

# Implications of Location of Strain Gauges and Excitation Voltage Over the Metrological Performance of Trapezoidal-Shaped Force Transducer



Richa Saxena and Harish Kumar

**Abstract** The present study discusses the effect of location of strain gauges and excitation voltage of the digital indicator over the metrological characterization of the force transducer. A trapezoidal-shaped force transducer of nominal capacity 50 kN has been investigated in which two locations for mounting the strain gauges have been identified based on FEA. The evaluation of metrological characteristics has been based on ISO 376: 2011. The relative deviations due to repeatability, reproducibility, interpolation, and expanded uncertainty of measurement has been reported in this work. A comparative analysis has been performed between the observations recorded at 5 V and 10 V excitation voltages. Results show that the effect of increased excitation voltage of the digital indicator is insignificant over the uncertainty of measurement of the force transducer. The location of strain gauges affects the sensitivity of the transducer, significantly.

**Keywords** Excitation voltage · Force measurement · Metrological characteristics · Uncertainty of measurement

## 1 Introduction

A strain-gauged trapezoidal-shaped force transducer has been investigated in this study for force measurement in applications like onsite calibration of large testing machines to test the value of externally applied loadings, identification of materials' strength, verification of uniaxial testing machines, calibration of hardness blocks, etc. [1, 2]. A Wheatstone bridge configuration is used for measurement of strain produced, upon applying an external unknown force. The gauge factor represents the sensitivity of the strain gauge.

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R. Saxena (✉)

Department of Mechanical Engineering, Government Polytechnic Kotana, Baghpat, UP, India  
e-mail: [richa.pn@gmail.com](mailto:richa.pn@gmail.com)

H. Kumar

Department of Mechanical Engineering, National Institute of Technology Delhi, Delhi, India

Mounting of strain gauges at the maximum stress/strain positions is desirable for achieving the maximum sensitivity of SGFT [3]. In this investigation, an attempt has been made to identify the performance of SGFT by mounting the strain gauges at two different locations. Excitation voltage is another parameter which could affect the transducer's sensitivity [4]. A comparison of metrological characterization of EN 8-based trapezoidal-shaped SGFT at 5 and 10 V excitation voltage is being discussed here.

## 2 Fabrication

The trapezoid geometry is machined from a EN 8 steel specimen using vertical milling machine. The dimensions are considered as follows: 180 mm outer length, 160 mm inner length, 35 mm width, and 30 mm end boss diameter [5]. The machined component is annealed at 800 °C for relieving the internal stresses. Annealing causes softening of the component. So, hardening is performed for increasing the hardness by oil quenching [6]. Surface finishing operation is performed for mounting strain gauges for force measurement [7, 8].

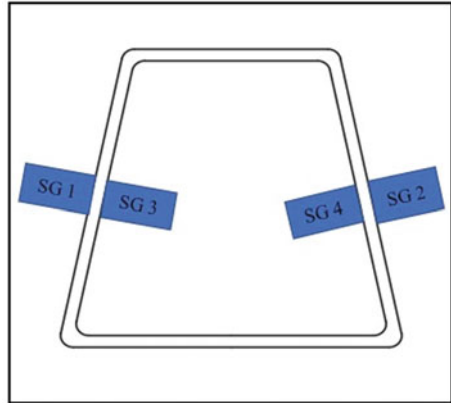
### 2.1 Mounting of Strain Gauges

The maximum stress–strain locations are selected for mounting strain gauges. Two positions are being identified in this case for examining the location-effect upon the metrological performance of the transducer [3, 9]. Strain gauges 1 and 2 are mounted orthogonally on the outer surface of the trapezoid geometry. Strain gauges 3 and 4 are mounted on the inner surface, orthogonally. These four strain gauges form a full Wheatstone bridge at Position A. Strain gauges 5, 6, 7, and 8 form another full Wheatstone bridge at Position B, as shown in Figs. 1 and 2.

