Impulse Damping In Structural Materials

By

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Submitted to the Department of Physics on 11 May 1990 in partial fulfillment of the requirements for the degree of Bachelor of Science.

Abstract

An experiment was devised and conducted to provide relative data on the impulse damping rates for a variety of materials selected for their utility in machine construction. Further, conventional wisdom indicates that there are substances which, when introduced into the core of a machine or tool, improve that tool’s vibration damping characteristics. This experiment provides conclusive evidence to support this wisdom but does not yield any clear, general rule for its application—rather the opposite in fact. Cast iron damps vibrations more quickly than steel, but titanium damps vibrations faster than any other material tested. Filling the core of a sample with oil generally improves it’s damping characteristics, but with copper the opposite occurs.

Thesis Supervisor: Professor Alexander H. Slocum

Title: Assistant Professor of Civil Engineering
Dedication

This thesis is dedicated to Alex Slocum, who has believed in my abilities and stood behind me throughout my MIT career. It was his confidence and enthusiasm that kept me both enrolled in, and interested in, MIT. I extend thanks to Hewlett Packard, which lent me a very nice oscilloscope that made my measurements possible, and to the Department of Physics, especially Gene Di Salvatore, for the use of an essential band-pass filter. I will be eternally grateful to Jennifer Hyman for making it all worthwhile. But mostly I thank my parents, who never failed to give the constant monetary support, and occasional emotional support, that has made my education possible.
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Chapter 1

Introduction to Vibration Damping

The Danger of more or less perpetual vibration of significant magnitude is one of the bugbears of designers of accurate instruments, and research leading to some practical data on this subject for various types of members is urgently required.
—T.N. Whitehead, *Instruments and Accurate Mechanism*

1.1 Background

If one considers the problem of threading a needle while sitting in a car travelling quickly over an uneven road, the limitations on accuracy imposed by vibration are made quite clear. In more significant applications, such as machine tools or robotics, vibrational problems manifest themselves in poor surface quality and limitations on achievable accuracy. Further, vibration (particularly when manifested as “tool chatter”) is one of the primary causes of tool failure.

Sources of vibration may be clearly divided into two groups: environmentally sourced, and internally sourced. The control of the former source is most conveniently managed by isolation technology. Although the latter source might conceivably also be isolated from the point of interest, this is generally not possible; for example a cutting head cannot conceivably be isolated from the vibrations which it generates. It is, therefore, of primary concern to machine tool designers to maximize the dissipation of vibrational energy.

It has long been known that the addition of lead shot and or oil is an effective means to damp vibration. “Dead Blow” hammers use rubber coated brass ampules filled with lead shot and oil for their heads. The conventional wisdom behind such advances is that acoustically dead materials damp vibration well. It is also commonly believed that viscous fluids dissipate vibrational energy quickly (though this theory is somewhat undermined by the spring-like behavior of fresh “go-jo” hand cleaner).
There is a tremendous amount of literature on the subject of vibration in general, and even a significant volume on the subject of material damping in particular. There is, however, almost no tabulated data on the behavior of materials with respect to their damping characteristics.

The data for the damping rates of materials which does exist [1] is of extremely limited scope and is further outdated by the fact that some of the few materials listed are no longer manufactured. Machine designers are given some limited theoretical basis for evaluating a given material’s damping characteristics† most of which is well out of the scope of the present treatment of the subject. Further, in the most interesting regime of large scale motion, there is no quantitative understanding [2]. No reference what-so-ever could be found treating the subject of metal-fluid boundaries as they effect vibrational energy dissipation.

1.2 Scope of Experiment

It was proposed that an experiment be devised to quantitatively measure the relative damping performance of various materials chosen for their pertinence to machine tool designers. This experiment was undertaken with the understanding of it being preliminary in nature to a more exhaustive set of measurements. This preliminary study was meant to provide some quantitative basis for evaluating the common wisdom of machine tool designers and to provide some basis for the preparation of future experiments.

It was believed at the outset that the addition of viscous materials would significantly improve the damping characteristics of most materials. It was also believed that the addition of lead shot in the core of a sample would significantly improve its damping characteristics. Fol-

† Most tabular data seems to have originated with *Energy Dissipation Mechanisms In Structures With Particular Reference To Material Damping* by B. Lazan. The paper was published in 1959 in the book *Structural Damping* edited by J. Ruzicka, © 1959, ASME.

‡ See, for example, *Vibration Damping* by A. Nashif, D. Jones, and J. Henderson, © 1985, John Wiley & Sons. Chapter three is particularly pertinent, as is chapter fourteen of *Mechanical Behavior Of Materials* by F. McClintock and A. Argon, ©1966, Addison-Wesley.
lowing the most straight-forward of logic, it was predicted that lead shot and oil would provide exceptional damping.

Further, from experience with machine tools and with day-to-day experience with different metals, a certain ranking was predicted without any deeper evaluation. It was predicted that cast iron would damp vibrations very well, and that brass would not (most machine tool bases are cast iron; many bells are made of brass). As crude as these estimates are, they are not uncharacteristic of the way a designer might select materials for non-critical applications (one would hope that for critical applications more care would be taken).

Interestingly enough, not all of the common sense predications turned out to be true, or even close to the measured results.
Chapter 2

Theory

2.1 Material Damping

Most solid materials exhibit some level of hysteresis when deformed mechanically, even over a small range. This is due to the dissipation of a certain amount of the elastic energy as heat or as plastic deformation. There are a number of mechanisms by which materials dissipate vibrational energy.

2.2 Damping Mechanisms

There are a tremendous number of mechanisms postulated to provide a degree of damping in a vibrating member. Only those most pertinent to the experiment at hand will be explored.

The two dominant modes of energy loss in our experiment would be acoustic excitation of the surrounding air, and mechanical loss to the table itself, which was not rigidly fixed. These modes of energy dissipation are not the subject of our current study, but cannot be ignored in the analysis.

Internally, a whole host of interactions might be taking place, which can be divided into two categories—linear and non-linear (rate independent and rate dependant) [3] [4]. It is thought that non-linear effects are dominant in most structural materials [5].

Most of the vibrational energy lost to damping ends up as heat in the end. Materials which are compressed tend to heat up. In the case of dynamic stress, the heat is not created in a homogenous fashion, which results in thermal potentials, and so in thermal currents. These currents represent a significant mode of loss.

Also significant, especially in the ferrous materials, is Snoek Damping [6]. When inter-
stitial atoms are in solution in a crystalline solid, their position is determined by energy minimization. When such a solid undergoes strain, the balance of energy is disturbed and the solute atoms tend to migrate. The considerations for this migration tend to be purely physical: the interstitial atoms distort the crystal; if the crystal is physically deformed then the interstitial atoms will tend to collect where their presence causes a minimum additional distortion to the crystal lattice. This migration takes time, and can only be accomplished efficiently at a certain frequency, at which there will be a peak in the damping of the material. The amplitude of the peak is proportional to the number of mobile atoms and available sites. In certain crystal structures this process will tend to be anisotropic.

In polycrystalline materials, there is the possibility of grain slip where the crystal structure rearranges itself, effectively suffering plastic deformation.

Finally, there is the creation of magnetic eddy currents in a moving conductor. These effectively damp motion by creating current loops, and therefore heat, and therefore dissipation of energy.
Chapter 3

Apparatus

3.1 Mechanical Structure

A large number of mechanical elements were designed and fabricated by the author to allow convenient and accurate measurements of the samples to be tested. In the interest of accuracy, the stiffness of the mounting assembly was of paramount importance. Due to the tremendous number of test samples (fifty four) it was also critical that the samples be changed easily and without compromising the accuracy of the test.

3.1.1 Test Specimen

There was little flexibility in the design of the test specimens because of the interest in including data for Al₂O₃ and granite samples of which had already been purchased (at great expense). The specimens measure three by three by sixteen inches (see figure 3-1). A table of the specimen costs and suppliers is provided in Appendix B.3. A table of the materials properties is given in Appendix B.2.

The specimens were designed as large as they are to more accurately simulate the condi-
tions that they might be used in as applied to machine tool manufacture. Unfortunately, the size of the samples prohibited providing a true "built in" clamp, as would be required to produce pure first mode oscillations. The hole was bored to provide a cavity which was filled with various substances expected to alter the damping rate of the sample, and selected on the basis of the practical merit. The criterion include low cost, ease of handling, and potential for actual use. Figure 3-2 shows the specimens and cores tested. The particular alloys were chosen for each specimen as being the most commonly used or most applicable to machine tool design.

### Figure 3-2: List of specimen and core materials tested.

<table>
<thead>
<tr>
<th>Specimen Materials</th>
<th>Core Materials</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cast Iron, Class 40</td>
<td>Air</td>
</tr>
<tr>
<td>Steel, 1018</td>
<td>Sand, White Play Sand</td>
</tr>
<tr>
<td>Stainless Steel, 303</td>
<td>Lead Shot, #8</td>
</tr>
<tr>
<td>Titanium, 6Al4V</td>
<td>Oil, 10W40</td>
</tr>
<tr>
<td>Aluminum, 6061</td>
<td>Sand And Oil</td>
</tr>
<tr>
<td>Brass, C360</td>
<td>Lead Shot And Oil</td>
</tr>
<tr>
<td>Copper, 101</td>
<td></td>
</tr>
<tr>
<td>Ceramic, 99.5% Al₂O₃</td>
<td></td>
</tr>
<tr>
<td>Granite, Gray</td>
<td></td>
</tr>
</tbody>
</table>

#### 3.1.2 Sample Vise

A standard machine vise was used to fixture the samples, but with certain modifications to improve its stiffness. The base of the vise, which originally allowed rotational adjustment, was removed. A pair of mounting holes with three-quarter-inch clearance were drilled in the front of the vise, and a set of four half-inch clearance holes were drilled through the back flange of the vise. The gib of the vise was reinforced with a one-inch square steel bar which bridged the gib and was bolted down to the table at either end. The most significant alteration was the replacement of the vise faces (the originals were only one-quarter of an inch thick) with more substantial plates shown in figure 3-3. These plates were designed to utilize the
original mounting holes drilled through the gib and base of the vise. The height of the faces

![Diagram of vise face showing measurements and details.](image)

**Figure 3-3**: Vise Face, showing measurements and details. Two faces were manufactured; only one with a Grounding Fixture.

were raised from one inch to three inches to improve the stability of the mounting system (the specimens were three inches square at the base). The faces were cut as thick as possible, the limiting factor being how wide the vise could be opened (five and half inches without any faces).

### 3.1.3 Test Bed

We were fortunate enough to find a surplus cyclic fatigue testing machine to use as our test bed. This machine was built with a cast iron table top approximately three feet square, three inches thick, and weighing about one ton.

The table's original purpose was to shake apart fatigue samples, and was still fitted with
the necessary apparatus, consisting of a massive spring mounted motor assembly which protruded through the middle of the table. This assembly would freely oscillate at about ten hertz, and so it was fitted with an aluminum clamp to fix it to the table and then pre-loaded against the clamp to keep it steady.

The entire table assembly was suspended on springs yielding natural frequencies of approximately one hertz vertically and approximately five hertz horizontally. It was originally believed that the spring suspension of the table would isolate the experiment from environmental vibrations and thus improve the accuracy. In retrospect, environmental isolation was unnecessary. It is possible, moreover, that the effective stiffness of the mount could have been increased and the coupling between the sample and the probe mount reduced had the table been rigidly fixed.

A number of holes were drilled and tapped into the table to hold the vise. These consisted of two three-quarter inch by twelve pitch holes under the front of the vise and four one-half—thirteen pitch holes in the back. Helicoil® inserts were used for all threads to insure a good bite in the cast iron.

3.1.4 Probe Support Post

It was deemed critical that the probe be held steady for obvious reasons. To this end all of our pre-experimental wisdom was brought to bear on producing a post with great stiffness and a tremendously fast damping rate.

The body of the post was an eighteen inch long section of rectangular steel tubing, six inches by four inches, with three-eighths inch thick walls as shown in figure 3-4. To stiffen the tube, a quarter inch thick plate was welded across the bottom of the tube with a water-

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† Threads cut into cast iron have a habit of stripping at the least provocation. Helicoil® manufactures stainless steel helical thread repair inserts. To use them, one must drill an oversized hole, tap it with their tap, and then screw in the insert. Once inserted, the stainless threads have a nearly indefinite lifetime, which is particularly useful in softer materials (such as cast iron or even plastics) and when threads have been accidently stripped.
tight bead running around the entire perimeter. The top of the post was cross braced by welding three-sixteenth by one-half inch strips of steel across opposite corners.

In order to fixture the post to the table a pair of runners were welded to the bottom of the post along the six inch dimension. At one end both runners were drilled and tapped for one-half inch by thirteen pitch bolts. The bolts were used to adjust the verticality of the post. The

![Diagram of the Probe Support Post]

**Figure 3-4**: The Probe Support Post is made of heavy steel tubing with welded reinforcements. The post is filled with cast concrete and has two channels running the length filled with lead shot and oil to make the post “dead”.
runners and bolts rode on inch thick precision ground parallels, which allowed three degrees of freedom to adjust the gap width and parallelize the face of the probe with the face of the sample.

In order to improve the stiffness yet further and to increase the damping capacity of the post, it was filled with concrete. Before pouring the concrete, two steel pipes, one and a quarter inches in diameter, were greased and set into the post. Once the concrete hardened, the pipes were removed and the resulting channels were filled with lead shot and then oil to make the post "dead"—a construction technique used in optical bench posts. The result was very well damped, particularly at higher frequencies (above about 250 hertz).

3.1.5 Probe Clamp

The probe itself was held in a clamp (figure 3-5) made in two halves, with a half inch hole bored to provide a slip fit with the probe.

Figure 3-5: The Probe Clamp assembly. The 0.500" hole is bored to provide a slip fit with the probe.
reamed through the middle to fit the probe itself as closely as possible (in fact, a clearance of 0.002” was maintained). The clamp had machined into it a Grounding Fixture identical to the one in the Vise Face. Cast iron was selected for both the clamp and for an angle bracket used to mount the clamp to the Probe Support Post as it is known to have good dimensional stability and fairly good damping characteristics, as well as providing a stiff mounting point. All threads in both the clamp and the bracket were reinforced with Helicoil® inserts so that they could be reused if need be, and to allow higher bolt torque settings, which would have stripped cast iron threads.

The clamp was bolted to a cast iron angle bracket (figure 3-6) which was modified to allow

![Diagram](image)

**Figure 3-6:** The Probe Clamp Mounting Bracket is an off-the-shelf flanged cast iron angle bracket with mounting holes drilled in it. The tapped holes are reinforced with Helicoil inserts. It to be fixed to the post and to have the clamp bolted to it by drilling four holes through its
five inch flange, and by tapping three holes in the four inch flange (with Helicoil® inserts).

3.1.6 Excitation Source

The mode of excitation was chosen to be an impulse as this was considered to be the most economical and feasible. A steel ball, approximately one inch in diameter was used as the "hammer". It was modified by welding a small stainless steel loop to the "top" from which the ball was suspended by means of a thin steel wire. In order to soften the blow, the ball was dipped in Plasticote®, thus enhancing the excitation of lower frequencies. The ball was hung from an aluminum frame shaped like an inverted "L" and bolted to the side of the test bed.

At the point where the arc of the ball's swing met the upright of the "L", an electromagnet made from a bolt and about twenty yards of magnet wire was mounted. The magnet was powered by 110 Volt AC wall current, rectified by a twelve amp bridge, and smoothed by a huge capacitor. The magnet was turned on by a momentary-on switch, and the ball was released when the magnet power was cut. The switch cut power before the variable transformer to reduce AC line noise during the measurement.

3.1.7 Assembly

Great care was taken during the assembly to insure that the entire structure was as stiff as possible and that there were no stray resonances which might throw off the measurement.

The vise and table were chemically cleaned and then epoxied together as well as being held by the six mounting bolts. Bolts in opposite corners of the vise were sequentially tightened to the maximum torque reasonably achieved with hand tools.

The Probe Support Post was set on a pair of ground parallels to allow forward and backward motion without disturbing the height and pitch adjustments. The angle bracket was bolted to the post by means of a pair of long three-eighths inch fixturing rods which connected the four through-holes in the bracket to a pair of steel "C" channels on the opposite side of the post. The bracket was held by nuts on either end of the four fixturing rods.
The Probe Clamp was bolted to the bracket. Then the capacitance probe was laid into the bottom half of the clamp. It was adjusted to extend from the face of the clamp by a few hundredths of an inch. A drop of Duco Cement® was used to ensure that the probe would not drift in the clamp without risking damage when the time came to remove the probe. The top half of the clamp was bolted on.

Using the two plumb adjusting screws on the back of the post (and a lot of patient struggling), the probe face was made parallel to the surface of the sample. The post was then bolted to the table by means of fixturing clamps† for which a set of tapped holes was drilled in the table.

