Experimental Stress Analysis on Non-Planar Links of 3-PRR Manipulator

MSRK Chaitanya[1]
B.Tech Mechanical Engineering
SASTRA University
Thannjavur, Tamilanadu.

Gokula Krishna KS[2]
B.Tech Mechanical Engineering
SASTRA University
Thannjavur, Tamilanadu.

Dr. A K Dash[3]
Professor (Mech Engg)
SASTRA University
Thannjavur, Tamilanadu.

Dr. M Varaprasada Rao [4]
Dean – Academics-GIET
No.1-62-19, mig-ii-95,
Sector-2, mvp colony,
Vizag-17, a.p, india

Abstract--The objective of this paper is to report on the experimental stress analysis of a 3-PRR planar parallel manipulator with non-planar links. The biaxial principal stresses, and shear stress are determined experimentally on the Aluminium link of the 3PRR manipulator.

For experimental strain measurement, strain gauge rosettes are installed on the inclined links of the manipulator, connected to a signal conditioning circuit with INA125U (instrumentation amplifiers) and analog to digital conversion is performed by ATmega328 AVR-microcontroller in Arduino Uno board. Handshaking in digital communication is used to transfer data to the computer for numerical computations and data-logging.

The installation of the strain gauge rosettes and instrumentation amplifiers has been in par with the industrial standards prescribed by BSSM (British Society for Strain Measurement) to ensure the accuracy of the results. Von Mises theory is used for criterion of failure.

Keywords: 3PRR manipulator, Strain Gauge rosette, Signal conditioning, Optimal loading, Von Mises stress theory, Static analysis, Failure analysis.

INTRODUCTION

Hrishi L.Shah[1], University of Buffalo, in his 2010 paper, “Kinematic, Dynamic and Workspace analysis of a Novel 6-DOF Parallel manipulator” and Xuping Zhang[2], University of Toronto, in his 2009 paper, “Modelling And active vibration control of a planar 3-PRR Parallel manipulator with three flexible Links” have proposed and analysed using a 3-PRR manipulator in place of the conventional 3-PRR planar parallel manipulator.

The applications of this 3PRR manipulator include controlled motion of higher loads in limited workspace, provide rapid multi-axis motion for flight simulators, various manufacturing industries, and medical surgery. Bhagyaraj.P and Vignesh.M[3], SASTRA University, 2013 paper on, “Design and Fabrication of 3-PRR parallel planar manipulator with non-planar links”, have arrived at the comparison between equivalent planar link manipulator to their work and they have found the non-planar manipulator links to be superior theoretically.

This paper describes the project on verification and validation of the theoretical results by Experimental Stress Analysis in real-time using strain gauge rosettes for biaxial stress analysis.

II. II. SENSORS: STRAIN GAUGE ROSETTES

Linear Strain Gauge undergoes compression or tension depending on the forces on the surface to which it is bonded and this results in the change in gage wire length which in-turn changes the resistivity of the gage. When this is connected to a Wheatstone bridge circuit, the resistivity change makes the bridge go out of balance and results in a differential voltage output across the bridge.

Strain Gage Rosettes have two or three gages at precision angles that can measure strains in respective angles. We have installed 0^o, 60^o, 120^o rosette on the non-planar aluminium link of the manipulator with 120Ω nominal gage resistance and gage factor 2 and the gages are self temperature compensated up to 80^oC. The measuring grids of the rosette are named 1,2,3 in counter clockwise and their respective strains are ε1, ε2, ε3 The conversion formula for bridge offset output to directional strain is as follows-

$$\varepsilon = -4 \times \frac{V_r}{GF(1+2V_r)} \times \left(1 + \frac{R_{wire}}{R_{gauge}}\right). \quad (1)$$

The reduction of three directional strains to two principal strains is as below.

$$\varepsilon \text{ in Principal axis P,Q} = \frac{\varepsilon_1+\varepsilon_2+\varepsilon_3}{3} \pm \frac{\sqrt{2}}{3}\sqrt{(\varepsilon_1-\varepsilon_2)^2+(\varepsilon_2-\varepsilon_3)^2+(\varepsilon_3-\varepsilon_1)^2}. \quad (2)$$

$$\sigma_P = \frac{E}{1-\upsilon^2}(\varepsilon_Q + \upsilon\varepsilon_P). \quad (3)$$

$$\sigma_Q = \frac{E}{1-\upsilon^2}(\varepsilon_Q + \upsilon\varepsilon_P). \quad (4)$$

The Principal directions for 0°, 60°, 120° rosette are given below.

$$\emptyset_{P,Q} = -\theta = \frac{1}{2}\tan^{-1}\left(\frac{\sqrt{3}(\varepsilon_2-\varepsilon_3)}{2\varepsilon_1-\varepsilon_2-\varepsilon_3}\right). \quad (5)$$

Formulae for angle determination are given below.

