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**"HANDS-ON" COURSE ON STRESS WAVE MEASUREMENTS**

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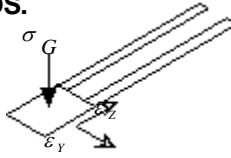
Dynasen's "Hands-On" course on stress wave measurements is a 3-day personalized and practical seminar which we offer to experimenters interested at learning or at improving their skills on the use of thin film stress sensors, with emphasis placed upon the measurements of non-planar shock waves. This course comprises 1) a review of fundamental shock wave definitions and concepts using simple mathematical formulations and 2) the performance by the participants (Hands-On) under our guidance of shock wave experiments using stress/strain gauge combinations and our fully-instrumented 2 1/2 Inch gas gun facility. Indeed, this seminar represents a unique opportunity to those interested in this subject, as it permits the participants to 1) learn at first-hand on the methods we have developed here at Dynasen over several years to measure non-planar waves using combined thin film stress/strain sensors 2) gather valuable experience in designing tests and in performing actual measurements and 3) provide an avenue to contribute to a very important but to-often neglected field of shock physics by suggesting new experiments, thus advancing the state-of-the-art and permitting one to publish on the subject. This seminar has been designed to provide its participants with maximum flexibility in its coverage so they can optimize their learning and investment. The material which we propose (but not limited to) to include in this course is as follows.

- A- Review of fundamental concepts and definitions of shock waves, stressing on physical meanings and simple phenomenological representations and those quantities which are typically measured in experimentation. Types of stress fields generated by impacts of solids.
- B- Constructions of commercially-produced thin film stress and strain sensors, principles of operations, limitations imposed by shock effects, Calibrations, Recording principles.
- C- Mounting of gauges in test assemblies, Description and functioning of excitation sources, Effects of cabling on signals, Inclusion effects on stress and strain fields.
- D- Combined effects of stresses and strains on thin film sensors, The use of a constantan strain gauge to infer strain on a given stress gauge and use of simple modeling to correct for its effect on the output of the stress gauge, Dynasen's past work on all types of thin film sensors.
- E- Types of gas gun tests that can be readily conducted to produce controlled planar and non-planar waves effects on thin film sensors, using well known solids such as PMMA. See reverse side for impact stress/strain scenarios that can be produced with Dynasen gas gun.

Upon arrival at Dynasen, the participants will be provided with a set of notes covering the materials presented during the course. At its conclusion, they also will be provided with hard-copy print-outs of gauge outputs generated by the tests performed, along with data stored on computer discs in Mac or DOS formats. This course is offered at a fixed price for attendance by two participants maximum and the performance a total of three impact tests for the period. See other side for typical scenarios achievable with our 2 1/2 Inch gas gun. Also presented, is a brief summary of simple modeling developed by Dynasen. The maximum velocity for our gun is .5 mm / microsecond. Our digital recording capability comprises 8 channels of 500Mhz, 4 channels of 350 Mhz. Data can be directly printed out from scope memories or transferred to our computer system for further analysis. A standard test comprises a total of four stress or strain gauges of any combination chosen by the participants. The target's and flyer's maximum diameters are 4 and 2 1/2 inches respectively. The number of thin film sensors per target can be increased to 8 at **\$225.50 per extra gauge**. This course can be extended to 4 or 5 days at an extra cost of **\$1075.00 per day**. The final designs of the desired gas gun test arrangements should be provided by FAX, email, or letter by attendees to Dynasen at least two weeks before the seminar to allow sufficient time for the preparation of targets and projectiles.

**\*\*COST: \$10,450.00 / 3 days minimum. 2-Attendees maximum. 3 or 4 persons may be accepted at \$1075.00 for each additional participant. \*\*Course booking and payment must be completed one month in advance. \*\***

**A. STRESS / STRAIN IMPACT SCENARIOS.**



**Stress / Strain Gauge**

**A. Plane Wave**

$$\sigma_X = \rho U_S U_P$$

$$\epsilon_X = \frac{U_P}{U_S}$$

$$\epsilon_Y = \epsilon_Z = 0$$

**B. Compression Stress / Compression Strain**

$$\sigma_G = \sigma_X \left( \cos^2 \theta + \left( \frac{r}{1-r} \right) \sin^2 \theta \right)$$

$$\epsilon_Z = (\sin^2 \theta) \epsilon_Y$$

where:  $0 < \theta < 90^\circ$

$$\lambda_P = \frac{2T_F}{C_L}$$

**C. Plane Wave Moment Compressive Stress / Tensile**

$$\sigma_G = f(t)$$

$$\epsilon_Y, \epsilon_Z = f(t)$$

**D. Diverging Wave Moment Compressive Stress / Tensile Strain**

$$\sigma_G = f(t)$$

$$\epsilon_Y = f(t)$$

$$\epsilon_Z = f(t)$$

**B. STRESS AND STRAIN EFFECT MODELING**

Our approach to stress and strain modeling rests upon using a dual-element thin film package that consists in a stress and a Constantan (Cn) strain elements mounted in a super-imposed or interlaced arrangement. Strain coefficients for both elements are derived from controlled stress/strain tests and material effect modeling. Experimentally it is found that a thin film stress gauge responds to both normal stress and lateral strains, whereas the Constantan strain gauge responds only to the effects of lateral strains. Because of close proximity and same size of elements, it is reasonable to stipulate that, when the above arrangement is exposed to a combined stress/strain field, both gauges will experience an identical normal stress and lateral strain effects. Therefore, we at Dynasen have proposed and used for many years a simple model which states that "the response of a thin film stress gauge in a stress/strain field is the sum of two distinct and independent effects, one being the normal stress and the other being the two lateral strains". Such model can be expressed by Eqs.1 and 2, realizing of course that its accuracy can be affected by large non-linear and non-symmetrical behaviors of gauges. We have also assumed in our modeling that the response to normal load by the stress element is identical to the one derived from plane wave calibration. Such modeling, however, has been found to be quite correct, simple and powerful when using our interlaced Manganin / Constantan grid gauge combination and bi-axially stretched PVDF/Bi-directional Constantan gauges. Improvement remains to be done on current modeling to extend its use with other types of stress gauges.

$$\frac{\Delta R}{R} = k_1 \sigma_G + G(\sum \epsilon_X, \epsilon_Z) \quad [1] \text{ [RESISTIVE GAUGES]} \quad \frac{Q}{A} = k_2 \sigma_G + \pi(\sum \epsilon_Y, \epsilon_Z) \quad [2] \text{ [PIEZOELECTRIC GAUGES]}$$

$$\frac{\Delta R}{R_0} = G(\sum \epsilon_Y, \epsilon_Z) \quad [3] \text{ [STRAIN SENSORS]}$$

WHERE :  $R$  = RESISTANCE,  $\sigma_G$  = NORMAL STRESS ON GAUGE,  $G$  = STRAIN FACTOR FOR RESISTIVE

GAUGE,  $\epsilon_Y, \epsilon_Z$  = LATERAL STRAINS,  $\pi$  = STRAIN FACTOR FOR PIEZOELECTRIC GAUGE.

$\frac{Q}{A}$  = CHARGE RELEASE PER UNIT AREA.