It was deduced that the table itself would be excited in resonance with the oscillating sample, so to minimize the energy of this oscillation transmitted to the post, a “sand box” was built around the post. Approximately one hundred pounds of sand was poured into a wooden box glued around the post. The edges of the box were sealed with caulking compound and five or six quarts of oil was poured over the sand to couple the table’s vibrations through the entire mass of the sand.

In order to “settle in” the sample in the vise following each sample change, a long procedure was rigorously followed. First the sample was set into the vise and gib tightened to about ten foot- pounds of torque. Then the sample was struck fifty times with a soft mallet. Then the gib was tightened to about twenty foot- pounds of torque, and the clamping bar over the gib was tightened to about ten foot- pounds, following which another fifty blows were struck. The procedure was repeated until a torque of about 50 foot- pounds was reached on both the gib and the clamping bar.

† Fixturing clamps are blocks and threaded rods used to fixture parts for machining. They generally consists of a set of blocks with dozens of little steps cut into them, a set of bars with matching steps cut in them and a hole in the middle, and a set of threaded rods of various lengths which fit through the holes. Machine tools generally have “T” slots cut their ways, and “T” slot blocks are provided with threaded holes for the bottom ends of the rods. Nuts clamp down the bars, threaded onto the top ends of the rods.
This procedure, long as it might seem, was found to be necessary to prevent the sample from shifting closer to the probe after each blow (which the probe was sensitive to). The shift following an impact when the sample had simply been clamped into place was on the order
of 0.001 - 0.005". Since the entire range of the probe is only 0.004", this level of shift was unacceptable. Following the settling-in procedure the shift was generally inconsequential.

Figure 3-7 shows a somewhat simplified view of the test assembly where non-essential details have been left out for the sake of clarity, and perspective has been ignored by necessity. Each of the labelled parts is described in function and dimension in the preceding text.

3.2 Instrument Chain

The instrument chain was required to perform three important tasks for each test run: first, facilitate proper calibration of the standoff for the capacitance probe (0.005"); second, allow easy assessment of problems with the test process; and third, record the necessary data.

Figure 3-8: The instrument chain and wiring diagram.
3.2.1 Capacitance Probe

The transducer used in this experiment was a capacitance probe. The probe senses the slight variation in capacitance as a function of the distance between the probe face and a conductive surface. Our probe was manufactured by Pioneer Technology of San Jose, CA. The probe had an effective range of 0.003" - 0.007", which required fairly precise alignment between the probe and the sample.

Capacitance probes measure distance rather than velocity or acceleration, and so are fairly linear in their response from DC to their frequency limit of about five hundred hertz. Their limitations as transducers in vibration measurement come from the narrow gap in which they operate (0.004") \(^\dagger\) which limits dynamic range, and from their narrow frequency response.

The probe itself works in conjunction with an amplifier also manufactured by Pioneer Technology. The amplifier sends a high frequency AC signal and generates an output signal proportional to the current flow to ground across the effective capacitor between the parallel planes of the probe and the sample face. The amplifier/probe combination has a cumulative noise floor of about five millivolts, and generates about five volts per thousandth of an inch change in the gap. The effective noise floor is therefore at approximately one millionth of an inch relative displacement, or one part in four thousand.

3.2.2 Filter Network

In order to clean up the incoming signal, it was passed through a band pass filter which was set to maximize response around the primary harmonic. The response of the filter is graphed in appendix D.2 for each of the settings used. For the metallic samples a high pass setting of 90 hertz and a low pass setting of 750 hertz was selected to allow maximum response around the 200 to 350 hertz primary harmonic. The non-metallic samples both had

\(^\dagger\) The granite sample actually struck the probe, breaking the glue which held it in place. In order to measure granite, the gap had to be adjusted to near the widest possible setting, which limited dynamic range severely.
primary harmonics centered at around half that figure, and so the filter settings were adjusted to approximately 15 hertz for the high pass, and 350 hertz for the low pass filters.

The filter was an analog type with two separate patches, each individually adjustable. Even with care taken insure that the minimum attenuation coincided with the primary harmonic, the signal still suffered a fifteen decibel loss passing though the filter.

3.2.4 Digital Oscilloscope

Hewlett Packard was nice enough to lend an HP 54110D Digitizing Oscilloscope with color display for this project. This oscilloscope is rated to one gigahertz, and claims an effective ten bits of resolution.

Two modes of capture and output were used. One allowed the capture of two channels simultaneously triggered, and then simultaneously displayed. This feature generated the paired time space graphs shown in appendix E. depicting filtered and un-filtered response for each sample. The second mode allowed the storage of four traces in memory, which were plotted overlaid. These also appear in appendix E., and generally indicate an absolutely incredible degree of repeatability.

Due to the magnification factor used to properly window the traces, the graphs only yield about seven bits of resolution. This limited the usefulness of the full time range of the data. The trace record length was chosen to be 250 milliseconds, but for all of the metallic samples only the first 100 milliseconds were significant.

3.2.5 Spectrum Analyzer

An Hewlett Packard HP 3562A Dynamic Signal Analyzer was used to analyze the power spectrum of the data. The spectrum analyzer was used in a mode similar to the dual trace mode of the oscilloscope, where two active channels grabbed the filtered and un-filtered signals at the same trigger. Both of these traces are plotted for each sample in appendix E., show-
ing the effect of the filter on the power spectrum, and providing information on the relative
amplitudes of the various frequency modes.

The analyzer was set up to provide a linear measurement of the power spectrum from one
hertz to 500 hertz. An Hanning window was used to minimize the generation of spurious har-
monics. The input was AC coupled to minimize the effects of DC drift and movement. The
input range was 5.02 Volts peak to peak, with the record being triggered by a 303 millivolt
threshold.

3.2.6 Additional Components

In order to facilitate easy calibration and quick analysis of problems, a digital multi-meter
and a Tektronix 2465A oscilloscope were connected to the signal train. Since the output of
the capacitance probe system was proportional to distance, it was an easy matter to set the
gap between the probe face and the sample to within a few millionths of an inch by watching
the output voltage on the multimeter.

The final output from both the digital scope and the spectrum analyzer was recorded on
an Hewlett Packard ColorPro Plotter.
Chapter 4

Procedure

4.1 Experimental Procedure

A rigorous procedure was developed during the testing process in order to quickly and accurately collect the data from fifty four individual samples. Over the course of several days of testing, some one hundred and sixty two data graphs were drawn (which appear in their grand entirety in appendix E.).

Each test began with settling-in the sample\(^\dagger\). Once that was achieved, the probe had to be aligned with the sample face. Although each of the samples had been sanded to provide a good surface to measure from, each sample was a little different in shape. Probe alignment required the use of the digital multi-meter which, being hand-held, could be set in a convenient place to watch the display while adjusting the gap distance. Parallelism was adjusted by eye, and rarely needed readjustment.

Once the sample and the probe were aligned and clamped down, the test instruments were armed. Under certain conditions the AC line current fluctuation caused by switching the electromagnet on would trip the instruments: on alternate test runs, the release pulse would trip them. Putting the instruments on an UPS\(^\ddagger\) only worsened matters as the UPS circuit was tripped by the line pulse, which, as often as not, completely shut down the instruments. An impromptu treaty was reached by running an extension cord across the room to a special power line installed for a sensitive computer system. It seems somewhat inappropriate that $55,000 worth of equipment would be incapacitated by a small line surge.

A trial run was recorded for each sample. The time space information (recorded by the digital oscilloscope) was used to determine proper scaling factors and to check how well set-

\(^\dagger\) The settling-in procedure is described in detail in chapter 3.1.7.

\(^\ddagger\) Uninterruptable Power Supply—with a high level of surge suppression.
tled-in the sample was. The frequency space information was used to confirm the filter settings, and to check for surprise resonances (which might indicate a loose bolt or fitting).

If all went well, a full record was taken on both the analyzer and the ‘scope for both the filtered and un-filtered signals (which accounts for four of the five graphs for each sample). If the sample hadn’t drifted too badly (which it generally didn’t if the settling-in procedure was followed correctly), then four more records were captured in the memory of the ‘scope. These four separate records are plotted superimposed on the remaining graph given for each sample. For most of the samples the four traces line up nearly perfectly, indicating an extraordinary level of phase cohesiveness and repeatability.

4.2 Data Reduction

Collecting the data was actually a very small part of the overall analysis. It was not possible to fully automate the data reduction process. The oscilloscope that Hewlett Packard lent us could not be interfaced to any of the computers in our lab, and so the process of taking the data from the fifty six graphs and entering it into a computer for analysis was done entirely by hand.

It was decided to grid the peaks of the decaying oscillations as being representative of the decay envelope. A transparency with a grid printed on it was used to find the coordinates of the oscillation peaks, which were entered one by one into a computer.

The overall envelope is defined by some combination of exponentially decaying, linearly decaying, and periodic envelopes. Since the goal of this project was to generate a ranking of the various decay rates, it was decided to try to pull out only the exponential term (which corresponds to a viscous decay function). A simple least squares curve fit to an exponential (as implemented in Cricket Graph®) was overwhelmingly biased by the amplitude of the early periodic beats in the envelope. The result was a $t = 0$ intercept at about half the original am-

† See chapter 6, especially 6.1 for a description of what I would have liked to have done differently.
A slightly modified version of the least squares fit algorithm was implemented as a Microsoft® BASIC program which clamped the amplitude at $t = 0$ at the amplitude of the first peak. This drastically improved the correspondence between the quantitative results and a qualitative comparison of the graphs, but was not fully satisfactory.

It was observed that the data had not been normalized (inconsequential) and had not been zeroed to the base line (quite significant). The curve fit program was modified to generate an error value as the absolute average of the differences between the curve fit and the original data. The linear displacement was then adjusted in small steps to minimize the error function. At the error minimum, the value of the exponent was returned. It was assumed that, since the variant term was linear, there would be no local minimums to confuse the program. The ranking as determined by the program is entirely in agreement with a qualitative visual assessment of the damping rates.

The program, named *Clamp Fit*, is listed in its entirety in appendix C. and was used to generate all final results. The process the author used to generate the data tables (not entirely recommended) was to enter the data into the Cricket Graph® which allowed easy visual inspection for erroneously entered datum, then to convert the data into a text file using Microsoft Word® where the proper format characters could be inserted. *Clamp Fit* then opened the text files and read the data.
Chapter 5

Results

5.1 Time-Space Interpretation

*Clamp Fit* used data entirely from the time domain. Unfortunately, the time domain is extremely chaotic due to the huge number of beating frequencies. This program implicitly assumed the equation of the envelope to be of the form

\[ A(t) = A_0 e^{-\alpha t} + b, \]  

(5.1)

where the data fit to this curve is taken from the peaks of the decaying sinusoidal equation defined by

\[ A(t) = A_0 \sin(\omega t + b_1) \times e^{-\alpha t} + b_2. \]  

(5.2)

The result of this function (with arbitrary phase, frequency, amplitude and decay rate) is shown in figure 5-1. The circles in the figure represent the points that would have been entered into the computer as datum. The top left point would have been entered as \(A_0\) at a time \(t_0\). The remaining data would be normalized to fit these initial conditions. As one look at the

![Figure 5-1: Idealized waveform which Clamp Fit is programmed to recognize and fit to. The circles represent datum that would be entered into the computer.](image-url)
graphs in appendix E. will make apparent, the data entered shared little resemblance with this idealized version.

5.2 Calculated Relative Impulse Damping Rates

It is difficult to summarize fifty four data points in single graph and make it both intelligible and quantitatively useful. Numeric data are presented in appendix A. where the first column, in millihertz, is the exponent, $\alpha$, from equation 5.1.

The data will be presented in two formats: a list of bar-graphs and a density plot. The bar graphs will probably be most useful for an engineer who is attempting to design a machine or tool. The density plot gives a quick qualitative overview of all the data collected.

![Density plot summary of data. Darker squares indicate faster damping rates. Blocks are grouped by material type.](image)

*Figure 5-2: Density plot summary of data. Darker squares indicate faster damping rates. Blocks are grouped by material type.*

It is clear from the density plot that no universal generalizations about the effects of core
materials are universally valid, which is not surprising considering the complexity of large scale dislocation and movement across boundaries and into inhomogenous materials.

It is important to note that the frequency of the primary harmonic of aluminum was at approximately 400 hertz, which is right near the upper limit of the frequency response of the probe. It is also curious that as the frequency of the primary harmonic decreases (444 Hz with air, 330 Hz with lead shot and oil), the initial displacement measured increases (310 mV with air, 390 mV with lead shot and oil), indicating that the aluminum-air sample oscillates at a rate above the functional ceiling of the test. It is also important to consider that since the damping coefficient that is being solved out of the equation is velocity dependant, that the damping rate would necessarily be faster for higher frequencies at the same range of displacement.

Titanium, notably, damps about twice as well as any other material measured.

Figures 5-3 through 5-11 show a comparison of the damping rates of various samples grouped by specimen material. The graphs are of arbitrary scale, and do not have graduated vertical axis as they are intended only to show relative damping. There is no reason to consider that the data collected is of any better than qualitative accuracy. Further, due to the differences in excitation frequency, it is not really valid to assume that the calculated damping rates are entirely reliable within a given specimen, let alone between specimen. It should be carefully noted that the primary excitation frequency can vary by as much as two hundred hertz—within a single specimen†.

Figure 5-12 shows a comparison of the damping rates of the air-core samples, indicating the range of values between materials. The damping rate of the Probe Support Post is also included. It is interesting to note that the post, with all the effort expended in making it as dead as possible, is still only slightly better damped than an empty titanium bar, and not near-

† The granite-air sample's primary harmonic was measured at 70.8 Hz, while the granite-sand/oil sample oscillated primarily at 268 Hz, a difference of 197 Hz.
Figure 5-3: Bar graph comparison of the damping rates for cast iron.

Figure 5-4: Bar graph comparison of the damping rates for steel.
Figure 5-5: Bar graph comparison of the damping rates for stainless steel.

Figure 5-6: Bar graph comparison of the damping rates for titanium.
Figure 5-7: Bar graph comparison of the damping rates for aluminum.

Figure 5-8: Bar graph comparison of the damping rates for brass.
Figure 5-9: Bar graph comparison of the damping rates for copper.

Figure 5-10: Bar graph comparison of the damping rates for ceramic.
Figure 5-11: Bar graph comparison of the damping rates for granite.

Figure 5-12: Comparison of damping rates of all samples with air cores and support.
ly so well damped as titanium and sand. On the other hand, the post is significantly better damped than any of the steel samples, even though its shape would tend to allow bell-like vibrations (as in tubular bells).

5.3 Frequency-Space Interpretation

A great deal of information about the damping characteristics of the samples was encrypted into the frequency-space graphs. Remembering that the frequency width of an impulse is proportional to the inverse of its lifetime, one can, with surprising success, measure directly from the frequency space graphs the lifetime, frequency, and amplitude of each excited resonance.

The exact relationship, assuming a gaussian distribution around the center frequency, is that the full width of the frequency-space peak at 1/e of its maximum is the inverse of the time it would take for the pulse to decay to 1/e of its initial amplitude in time-space. Unfortunately, there is a significant amount of noise in the frequency-space, which would preclude using this measurement system with any hope of significant accuracy. Another problem would be in determining a useful system of comparing the values so determined.

As a simple example, take the ceramic-air sample. At the beginning of the pulse the amplitude on the graph measures 3.3 centimeters\(^\dagger\) at 72 Hz. A measurement of the frequency width yields approximately 9.2 Hz\(^\ddagger\). If we fit these numbers into equation 5.2, but rewritten as

\[
A(t) = H_{gt} \times \cos(2\pi ft) \times e^{-\text{width} \times t},
\]

(5.3)

where "Hgt" is the height of the pulse, "f" is the frequency and "width" is the width of the pulse in frequency space and graph A(t) we get Figure 5-13. Excitingly enough, though these numbers were actually measured right off the frequency space graph, the overall decay time of even this simple pulse is fairly close to the actual pulse decay in appendix E.

\(^\dagger\) We might as well use centimeters as millivolts since we are only interested in the relative amplitude.

\(^\ddagger\) For the frequency we will stick to exact units so our result will come out in seconds.
Figure 5-13: Plot of equation 5.3, representing the primary harmonic of the ceramic-air sample.

Clearly, looking at the frequency space graph, the primary harmonic is only slightly dominant over a tremendous number of frequencies all working together. If we fit the measured values of the biggest peaks into

\[ A(t) = \frac{H_1}{\omega_1} \cos(\omega_1 t) e^{-\omega_1 t} + \frac{H_2}{\omega_2} \cos(\omega_2 t) e^{-\omega_2 t} + \text{et...} \]  \hspace{1cm} (5.4)

where \( H_1 \) and \( H_2 \) are the measured heights of the peaks, the \( \omega \)'s are the center frequencies of the peaks, and the \( W \)'s are the widths in hertz for, say, the six dominant peaks in the ceramic-air sample, the plot would look like figure 5-14\(^\dagger\).

Figure 5-14 is especially interesting when one considers that the horizontal axis, the time axis, is scaled in seconds, and that the calculated wave form is surprisingly similar to the wave form of the real time-space graph in appendix E., even from an extremely limited six term equation. It was assumed that all phases are at a maximum at \( t = 0 \), which is not unreasonable.

