accelerometers of the differential transformer type or the inductance bridge type. The AC outputs of these vary in phase as well as amplitude. They are converted into DC by means of a phase-sensitive demodulator.

Servo accelerometers: These use the closed loop servo systems of force-balance, torque-balance or null-balance to provide close accuracy. Acceleration causes a seismic mass to move. The motion is detected by one of the motion-detection devices, which generate a signal that acts as an error signal in the servo-loop. The demodulated and amplified signal is then passed through a passive damping network and then applied to the torquing coil located at the axis of rotation of the mass. The torque is proportional to the coil current, which is in turn proportional to the acceleration.

Strain Gage accelerators: these can be made very small in size and mass. The displacement of the spring-mass system is converted into a change in resistance, due to strain, in four arms of a Wheatstone bridge. The signal is then post-processed to read the acceleration.

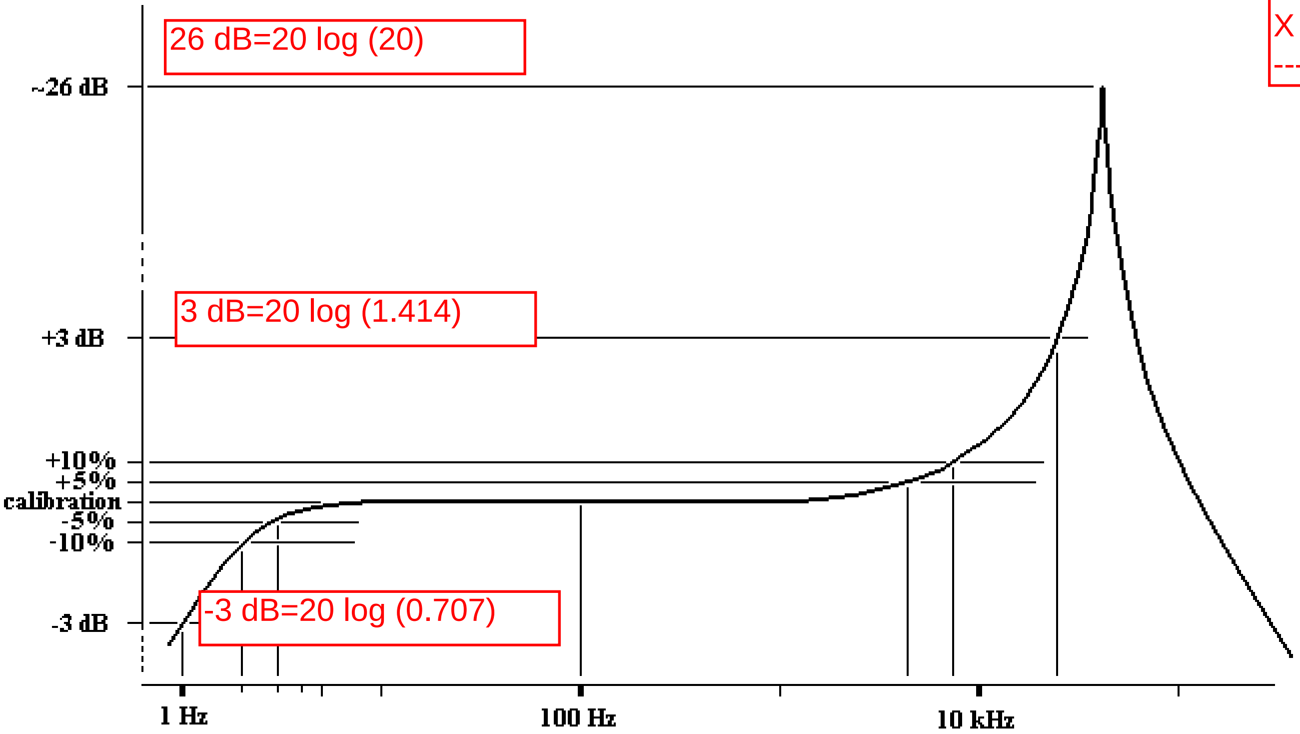
Accelerometer



Accelerometer frequency response example (786A)

± 5% ....3 - 5,000 Hz
±10% ....1 - 9,000 Hz
± 3 dB ....0.5 - 14,000 Hz

X dB= 20 log (amplitude ratio)
X dB = 10 log (power ratio)
----- log base 10

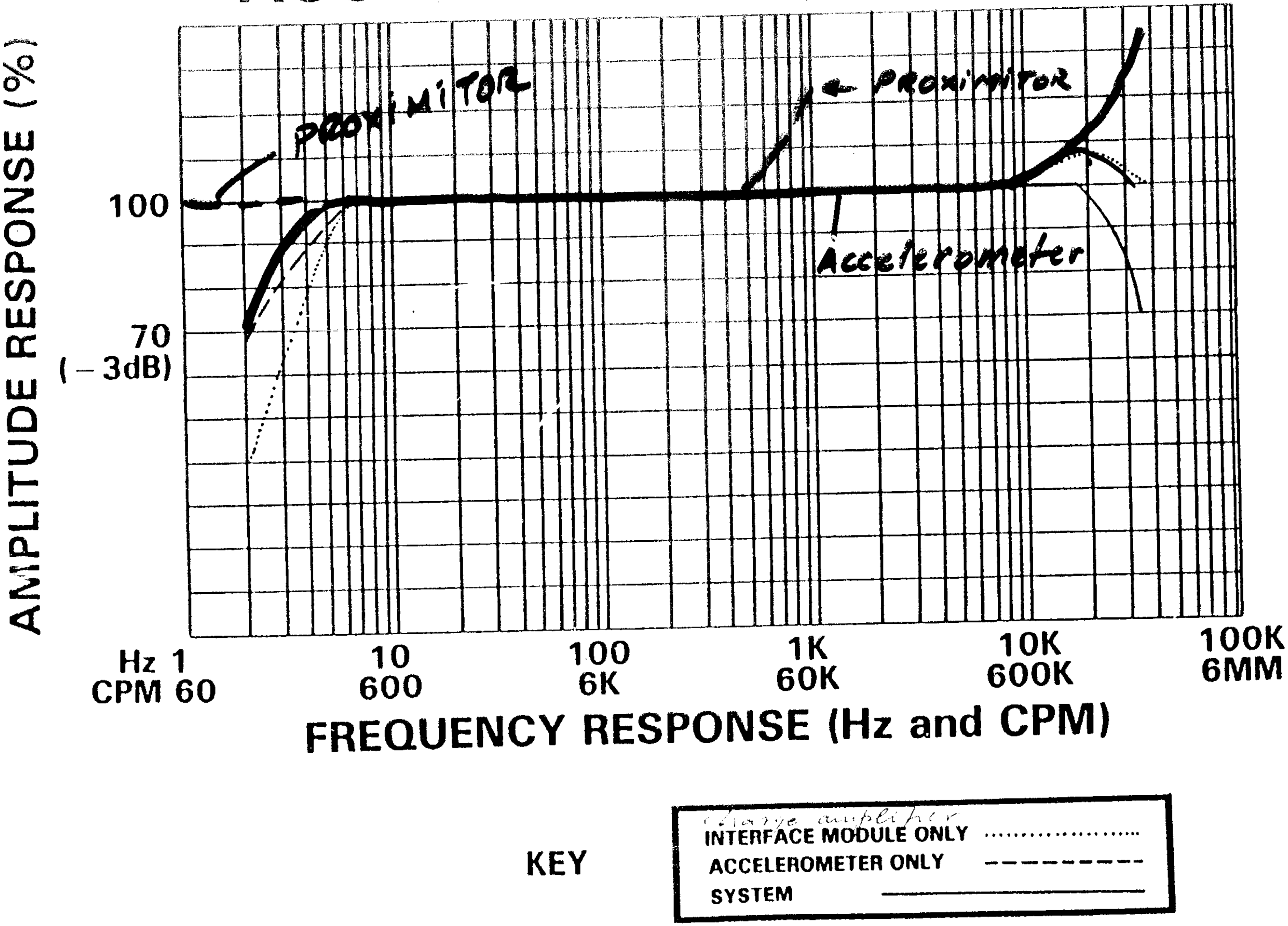


26 dB=20 log (20)

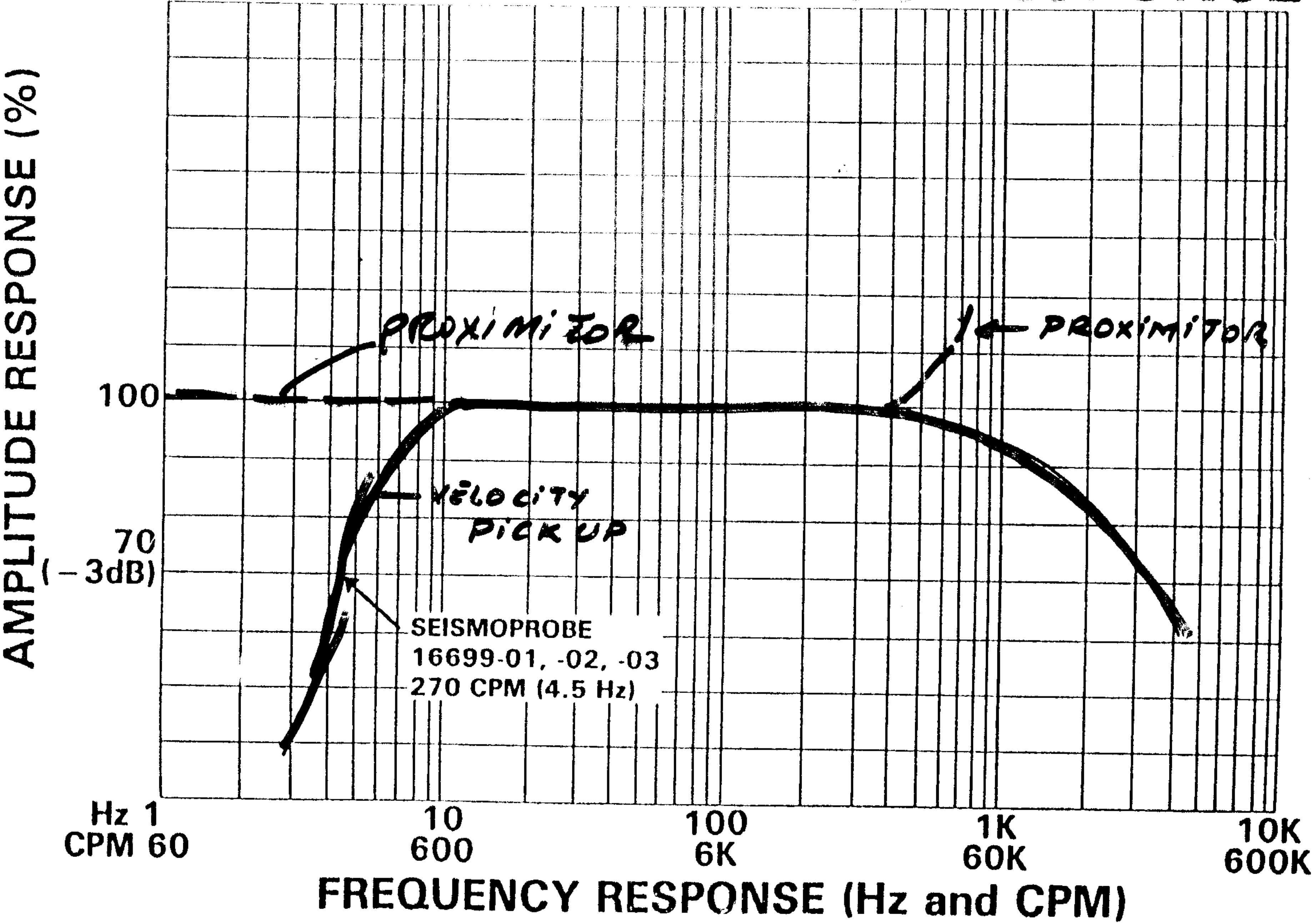
3 dB=20 log (1.414)

-3 dB=20 log (0.707)

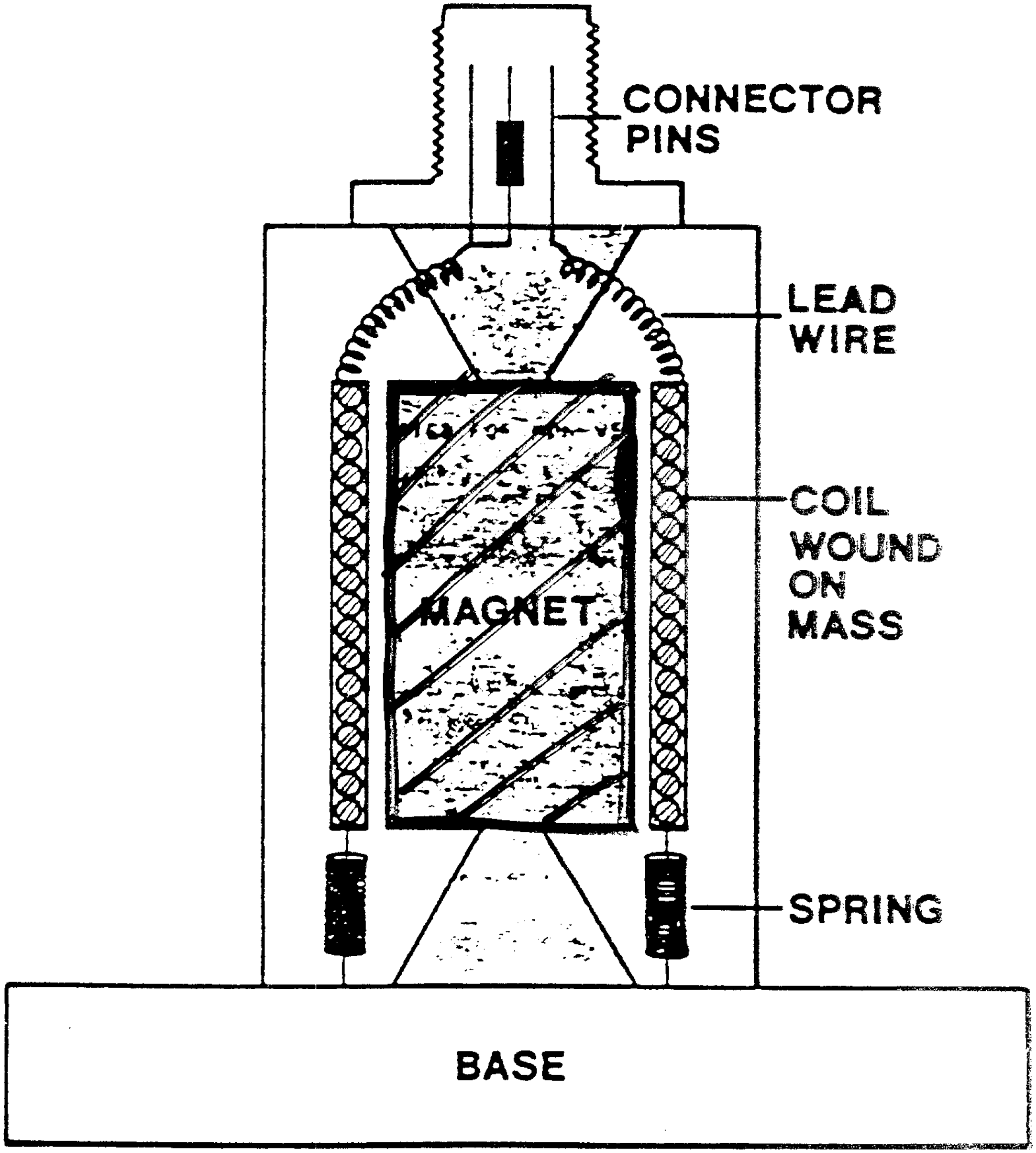
ACCELEROMETER RESPONSE



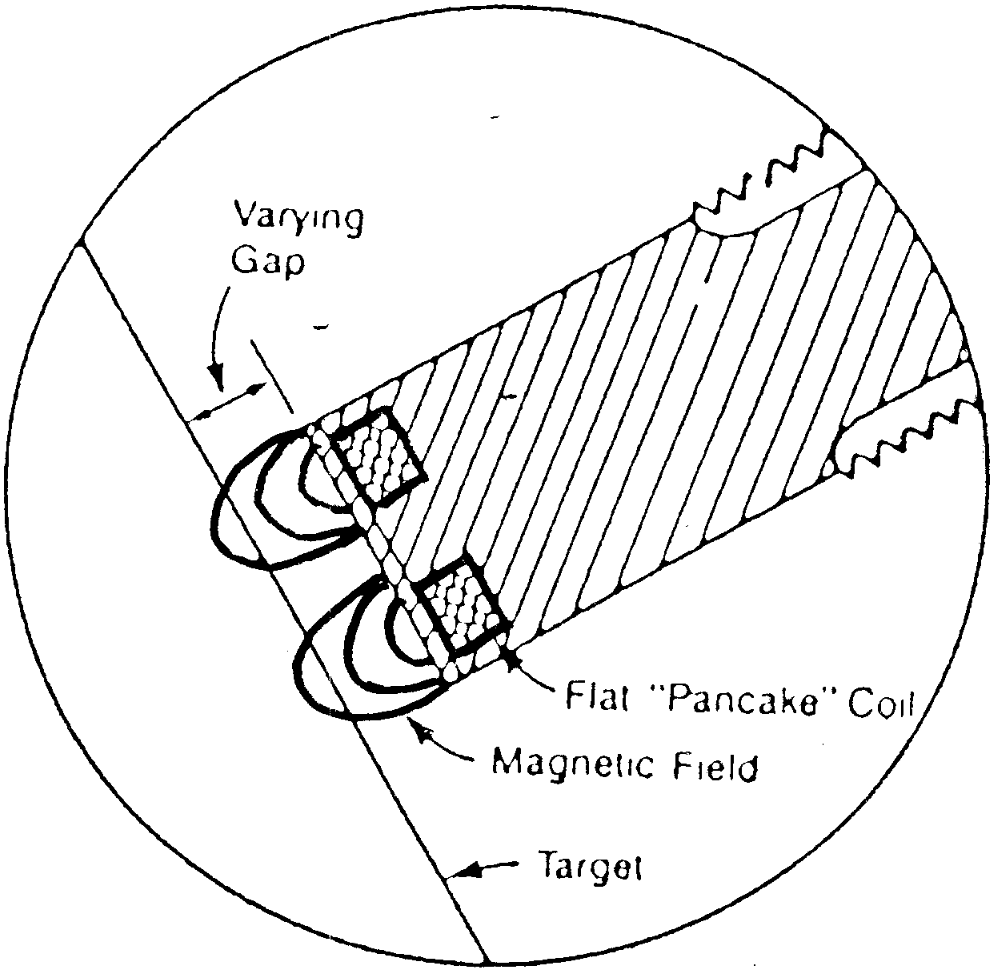
VELOCITY SEISMOPROBE RESPONSE



Velocity Pick Up.



Eddy current sensor for measurement of rotor vibrations



Eddy Probe Tip

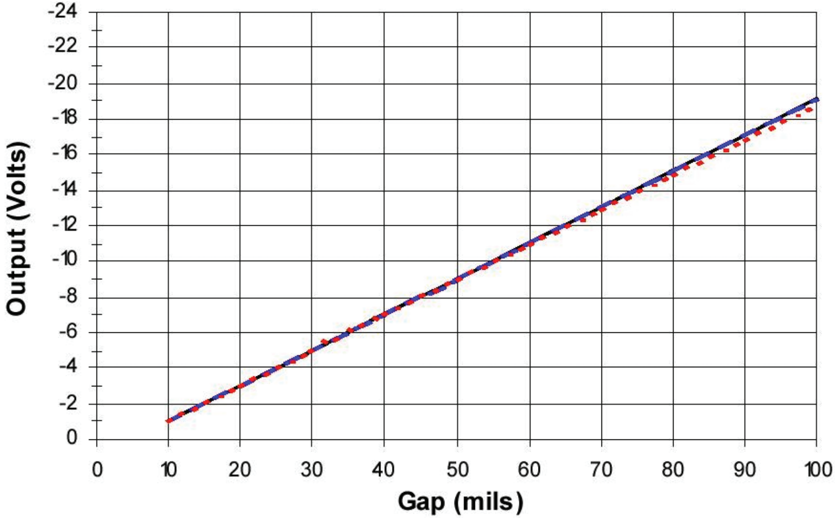
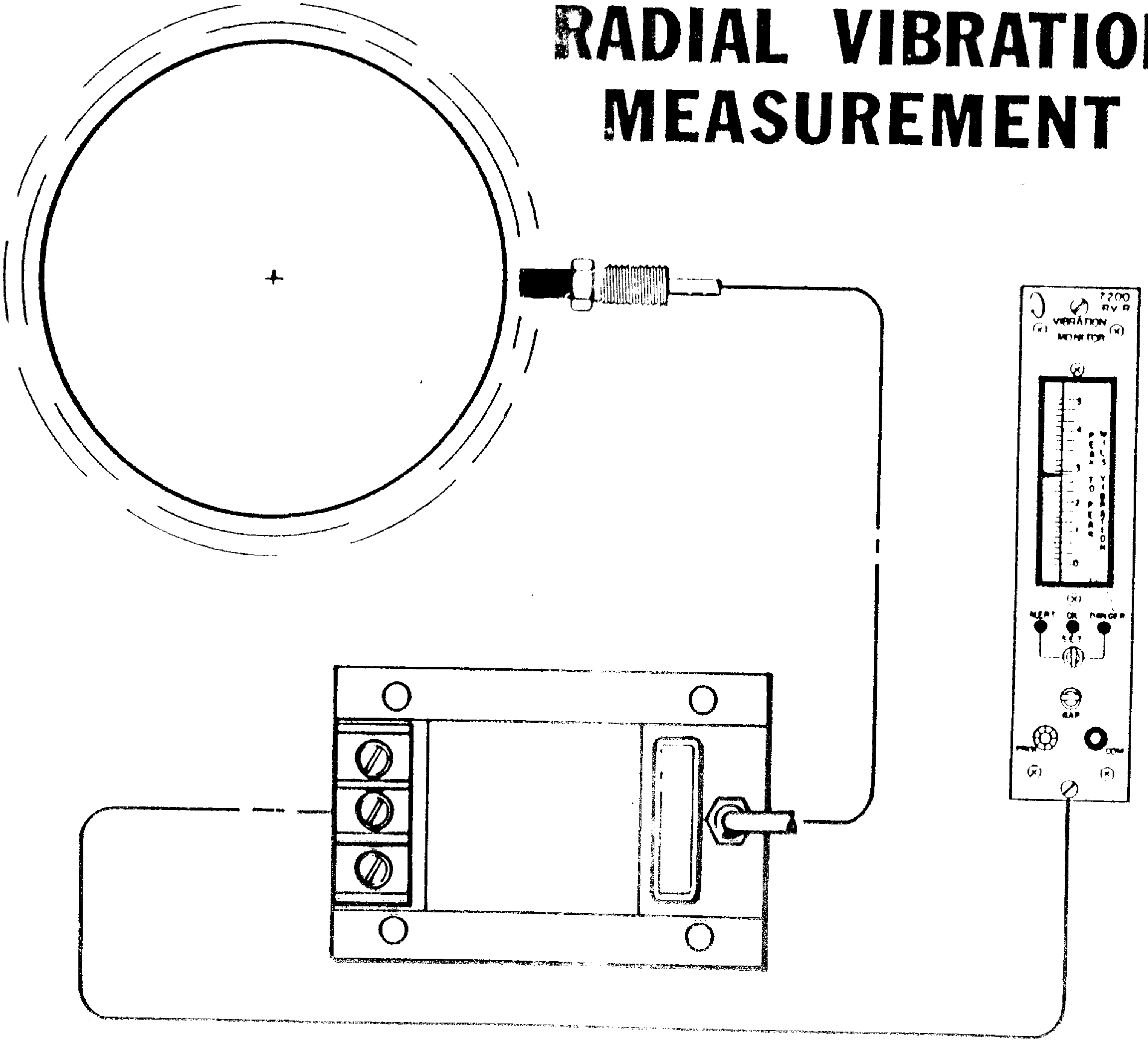


Figure 6. Actual probe voltage versus gap response (red) overlaid on expected output (blue) showing that the probe response is highly linear.

