

Strain Capacity of the Gauge:

The maximum strain handled by a strain-gauge element is limited by factors such as strength, creep problems associated with the bonding material (epoxy), and hysteresis.

ϵ_{max} limit is specified by Manufacturer: typically $3000 \mu\epsilon$

If Max Torque that the sensor should handle is T_{max}

(Page 71 Notes) Equation $\epsilon = \frac{\gamma}{2GJ} \cdot T$; $\frac{\gamma}{2GJ} T_{max} \leq \epsilon_{max}$

or $J \geq \frac{\gamma}{2G} \cdot \frac{T_{max}}{\epsilon_{max}}$; ϵ_{max} and T_{max} Specified by Manufacturer.

Strain-Gauge Nonlinearity Limit:

For large strains, the characteristic equation of a strain gauge becomes increasingly nonlinear. This is particularly true for SC gauges.

Recall $\frac{\delta R}{R} = S_1 \epsilon + S_2 \epsilon^2$ For a specific non-linearity, an upper limit

Linear gauge factor

for strain can be determined by $\frac{\gamma}{2GJ} T_{max} = \epsilon_{max} \leq \frac{N_p S_1}{50 S_2}$

and J is given by: $J \geq \frac{25 S_2}{G S_1} \cdot \frac{T_{max}}{N_p}$ ← %ge Non-Linearity

Sensitivity Requirement:

The signal level of the amplifier output has to be sufficiently high so that the SNR is adequate, otherwise, serious noise problems can result.

Typically Max Voltage in order of $\pm 10V$ is desired

Recall Amplifier output $V = K_a \delta V_0$ ← bridge output before Amplification
← Amplifier Gain.

Gain has limitation \rightarrow Saturation.

Saturation \rightarrow instability such as drift

∴ Improve Sensitivity through Mechanical considerations.

Using $T = \frac{8GJ}{K S_3 r} \cdot \frac{\delta V_0}{V_{ref}}$ and substituting into $V = K_a \delta V_0$

We get $V_0 \leq \frac{K_a K S_3 r V_{ref}}{8GJ} T_{max}$

Lower Limit of Bridge output \therefore Limiting design value of $J \leq \frac{K_a K S_3 r V_{ref}}{8G} \cdot \frac{T_{max}}{V_0}$ ← Specified.

Stiffness Requirement

The lower limit of the overall stiffness of the system is constrained by:

- Speed of response (represented by system bandwidth) and
- Steady-state error (represented by system gain).

The polar moment of area J should be chosen such that the stiffness of the torsional element does not fall below a specified limit K .

For shaft length ' L ', radius ' r ', twist angle θ

$$\text{shear strain } \gamma = \frac{r\theta}{L}$$

$$\text{shear stress } \tau = \frac{G r \theta}{L}$$

Note shear stress of a shaft is $\tau = \frac{T r}{J}$

\therefore Torsional stiffness is given by $\frac{T}{\theta}$:

$$\frac{T \cdot r}{J} = \frac{G r \theta}{L}$$

$$\therefore \boxed{\frac{T}{\theta} = \frac{G J}{L}} \quad G J A ; \text{ stiffness } \uparrow \begin{array}{l} \text{Rotor} \\ \text{sensitivity} \\ \text{goes down} \end{array}$$

Assuming stiffness limit $\left(\frac{T}{\theta}\right) = K$ (Some Specified)

• select shortest possible ' L ' in sensor

$$\therefore J \geq \frac{L}{G} K \quad : \quad \text{Advantage: won't affect Bridge sensitivity}$$

Deflection Torque Sensors:

Instead of measuring strain in the sensor element, the actual deflection or deformation (twisting or bending) may be measured and used to determine torque, through a suitable calibration constant. For a circular-shaft (solid or hollow) torsional element, the governing relationship for the angle of twist θ for an applied torque T is given by:

$$T = \left(\frac{GJ}{L} \right) \theta$$

← Calibration Constant.

$\frac{GJ}{L}$ should be small to get high sensitivity

⇒ Low stiffness → which limits the Bandwidth

Limiting Bandwidth → Speed of Response

Limits Gain → leads to steady-state Error of System.

For high BW → θ should be small

* Dealing With 3-types of displacements

1- Sensor directly measures the angle of TWIST

2- Sensor uses the change in magnetic Induction associated with sensor deformation

3- uses reverse Magnetostriction

Change dimension/shape during Magnetization.

- Energy loss due to frictional heating
- Also responsible for low-pitched humming sound (from transformer).