International Journal of Advance Studies in Engineering and Scientific Inventions
Volume 3 Number 1, JULY 2015. ISSN (Print): 1741-8763 ISSN (Online):1741-8771

STRAIN INSTRUMENTATION SYSTEM MODELING AND PERFROMANCE ANALYSIS

[1]R. A. Abarshi, [2]R. S. Shehu & [3]S. M. Lawal
[1,2&3]Department of Electrical and Electronics Engineering
College of Engineering, Kaduna Polytechnic, Kaduna

Abstract
Measuring strain onmechanical systems and components during operation is important in order to prevent system's malfunction and failures. The paper studied output time response performance of a strain measuring system simulation model when certain parameters namely strain gauge factor and time constant are varied. The model consisting of a dc bridge, amplifier-filter network was constructed using simscape tools of the Matlab Simulink. Results showing the significance of the parameters in deciding favorable behavior of a given strain monitoring system are generated.

Keywords: *Strain Gauge, Bridge, Amplifier-filter, Instrumentation, Model, Filter, Performance, Parameter.*

Background to the Study
Strain measuring instruments are used to measured applied strain or force on a body. The instrument may consist of a strain gauge resistance wire, a Wheatstone bridge circuit and an amplifier network. The strain gauge is a small, metal foil wire resistance that changes when force is applied on it. Of importance to strain measurement instrument is the impact of the strain gauge sensitivity often referred to as the gauge factor to the static performance in terms of the overall instrument gain. In this paper, static and dynamic performance of a simulated strain measuring instrument model will be represented and studied. Two performance indices namely the instrument output response time and final value would be used for the assessment.

Monitoring strain in mechanical systems during operation is an important process in auto industries. The process ensures equipment safety and general performance. Strain gauge is a resistor whose electrical resistance varies in proportion to the amount of strain applied to it. The strain gauge is widely used for monitoring strain on mechanical bodies, weight and force measurement, and torque measurement in motor shafts.

Strain gauge is fine, commonly foil metallic resistance wire arranged in grid pattern. It is bonded on to a thin backing support; the backing is bonded on to a test specimen body where strain is to be measured. Different strain gauge type's and their operational principle can be found in Omega (Omega, 2014) and Yee (Yee, 2014). Works on the use of strain gauge instrument for vibration detection have been reported (Stanley, Kenn & Roberto, 2007; Yan, Waechter, Blacow & Prasad, 2002). Its applications for motion and displacement sensing and control have been also well reported (Aarne, IIkka & Sami, 2014; Kam, Yingfen, Sisi & Kwang, 2012).

While shunt calibration of strain gauge instrument with gauge factor relatively fixed was studied in Vishay (Vishay, 2015), impact of gauge factor and time constant on strain instrument will be investigated in this paper.

Objective to the Study
To evaluate strain instrumentation system modality and performance analysis

Materials and Method
System model
A Strain Measuring System may Consist of the Functional Blocks Shown in Fig.1.

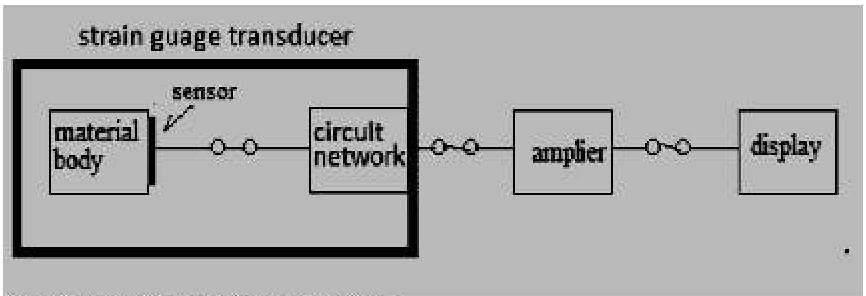

Fig.1: Strain Measurement System

Strain Gauge Transducer Model
Strain gauge is a tiny flexible wire that has its resistance changed when folded or depressed by force applied. By bonding the wire on a body and force or bending pressure applied on the body will create strain and this can be measured if the wire was used in a circuit network that can provide an indication of the change in resistance of the strain gauge. In this regard, we consider a dc bridge with strain gauge on one of the arm in Fig.2.