RADIAL VIBRATION MEASUREMENT



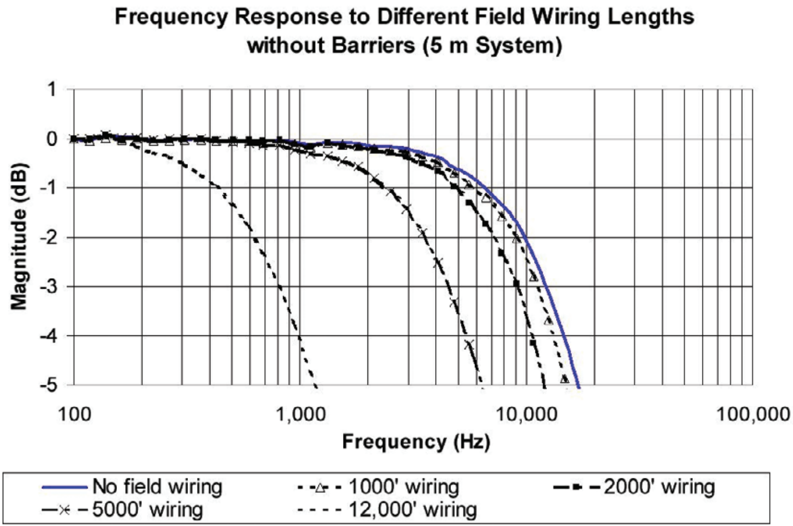


Figure 7. Added capacitance of long field wiring lengths will affect the frequency response of the probe system, behaving essentially as a low-pass filter. This effect must be carefully considered, particularly when the probe system will be required to detect very high frequencies, such as observing a toothed wheel or detecting vibration harmonics on a high-speed machine such as a turbo-expander.

A FEW SENSOR TYPES USED FOR COMMON VIBRATION MEASUREMENTS

Disclaimer: The material in this document was copied ad-verbatim from the sources noted. Its accuracy can not be warranted.

1) Accelerometers (piezoelectric)
2) Velocity Sensor
3) Proximity Probes (capacitance or eddy current)
4) Laser displacement sensors

1) ACCELEROMETERS

REFERENCE: WWW.OMEGA.COM

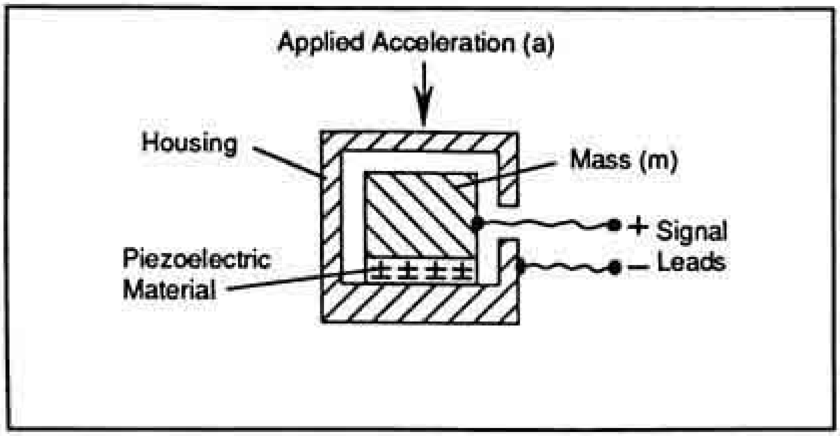
An accelerometer is a device that measures the vibration, or acceleration of motion of a structure. The force caused by vibration or a change in motion (acceleration) causes the mass to "squeeze" the piezoelectric material which produces an electrical charge that is proportional to the force exerted upon it. Since the charge is proportional to the force, and the mass is a constant, then the charge is also proportional to the acceleration.

There are two types of piezoelectric accelerometers (vibration sensors). The first type is a "high impedance" charge output accelerometer. In this type of accelerometer the piezoelectric crystal produces an electrical charge which is connected directly to the measurement instruments. This type of accelerometer is also used in high temperature applications (>120C) where low impedance models cannot be used.

The second type of accelerometer is a low impedance output accelerometer. A low impedance accelerometer has a charge accelerometer as its front end but has a tiny built-in micro-circuit and FET transistor that converts that charge into a low impedance voltage that can easily interface with standard instrumentation.

Piezoelectric Accelerometers Reference : www.pcb.com

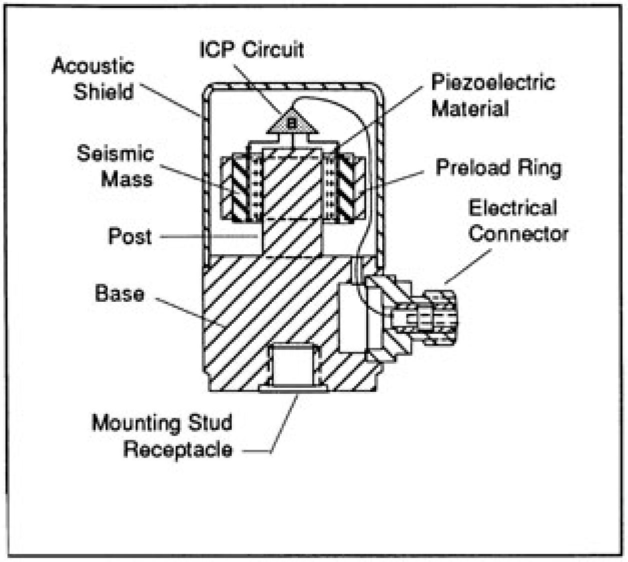
Piezoelectric accelerometers rely on the piezoelectric effect of quartz or ceramic crystals to generate an electrical output that is proportional to applied acceleration. The piezoelectric effect produces an opposed accumulation of charged particles on the crystal. This charge is proportional to applied force or stress. A force applied to a quartz crystal lattice structure alters alignment of positive and negative ions, which results in an accumulation of these charged ions on opposed surfaces. These charged ions accumulate on an electrode that is ultimately conditioned by transistor microelectronics.



In an accelerometer, the stress on the crystals occurs as a result of the seismic mass imposing a force on the crystal. Over its specified frequency range, this structure approximately obeys Newton's law of motion, F=ma. Therefore, the total amount of accumulated charge is proportional to the applied force, and the applied force is proportional to acceleration. Electrodes collect and wires transmit the charge to a signal conditioner that may be remote or built into the accelerometer.

Shear Mode Accelerometer

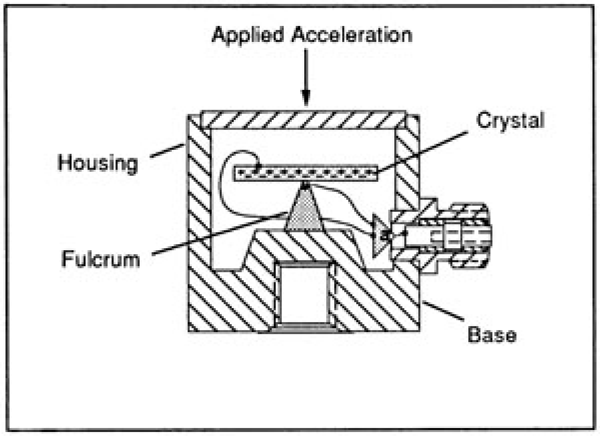
Shear mode designs bond, or "sandwich," the sensing crystals between a center post and seismic mass. A compression ring or stud applies a preload force required to create a rigid linear structure. Under acceleration, the mass causes a shear stress to be applied to the sensing crystals. By isolating the sensing crystals from the base and housing, shear accelerometers excel in rejecting thermal transient and base bending effects. Also, the shear geometry lends itself to small size, which minimizes mass loading effects on the test structure.



Shear Mode Accelerometer

Flexural Mode Accelerometer

Flexural mode designs utilize beam-shaped sensing crystals, which are supported to create strain on the crystal when accelerated. The crystal may be bonded to a carrier beam that increases the amount of strain when accelerated. This design offers a low profile, light weight, excellent thermal stability, and an economical price. Insensitivity to transverse motion is also an inherent feature of this design. Generally, flexural beam designs are well suited for low-frequency, low-g-level applications like those which may be encountered during structural testing.

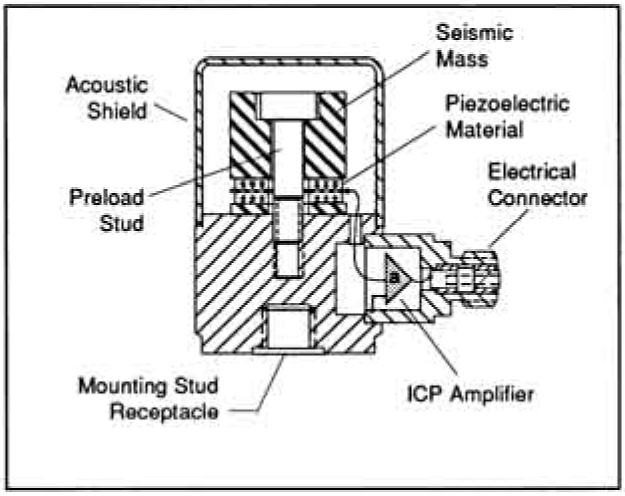


Flexural Mode Accelerometer

Compression Mode Accelerometer

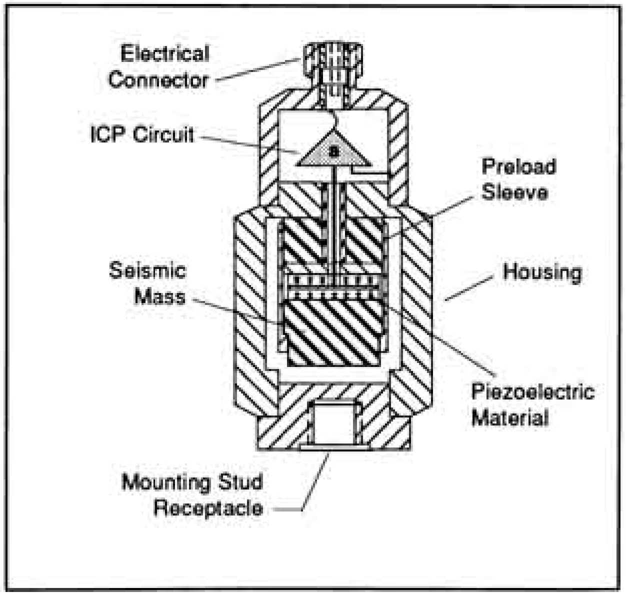
Compression mode accelerometers offer simple structure, high rigidity, and historical availability. There are basically three types of compression designs: upright, inverted, and isolated.

Upright compression designs sandwich the piezoelectric crystal between a seismic mass and rigid mounting base. An elastic stud or screw secures the sensing element to the mounting base. When the sensor is accelerated, the seismic mass increases or decreases the amount of force acting upon the crystal, and a proportional electrical output results. The larger the seismic mass is, the greater the stress and, hence, the output are.



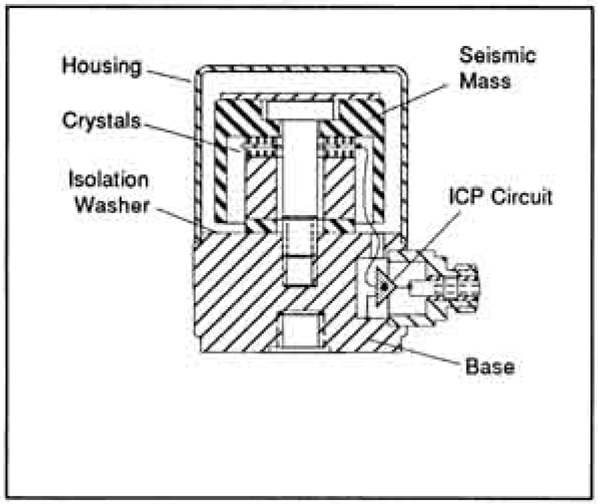
Upright Compression Accelerometer

Inverted compression designs isolate the sensing crystals from the mounting base, reducing base bending effects and minimizing the effects of a thermally unstable test structure. Many reference standard calibration accelerometers use this design.



Inverted Compression Accelerometer

Isolated compression designs reduce erroneous outputs due to base strain and thermal transients. These benefits are achieved by mechanically isolating the sensing crystals from the mounting base and utilizing a hollowed-out seismic mass that acts as a thermal insulation barrier. These mechanical enhancements allow stable performance at low frequencies, where thermal transient effects can create signal "drift" with other compression designs.



Isolated Compression

Piezoelectric Material

There are two types of piezoelectric material that are used in PCB accelerometers: quartz and polycrystalline ceramics. Quartz is a natural crystal, while ceramics are man-made. Each material offers certain benefits, and material choice depends on the particular performance features desired of the accelerometer.

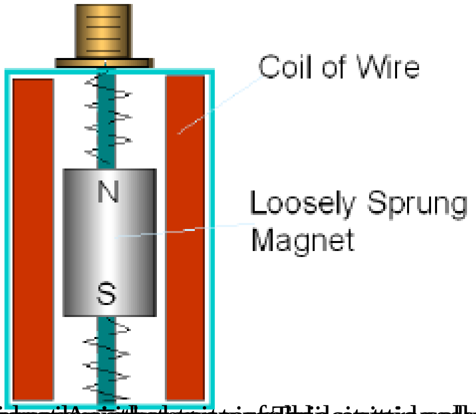
Quartz is widely known for its ability to perform accurate measurement tasks and contributes heavily in everyday applications for time and frequency measurements.

2) VELOCITY SENSORS

Theory of Operation REFERENCE : www.reliabilitydirect.com

When a coil of wire is moved through a magnetic field, a voltage is induced across the end wires of the coil. The induced voltage is caused by the transferring of energy from the flux field of the magnet to the wire coil. As the coil is forced through the magnetic field by vibratory motion, a voltage signal representing the vibration is produced.

The Velocity Probe **Reference:www.dliengineering.com**



[illegible] is by all

The velocity probe was one of the first vibration transducers to be built. It consists of a coil of wire and a magnet so arranged that if the housing is moved, the magnet tends to remain stationary due to its inertia. The relative motion between the magnetic field and the coil induces a current that is proportional to the velocity of motion. The unit thus produces a signal directly proportional to vibration velocity. It is self-generating and needs no conditioning electronics in order to operate, and it has a relatively low electrical output impedance making it fairly insensitive to noise induction.

3) CAPACITIVE and EDDY CURRENT SENSORS

REFERENCE: www.lionprecision.com

Capacitive sensors use the electrical property of "capacitance" to make measurements. Capacitance is a property that exists between any two conductive surfaces within some reasonable proximity. Changes in the distance between the surfaces change the capacitance. It is this change of capacitance that capacitive sensors use to indicate changes in position of a target. High-performance displacement sensors use small sensing surfaces and as result are positioned close to the targets .

CAPACITIVE SENSOR Reference: www.news.thomasnet.com

REFERENCE : www.thomasnet.com

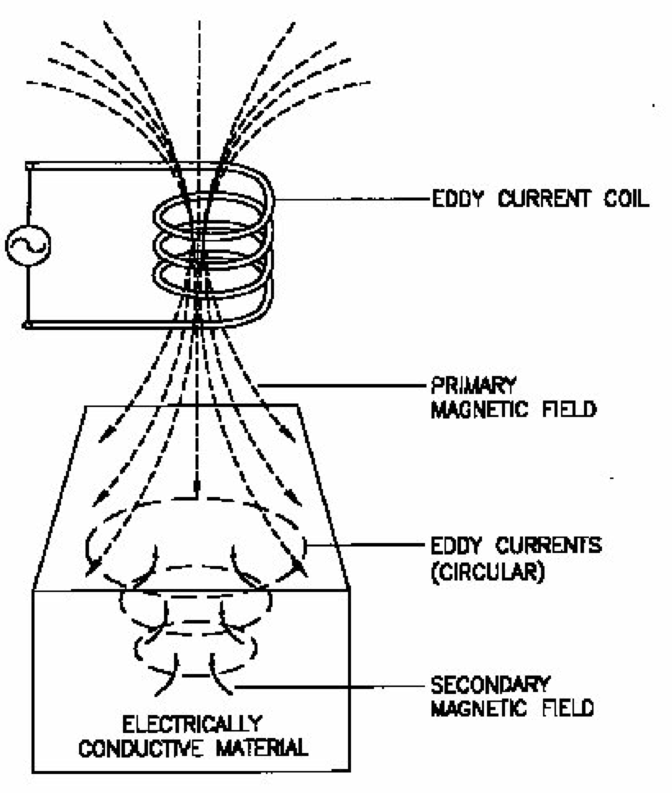
d

EDDY CURRENT SENSOR PROBE

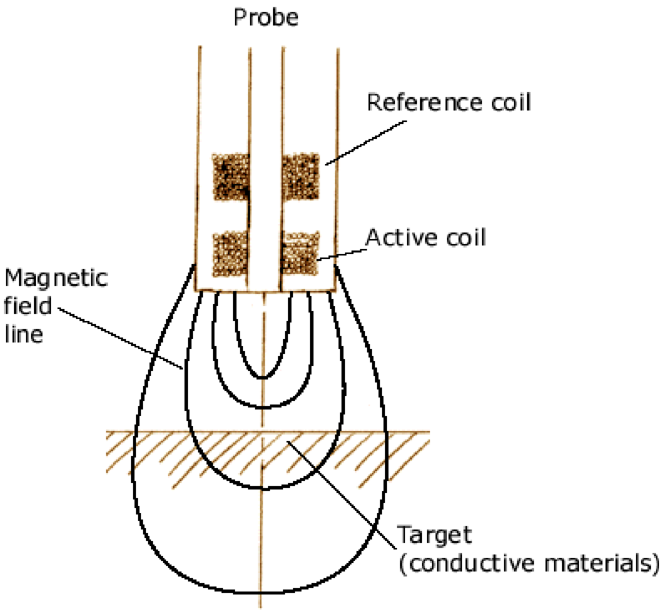
The working principle of the eddy current sensor is described below.

Eddy currents are formed when a moving (or changing) magnetic field intersects a conductor, or vice-versa. The relative motion causes a circulating flow of electrons, or currents, within the conductor. These circulating eddies of current create electromagnets with magnetic fields that oppose the effect of the applied magnetic field. The stronger the applied magnetic field, or greater the electrical conductivityy of the conductor, or greater the relative velocity of motion, the greater the currents developed and the greater the opposing field (Reference : www.wikipedia.org).

Eddy current probes sense this formation of secondary fields to find out the distance between the probe and the target material.

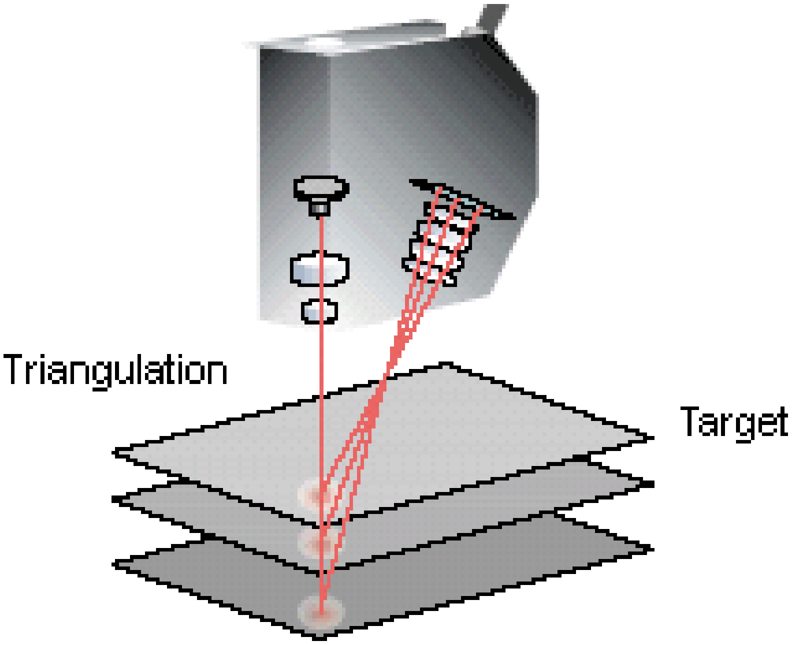


REFERENCE: www.geocities.com/raobpc/



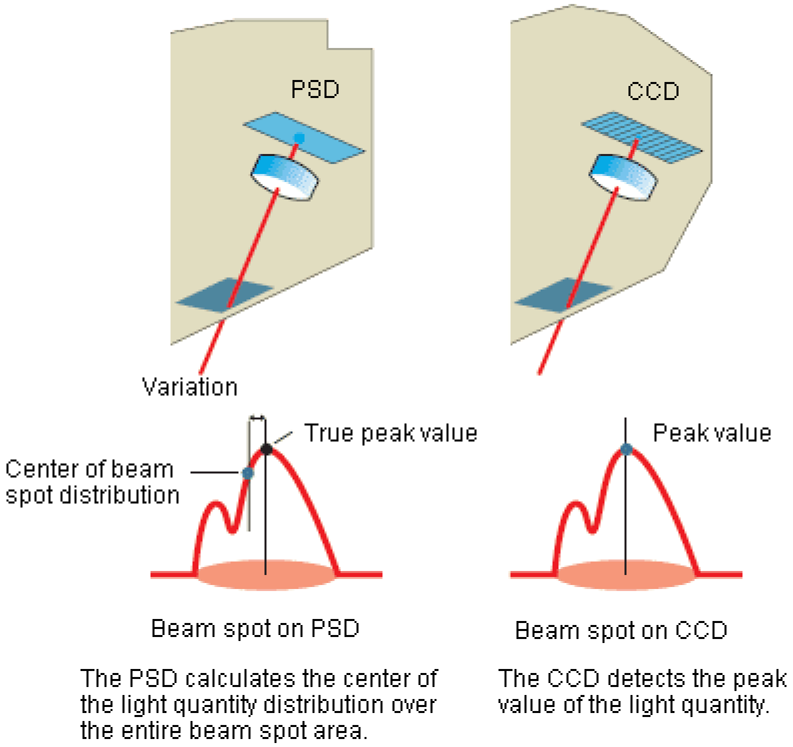
REFERENCE :www.efunda.com

4) LASER DISPLACEMENT SENSOR **Reference : www.keyence.com**



The Charge coupled device (CCD) laser displacement sensor uses a triangulation measurement system. Conventional laser displacement sensors employ a Position sensitive detector (PSD) as the light-receiving element.. The light reflected by a target passes through the receiver lens and is focused on the PSD or CCD. The PSD uses the light quantity distribution of the entire beam spot entering the light receiving element to determine the beam spot center and identifies this as the target position. However, the distribution of light quantity is affected by the surface condition of the target, causing variations in measured values. The CCD detects the peak value of the light quantity distribution of the beam spot for each pixel and identifies this as the target position. Therefore, the CCD enables stable highly accurate displacement measurement, regardless of the light quantity distribution of the beam spot.

