Wireless tool vibration monitoring for milling

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Abstract

Real-time monitoring of vibrations from the tool holder of Computer Numerical Control Machines simultaneously is important for some physical problems that may occur on a piece of working through solution of immediate detection and analysis in case of obtaining information. In this study, tool holder head to be used in machine tools, especially in real-time monitoring of vibrations were used in the development of a condition monitoring data acquisition system. Condition monitoring data acquisition system transfers vibration data obtained from the acceleration detector to a remote computer by Bluetooth. Vibration data is transferred to a computer can be monitored and recorded simultaneously with the PC software which is developed on Labview platform. Used in wireless communications, added flexibility in the use of the system, the hardware used for data exchange has decreased. As a result, the system reduces installation and operating costs.

Keywords: Machining, Wireless condition monitoring data acquisition system, Acceleration detector, Bluetooth

1. Introduct ion

Wireless process control has numerous benefits including a low profile, ease of deployment, and the ability to monitor from a central location [1]. Condition monitoring is the process of monitoring a parameter of condition in machinery, such that a significant change is indicative of a developing failure. It is a major component of predictive maintenance. The use of conditional monitoring allows maintenance to be scheduled, or other actions to be taken to avoid the consequences of failure, before the failure occurs. Nevertheless, a deviation from a reference value (e.g. temperature or vibration behavior) must occur to identify impeding damages. Predictive Maintenance does not predict failure. Machines with defects are more at risk of failure than defect free machines. Once a defect has been identified, the failure process has already commenced and condition monitoring systems can only measure the deterioration of the condition. Intervention in the early stages of deterioration is usually much more cost effective than allowing the machinery to fail. Condition monitoring has a unique benefit in that the actual load, and subsequent heat dissipation that represents normal service can be seen and conditions that would shorten normal lifespan can be addressed before repeated failures occur. Serviceable machinery includes rotating equipment and stationary plant such as boilers and heat exchangers.

The modern condition monitoring systems are employing a new family of sensors called micro-machined accelerometers. Micromachining refers to the technique of manufacturing tiny moving mechanical structures out of silicon and other materials. Some of the IC manufacturing techniques such as deposition, photolithography and etching are employed for making micro-machined devices. The new accelerometers include both the signal conditioning circuitry and the sensor, fabricated together on a single monolithic chip at very low cost with high reliability. The recent advances in Micro Electro Mechanical Systems (MEMS) have made high-performance, high accuracy, and low cost accelerometers.

In this article, the main focus is tried to transmit acceleration data from a dynamic shaker platform to a computer and save. The accelerometer MEMS sensor is mounted onto a dynamic shaker platform. The shaker platform has been considered kind of an end mill tool. The obtained knowledge from this study can be used for milling in future studies. The complete electronic circuit design consisted of a single-axis accelerometer, an AC coupling circuit, a signal conditioning and amplifier (Op-amp) circuits, and a wireless circuit with Bluetooth module. It was made on a single printed circuit board (PCB). The

overall circuit was designed for 0-10g rms acceleration sensing. The output of the accelerometer was an input to ac coupling. Then, it was connected to an Op-amp device that finally sent data to a computer by the Bluetooth transmitter and receiver module devices.

2. Material and Method

2.1. MEMS Accelerometer Sensor

An accelerometer is an electromechanical device that measures acceleration forces. These forces may be static, like the constant force of gravity pulling at our feet, or they could be dynamic - caused by moving or vibrating the accelerometer. There are many types of accelerometers developed and reported in the literature. Based on MEMS (micro electromechanical systems) accelerometers are the most popular and widely used lately. Figure 1 is a simplified view of the sensor structure. This part is ideal for industrial, medical, and military applications where wide bandwidth, small size, low power, and robust performance are essential. The industrial vibration transmitter was designed using MEMS capacitive accelerometer. The ADXL150 is a single axis accelerometer with signal conditioning on a single monolithic IC from Analog Devices, Inc.[2].

