

Cost Effective Design of signal conditioner for vibration measurement

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Abstract— The Prime objective of this paper is to present a very low cost signal conditioning circuit by design a current exciter for vibration sensor, high frequency & wide range bandpass filter for vibration measurement system and convert the available acceleration signal into velocity (Integrator) with the use of op-amp & also compare the result of the same with simulated signal on LabVIEW. Vibration is very critical and nonlinear parameter, thus its measurement is very needful in mechanical and electrical industries to monitor the machine health & to take predictive maintenance steps before failure occur. This paper proposes a method to optimize the design of analog signal conditioner for minimum noise and nonlinear distortions. Here, An active second order Butterworth band-pass filter with sallen key topology is designed for the front-end system because all signals outside the 5 Hz-10 kHz (± 3 db slope) time-varying signal backscattered by the sensor need to be rejected. The second part of the proposed design is precise integrator for conversion of acquired acceleration data into velocity which is important to increase usability and viability of presented design. After the conversion it is crucial to amplify and rectify the signal for better match with any type of microcontroller so we can use obtained vibration signal further for transmitting and analyzing purpose. For verification of proposed signal conditioner circuit the results of the simulation in Multisim are compared to LabVIEW simulation results. The total number of components used in these circuits is less, compact, inexpensive and the designs for current exciter, filter & converter (Acceleration-Velocity) are attractive. The paper presents a scientific direction and development of vibration signals measurement.

Keywords— Acceleration to velocity converter, Analog Bandpass Filter design, Current source design, Multisim, Signal conditioning circuit for vibration measurement

I. INTRODUCTION

Vibration is a characteristic of major mechanical machineries, there is a massive interest in acquiring, analyzing and quantifying this parameter since it is indicative of the state and health of the machinery. The decisions of repair and maintenance of machines are not based on time period but on the condition (state) of machines. The so called “vibration signature” of the device will tell the operator whether the

device is operating properly or not and can offer an early warning if the machine is beginning to fail.

The signal conditioner is essential in vibration measurement, provides signal conditioning, signal conversion and re-transmission for continues machinery monitoring application. It converts a sensor input into a 4-20 mA, 0-5 V DC, or a 0-10 V DC output and provides a buffered dynamic output of the vibration waveform. Here, in proposed design, it converts sensor input into 0-5 V DC in which following blocks are included.

- 2.1 mA current exciter for vibration sensor(Accelerometer)
- Buffer Amplifier
- Wide range(5Hz- 10KHz) Butterworth Bandpass filter
- Acceleration to velocity converter(Precise integrator) using op-amp
- AC coupled Amplifier
- Precise full wave rectifier

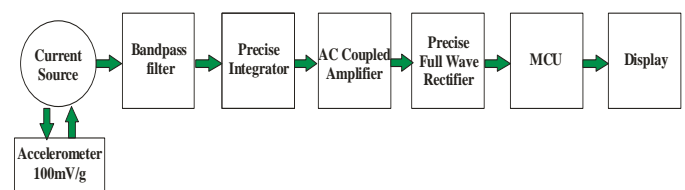


Fig.1. Block diagram of cost effective signal conditioner

The signal conditioner can take an input from an accelerometer and can be set to output the 0-5 V DC signal in proportion to acceleration. Here, Accelerometer is getting excitation from the current exciter (source) of 2.1 mA since for vibration sensor AC102-1A (CTC, USA) constant current range is 2-10 mA .

In signal conditioning circuit of vibration measurement, high performance filters are required to remove undesired signals, such as noise from incoming signals that the sensor receives at the sensing frequency, and harmonics after the mixing

operation. All analog filters fall in one of two categories: passive or active. In this vibration measurement system, active filters are used because of the following advantages:

- Active filter can generate a gain larger than one.
- higher order filters can easily be cascaded since each op-amp can be second order
- Filters are smaller in size as long as no inductors are used, which makes it very useful as integrated circuits.