If $\varepsilon_1 > \frac{\varepsilon_2+\varepsilon_3}{2}$, then $\emptyset_{P,Q} = \emptyset_P$. (6)

If $\varepsilon_1 < \frac{\varepsilon_2+\varepsilon_3}{2}$, then $\emptyset_{P,Q} = \emptyset_Q$. (7)

If $\varepsilon_1 = \frac{\varepsilon_2+\varepsilon_3}{2}$, and $\varepsilon_2 < \varepsilon_1$ then $\emptyset_{P,Q} = \emptyset_P = -45°$. (8)

If $\varepsilon_1 = \frac{\varepsilon_2+\varepsilon_3}{2}$, and $\varepsilon_2 > \varepsilon_1$ then $\emptyset_{P,Q} = \emptyset_P = +45°$. (9)

If $\varepsilon_1 = \varepsilon_2 = \varepsilon_2$, then $\emptyset_{P,Q}$ is indeterminate (10)

(Equal biaxial strain)

Formulae for shear strain and shear stress are as below.

$$\gamma_{MAX} = \varepsilon_P - \varepsilon_Q. \quad (11)$$

$$\tau_{xy} = G\gamma = \frac{E}{2(1+\upsilon)}\gamma_{xy}. \quad (12)$$

Von Mises criterion is as below.

$$\sigma_{vm} = \sqrt{{\sigma_{11}}^2 - \sigma_{11}\sigma_{22} - {\sigma_{11}}^2} \leq \sigma_Y \quad (13)$$

III. PROGRAM ON THE MICROCONTROLLER SIDE

The Wheatstone bridge output from each of the three gages in the rosette is amplified by three Instrumentation amplifiers, one for each wheat-stone bridge. The amplifier gain is set by an external resistor. The amplified signals are fed to Analog input of the Arduino Uno board for Analog-to-digital conversion. The board has a 10-bit ADC and hence the analog input from 0 to 5V is read from 0 to 1023 discrete numbers. The microcontroller back-calculates the amplified voltage, and then calculates the actual output from the bridge by dividing out the amplifier gain. The three voltage values are sent in order, serially, as comma separated values to the Serial port of the computer.

IV. COMPUTER-SIDE PROGRAM FOR NUMERICAL COMPUTATIONS AND DATA LOGGING

A Java program in Processing IDE is used to perform handshake for digital communication, in order to ensure the order and timing of the data received, and store it to an array. It then performs the computations using the set of formulae above and writes to a CSV (Comma separated value) text file for post-processing, or for live plotting via softwares like Live-graph. This format of the log can also be imported to Computational softwares like Scilab, Octave, Matlab, etc.