These sensors can be used in high temperature environments.

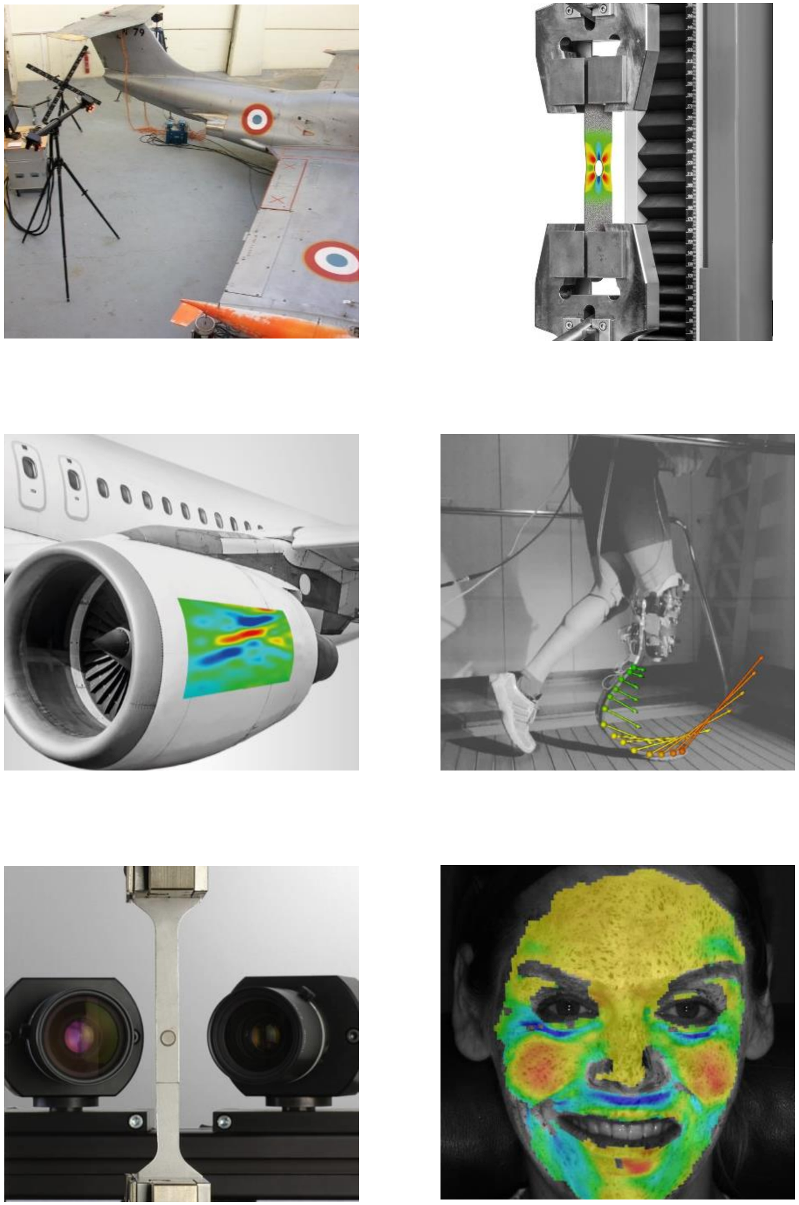


Light quantity distribution of beam spot on light-receiving element

Digital image correlation

Introduction and theory

Courtesy of
Trilion Quality Systems



WHAT

IS THIS COURSE?

OBJECTIVES

A GENERAL BACKGROUD

1. Know what is digital image correlation
2. Visualize the measuring volume and the epipolar line
3. Know the difference between facet size and point distance
4. Understand what is the intersection deviation
5. Be able to name a few application examples

B USE

1. Know how to prepare a specimen for DIC
2. Be able to do a measurement and acquire analog signals
3. Know how to evaluate the noise in a measurement
4. Feel capable of searching in the available learning ressources

C POST-PROCESSING

1. Know how to obtain a visual representation of displacements and strains
2. Understand the workflow to analyze data
3. Be able to export data as video, PDF or CSV
4. Feel that using GOM CORRELATE is simple

SHOULD WE USE ARAMIS?

What equipment or instrument would you need to do all the following static and dynamic measurements?

- Position
- Dynamic displacement
- Dynamic deformation
- Speed / velocity
- Acceleration
- Strain

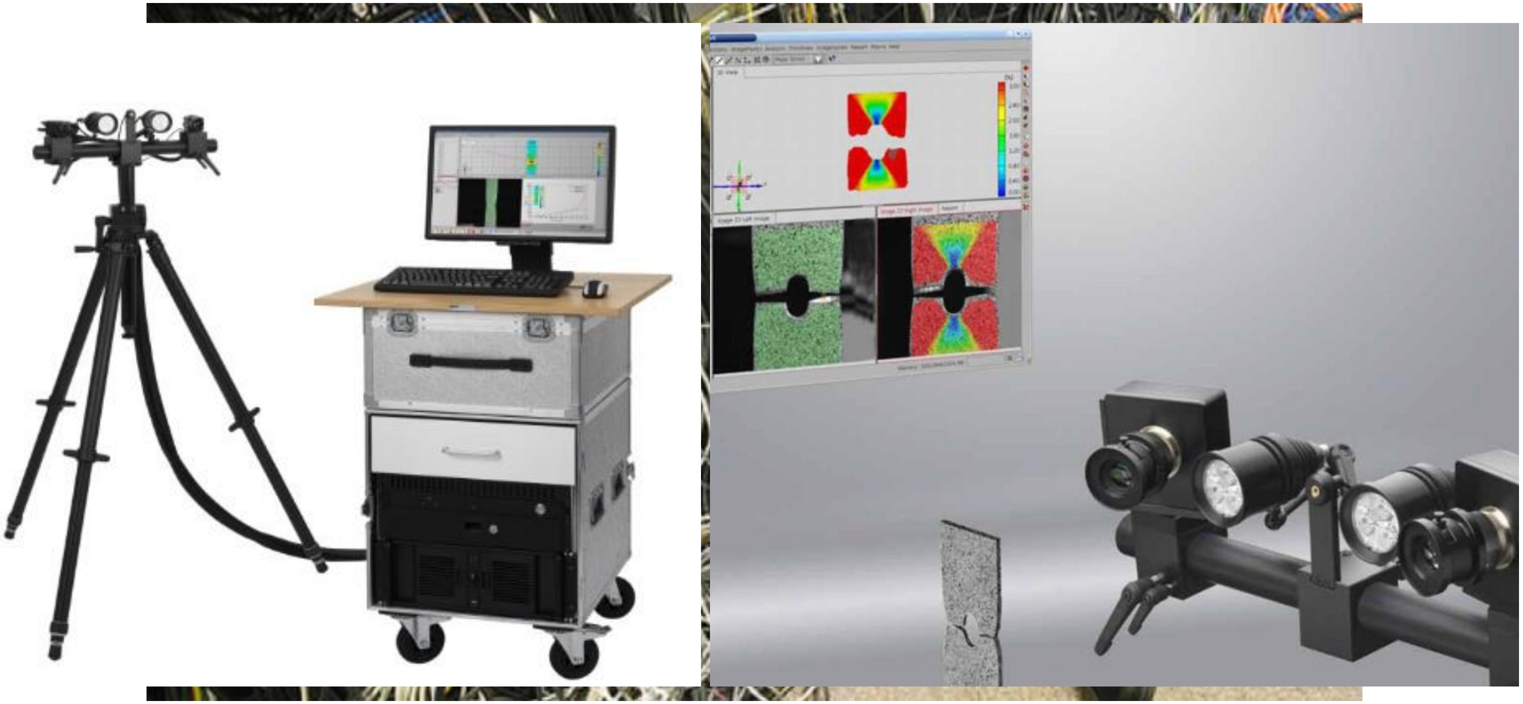
Previous solutions

- Accelerometers
- LVDT
- Strain Gages
- Draw Wire Sensors
- Displacement Sensors
- Laser trackers
- Extensometers
- Clip gages
- Profilometer

WHY

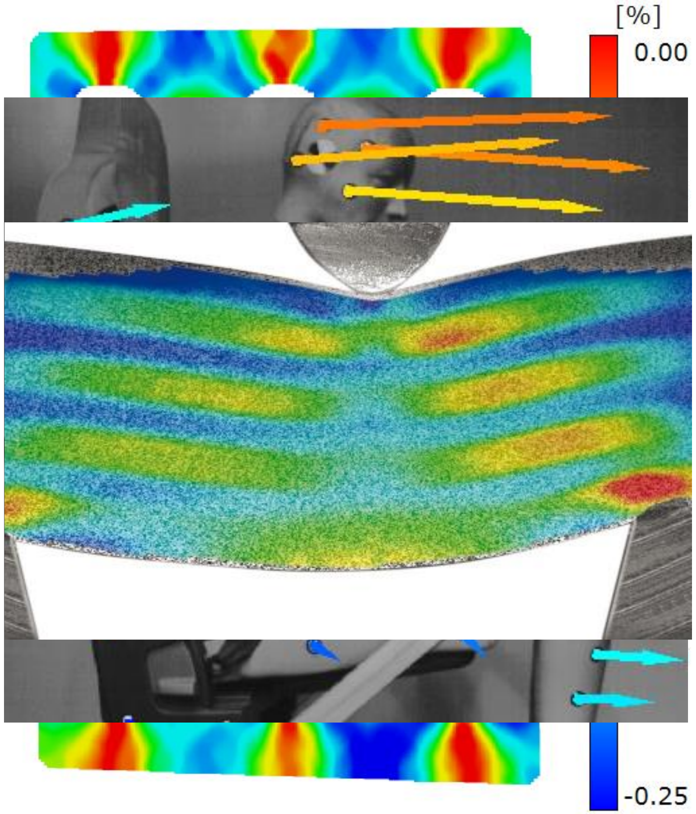
SHOULD WE USE ARAMIS?

TO OBTAIN FULL FIELD DISPLACEMENTS AND STRAIN MAP EASILY



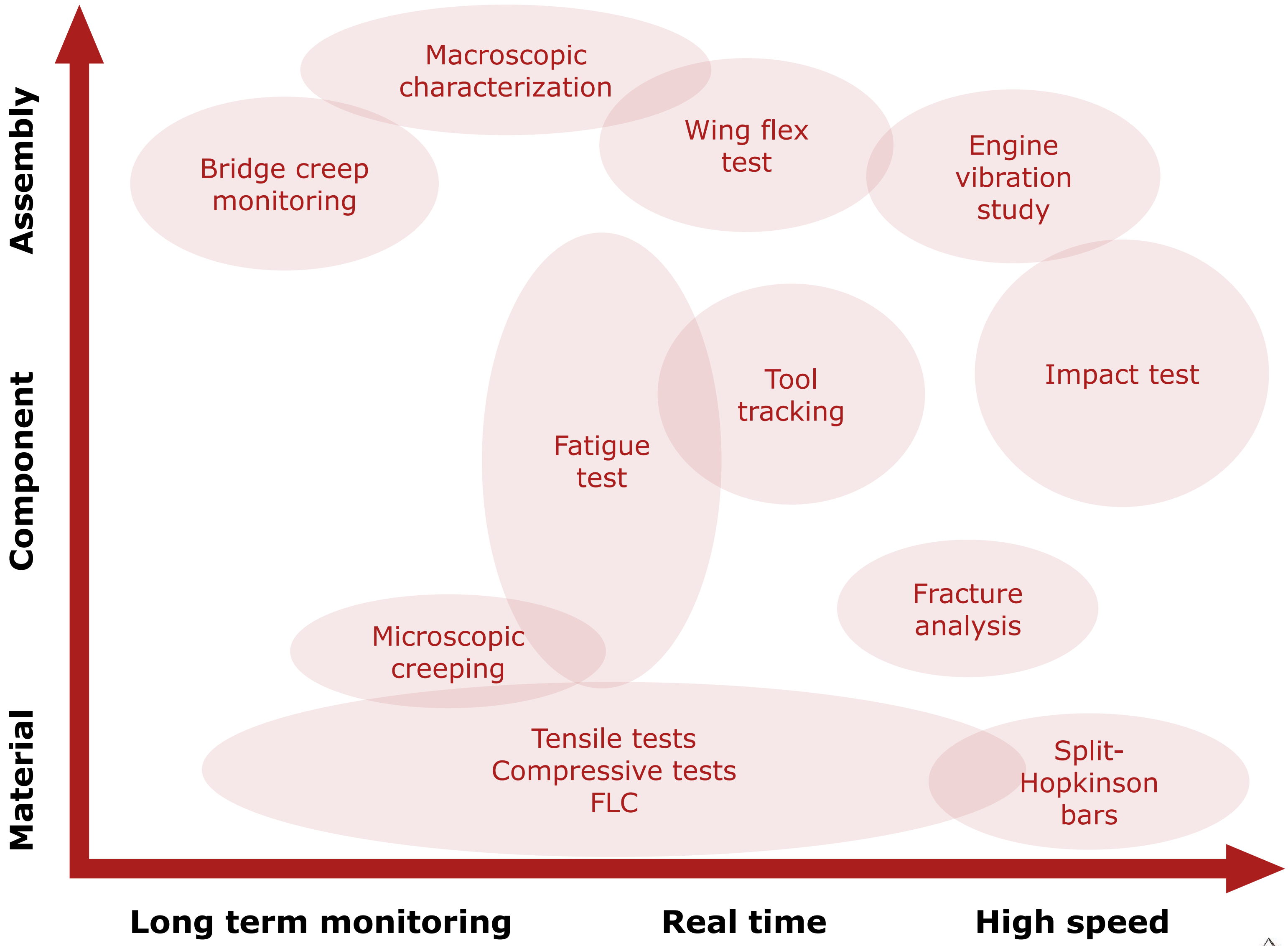
SHOULD WE USE ARAMIS?
POSSIBLE APPLICATIONS

- Determination of material properties (i.e. FLC)
- Component analysis
- Structural testing and vibration analysis (i.e. ODS)
- Validation and improvement of Finite Element Analysis
- High-speed measurements
- Examination of non-linear behavior
- Real-time control of testing machines
- Crash and impact tests
- Characterization of creep and aging processes
- NDT (Non Destructive Testing)



SHOULD WE USE ARAMIS?

MATERIAL, TIME AND SCALE INDEPENDENT



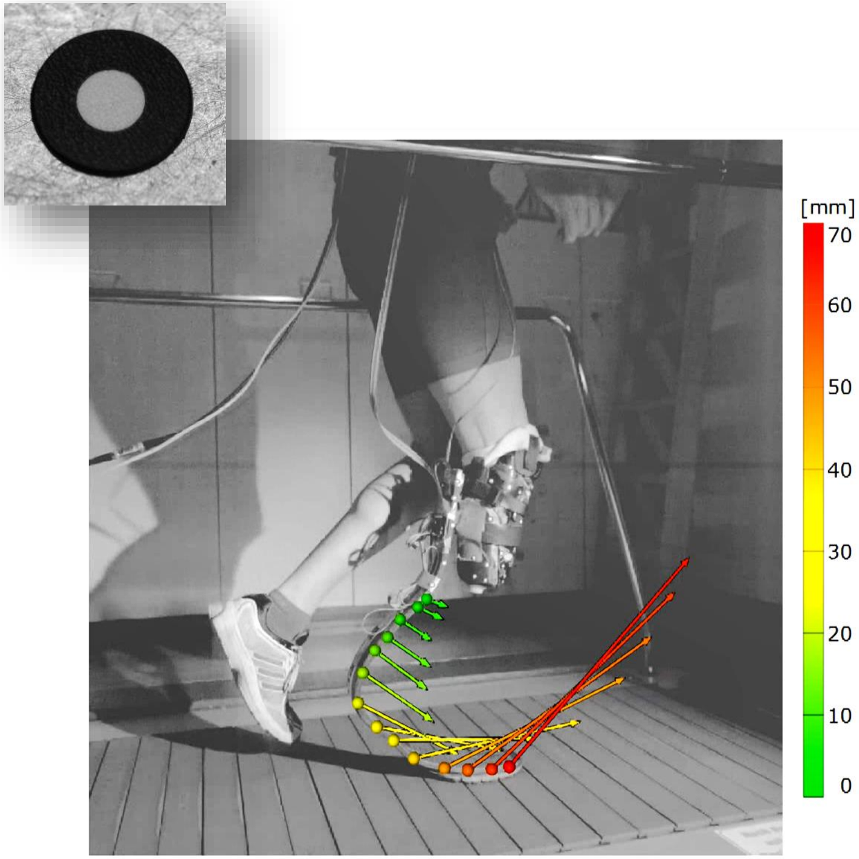
IS IT A BETTER TECHNOLOGY?

FEATURES AND BENEFITS OF 3D IMAGE CORRELATION

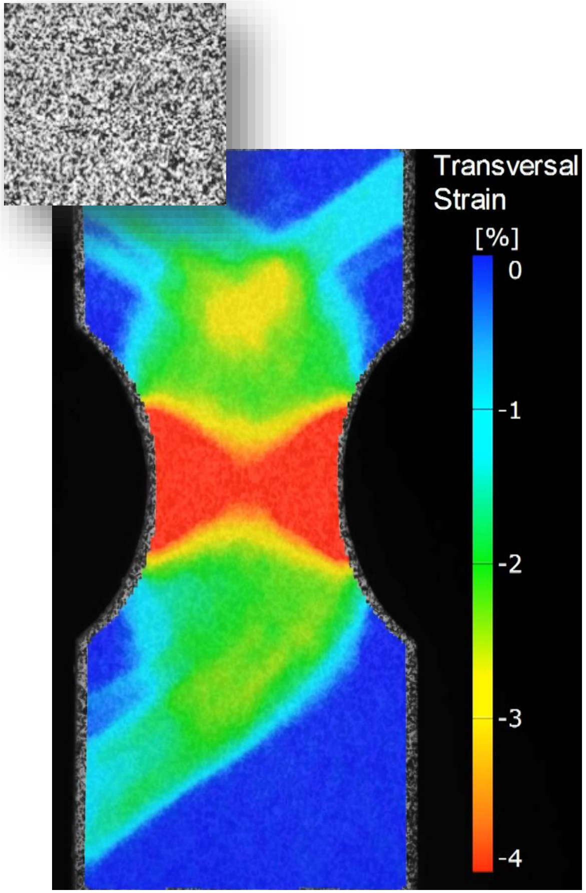
- ✓ Non-contact measurement
- ✓ Robustness and ease of use
- ✓ Modular and integrated system
- ✓ 3D coordinates, 3D deformation and strain measurement
- ✓ Shape analysis and CAD comparison
- ✓ Verification of Numerical Models and Simulations
  - *Full-field, real-time results*
  - *Rapid, wide area coverage*
- ✓ Broad range of materials and stressing mechanisms
  - *Thermal, vibration, mechanical, etc.*
- ✓ 100 microns to 100 meters field of view

WHAT IS DIC?

FULL-FIELD NON-CONTACT MEASUREMENT



Point tracking

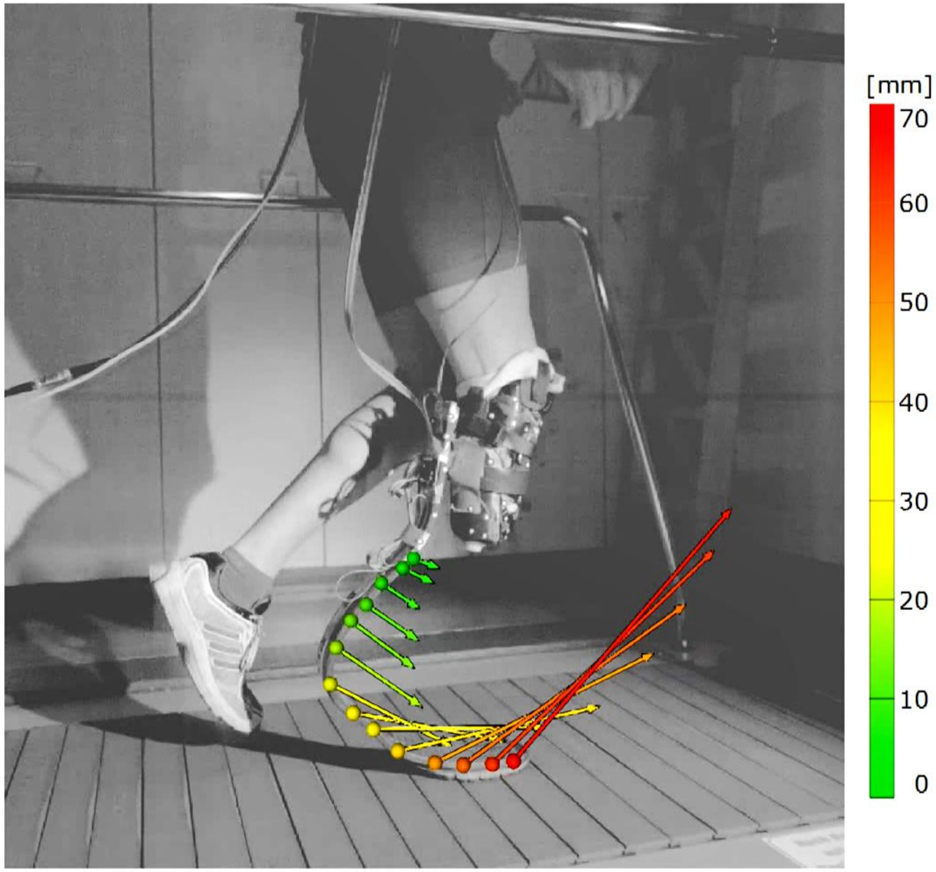


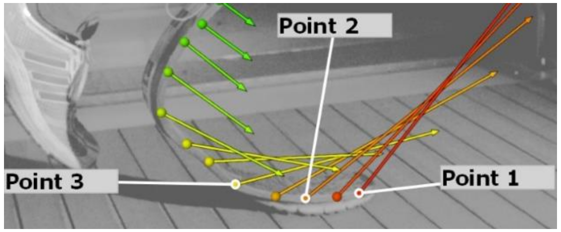
Surface correlation

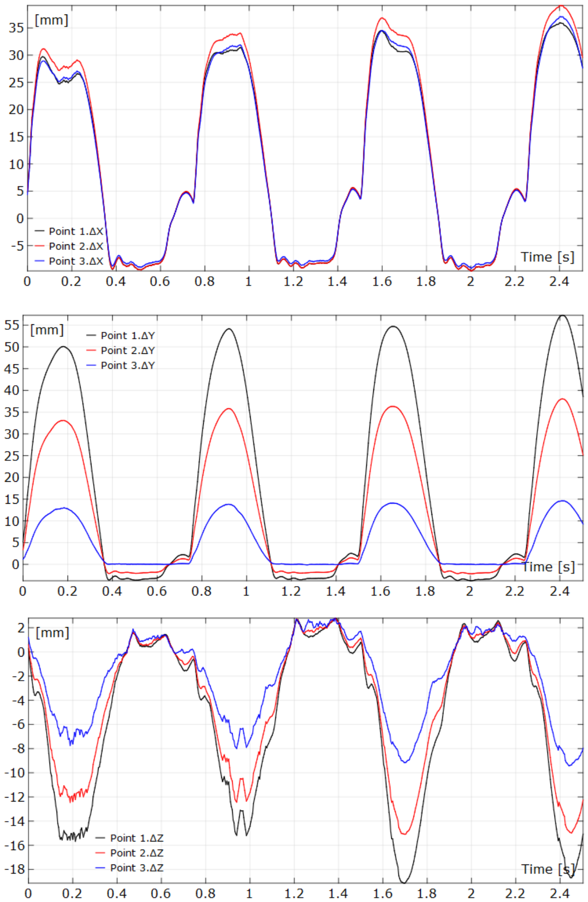
WHAT

CAN YOU DO WITH DIC?