\(^\dagger\) The graph in figure 5-14 (and 5-13) was generated using Mathematica\textregistered. The command line used was: Plot[((3.3/453^2) Cos[453 t] Exp[-11.5 t]) + ((2.2/758^2) Cos[758 t] Exp[-4.6 t]) + ((1.4/937^2) Cos[937 t] Exp[-2.3 t]) + ((2.2/1130^2) Cos[1130 t] Exp[-3.46 t]) + ((2/1173^2) Cos[1173 t] Exp[-4.38 t]) + ((2.5/2471^2) Cos[2471 t] Exp[-5.77 t]), \{t, 0..25\}, PlotPoints -> 2400, PlotRange -> All]
Clearly there is a great deal of promise in the frequency space evaluation of the damping characteristics, in fact, frequency space is often the space of choice for certain evaluations of periodic and impulse related behavior [7].

**Figure 5-14**: Superposition of the six dominant frequency terms from frequency space plot of ceramic-air sample.
Chapter 6

Lessons

This chapter is comprised of a collected list of improvements to the measurement process as determined by hard experience and clear hindsight.

6.1 Improved Data Collection

The primary alteration to the method of collecting the data would be to automate it. Once the data has been stored digitally, it should stay that way until it is fully reduced and readable. It is recommended that either a analog to digital interface be used with a personal computer right off, or a complete HPIB system or its equivalent be set up for numeric processing.

If this particular experiment is repeated, or another similar one, I would suggest that the data be rectified (or squared) and a large number of runs be averaged. An alternative is to break the record down into equal time length segments, then integrate the absolute value over the segment length, average a number of runs, and then fit the runs to a curve.

6.2 Improved Experimental Set Up

Of primary importance in measuring the oscillations of any sample is that the sample oscillate. Massive steel members tend not to move significantly and are therefore somewhat impractical for dynamic testing. Furthermore, it is next to impossible to devise a fixture strong enough to hold a three inch square bar of stainless steel steady whilst it whips around. Reducing the thickness of the samples by a factor of three, and replacing the one large cavity with a row of smaller cavities would result in large, more easily measurable deflections. Further, making the sample significantly rectangular would reduce inter-modal coupling.

The base of the system must be made as absolutely massive as possible to simplify the motion of the beam. In the same vein, the instrument post should be as stable as possible, even
to the point of mounting it on the floor if need be, to eliminate coupling between the sample and the post. Random vibrations from other equipment are not nearly so difficult to unravel as two pseudo-cantilever beams oscillating synchronously. It is almost certain that the coupling between the sample and the post was responsible for the overall sinusoidal envelope that made the data so difficult to fit to an exponential curve.

The capacitance probe was not optimal for vibration testing either. A voice coil would have worked quite well, or a microphone and acoustically coupled tube. Either of these would provide an extremely low noise floor (potentially), broad frequency response, and good dynamic range as well as being simpler and less expensive than the probe.

6.3 Improved Excitation Sources

There is significant merit to a simple impact test, especially when evaluating the rate at which a given object will damp out vibrations caused by an impact. The harmonic content of an impact test is controlled to a great degree by the geometry of the object, and the damping rate of the material is a function of frequency. It is therefore difficult to compare data generated in such an uncontrolled experiment.

A very elegant and expensive way to improve the control of the experiment is to use a high force voice coil to drive the sample. Using, say, the HP 3562A, one could set it to sweep a sine wave into a 10kw amplifier which could drive a large coil and flex the sample in an extremely controlled manner. Voice coils are manufactured with up to five hundred pounds of force continuous, and up to ten times that if actively cooled.

Far less expensive would be to couple an AC servo motor through a spring to the sample. The speed of the motor (and hence frequency of excitation) could be regulated by a control system easily. The only detraction would be that the driving force becomes irrevocably a function of frequency.
Chapter 7
Conclusion

7.1 Value Of This Experiment

The data collected in this experiment reveals some rather interesting trends, and reinforces a great deal that was believed without proof. Probably most pertinent is the rather gratifying data indicating that cast iron is significantly damped by the addition of oil, which could have an immediate effect on the design of machine tools. Most machine tools are manufactured from cast iron already, and generally have oil channels already designed into them for lubrication. It would be a fairly straightforward matter to enlarge some of the channels to provide an oil reservoir where vibrations are a problem.

It has been known for some time that certain alloys of titanium damp very well, and this study provides a benchmark for further exploration into “superalloys” such as Type 403 which might have twice the damping capacity of even titanium.

This experiment also provided a significant body of practical knowledge on how to conduct a test like this one.

7.2 Areas Of Future Research

The preliminary data generated in this study indicates just how much more needs to be learned. Damping is of significant concern to designers in fields ranging from precision machinery to aerospace. It is clear that more research needs to be done if a significantly useful body of data is to be built up.

Further, the process by which the damping itself is occurring need to be studied. There is, as of yet, no theory good enough to predict damping rates for materials under large scale oscillations.
I would recommend that an experiment be set up using the practical knowledge gained in this experiment to test a much larger number of samples, with emphasis on measuring various alloys of the same basic material. I would also recommend that this experiment be set up to allow data to be gathered as a function of frequency which should yield interesting information about the dominant modes of loss in various materials.
## Appendix A

### Summary of Calculable Properties

<table>
<thead>
<tr>
<th>Sample</th>
<th>Damping Rate (mHz)</th>
<th>Time to $1/e \cdot A_0$ (msec)</th>
<th>Primary Frequency (Hz)</th>
<th>Initial Displacement (mV)</th>
<th>Sample Mass (Kg)</th>
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</thead>
<tbody>
<tr>
<td>Cast Iron - Air</td>
<td>-0.0159</td>
<td>62.9</td>
<td>237</td>
<td>405</td>
<td>14.37</td>
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¹Non-calibrated impact.
Appendix B

Materials Data

B.1 Volumes and Masses of Components

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<tr>
<th>Component</th>
<th>Volume/Mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard Test Specimen</td>
<td>$2.01 \times 10^{-3}$ m$^3$</td>
</tr>
<tr>
<td>Test Specimen Bore</td>
<td>$3.48 \times 10^{-4}$ m$^3$</td>
</tr>
<tr>
<td>Sand Core</td>
<td>0.557 Kg</td>
</tr>
<tr>
<td>Lead Shot Core</td>
<td>2.11 Kg</td>
</tr>
<tr>
<td>Oil Core</td>
<td>0.331 Kg</td>
</tr>
<tr>
<td>Sand and Oil Core</td>
<td>0.714 Kg</td>
</tr>
<tr>
<td>Lead Shot and Oil Core</td>
<td>2.27 Kg</td>
</tr>
</tbody>
</table>

B.2 Material Properties

<table>
<thead>
<tr>
<th>Material</th>
<th>Modulus $E$ (GN/m$^2$)</th>
<th>Poisson’s Ratio $v$</th>
<th>Shear Modulus $G$ (GN/m$^2$)</th>
<th>Coefficient of Expansion $\alpha$ $(10^{-6}/\text{C})$</th>
<th>Density $\rho$ $(10^3 \text{kg/m}^3)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cast Iron</td>
<td>110</td>
<td>0.25</td>
<td>45</td>
<td>10.4</td>
<td>7.15</td>
</tr>
<tr>
<td>Steel</td>
<td>205</td>
<td>0.27</td>
<td>79</td>
<td>11.4</td>
<td>7.79</td>
</tr>
<tr>
<td>Stainless Steel, 303</td>
<td>200</td>
<td>0.30</td>
<td>73.1</td>
<td>17.3$^2$</td>
<td>7.80</td>
</tr>
<tr>
<td>Titanium</td>
<td>110</td>
<td>0.34</td>
<td>41.4</td>
<td>8.82</td>
<td>4.51</td>
</tr>
<tr>
<td>Aluminum, 6061</td>
<td>73</td>
<td>0.33</td>
<td>26</td>
<td>22</td>
<td>2.77</td>
</tr>
<tr>
<td>Brass</td>
<td>105</td>
<td>0.35</td>
<td>38</td>
<td>20.4</td>
<td>8.43</td>
</tr>
<tr>
<td>Copper</td>
<td>117</td>
<td>0.35</td>
<td>64</td>
<td>16.7</td>
<td>8.95</td>
</tr>
<tr>
<td>Ceramic Al$_2$O$_3$ 99.5%</td>
<td>372$^4$</td>
<td>0.22$^4$</td>
<td>152$^4$</td>
<td>8.0$^4$</td>
<td>3.89$^4$</td>
</tr>
<tr>
<td>Granite (Rock of Ages)</td>
<td>20$^3$</td>
<td>0.01$^3$</td>
<td>-6.2$^3$</td>
<td></td>
<td>2.64$^3$</td>
</tr>
<tr>
<td>Sand (Play Sand, White, Dry, as packaged)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.6$^6$</td>
</tr>
<tr>
<td>Lead Shot (#8, aggregate density)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>6.07$^5$</td>
</tr>
<tr>
<td>Oil (10w-40 Motor Oil)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.9$^2$</td>
</tr>
</tbody>
</table>

3 Phone Conversation, “John” of Rock of Ages Corp. (802) 476-3115, 3 May 1990.
4 Phone Conversation, “Cathy” of Coors Ceramics, (303) 277-4082; 20 March 1990.
5 Measured by Arnold H. Gessel, 19 March 1990.
6 Phone Conversation, “Jim” of Sommerville Lumber, (617) 623-2800; 19 March 1990.
## B.3 Specimen Costs And Suppliers

<table>
<thead>
<tr>
<th>Material</th>
<th>Price</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class 40 Cast Iron rounded corner</td>
<td>50.46</td>
<td>-Peterson</td>
</tr>
<tr>
<td>1018 Steel, cold ground</td>
<td>46.18</td>
<td>-Peterson</td>
</tr>
<tr>
<td>303 Stainless Steel</td>
<td>380.00</td>
<td>-Royce</td>
</tr>
<tr>
<td>6AL4V Titanium</td>
<td>246.25</td>
<td>-President</td>
</tr>
<tr>
<td>Aluminum, 6061-T6511</td>
<td>44.55</td>
<td>-Admiral</td>
</tr>
<tr>
<td>C360 Cartridge Brass</td>
<td>120.45</td>
<td>-Admiral</td>
</tr>
<tr>
<td>Copper (oxy free) 101</td>
<td>306.00</td>
<td>-Kelco</td>
</tr>
<tr>
<td>$Al_2O_3$ 99.5% pure</td>
<td>2500.00</td>
<td>-Coors</td>
</tr>
<tr>
<td>Granite</td>
<td>1000.00</td>
<td>-Rock Of Ages</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Supplier</th>
<th>Location</th>
<th>Phone Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Admiral Metals</td>
<td>Woburn, MA</td>
<td>(617) 933-8300</td>
</tr>
<tr>
<td>Peterson Metals</td>
<td>Wocster, MA</td>
<td>(800) 325-3245</td>
</tr>
<tr>
<td>Kelco Metals</td>
<td>Rockland, MA</td>
<td>(617) 773-5711</td>
</tr>
<tr>
<td>President Steel and Titanium</td>
<td>Hanson, MA</td>
<td>(617) 294-0991</td>
</tr>
<tr>
<td>Royce Aerospace Metals</td>
<td>NY</td>
<td>(800) 645-9530</td>
</tr>
<tr>
<td>Coors Ceramics Division</td>
<td>Golden, CO</td>
<td>(303) 277-4082</td>
</tr>
<tr>
<td>Rock Of Ages</td>
<td>Barre, VT</td>
<td>(802) 476-3115</td>
</tr>
</tbody>
</table>

1The exact prices of the ceramic and granite samples are unknown due to circumstances beyond my control.
Appendix C

_Clamp Fit_, A Recursive Error Minimization Program For
The Macintosh Computer In Microsoft® Basic

This is a complete listing of the Microsoft® Basic program _Clamp Fit_ which was written
by the author to analyze the data. In the following listing explanatory comments are identified
by a “⇒” character.

⇒ The following commands set up the Macintosh window environment and a pleasing
text face, the basic operational instructions are then displayed.

    CALL TEXTFONT(2)
    CALL TEXTSIZE(12)
    CALL MOVETO(10,15)
    PRINT “This program will fit the data point by point to an exponential curve,"
    CALL MOVETO(10,30)
    PRINT “holding the first point fixed. The number the program outputs is the”
    CALL MOVETO(10,45)
    PRINT “average value of the resultant exponential amplitude.”
    CALL MOVETO(10,60)
    PRINT “The data must be arranged ‘time, amplitude’.”

    DIM tme(200),amp(200),tmeamp(200),tmesqr(200)

⇒ The following section calls up a standard window interface to the New File System
which allows the user to interactively scroll through the file system tree.

start:
CALL MOVETO(10,75)

PRINT "You will be asked to select a data file. Press any key to continue"

dummy$ = INPUTS(1)

CLS

flnme$ = FILES$(1,'"

⇒ Once the proper data file has been selected, the program opens it and fills an array with the data contained therein.

OPEN flnme$ FOR INPUT AS #1

x = 0 : tmesum = 0 : ampsum = 0 : tmeampsum = 0 : tmesqrsum = 0

WHILE NOT EOF(1)

INPUT #1,tme(x),amp(x)

IF tme(x) = 0! THEN x = x - 1 : GOTO 20

x = x + 1

WEND

⇒ Following the initialization of the data array, the program initializes some variables that it will need reset for each pass of the recursion. The top of the recursion loop is labeled “20”. The recursion attempts to minimize the error, labelled “epsilon” by adjusting the linear displacement “beta”.

20 nmb = x

beta = 0

delta = .0001

itr$ = "one"

⇒ The time axis is zeroed for each element of the array.
FOR x = 0 TO nmb

tme(x) = tme(x) - tme(0)

NEXT x

⇒ The following loop, labelled “loop:”, calculates the average value of the exponent, \( \alpha \), in the equation defining the amplitude of the decay envelope at any positive time:

\[
A(t) = A_0 e^{-\alpha t} + \beta,
\]

for each element of the array “amp(x)” by “tme(x)”.

loop:

epsilon = 0

\( \alpha = 0 \)

FOR x = 1 TO nmb

\( \text{tmpa} = (\log((\text{amp}(x) / (\text{amp}(0) - \beta)) - \beta) / \text{tme}(x)) \)

\( \alpha = \alpha + \text{tmpa} \)

NEXT x

\( \alpha = \alpha / \text{nmb} \)

⇒ The following “FOR - NEXT” loop calculates the average error, “epsilon”. The virtue of each recursion is measured by the minimization of epsilon by incrementing beta by an amount delta. The step size (delta) is fixed so that the variation in \( \alpha \) between steps is less than 1%.

FOR x = 0 TO nmb

\( \text{tmpd} = \text{amp}(x) - ((\text{amp}(0) - \beta) * \exp(\alpha * \text{tme}(x)) + \beta) \)

\( \epsilon = \epsilon + \text{ABS} (\text{tmpd}) \)

NEXT x
\[ \epsilon = \frac{\epsilon}{nmb + 1} \]

\[ \Rightarrow \] The following block provides a status report for the curious user.

```
CALL MOVETO(10,25)
PRINT "alpha: ";alpha
CALL MOVETO(10,40)
PRINT "beta: ";beta
CALL MOVETO(10,55)
PRINT "epsilon: ";epsilon
CALL MOVETO(10,70) : PRINT "previous epsilon: ";eps
```

\[ \Rightarrow \] The following block checks the improvement in epsilon. If the improvement is initially negative, delta is negated so that the direction of the search is reversed. If the improvement becomes negative at some later time, the value of alpha is called optimized and the program quits out of the recursion loop.

```
IF itr$ = "one" THEN beta = delta : itr$ = "two" : eps = epsilon : GOTO loop
IF itr$ = "two" AND eps < epsilon THEN delta = -1 * delta : beta = delta : itr$ = "more" : GOTO loop
itr$ = "more"
IF eps < epsilon THEN GOTO done
eps = epsilon
beta = beta + delta
GOTO beta + delta
```

\[ \Rightarrow \] Since the value of beta must be incremented one delta past it's optimum value, the displayed values of alpha and beta are recomputed at the value beta held one step earlier in the
recursion.

done:

\[ \beta = \beta - \delta \]

\[ \epsilon = 0 \]

\[ \alpha = 0 \]

\[ \text{FOR } x = 1 \text{ TO } nmb \]

\[ \text{tmpa} = (\log((\text{amp}(x) / (\text{amp}(0) - \beta)) - \beta) / \text{tme}(x)) \]

\[ \alpha = \alpha + \text{tmpa} \]

\[ \text{NEXT } x \]

\[ \alpha = \alpha / nmb \]

\[ \text{FOR } x = 0 \text{ TO } nmb \]

\[ \text{tmpd} = \text{amp}(x) - ((\text{amp}(0) - \beta) \times \exp(\alpha \times \text{tme}(x)) + \beta) \]

\[ \epsilon = \epsilon + \text{ABS}(\text{tmpd}) \]

\[ \text{NEXT } x \]

\[ \epsilon = \epsilon / (nmb + 1) \]

\[ \Rightarrow \text{Finally, the optimized values are displayed, along with a message reminding the user} \]

\[ \text{just which file has been optimized.} \]

\[ \text{CALL MOVETO(5,130)} \]

\[ \text{PRINT } "\text{Data for file: }";\text{flnme}$ \]

\[ \text{CALL TEXTFACE(1)} \]
CALL MOVETO(25,160)
PRINT "The calculated damping rate (alpha) is: "; alpha

CALL MOVETO(25,190)
PRINT "The linear displacement is: "; beta

CALL MOVETO(25,220)
PRINT "The average error is: "; epsilon

CLOSE

closingbits:

CALL MOVETO(20,260)
CALL TEXTFACE(0)
PRINT "Wanna do another (y or n)? ": overag$ = INPUT$(1)

IF overag$ = "y" THEN CLS : GOTO start

IF overag$ = "n" THEN END

BEEP : GOTO closingbits
Appendix D.