The principal characteristic of a Band Pass Filter is its ability to pass frequencies relatively unattenuated over a specified band or spread of frequencies called the "Pass Band". However, the Active Band Pass Filter is slightly different in that it is a frequency selective filter circuit used in electronic systems to separate a signal at one particular frequency, or a range of signals that lie within a certain "band" of frequencies from signals at all other frequencies. This band or range of frequencies is set between two cut-off or corner frequency points labeled the "lower frequency" (f_L) and the "higher frequency" (f_H) while attenuating any signals outside of these two points.[8]

Here, for proposed second order active bandpass filter (5Hz-10 kHz with ± 3 db slope) design, op-amp LM358AD and for converter (A-V) or integrator design, op- amp OP07AH is used.

Here, we use the Multisim (NI) software which is a circuit simulator based on SPICE (standard for circuit simulation). It contains a database of components that you can use to build a circuit and many of these components are simulatable.[4] You can also find virtual instruments (scope, signal generators, and so on) that you can connect to your circuit in order to take measurements. It is a powerful, essential tool for electronic engineers or technicians.

In the second section of this paper, the band-pass filter design will be determined with its specifications and then implementation of second order Butterworth band-pass filter will be carried out in order to meet the design specifications.

At last, design of converter (Integrator) using op-amp that convert available acceleration signal (g) into velocity and also compare the result of both design with simulated signal on LabVIEW with same amplitude and frequencies. [10]

II. SIMULATION ON MULTISIM SOFTWARE

For designing and simulation of signal conditioning circuit for vibration measurement, we select the prominent software "Multisim".

Fig. 2 shows the basic circuit of 2.1 mA current exciter(source) for the accelerometer which is design by our self and its manufacturing cost is very low because of basic electronic components are used and thus, compare to other manufactures

our exciter cost is less, so we reduce the overall cost of the signal conditioner.

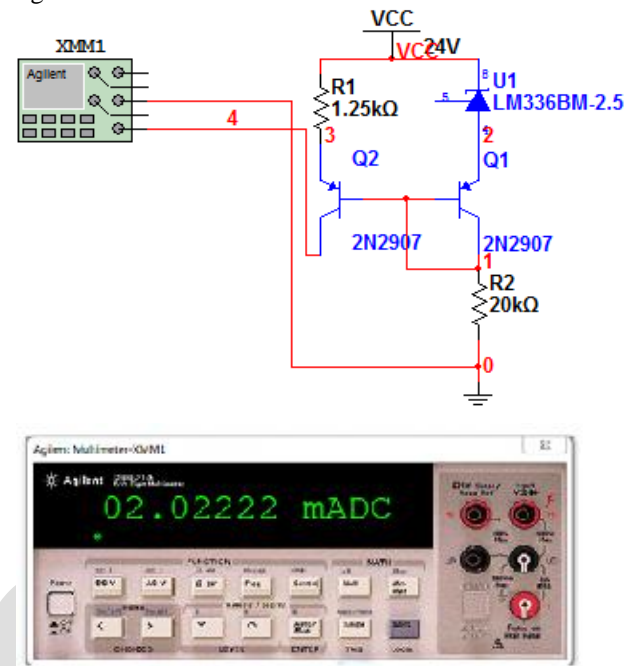


Fig.2. Current exciter for accelerometer (AC102-1A)

For Accelerometer AC102-1A, current excitation range is 2-10 mA. Above circuit gives 2.1mA constant excitation to the sensor which is desirable for the same, the vibration signal available at the sensing point is also retransmitted data towards signal conditioning circuit.

