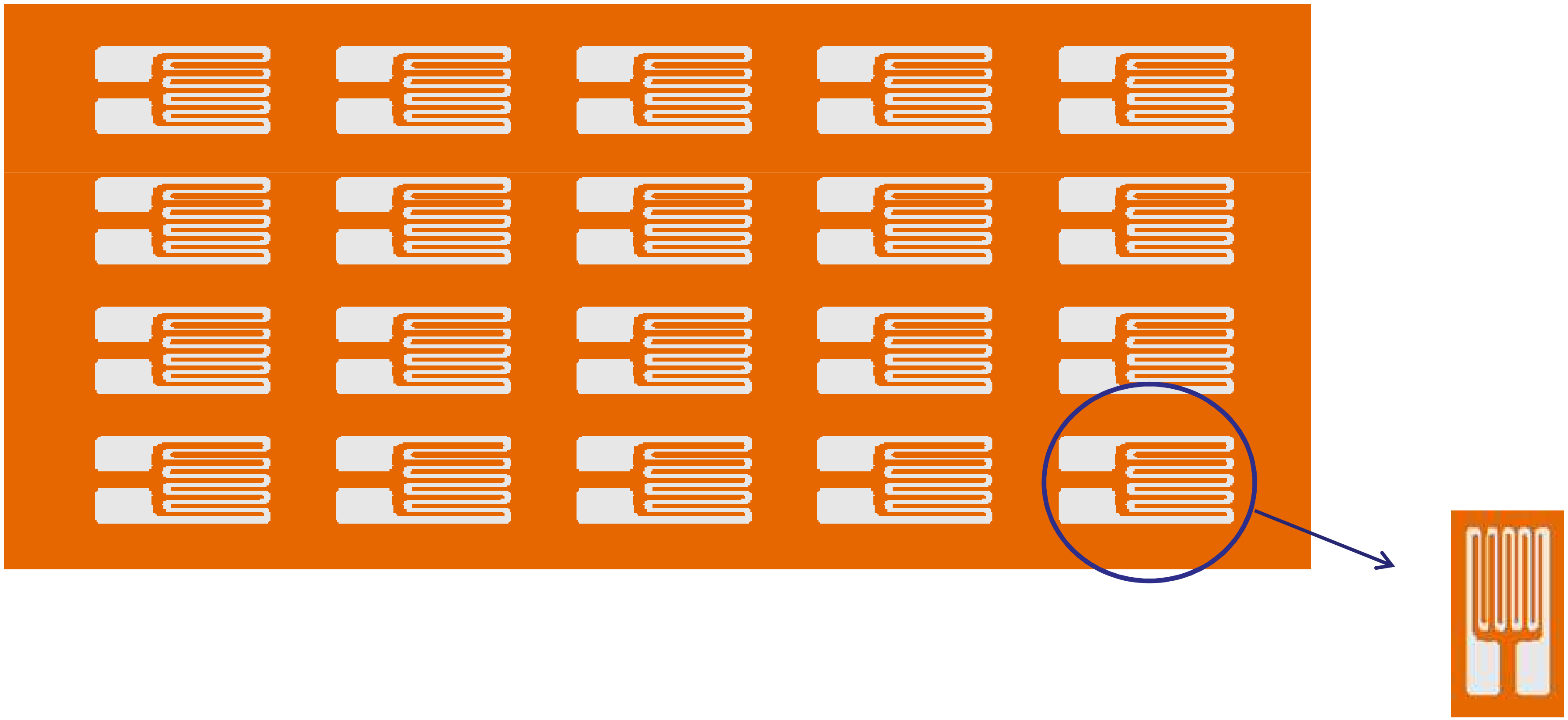
Strain Gage Calibration Factors for Constant Room Temperature Conditions