PROSTHESIS MOTION ANALYSIS



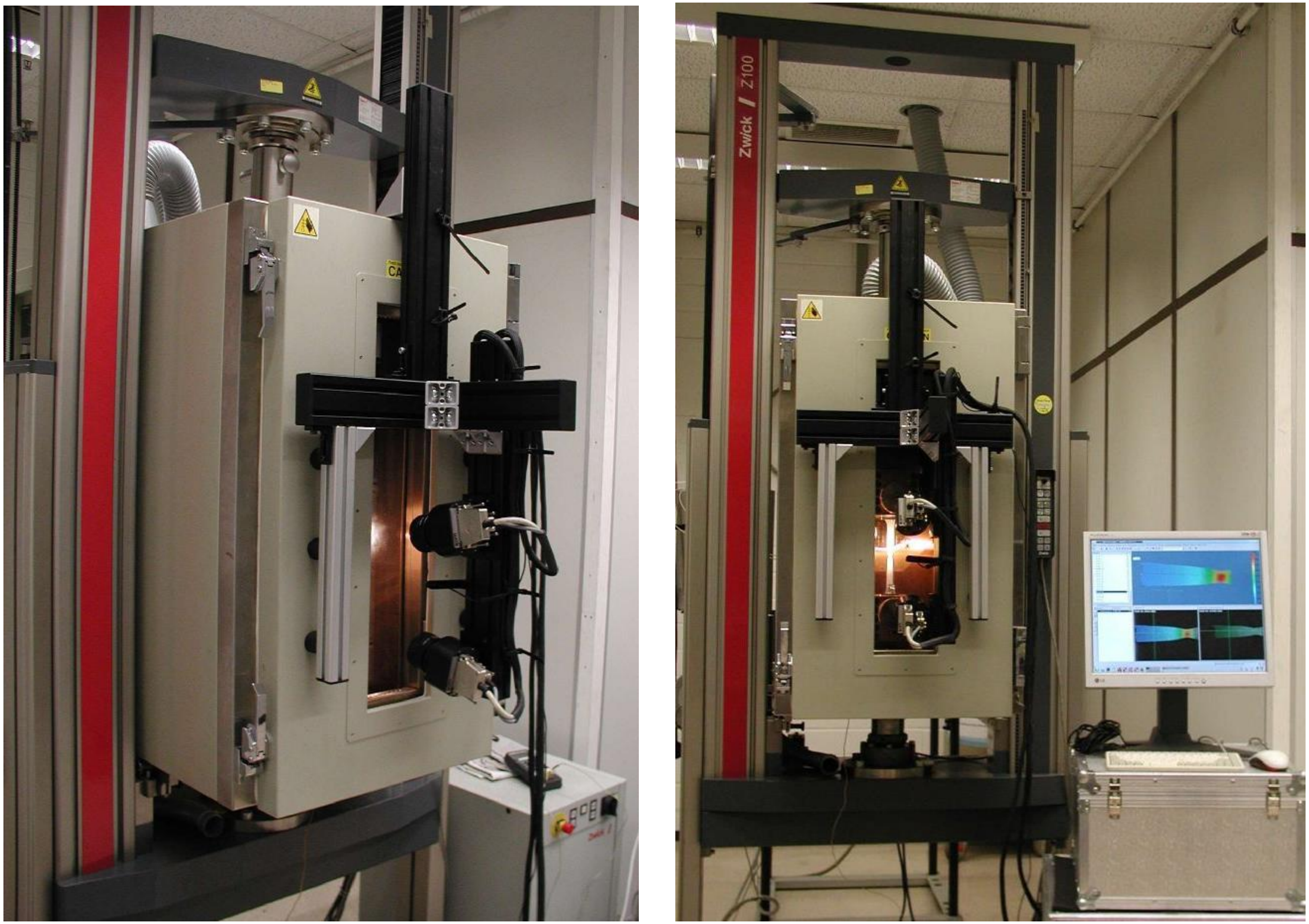




WHAT

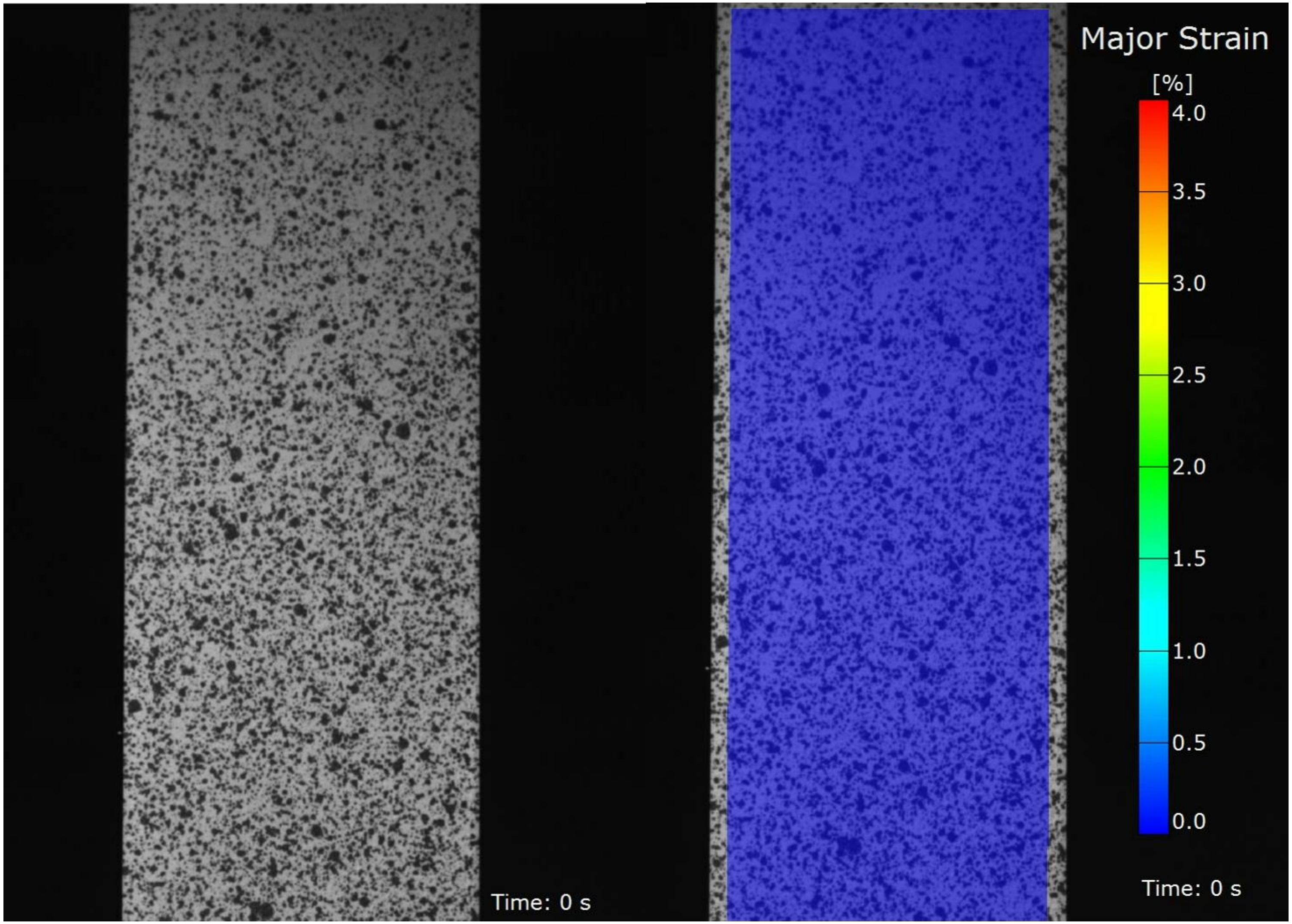
CAN YOU DO WITH DIC?

TENSILE TEST OF MAGNESIUM AT 300°C



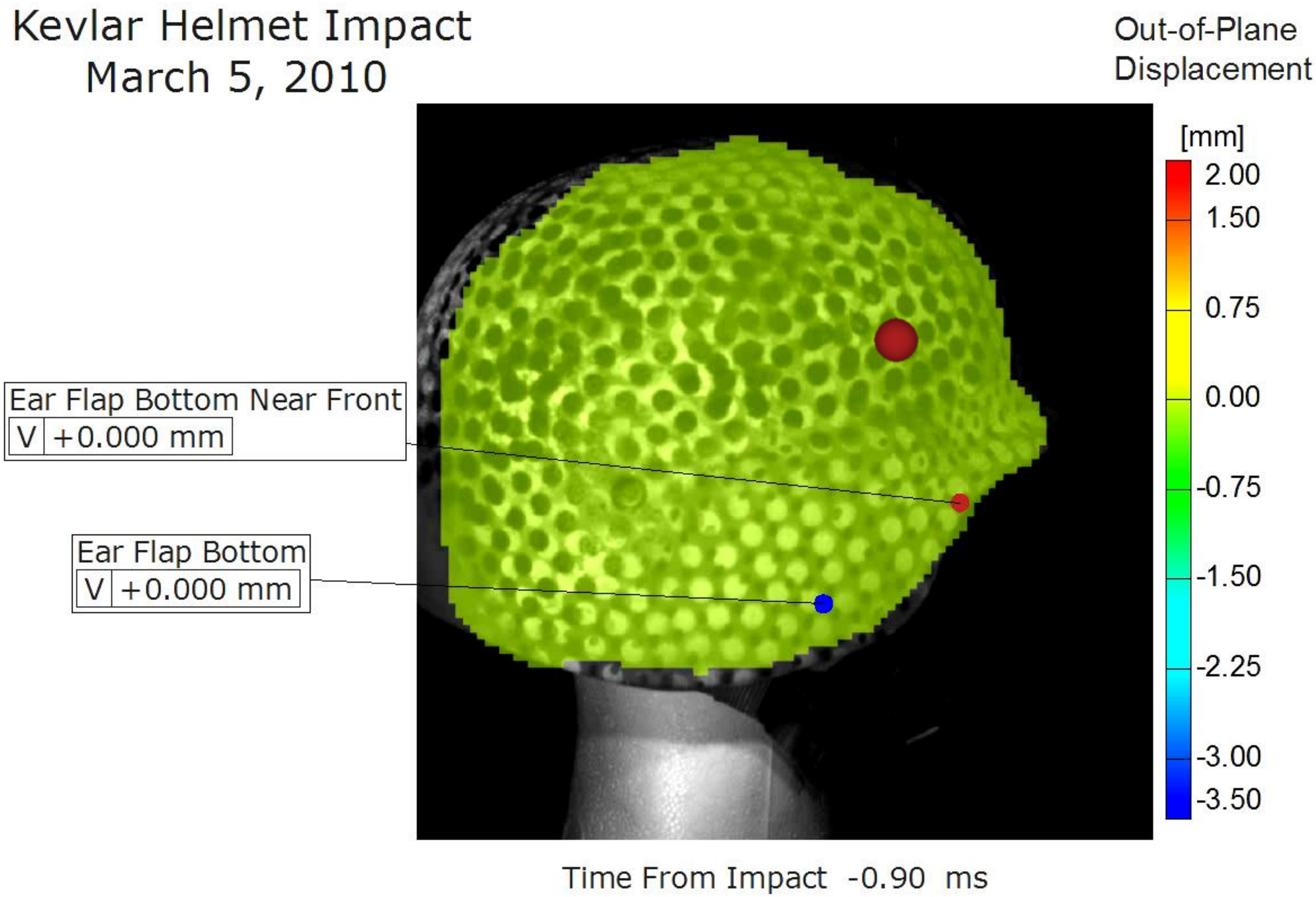
CAN YOU DO WITH DIC?

TENSILE TEST OF MAGNESIUM AT 300˚C

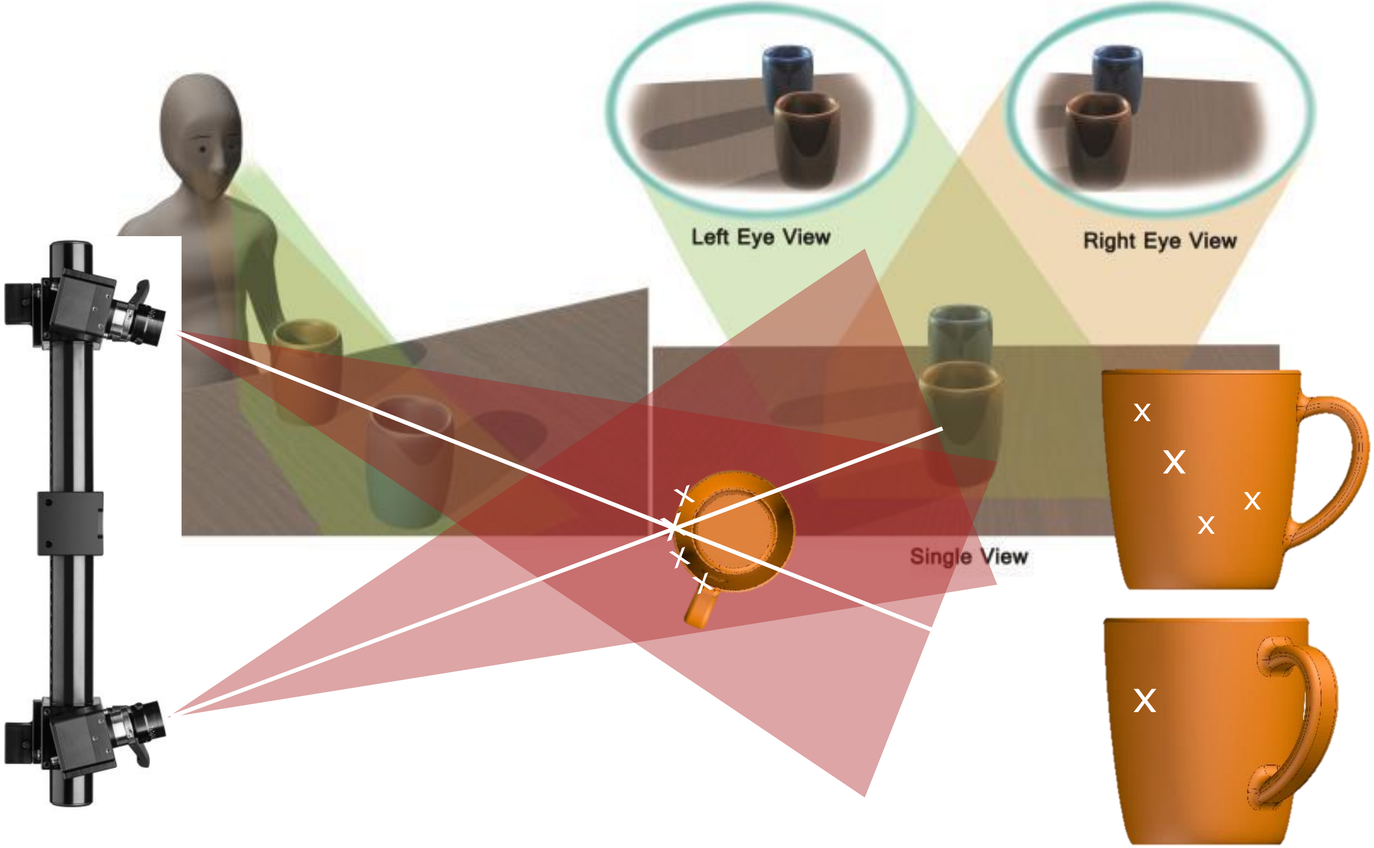


WHAT CAN YOU DO WITH DIC?

KEVLAR HELMET IMPACT

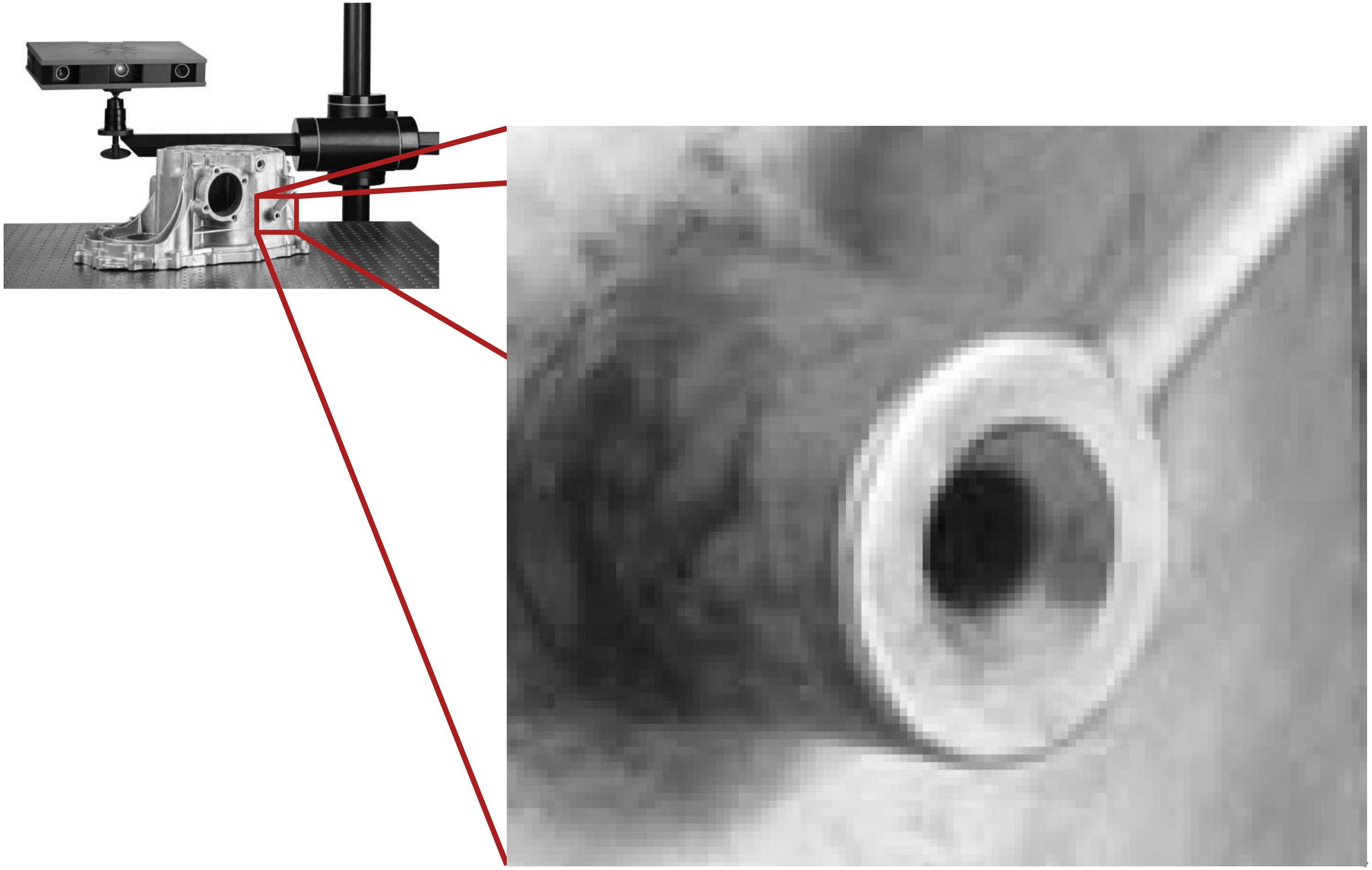


IS DIC?



WHAT IS DIC?

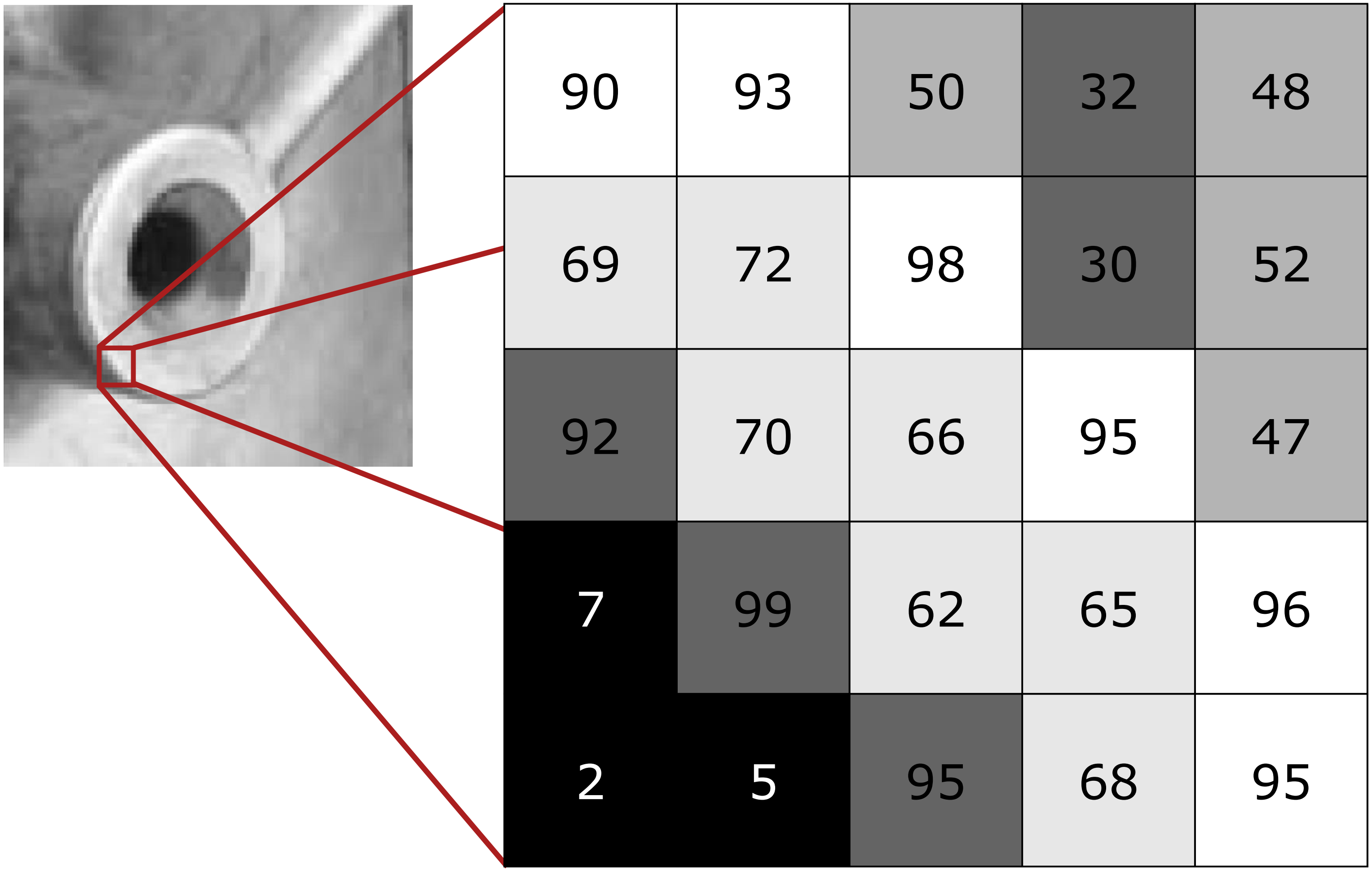
BASIC IMAGE PROCESSING



WHAT

IS DIC?