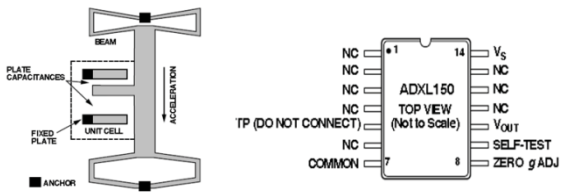


Figure 1 Simplified view of sensor and pinout ADXL150 (Analog Devices, Inc.)

The accelerometer output channel passes through a wide bandwidth differential-to-single-ended converter, which allows access to the full mechanical performance of the sensor. The ADXL150 offer lower noise and typical S/N is 80 dB, allowing resolution of signals as low as 10 mg, yet still providing a ±50 g full-scale range and the frequency bandwidth is dc to 1000Hz. Device scale factor can be increased from 38 mV/g to 76 mV/g by connecting a jumper between Vout and the offset null pin. Zero g drift has been reduced to 0.4 g over the industrial temperature range. Power consumption is a modest 1.8 mA per axis.

The scale factor and zero g output level are both ratiometric to the power supply, eliminating the need for a voltage reference when driving ratiometric A/D converters such as those found in most microprocessors. A power supply bypass capacitor is the only external component needed for normal operation.

2.2. Data Transmission Method

Bluetooth is a universal short-range low-power radio protocol operating in the unlicensed industrial, automotive, scientific, and medical frequency band. Bluetooth technology was designed primarily to support simple wireless networking of personal consumer devices and peripherals, including cell phones, PDAs and laptops. Wireless signals transmitted with Bluetooth cover short distances, typically up to 10m for Bluetooth® class 2 and 100m for Bluetooth class 1. It allows both data and voice connections, with a nominal maximum data of 723 kbps by Bluetooth 1.2 version and 3 Mbps by Bluetooth 2.0 + enhanced data rate (EDR version), as shown in Table 1. The modulation for Bluetooth technique is Gaussian frequency-shift keying, with transmission at a rate of 1 M symbol/s on one of 79 channels with 1MHz spacing in the 2.402–2.480 GHz band [3].

Table 1 Bluetooth transmission data rate

Version	Data rate
Version 1.2	723 Kbps
Version 2.0 + EDR	3 Mbps
WiMedia Alliance (proposed)	53-480 Mbps

The Bluetooth® universal data interface is implemented with a mature Bluetooth® 2.0 + EDR module. The system structure is shown in Fig. 3. All significant data from the vehicle, such as fuel cell output voltage and current, minimal cell voltage, hydrogen pressure, motor speed, state of charge (SoC) of the power battery, working state of each device, and error code, can be measured by each distributed control sub-system and gathered to the VCU via CAN bus. As a gateway between CAN and Bluetooth® networks, VCU transmits the data over a secure Bluetooth connection according to the predefined protocol. Any Bluetooth® device, such as a cell phone, can communicate with VCU through the Bluetooth® interface. The data can, for example, be monitored in real-time with a J2ME application running on a smart cell phone. The data exchange between the cell phone and VCU is highly secure given the guarantee of the Bluetooth® pairing and authentication mechanism. For this work, a commercially available RN-41

(Rovingnetworks, Inc.) Bluetooth® module is used (Figure 2).



Figure 2 RN-41 Bluetooth® module (Rovingnetworks, Inc.).

The RN41 is a small form factor, low power; highly economic Bluetooth® radio for OEM's adding wireless capability to their products. The RN41 supports multiple interface protocols, is simple to design in and fully certified, making it a complete embedded Bluetooth solution. With its high performance on chip antenna and support for Bluetooth® Enhanced Data Rate (EDR), the RN41 delivers up to 3 Mbps data rate for distances to 100 m. Designers can easily customize their application using up to 8 Mbits of flash memory (Table 2).