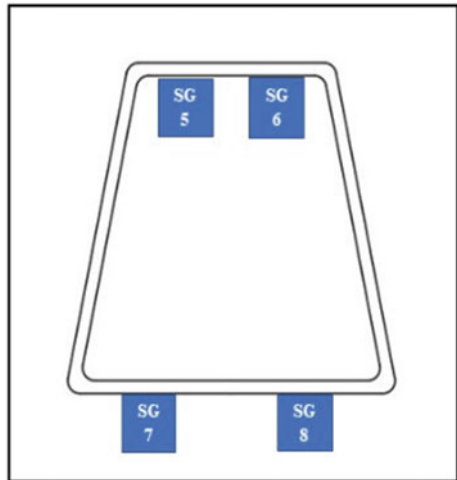
## 3 Evaluation of Uncertainty of Measurement

The measurement result has to be stated as a magnitude value of force along with its uncertainty, including the SI unit of force. The measured force value must be linked to a reference through a recognized continual traceability chain. An essential tool in ensuring the traceability of measurement is the calibration of the force measuring instrument. Calibration establishes the performance characteristics of a transducer before its actual use [10]. Calibration in accordance to ISO 376: 2011 [11] is followed for evaluating the metrological performance of the developed force proving instrument and transducer. It is a crucial step in determining the performance characteristics of the force measurement device. The concept of uncertainty was introduced in the

**Fig. 1** A schematic diagram showing arrangement of four strain gauges at Position A



**Fig. 2** A schematic diagram showing arrangement of four strain gauges at Position B



late 1980s. It is a statistical expression that displays the dispersion of values from the true value of the measurand [12, 13]. Following are the steps involved in evaluating UoM [14]:

- (a) Specification of measurand
- (b) Mathematical model of measurand as per ISO 376: 2011
- (c) Identification of sources of uncertainty
- (d) Evaluation of input quantities
- (e) Determine standard UoM of each component
- (f) Calculate combined standard UoM
- (g) Calculate expanded UoM
- (h) Result analysis.

SGFT has been calibrated in compression and tension for the nominal load capacity of 15 kN. The transducer has been subjected to 12% overload to the nominal capacity for 90 s four times. The overload test has been found satisfactory. 50 kN deadweight force machine has been used to calibrate the transducer following the calibration steps. The observations are recorded using a high-resolution digital indicator (10–5 mV/V) [5]. The resolution of an instrument plays a crucial role in displaying the output nearest to the true value. Higher the resolution, closest would be the output to the true value. The temperature compensation mechanism has not been included as the calibration is to be done in a controlled environment, as specified in ISO 376:2011 metrology standard. Analysis of the observations has been conducted for evaluating the UoM.

Excitation voltage of 5 V is given as an input to power the bridge initially. Three sets of observations have been recorded for a nominal tensile force of 15 kN

- Voltage output at Position A (5 V, excitation voltage)
- Voltage output at Position B (5 V, excitation voltage)
- Voltage output at Position A (10 V, excitation voltage).

### 3.1 Metrological Characterization of EN 8 SGFT, Position A

Initially, 5 V is given to the bridge connected at Position A, and the observations are recorded for further evaluation. The relative uncertainty contribution of individual parameters is summarized in Table 1 [15, 16].

**Table 1** UoM of EN 8 trapezoidal-shaped SGFT (tension) with contributing factors (Position A, 5 V)

Force (kN)	Mean value of observations (mV/V)	Relative contribution to the combined standard UoM (%)						Expanded UoM (%) $k = 2$
		zer (2a)	res (2a)	rpr (2a)	rep (2a)	int (2a)	cmc (2a)	
1	0.03950	0.019	0.025	0.228	0.152	0.169	0.015	0.178
3	0.11822	0.019	0.008	0.102	0.118	0.044	0.015	0.092
5	0.19686	0.019	0.005	0.168	0.036	0.036	0.015	0.083
7	0.27552	0.019	0.004	0.152	0.025	0.030	0.015	0.075
9	0.35412	0.019	0.003	0.116	0.008	0.006	0.015	0.058
11	0.43269	0.019	0.002	0.090	0.039	0.024	0.015	0.057
12	0.47204	0.019	0.002	0.085	0.023	0.022	0.015	0.052
13	0.51148	0.019	0.002	0.082	0.033	0.005	0.015	0.051
14	0.55087	0.019	0.002	0.044	0.005	0.001	0.015	0.037
15	0.59034	0.019	0.002	0.068	0.039	0.018	0.015	0.050