BASIC IMAGE PROCESSING

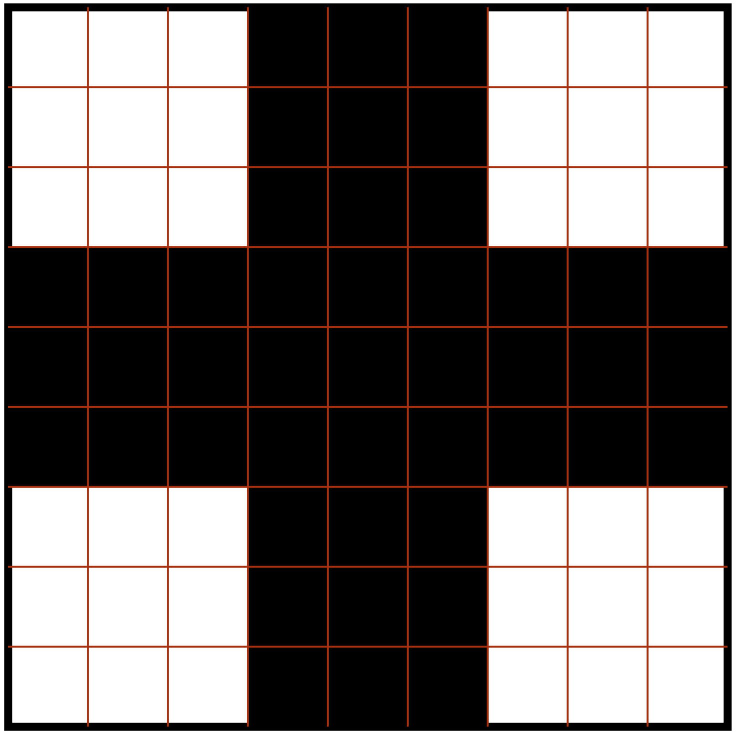


90	93	50	32	48
69	72	98	30	52
92	70	66	95	47
7	99	62	65	96
2	5	95	68	95

WHAT

IS DIC?

BASIC PRINCIPLE



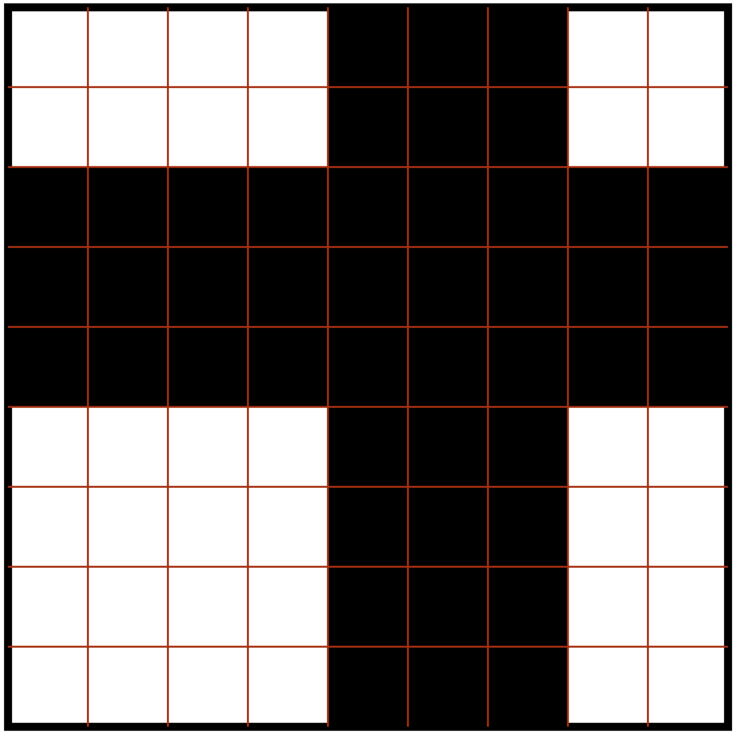
Real image (9x9 pixels)

100	100	100	0	0	0	100	100	100
100	100	100	0	0	0	100	100	100
100	100	100	0	0	0	100	100	100
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
100	100	100	0	0	0	100	100	100
100	100	100	0	0	0	100	100	100
100	100	100	0	0	0	100	100	100

As seen in the computer's memory

WHAT

IS DIC?
BASIC PRINCIPLE



100	100	100	100	0	0	0	100	100
100	100	100	100	0	0	0	100	100
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
100	100	100	100	0	0	0	100	100
100	100	100	100	0	0	0	100	100
100	100	100	100	0	0	0	100	100
100	100	100	100	0	0	0	100	100

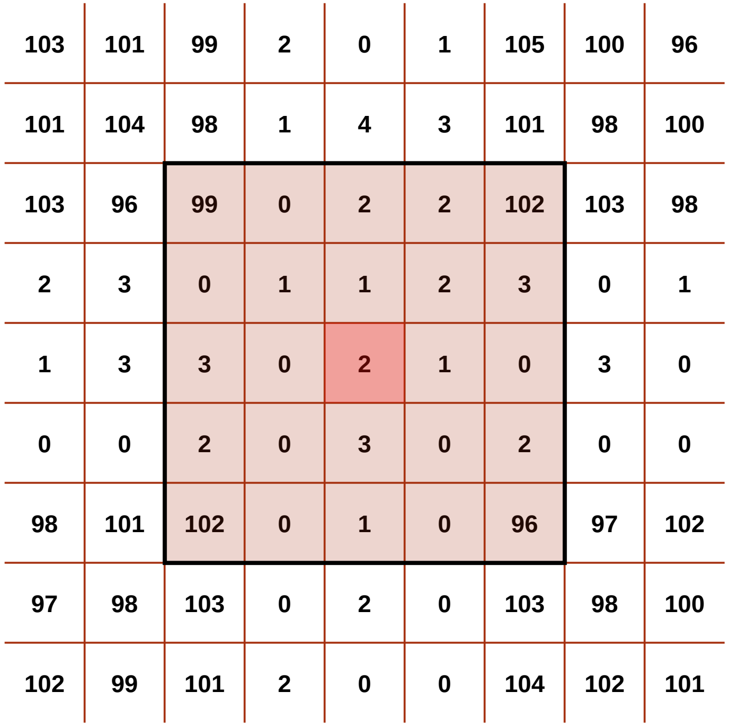
After motion

As seen in the computer’s memory

WHAT

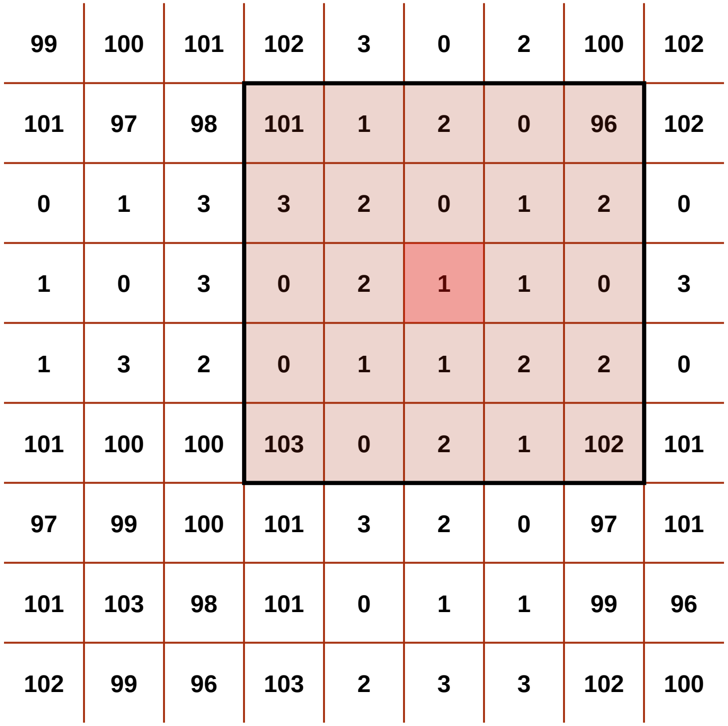
IS DIC?

BASIC PRINCIPLE WITH NOISE CONSIDERATION



103	101	99	2	0	1	105	100	96
101	104	98	1	4	3	101	98	100
103	96	99	0	2	2	102	103	98
2	3	0	1	1	2	3	0	1
1	3	3	0	2	1	0	3	0
0	0	2	0	3	0	2	0	0
98	101	102	0	1	0	96	97	102
97	98	103	0	2	0	103	98	100
102	99	101	2	0	0	104	102	101

Before motion

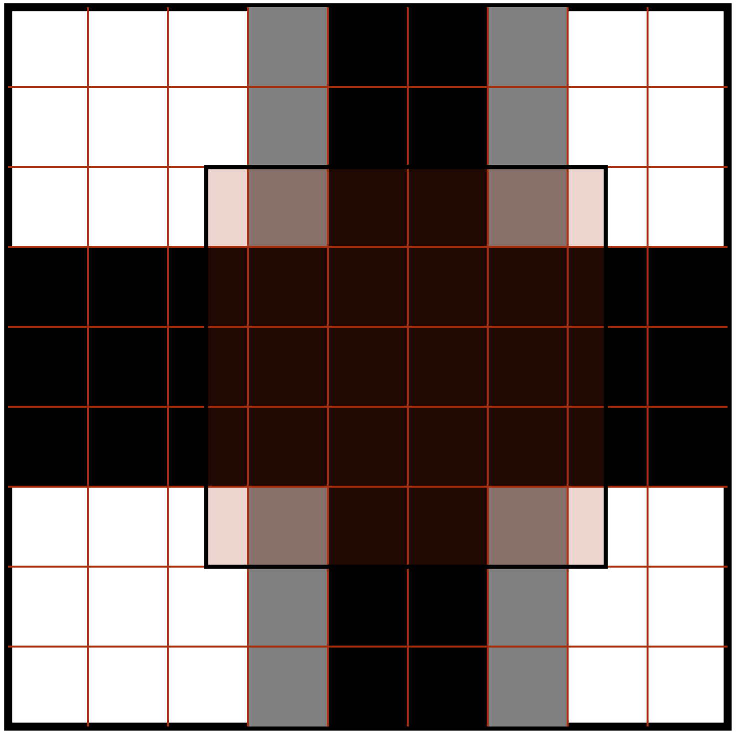


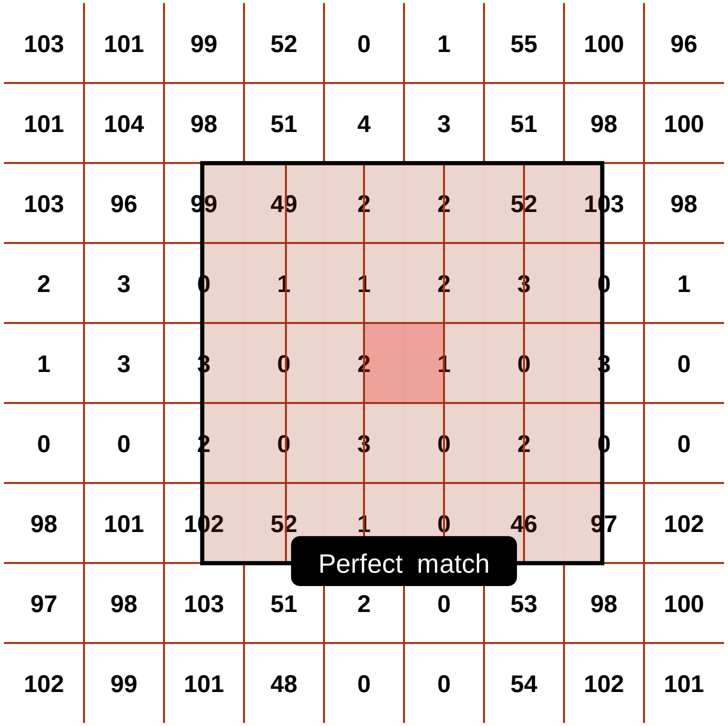
99	100	101	102	3	0	2	100	102
101	97	98	101	1	2	0	96	102
0	1	3	3	2	0	1	2	0
1	0	3	0	2	1	1	0	3
1	3	2	0	1	1	2	2	0
101	100	100	103	0	2	1	102	101
97	99	100	101	3	2	0	97	101
101	103	98	101	0	1	1	99	96
102	99	96	103	2	3	3	102	100

After motion

WHAT IS DIC?

BASIC PRINCIPLE AND SUBPIXEL INTERPOLATION

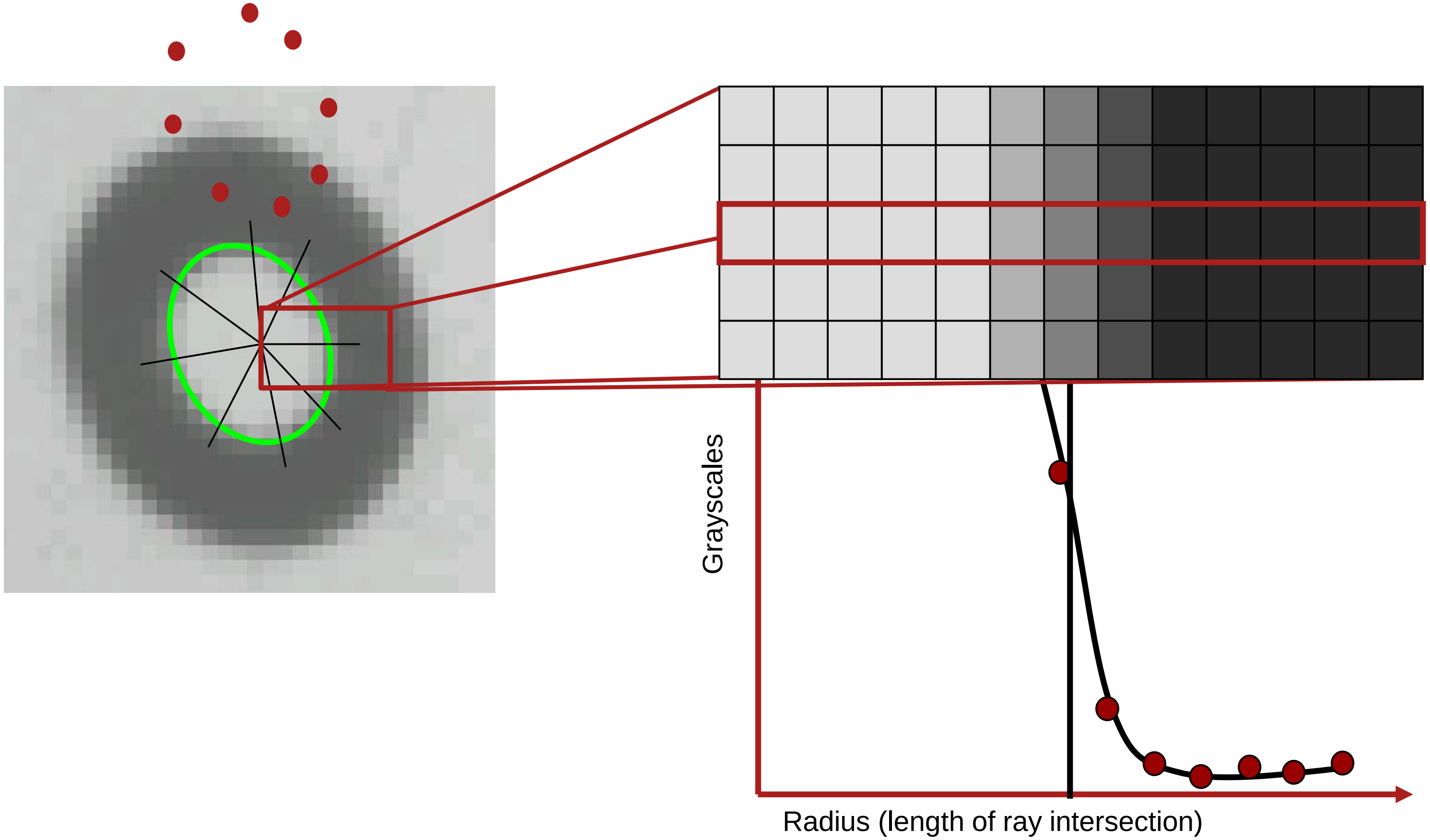




103	101	99	52	0	1	55	100	96
101	104	98	51	4	3	51	98	100
103	96	99	49	2	2	52	103	98
2	3	0	1	1	2	3	0	1
1	3	3	0	2	1	0	3	0
0	0	2	0	3	0	2	0	0
98	101	102	52	1	0	46	97	102
97	98	103	51	2	0	53	98	100
102	99	101	48	0	0	54	102	101

Perfect match

IS DIC?
WITH ROUND TARGET MARKERS



WHAT IS THIS COURSE?

OBJECTIVES

A GENERAL BACKGROUD

1. Know what is digital image correlation
2. Visualize the measuring volume and the epipolar line
3. Know the difference between facet size and point distance
4. Understand what is the intersection deviation
5. Be able to name a few application examples

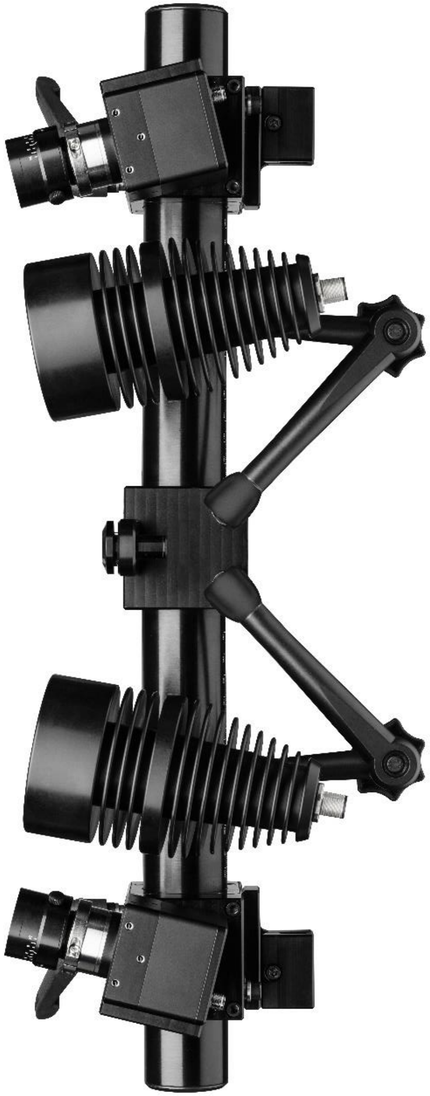
B USE

1. Know how to prepare a specimen for DIC
2. Be able to do a measurement and acquire analog signals
3. Know how to evaluate the noise in a measurement
4. Feel capable of searching in the available learning ressources

C POST-PROCESSING

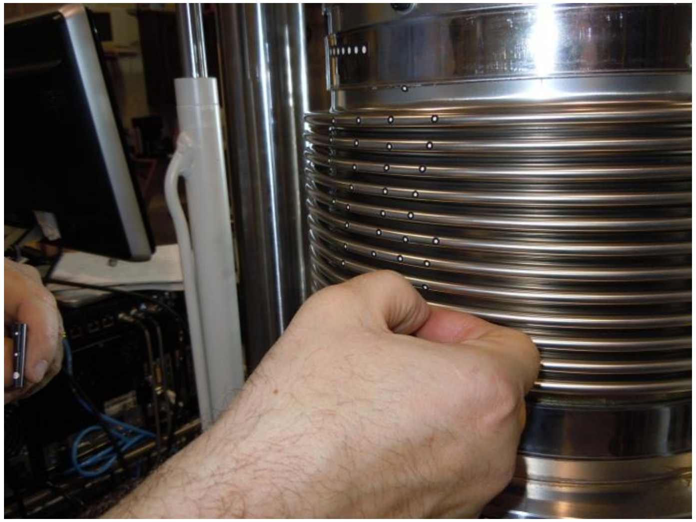
1. Know how to obtain a visual representation of displacements and strains
2. Understand the workflow to analyze data
3. Be able to export data as video, PDF or CSV
4. Feel that using GOM CORRELATE is simple

TO USE
BASIC WORKFLOW



1. Decide field of view and frame rate
2. Apply adequate stochastic pattern
3. Set up cameras
    a. Focus (with aperture fully open)
    b. Apply desired frame rate and close aperture
4. Pre-test (pattern and noise check)
5. Data Acquisition
6. Data processing
7. Reporting

TO USE
SURFACE PREPARATION AND PATTERNING



Standard spray paint patterning

- Dot size 5 Pixels
- Degrease / sand the Surface
- Uniform white background coating
- Apply appropriate sized black dots
- Use developer (Talc powder) for removable coating
- Use discrete black and white dots for compression testing, low strength materials or for discrete point tracking

Alternative patterning methods

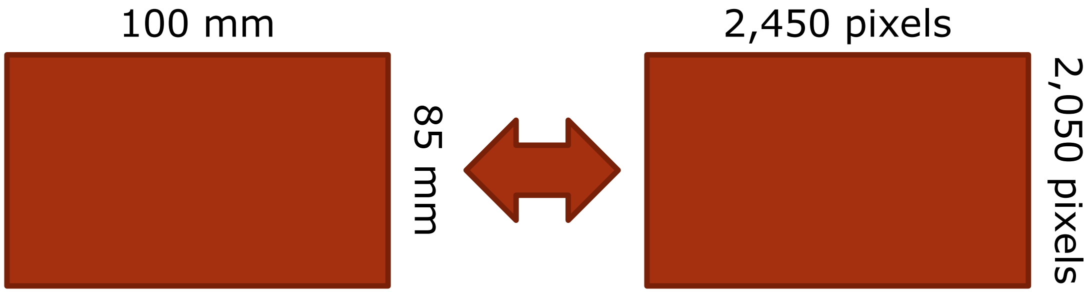
- Sharpy Marker
- Perforated Sheets for Dots > 1/8”
- Tattoo Sheets
- Rubber Stamps
- Nothing…

HOW

TO USE

DEFINE THE FIELD OF VIEW AND THE SIZE OF THE PATTERN

- What is the size of one pixel?



$$\frac{100\ \text{mm}}{2{,}450\ \text{px}} = x\,\frac{\text{mm}}{\text{px}} \Rightarrow \mathbf{0.04\ mm/pixel}$$

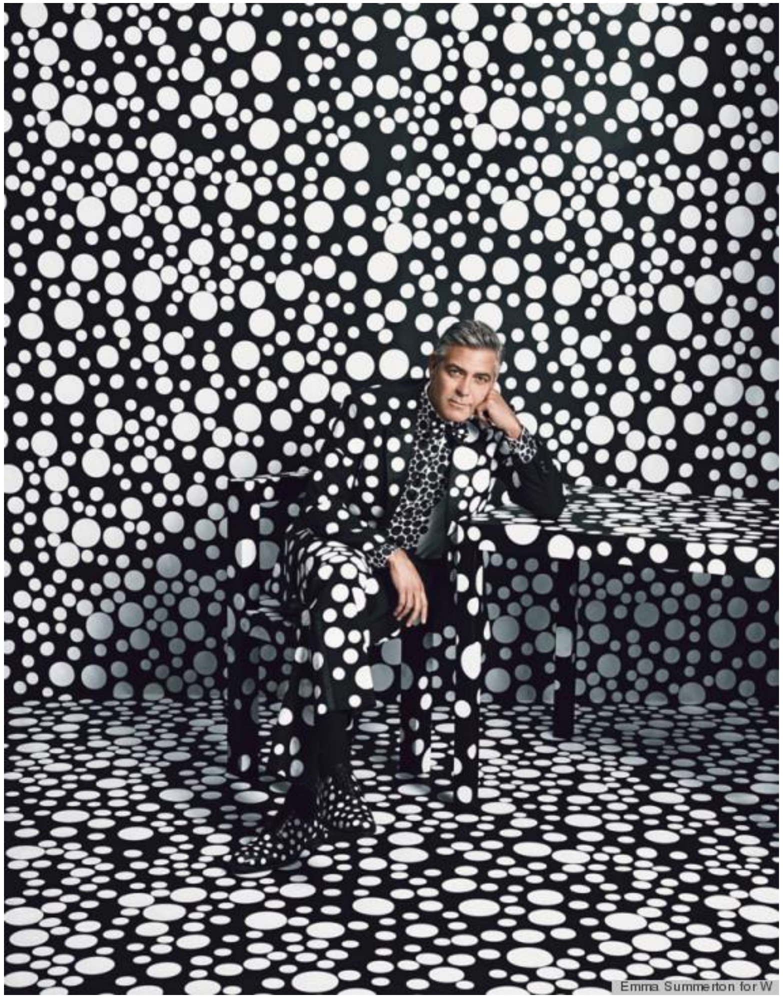
- What is the size of a dot?