Table 2 Features for RN-41 Bluetooth® module [4]

Item	Specifications
Frequency	2402-2480MHz
Modulation	FHSS/GFSK
Channel intervals	1MHz
Number of channels	79
Transmission rate	721kbps-2.0Mpbs
Receive sensitivity	-80dBm typ.
Output level (Class1)	15dBm max

2.3. Microcontroller

In this study, an 8-bit AVR RISC-based microcontroller, ATmega644 (Atmel Corp.) has been chosen [5]. The microcontroller combines 64 KB ISP flash memory with read-while-write capabilities, 2kb EEPROM, 4kb SRAM, 32 general purpose I/O lines, 32 general purpose working registers, real time counter, three flexible timer/counters with compare modes and PWM, 2 USARTs, byte oriented 2-wire serial interface, 8-channel/10-bit A/D converter with optional differential input stage with programmable gain, programmable watchdog timer with internal oscillator, SPI serial port, JTAG (IEEE 1149.1 compliant) test interface for on-chip debugging and six software selectable power saving modes. The device operates between 2.7-5.5 volts (Figure 3).

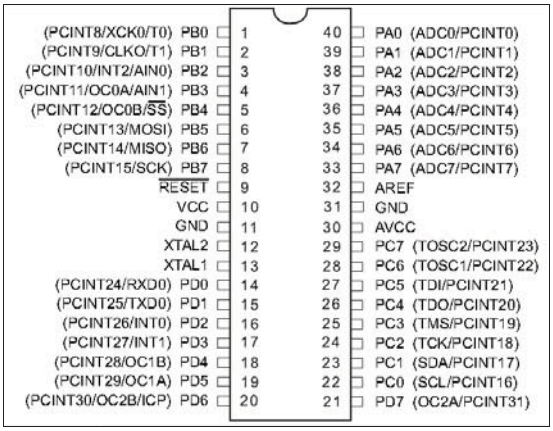


Figure 3 Pinout ATmega644 microcontroller (Atmel Corp.)

2.4. Electronics circuit design

The complete electronics wireless transmitter and receiver circuit design is made on a single printed circuit board (PCB) with proper mechanical slots for mounting with the mechanical housing. It consists of single axis accelerometer, ac coupling circuit, signal conditioning, microcontroller and Bluetooth transmitter-receiver modules block diagram as shown in Figure 4.

The circuit components are based on SMD ICs so that the overall size of the transmitter unit with mechanical assembly is small. The overall circuit is designed for 0-10g rms acceleration sensing, with current as the output of the circuit. It is a loop powered transmitter with 4-20mA current output corresponding to 0-10g rms acceleration input [6]. There is no separate power supply for neither sensors or any other ICs. The internal current loop circuit supplies power for all the ICs. The ADXL150, a single axis MEMS accelerometer is used as an acceleration sensor which measures accelerations that result from an applied force. The sensitivity of the chip is the output voltage change per g unit of acceleration applied, specified at the Vo pin in mV/g. The output voltage, Vo of the sensor is a function of both the acceleration input g and the power supply voltage (Vs) as given by equation (1). Where, S is the sensitivity and g is the input acceleration.