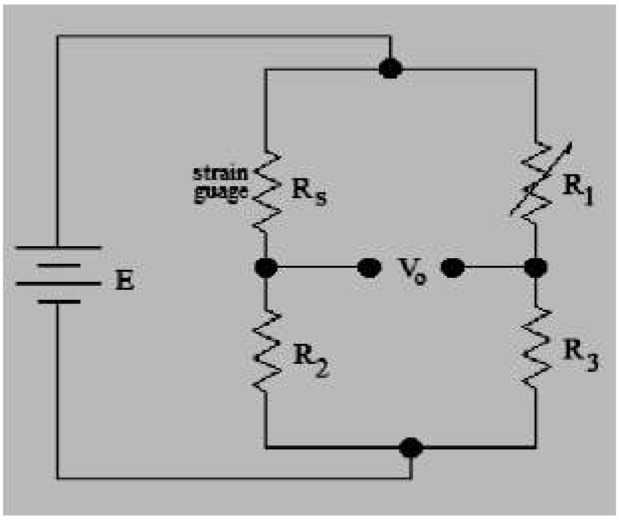

Fig.2: Strain Measuring Circuit

Where R_s is the strain gauge resistance, $R_1$is variable resistor for establishing initial balance of the bridge, R_2 and R_3 are fixed resistors. To detect or measure an applied strain on a body, the strain guage $R_s$is bonded unto the body, under strained condition, the measure in volts is written as

$$V_o = E\left[\frac{R_s+\Delta R_s}{R_s+\Delta R_s+R_2} - \frac{R_1}{R_1+R_3}\right] \qquad (1)$$

Where ΔR_s is change in strain gauge resistance? If ΔR_s is the applied strain, a sensitivity factor K for strain gauge element is (Sawhney, 2005)

$$K = \frac{\Delta R_s}{\varepsilon R_s}$$

Amplifier filter Circuit model

To amplify $V_o$in (1), an amplifier-filter network of the form shown in Fig.4 can be used, yielding an output

$$V_b = \xi(s)\varepsilon \qquad (2)$$

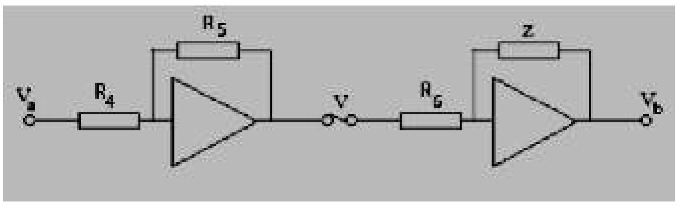

Fig.3: Amplifier-filter Network Model

The function $\xi(s)$ in (2) is the bridge and amplifier transfer function expressed as

$$\xi(s) = K_{st} K_A Z \;;$$

Where K_{st} is the bridge constant, K_A is amplifier gain, the filter transfer function is

$$Z = \frac{R_6 \cdot 1/sC}{R_6 + 1/sC} = \frac{R_6}{\tau s + 1}$$

Where $\hat{\alpha}$ = $R_6 C$ is the filter time constant and its effect is to be studied later in the work. The strain transducer circuit model provided in Matlab2009b (Matlab2009b, 2009) can be adopted for this study as shown Fig.4.