Multiply by 5

Between 0.2 mm in size

HOW TO USE

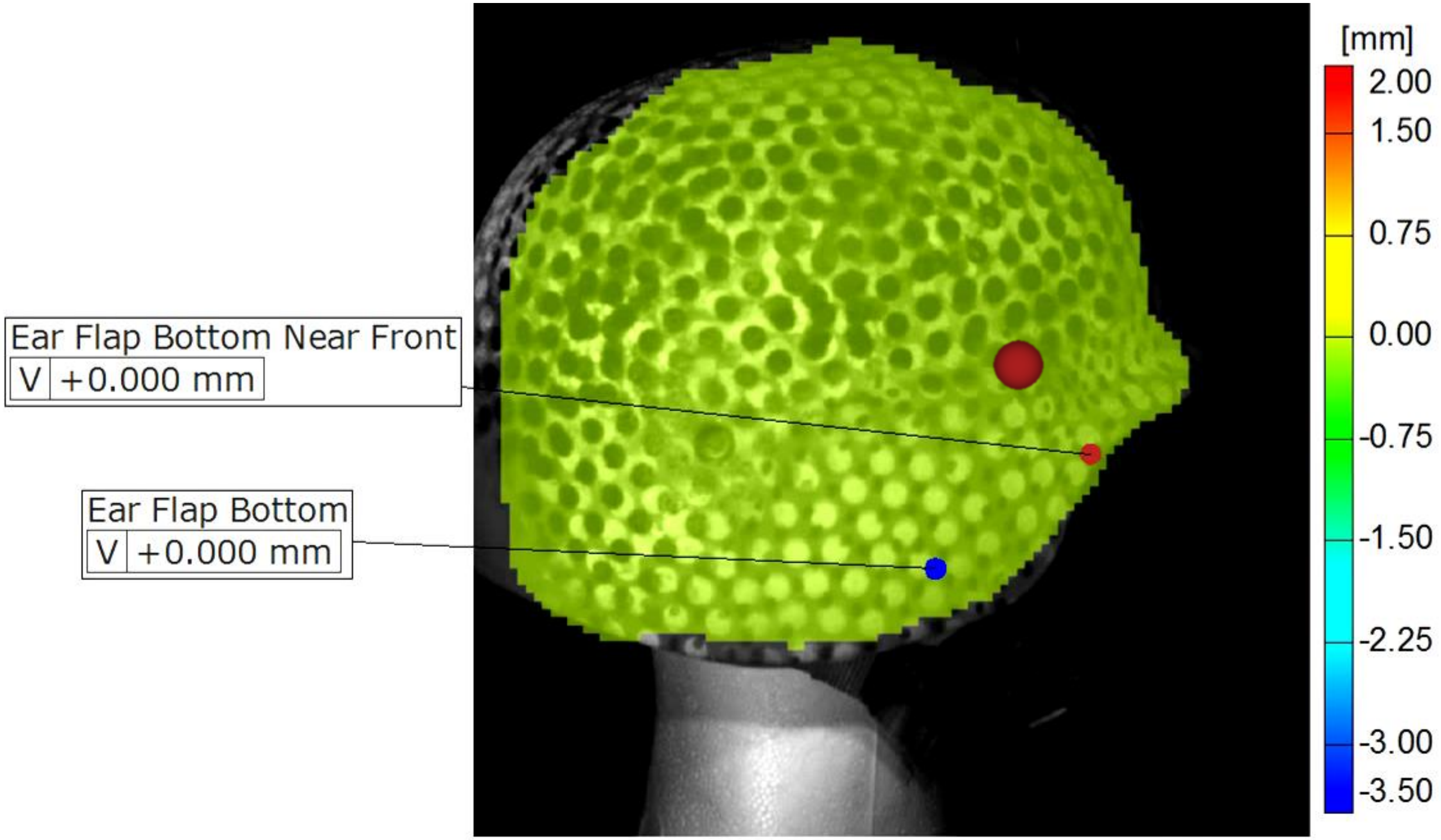
PREPARE YOUR SURFACES LIKE GEORGES AND BE CREATIVE!!!



WHAT

CAN YOU DO WITH DIC?

KEVLAR HELMET IMPACT

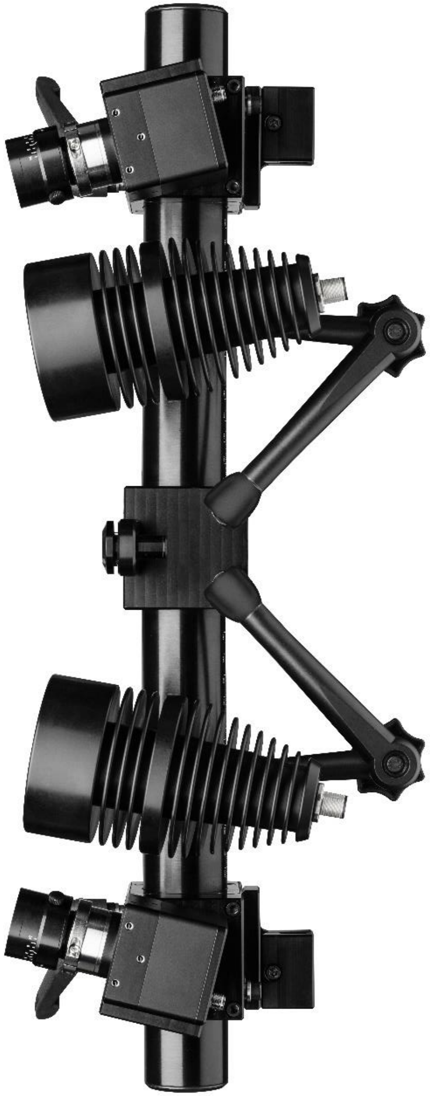


Time From Impact -0.90 ms

- What do you notice about this pattern?
- Can you describe this pattern?

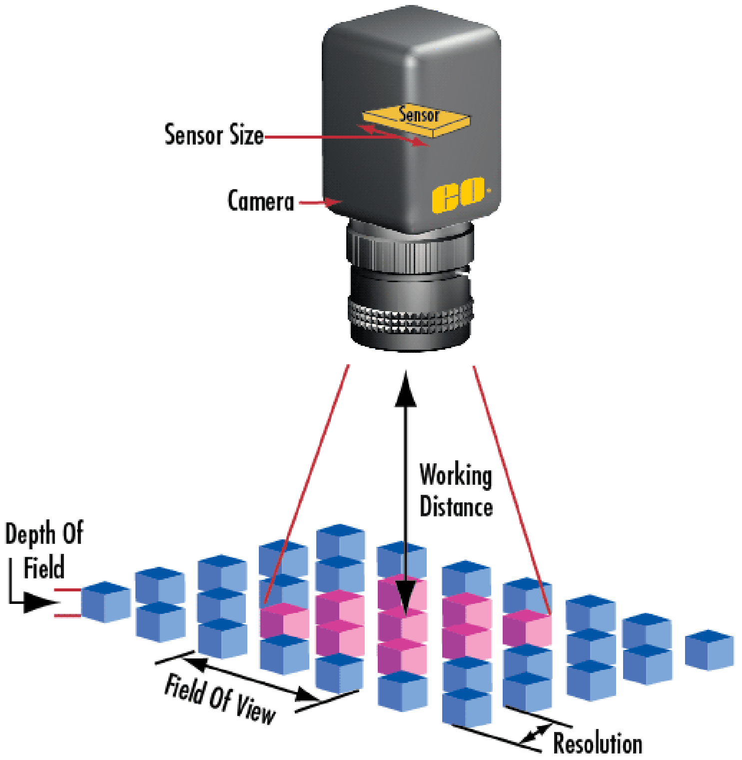
TO USE
BASIC WORKFLOW

1. Decide field of view and frame rate
2. Apply adequate stochastic pattern
3. Set up cameras
    a. Focus (with aperture fully open)
    b. Apply desired frame rate and close aperture
4. Pre-test (pattern and noise check)
5. Data Acquisition
6. Data processing
7. Reporting



KEY PHYSICAL SETUP PARAMETERS

- **Field of view**
  The viewable area of the object under inspection. This is the portion of the object that fills the camera’s sensor
- **Measuring distance**
  The distance from the front of the lens to the object under inspection
- **Depth of field**
  The maximum object depth that can be maintained entirely in acceptable focus. DOF is also the amount of object movement (in and out of best focus) allowable while maintaining focus
- **Aperture**
  The unit of measurement that defines the size of the opening in the lens that can be adjusted to control the amount of light reaching the digital sensor
- **Focus distance**
  The distance between the lens and the subject to make light rays converge to form a clear and sharply defined image of the subject
- **Slider distance**
  The distance between the 2 cameras



http://www.edmundoptics.com/resources/application-notes/imaging/5-fundamental-parameters-of-an-imaging-system/

KEY PHYSICAL SETUP PARAMETERS

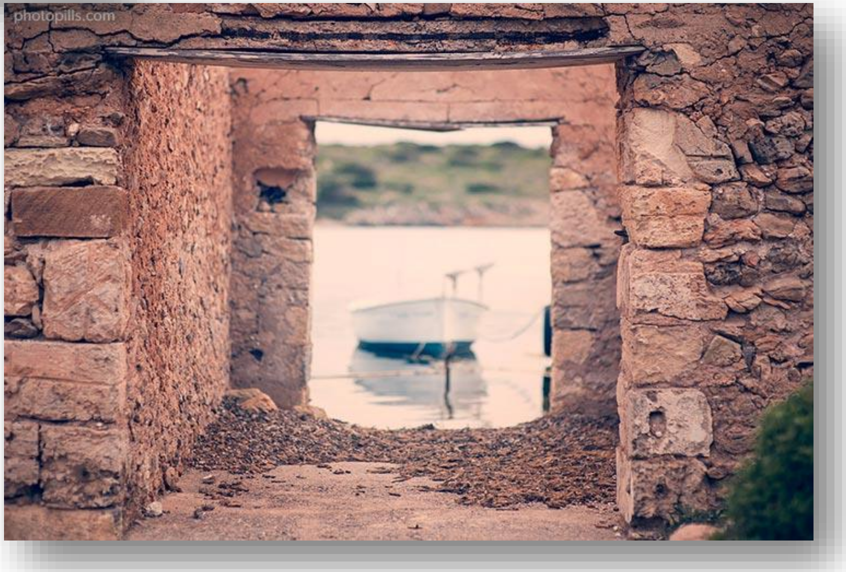
FIELD OF VIEW AND LENSE CHOICE (MEASURING DISTANCE OF 6 METERS)

24mm lens
i.e. 175mm for a FOV of 50mm

100 mm lens
i.e. 800mm for a FOV of 50mm

KEY PHYSICAL SETUP PARAMETERS
FIELD OF VIEW VS MEASURING DISTANCE

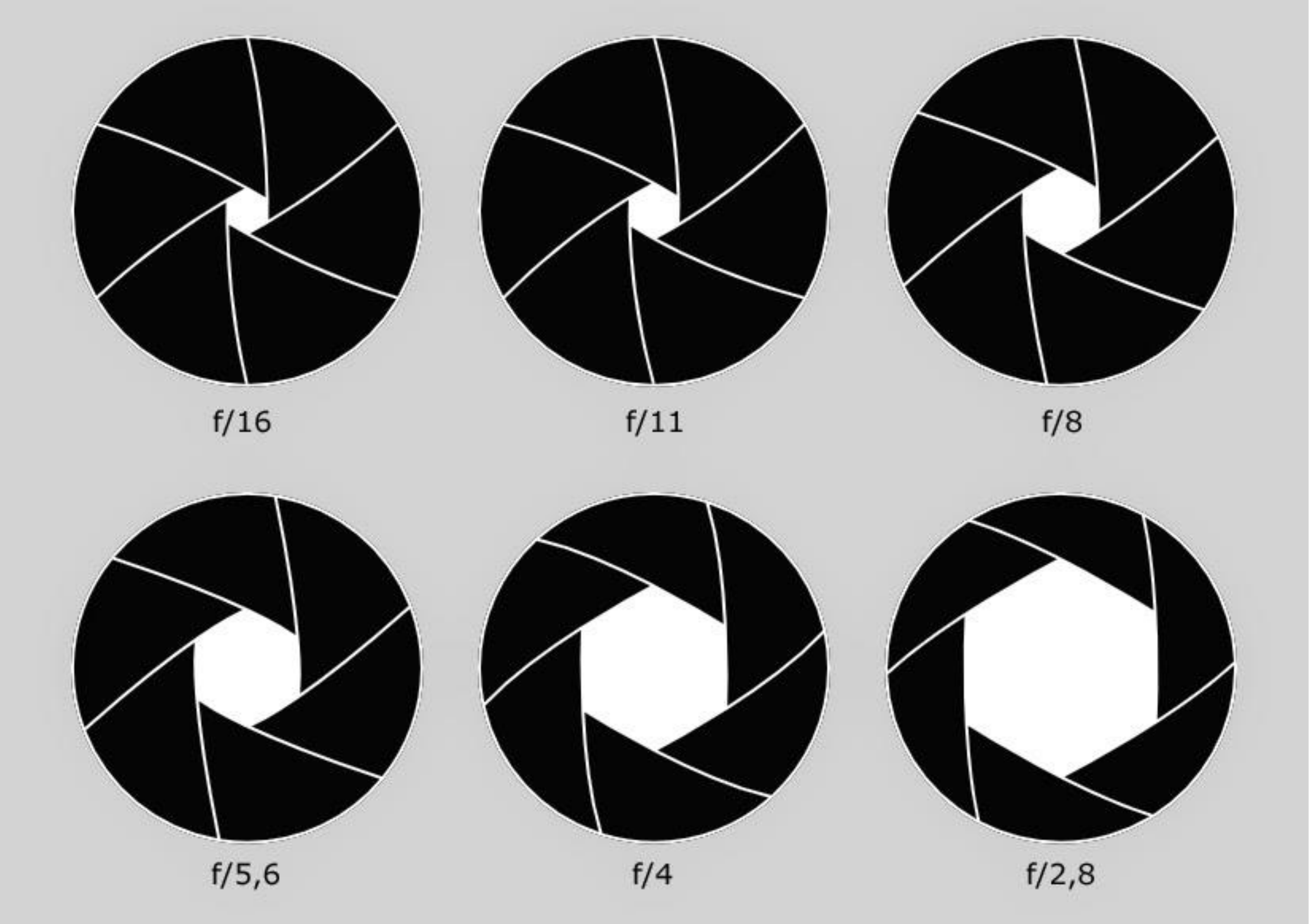
2m from the hut
Total DOF = 0.06m



10m from the hut
Total DOF = 1.66m

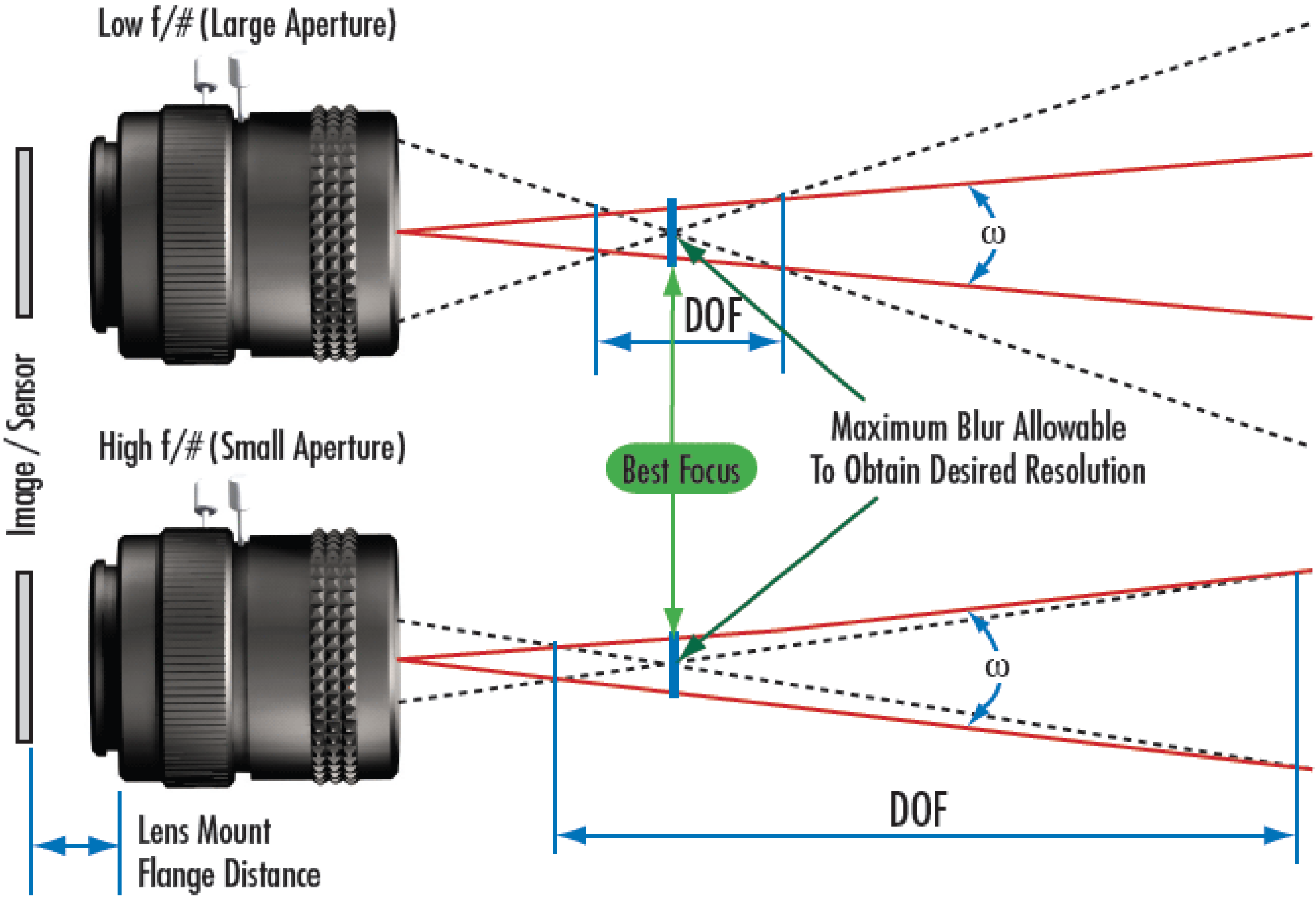
KEY PHYSICAL SETUP PARAMETERS

APERTURE VS DEPTH OF FIELD



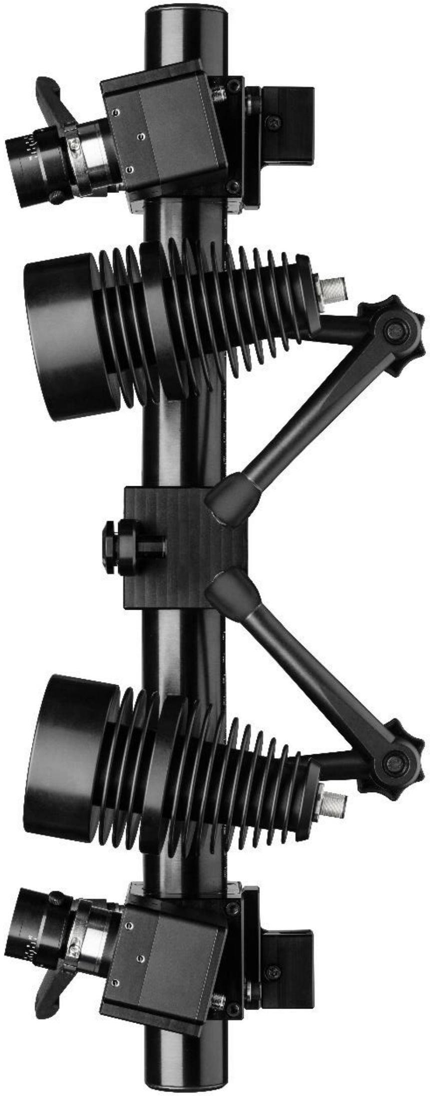
KEY PHYSICAL SETUP PARAMETERS

APERTURE VS DEPTH OF FIELD



TO USE
BASIC WORKFLOW

1. Decide field of view and frame rate
2. Apply adequate stochastic pattern
3. Set up cameras
    a. Focus (with aperture fully open)
    b. Apply desired frame rate and close aperture
4. Pre-test (pattern and noise check)
5. Data Acquisition
6. Data processing
7. Reporting



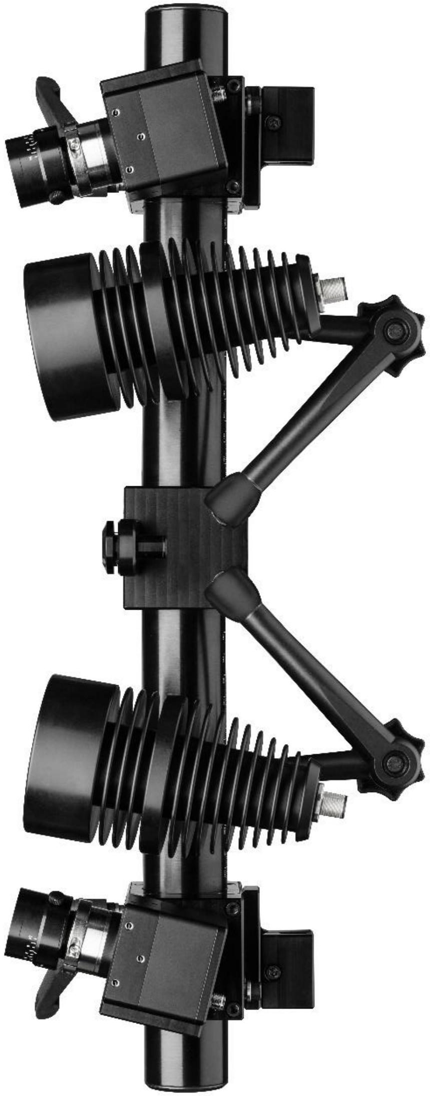
TO SETUP
THE SYSTEM AND CALIBRATE

Cameras setup

- Maximize size of sample in field of view
- Take into account motion and stretch of object for the field of view
- Focus with aperture wide open
- Close aperture to increase depth of field
- Cross polarization

TO USE
BASIC WORKFLOW

1. Decide field of view and frame rate
2. Apply adequate stochastic pattern
3. Set up cameras
    a. Focus (with aperture fully open)
    b. Apply desired frame rate and close aperture
4. Pre-test (pattern and noise check)
5. Data Acquisition
6. Data processing
7. Reporting



TO SETUP
THE PRE-TEST AND THE EXPECTED SENSITIVITY

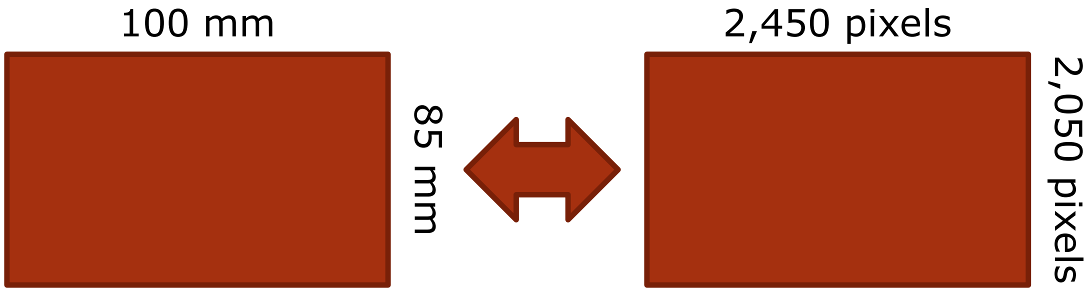
- Based on the computation, the noise should be about **1/30 of a pixel out-of-plane**
- In-plane, the noise should be 3 times lower
- Since strain is a relative value based on the displacements, we typically have noise level around 50-100 microstrain
- Filtering reduces noise and increases accuracy but it also reduces spatial resolution

Example for a 5MP sensor:

Field of View	Out-of-plane displacement sensitivity
10 x 8 mm	0.15 microns
100 x 80 mm	1.5 microns
1 meter x 800 mm	15 microns

TO USE
DEFINE THE FIELD OF VIEW AND THE RESOLUTION

- What is the size of one pixel?