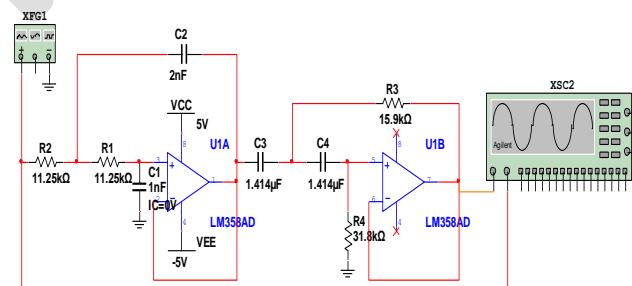


Fig 3. Simulation of active Butterworth bandpass filter (5 Hz-10 kHz)

Fig.3 shows the simulation of active bandpass Butterworth filter for wide range of frequencies (5 Hz-10 kHz) with +3db to -3db slope because we cannot say, vibration is very low or high frequency signal but The frequency of vibration signal depends on the RPM of the machineries. Here, we choose LM358AD OP-AMP of Texas instruments because it is advantageous over others.

- The Input Bias Current and unity Gain cross frequency is Temperature Compensated.
- Two Internally Compensated Op Amps.
- Eliminates Need for Dual Supplies.

- Allows Direct Sensing near GND and VOUT also goes to GND.
- Compatible with All Forms of Logic.
- Power Drain Suitable for Battery Operation

For choosing the values of passive components, here for the research purpose we use very fast, accurate and robust the Texas instruments software FilterPro 3.1.0.

In proposed design, we cannot directly design bandpass filter because for wide range bandpass filter, order of the filter is increased so the numbers of components is also increased. Hence here, bandpass filter is designed by using high pass & low pass filter specifications as per fig. 4.in filter pro software and implement the same in multisim .

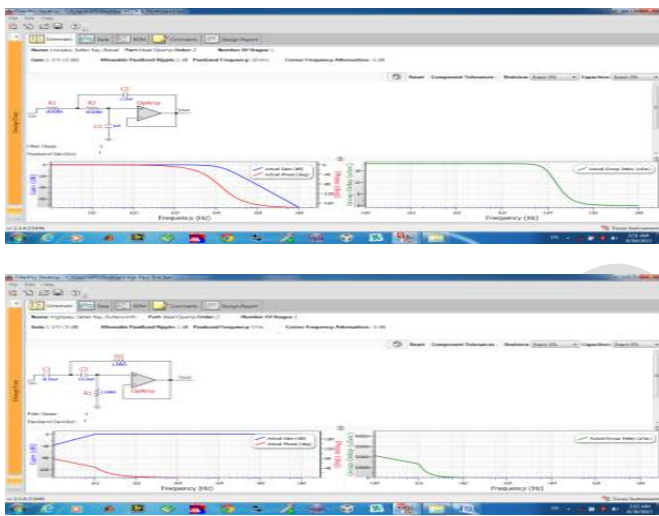


Fig.4 selection of passive components for lowpass & highpass filters

we can also see the data like gain(db),phase(degree, radian) and groupdelay (µsec) for each and every frequency which is beneficial to designer.

In vibration measurement, three big EU'S are there as acceleration, velocity and displacement. In many cases we are confronted with Acceleration, Velocity, or Displacement, but are not happy with it. Maybe we have taken the measurement in acceleration, but the model calls for displacement. Maybe we have taken the data in displacement, but the manufacturer quoted the equipment specifications in velocity. [5] With below mention simulation we can change acceleration signal into velocity. Simulation can be done in multisim as well as in Lab VIEW as shown in fig.5 and fig.6 accordingly.