$$V_0 = \frac{V_s}{2-\left(\frac{SxgxV_s}{5V}\right)} \quad (1)$$

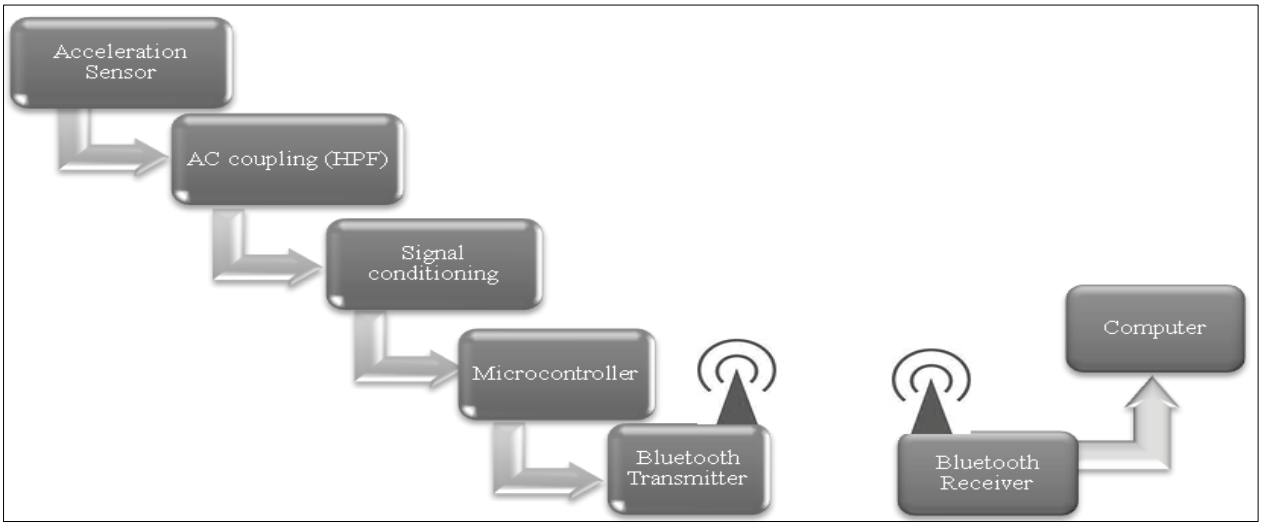


Figure 4 Block diagram of wireless vibration transmitter and receiver.

The accelerometer chip is operated with positive power supply of 5 volts. The full scale acceleration range considered here is ± 10g. The full scale range can be set by the resistor values (Table 3).

Table 3 Typical component values for AC coupled circuit.

Buffer gain	FS Range [g]	R2 [kΩ]	C3 value for 3dB corner freq [µF]		
			1Hz	3Hz	10Hz
2	±25	1.10^3	0.15	0.05	0.015
4	±12.5	332	0.47	0.15	0.047
5	±10	249	0.68	0.22	0.022

The full scale range can be changed by the resistor settings as described in the AC coupling circuit [3]. The circuit component (OP196GS) is a Micropower, Rail-to-Rail input and output operational amplifier (Op-Amp). The AC coupling used for vibration measurement, is employed between the accelerometer chip's output and operational amplifier's input as shown in Figure 5.

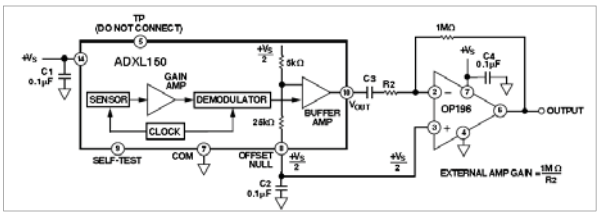


Figure 5 The pinout ADXL150 and AC coupled connection using an external Op-Amp.

The use of AC coupling virtually eliminates any zero *g* drift and allows the maximum external amp gain without clipping. Resistor R2 and capacitor C3 together form a high pass filter whose corner frequency given by equation (2).

$$F_c = \frac{1}{2\pi R_2 C_3} \quad (2)$$

This filter (or ac coupling) will reduce the signal from the accelerometer by 3 dB at the corner frequency (F_c), and it will continue to reduce it at a rate of 6 dB (20 dB per decade) for signals below the corner frequency. The corner frequency can be set by the proper selection of capacitor and the resistors. Capacitor C3 should be a nonpolarized, low leakage type. If AC coupling is used, the self-test feature must be monitored at the accelerometer's output rather than at the external amplifier output (since the self-test output is a dc voltage). In case of velocity measurement, the preferred lower (corner) frequency considered is 10 Hz. For almost all the machinery, the frequency bandwidth of 1.5 Hz to 1 kHz will catch all the normal vibrations. The proper selection of accelerometers is needed to sense those high frequency vibrations. In this design, the corner frequency considered is 3 Hz. The value of the resistor is 249kΩ and capacitor is 0.22µF corresponding to this frequency.

