2006-2619: NON CONTACT VIBRATION ANALYSIS USING INNOVATIVE LASER BASED METHODOLOGY

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NON CONTACT VIBRATION ANALYSIS USING INNOVATIVE LASER BASED METHODOLOGY

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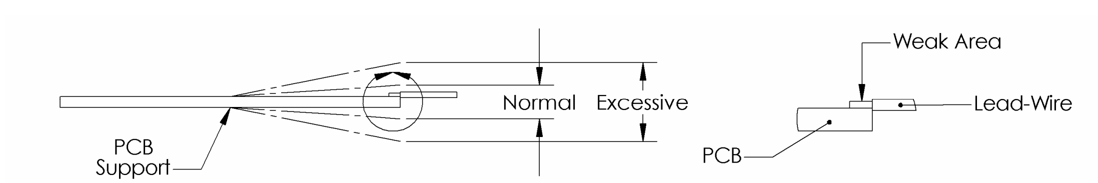
ABSTRACT

Due to increasing requirements in performance, in areas such as computers and automobiles, manufacturing companies have been forced to produce within tighter tolerances and perform more elaborate testing to validate their products. In the case of automotive manufacturers the measurement of vibration is essential. In the past, equipment such as strain gauges and piezoelectric accelerometers have been adequate in measuring it. However, they have had several disadvantages. One disadvantage being that the part must be mounted on the surface of the object being measured. This can result in the mass altering the frequency and mode shape of the vibrating object. Laser technology is a non-contact measuring method providing the resolution needed to satisfy the changing requirements. At this time however, the cost of this equipment prevents companies from pursuing it as a solution. This paper provides an innovative method of detecting vibration using a low cost laser based method. It is not only a research tool, but can also be used in the education of scientists, engineers and technologists. The paper outlines the design methodology and test results.

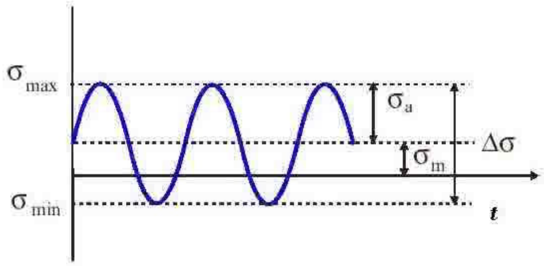
INTRODUCTION:

One of the most critical tasks during the design of a system that has moving parts is to determine the level of vibration that the system will be exposed to and where this vibration could become a liability.

The fan industry for example; has experienced fatigue failures in their lead-wires due to higher deflection at specific frequencies than expected. The higher deflection increased the stress loading at the connection between the wires and the printed circuit boards causing the wires to break and in some cases for product to be recalled.



In most engineering materials, a stress that fluctuates between two given values, σ_{min} and σ_{max} is most likely to cause failure than a steady stress equal to σ_{max}.[1]



Companies would be able to prevent these types of failures by determining a stress ratio:

$R = \sigma_{min} / \sigma_{max}$

However, in order to determine the maximum and minimum stress values; fatigue test would have to be performed. These tests tend to be expensive and time consuming. With customers pushing for lower cost and products been developed at very fast pace; companies in many cases can not afford the cost or time associated with these test.

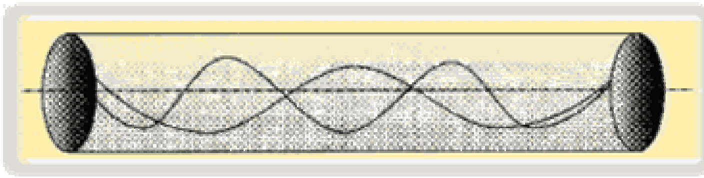
This has forced companies to look elsewhere to find other types of tests that can provide them with the necessary accuracy to measure vibration at a lower cost within a shorter period of time. These test methods include the use of piezoelectric accelerometers, strain gauges and laser measuring equipment.

ANALYSIS:

Of all methods used to measure vibration; the use of lasers is the most appealing since the equipment has minimum or no contact with the object to be measured. The purpose of this project is to develop a non contact vibration analysis system using innovative laser based methodology at a lower cost than the current systems available.

Currently the laser Doppler scanning vibrometer is the most commonly used laser based vibration measuring system.