Apparatus Data

The following pages contain the original data as it was plotted. The graphs are, excepting the addition of an identifying legend, exactly photo-reproduced from the originals. It was impossible to alter the layout of the graphs to match the orientation of the thesis without losing significant data and/or clarity. In the interest of preserving the full value of the original data, no compromise was made to aesthetic unity.

Appendix D.1 Probe Support Post Behavior

Appendix D.1 shows graphs of the behavior of the probe support post as measured using the same instrumentation in the same configuration as for the measurement of the samples. The post was excited by a hammer blow, and so a comparison of the initial displacement amplitudes is meaningless.

Appendix D.2 Filter Response

Appendix D.2 shows the response of the two band pass filter configurations used to improve the clarity of the data. The graphs were recorded using the Hewlett Packard spectrum analyzer’s “swept sine” mode. The analyzer generates a sine wave output and sweeps it through a given frequency simultaneously measuring the filter’s response to that frequency.

The first plot is of the filter response used with the metallic samples. The second plot shows the response of the filter configuration used with the non-metallic samples.
Ch. I = 75.00 mvolts/div
Timebase = 25.0 ms/div

Ch. I Parameters
Rise Time = 3.92708 ms
Preshoot = 0.000 volts
RMS Volts = 174.0 mvolts

Freq. + Width = 81.6326 Hz
Frequ. = 6.26667 ms
Overshoot = 0.000 volts
Dutycycle = 51.15 %

Trace: Probe Support: Uncalibrated Impact
Filttered Input

Page: 56
Ch. 1 = 200.0 mvolts/div
Ch. 2 = 1.000 volts/div
Timebase = 25.0 ms/div
Ch. 2 Parameters
Freq. = 84.0764 Hz
Period = 11.8939 ms
Rise Time = 3.78186 ms
+ Width = 5.85227 ms
- Width = 6.04167 ms
Fall Time = 2.35920 ms
Preshoot = 0.000 volts
Overshoot = 0.000 volts
P-P Volts = 3.000 volts
RMS Volts = 1.040 volts
Duty cycle = 49.20%
Offset = 0.000 volts
Delay = 0.00000 s

Top Trace: Probed Support: Uncalibrated Impact
Bottom Trace: Probed Support: Uncalibrated Impact
X = 217.18 Hz
Ya = -18.252 dBv rms

Power Spec 1

X = 38.904 Hz
Y_a = -19.271 dB Vrms

POWER SPEC 1

Appendix E.

Original Data

The following pages contain the original data as it was plotted. The graphs are, excepting the addition of an identifying legend, exactly photo-reproduced from the originals. It was impossible to alter the layout of the graphs to match the orientation of the thesis without losing significant data and/or clarity. In the interest of preserving the full value of the original data, no compromise was made to aesthetic unity.

In the following appendix, there are three pages devoted to each sample. The first page shows the four trace overlay from which data was taken and analyzed using Curve Fit. The second page shows a typical time-space record and a trace of the un-filtered time-space record. The third page shows the frequency-space record for each sample both filtered and un-filtered. All four graphs were recorded simultaneously. The temperature of the samples was between twenty one and twenty three degrees Celsius.

The graphs are presented in the same order as the list of samples in appendix A.
<table>
<thead>
<tr>
<th>Timebase</th>
<th>Memory 1</th>
<th>Memory 2</th>
<th>Memory 3</th>
<th>Memory 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>25.0 ms/div</td>
<td>100.0 mvolts/div</td>
<td>100.0 mvolts/div</td>
<td>100.0 mvolts/div</td>
<td>100.0 mvolts/div</td>
</tr>
<tr>
<td>Delay</td>
<td>Offset</td>
<td>Delay</td>
<td>Offset</td>
<td>Delay</td>
</tr>
<tr>
<td>0.00000 s</td>
<td>0.000 volts</td>
<td>0.00000 s</td>
<td>0.000 volts</td>
<td>0.00000 s</td>
</tr>
<tr>
<td>Freq.</td>
<td>+ Width</td>
<td>- Width</td>
<td>Preshoot</td>
<td>Overshoot</td>
</tr>
<tr>
<td>218.976 Hz</td>
<td>2.19117 ms</td>
<td>2.37554 ms</td>
<td>0.000 volts</td>
<td>0.000 volts</td>
</tr>
<tr>
<td>Rise Time</td>
<td>Fall Time</td>
<td>P-P Volts</td>
<td>RMS Volts</td>
<td>Dutycycle</td>
</tr>
<tr>
<td>1.98830 ms</td>
<td>1.86560 ms</td>
<td>712.6 mvolts</td>
<td>202.7 mvolts</td>
<td>47.98 %</td>
</tr>
</tbody>
</table>

Trace: Cast Iron Specimen | Air Core

Filtered Input

Four Trace Overlay in Time-Space

Page: 62
Ch. 1 = 200.0 mvolts/div
Ch. 2 = 1.000 volts/div
Timebase = 25.0 ms/div
Ch. 2 Parameters
Rise Time = 289.473 us
Fall Time = 582.465 us
P-P Volts = 2.718 volts
Freq. = 233.065 Hz
Period = 4.29065 ms
Offset = 0.000 volts
Delay = 0.00000 s

Top Trace: Cast Iron Specimen
Bottom Trace: Cast Iron Specimen

Page: 63
Top Trace: Cast Iron Specimen  Air Core  Filtered Input  Frequency-Space
Bottom Trace: Cast Iron Specimen  Air Core  Un-filtered Input  Frequency-Space
Timebase = 25.0 ms/div
Memory 1 = 100.0 mvolts/div
Timebase = 25.0 ms/div
Memory 2 = 100.0 mvolts/div
Timebase = 25.0 ms/div
Memory 3 = 100.0 mvolts/div
Timebase = 25.0 ms/div
Memory 4 = 100.0 mvolts/div
Timebase = 25.0 ms/div
Mem 1 Parameters
Rise Time = 2.02577 ms + Width = 2.29067 ms
Fall Time = 1.68369 ms Preshoot = 0.000 volts
P-P Volts = 725.1 mvolts RMS Volts = 211.7 mvolts
Delay = 0.00000 s
Offset = 0.000 volts
Delay = 0.00000 s
Offset = 0.000 volts
Delay = 0.00000 s
Offset = 0.000 volts
Delay = 0.00000 s
Offset = 0.000 volts
Delay = 0.00000 s
Offset = 0.000 volts
Delay = 0.00000 s
Offset = 0.000 volts
Delay = 0.00000 s
Offset = 0.000 volts
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Delay = 0.00000 s
Offset = 0.000 volts
Delay = 0.00000 s
Offset = 0.000 volts
Delay = 0.00000 s
Offset = 0.000 volts
Delay = 0.00000 s
Offset = 0.000 volts
Delay = 0.00000 s
Offset = 0.000 volts
Delay = 0.00000 s
Offset = 0.000 volts
Period = 4.65548 ms
- Width = 2.36481 ms
Overshoot = 0.000 volts
Dutycycle = 49.20 %

Trace: Cast Iron Specimen Sand Core

Filtered Input

Four Trace Overlay in Time-Space

Page: 65
Ch. 1 = 200.0 mvolts/div
Ch. 2 = 1.000 volts/div
Timebase = 25.0 ms/div
Ch. 2 Parameters
Freq. = 229.885 Hz
Period = 4.35000 ms
Rise Time = 809.408 us
+ Width = 1.85392 ms
Delay = 0.00000 s
Fall Time = 809.553 us
- Width = 2.49608 ms
Preshoot = 0.000 volts
Overshoot = 0.000 volts
P-P Volts = 2.687 volts
RMS Volts = 1.122 volts
Dutycycle = 42.61 %

Top Trace: Cast Iron Specimen Sand Core Filtered Input
Bottom Trace: Cast Iron Specimen Sand Core Un-filtered Input
Page: 66
X = 216.87 Hz
Ya = -52.54 dBVrms

POWER SPEC1
1Avg 0%Ov1p Hann 0v1

-30.0 dB

rms \sqrt{V^2}

-110

Fxd Y 0 Hz
CAST IRON-SAND 500

POWER SPEC2
1Avg 0%Ov1p Hann 0v2

-30.0 dB

rms \sqrt{V^2}

-110

Fxd Y 0 Hz
CAST IRON-SAND 500

Top Trace:
Cast Iron Specimen
Sand Core
Filtered Input

Bottom Trace:
Cast Iron Specimen
Sand Core
Un-filtered Input

Frequency-Space
Trace: Cast Iron Specimen  Lead Shot Core

Filtered Input

Four Trace Overlay in Time-Space
Ch. 1 = 200.0 mvolts/div
Ch. 2 = 1.000 volts/div
Timebase = 25.0 ms/div

Ch. 2 Parameters
Freq. = 75.2930 Hz
Period = 13.2814 ms
Preshoot = 0.000 volts
Overshoot = 31.25 mvolts
Rise Time = 1.85647 ms
+ Width = 5.49265 ms
- Width = 7.78879 ms
Fall Time = 2.00513 ms
RMS Volts = 1.074 volts
Dutycycle = 41.35%

Top Trace: Cast Iron Specimen  Lead Shot Core  Filtered Input  Time-Space
Bottom Trace: Cast Iron Specimen  Lead Shot Core  Un-filtered Input

Page: 69
X = 218.75 Hz
Ya = -56.086 dBVrms

POWER SPEC1
-30.0

Top Trace: Cast Iron Specimen
Bottom Trace: Cast Iron Specimen

POWER SPEC2
-30.0

Fxd Y 0 Hz
Yb = -41.793 dBVrms

Fxd Y 0 Hz

Filtered Input
Un-filtered Input
Frequency-Space

Page: 70
Timebase = 25.0 ms/div
Memory 1 = 125.0 mvolts/div
Timebase = 25.0 ms/div
Memory 2 = 125.0 mvolts/div
Timebase = 25.0 ms/div
Memory 3 = 125.0 mvolts/div
Timebase = 25.0 ms/div
Memory 4 = 125.0 mvolts/div
Timebase = 25.0 ms/div

Mem 1 Parameters
Rise Time = 1.69971 ms
Fall Time = 1.48703 ms
P-P Volts = 687.6 mvolts

Freq. = 220.127 Hz
+ Width = 2.23691 ms
Preshoot = 0.000 volts
RMS Volts = 206.9 mvolts

Delay = 0.00000 s
Offset = 0.000 volts
Delay = 0.00000 s
Offset = 0.000 volts
Delay = 0.00000 s
Offset = 0.000 volts
Delay = 0.00000 s
Offset = 0.000 volts
Delay = 0.00000 s
Period = 4.54283 ms
- Width = 2.30591 ms
Overshoot = 0.000 volts
Dutycycle = 49.24 %

Trace: Cast Iron Specimen	Oil Core

Filtered Input

Four Trace Overlay in Time-Space
Ch. 1 = 200.0 mvolts/div
Ch. 2 = 1.000 volts/div
Timebase = 25.0 ms/div
Offset = 0.000 volts
Delay = 0.00000 s
Ch. 2 Parameters
Freq. = 225.988 Hz
Period = 4.42500 ms
Rise Time = 424.671 us
+ Width = 1.98621 ms
- Width = 2.43879 ms
Fall Time = 639.269 us
Preshoot = 0.000 volts
Overshoot = 0.000 volts
P-P Volts = 2.687 volts
RMS Volts = 1.247 volts
Dutycycle = 44.88%

Top Trace: Cast Iron Specimen Oil Core Filtered Input Time-Space
Bottom Trace: Cast Iron Specimen Oil Core Un-filtered Input

Page: 72
X = 216.87 Hz
Y_a = -61.528 dBVrms

POWER SPEC1
-30.0

dB

rms

-110

Fxd Y 0 Hz

Y_b = -47.441 dBVrms

POWER SPEC2
-30.0

dB

rms

-110

Fxd Y 0 Hz

Top Trace:
Cast Iron Specimen
Oil Core
Filtered Input
Frequency-Space

Bottom Trace:
Cast Iron Specimen
Oil Core
Un-filtered Input

Page: 73
Ch. 1 = 200.0 mvolts/div  
Ch. 2 = 1.000 volts/div  
Timebase = 25.0 ms/div  

Ch. 2 Parameters  
Freq. = 209.183 Hz  
Period = 4.78050 ms  
Rise Time = 779.721 us  
Fall Time = 755.381 us  
P-P Volts = 2.687 volts  

Top Trace: Cast Iron Specimen  Sand/Oil Core  Filtered Input  Time-Space  
Bottom Trace: Cast Iron Specimen  Sand/Oil Core  Un-filtered Input  
Page: 75
X = 218.75 Hz
Ya = -57.651 dBVrms

POWER SPEC1
-30.0

TOP TRACE:
Cast Iron Specimen
Lead Shot/Oil Core
Filtered Input
Frequency-Space

Bottom Trace:
Cast Iron Specimen
Lead Shot/Oil Core
Un-filtered Input

Yb = -43.524 dBVrms

POWER SPEC2
-30.0

Fxd Y 0 Hz
-110

Fxd Y 0 Hz
-110
Timebase = 25.0 ms/div
Memory 1 = 100.0 mvolts/div
Timebase = 25.0 ms/div
Memory 2 = 100.0 mvolts/div
Timebase = 25.0 ms/div
Memory 3 = 100.0 mvolts/div
Timebase = 25.0 ms/div
Memory 4 = 100.0 mvolts/div
Mem 1 Parameters
Rise Time = 2.07754 ms
Fall Time = 1.75481 ms
P-P Volts = 700.1 mvolts
Freq. = 202.899 Hz
Width = 2.43137 ms
Preshoot = 0.000 volts
Delay = 0.00000 s
Offset = 0.00000 s
Overshoot = 0.000 volts
Dutycycle = 49.33 %
Trace: Steel Specimen Air Core
Filtered Input
Four Trace Overlay in Time-Space
Page: 80
Ch. 1 = 200.0 mvolts/div
Ch. 2 = 1.000 volts/div
Timebase = 25.0 ms/div

Ch. 2 Parameters
Freq. = 215.960 Hz
Period = 4.63048 ms
Delay = 0.00000 s
Offset = 0.000 volts

Rise Time = 409.421 us
+ Width = 2.13636 ms
- Width = 2.49412 ms
Preshoot = 0.000 volts
Overshoot = 0.000 volts
Dutycycle = 46.13%

Top Trace: Steel Specimen Air Core Filtered Input Time-Space
Bottom Trace: Steel Specimen Air Core Un-filtered Input

Page: 81
$X = 216.87 \text{ Hz}$
$Y_a = -45.668 \text{ dBVrms}$

**POWER SPEC1**

<table>
<thead>
<tr>
<th>dB</th>
<th>rms $v^2$</th>
<th>$-110$</th>
</tr>
</thead>
</table>

**POWER SPEC2**

<table>
<thead>
<tr>
<th>dB</th>
<th>rms $v^2$</th>
<th>$-110$</th>
</tr>
</thead>
</table>

**Fxd Y 0 Hz STEEL-AIR 500**

*Top Trace:* Steel Specimen  Air Core  Filtered Input  Frequency-Space

*Bottom Trace:* Steel Specimen  Air Core  Un-filtered Input  Page: 82
Timebase = 25.0 ms/div
Memory 1 = 100.0 mvolts/div
Timebase = 25.0 ms/div
Memory 2 = 100.0 mvolts/div
Timebase = 25.0 ms/div
Memory 3 = 100.0 mvolts/div
Timebase = 25.0 ms/div
Memory 4 = 100.0 mvolts/div
Timebase = 25.0 ms/div
Mem 2 Parameters
Rise Time = 2.52431 ms
Fall Time = 1.98643 ms
P-P Volts = 737.6 mvolts
Freq. = 187.524 Hz
Delay = 0.00000 s
Offset = 0.00000 s
Delay = 0.00000 s
Offset = 0.00000 s
Delay = 0.00000 s
Offset = 0.00000 s
Delay = 0.00000 s
Offset = 0.00000 s
Delay = 0.00000 s
Period = 5.33266 ms
-Width = 2.57025 ms
Overshoot = 0.000 volts
Dutycycle = 51.80 %