The MEMS accelerometer ADXL150 is characterized through its output voltage. A vibration measurement (Figure 6) and prototype circuit is configured on a PCB as shown in Figure7. The design is utilised the on-board 10 bit analogue to digital converter of the ATmega644.

The range of supply voltage is arranged as 5 volts for the accelerometer sensor and main circuit. To accomplish this, a sinusoidal vibration input is generated using a shaker platform. The device under test is mounted onto a dynamic shaker platform and the input - output voltage of the circuit was measured by using a oscilloscope and true rms multimeter. Theoretically, the output voltage can be calculated by using Equation (1) with the sensitivity of 38mV/g. Figure 6 shows the shaker table and attached sensors and corresponding device under test block diagram.

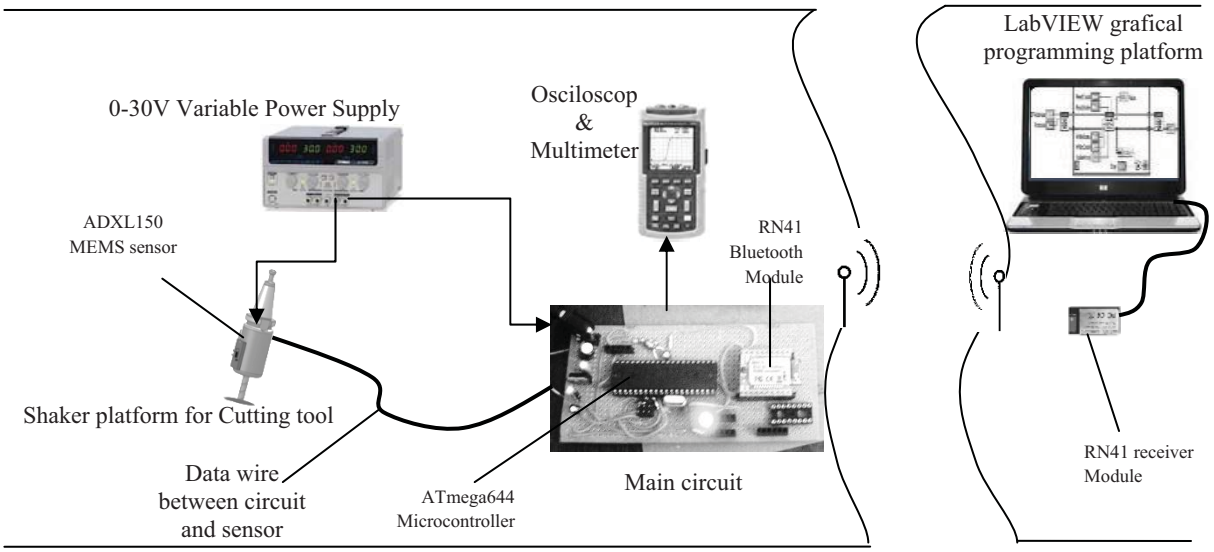


Figure 6 Vibration measurement setup

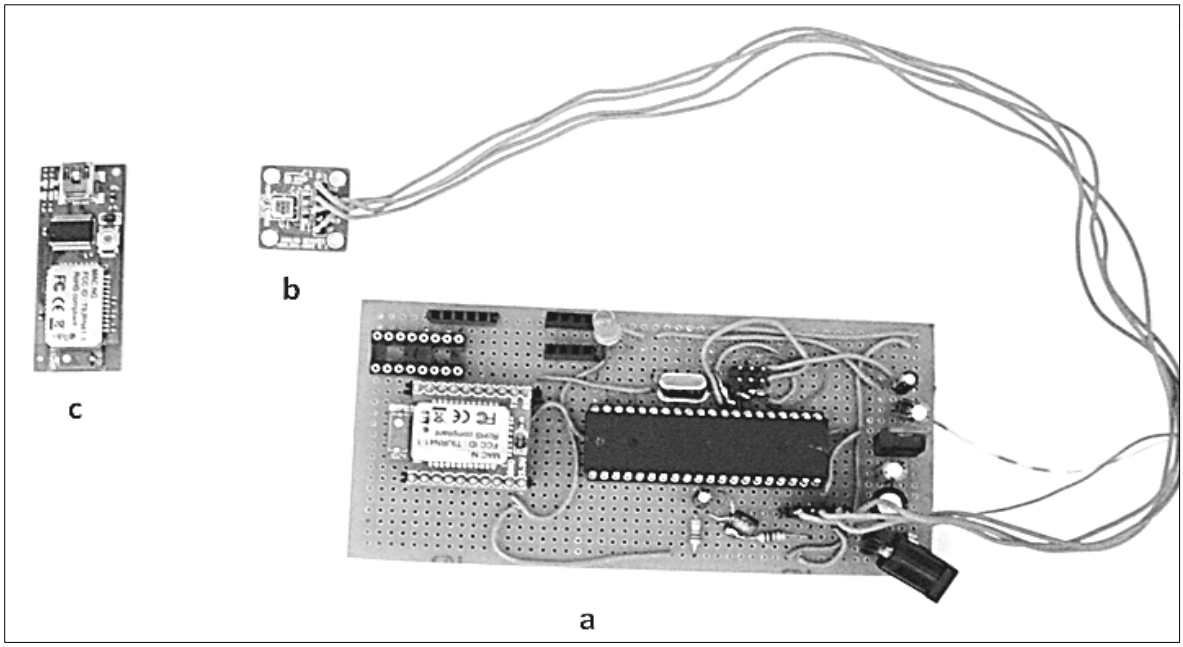


Figure 7 Prototype circuit (a), Accelerometer sensor (b) and Bluetooth receiver (c)

3. Result s and Discussion

The design, test of a vibration measuring unit using an MEMS accelerometer ADXL150 are presented in this study. The sensor has several advantages in terms of its compact size, low cost and high sensitivity. The system is designed as based on Bluetooth technology that can measure vibrations in real time. On the other hand, the obtained data are displayed as graphical on Labview® (National Instruments Corp.) graphical programming platform. The results showed that the device was capable of measuring vibrations where the

accelerometer output corresponded with the acceleration changes. It seems that the theoretically data are in close agreement with the experimental results. Figure 8 shows the comparison of the theoretical and experimental results of the ADXL150 accelerometer.

The graph shows an equal pattern between the analytical and simulation results but deviated in small values. In order to determine the optimal supply voltage, several justifications should be considered such as low power consumption, less total percentage error and high sensitivity. The output voltage linearly changed with the increase of voltage between from 4 to 6 volts. The screen displayed the desired output corresponding to the applied acceleration. This remote continuous data monitoring will be saved and the report of the information can be received by computer. The development of a vibration measuring device will act as the fundamental measurement and monitoring study for a future design wireless vibration sensor monitoring system for milling.