The Doppler Effect:
It is basically the change in frequency (f) of the laser beam wavelength (λ).



A laser beam emits a continuous wave with the frequency f and the wavelength λ. A series of successive waves spaced at regular intervals (wave train) with a wavelength λ pass a stationary object in the time T = 1/f. If the object moves away from the beam source at the speed v, then the wave train needs a slightly longer time T', to pass the object. The total distance cT then becomes λ + vT'.[2]

$c T' = \lambda + vT' \Rightarrow (c - v)T' = \lambda$

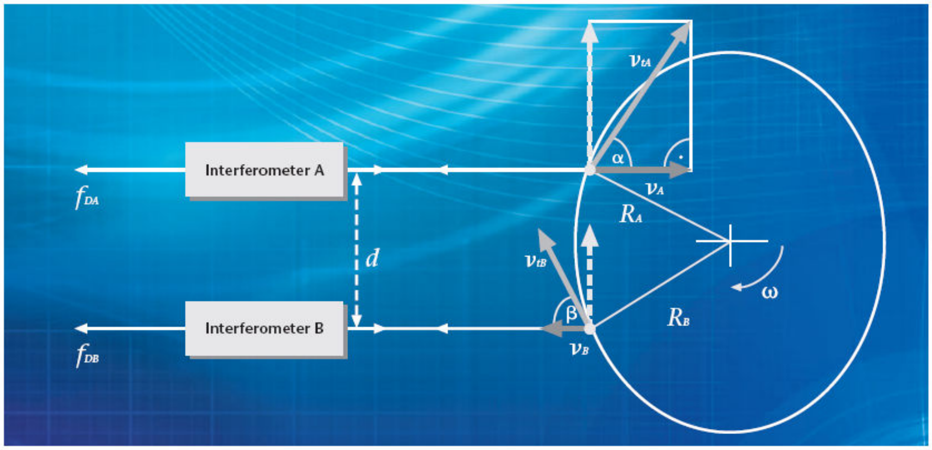
The wave vibration for the objects has the cycle duration T'.

Therefore:
$T' = 1/f' \Rightarrow f' = 1/T'$ &
$\lambda = c/f \Rightarrow (c - v)f' = c/f$ &
$f' = f(c - v)/c = f(1 - v/c)$

This indicates that if the object moves away from the beam source ($v > 0$), then the beam frequency will be shifted to smaller values and if it moves towards the beam source ($v < 0$), then an increased frequency will be measured.

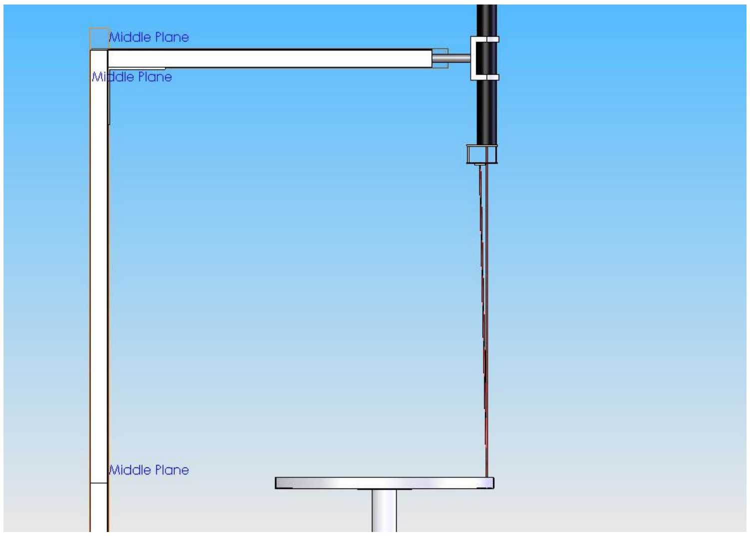
The motion of these objects is induced by vibration created by the use of speakers at specific frequencies.

The biggest limitation of the laser Doppler scanning vibrometer is that it is designed to measure linear vibration. If the customer required the measurement of dynamic vibration; such as in a turbine rotor or a fan blade, they would have to use either two lasers or measure the same points from two different angles. These steps result in an increase in cost and time.