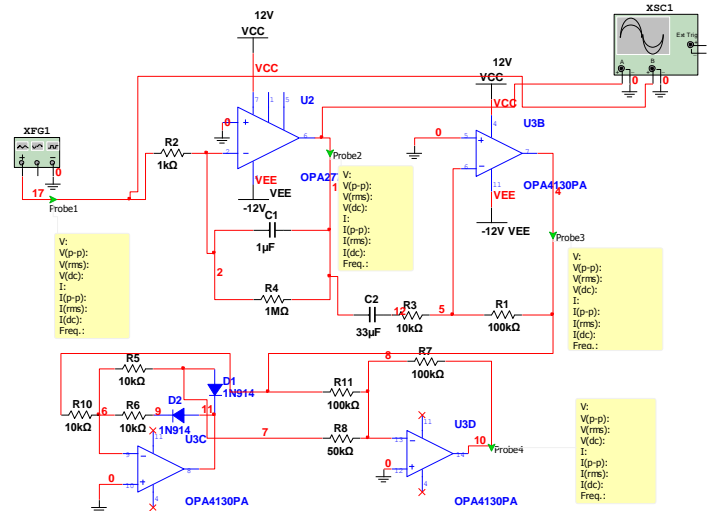


Fig.5. simulation of converter(A-V) or integrator

Here in fig. 5, for EU converter design, We use OP07AH, In above circuit, the first OP-AMP acts as an integrator which integrates the available acceleration i/p and gives the output in velocity. Than after the o/p of the same is given to the Ac coupled Amplifier which converts the velocity signal into pure Ac output with multiplication with appropriate gain. Than the o/p of Ac coupled Amplifier is given to the rectifier to convert the o/p in pure DC to match with microcontroller. For validation of proposed analog circuit, we simulate the same in LabVIEW graphical environment (fig. 6), which is a powerful and very accurate software with Sound & Vibration tool with higher cost.

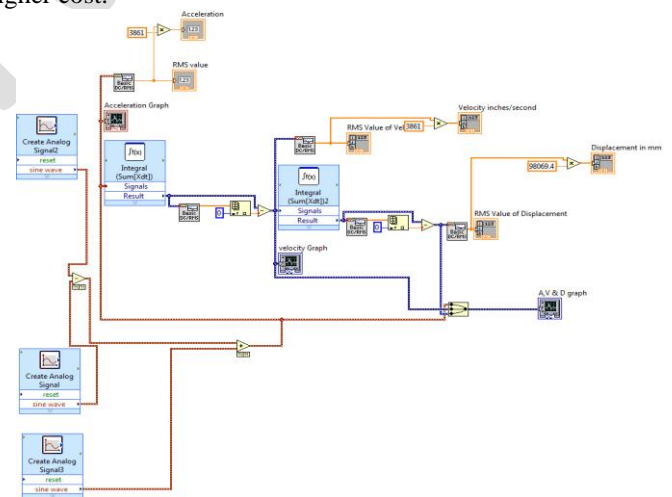


Fig 6. Block diagram of converter(A-V-D) in LabVIEW Where, A-Acceleration, V-velocity, D-displacement

In Fig.6, we create the analog signal with same amplitude and frequencies as given by function generator in Multisim. In above virtual instrument the generated signal is then integrated. So from the acceleration, we can get velocity and its RMS value which is further used for analysis purpose.

III. MATHEMATICAL CALCULATION

Mathematical calculation for 2.1 mA current exciter (fig.2) is given below.

Applying Kirchoff's voltage law for the loop R1-Q2-Q1-U1-R1 as in fig.2 .

$$\begin{aligned}
 -IR - V_{be} + V_{be} + V_z &= 0 & (1) \\
 IR &= V_z \\
 I &= \frac{V_z}{R} \\
 &= \frac{2.5}{1.25 \text{ K}\Omega} \\
 &= 2.1 \text{ mA}
 \end{aligned}$$

Here (fig.3) for better resolution, we design a bandpass filter by combining lowpass and high pass filter. Select the passive components of the low pass and highpass 2nd order Butterworth filter so that,

$$f_H = \frac{1}{2\pi \sqrt{R_1 R_2 C_1 C_2}}$$

Where f_H = high cutoff frequency (Hz)
 $R_1 = R_2 = R$
 $C_1 = C_2 = C$

For highpass filter,

$$f_L = \frac{1}{2\pi \sqrt{R_1 R_2 C_1 C_2}}$$

Where f_L = low cutoff frequency (Hz)
 $R_1 = R_2 = R$
 $C_1 = C_2 = C$

Basically, There are two types of bandpass filters:

1. Wide bandpass filter
2. Narrow bandpass filter

Here, we use Wide band pass filter having bandwidth 5 Hz-10 KHz with quality factor $Q < 10$. Q is a measure of selectivity, meaning the higher the value of Q , the more selective is the filter or narrower its bandwidth (BW). [15] The relationship between Q , the 3-db bandwidth, and the center frequency f_c is,

$$Q = \frac{f_c}{BW} \tag{2}$$

For wide bandpass filter the center frequency f_c can be defined as,

$$f_c = \sqrt{f_H f_L} \tag{3}$$

Where f_H = high cutoff frequency (Hz)
 f_L = low cutoff frequency (Hz)

IV. HARDWARE SETUP

In hardware setup of proposed design we have included the vibration sensor AC102-1A, current source, signal conditioner circuit and for verification purpose The NI data acquisition card as shown in Fig.7.

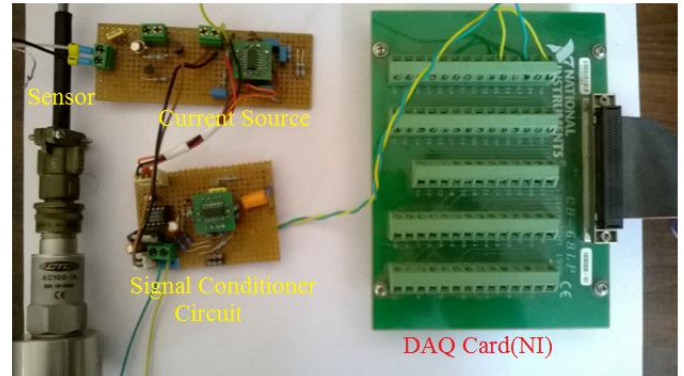


Fig 7. Hardware setup of proposed design

Proposed hardware is troubleshot, tested and also calibrated with standard one. From this circuitary one can also acquire the real time signal conditioned vibration signal and get the satisfactory results.

V. RESULTS AND DISCUSSION

Results of proposed vibration signal conditioner is discussed below. As mention above, 1st part of the design is 2.1 mA current source circuit for giving the excitation to the vibration sensor. (accelerometer- AC102-1A)

For proposed design shown in fig.3, the 2nd order butterworth bandpass filter whose range is 5hz-10khz, result for the same is showing below in fig.8

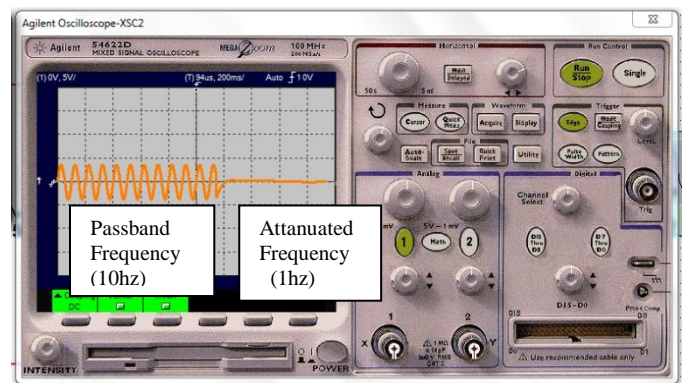


Fig 8. Result of bandpass filter design in virtual oscilloscope in multisim

Fig 8 tells that the proposed filter passes all the frequencies in the range of passband (5Hz-10 KHz) and attenuate the remaining all frequency signals. We can also modify the passband range in multisim software according to our requirement. So we can get the actual vibration signature and use it for further measurement and analysis purpose.

