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SELF-MADE TRI-AXIAL ACCELEROMETER DESIGN CONSIDERATIONS FOR VALIDATION OF SIMULTANEOUS MULTI AXIS ACCELEROMETER CALIBRATION SYSTEM

C. S. Veldman

NMISA, Pretoria, South Africa, CSVeldman@NMISA.org

Abstract:
This paper describes geometric design consideration for the creation (manufacture) of a tri-axial accelerometer intended for the validation of multi axis calibration systems that implements simultaneous axis calibration methods. Two mounting geometries were investigated, and the results obtained using them are reported. The one configuration, a cube with counterweights. The second configuration see the accelerometers mounted on "recessed" faces, aiming at placing (aligning) the individual accelerometers close to the vibration excitation vector.

Keywords: tri-axial; accelerometer; simultaneous; calibration

1. INTRODUCTION

Tri-axial accelerometers, used to measure vibration in three axis, x-, y-, and z, have been in use for many years. In most circumstances, the manufacturing involves the mounting of three individual accelerometers in close proximity in a hermetically sealed casing. This provides for a relatively compact and robust multi-axis sensor.

With the advent of Micro Electro-Mechanical Systems (MEMSs) sensors, the tri-axial accelerometer form factor was reduced significantly. MEMS based tri-axial accelerometers are manufactured in their millions each year. The availability of tiny multi axis sensors revolutionized applications utilizing multi axial accelerometers, including tri-axial accelerometers. As a result, these devices are being used in a wide range of applications, including non-critical applications such as smart phones, gaming systems, exercise and health monitors and drones. It is also used in critical applications such as in medical devices, vehicles, military- and aerospace systems.

Through the Consultative Committee for Acoustics, Ultrasound and Vibration (CCAUV) [1], National Measurement Institutes (NMIs) have taken cognizance of these developments. The CCAUV recognizes this, as reported in its 2019 to 2029 Strategy document [2] and summarizes it [3] stating that "Miniaturization technologies for inertial measurement units is driving new applications, significant growth in their production, and needs for primary calibration technologies to support new applications. Compatibility with digital sensor interfaces is also requested; this need is recognized to be a cross-cutting need in AUV as well as other CCs."

For metrologist, providing a cost effective, scientifically sound calibration services of tri-axial accelerometers is a challenge. The most common method is to calibrate each axis individually, by comparison to a reference transducer [4] or by laser interferometry [5]. This is a time-consuming procedure, which does not fully take into account the manner in which the device will be used.

Systems that perform the calibration of all three axis simultaneously have been reported on [6 - 8]. A metrological as well as a quality system requirement, is the validation of the calibration system. This validation data serves as evidence of the system performance within the stated uncertainty of measurement and assures confidence in the calibration results.

In section 2, the author provides a brief overview of the simultaneous three axis calibration system implemented at the NMISA. In Section 3, the author provides detail of design configuration of two tri-axial accelerometers, and the individual calibration results. The Author reviews the calibration results and draws some conclusions in section 4.

2. SIMULTANEOUS AXIS CALIBRATION USING A WEDGE

2.1. Tri-Axial Accelerometer Calibration Method

A multi axis calibration system based on [7], Method 2, was implemented and investigated at NMISA. Method 2 involves the simultaneous excitation of the three axes of the accelerometer under test.

The simultaneous excitation of the three axis is achieved by mounting the accelerometer on the surface of a wedge with an angle θ = 35° with respect to the horizontal plane on which the motion is realised. The accelerometer is rotated on the wedge surface at an angle α = 45°. The more accurate value of the specified angle, θ, of the wedge was measured using a CMM at NMISA. The mounting configuration is depicted in Figure 1 below.

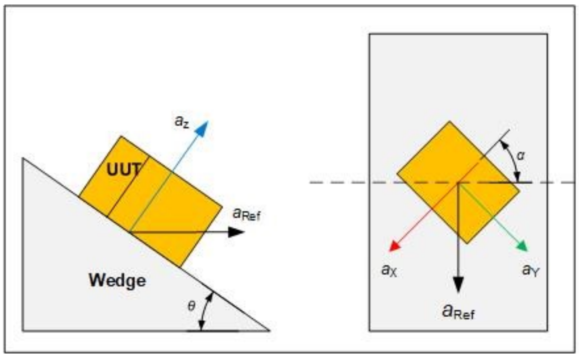

Figure 1: Inclined clamp (wedge) configuration

With such a setup, accelerations of similar amplitudes are generated along the three axis to be calibrated. The individual acceleration amplitudes generated along the three axis can be calculated using (1), (2) and (3):

$$a_x(t) = a_{\text{Ref}}(t) \cdot \cos(\theta) \cdot \sin(\alpha) , \tag{1}$$

$$a_y(t) = a_{\text{Ref}}(t) \cdot \cos(\theta) \cdot \cos(\alpha) , \tag{2}$$

$$a_z(t) = a_{\text{Ref}}(t) \cdot \sin(\theta) . \tag{3}$$

where $a_{\text{Ref}}(t)$ is the time-varying acceleration in the motion direction, measured by a reference sensor.