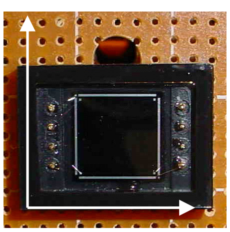

Interferometer A
Interferometer B
f_{DA}
f_{DB}
d
v_{tA}
v_A
R_A
α
v_{tB}
v_B
R_B
β
ω

Proposed System:

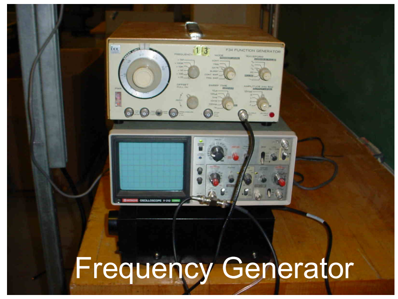
The main application of this laser measuring system is to measure displacement in 2-axis in order to determine dynamic vibration. This system consist of a laser beam reflected into a position sensing detector (PSD) off a reflective tape (1x1 mm) which is placed on the surface of the object to be measured.



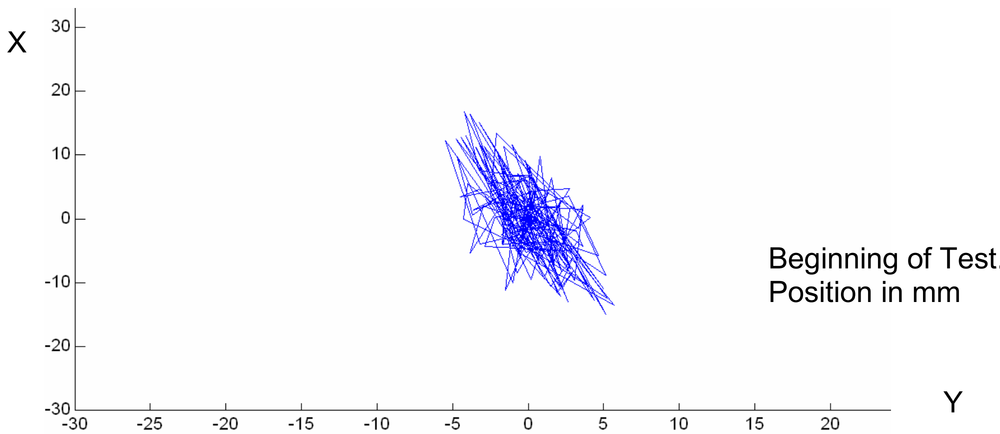
The PSD consist of a resistive layer which creates an electric charge proportional to the laser bean intensity that is incident on its surface. The PSD original position (x_0 , y_0) would be defined as the location of the laser beam on the PSD prior to the object been placed in motion. This PSD has an x-axis and a y-axis.