**Table 2** UoM of EN 8 trapezoidal-shaped SGFT (tension) with contributing factors (Position B, 5 V)

Force (kN)	Mean value of observations (mV/V)	Relative contribution to the combined standard UoM (%)						Expanded UoM (%) $k = 2$
		zer (2a)	res (2a)	rpr (2a)	rep (2a)	int (2a)	cmc (2a)	
1	0.00630	0.032	0.159	0.317	0.159	0.369	0.015	0.308
3	0.01887	0.032	0.053	0.212	0.106	0.168	0.015	0.164
5	0.03137	0.032	0.032	0.159	0.096	0.015	0.015	0.094
7	0.04387	0.032	0.023	0.137	0.091	0.037	0.015	0.089
9	0.05646	0.032	0.018	0.124	0.089	0.067	0.015	0.094
11	0.06890	0.032	0.015	0.131	0.087	0.079	0.015	0.099
12	0.07518	0.032	0.013	0.133	0.093	0.051	0.015	0.093
13	0.08154	0.032	0.012	0.135	0.098	0.057	0.015	0.096
14	0.08777	0.032	0.011	0.125	0.091	0.006	0.015	0.083
15	0.09404	0.032	0.011	0.138	0.096	0.000	0.015	0.087

UoM is found upto 0.10% within 20–100% of the transducer’s working range. The relative uncertainty of the contributing factors is also within the permissible limits.

### 3.2 Metrological Characterization of EN 8 SGFT, Position B

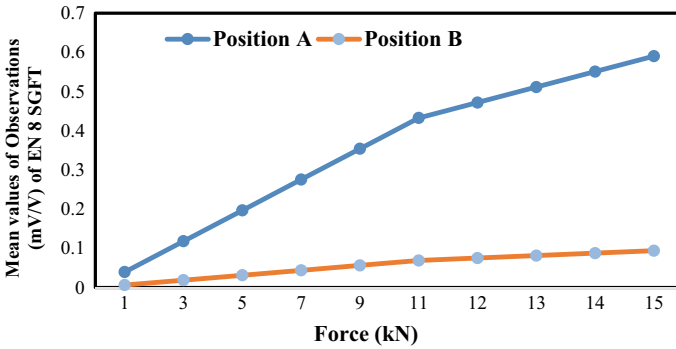
The metrological performance evaluation of EN 8 SGFT at Position B would reveal the effect of the changed location over the metrological performance of the transducer. A summarized analysis of UoM of EN 8 SGFT at Position B has been given in Table 2.

Based on the mean values of observations at various force steps, a comparative graphical analysis is being presented in Fig. 3. It is observed that the output values are too less at Position B for the same applied force, affecting the transducer’s sensitivity.

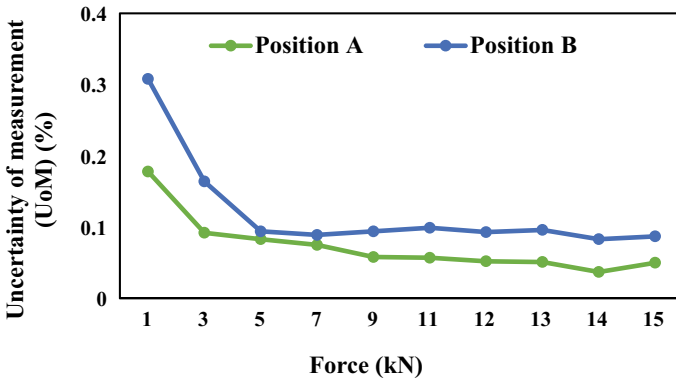
A comparative graphical analysis of UoM of EN 8 SGFT at Position A and Position B is shown in Fig. 4. This figure depicts that the higher UoM is observed at Position B than at Position A. However, the decreasing pattern of the UoM values is identical as of Position A.