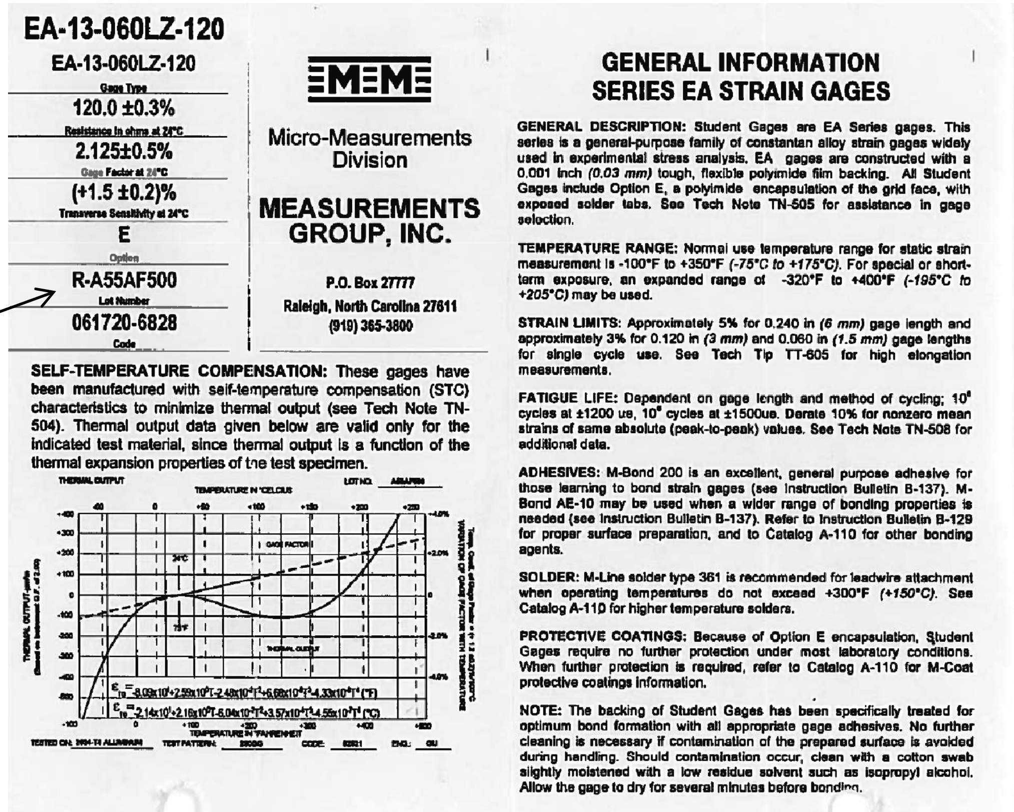
(Or equivalently, measurement of the room temperature *Gage Resistance*, *Gage Factor* and *Transverse Sensitivity Coefficient*)

As previously discussed, photolithography is used to produce a large number of strain gages from a single parent metal foil…called a strain gage "lot"



The lot number is provided by the manufacturer when a strain gage is purchased:

Lot Number



EA-13-060LZ-120

EA-13-060LZ-120
Gage Type
120.0 ±0.3%
Resistance in ohms at 24°C
2.125±0.5%
Gage Factor at 24°C
(+1.5 ±0.2)%
Transverse Sensitivity at 24°C
E
Option
R-A55AF500
Lot Number
061720-6828
Code

MM

Micro-Measurements Division

MEASUREMENTS GROUP, INC.

P.O. Box 27777
Raleigh, North Carolina 27611
(919) 365-3800

SELF-TEMPERATURE COMPENSATION: These gages have been manufactured with self-temperature compensation (STC) characteristics to minimize thermal output (see Tech Note TN-504). Thermal output data given below are valid only for the indicated test material, since thermal output is a function of the thermal expansion properties of the test specimen.

GENERAL INFORMATION SERIES EA STRAIN GAGES

GENERAL DESCRIPTION: Student Gages are EA Series gages. This series is a general-purpose family of constantan alloy strain gages widely used in experimental stress analysis. EA gages are constructed with a 0.001 inch *(0.03 mm)* tough, flexible polyimide film backing. All Student Gages include Option E, a polyimide encapsulation of the grid face, with exposed solder tabs. See Tech Note TN-505 for assistance in gage selection.

TEMPERATURE RANGE: Normal use temperature range for static strain measurement is -100°F to +350°F *(-75°C to +175°C)*. For special or short-term exposure, an expanded range of -320°F to +400°F *(-195°C to +205°C)* may be used.