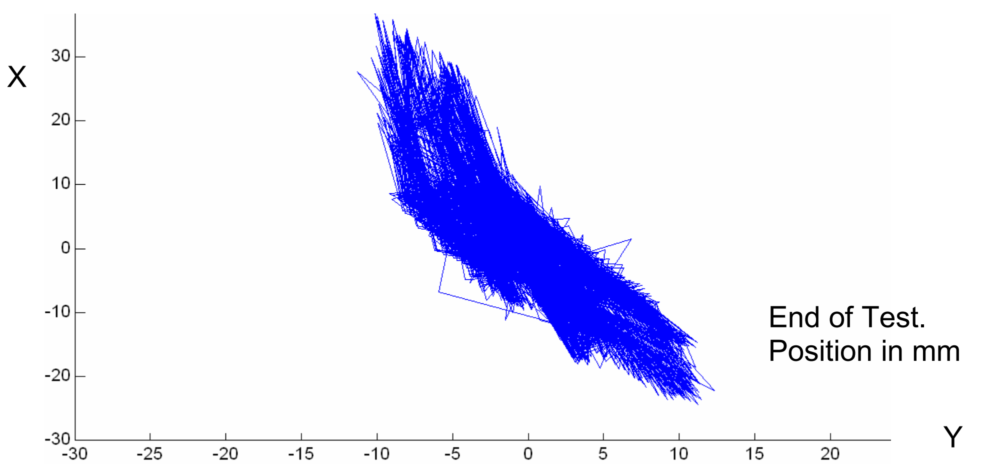


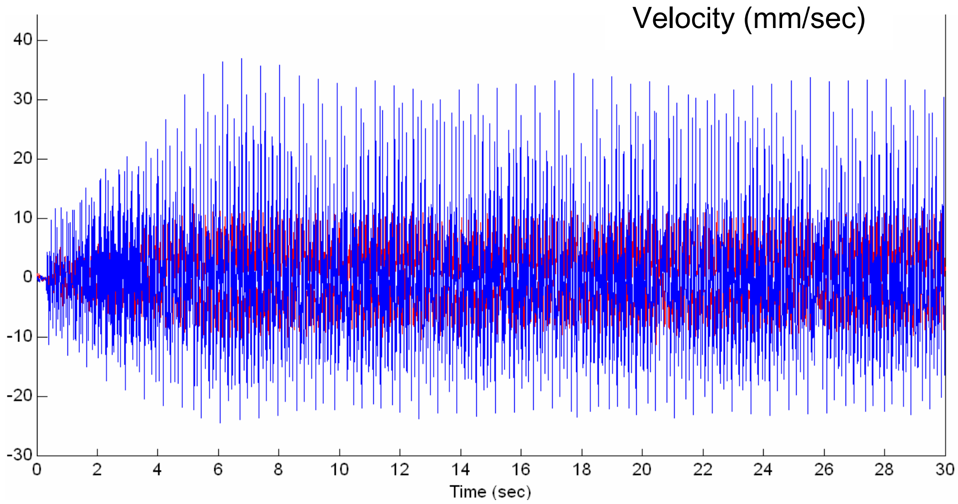
The motion of the object would be induced by vibration created by the use of a single speaker at specific frequencies. These frequencies will be generated and controlled by a frequency generator.



The PSD converts the laser beam position changes into a signal that can be analyzed with vissim. The vissim program written for this project converts the signal into a position or velocity output ($s = ut + 0.5at^2$).







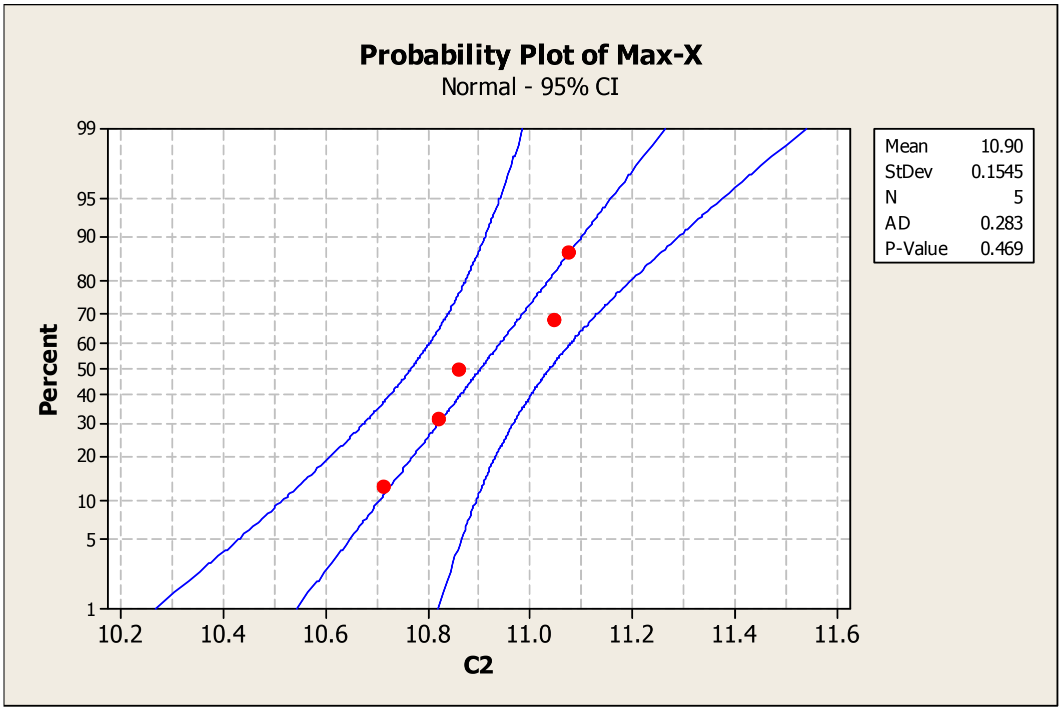
Various tests were performed to determine if the readings are repeatable.
The presumption was made that there is no difference between the averages of the high and low peaks of the signal.