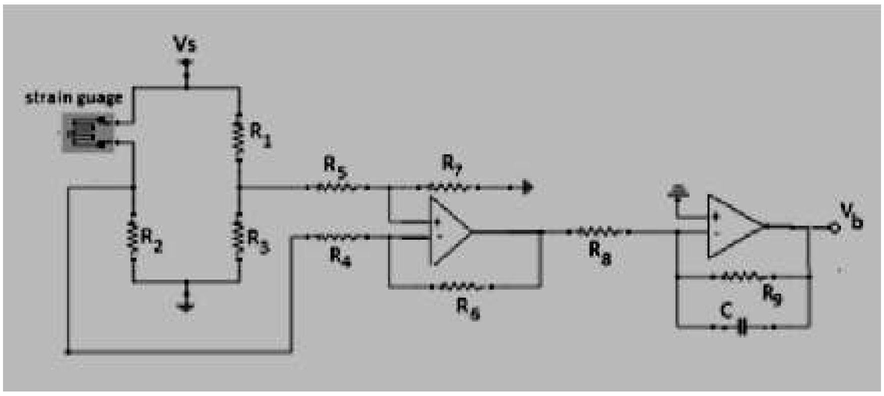

Fig.4: Strain Transducer Circuit Model

Simulation

We consider the measuring circuit condition cases for performance analysis as follows:

Case 1: Nominal condition

R_1 = 100Ω, R_2 = 100? , R_3 = 100? , R_4 = R_5 = 10k? , K (strain gauge factor) = 2

R_6 = 10k? , R_7 = 10k? , R_8 = 1k? , R_9 = 100k? , C=1μF, K_{st} = 1, K_A = 1. ô = 0.01s.

Case 2: At increased gauge factor, K = 10.

Case 3: Under reduced filter time constant, ô = 0.005s.

To Ensure Positive Oriented Response, here the Modified form of Simulated Network shown in Fig.5 was used.

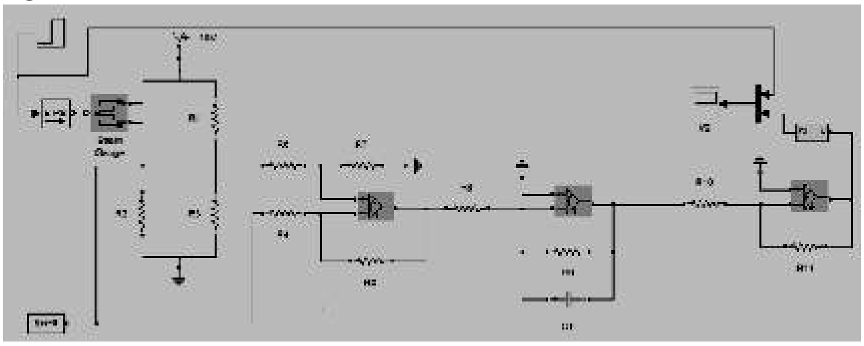

Fig.5: Strain Simulation Measurement Circuit

Results

Taking 0.01 as step signal input, two performance indices are to be read: steady state value of the output response and the response rise time. Final value refereeing to the Y-axis value when the response remain steady; signifies an achievable gain of the measuring network, rise time is that time when the response first enters steady state; tells about the networks' speed of response. Figs.6 shows results of the simulation process under nominal condition.