2.2. Calibration System

The basic building blocks used for the implementation of the calibration system are:

- A four-channel conditioning amplifier.
- A four-channel data acquisition unit.
- A PC, with dedicated software to perform the data capturing and signal processing.
- A signal generator to drive the vibration exciter at the desired acceleration level and frequency via a suitable power amplifier.

The application required software automation of the measurement procedure. The automation was developed in-house using Delphi™. The application allows for minimum input required by the metrologist once all the parameters and required data have been captured.

3. ACCELEROMETERS INVESTIGATED

During the time of the system development and performance validation, the Laboratory did not possess a commercial tri-axial accelerometer. It was surmised, at the time, that the equivalent of a tri-axial could be constructed using three commercial single axis accelerometers. Three Endevco 7259B-100 accelerometers were selected for this purpose. These devices are relatively small in design, weighing only 4.4 grams. They have a nominally high sensitivity of 10 mV/(m/s^2) over a very wide frequency range (1 Hz to 30 kHz).

3.1. Cube Tri-axial Accelerometer

The initial device implemented as a tri-accelerometer was constructed by mounting three of the above-mentioned accelerometers on three sides of a 10 mm^3 aluminium cube, as shown in Figure 2 below.


Figure 2: Cube tri-axial accelerometer showing the 10 mm^3 aluminium block, three ENDEVCO accelerometers and two M5 allen screw/nut counterweights

Care was taken to have the centre of mass close to the centre of the cube. This was achieved by adding M5 allen screws with nuts as counterweights on the opposite sides of each accelerometer, except for the Z-axis. The three accelerometers used are refenced as WStd-16, WStd-25, and WStd-28, as per their designated inventory numbers.

The calibration results obtained using this configuration are shown in Figure 3. For this calibration, WStd-16 was mounted in the X-axis position, WStd-25 in the Y-axis position and WStd-28 in the Z-axis position. The calibration results were obtained by comparison to a reference transducer [4]. The flat frequency response line, S_{u11} (in yellow) shown in Figure 4, is the calibration result obtained for WStd-16, calibrated as an accelerometer (not in tri-axial configuration) using laser interferometry as per [5].

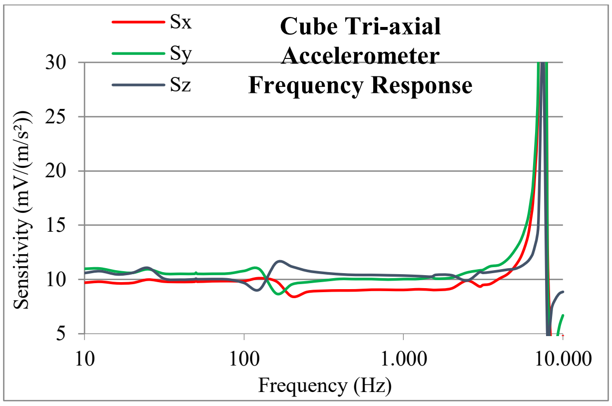

Figure 3: Cube tri-axial accelerometer frequency response

It has been reported [7, 8] that this method is susceptible to transverse sensitivity effects. Considering this work, transverse sensitivity effects were investigated as a source of the offsets in sensitivity values. As part of the investigation, the three accelerometers where rotated and mounted in all three of the axis positions so that each of the three accelerometers where calibrated in a configuration with it mounted in x-, y- & z positions, on the cube.

The calibration results obtained for WStd-16 when mounted in all three the axis orientations are reported in Figure 4 below, as well as the calibration results for WStd-16 when calibrated as a single axis accelerometer, using primary methods.