STRAIN LIMITS: Approximately 5% for 0.240 in *(6 mm)* gage length and approximately 3% for 0.120 in *(3 mm)* and 0.060 in *(1.5 mm)* gage lengths for single cycle use. See Tech Tip TT-605 for high elongation measurements.

FATIGUE LIFE: Dependent on gage length and method of cycling; 10^6 cycles at ±1200 ue, 10^8 cycles at ±1500ue. Derate 10% for nonzero mean strains of same absolute (peak-to-peak) values. See Tech Note TN-508 for additional data.

ADHESIVES: M-Bond 200 is an excellent, general purpose adhesive for those learning to bond strain gages (see Instruction Bulletin B-137). M-Bond AE-10 may be used when a wider range of bonding properties is needed (see Instruction Bulletin B-137). Refer to Instruction Bulletin B-129 for proper surface preparation, and to Catalog A-110 for other bonding agents.

SOLDER: M-Line solder type 361 is recommended for leadwire attachment when operating temperatures do not exceed +300°F *(+150°C)*. See Catalog A-110 for higher temperature solders.

PROTECTIVE COATINGS: Because of Option E encapsulation, Student Gages require no further protection under most laboratory conditions. When further protection is required, refer to Catalog A-110 for M-Coat protective coatings information.

NOTE: The backing of Student Gages has been specifically treated for optimum bond formation with all appropriate gage adhesives. No further cleaning is necessary if contamination of the prepared surface is avoided during handling. Should contamination occur, clean with a cotton swab slightly moistened with a low residue solvent such as isopropyl alcohol. Allow the gage to dry for several minutes before bonding.

Typical data sheet provided with strain gages

Gage Resistance, Gage Factor and Transverse Sensitivity

• The gage resistance, gage factor (S_g) and transverse sensitivity coefficient (K_t) are strain gage calibration constants *measured by the gage manufacturer* and provided to the user (average and standard deviation of the lot provided):

Gage Resistance

Gage Factor, S_g

Transverse Sensitivity Coefficient, K_t

EA-13-060LZ-120

EA-13-060LZ-120
Gage Type

120.0 ±0.3%
Resistance in ohms at 24°C

2.125±0.5%
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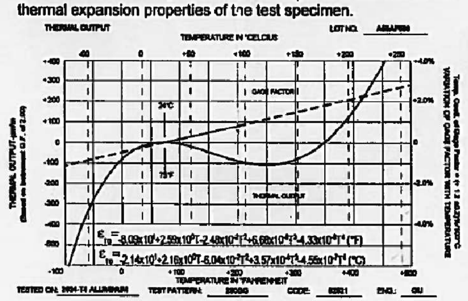

GENERAL INFORMATION
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Typical data sheet provided with strain gages

Gage Resistance, Gage Factor and Transverse Sensitivity

- The gage resistance, gage factor (S_g) and transverse sensitivity coefficient (K_t) are strain gage calibration constants *measured by the gage manufacturer* and provided to the user (average and standard deviation of the lot provided):
    - The gage factor S_g relates the change in gage resistance due to axial strains
    - The transverse sensitivity coefficient K_t relates the change in gage resistance to transverse strains
- Both S_g and K_t are measured in accordance with ASTM E251-92

Measurement of the Gage Factor

- Several gages from a lot of gages are bonded to a constant stress cantilever beam described in the E251 standard and made from a standard calibration material (normally 1018 steel).
- Specimen design and loading frame allows both tensile and compressive stress/strains to be easily applied

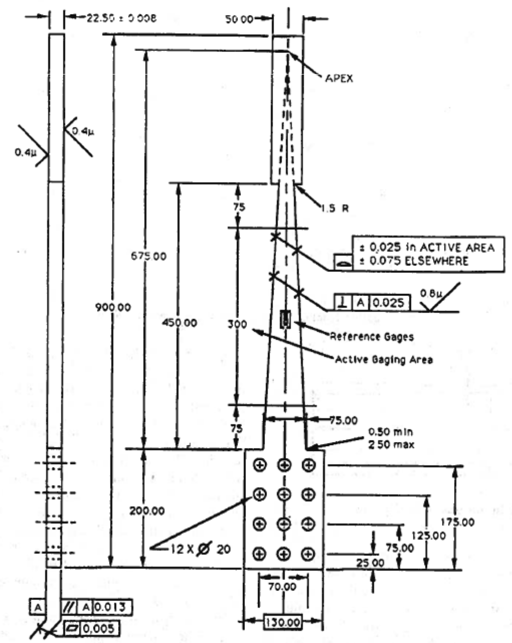


FIG. 6 Constant Stress Cantilever Beam

Sketch of constant stress beam
(from ASTM E251-92)