### 3.3 Effect of Excitation Voltage Over Metrological Characteristics of EN 8 SGFT, Position A

Excitation voltage is given as an input to the Wheatstone bridge that powers the bridge. The observations of the SGFT’s output are recorded at 5 and 10 V excitation



**Fig. 3** A comparative graphical analysis between the mean values of observations (mV/V) obtained at Position A and Position B



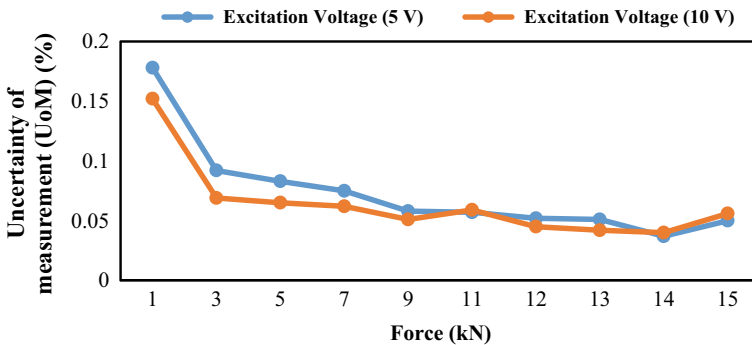
**Fig. 4** Plot showing UoM ( $k = 2$ ) of EN 8 SGFT at two positions of strain gauge arrangements (Position A and Position B)

voltage at Position A. The effect of excitation voltage over the metrology of EN 8 SGFT has been investigated based on metrological characteristics evaluation of the SGFT’s output at 10 V excitation voltage, Table 3 [4].

It has been observed that an increase in excitation voltage does not have much impact on UoM. But it has a minor effect on the mean observations. The deviation between the UoM obtained from the two excitation voltages is shown in Fig. 5.

**Table 3** UoM of EN 8 trapezoidal-shaped SGFT (tension) with contributing factors (Position A, 10 V)

Force (kN)	Mean value of observations (mV/V)	Relative contribution to the combined standard UoM (%)						Expanded UoM (%) $k = 2$
		zer (2a)	res (2a)	rpr (2a)	rep (2a)	int (2a)	cmc (2a)	
1	0.03755	0.019	0.027	0.053	0.133	0.178	0.015	0.152
3	0.11624	0.019	0.009	0.017	0.103	0.017	0.015	0.069
5	0.19492	0.019	0.005	0.118	0.021	0.037	0.015	0.065
7	0.27357	0.019	0.004	0.117	0.015	0.030	0.015	0.062
9	0.35218	0.019	0.003	0.088	0.023	0.006	0.015	0.051
11	0.43074	0.019	0.002	0.067	0.065	0.024	0.015	0.059
12	0.47009	0.019	0.002	0.064	0.000	0.022	0.015	0.045
13	0.50953	0.019	0.002	0.063	0.012	0.005	0.015	0.042
14	0.54892	0.019	0.002	0.046	0.026	0.001	0.015	0.040
15	0.58839	0.019	0.002	0.068	0.058	0.018	0.015	0.056



**Fig. 5** Plot showing UoM ( $k = 2$ ) of EN 8 SGFT at Position A; 5 and 10 V excitation voltages

### 4 Conclusion

The metrological characteristics of EN 8 SGFT have been found within the permissible limits to be applied in precision force measurement applications. The selection of the location of strain gauging affects the transducer’s sensitivity that has been concluded from an experiment performed using EN 8 SGFT. The strain gauging is performed at Position A and Position B. It is observed that the mean values of observations are less at Position B, because of the presence of low stress–strain values at this location. The effect of excitation voltage has been examined by supplying an excitation voltage of 10 V to EN 8 SGFT at Position A. A comparative graph of

UoM between 5 V and 10 V excitation voltage shows that the difference between the values is insignificant.

## Nomenclature

FEA	Finite element analysis
DWFM	Deadweight force machine
SGFT	Strain gauge force transducer
zer	Relative uncertainty due to zero offset
res	Relative uncertainty due to resolution
rep	Relative uncertainty due to repeatability
rpr	Relative uncertainty due to reproducibility
int	Relative uncertainty due to interpolation
cmc	Machine uncertainty
UoM	Uncertainty of measurement
<i>k</i>	Convergence factor
<i>a</i>	Parameter refers to the difference between mean and maximum values of a factor

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