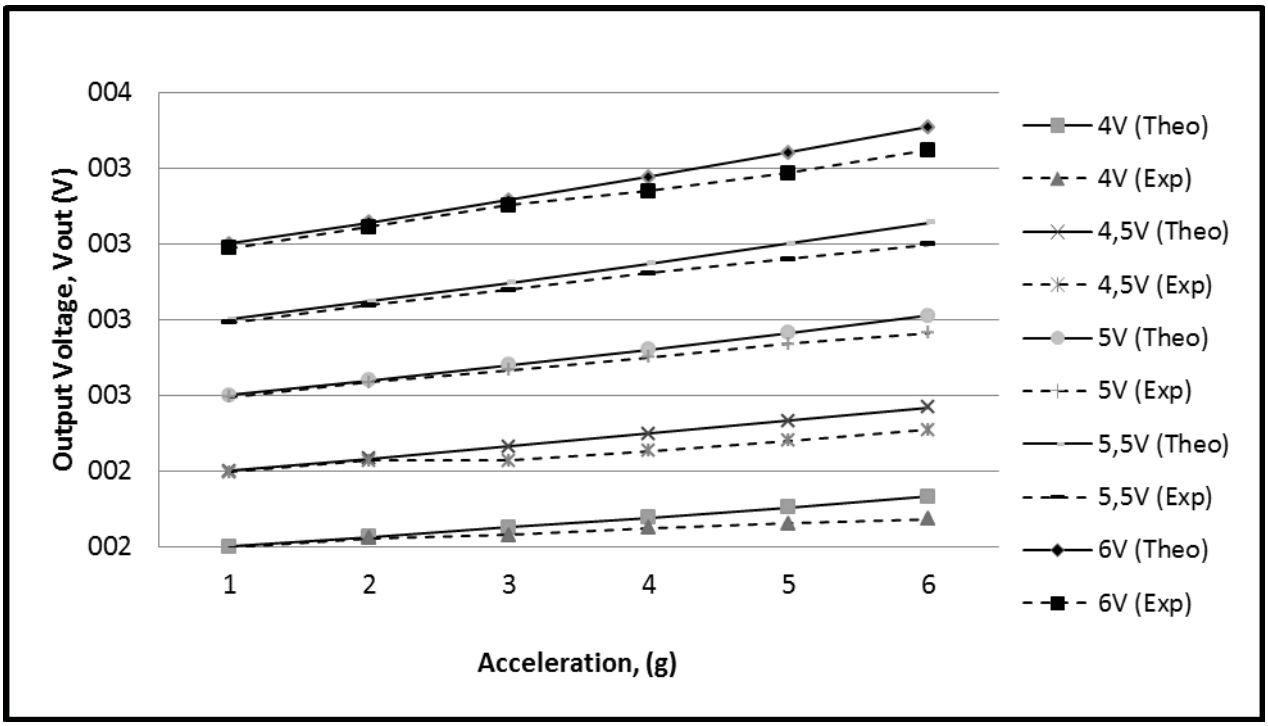


Figure 8 Output voltage versus acceleration for accelerometer.

References

[1] C. A. Suprock, R. Z. Hassan, R. B. Jerard, B. K. Fussell: Predicting Endmill Tool Chatter with a Wireless Tool Tip Vibration Sensor. Department of Mechanical Engineering, University of New Hampshire, Durham New Hampshire 03824 USA, 2008.

[2] Datasheet, ADXL150/ADXL250, Analog Devices http://www.datasheetcatalog.org/datasheet/analogdevices/573918736ADXL150_250_0.pdf.

[3] J. Hua, X. Lin, L. Xu, J. Li, M. Ouyang: Bluetooth wireless monitoring, diagnosis and calibration interface for control system of fuel cell bus in Olympic demonstration, Journal of Power Sources 186, 478–484. 2009

[4] Datasheet, RN41 Class 1 Bluetooth Module, Roving Networks, Inc., http://www.rovingnetworks.com/documents/RN-41.pdf

[5] Datasheet, ATmega644, Atmel Corporation http://www.atmel.com/dyn/resources/prod_documents/doc2593.pdf

[6] Jagadeesh Pandiyan, M Umapathy, S Balachandar, M Arumugam, S Ramasamy and Nilesh C Gajjar, 2006. Design of Industrial Vibration Transmitter Using MEMS Accelerometer. Journal of Physics: Conference Series, 34: 442-447. DOI: 10.1088/1742-6596/34/1/072