Trace:
Steel Specimen
Sand Core

Filtered Input

Four Trace Overlay in Time-Space
Ch. 1 = 200.0 mvolts/div  
Ch. 2 = 1.000 volts/div  
Timebase = 25.0 ms/div  

Ch. 2 Parameters  
Freq. = 182.110 Hz  
Period = 5.49118 ms  
Rise Time = 409.091 us  
+ Width = 2.50000 ms  
- Width = 2.99118 ms  
Fall Time = 409.091 us  
Preshoot = 0.000 volts  
Overshoot = 0.000 volts  
P-P Volts = 2.812 volts  
RMS Volts = 1.361 volts  
Dutycycle = 45.52 %

Top Trace:  
Steel Specimen  
Sand Core  
Filtered Input  
Time-Space

Bottom Trace:  
Steel Specimen  
Sand Core  
Un-filtered Input  
Page: 84
X = 201.25 Hz
Y_a = -52.337 dBVrms

POWER SPEC1
-30.0

F_xd Y 0 Hz
STAINLESS-SAND 500

POWER SPEC2
-30.0

F_xd Y 0 Hz
STAINLESS-SAND 500

Top Trace: Steel Specimen
Bottom Trace: Steel Specimen

Sand Core

Filtered Input
Frequency-Space

Un-filtered Input

Page: 85
Timebase = 25.0 ms/div
Memory 1 = 125.0 mvolts/div
Timebase = 25.0 ms/div
Memory 2 = 125.0 mvolts/div
Timebase = 25.0 ms/div
Memory 3 = 125.0 mvolts/div
Timebase = 25.0 ms/div
Memory 4 = 125.0 mvolts/div
Mem 1 Parameters
Rise Time = 1.93250 ms
Fall Time = 2.05413 ms
P-P Volts = 777.4 mvolts
Trace: Steel Specimen

Freq. = 202.716 Hz
+ Width = 2.27625 ms
Preshoot = 0.000 volts
RMS Volts = 229.2 mvolts
Trace: Lead Shot Core

Delay = 0.00000 s
Offset = 0.000 volts
Delay = 0.00000 s
Offset = 0.000 volts
Delay = 0.00000 s
Offset = 0.000 volts
Delay = 0.00000 s
Offset = 0.000 volts
Delay = 0.00000 s
Offset = 0.000 volts
Delay = 0.00000 s
Offset = 0.000 volts
Delay = 4.93301 ms
Period = 4.93301 ms
- Width = 2.65676 ms
Overshoot = 0.000 volts
Dutycycle = 46.14 %

Four Trace Overlay in Time-Space
Ch. 1 = 200.0 mvolts/div
Ch. 2 = 1.000 volts/div
Timebase = 25.0 ms/div
Offset = 0.000 volts
Delay = 0.00000 s

Ch. 2 Parameters
Freq. = 203.707 Hz
Period = 4.90902 ms
Preshoot = 0.000 volts
Overshoot = 0.000 volts
Dutycycle = 49.12%

Top Trace: Steel Specimen
Bottom Trace: Steel Specimen

Page: 87
X = 216.87 Hz
Y_a = -50.37 dBVRms

POWER SPEC1

1Avg  0%0vlp Hann
0v1

-40.0 dB

-rms

-v2

-120

Fx d Y 0 Hz STEEL-SHOT 500

Y_b = -36.255 dBVRms

POWER SPEC2

1Avg  0%0vlp Hann
0v2

-40.0 dB

-rms

-v2

-120

Fx d Y 0 Hz STEEL-SHOT 500

Top Trace: Steel Specimen Lead Shot Core Filtered Input Frequency-Space

Bottom Trace: Steel Specimen Lead Shot Core Un-filtered Input
Ch. 1 = 200.0 mvolts/div
Ch. 2 = 1.000 volts/div
Timebase = 25.0 ms/div
Ch. 2 Parameters
Freq. = 202.817 Hz
Rise Time = 400.08 us
P-P Volts = 2.875 volts
Offset = 0.000 volts
Preshoot = 0.000 volts
Delay = 0.00000 s
P-P Volts = 2.875 volts
RMS Volts = 1.392 volts
Overshoot = 0.000 volts
Dutycycle = 50.70 %

Top Trace: Steel Specimen Oil Core
Bottom Trace: Steel Specimen Oil Core

Filtered Input
Time-Space
Un-filtered Input
Page: 90
X=216.87 Hz
Ya=-47.339 dBVrms

POWER SPEC1
-30.0

Fxd Y 0 Hz
Yb=-33.446 dBVrms

POWER SPEC2
-30.0

Top Trace:
Steel Specimen
Oil Core
Filtered Input
Frequency-Space

Bottom Trace:
Steel Specimen
Oil Core
Un-filtered Input
<table>
<thead>
<tr>
<th>Timebase</th>
<th>Memory 1</th>
<th>Timebase</th>
<th>Memory 2</th>
<th>Timebase</th>
<th>Memory 3</th>
<th>Timebase</th>
<th>Memory 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>25.0 ms/div</td>
<td>100.0 mvolts/div</td>
<td>25.0 ms/div</td>
<td>100.0 mvolts/div</td>
<td>25.0 ms/div</td>
<td>100.0 mvolts/div</td>
<td>25.0 ms/div</td>
<td>100.0 mvolts/div</td>
</tr>
</tbody>
</table>

**Mem 1 Parameters**

- **Rise Time**: 1.60326 ms
- **Fall Time**: 1.699369 ms
- **P-P Volts**: 700.1 mvolts
- **Freq.**: 192.923 Hz
- **Delay**: 0.00000 s
- **Offset**: 0.000 volts
- **Preshoot**: 0.000 volts
- **Overshoot**: 0.000 volts
- **Dutycycle**: 45.32 %

**Trace:**

- **Steel Specimen**
- **Sand/Oil Core**

- **Filtered Input**

- **Four Trace Overlay in Time-Space**

Page: 92
X = 216.87 Hz
Y_a = -56.071 dBVrms

POWER SPEC1
1Avg 0%0v1p Hann 0v1
-30.0

dB

rms

v2

-110

STEEL-SAND-OIL

500

Fxd Y 0 Hz

Y_b = -41.988 dBVrms

POWER SPEC2
1Avg 0%0v1p Hann 0v2
-30.0

dB

rms

v2

-110

STEEL-SAND-OIL

500

Top Trace:

Steel Specimen
Sand/Oil Core
Filtered Input
Frequency-Space

Bottom Trace:

Steel Specimen
Sand/Oil Core
Un-filtered Input
Timebase = 25.0 ms/div
Memory 1 = 125.0 mvolts/div
Timebase = 25.0 ms/div
Memory 2 = 125.0 mvolts/div
Timebase = 25.0 ms/div
Memory 3 = 125.0 mvolts/div
Timebase = 25.0 ms/div
Memory 4 = 125.0 mvolts/div

Mem 1 Parameters
Rise Time = 2.54492 ms
Fall Time = 2.18000 ms
P-P Volts = 789.1 mvolts

Freq. = 175.070 Hz
Width = 2.33403 ms
Preshoot = 0.000 volts
RMS Volts = 195.9 mvolts

Delay = 0.00000 s
Offset = 0.000 volts
Delay = 0.00000 s
Offset = 0.000 volts
Delay = 0.00000 s
Offset = 0.000 volts
Delay = 0.00000 s
Offset = 0.000 volts
Delay = 0.00000 s

Period = 5.71200 ms
Overshoot = 3.37797 ms
Dutycycle = 40.86 %

Trace:
Steel Specimen
Lead Shot/Oil Core

Filtered Input

Four Trace Overlay in Time-Space
Ch. 1 = 200.0 mvolts/div  
Ch. 2 = 1.000 volts/div  
Timebase = 25.0 ms/div  
Ch. 2 Parameters  
Rise Time = 408.713 us  
Fall Time = 742.940 us  
P-P Volts = 2.937 volts  
Freq. = 180.926 Hz  
+ Width = 2.60809 ms  
- Width = 2.91901 ms  
Preshoot = 0.000 volts  
Overshoot = 0.000 volts  
RMS Volts = 1.382 volts  
Dutycycle = 47.18 %

Top Trace: Steel Specimen  
Bottom Trace: Steel Specimen  
Filtred Input  
Un-filtered Input  
Page: 96
X = 201.25 Hz
Yα = -53.152 dBVrms

POWER SPEC1

-40.0

dB

rms

v^2

-120

Fxd Y 0 Hz

STEEL-SHOT-OIL

500

POWER SPEC2

-40.0

dB

rms

v^2

-120

Fxd Y 0 Hz

STEEL-SHOT-OIL

500

Top Trace: Steel Specimen
Lead Shot/Oil Core
Filtered Input
Frequency-Space

Bottom Trace: Steel Specimen
Lead Shot/Oil Core
Un-filtered Input
Page: 97
Trace: Stainless Steel Specimen Air Core

Filtered Input

Four Trace Overlay in Time-Space
Ch. 1 = 200.0 mvolts/div
Ch. 2 = 1.000 volts/div
Timebase = 25.0 ms/div

Ch. 2 Parameters
Freq. = 181.722 Hz
Period = 5.50291 ms
Offset = 0.000 volts
Delay = 0.00000 s
Offset = 0.000 volts

Rise Time = 395.349 us
+ Width = 2.50588 ms
- Width = 2.99702 ms

P-P Volts = 2.687 volts
RMS Volts = 1.323 volts
Filtreder Input

Stainless Steel Specimen
Air Core

Top Trace: Stainless Steel Specimen Air Core
Bottom Trace: Stainless Steel Specimen Air Core

Page: 99
X = 201.25 Hz
Y_a = -49.575 dBVrms

POWER SPEC1

1Avg 0%0v1p Hann 0v1

Top Trace:
Stainless Steel Specimen
Air Core
Filtred Input
Frequency-Space

Bottom Trace:
Stainless Steel Specimen
Air Core
Un-filtered Input
Page: 100

Fxd Y 0 Hz
STAINLESS-AIR

Y_b = -35.281 dBVrms

POWER SPEC2

1Avg 0%0v1p Hann

Fxd Y 0 Hz
STAINLESS-AIR

-30.0 dB

-110

rms V^2

Top Trace:
Stainless Steel Specimen
Air Core
Filtred Input
Frequency-Space

Bottom Trace:
Stainless Steel Specimen
Air Core
Un-filtered Input
Page: 100
Timebase = 25.0 ms/div
Memory 1 = 100.0 mvolts/div
Timebase = 25.0 ms/div
Memory 2 = 100.0 mvolts/div
Timebase = 25.0 ms/div
Memory 3 = 100.0 mvolts/div
Timebase = 25.0 ms/div
Memory 4 = 100.0 mvolts/div
Timebase = 25.0 ms/div
Mem 1 Parameters
Freq. = 203.126 Hz
Rise Time = 2.06118 ms
Fall Time = 1.94705 ms
P-P Volts = 712.6 mvolts
Trace: Stainless Steel Specimen
Sand Core
Delay = 0.00000 s
Offset = 0.00000 s
Delay = 0.00000 s
Offset = 0.00000 s
Delay = 0.00000 s
Offset = 0.00000 s
Delay = 0.00000 s
Offset = 0.00000 s
Period = 4.92305 ms
- Width = 2.56299 ms
Overshoot = 0.000 volts
Dutycycle = 47.93 %

Four Trace Overlay in Time-Space
Ch. 1 = 200.0 mvolts/div
Ch. 2 = 1.000 volts/div
Timebase = 25.0 ms/div

Ch. 2 Parameters
Freq. = 219.246 Hz
Period = 4.56109 ms
Rise Time = 254.136 us
+ Width = 2.25117 ms
Fall Time = 251.181 us
- Width = 2.30992 ms
P-P Volts = 2.687 volts
RMS Volts = 1.292 volts
Dutycycle = 49.35 %

Top Trace: Stainless Steel Specimen Sand Core
Bottom Trace: Stainless Steel Specimen Sand Core
X=216.87 Hz
Ya=-48.278 dBVrms
POWER SPEC1

1Avg 0%Ovlp Hann 0v1

-30.0

-110 dB

rms v2

Fxd Y 0 Hz

STEEL-SAND

500

Yb=-34.275 dBVrms
POWER SPEC2

-30.0

-110 dB

rms v2

Fxd Y 0 Hz

STEEL-SAND

500

Top Trace: Stainless Steel Specimen Sand Core Filtered Input Frequency-Space

Bottom Trace: Stainless Steel Specimen Sand Core Un-filtered Input

Page: 103
Timebase = 25.0 ms/div
Memory 1 = 100.0 mvolts/div
Timebase = 25.0 ms/div
Memory 2 = 100.0 mvolts/div
Timebase = 25.0 ms/div
Memory 3 = 100.0 mvolts/div
Timebase = 25.0 ms/div
Memory 4 = 100.0 mvolts/div
Mem 3 Parameters
Rise Time = 2.49737 ms
Fall Time = 1.58187 ms
P-P Volts = 725.1 mvolts
Freq. = 204.083 Hz
Delay = 0.00000 s
Offset = 0.00000 s
Delay = 0.00000 s
Offset = 0.00000 s
Delay = 0.00000 s
Offset = 0.00000 s
Period = 4.89997 ms
Delay = 0.00000 s
Offset = 0.00000 s
Delay = 0.00000 s
Offset = 0.00000 s
Delay = 0.00000 s
Offset = 0.00000 s
RMS Volts = 201.7 mvolts
Dutycycle = 53.11 %

Trace:
Stainless Steel Specimen
Lead Shot Core

Four Trace Overlay in Time-Space
Ch. 1 = 200.0 mvolts/div Offset = 0.000 volts
Ch. 2 = 1.000 volts/div Offset = 0.000 volts
Timebase = 25.0 ms/div Delay = 0.00000 s
Ch. 2 Parameters Freq. = 201.044 Hz Period = 4.97403 ms
Rise Time = 400.000 us + Width = 2.04514 ms - Width = 2.92889 ms
Fall Time = 628.472 us Preshoot = 0.000 volts Overshoot = 0.000 volts
P-P Volts = 2.656 volts RMS Volts = 1.262 volts Dutycycle = 41.11 %

Top Trace: Stainless Steel Specimen Lead Shot Core Filtered Input Time-Space
Bottom Trace: Stainless Steel Specimen Lead Shot Core Un-filtered Input

Page: 105
X = 201.25 Hz
Y_a = -49.22 dBVrms

POWER SPEC1
1Avg 0%Ovlp Hann 0v1

POWER SPEC2
1Avg 0%Ovlp Hann 0v2

Top Trace:
Stainless Steel Specimen
Lead Shot Core
Filtered Input
Frequency-Space

Bottom Trace:
Stainless Steel Specimen
Lead Shot Core
Un-filtered Input
Timebase = 25.0 ms/div
Memory 1 = 100.0 mvolts/div
Timebase = 25.0 ms/div
Memory 2 = 100.0 mvolts/div
Timebase = 25.0 ms/div
Memory 3 = 100.0 mvolts/div
Timebase = 25.0 ms/div
Memory 4 = 100.0 mvolts/div
Timebase = 25.0 ms/div
Mem 1 Parameters
Rise Time = 2.17622 ms + Width = 2.44249 ms
Fall Time = 2.03048 ms Preshoot = 0.000 volts
P-P Volts = 725.1 mvolts RMS Volts = 200.8 mvolts
Delay = 0.00000 s Offset = 0.000 volts
Delay = 0.00000 s Offset = 0.000 volts
Delay = 0.00000 s Offset = 0.000 volts
Delay = 0.00000 s Offset = 0.000 volts
Delay = 0.00000 s
Freq. = 195.781 Hz Period = 5.10775 ms
- Width = 2.66527 ms Overshoot = 0.000 volts
Dutycycle = 47.81 %

Trace: Stainless Steel Specimen Oil Core

Four Trace Overlay in Time-Space
X = 201.25 Hz
Ya = -52.695 dBVrms

POWER SPEC1
-30.0

-110

STAINLESS-OIL

500

Fxd Y 0 Hz

Yb = -38.11 dBVrms

POWER SPEC2
-30.0

-110

STAINLESS-OIL

500

Top Trace: Stainless Steel Specimen Oil Core Filtered Input Frequency-Space
Bottom Trace: Stainless Steel Specimen Oil Core Un-filtered Input
Timebase = 25.0 ms/div
Memory 1 = 100.0 mvolts/div
Timebase = 25.0 ms/div
Memory 2 = 100.0 mvolts/div
Timebase = 25.0 ms/div
Memory 3 = 100.0 mvolts/div
Timebase = 25.0 ms/div
Memory 4 = 100.0 mvolts/div

Mem 1 Parameters
Rise Time = 2.08447 ms + Width = 2.40014 ms
Fall Time = 1.91509 ms Preshoot = 0.000 volts
P-P Volts = 725.1 mvolts RMS Volts = 207.3 mvolts

Delay = 0.00000 s Offset = 0.000 volts
Delay = 0.00000 s Offset = 0.000 volts
Delay = 0.00000 s Offset = 0.000 volts
Delay = 0.00000 s Offset = 0.000 volts
Delay = 0.00000 s Offset = 0.000 volts