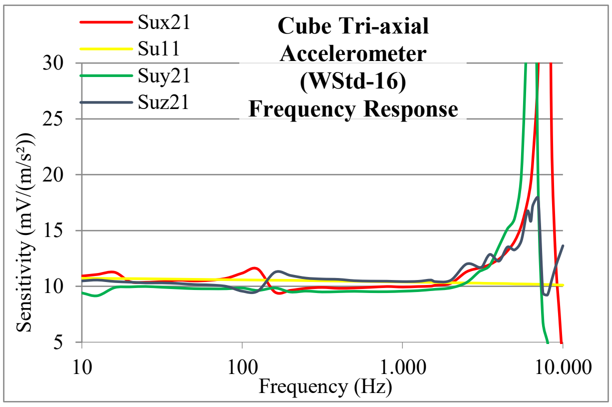

Figure 4: WStd-16 frequency response, mounted in x, y, and z axis positions and the single axis primary calibration result (S_{u11})

Considering the results in Figures 3 & 4, it is evident that the transverse sensitivity of the individual accelerometer has an insignificant effect on the calibration offset, and that the offset is rather dependent on the axis position an accelerometer is mounted on.

3.2. Pseudo Tri-axial Accelerometer

Considering the findings reported in [9], it was surmised that the location of the individual accelerometers, specifically the accelerometer sensing element, being relatively far from the acceleration vector, contributed to the systematic offsets.

To account for this, the wedge (Figure 1) was re-designed to facilitate the mounting of the individual accelerometers directly onto the wedge as depicted in Figure 5 below. The design goal was to place the individual accelerometer sensing element closer to the mounting centre line and acceleration vector.

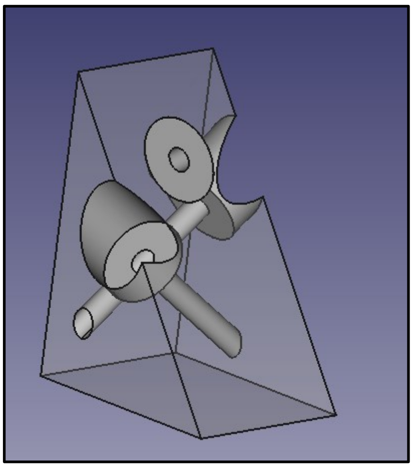
Figure 5: Wedge design for embedded tri-axial accelerometers

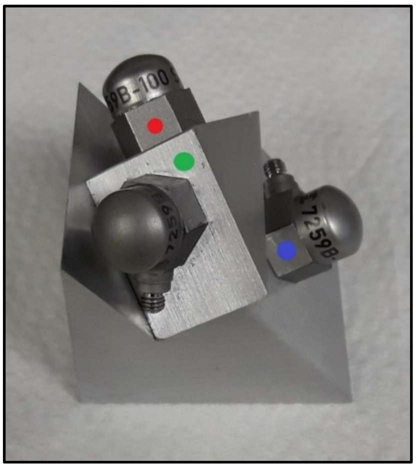
Figure 6: Pseudo tri-axial accelerometer

The preferred designed (Figure 5) made for a very complicated and nearly impossible wedge to manufactured. As a compromise, the wedge was manufactured in two parts, simplifying the manufacturing process substantially. This two-component pseudo tri-axial accelerometer, complete with accelerometers mounted, is shown in Figure 6.

The frequency response results obtained using this design is reported in Figure 7 below. The results show a reduction in the systematic offsets, supporting hypothesis that the systematic offsets could be attributed to the location of the accelerometer sensing element in relation to the applied acceleration vector and not due to transverse sensitivities.

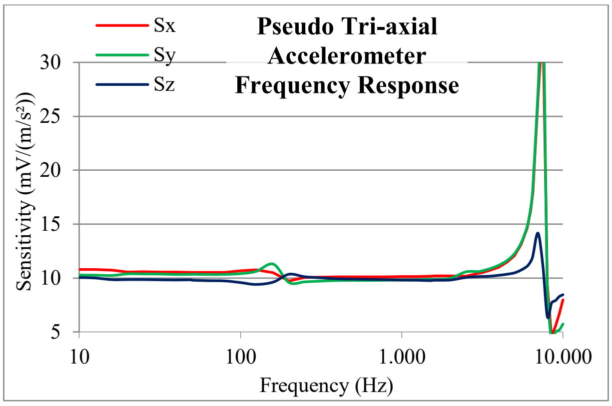

Figure 7: Pseudo tri-axial accelerometer frequency response

4. SUMMARY

Validation data of a newly established simultaneous multi-axis accelerometer calibration system indicated systematic offsets compared to single axis calibration systems. The multi-axis calibration system is based on mounting the tri-axial accelerometer on a complex angle. This is achieved using a 35° wedge. Transverse sensitivity of accelerometers and the geometric location of the accelerometer sensing element with respect to the applied acceleration vector was considered and investigated. Two different geometric configurations for accelerometer assemblies in the formation of a tri-axial accelerometer were investigated. Calibration results emphasised the relevance of the location of the accelerometer sensing element with respect to the applied vibration vector.

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