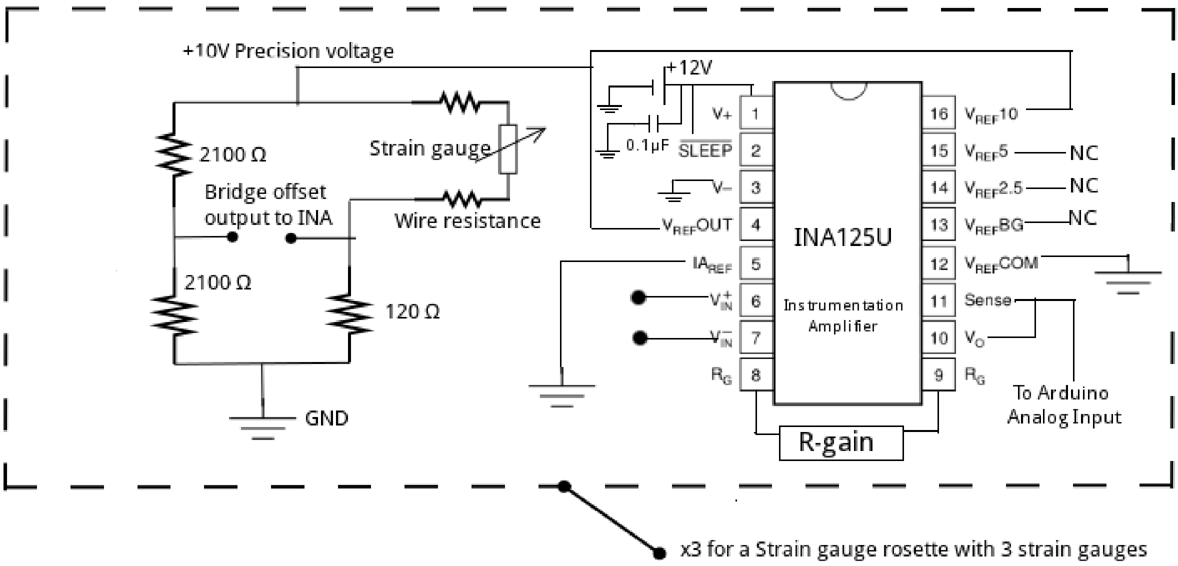

Fig.1. Circuit diagram of signal conditioning unit.

Fig.2.3PRR manipulator with non planar links

Fig.3. Stress analysis on the Link (Highlighted by arrow)

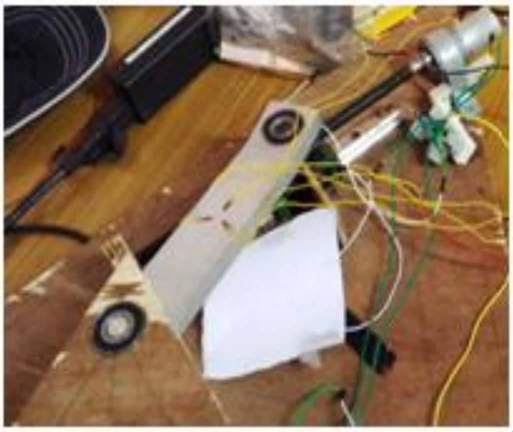

Fig.4.Strain Gauge Rosette installed on non-planar link

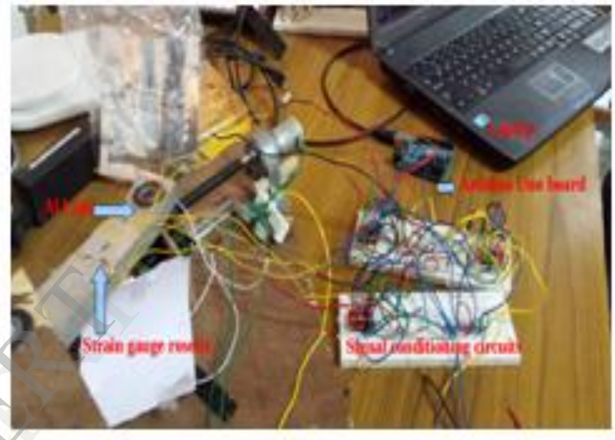

Fig.5.Integration of rosette with signal conditioning circuit to computer.