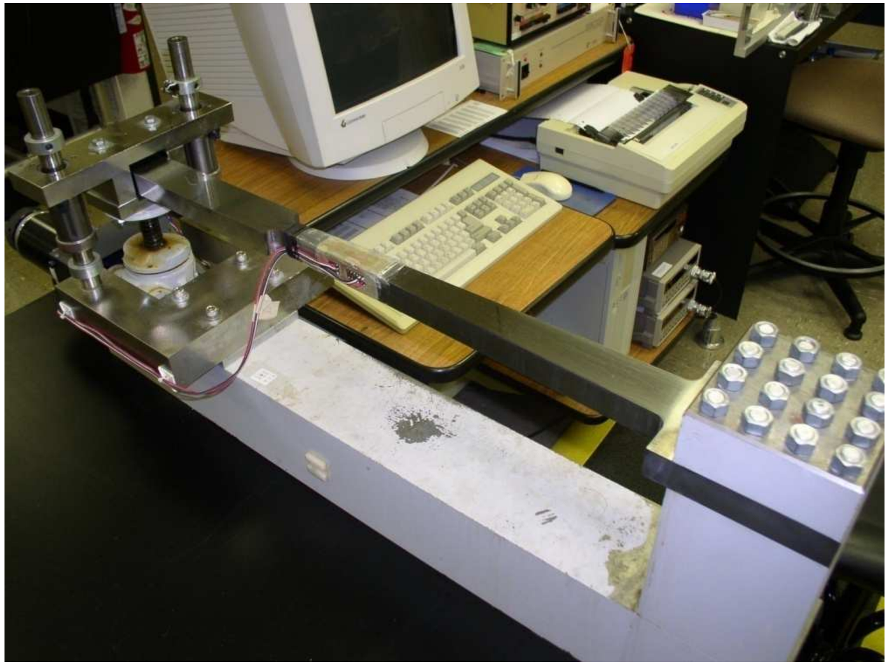


Photo courtesy Becky Showalter, M-M Group

Measurement of the Gage Factor (cont'd)

- Initial resistance is measured (R)
- Stress is increased until an axial strain $\varepsilon = \pm 1000\ \mu\varepsilon$ is induced at gage site (i.e., separate gages mounted on tensile and compressive sides of cantilever beam)
- Corresponding change in resistance is measured (ΔR)
- Gage factor calculated: $S_g = \dfrac{\left(\Delta R / R\right)}{\varepsilon}$
- Measurement repeated for several gages; average and tolerance provided to user

Measurement of the Gage Factor (cont'd)

- Note: The strain sensitivity of the gage alloy, S_A, is often confused with the gage factor , S_g:

$$S_A = \frac{\left(\Delta R / R\right)}{\varepsilon} \qquad\qquad S_g = \frac{\left(\Delta R / R\right)}{\varepsilon}$$

(….confusion is understandable!!)

- Suppose a constantan foil gage is used. Would you expect the gage factor for the constantan foil gage to differ from the strain sensitivity of the constantan wire?

Measurement of the Gage Factor (cont'd)

- During measurement of S_A the constantan ***wire*** is subjected to a uniaxial stress and allowed to contract "naturally" (i.e., according to the Poisson ratio of constantan, ν_{const})

- During measurement of S_g the constantan foil is bonded to a ***calibration material***, and the assembly is subjected to a uniaxial stress; the constantan foil gage does not contract "naturally", but rather is forced to contract according to the Poisson ratio of the calibration material, ν_o (Poisson ratio of 1018 steel is 0.285)

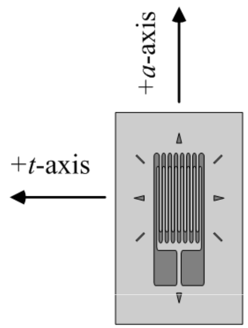
- So, the state of strain during measurement of S_A is not necessarily equivalent to the state of strain during measurement of S_g ….