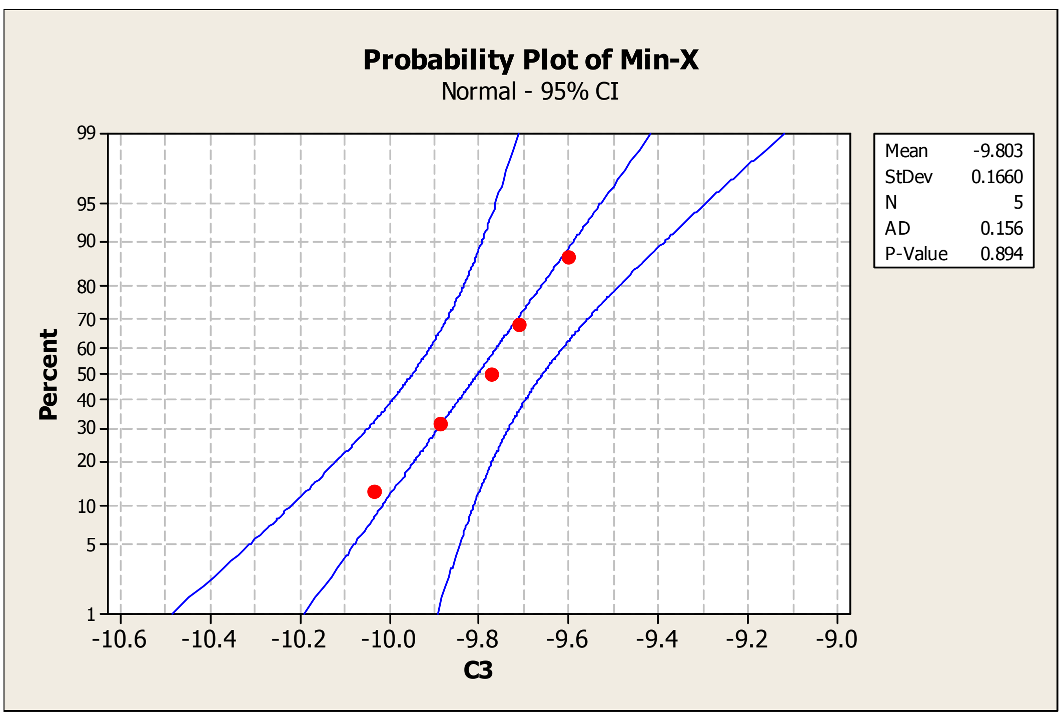
Null Hypothesis:
H_o: $\mu_a = \mu_b = \mu_c = \mu_d = \mu_e$

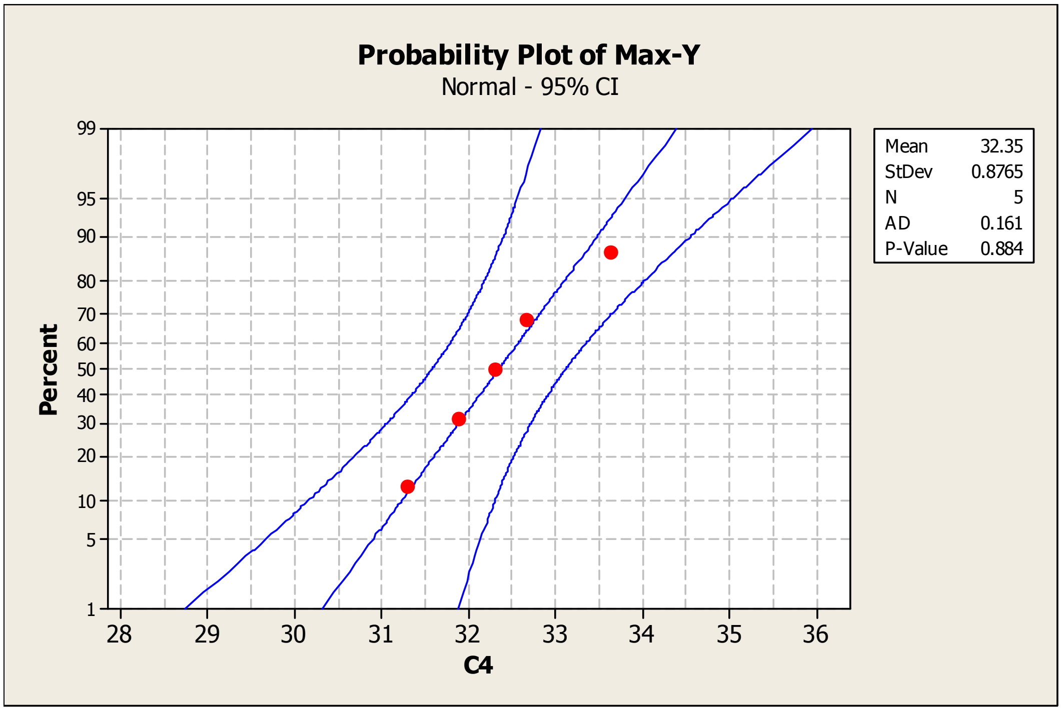
If the P-value is greater than 0.005, then the hypothesis is true.
If the P-Value is less than 0.005, then the hypothesis is false.