Freq. = 200.000 Hz Period = 5.00000 ms

Stainless Steel Specimen Sand/Oil Core

Four Trace Overlay in Time-Space
Ch. 1 = 200.0 mvolts/div
Ch. 2 = 1.000 volts/div
Timebase = 25.0 ms/div
Ch. 2 Parameters
Rise Time = 796.594 us
Fall Time = 703.125 us
P-P Volts = 2.656 volts
Freq. + Width = 203.175 Hz
Preshoot = 0.000 volts
Offset = 0.000 volts
Delay = 0.00000 s
Period = 4.92188 ms
Overshoot = 0.000 volts
Dutycycle = 46.56 %

Top Trace:
Stainless Steel Specimen
Sand/Oil Core
Filtered Input
Time-Space

Bottom Trace:
Stainless Steel Specimen
Sand/Oil Core
Un-filtered Input

Page: 111
X = 415.62 Hz
Ya = -108.44 dBVrms

Top Trace: Stainless Steel Specimen  Sand/Oil Core  Filtered Input  Frequency-Space
Bottom Trace: Stainless Steel Specimen  Sand/Oil Core  Un-filtered Input
Timebase = 25.0 ms/div
Memory 1 = 100.0 mvolts/div
Timebase = 25.0 ms/div
Memory 2 = 100.0 mvolts/div
Timebase = 25.0 ms/div
Memory 3 = 100.0 mvolts/div
Timebase = 25.0 ms/div
Memory 4 = 100.0 mvolts/div
Timebase = 25.0 ms/div
Mem 1 Parameters
Rise Time = 2.04626 ms + Width = 2.57031 ms
Fall Time = 2.20241 ms Preshoot = 0.000 volts
P-P Volts = 712.6 mvolts RMS Volts = 208.8 mvolts
Freq. = 187.648 Hz
Offset = 0.00000 s
Delay = 0.00000 s
Period = 5.32912 ms
- Width = 2.75882 ms
Overshoot = 0.000 volts
Dutycycle = 48.23 %

Filtered Input

Four Trace Overlay in Time-Space
Ch. 1 = 200.0 mvolts/div
Ch. 2 = 1.000 volts/div
Timebase = 25.0 ms/div

Ch. 2 Parameters
Freq. = 208.615 Hz
Period = 4.79351 ms
Delay = 0.00000 s
Offset = 0.000 volts

Rise Time = 746.670 us
Width = 2.19355 ms
- Width = 2.59997 ms
Preshoot = 31.25 mvolts
Overshoot = 0.000 volts

P-P Volts = 2.687 volts
RMS Volts = 1.162 volts
Dutycycle = 45.76 %

Top Trace: Stainless Steel Specimen  Lead Shot/Oil Core  Filtered Input  Time-Space
Bottom Trace: Stainless Steel Specimen  Lead Shot/Oil Core  Un-filtered Input
X = 201.25 Hz  
Ya = -46.969 dBVrms

POWER SPEC1
-30.0

dB

rms v^2

-110

Fx d Y 0 Hz
STAINLESS SHOT OIL 500

Yb = -32.623 dBVrms

POWER SPEC2
-30.0

dB

Top Trace: Stainless Steel Specimen  Lead Shot/Oil Core  Filtered Input  Frequency-Space

Bottom Trace: Stainless Steel Specimen  Lead Shot/Oil Core  Un-filtered Input
Timebase = 25.0 ms/div
Memory 1 = 125.0 mvolts/div
Memory 2 = 125.0 mvolts/div
Memory 3 = 125.0 mvolts/div
Memory 4 = 125.0 mvolts/div
Rise Time = 1.66922 ms
Fall Time = 1.52639 ms
P-P Volts = 750.1 mvolts
Freq. = 209.316 Hz
Period = 4.77747 ms
Delay = 0.00000 s
Offset = 0.00000 s
Preshoot = 0.000 volts
Overshoot = 0.000 volts
Dutycycle = 44.24 %
Trace:
  1: Titanium Specimen
  2: Air Core
  3: Filtered Input

Four Trace Overlay in Time-Space
Ch. 1 = 200.0 mvolts/div
Ch. 2 = 1.000 volts/div
Timebase = 25.0 ms/div

Ch. 2 Parameters
Freq. = 253.548 Hz
Period = 3.94403 ms

Rise Time = 792.057 us
Width = 1.61221 ms

Fall Time = 400.009 us
Preshoot = 0.000 volts

P-P Volts = 2.875 volts
RMS Volts = 1.263 volts

Dutycycle = 40.87 %
X = 218.75 Hz
Ya = -62.592 dBVrms

POWER SPEC1

-40.0 dB

Fxd Y 0 Hz
TITANIUM-AIR

500

Top Trace:
Titanium Specimen
Air Core
Filtered Input
Frequency-Space

Page: 118
Ch. 1 = 200.0 mvolts/div
Ch. 2 = 1.000 volts/div
Timebase = 25.0 ms/div
Start = 2.64407 ms  Stop = 7.14167 ms
Vmarker1 = -1.2800 volts  Vmarker2 = 1.4100 volts
Offset = 0.000 volts  Delay = 0.00000 s
Delta T = 4.49760 ms  Delta V = 2.690 volts

Top Trace:  Titanium Specimen  Sand Core
Bottom Trace:  Titanium Specimen  Sand Core
X = 218.75 Hz
Ya = -64.318 dBVrms

POWER SPEC1
-40.0

dB

dB

rms

v^2

-120

Fxd, Y 0, Hz

TITANIUM-SAND

500

Top Trace:
Titanium Specimen
Sand Core
Filtered Input
Frequency-Space

Bottom Trace:
Titanium Specimen
Sand Core
Un-filtered Input

Page: 121
Timebase = 25.0 ms/div
Memory 1 = 125.0 mvolts/div
Timebase = 25.0 ms/div
Memory 2 = 125.0 mvolts/div
Timebase = 25.0 ms/div
Memory 3 = 125.0 mvolts/div
Timebase = 25.0 ms/div
Memory 4 = 125.0 mvolts/div
Mem 1 Parameters
Rise Time = 1.30987 ms
Fall Time = 1.57229 ms
P-P Volts = 722.7 mvolts
Freq. = 231.189 Hz
+ Width = 2.05485 ms
Preshoot = 0.000 volts
RMS Volts = 244.3 mvolts
Delay = 0.00000 s
Offset = 0.00000 s
Offset = 0.00000 s
Delay = 0.00000 s
Delay = 0.00000 s
Delay = 0.00000 s
Delay = 4.32546 ms
Period = 2.27060 ms
Overshoot = 0.000 volts
Dutycycle = 47.50 %
Trace: Titanium Specimen Lead Shot Core Filtered Input
Four Trace Overlay in Time-Space
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ch. 1</td>
<td>200.0 mvolts/div</td>
</tr>
<tr>
<td>Ch. 2</td>
<td>1.000 volts/div</td>
</tr>
<tr>
<td>Timebase</td>
<td>25.0 ms/div</td>
</tr>
<tr>
<td>Ch. 2 Parameters</td>
<td></td>
</tr>
<tr>
<td>Rise Time</td>
<td>9.76573 ms</td>
</tr>
<tr>
<td>Fall Time</td>
<td>797.751 us</td>
</tr>
<tr>
<td>P-P Volts</td>
<td>2.906 volts</td>
</tr>
<tr>
<td>Freq.</td>
<td>299.516 Hz</td>
</tr>
<tr>
<td>+ Width</td>
<td>897.917 us</td>
</tr>
<tr>
<td>Preshoot</td>
<td>0.000 volts</td>
</tr>
<tr>
<td>- Width</td>
<td>2.44080 ms</td>
</tr>
<tr>
<td>Overshoot</td>
<td>0.000 volts</td>
</tr>
<tr>
<td>RMS Volts</td>
<td>930.5 mvolts</td>
</tr>
<tr>
<td>Offset</td>
<td>0.000 volts</td>
</tr>
<tr>
<td>Delay</td>
<td>0.00000 s</td>
</tr>
<tr>
<td>Period</td>
<td>3.33872 ms</td>
</tr>
</tbody>
</table>

**Top Trace:**
- Titanium Specimen
- Lead Shot Core

**Bottom Trace:**
- Titanium Specimen
- Lead Shot Core
X = 218.75 Hz
Y_a = -64.094 dBVrms

POWER SPEC1
-40.0 dB

rms v^2
-120

Fxd Y 0 Hz TITANIUM-SHOT 500

Y_b = -50.09 dBVrms

POWER SPEC2
-40.0 dB

rms v^2
-120

Fxd Y 0 Hz TITANIUM-SHOT 500

Top Trace: Titanium Specimen
Bottom Trace: Titanium Specimen

Lead Shot Core
Filtrered Input
Un-filtered Input
Frequency-Space
X = 238.75 Hz
Ya = -59.61 dBVrms

POWER SPEC1
-40.0

1Avg 0% Ovlp Hann 0v1

Fxd Y 0 Hz
TITANIUM-OIL 500

Yb = -45.987 dBVrms
POWER SPEC2
-40.0

1Avg 0% Ovlp Hann 0v2

Fxd Y 0 Hz
TITANIUM-OIL 500

Top Trace: Titanium Specimen Oil Core Filtered Input Frequency-Space

Bottom Trace: Titanium Specimen Oil Core Un-filtered Input
Timebase = 25.0 ms/div
Memory 1 = 125.0 mvolts/div
Timebase = 25.0 ms/div
Memory 2 = 125.0 mvolts/div
Timebase = 25.0 ms/div
Memory 3 = 125.0 mvolts/div
Timebase = 25.0 ms/div
Memory 4 = 125.0 mvolts/div

Mem 1 Parameters
Freq. = 212.847 Hz
Period = 4.69822 ms
Delay = 0.00000 s
Offset = 0.00000 s
Preshoot = 0.000 volts
Overshoot = 0.000 volts
Dutycycle = 41.99%
Rise Time = 1.28799 ms
Fall Time = 1.60959 ms
P-P Volts = 726.6 mvolts
RMS Volts = 211.1 mvolts

Trace: Titanium Specimen Sand/Oil Core Filtered Input

Four Trace Overlay in Time-Space
Ch. 1 = 200.0 mvolts/div
Ch. 2 = 1.000 volts/div
Timebase = 25.0 ms/div
Ch. 2 Parameters
Freq. = 338.164 Hz
Rise Time = 10.5021 ms
Fall Time = 747.673 us
P-P Volts = 2.875 volts
Offset = 0.000 volts
Delay = 0.00000 s
Width = 1.06404 ms
Overshoot = 0.000 volts
Dutycycle = 35.98 %
X = 218.75 Hz
Ya = -62.447 dBVrms

POWERSPEC1
1Avg 0%0v1p Hann 0v1

-40.0

0 dB

rms V^2

-120

TITANIUM-SAND-OIL

500

Fxd Y Hz

Yb = -48.523 dBVrms

POWERSPEC2
1Avg 0%0v1p Hann 0v2

-40.0

0 dB

rms V^2

-120

TITANIUM-SAND-OIL

500

Fxd Y Hz

Top Trace: Titanium Specimen Sand/Oil Core Filtered Input Frequency-Space
Bottom Trace: Titanium Specimen Sand/Oil Core Un-filtered Input

Page: 130
Timebase = 25.0 ms/div
Memory 1 = 125.0 mvolts/div
Memory 2 = 125.0 mvolts/div
Memory 3 = 125.0 mvolts/div
Memory 4 = 125.0 mvolts/div
Mem I Parameters
Rise Time = 1.66618 ms
Fall Time = 1.91362 ms
P-P Volts = 773.5 mvolts

Delay = 0.00000 s
Offset = 0.000 volts

Freq. = 217.269 Hz
Period = 4.60259 ms

Preshoot = 0.000 volts
Overshoot = 0.000 volts
Dutycycle = 46.30 %

Trace: Titanium Specimen
Trace: Lead Shot/Oil Core
Trace: Filtered Input

Four Trace Overlay in Time-Space
Ch. 1 = 200.0 mvolts/div
Ch. 2 = 1.000 volts/div
Timebase = 25.0 ms/div
Ch. 2 Parameters:
Freq. = 234.010 Hz
Period = 4.27332 ms
Offset = 0.000 volts
Delay = 0.00000 s
Rise Time = 752.039 us
Preshoot = 31.25 mvolts
Overshoot = 0.000 volts
Fall Time = 404.339 us
RMS Volts = 1.284 volts
Dutycycle = 51.16 %

Top Trace: Titanium Specimen  Lead Shot/Oil Core  Filtered Input  Time-Space
Bottom Trace: Titanium Specimen  Lead Shot/Oil Core  Un-filtered Input
X = 238.75 Hz
Ya = -61.268 dBVrms

POWER SPEC1

-40.0 dB

dB

rms

v^2

-120

Fxd Y 0 Hz TITANIUM-SHOT-OIL 500

Yb = -47.465 dBVrms

POWER SPEC2

-40.0 dB

dB

rms

v^2

-120

Fxd Y 0 Hz TITANIUM-SHOT-OIL 500

Top Trace:
Titanium Specimen
Lead Shot/Oil Core
Filtered Input
Frequency-Space

Bottom Trace:
Titanium Specimen
Lead Shot/Oil Core
Un-filtered Input

Page: 133
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Timebase</td>
<td>25.0 ms/div</td>
</tr>
<tr>
<td>Memory 1</td>
<td>100.0 mvolts/div</td>
</tr>
<tr>
<td>Memory 2</td>
<td>100.0 mvolts/div</td>
</tr>
<tr>
<td>Memory 3</td>
<td>100.0 mvolts/div</td>
</tr>
<tr>
<td>Memory 4</td>
<td>100.0 mvolts/div</td>
</tr>
<tr>
<td>Mem 1 Parameters</td>
<td></td>
</tr>
<tr>
<td>Freq.</td>
<td>580.001 Hz</td>
</tr>
<tr>
<td>Rise Time</td>
<td>840.823 us</td>
</tr>
<tr>
<td>Fall Time</td>
<td>2.41033 ms</td>
</tr>
<tr>
<td>P-P Volts</td>
<td>525.0 mvolts</td>
</tr>
<tr>
<td>Delay</td>
<td>0.00000 s</td>
</tr>
<tr>
<td>Offset</td>
<td>0.000 volts</td>
</tr>
<tr>
<td>Delay</td>
<td>0.00000 s</td>
</tr>
<tr>
<td>Offset</td>
<td>0.000 volts</td>
</tr>
<tr>
<td>Delay</td>
<td>0.00000 s</td>
</tr>
<tr>
<td>Offset</td>
<td>0.000 volts</td>
</tr>
<tr>
<td>Delay</td>
<td>0.00000 s</td>
</tr>
<tr>
<td>Offset</td>
<td>0.000 volts</td>
</tr>
<tr>
<td>Period</td>
<td>1.72414 ms</td>
</tr>
<tr>
<td>+ Width</td>
<td>1.22869 ms</td>
</tr>
<tr>
<td>- Width</td>
<td>495.442 ms</td>
</tr>
<tr>
<td>Overshoot</td>
<td>0.000 volts</td>
</tr>
<tr>
<td>Duty cycle</td>
<td>71.26 %</td>
</tr>
<tr>
<td>Trace:</td>
<td></td>
</tr>
<tr>
<td>Aluminum Specimen</td>
<td></td>
</tr>
<tr>
<td>Air Core</td>
<td></td>
</tr>
<tr>
<td>Filtered Input</td>
<td></td>
</tr>
</tbody>
</table>

Four Trace Overlay in Time-Space

Page: 134
\[ X = 458.12 \text{ Hz} \quad \Delta X = 67.5 \text{ Hz} \]
\[ Y_a = -69.447 \quad \Delta Y_a = 8.495 \quad \text{Avg} = -90.38 \text{ dBVrms} \]

**POWER SPEC1**
-40.0
\[ \text{dB} \]
\[ \text{rms} \]
\[ \text{v}^2 \]
\[ -120 \]

**Fxd Y 0 Hz**

ALUMINUM
\[ Y_b = -53.104 \quad \Delta Y_b = 7.356 \quad \text{Avg} = -74.503 \text{ dBVrms} \]

**POWER SPEC2**
-40.0
\[ \text{dB} \]
\[ \text{rms} \]
\[ \text{v}^2 \]
\[ -120 \]

**Fxd Y 0 Hz**

ALUMINUM

Top Trace: Aluminum Specimen Air Core Filtered Input Frequency-Space
Bottom Trace: Aluminum Specimen Air Core Un-filtered Input
Ch. 1 = 200.0 mvolts/div
Ch. 2 = 1.000 volts/div
Timebase = 25.0 ms/div
Ch. 2 Parameters
Freq. = 497.958 Hz
Period = 2.00820 ms
Delay = 0.00000 s
Rise Time = 400.000 us + Width = 1.48159 ms
Preshoot = 0.000 volts
Fall Time = 2.65332 ms - Width = 526.612 us
Overshoot = 0.000 volts
P-P Volts = 2.656 volts
RMS Volts = 1.064 volts
Dutycycle = 73.77 %