- Would you expect the gage factor for the constantan foil gage to differ from the strain sensitivity of the constantan wire?

  Yes (….unless $\nu_o = \nu_{const}$ ….)

Significance of the Transverse Sensitivity Coefficient

- Given: a strain gage subjected to in-plane strains referenced to the *a-t* coordinate system: ε_a, ε_t, γ_{at}



- Define three types of strain gage strain sensitivities

S_a = axial strain sensitivity = $(\Delta R/R)/\varepsilon_a$

S_t = transverse strain sensitivity = $(\Delta R/R)/\varepsilon_t$

S_s = shear strain sensitivity = $(\Delta R/R)/\gamma_{at}$

Significance of the Transverse Sensitivity Coefficient

- Assuming gage alloys exhibits linear strain sensitivities, principle of superposition applies:

$$\frac{\Delta R}{R} = S_a \varepsilon_a + S_t \varepsilon_t + S_s \gamma_{at} \qquad (6.4)$$

- Experimental measurements show:

S_s = shear strain sensitivity = 0

- Define the transverse sensitivity coefficient: $K_t = S_t/S_a$

Eq (6.4) becomes:

$$\frac{\Delta R}{R} = S_a (\varepsilon_a + K_t \varepsilon_t) \qquad (6.5)$$

Significance of the Transverse Sensitivity Coefficient

- During measurement of the S_g:

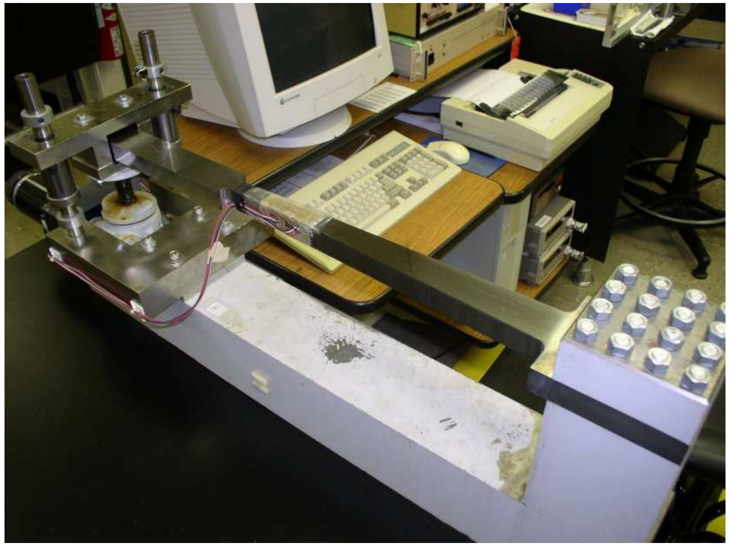
$$\varepsilon_t = -\nu_o \varepsilon_a$$

- According to Eq (6.5) then:

$$\frac{\Delta R}{R} = S_a (1 - \nu_o K_t) \varepsilon_a$$

- Therefore:

$$S_g = \frac{\left(\Delta R / R\right)}{\varepsilon_a} = S_a (1 - \nu_o K_t)$$



Measurement of the Transverse Sensitivity Coefficient

- K_t is measured using a special fixture that induces an (in-plane) uniaxial *strain* field (described in ASTM E251 standard)

- Separate gages oriented to measure
  - Axial strain: $S_a = (\Delta R/R)/\varepsilon_a$
  - Transverse strain: $S_t = (\Delta R/R)/\varepsilon_t$
  - $K_t = S_t/S_a$