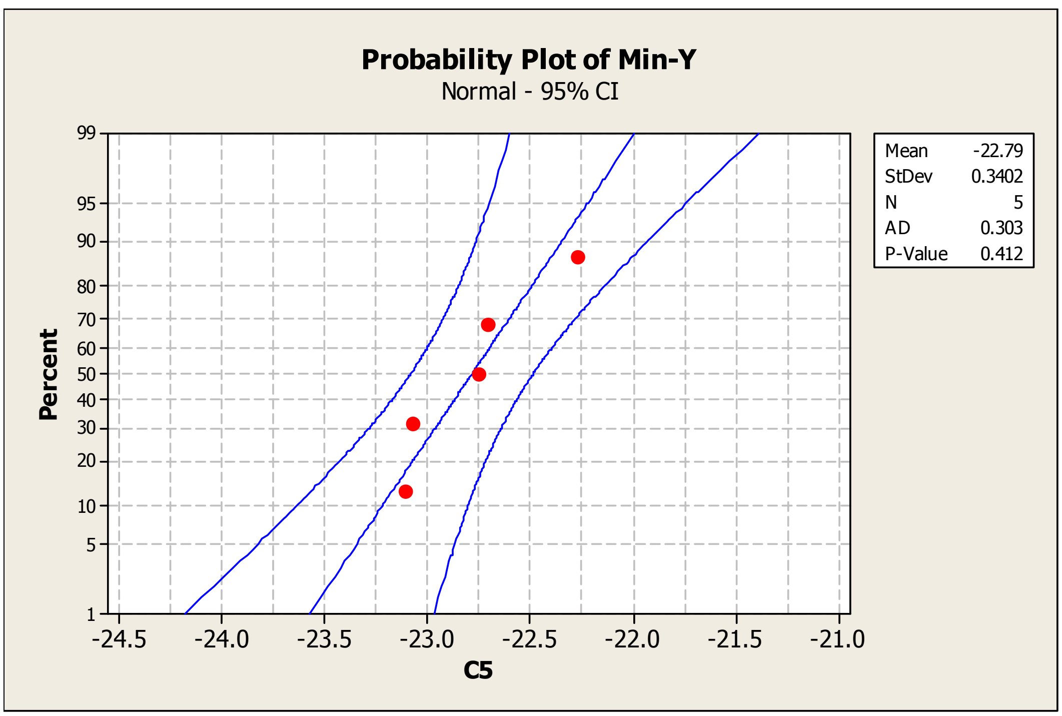
Averages

	Max - X	Min - X	Max - Y	Min - Y
Test 1	10.7118	-9.6036	31.2896	-22.2734
Test 2	10.8194	-9.7747	31.8700	-22.7055
Test 3	10.8592	-9.7137	32.6553	-22.7550
Test 4	11.0466	-10.0358	32.3059	-23.0795
Test 5	11.0746	-9.8897	33.6240	-23.1125


Probability Plot of Max-X
Normal - 95% CI
Percent
C2
Mean 10.90
StDev 0.1545
N 5
AD 0.283
P-Value 0.469