Now, for vibration signal conditioner, it is also very important to do conversions between 3 big Engineering Unit's. As discussed before in fig.4 and the result of the same obtained as per fig.9,11,13 for different values of frequencies in multisim(NI) and also compared with the result of LabVIEW (fig.10,12,14)

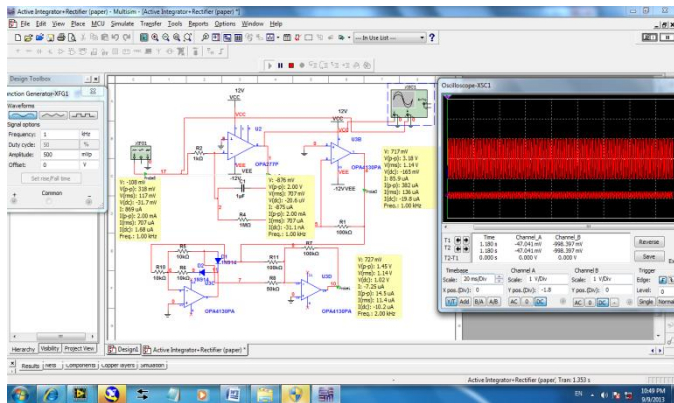


Fig 9. Result of Acceleration to Velocity converter (1khz,500 mVp) in multisim

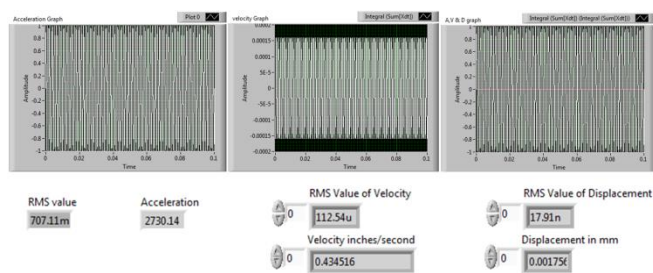


Fig.10. Result of Acceleration to Velocity converter (1 kHz, 500 mVp) in LabVIEW

As shown in fig.9, 11, 13 four probes are connected and their values shown in pale yellow background.

- Probe1: indicates input signal data (Acceleration)
- Probe2: measures integrated input signal data (Velocity)
- Probe3: measures amplified velocity data
- Probe4: rectified velocity output

The data like V_i , V_{p-p} , V (rms), V (dc) etc is indicated.

In the same figs., the virtual oscilloscope shows two channel output. One is for acceleration signal and other is for converted velocity output.

Here in fig 9, 11, 13 represent proposed design results with different frequency like 1 KHz, 500 Hz and 2 KHz accordingly.

In multisim, 1st we integrate the acceleration data into velocity, than amplify the data comparable with any microcontroller resolution. Than rectified the amplified data,

for removing the dc components .

For compare the velocity value (inch/s) of Lab VIEW with multisim,

1. Read the Vrms data from probe no.4
2. Convert that data into appropriate velocity unit, here in inch/s.
3. Because of data is amplified by buffer amplifier, divide that value by gain (here, 1000) and get the comparable result with LabVIEW.

Like an example in fig 9 the probe No. 4 shows the velocity RMS value 1.14 V. Now to compare it with LabVIEW result it convert into meter/second according to the sensitivity of the sensor 100 mV/g.

We got the velocity RMS 111.72mV. then divide it by 1000 because in Multisim it is amplified by the gain value 1000. So finally we got the velocity RMS value 112.72 micron which is comparable to the LabVIEW result shown in fig.10.

Again also convert the velocity result into inch/second and compare with the LabVIEW, got the same result in both designs.

Above calculations and verifications are also applicable for all different frequency result shown in fig.11,13 with fig.12,14.

In LabVIEW we generate the vibration signal by merging three different frequencies signals with same specifications as multisim input signal. And then both simulations have same results which can see from fig.9, 11, 13 and fig. 10, 12, 14.

From the fig. We can see that as the frequency increases Amplitude decreases in velocity measurement.

RMS value of vibration in terms of velocity provides information about deterioration rate of healthy condition of machine.