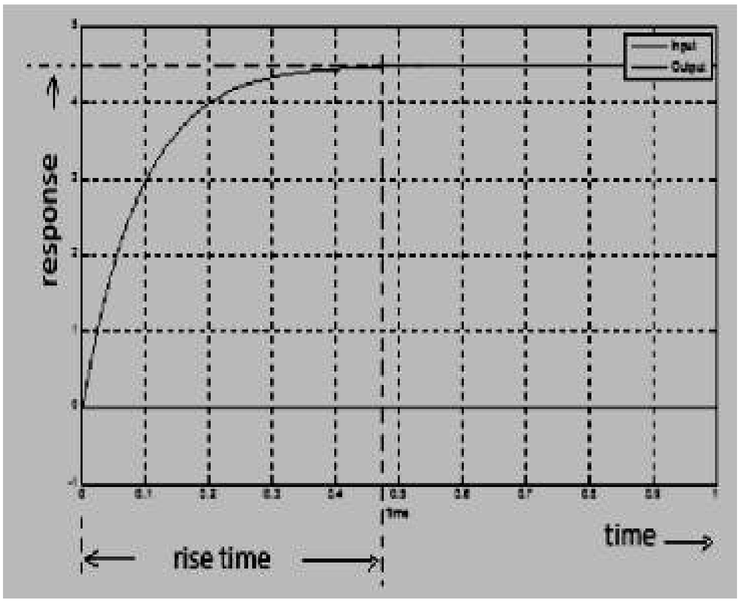

Fig.6: Measuring Network Response at Nominal

Condition

As shown in Fig.6, the final value of the responses and rise time are 4.67 and 0.48 seconds. Taking the strain gauge factor as K =10, the network response obtained is shown Fig.7.

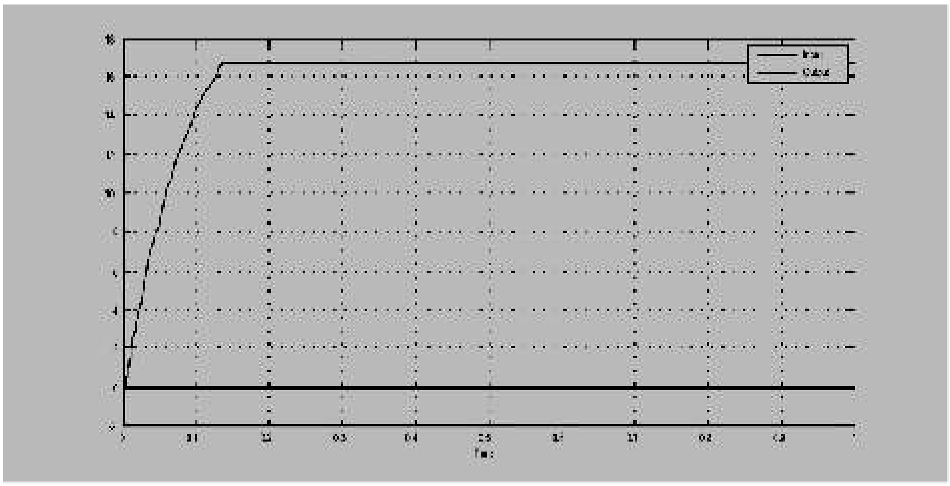

Fig.7: Response at Increased Gauge Factor

Increasing the gauge factor by 1000% resulted in a response having 16.6 final value and a rise time of 0.13 seconds. In the next case, keeping the gauge factor at nominal and reducing the network time constant to 0.005 seconds, Fig.8 shows the network output response.