Probability Plot of Min-X
Normal - 95% CI
Percent
C3
Mean -9.803
StDev 0.1660
N 5
AD 0.156
P-Value 0.894


Probability Plot of Max-Y
Normal - 95% CI
Percent
C4
Mean 32.35
StDev 0.8765
N 5
AD 0.161
P-Value 0.884


Probability Plot of Min-Y
Normal - 95% CI
Percent
C5
Mean -22.79
StDev 0.3402
N 5
AD 0.303
P-Value 0.412

Peaks from data

	Max-X	Min-X	Max-Y	Min-Y
TEST 1	10.4731	-9.1436	32.9133	-22.4588
	11.3747	-9.6285	32.9320	-21.5135
	10.9845	-9.6064	30.5068	-24.0014
	10.9487	-10.3615	32.4567	-22.2103
	10.6129	-9.9738	30.8267	-21.7266
	11.0273	-9.4024	31.0760	-22.2212
	10.4530	-9.3669	31.3338	-21.5348
	10.2765	-9.2410	29.1243	-22.5373
	10.2556	-9.7081	30.4365	-22.2565
TEST 2	11.6669	-9.0068	30.2258	-22.9480
	10.9776	-10.5633	35.1565	-23.3499
	10.7392	-10.4597	32.3112	-22.6000
	10.7609	-10.1581	32.7193	-23.4098
	10.6927	-9.5600	32.9037	-22.5484
	10.6370	-9.7522	31.7701	-21.8714
	10.1601	-9.6947	29.7003	-22.3698
	12.1469	-9.3000	33.1943	-24.4781
	10.4201	-9.8780	31.6022	-21.5063
	10.3231	-9.8757	30.1335	-22.6721
	10.4887	-9.2731	30.8532	-22.0070
TEST 3	11.7178	-9.6675	34.9275	-23.6077
	10.8939	-10.4805	35.1709	-23.5640
	11.3675	-9.3406	30.9812	-22.7182
	10.4042	-10.1648	32.8634	-23.2743
	10.4094	-9.7942	32.3791	-22.3322
	10.5516	-9.5409	31.1132	-22.2574
	10.4852	-9.4575	31.8301	-22.6298
	11.3128	-9.2263	33.0106	-22.1987
	11.0718	-9.8290	30.7959	-21.8753
	10.2891	-9.2963	32.6020	-23.0856
	10.9481	-10.0526	33.5343	-22.7618
TEST 4	11.8582	-13.4169	31.9291	-24.6740
	11.3788	-9.9207	31.8769	-22.7869
	10.9310	-9.7338	33.1889	-22.9938
	10.9907	-9.9499	33.6133	-22.4568
	11.3306	-9.6333	31.9652	-23.1603
	10.8355	-9.7504	31.7237	-23.1181
	10.4666	-9.6945	31.7906	-23.1452
	10.9497	-9.8566	33.1750	-22.5770
	10.5626	-9.8365	31.0161	-23.0637
	10.9371	-9.4157	31.9547	-23.0343
	11.2720	-9.1857	33.1310	-22.8641
TEST 5	10.3433	-9.0870	30.7700	-21.7876
	12.3221	-10.1617	36.9136	-24.3763
	11.1350	-9.9906	35.8370	-23.1622
	11.1725	-9.9552	33.1011	-22.6146
	11.0203	-10.3452	32.5798	-23.6581
	10.5644	-9.5772	33.1323	-22.6643
	11.2720	-9.8231	34.3410	-23.3673
	11.3379	-11.2823	32.9522	-23.5371
	10.4269	-9.4684	33.2069	-23.1737
	11.0335	-9.3330	33.6525	-22.9154
	11.1925	-9.7625	33.3779	-22.9805

CONCLUSION:

In this paper a new method to measure vibration has been presented. The preliminary testing that has been performed shows that the objective of this project can be achieved.

Special Thanks:
Jun Kondo, Research Engineer / Associate professor

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[1] Deutschman, Michels, Wilson, *Machine Design Theory and Practice,* McMillan, New York, 1975

[2] R. K. Vierck, *Vibration Analysis,* International, 1967

[3] M. R. Lindeburg, *Engineering in-training Reference Manual,* Professional, 1990