100 mm

85 mm

2,450 pixels

2,050 pixels

$$\frac{100\ \text{mm}}{2{,}450\ \text{px}} = x\,\frac{\text{mm}}{\text{px}} \Rightarrow \mathbf{0.04\ mm/pixel}$$

SUMMARY
BEST PRACTICES ON HOW TO USE, SETUP AND ACQUIRE DATA

Apply a good speckle pattern, make sure you have uniform lighting and calibrate frequently to ensure consistent quality

Always do a pre-test to check the sensitivity

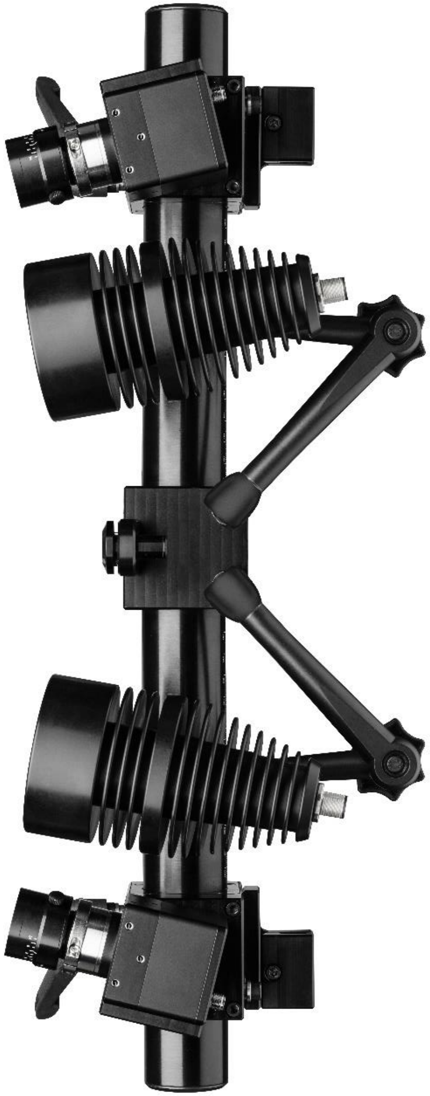
- Snap a few images with no load and compute displacements and strains
- Make sure that there are no major holes in the data
- Check average and peak strains
- Look for false hot spots

And above all:

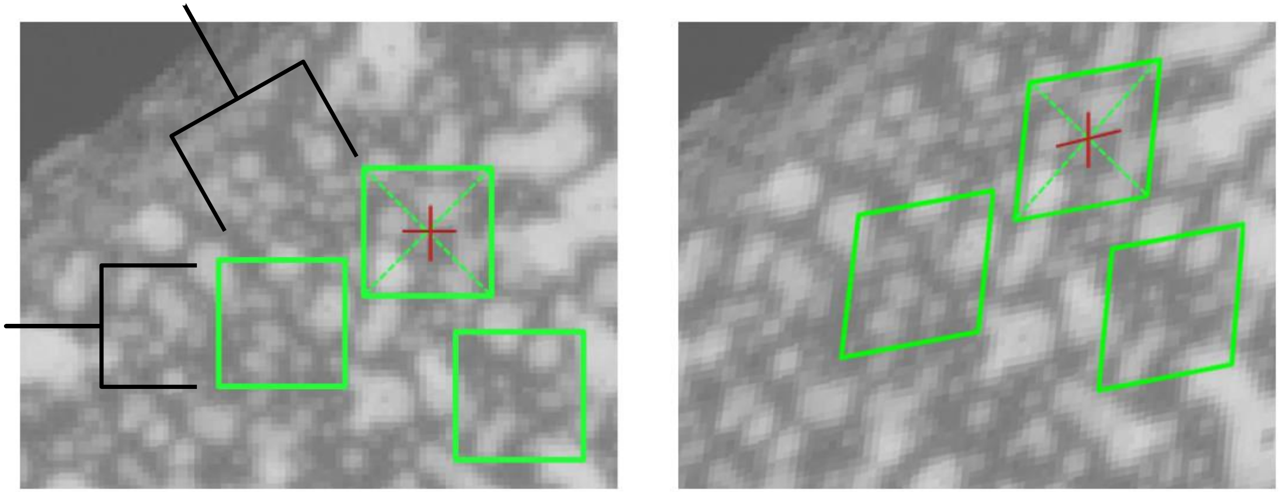
- 5 pixels per paint dot
- Check the pattern and verify the noise level
- Intersection error must be lower than 0.3
- Be aware of the coordinate system of your results

TO USE
BASIC WORKFLOW

1. Decide field of view and frame rate
2. Apply adequate stochastic pattern
3. Set up cameras
    a. Focus (with aperture fully open)
    b. Apply desired frame rate and close aperture
4. Pre-test (pattern and noise check)
5. Data Acquisition
6. Data processing
7. Reporting



THEORY
FACET PARAMETERS

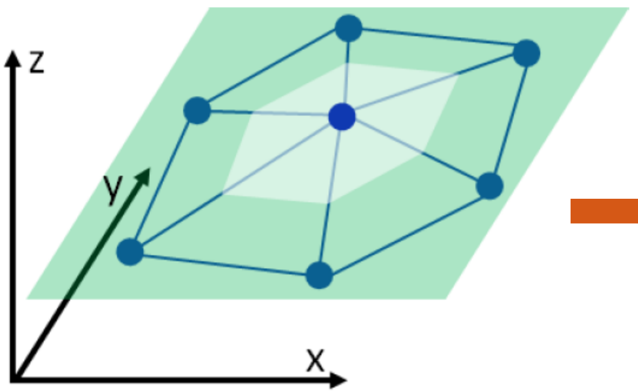


Point distance
(granularity of the mesh)

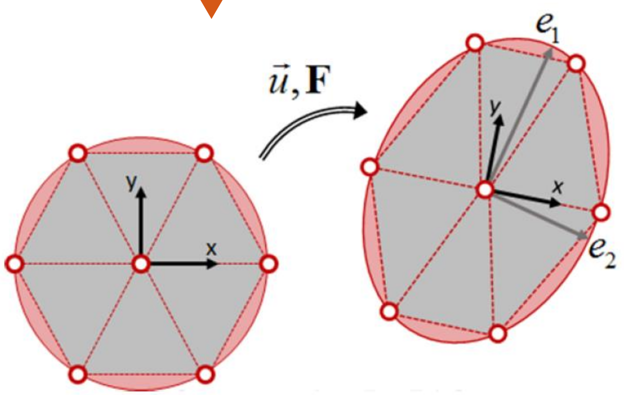
Facet size
at least 3 to
5 speckles

Facets in their original state (left) and deformed (right)

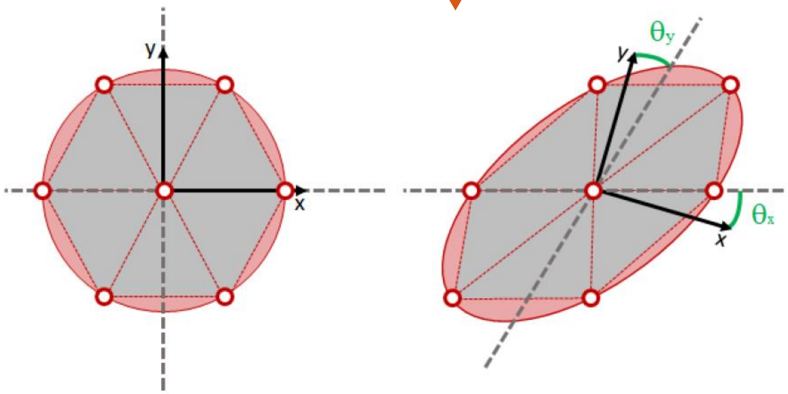
THEORY
STRAIN COMPUTATION



Local compensation plane



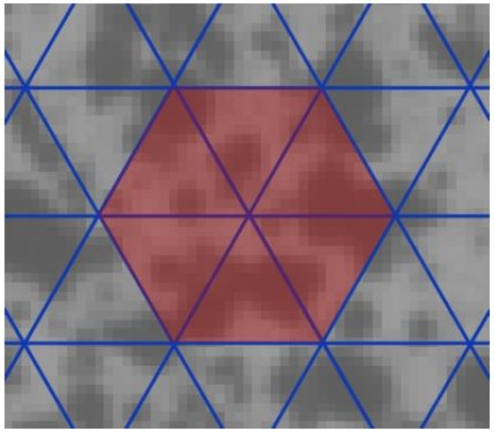
Graphical representation of the directions



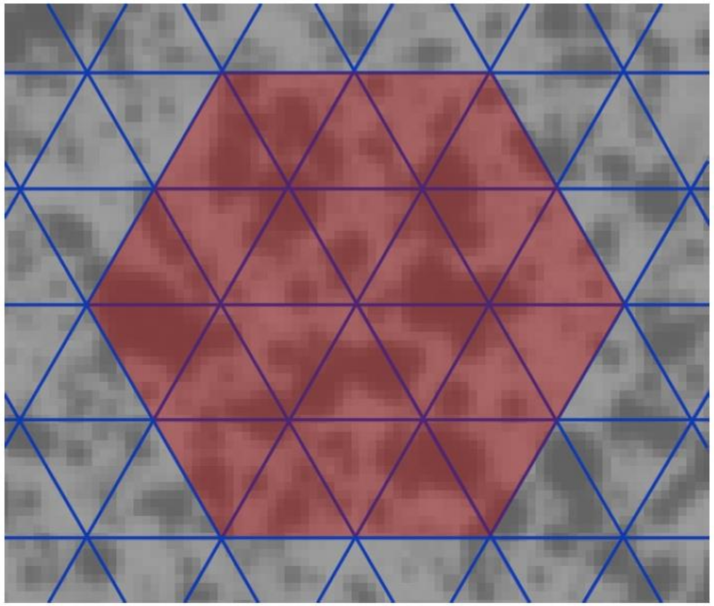
Graphical representation of the shear angle

THEORY

STRAIN TENSOR NEIGHBORHOOD AND STRAIN GAUGE LENGTH



Neighborhood size 1



Neighborhood size 2

The equivalent strain gauge length is the product of:

- Point distance
- Strain tensor neighborhood
- Size of a pixel in the field of view

THEORY
FILTERING

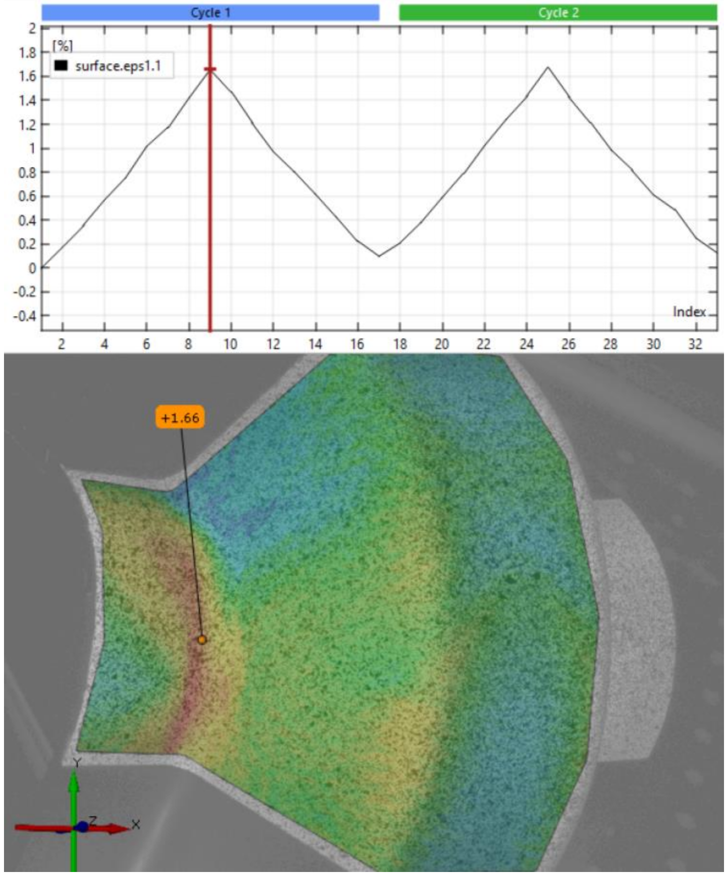
Spatial filter

- Average each data point with its neighbors
- Spreads hotspots
- Useful when material is uniform

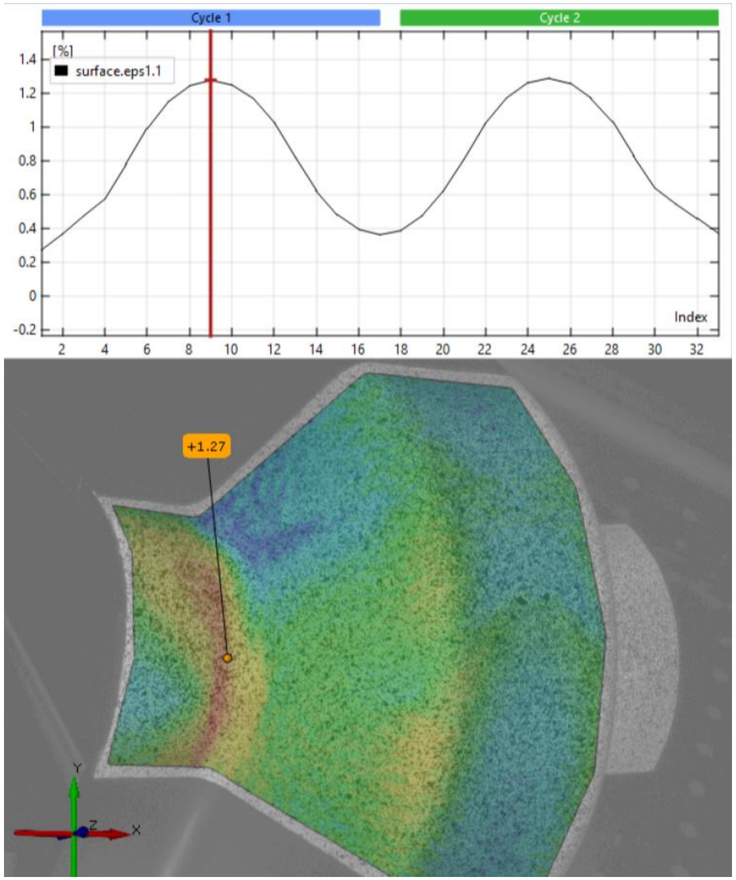
Time filter

- Average each data point with the previous and next stages
- Spreads hotspots
- Useful when acquisition speed are not quite adequate for the test speed
- Useful to smooth quasi-static data

THEORY
TEMPORAL FILTERING

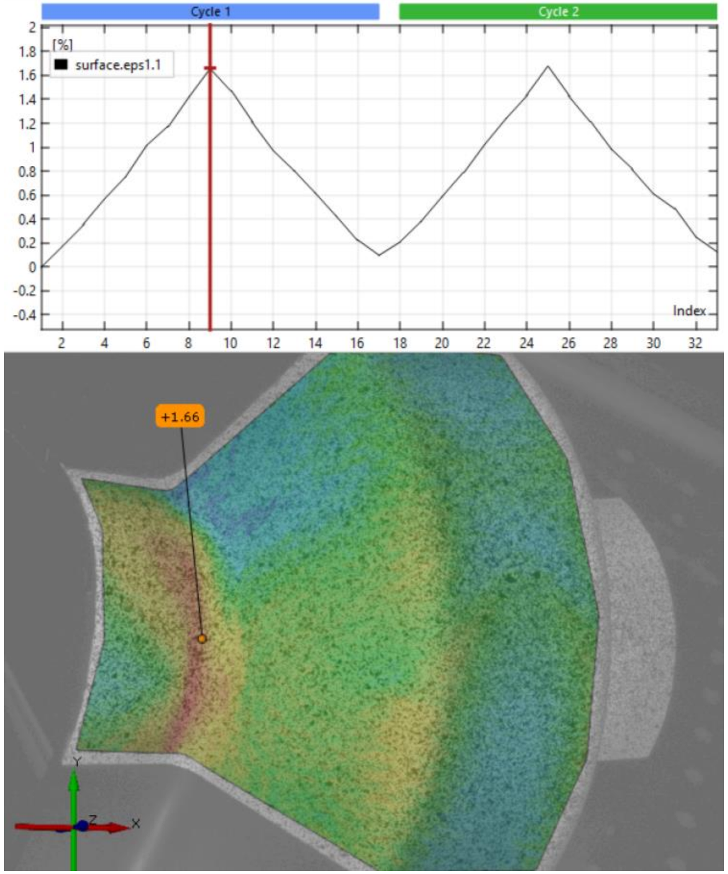


No filter

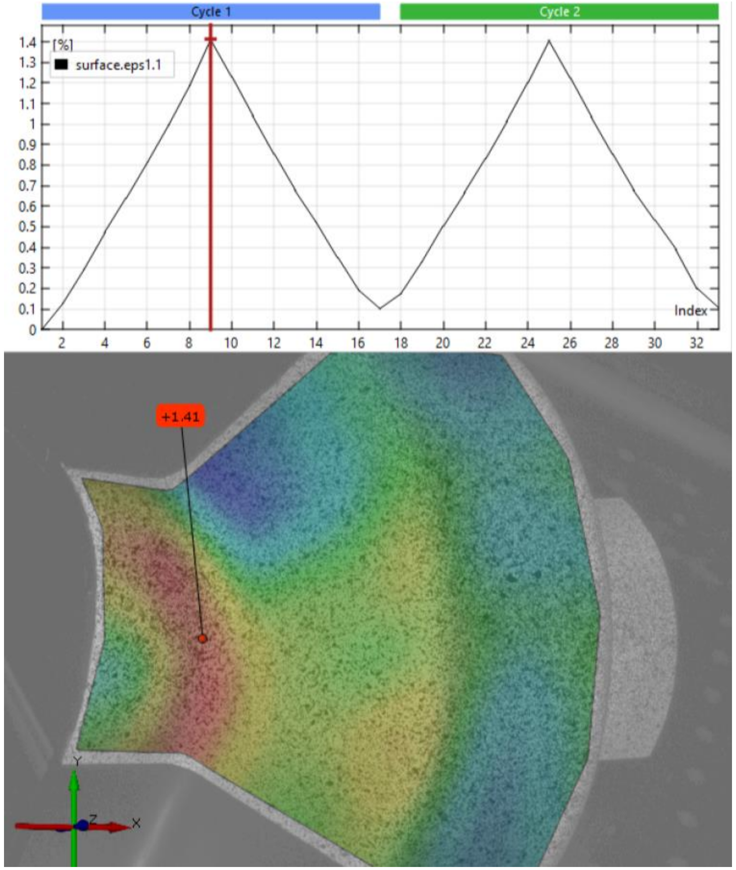


Time filter (5 passes)

THEORY
SPATIAL FILTERING



No filter



Spatial filter(5 passes)

THANK YOU
FOR YOUR ATTENTION

For more information, feel free to contact Trilion Quality Systems:

Jonathan Pickworth

Trilion Quality Systems
jopick@trilion.com
267.565.8062

Charles-Olivier Amyot

Trilion Quality Systems
charles@trilion.com
418.456.4327

Application Note

Nature & Technology: Vibrations Everywhere!

Field of Application

- A Aerospace
- B Audio & Acoustics
- C Automotive
- D Data Storage
- **G General Vibrometry**
- M MEMS & Microstructures
- P Production Testing
- S Scientific & Medical
- T Structural Testing
- U Ultrasonics

Polytec's Vibrometers are Indispensable Tools to Optimize Parts and Goods and to Investigate Natural Dynamic Processes

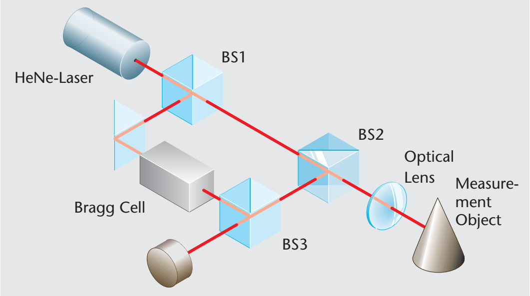
Originally developed to characterize man-made products, technology and systems, non-contact laser-Doppler vibrometry is also exploring measurements that unravel the mysteries of biological structures. Read on to learn more about vibrations in both nature and technical products and processes. Discover how these vibrations are detected and studied using laser vibrometry. Find more interesting applications and Polytec Application Notes on www.polytec.com/applications.

Introduction

The heart beats, wings flap, sounds are sent out and received – life would be much too quiet without vibrations. To investigate vibrating systems in nature requires sensitive and flexible measurements that don't disturb the specimen. Challenging tasks in medicine, biology and many other sciences take advantage of Polytec's universal modular vibrometers, single-box portable devices, or high-end scanning systems.

In the field of industrial research and development, Polytec's vibrometers are used to study objects of very different sizes including large automobile bodies, airplane fuselages, ship engines and buildings as well as tiny silicon micromachines, hard disk drive components and wirebonders. There are numerous other research applications in mechanical and civil engineering.