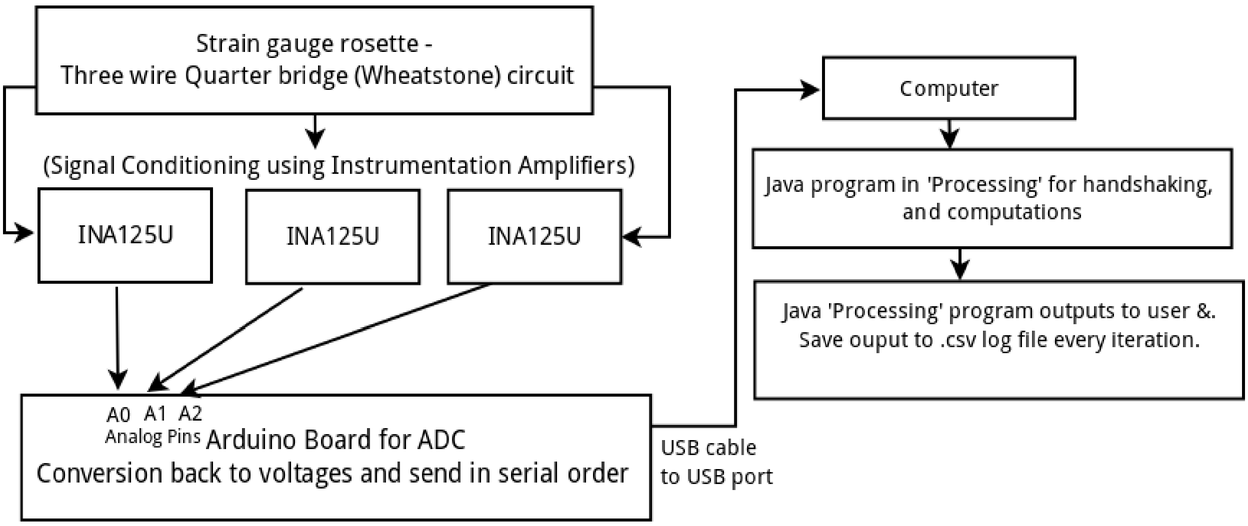

Fig.6.Block diagarm of the experimental setup.

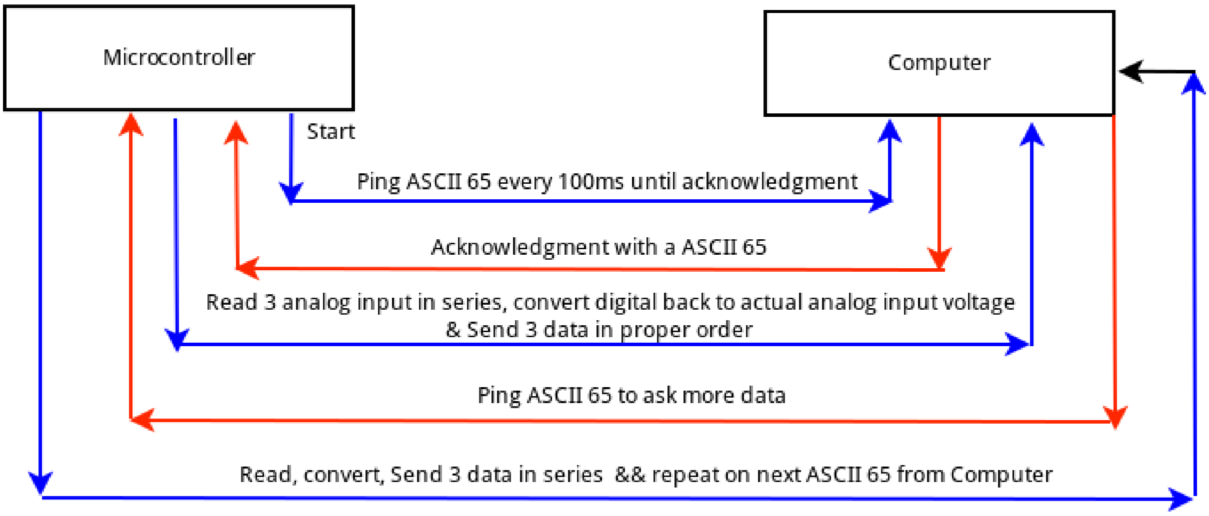

Fig.7. Handshake implementation for digital communication

iv. RESULTS

The experimental stress analysis was done under different load conditions in steps of incremental loads. Under a static load of 12 kg, the Principal stresses are found to be 68.5 MPa and 64.3 MPa, with maximum shear stress in the system as 1.4 MPa. The Von-Mises criterion is therefore verified and the angles of principal axes from Grid 1 of the rosette are also calculated. The maximum optimal load suggested by theoretical analysis and ANSYS analysis was 20kg above which the Von-Mises criterion will be violated as the Von-mises Stress will exceed the yield stress 110MPa of Al 6061 T4 alloy link.

v. SUMMARY

Experimental stress analysis is done using Strain Gauge rosette which is installed on the Aluminium link as per standards described by BSSM (British Society for Strain Measurement) in coalition with signal conditioning unit. Analog to digital conversion is performed by ATmega328 AVR-microcontroller in Arduino Uno board. Loading is done in steps and corresponding values are computed and stored in computer in real-time via handshaking process in digital communication. Von Mises criterion is also checked by the computer after which optimal load is determined.

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