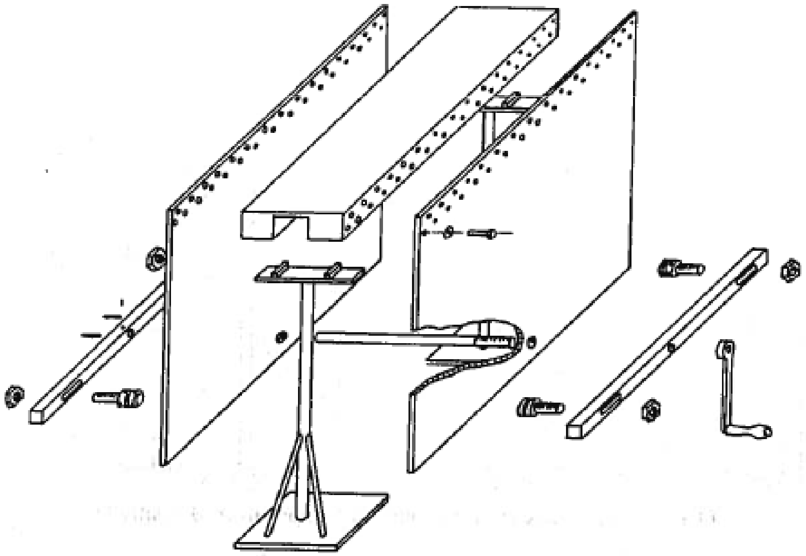


FIG. 14 Transverse-Sensitivity Test Rig

Sketch of transverse sensitivity test rig (from ASTM E251-92)

Photo courtesy Becky Showalter, M-M Group

Measurement of the Transverse Sensitivity Coefficient

- Transverse sensitivity is an undesirable effect…gage manufacturers have successfully minimized (but not eliminated) this phenomenon

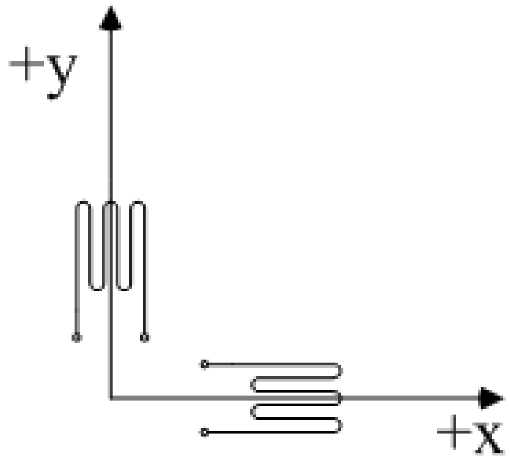
Table 6.3

Gage factor S_g, axial sensitivity S_a, transverse sensitivity S_t, and transverse-sensitivity factor K_t for several different foil-type strain gages.

Gage Designation	S_g	S_a	S_t	K_t (%)
EA-06-015CK-120	2.13	2.14	0.0385	1.8
EA-06-030TU-120	2.02	2.03	0.0244	1.2
WK-06-030TU-350	1.98	1.98	0.0040	0.2
EA-06-062DY-120	2.03	2.04	0.0286	1.4
WK-06-062DY-350	1.96	1.96	−0.0098	−0.5
EA-06-125RA-120	2.06	2.07	0.0228	1.1
WK-06-125RA-350	1.99	1.98	−0.0297	−1.5
EA-06-250BG-120	2.11	2.11	0.0084	0.4
WA-06-250BG-120	2.10	2.10	−0.0063	−0.3
WK-06-250BG-350	2.05	2.03	−0.0690	−3.4
WK-06-250BF-1000	2.07	2.06	−0.0453	−2.2
EA-06-500AF-120	2.09	2.09	0.0	0
WK-06-500AF-350	2.04	1.99	−0.1831	−9.2
WK-06-500BH-350	2.05	2.01	−0.1347	−6.7
WK-06-500BL-1000	2.06	2.03	−0.0893	−4.4

*This data is approximate as the values depend on the lot of foil used in gage fabrication.

Correcting for Transverse Sensitivity Effects
Biaxial (Tee) Rosettes



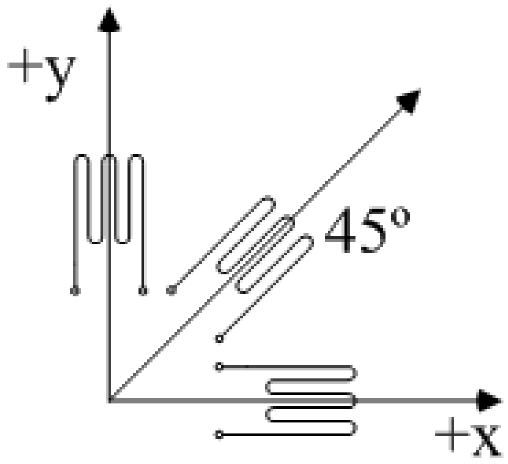
- Denote measured strains as ε_{mx} and ε_{my}
- Strains corrected for transverse sensitivity effects are:

$$\varepsilon_x = \frac{(1-\nu_o K_t)}{(1-K_t^2)}\left[\varepsilon_{mx} - K_t \varepsilon_{my}\right]$$

$$\varepsilon_y = \frac{(1-\nu_o K_t)}{(1-K_t^2)}\left[\varepsilon_{my} - K_t \varepsilon_{mx}\right]$$

where:
K_t = transverse sensitivity coefficient
ν_o = Poisson ratio of the calibration material used by gage manufacturer (usually $\nu_o = 0.285$)

Correcting for Transverse Sensitivity Effects
3-Element Rectangular Rosettes



- Denote measured strains as ε_{mx}, ε_{m45}, and ε_{my}
- Strains corrected for transverse sensitivity effects are:

$$\varepsilon_x = \frac{(1-\nu_o K_t)}{(1-K_t^2)}\left[\varepsilon_{mx} - K_t \varepsilon_{my}\right]$$

$$\varepsilon_{45} = \frac{(1-\nu_o K_t)}{(1-K_t^2)}\left[\varepsilon_{m45} - K_t(\varepsilon_{mx} + \varepsilon_{my} - \varepsilon_{m45})\right]$$

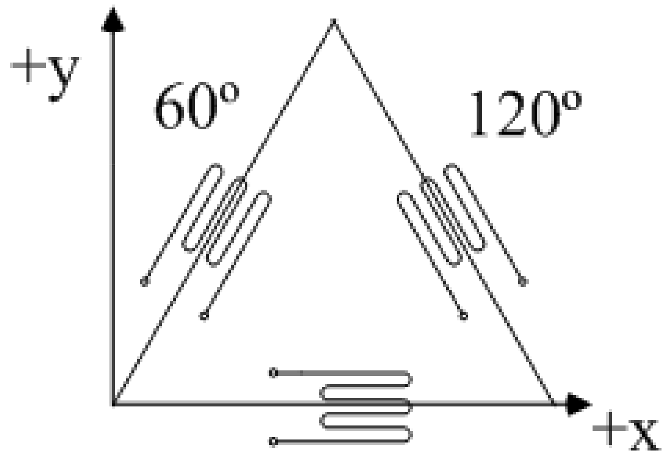
$$\varepsilon_y = \frac{(1-\nu_o K_t)}{(1-K_t^2)}\left[\varepsilon_{my} - K_t \varepsilon_{mx}\right]$$

where:

K_t = transverse sensitivity coefficient

ν_o = Poisson ratio of the calibration material used by gage manufacturer (usually $\nu_o = 0.285$)

Correcting for Transverse Sensitivity Effects
3-Element Delta Rosettes



- Denote measured strains as ε_{mx}, ε_{m60}, and ε_{m120}
- Strains corrected for transverse sensitivity effects are:

$$\varepsilon_x = \frac{(1-\nu_o K_t)}{(1-K_t^2)}\left[\left(1+\frac{K_t}{3}\right)\varepsilon_{mx} - \frac{2K_t}{3}\left(\varepsilon_{m60}+\varepsilon_{m120}\right)\right]$$

$$\varepsilon_{60} = \frac{(1-\nu_o K_t)}{(1-K_t^2)}\left[\left(1+\frac{K_t}{3}\right)\varepsilon_{m60} - \frac{2K_t}{3}\left(\varepsilon_{mx}+\varepsilon_{m120}\right)\right]$$

$$\varepsilon_{120} = \frac{(1-\nu_o K_t)}{(1-K_t^2)}\left[\left(1+\frac{K_t}{3}\right)\varepsilon_{m120} - \frac{2K_t}{3}\left(\varepsilon_{mx}+\varepsilon_{m60}\right)\right]$$

where:

K_t = transverse sensitivity coefficient

ν_o = Poisson ratio of the calibration material used by gage manufacturer (usually ν_o = 0.285)