Top Trace:
Aluminum Specimen
Sand Core
Filttered Input

Bottom Trace:
Aluminum Specimen
Sand Core
Un-filtered Input

Page: 138
$X = 458.12 \, \text{Hz} \quad \Delta X = 67.5 \, \text{Hz}$

$Y_a = -73.46 \quad \Delta Y_a = 10.9 \quad \text{Avg} = -92.73 \, \text{dBVrms}$

Top Trace:
- Aluminum Specimen
- Sand Core
- Filtered Input

Bottom Trace:
- Aluminum Specimen
- Sand Core
- Un-filtered Input

Page: 139
Timebase = 25.0 ms/div
Memory 1 = 100.0 mvolts/div
Timebase = 25.0 ms/div
Memory 2 = 100.0 mvolts/div
Timebase = 25.0 ms/div
Memory 3 = 100.0 mvolts/div
Timebase = 25.0 ms/div
Memory 4 = 100.0 mvolts/div
Delay = 0.00000 s
Offset = 0.00000 s
Preshoot = 0.000 volts
Period = 1.81445 ms

Aluminum Specimen
Freq. = 551.133 Hz
+ Width = 261.489 us
Rise Time = 1.15056 ms
- Width = 1.55296 ms
Fall Time = 5.17324 ms
Overshoot = 0.000 volts
P-P Volts = 562.5 mvolts
Dutycycle = 14.41 %
RMS Volts = 117.4 mvolts

Trace: Aluminum Specimen Lead Shot Core

Four Trace Overlay in Time-Space

Page: 140
Ch. 1 = 200.0 mvolts/div
Ch. 2 = 1.000 volts/div
Timebase = 25.0 ms/div
Offset = 0.000 volts
Delay = 0.00000 s

Ch. 2 Parameters
Freq. = 345.455 Hz
Period = 2.89474 ms

Rise Time = 404.687 ms
+ Width = 1.39180 ms
- Width = 1.50294 ms

Fall Time = 409.505 ms
Preshoot = 0.000 volts
Overshoot = 0.000 volts

P-P Volts = 2.687 volts
RMS Volts = 1.210 volts
Dutycycle = 48.08 %

Top Trace: Aluminum Specimen Lead Shot Core Filtered Input Time-Space
Bottom Trace: Aluminum Specimen Lead Shot Core Un-filtered Input

Page: 141
X = 418.75 Hz
Ya = -78.657 dBVrms

POWER SPEC1: 1Avg 0%0v1p Hann 0v1

Top Trace:
Aluminum Specimen
Lead Shot Core
Filtered Input
Frequency-Space

Bottom Trace:
Aluminum Specimen
Lead Shot Core
Un-filtered Input

Fx  Y 0 Hz ALUMINUM-SHOT 500
Yb = -63.213 dBVrms

POWER SPEC2: 1Avg 0%0v1p Hann 0v2

Fx  Y 0 Hz ALUMINUM-SHOT 500
Timebase = 25.0 ms/div
Memory 1 = 100.0 mvolts/div
Timebase = 25.0 ms/div
Memory 2 = 100.0 mvolts/div
Timebase = 25.0 ms/div
Memory 3 = 100.0 mvolts/div
Timebase = 25.0 ms/div
Memory 4 = 100.0 mvolts/div
Delay = 0.00000 s
Offset = 0.000 volts
Delay = 0.00000 s
Offset = 0.000 volts
Delay = 0.00000 s
Offset = 0.000 volts
Delay = 0.00000 s
Offset = 0.000 volts
Delay = 0.00000 s
Offset = 0.000 volts
Delay = 0.00000 s
Offset = 0.000 volts
Freq. = 321.521 Hz
Period = 3.11021 ms
Preshoot = 0.000 volts
Overshoot = 0.000 volts
Dutycycle = 42.99 %
\( X = 415.62 \text{ Hz} \)
\( Y_a = -78.134 \text{ dBVrms} \)

**POWER SPEC1**

-30.0 dB

**POWER SPEC2**

-110 dB

**Fxd Y**

0 Hz

**ALUMINUM-OIL**

500 Hz

Top Trace: Aluminum Specimen

Bottom Trace: Aluminum Specimen

Oil Core

Filtered Input

Un-filtered Input

Frequency-Space

Page: 145
Timebase = 25.0 ms/div
Memory 1 = 100.0 mvolts/div
Timebase = 25.0 ms/div
Memory 2 = 100.0 mvolts/div
Timebase = 25.0 ms/div
Memory 3 = 100.0 mvolts/div
Timebase = 25.0 ms/div
Memory 4 = 100.0 mvolts/div
Timebase = 25.0 ms/div
Mem 1 Parameters
FREQ. = 256.632 Hz
Rise Time = 1.21272 ms
Fall Time = 1.96597 ms
P-P Volts = 700.1 mvolts
Aluminum Specimen
Sand/Oil Core
Delay = 0.00000 s
Offset = 0.000 volts
Delay = 0.00000 s
Offset = 0.000 volts
Delay = 0.00000 s
Offset = 0.000 volts
Delay = 0.00000 s
Offset = 0.000 volts
Delay = 0.00000 s
Offset = 0.000 volts
Delay = 0.00000 s
Offset = 0.000 volts
Period = 3.89664 ms
- Width = 2.30803 ms
Overshoot = 0.000 volts
Dutycycle = 40.76 %

Four Trace Overlay in Time-Space
Top Trace: Aluminum Specimen  Sand/Oil Core  Filtered Input  Time-Space
Bottom Trace: Aluminum Specimen  Sand/Oil Core  Un-filtered Input

Ch. 1 = 200.0 mvolts/div  Offset = 0.000 volts
Ch. 2 = 1.000 volts/div  Offset = 0.000 volts
Timebase = 25.0 ms/div  Delay = 0.00000 s

Ch. 2 Parameters
Freq. = 322.863 Hz  Period = 3.09729 ms
Rise Time = 610.256 us  + Width = 1.20798 ms  - Width = 1.88930 ms
Fall Time = 697.821 us  Preshoot = 0.000 volts  Overshoot = 0.000 volts
P-P Volts = 2.687 volts  RMS Volts = 1.106 volts  Dutycycle = 39.00 %
$X = 390.62 \text{ Hz}$
$Ya = -60.616 \text{ dBVrms}$

**POWER SPEC1**

-30.0 dB

**Fxd Y 0 Hz**

ALUMINUM-SAND-OIL

$Yb = -45.378 \text{ dBVrms}$

**POWER SPEC2**

-30.0 dB

**Fxd Y 0 Hz**

ALUMINUM-SAND-OIL

Top Trace: Aluminum Specimen    Sand/Oil Core    Filtered Input    Frequency-Space
Bottom Trace: Aluminum Specimen    Sand/Oil Core    Un-filtered Input
Trace: Aluminum Specimen          Lead Shot/Oil Core        Filtered Input

Four Trace Overlay in Time-Space

Page: 149
Ch. 1 = 200.0 mvolts/div
Ch. 2 = 1.000 volts/div
Timebase = 25.0 ms/div

Ch. 2 Parameters
Freq. = 267.111 Hz
Rise Time = 704.340 us
+ Width = 2.17739 ms
Fall Time = 404.687 us
Preshoot = 0.000 volts
P-P Volts = 2.687 volts
RMS Volts = 1.070 volts

Offset = 0.000 volts
Delay = 0.00000 s
Period = 3.74377 ms
- Width = 1.56637 ms
Overshoot = 0.000 volts
Dutycycle = 58.16 %

Top Trace: Aluminum Specimen
Bottom Trace: Aluminum Specimen

Lead Shot/Oil Core
Filterred Input
Time-Space

Page: 150
X = 418.75 Hz
Ya = -83.096 dBVrms

POWER SPEC1
-30.0

1Avg 0%Ovlp Hann 0v1

dB

rms

v2

-110

Fxd Y Hz

ALUMINUM-SHOT-OIL 500

Yb = -67.625 dBVrms

POWER SPEC2
-30.0

1Avg 0%Ovlp Hann 0v2

Top Trace: Aluminum Specimen Lead Shot/Oil Core Filtered Input Frequency-Space

Bottom Trace: Aluminum Specimen Lead Shot/Oil Core Un-filtered Input
Timebase = 25.0 ms/div
Memory 1 = 100.0 mvolts/div
Timebase = 25.0 ms/div
Memory 2 = 100.0 mvolts/div
Timebase = 25.0 ms/div
Memory 3 = 100.0 mvolts/div
Timebase = 25.0 ms/div
Memory 4 = 100.0 mvolts/div
Timebase = 25.0 ms/div

Mem 4 Parameters
Rise Time = 1.28215 ms
Preshoot = 262.5 mvolts
P-P Volts = 675.1 mvolts
Freq. = 194.670 Hz
Width = 1.53095 ms
RMS Volts = 207.1 mvolts

Trace: Brass Specimen Air Core
Delay = 0.00000 s
Offset = 0.00000 s

Filtered Input
Four Trace Overlay in Time-Space
Page: 152
Ch. 1 = 200.0 mvolts/div  
Ch. 2 = 1.000 volts/div  
Timebase = 50.000 ms/div

Top Trace: Brass Specimen  
Bottom Trace: Brass Specimen

<table>
<thead>
<tr>
<th>Trace</th>
<th>Parameters</th>
<th>Value</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Top</td>
<td>Freq.</td>
<td>222.341 Hz</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bottom</td>
<td>Period</td>
<td>4.49760 ms</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Top</td>
<td>Rise Time</td>
<td>795.111 us</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bottom</td>
<td>- Width</td>
<td>2.46502 ms</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Top</td>
<td>Fall Time</td>
<td>770.165 us</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bottom</td>
<td>+ Width</td>
<td>2.03258 ms</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Top</td>
<td>P-P Volts</td>
<td>2.687 volts</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bottom</td>
<td>Preshoot</td>
<td>0.000 volts</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Top</td>
<td>RMS Volts</td>
<td>1.143 volts</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bottom</td>
<td>Overshoot</td>
<td>0.000 volts</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Top</td>
<td>Offset</td>
<td>0.000 volts</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bottom</td>
<td>Delay</td>
<td>0.00000 s</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Top</td>
<td>Dutycycle</td>
<td>45.19 %</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Bottom</td>
<td>Filtered Input</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Top</td>
<td>Time-Space</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bottom</td>
<td>Un-filtered Input</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Page: 153
X = 218.5 Hz  
Ya = -43.404 dBVrms  
POWER SPEC1  
-20.0 dB  

Yb = -28.91 dBVrms  
POWER SPEC2  
-20.0 dB  

Top Trace:  Brass Specimen  Air Core  Filtrered Input  Frequency-Space  
Bottom Trace:  Brass Specimen  Air Core  Un-filtered Input  

Page: 154
Timebase = 25.0 ms/div  Delay = 0.00000 s
Memory 1 = 100.0 mvolts/div  Offset = 0.000 volts
Timebase = 25.0 ms/div  Delay = 0.00000 s
Memory 2 = 100.0 mvolts/div  Offset = 0.000 volts
Timebase = 25.0 ms/div  Delay = 0.00000 s
Memory 3 = 100.0 mvolts/div  Offset = 0.000 volts
Timebase = 25.0 ms/div  Delay = 0.00000 s
Memory 4 = 100.0 mvolts/div  Offset = 0.000 volts
Delay = 0.00000 s
Mem 4 Parameters
Rise Time = 1.99507 ms + Width = 2.34613 ms - Width = 2.73426 ms
Fall Time = 1.98890 ms Preshoot = 0.000 volts Overshoot = 0.000 volts
P-P Volts = 650.1 mvolts RMS Volts = 192.8 mvolts Dutycycle = 46.18 %
Trace: Brass Specimen Sand Core Filtered Input
Four Trace Overlay in Time-Space
Ch. 1 = 200.0 mvolts/div
Ch. 2 = 1.000 volts/div
Timebase = 25.0 ms/div
Offset = 0.000 volts
Delay = 0.00000 s
Freq. = 219.898 Hz
Period = 4.54757 ms
Rise Time = 594.167 us
+ Width = 1.76206 ms
- Width = 2.78550 ms
Fall Time = 309.859 us
Preshoot = 0.000 volts
Overshoot = 968.7 mvolts
P-P Volts = 2.687 volts
RMS Volts = 1.233 volts
Dutycycle = 38.74 %
<table>
<thead>
<tr>
<th>Frequency</th>
<th>Top Trace: Brass Specimen</th>
<th>Sand Core</th>
<th>Filtered Input</th>
<th>Frequency-Space</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 Hz</td>
<td>2Avg 0%0vlp Hann 0v1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 Hz</td>
<td>2Avg 0%0vlp Hann 0v2</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

X = 217.5 Hz
Y_a = -47.721 dBVrms

Y_b = -32.984 dBVrms

Page: 157
Timebase = 25.0 ms/div
Memory 1 = 100.0 mvolts/div
Timebase = 25.0 ms/div
Memory 2 = 100.0 mvolts/div
Timebase = 25.0 ms/div
Memory 3 = 100.0 mvolts/div
Timebase = 25.0 ms/div
Memory 4 = 100.0 mvolts/div
Mem 1 Parameters
Rise Time = 2.05248 ms
Fall Time = 1.73123 ms
P-P Volts = 650.1 mvolts
Freq. = 193.939 Hz
+ Width = 2.47727 ms
Preshoot = 0.000 volts
RMS Volts = 194.2 mvolts
Delay = 0.00000 s
Offset = 0.000 volts
Delay = 0.00000 s
Offset = 0.000 volts
Delay = 0.00000 s
Offset = 0.000 volts
Delay = 0.00000 s
Offset = 0.000 volts
Delay = 5.15625 ms
Period = 5.15625 ms
Overshoot = 0.000 volts
Dutycycle = 48.04 %

Trace: Brass Specimen Lead Shot Core

Four Trace Overlay in Time-Space
\[ X = 195 \text{ Hz} \]
\[ Y_a = -52.658 \text{ dBVrms} \]

**POWER SPEC1**

1Avg 0\%Ovlp Hann

\[ -30.0 \]

<table>
<thead>
<tr>
<th>dB</th>
</tr>
</thead>
<tbody>
<tr>
<td>rms V^2</td>
</tr>
</tbody>
</table>

\[ -110 \]

**FXd Y 0 Hz**

BRASS-SHOT 500

Yb = -38.112 dBVrms

**POWER SPEC2**

1Avg 0\%Ovlp Hann

\[ -30.0 \]

<table>
<thead>
<tr>
<th>dB</th>
</tr>
</thead>
<tbody>
<tr>
<td>rms V^2</td>
</tr>
</tbody>
</table>

\[ -110 \]

**FXd Y 0 Hz**

BRASS-SHOT 500

Top Trace:
Brass Specimen
Brass Specimen
Filtered Input
Frequency-Space

Bottom Trace:
Brass Specimen
Lead Shot Core
Lead Shot Core
Un-filtered Input

Page: 160
Ch. 1 = 200.0 mvolts/div
Ch. 2 = 1.000 volts/div
Timebase = 25.0 ms/div

Ch. 2 Parameters
Freq. = 221.134 Hz
Period = 4.52215 ms
Rise Time = 616.296 us
+ Width = 2.45667 ms
Fall Time = 720.387 us
- Width = 2.06549 ms
P-P Volts = 2.750 volts
Preshoot = 0.000 volts
Overshoot = 0.000 volts
RMS Volts = 1.239 volts
Dutycycle = 54.32 %

Top Trace: Brass Specimen Oil Core
Bottom Trace: Brass Specimen Oil Core
Timebase = 25.0 ms/div
Memory 1 = 100.0 mvolts/div
Timebase = 25.0 ms/div
Memory 2 = 100.0 mvolts/div
Timebase = 25.0 ms/div
Memory 3 = 100.0 mvolts/div
Timebase = 25.0 ms/div
Memory 4 = 100.0 mvolts/div
Mem 4 Parameters
Rise Time = 2.05886 ms
Fall Time = 2.15113 ms
P-P Volts = 675.1 mvolts
Freq. = 193.070 Hz
Delay = 0.00000 s
Offset = 0.00000 s
Delay = 0.00000 s
Offset = 0.00000 s
Delay = 0.00000 s
Offset = 0.00000 s
Delay = 0.00000 s
Offset = 0.00000 s
Period = 5.17947 ms
- Width = 2.71490 ms
Overshoot = 0.000 volts
Dutycycle = 47.58 %