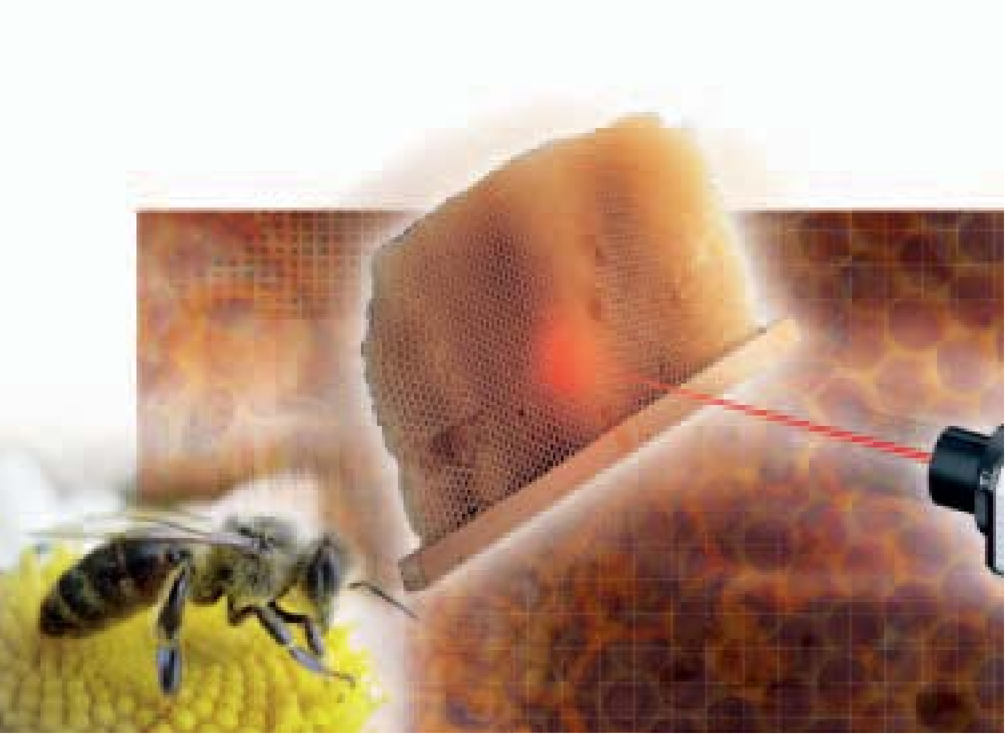
Demanding applications such as measurements on hot running exhausts, rotating surfaces, underwater objects, delicate structures or ultrasonic devices are all made possible by non-contact laser vibrometry.



At the heart of every Polytec vibrometer system is the laser Doppler vibrometer – a very precise optical transducer used for determining the vibration velocity and displacement at a point by sensing the frequency shift and phase variation of back scattered laser light from a moving surface.
To learn more about laser Doppler vibrometry, please visit **www.polytec.com/vib-university**

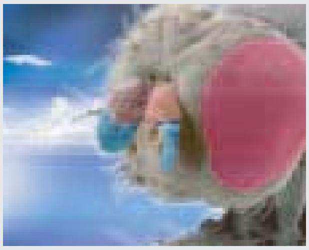
Polytec GmbH
Optical Measurement Systems
Application Note
VIB-G-05

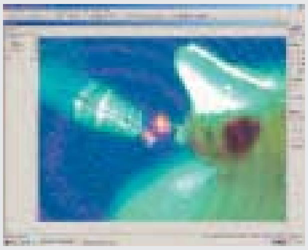
June 2006



Measurement of honeycomb vibrations generated by dancing bees

Drosophila head and laser spot focused onto its antenna sound receiver





Biology

For numerous living species on our planet there are corresponding biological applications of laser vibrometry. One of the most prominent is insect communication. Some insect sounds are quite loud, such as the singing of the cicada; while others are supersonic and can't be heard. Some insects are so small that their songs are transmitted mainly through a plant rather than air. Entomologists use vibrometers to record this unheard noise for later study. Consider honeycomb vibrations in beehives; these signals can only be measured with highly sophisticated equipment. Other bio applications include measuring communication between elephants, fruit ripeness, spider web motion, and the hearing mechanism in frogs and fruit flies.
www.polytec.com/research

Laser Audiometer providing full ear diagnostics within a couple of seconds

Laser vibrometer measurements of the vibration patterns of dental ultrasonic scaling equipment

Medical and Health Care

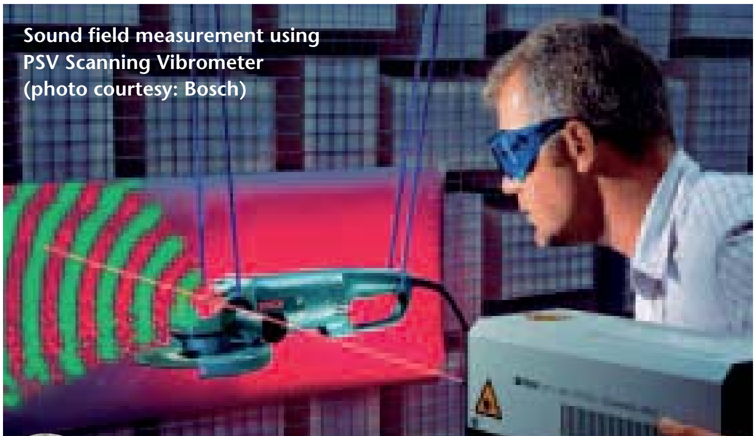
Laser vibrometry can assist with eardrum diagnostics and research on the middle and inner ear. In addition, vibrometers have been used for vibration measurements on artificial heart valves, mechanical properties of tendons, analysis of vibrations while bone drilling or medical laser ablation, and detection of bone crack propagation.

Medical, safety and health care devices like tooth brushes, dental scalers and respirators have been investigated using Polytec vibrometers. The vibrometer can also function as a non-contact polygraph detector recording artery pulse waves and respiratory activity, or as a remote voice detector as a part of a multi-media surveillance system.
www.polytec.com/research

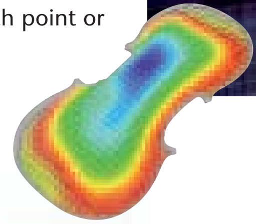
Scanning vibrometer representation of heart valve motion

Acoustics

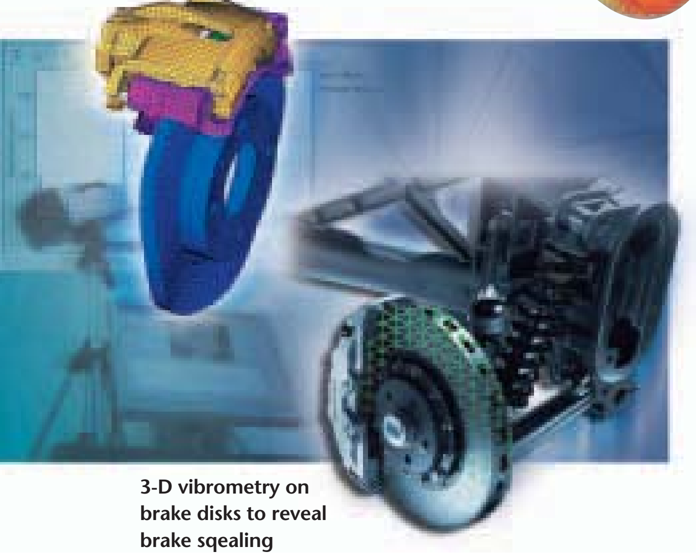
Musical instruments generate wonderful, inspiring sounds through their vibrations. Polytec vibrometers can help us understand how this happens with early work already done on violins, cembalos and dulcimers. Vibrometers are also indispensable tools for loudspeaker design identifying diaphragm resonances that are deleterious to the sound quality. Vibrometer measurements provide an experimental basis for sophisticated acoustic investigations like structural-acoustic response (sound field) predictions, acoustic imaging and anti-sound research. Acoustics are also increasingly important in product design. The focus is on how and where are undesired noises generated and at which point or location can countermeasures be taken.



Sound field measurement using PSV Scanning Vibrometer (photo courtesy: Bosch)



Operational deflection shape of a violin



3-D vibrometry on brake disks to reveal brake sqealing

3-D scanning measurement of structural dynamics of a car body

Valve train measurement using High Speed Vibrometer (photo courtesy: Porsche)

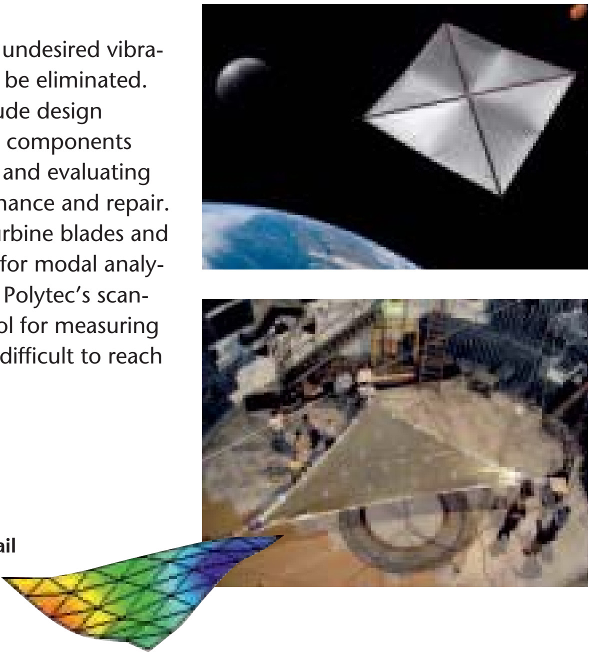
Automotive Development

To certify that a new part meets noise and vibration specifications, automotive engineers favor testing instruments that are easy to set up and operate, and that can exchange data with existing CAE equipment and software. Polytec's laser vibrometers are widely used both for structural dynamics measurements in the R&D labs and for quality control purposes in the production process. Laser vibrometry gives the opportunity to optimize dynamic automotive FE models by matching the parameters derived from vibration measurements on prototypes to the FE model. Scanning vibrometers provide time saving measurements without mass loading regardless whether on large areas, hot components, rotating parts, light weight surfaces, or at high frequencies.

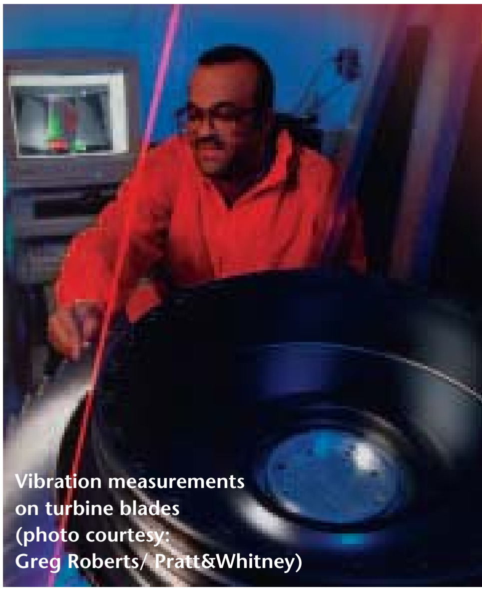
www.polytec.com/automotive

Aerospace Industry

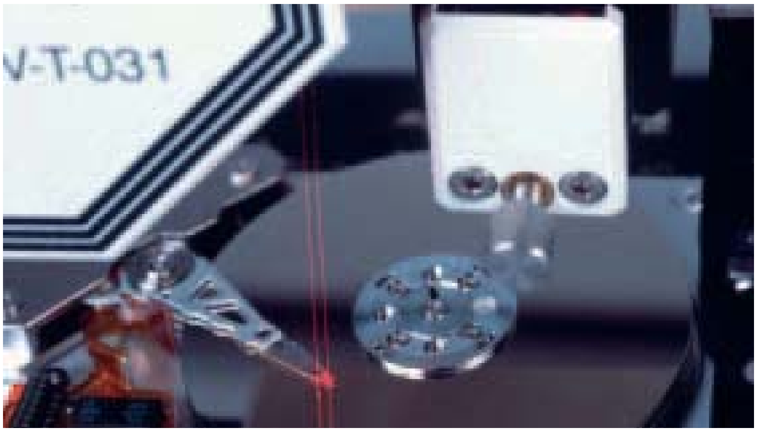
In the aerospace industry there are undesired vibrations of parts and bodies that must be eliminated. Typical aerospace applications include design verification, characterizing airframe components for production and quality control, and evaluating aging aircraft structures for maintenance and repair. Measurements on aircraft wings, turbine blades and space structures can be performed for modal analysis and subsequent FEM validation. Polytec's scanning vibrometer is also the ideal tool for measuring surfaces of large aerospace objects difficult to reach with contact methods.
www.polytec.com/aerospace



Modal tests for validation of a solar sail design (photos courtesy: NASA)



Vibration measurements on turbine blades (photo courtesy: Greg Roberts/ Pratt&Whitney)



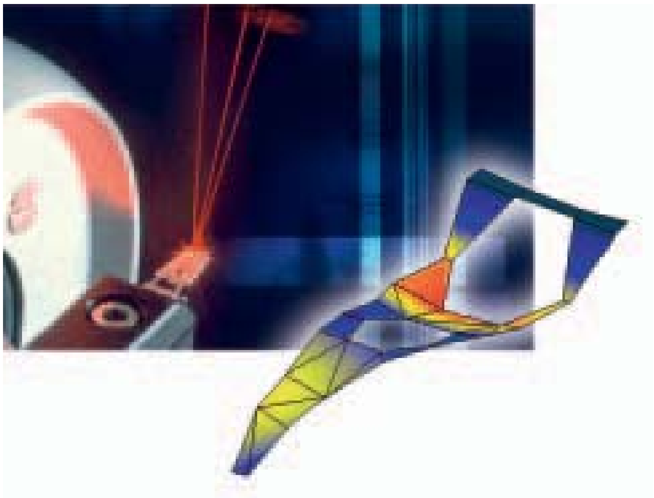
Determination of stable flying heights for a hard disk read/write head

Data Storage

In designing hard disk drives, one of the challenges is to understand how mechanical interactions affect positioning. Methods accompanying design, optimization and quality control have to be fast but highly sensitive and precise. When verifying a new drive design, fast testing time is paramount. Laser-Doppler vibrometers have been effectively used for many years in design of data storage media. Disk and tape drives and their components encompass a wide range of dynamic applications.
www.polytec.com/datastorage

Noise investigation in hard disk spindle motors using scanning vibrometry

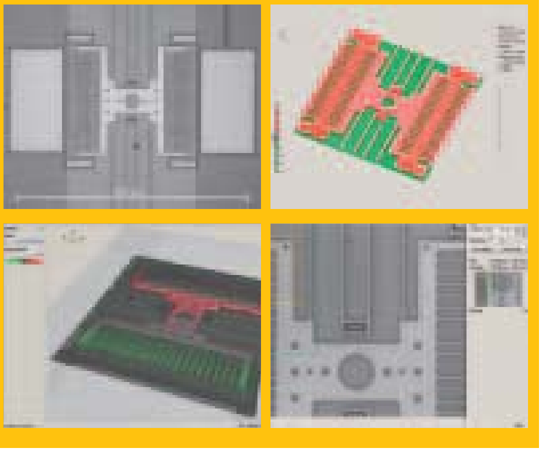
3-D vibration measurements for modal test on a disk drive suspension



MEMS and Microstructures

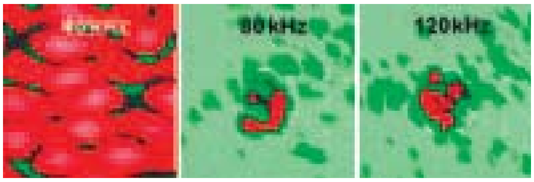
MEMS (Micro-Electro-Mechanical Systems) find numerous applications in the automotive, medical, bio-chemical and aeronautic industry. As a consequence there is a huge demand for standardized MEMS testing for both packaged and unpackaged devices (single die and wafer-level testing). Polytec's instrumentation for micro motion analysis enables the systematic testing of the dynamic mechanical response to important electrical and physical inputs, as well as the dynamic investigation of other microscopic structures ranging from natural objects to semiconductor components.
www.polytec.com/microstructures

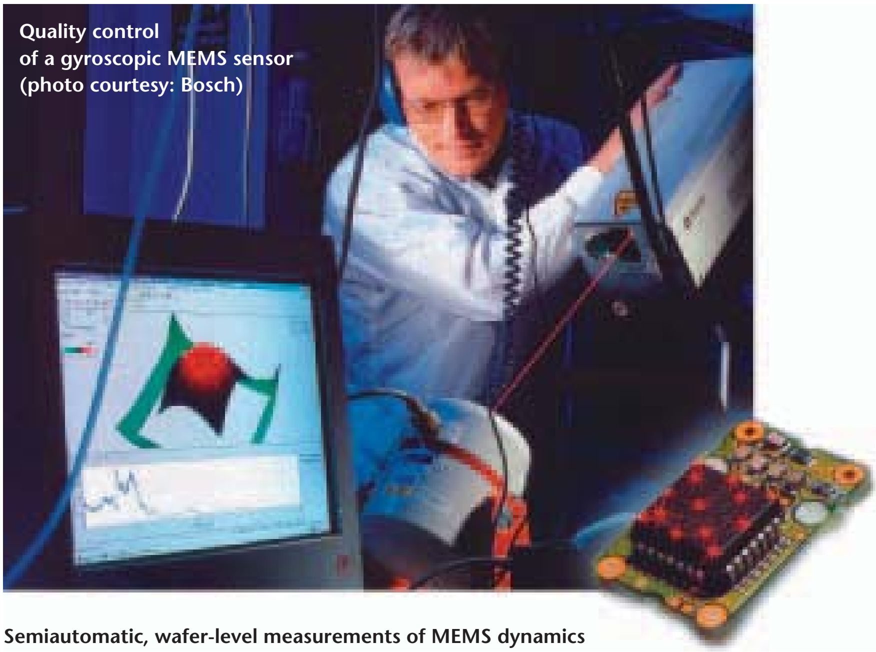
Combined measurement of surface topography, out-of-plane and in-plane vibration on a MEMS comb drive using the Polytec Micro System Analyzer



Vibration measurement on a cable-stayed bridge

Non-destructive testing of delamination in a composite material





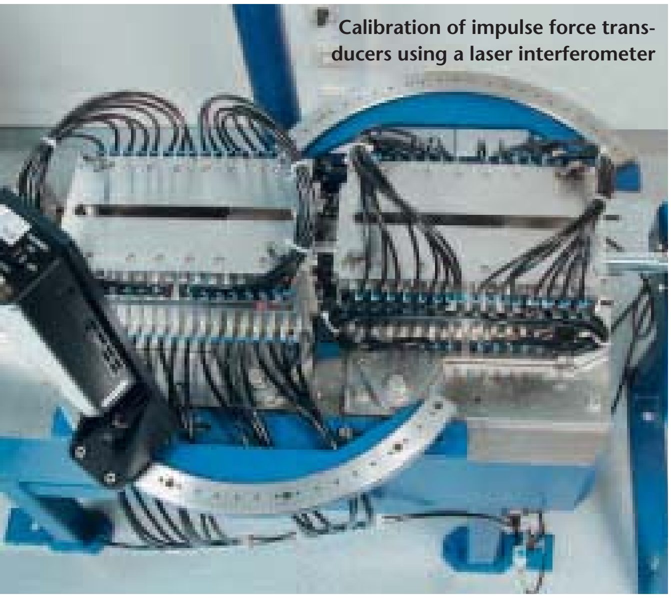
Quality control of a gyroscopic MEMS sensor (photo courtesy: Bosch)

Semiautomatic, wafer-level measurements of MEMS dynamics

Materials Research, Mechanical and Civil Engineering

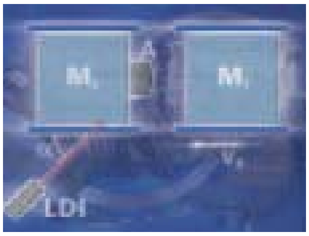
Laser vibrometry is an ideal tool for the measurement of structural dynamics and for non-destructive flaw detection (fracture, delamination, fatigue) in all kinds of materials, parts and components. For instance, vibrometry can be used for non-destructive testing and for the investigation of ultrasonic wire bonding.

Regarding buildings and industrial plants, there are many applications for in-the-field structural health monitoring on wind turbines, building vibration and displacement, and cable-stayed bridges to prevent bridge resonance failure. Geological applications include detection of land mines, rock failures and earthquake-induced defects in concrete.


Calibration of impulse force transducers using a laser interferometer

Metrology and Calibration

Primary calibration of vibration transducers by laser Interferometry has the unique advantage that measurements of surface acceleration, velocity or displacement are made with a precision that is traceable directly to the wavelength of laser light. Also, laser vibrometric velocity measurements offer the possibility to perform traceable impulse calibrations of transducers subjected to known impulse loads.

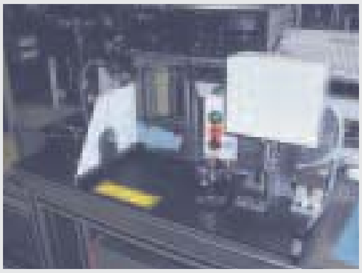


Production Testing

The optimization of products and processes plays an important role in a company's economic success. In industrial production, process and quality control relies on fast, automated and rugged measurement instrumentation. For both 100% quality control of manufactured products and on-line monitoring in continuous production, Polytec provides interferometric sensors that optically measure vibration, but also velocity, length and surface integrity. In addition, they offer many specific advantages for industrial production applications such as precise results without contact, a flexible retrofitting and continuous operation under industrial conditions with low maintenance.
www.polytec.com/industrial


Automated 100% quality assurance of vehicle components (photo courtesy: P. Marpe, TRW Automotive)


Semiautomatic test station based on a Compact Laser Vibrometer for quality control of medical devices


Automatic vibration analysis for crack testing of cam rings

Please find more interesting applications and Polytec Application Notes on **www.polytec.com/applications**

Polytec GmbH (Germany)
Polytec-Platz 1-7
76337 Waldbronn
Tel. +49 7243 604-0
Fax +49 7243 69944
info@polytec.de

Polytec France S.A.S.
Bâtiment Orion – 1er étage
39, rue Louveau
92320 Châtillon
Tel. +33 1 496569-00
Fax +33 1 57214068
info@polytec.fr

Polytec Ltd.
(Great Britain)
Lambda House, Batford Mill
Harpenden, Herts AL5 5BZ
Tel. +44 1582 711670
Fax +44 1582 712084
info@polytec-ltd.co.uk

Polytec Japan
Arena Tower, 13th floor
3-1-9, Shinyokohama,
Kohoku-ku, Yokohama-shi,
Kanagawa, 222-0033
Tel. +81 45 478-6980
Fax +81 45 478-6981
info@polytec.co.jp

Polytec, Inc. (USA)
North American Headquarters
16400 Bake Parkway
Suites 150 & 200
Irvine, CA 92618
Tel. +1 949 943-3033
Fax +1 949 679-0463
info@polytec.com

Central Office
1046 Baker Road
Dexter, MI 48130
Tel. +1 734 253-9428
Fax +1 734 424-9304

East Coast Office
25 South Street, Suite A
Hopkinton, MA 01748
Tel. +1 508 417-1040
Fax +1 508 544-1225

Advancing Measurements by Light