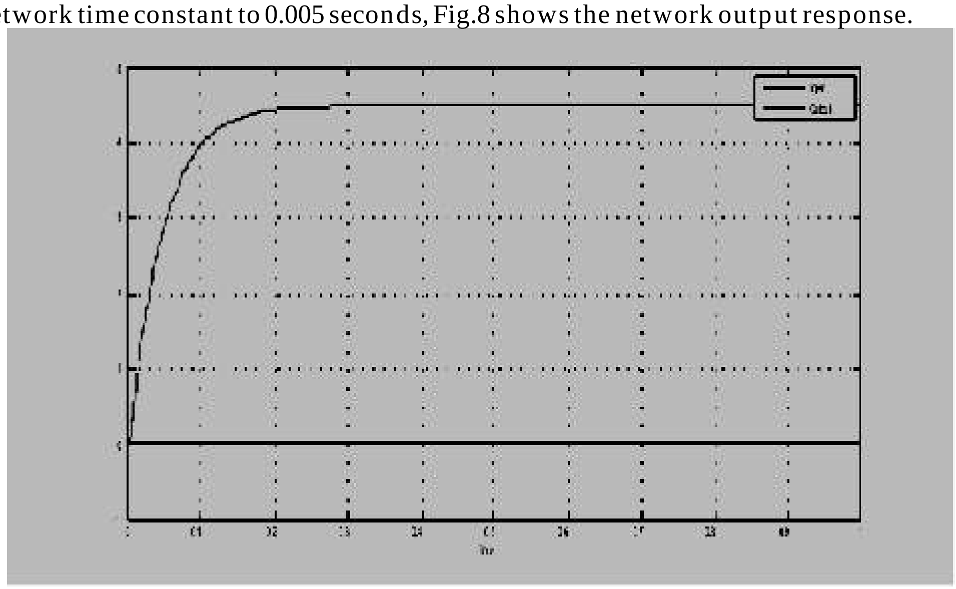

Fig.8: Response at Reduced Time Constant

The final value and rise time as shown in Fig.8 are 4.76 and 0.23 seconds respectively

Analysis of results

Under nominal condition of the measuring circuit, the final value and rise time as observed in Fig.6 are 4.67 and 0.48 second. When gauge factor is increased keeping other parameters unchanged at nominal, a final value of 16.6 and rise time of 0.13 second are observed as shown in Fig.7. And changing time constant to a lesser value of 0.005 second yields a response with final value of about 4.67 and 0.23 second respectively, this is shown in Fig.8.

Conclusion

The paper modeled and carried out performance analysis on a strain instrumentation system in a simulation manner. Using step input as a physical force on a strain gauge placed on one arm of a dc bridge, an amplifier-filter network was used to complete the sensing and transducer parts of the system. Results of the simulation under three different network conditions representing nominal and varied situations are generated. The strain measuring system was shown to have good gain when the gauge factor of sensor is increased, and have fast response when time constant is reduced.

Recommendations

Based on the results obtained, it is important that strain measuring transducers should be made to have high gauge factors so that wider range of outputs can be attained and in an applications that require distant transmission of signals, cost of compensating losses along lines are reduced. Fast response time is also important; therefore smaller time constant filters are recommended. Further performance study should be carrying out to assess the measuring circuit under dynamic nonlinearity along the signal transmission path.

References

Aarne, H. IIkka, L. & Sami, S. (2014),“Development of work partner-robot design of actuating and motion controlsystem.“ Retrieved from www.atomation.tkk.ti / attach / ... / halme99-2.pdf. ,December, 2014.

Kam, K.C., Yingfen, S. & Kwang, J.K. (2012), “Integrated sensing for IPMC actuators using strain gages for underwater application.” IEEE / ASME Trans on Mechatronics, 17, 2, pp 345-355.

Matlab, (2009), “PC Matlab Simulink.” Version 7.9.0529, (R2009b).

Omega, (2014), “Strain Sensor.” Retrieved from Omega.com / literature / … / StarinGage_an0… / , December, 2014

Stanley, K., Kenn, O. & Roberto, H. (2007), “Piezoresistance and piezoelectric MEMS strain sensor for vibration detection.” Proceedings of SPIE, 6529. doi: 10.1117 / 12.715814.

Sawhney, A.K. & Sawhney P. (2005), “A Course in Electrical and Electronics measurements & Instrumentation.” New Delhi: Dhanpat Rai & Co., pp.913-1000.

Vishay Group (2015), “Shunt Calibration of Strain Gauge Instrumentation.” Technical Note, Retrieved from www.intertechnology.com / Sishay / pdf / Technotes-TechTips / TN514.pdf, May, 2015

Yan, B., Waechter, D., Blacow, R. & Prasad, S. E. (2002),“A configurable control system for smart structures research.” Retrieved from www.me.berkeley.edu / ... / 162C_ / con_SPI..., December, 2014

Yee, C. (2014), “Fiber-optics strain gauges.” Retrieved from www.Spacegrant.hawaii.edu / ... / Yee.pdf December, 2014