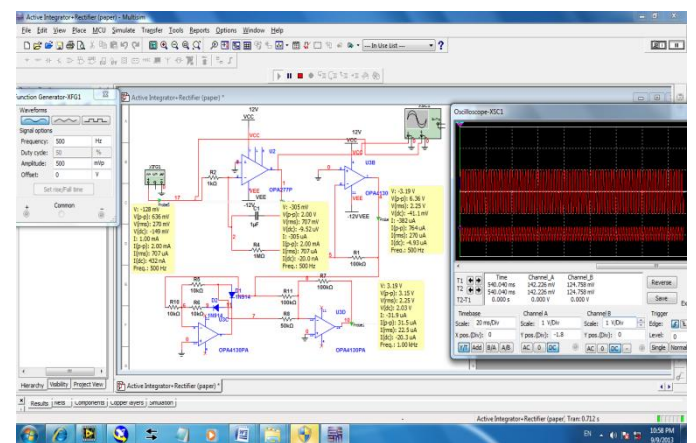


Fig.11. Result of Acceleration to Velocity converter (500hz,500 mVp) in

multisim

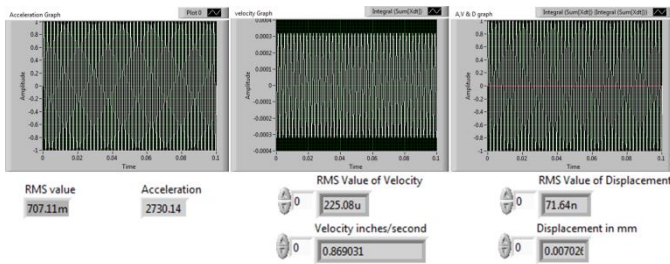


Fig.12. Result of Acceleration to Velocity converter (500hz,500 mVp) in LabVIEW

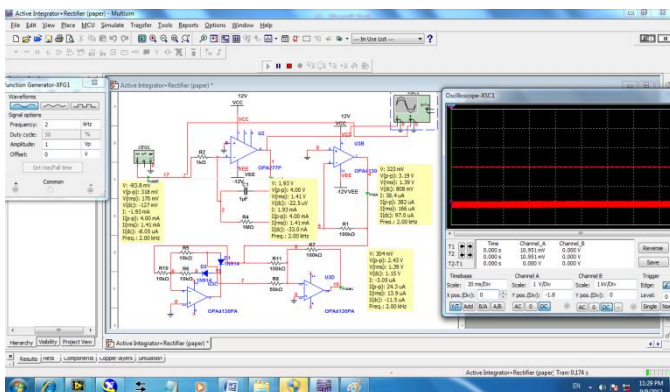


Fig.13. Result of Acceleration- Velocity converter(2khz,1Vp) in multisim

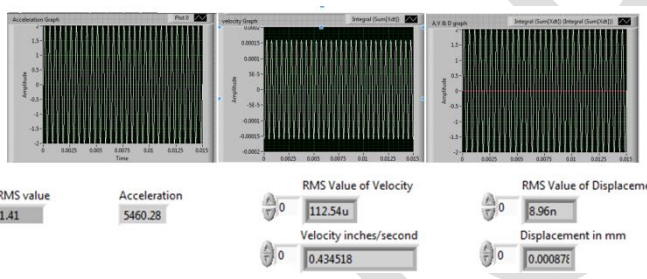


Fig.14. Result of Acceleration- Velocity converter (500hz,500 mVp) in LabVIEW

VI. CONCLUSION

In India, there is a very little amount of work done on vibration parameter. Even we have to import signal conditioner with higher cost. So we have get an idea to design a cost effective solution for the same and put the maximum efforts, finally proposed research ends with impressive, cost effective, well proven and compact design for signal conditioner Which can be very favorable for the small or medium scale electrical and mechanical industries or companies who cannot afford that costly solution. Here, we also provide an extra feature which can convert the acceleration data into velocity and it is useful for many applications. User can get the information about velocity and acceleration of vibration signal as well as its RMS values which are very important in fault diagnosis of mechanical machineries. This feature incorporated with versatility of the

Multisim software. This fundamental research helps to provide the fine vibration signature which may be used for analysis purpose and helps the company people to identify unhealthy condition of machines.

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