Trace:
Brass Specimen
Sand/Oil Core

Four Trace Overlay in Time-Space
<table>
<thead>
<tr>
<th>Ch. 1</th>
<th>200.0 mvolts/div</th>
<th>Offset = 0.000 volts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ch. 2</td>
<td>1.000 volts/div</td>
<td>Offset = 0.000 volts</td>
</tr>
<tr>
<td>Timebase</td>
<td>25.0 ms/div</td>
<td>Delay = 0.00000 s</td>
</tr>
<tr>
<td>Ch. 2 Parameters</td>
<td>Freq. = 214.655 Hz</td>
<td>Period = 4.65864 ms</td>
</tr>
<tr>
<td></td>
<td>+ Width = 1.68304 ms</td>
<td>- Width = 2.97561 ms</td>
</tr>
<tr>
<td>Rise Time</td>
<td>519.059 us</td>
<td>Preshoot = 0.000 volts</td>
</tr>
<tr>
<td>Fall Time</td>
<td>341.923 us</td>
<td>Overshoot = 1.062 volts</td>
</tr>
<tr>
<td>P-P Volts</td>
<td>2.718 volts</td>
<td>Dutycycle = 36.12 %</td>
</tr>
<tr>
<td>RMS Volts</td>
<td>1.156 volts</td>
<td></td>
</tr>
</tbody>
</table>

Top Trace: Brass Specimen  Sand/Oil Core  Filtered Input  Time-Space
Bottom Trace: Brass Specimen  Sand/Oil Core  Un-filtered Input

Page: 165
X = 217.5 Hz
Ya = -50.735 dBVrms

POWER SPEC1
1Avg 0% Ovlp Hann 0v1

-20.0 dB

Fxd Y 0 Hz
Yb = -36.24 dBVrms

POWER SPEC2
1Avg 0% Ovlp Hann

-20.0 dB

Top Trace: Brass Specimen Sand/Oil Core Filtered Input Frequency-Space
Bottom Trace: Brass Specimen Sand/Oil Core Un-filtered Input
X = 195 Hz
Ya = -52 dBVrms
POWER SPEC1
-30.0

Top Trace:
Brass Specimen
Lead Shot/Oil Core
Filtered Input
Frequency-Space

Bottom Trace:
Brass Specimen
Lead Shot/Oil Core
Un-filtered Input

Brass Specimen Lead Shot/Oil Core Filtered Input

POWER SPEC2
-30.0

Freq Y 0 Hz
Yb = -37.85 dBVrms
BRASS-SHOT-OIL 500
Timebase = 25.0 ms/div
Memory 1 = 125.0 mvolts/div
Timebase = 25.0 ms/div
Memory 2 = 125.0 mvolts/div
Timebase = 25.0 ms/div
Memory 3 = 125.0 mvolts/div
Timebase = 25.0 ms/div
Memory 4 = 125.0 mvolts/div

Mem 1 Parameters
Rise Time = 2.01334 ms  
Fall Time = 1.92471 ms  
P-P Volts = 687.6 mvolts
Freq. = 215.294 Hz
+ Width = 2.10413 ms
Preshoot = 0.000 volts
RMS Volts = 192.8 mvolts

Delay = 0.00000 s
Offset = 0.00000 s
Delay = 0.00000 s
Offset = 0.00000 s
Delay = 0.00000 s
Offset = 0.00000 s
Delay = 0.00000 s
Offset = 0.00000 s

Period = 4.64481 ms
- Width = 2.54068 ms
Overshoot = 0.000 volts
Dutycycle = 45.30 %

Trace: Copper Specimen Air Core

Four Trace Overlay in Time-Space
Page: 170
Ch. 1 = 200.0 mvolts/div
Ch. 2 = 1.000 volts/div
Timebase = 25.0 ms/div

Ch. 2 Parameters
Freq. = 251.768 Hz
Period = 3.97192 ms
Rise Time = 799.568 us
+ Width = 1.52434 ms
- Width = 2.44758 ms
Fall Time = 796.192 us
Preshoot = 0.000 volts
Overshoot = 0.000 volts
P-P Volts = 2.750 volts
RMS Volts = 1.111 volts
Dutycycle = 38.37 %

Top Trace:
Copper Specimen
Air Core
Filtrered Input
Time-Space

Bottom Trace:
Copper Specimen
Air Core
Un-filtered Input
\[ x = 216.87 \text{ Hz} \]
\[ y_a = -50.962 \text{ dBVrms} \]

**POWER SPEC1**

-20.0 dB

**POWER SPEC2**

-20.0 dB

Top Trace: Copper Specimen

Bottom Trace: Copper Specimen

Copper Specimen

Air Core

Filtered Input

Un-filtered Input

Frequency-Space

Page: 172
Timebase = 25.0 ms/div
Memory 1 = 125.0 mvolts/div
Timebase = 25.0 ms/div
Memory 2 = 125.0 mvolts/div
Timebase = 25.0 ms/div
Memory 3 = 125.0 mvolts/div
Timebase = 25.0 ms/div
Memory 4 = 125.0 mvolts/div

Mem 3 Parameters
Freq. = 214.932 Hz
Rise Time = 2.06776 ms
Fall Time = 1.85868 ms
P-P Volts = 687.5 mvolts

Delay = 0.00000 s
Offset = 0.000 volts
Rise Width = 2.06062 ms
Preshoot = 0.000 volts
RMS Volts = 196.6 mvolts
Period = 4.65263 ms
Delay = 0.00000 s
- Width = 2.59200 ms
Preshoot = 0.000 volts
Overshoot = 0.000 volts
Dutycycle = 44.28 %

Trace: Copper Specimen Sand Core

Four Trace Overlay in Time-Space

Page: 173
$X = 218.75 \text{ Hz}$

$Y_a = -54.763 \text{ dBVrms}$

**Power Spectral Density 1**

$Y_b = -40.285 \text{ dBVrms}$

**Power Spectral Density 2**

- Top Trace: Copper Specimen, Sand Core, Filtered Input
- Bottom Trace: Copper Specimen, Sand Core, Un-filtered Input

Frequency-Space Page: 175
Timebase = 25.0 ms/div
Memory 1 = 125.0 mvolts/div
Timebase = 25.0 ms/div
Memory 2 = 125.0 mvolts/div
Timebase = 25.0 ms/div
Memory 3 = 125.0 mvolts/div
Timebase = 25.0 ms/div
Memory 4 = 125.0 mvolts/div
Timebase = 25.0 ms/div
Mem 4 Parameters
Freq. = 203.193 Hz
Rise Time = 1.70107 ms
Fall Time = 1.85618 ms
P-P Volts = 722.7 mvolts
Trace: Copper Specimen Oil Core

Delay = 0.00000 s
Offset = 0.000 volts
Delay = 0.00000 s
Offset = 0.000 volts
Delay = 0.00000 s
Offset = 0.000 volts
Delay = 0.00000 s
Offset = 0.000 volts
Delay = 0.00000 s
Offset = 0.000 volts
Delay = 4.92143 ms
Period = 4.92143 ms
- Width = 2.81643 ms
Overshoot = 0.000 volts
Dutycycle = 42.77 %

Filtrered Input

Four Trace Overlay in Time-Space
Ch. 1 = 200.0 mvolts/div
Ch. 2 = 1.000 volts/div
Timebase = 25.0 ms/div

Ch. 2 Parameters
Freq. = 241.012 Hz
Period = 4.14917 ms
Rise Time = 714.150 us
+ Width = 1.66895 ms
Fall Time = 404.687 us
Preshoot = 0.000 volts
P-P Volts = 2.687 volts

Bottom Trace: Copper Specimen Oil Core Un-filtered Input
Timebase = 25.0 ms/div
Memory 1 = 125.0 mvolts/div
Timebase = 25.0 ms/div
Memory 2 = 125.0 mvolts/div
Timebase = 25.0 ms/div
Memory 3 = 125.0 mvolts/div
Timebase = 25.0 ms/div
Memory 4 = 125.0 mvolts/div
Timebase = 25.0 ms/div
Mem 1 Parameters

Rise Time = 1.98392 ms  + Width = 2.13337 ms
Fall Time = 2.00847 ms  Preshoot = 0.000 volts
P-P Volts = 711.0 mvolts  RMS Volts = 201.4 mvolts

Delay = 0.00000 s  Offset = 0.000 volts
Delay = 0.00000 s  Offset = 0.000 volts
Delay = 0.00000 s  Offset = 0.000 volts
Delay = 0.00000 s  Offset = 0.000 volts
Delay = 0.00000 s  Offset = 0.000 volts
Delay = 0.00000 s  Offset = 0.000 volts
Delay = 0.00000 s  Offset = 0.000 volts
Delay = 0.00000 s  Offset = 0.000 volts

Freq. = 208.535 Hz  Period = 4.79536 ms
- Width = 2.66199 ms  Overshoot = 0.000 volts
Dutycycle = 44.48 %

Trace: Copper Specimen  Sand/Oil Core

Four Trace Overlay in Time-Space

Page: 182
Ch. 1 = 200.0 mvolts/div
Ch. 2 = 1.000 volts/div
Timebase = 25.0 ms/div

Ch. 2 Parameters
Freq. = 226.869 Hz
Period = 4.40783 ms
Preshoot = 0.000 volts
Overshoot = 0.000 volts
Dutycycle = 45.00 %

Top Trace: Copper Specimen Sand/Oil Core Filtered Input Time-Space
Bottom Trace: Copper Specimen Sand/Oil Core Un-filtered Input

Page: 183
X = 218.75 Hz
Ya = -49.227 dBVrms

POWER SPEC1
-30.0 dB

rms
\(v^2\)

Fxd Y 0 Hz COPPER-SAND-OIL 500
Yb = -34.959 dBVrms

POWER SPEC2
-30.0 dB

rms
\(v^2\)

Fxd Y 0 Hz COPPER-SAND-OIL 500

Top Trace: Copper Specimen Sand/Oil Core Filtered Input Frequency-Space
Bottom Trace: Copper Specimen Sand/Oil Core Un-filtered Input

Page: 184
Timebase = 25.0 ms/div
Memory 1 = 100.0 mvolts/div
Timebase = 25.0 ms/div
Memory 2 = 100.0 mvolts/div
Timebase = 25.0 ms/div
Memory 3 = 100.0 mvolts/div
Timebase = 25.0 ms/div
Memory 4 = 100.0 mvolts/div
Mem 4 Parameters
Rise Time = 1.28785 ms
Fall Time = 1.62531 ms
P-P Volts = 625.1 mvolts

Trace:
Copper Specimen
Lead Shot/Oil Core
Filtered Input

Four Trace Overlay in Time-Space

Page: 185
Ch. 1 = 200.0 mvolts/div
Ch. 2 = 1.000 volts/div
Timebase = 25.0 ms/div

Ch. 2 Parameters
Freq. = 225.917 Hz
Period = 4.42641 ms
Rise Time = 529.482 us
+ Width = 2.48452 ms
- Width = 1.94188 ms
Fall Time = 482.251 us
Preshoot = 1.031 volts
Overshoot = 0.000 volts
P-P Volts = 2.718 volts
RMS Volts = 1.174 volts
Dutycycle = 56.12 %

Top Trace: Copper Specimen Lead Shot/Oil Core Filtrered Input Time-Space
Bottom Trace: Copper Specimen Lead Shot/Oil Core Un-filtered Input
X = 218.75 Hz
Ya = -50.613 dBVrms

POWER SPEC1

-30.0 dB

Fxd Y 0 Hz COPPER-SHOT-OIL 500

Yb = -36.547 dBVrms

POWER SPEC2

-30.0 dB

Fxd Y 0 Hz COPPER-SHOT-OIL 500

Top Trace:  Copper Specimen  Lead Shot/Oil Core  Filtered Input  Frequency-Space
Bottom Trace:  Copper Specimen  Lead Shot/Oil Core  Un-filtered Input

Page: 187
Timebase = 25.0 ms/div
Memory 1 = 100.0 mvolts/div

Timebase = 25.0 ms/div
Memory 2 = 100.0 mvolts/div

Timebase = 25.0 ms/div
Memory 3 = 100.0 mvolts/div

Timebase = 25.0 ms/div
Memory 4 = 100.0 mvolts/div

Mem 1 Parameters
Rise Time = -10.7782 ms
 Fall Time = 28.8570 ms
P-P Volts = 662.6 mvolts

Freq. = 76.9250 Hz
+ Width = 10.6934 ms
Preshoot = 250.0 mvolts
RMS Volts = 176.1 mvolts

Delay = 0.00000 s
Offset = 0.00000 s

Delay = 0.00000 s
Offset = 0.00000 s

Delay = 0.00000 s
Offset = 0.00000 s

Delay = 0.00000 s
Offset = 0.00000 s

Period = 12.9997 ms
Overshoot = 82.25 %
Dutycycle = 82.25 %

Trace: Ceramic Specimen
Air Core

Filtered Input

Four Trace Overlay in Time-Space
X = 38.75 Hz
Ya = -53.42 dBVrms

POWER SPEC1

-30.0 dB

rms V^2

-110

Fxd Y 0 Hz

CERAMIC-AIR

0 500

1Avg 0%0vlp Hann

Top Trace: Ceramic Specimen Air Core Filtered Input Frequency-Space

Bottom Trace: Ceramic Specimen Air Core Un-filtered Input

Yb = -38.062 dBVrms

POWER SPEC2

-30.0 dB

rms V^2

-110

Fxd Y 0 Hz

CERAMIC-AIR

0 500

1Avg 0%0vlp Hann
Timebase = 25.0 ms/div
Memory 1 = 100.0 mvolts/div
Timebase = 25.0 ms/div
Memory 2 = 100.0 mvolts/div
Timebase = 25.0 ms/div
Memory 3 = 100.0 mvolts/div
Timebase = 25.0 ms/div
Memory 4 = 100.0 mvolts/div
Timebase = 25.0 ms/div

Freq. = 76.4814 Hz
Period = 13.0751 ms
Delay = 0.00000 s
Offset = 0.00000 s

Rise Time = 7.52663 ms
Width = 7.60426 ms
Delay = 0.00000 s
Offset = 0.00000 s

Fall Time = 17.7435 ms
Preshoot = 0.000 volts
Delay = 0.00000 s
Offset = 0.00000 s

P-P Volts = 675.1 mvolts
RMS Volts = 184.7 mvolts
Delay = 0.00000 s
Offset = 0.00000 s

Trace: Ceramic Specimen Sand Core

Filtered Input

Four Trace Overlay in Time-Space
Ch. 1 = 200.0 mvolts/div
Ch. 2 = 1.000 volts/div
Timebase = 25.0 ms/div

Ch. 2 Parameters
Freq. = 77.2727 Hz
Preshoot = 31.25 mvolts
RMS Volts = 872.5 mvolts

Top Trace: Ceramic Specimen  Sand Core
Bottom Trace: Ceramic Specimen  Sand Core

Offset = 0.000 volts
Delay = 0.00000 s

Page: 192
X = 38.75 Hz
Ya = -56.541 dBVrms

POWER SPEC1
-50.0
dB

1Avg 0%Ovlp Hann 0v1

Yb = -40.835 dBVrms
POWER SPEC2
-30.0
dB

Top Trace: Ceramic Specimen Sand Core Filtered Input Frequency-Space
Bottom Trace: Ceramic Specimen Sand Core Un-filtered Input
Page: 193
Timebase = 25.0 ms/div
Memory 1 = 100.0 mvolts/div
Timebase = 25.0 ms/div
Memory 2 = 100.0 mvolts/div
Timebase = 25.0 ms/div
Memory 3 = 100.0 mvolts/div
Timebase = 25.0 ms/div
Memory 4 = 100.0 mvolts/div
Mem 1 Parameters
Rise Time = 3.78681 ms
Fall Time = 3.01284 ms
P-P Volts = 675.1 mvolts

Freq. = 69.1333 Hz
+ Width = 4.29836 ms
Preshoot = 250.0 mvolts
RMS Volts = 204.1 mvolts

Offset = 0.00000 s
Delay = 0.00000 s
Offset = 0.00000 s
Delay = 0.00000 s
Offset = 0.00000 s
Delay = 0.00000 s
Offset = 0.00000 s
Delay = 0.00000 s

Period = 14.4648 ms
- Width = 10.1664 ms
Overshoot = 0.000 volts
Dutycycle = 29.71 %
X = 41.25 Hz
Y_a = -48.404 dBVrms

POWER SPEC1

-20.0 dB

rms v^2

-180

0 Hz CERAMIC-SHOT

POWER SPEC2

-30.0 dB

rms v^2

-110

Fxd Y 0 Hz CERAMIC-SHOT

Top Trace: Ceramic Specimen, Lead Shot Core, Filtered Input
Bottom Trace: Ceramic Specimen, Lead Shot Core, Un-filtered Input

Frequency-Space

Page: 196
Ch. 1 = 200.0 mvolts/div
Ch. 2 = 1.000 volts/div
Timebase = 25.0 ms/div

Ch. 2 Parameters
Freq. = 273.020 Hz
Period = 3.66273 ms
Delay = 0.00000 s

Rise Time = 239.982 us
Preshoot = 0.000 volts
Offset = 0.000 volts

Fall Time = 242.839 us
Overshoot = 1.062 volts
Delay = 0.00000 s

P-P Volts = 2.656 volts
RMS Volts = 1.182 volts
Dutycycle = 67.28 %

Top Trace: Ceramic Specimen Oil Core Filtered Input Time-Space
Bottom Trace: Ceramic Specimen Oil Core Un-filtered Input

Page: 198
X=40 Hz
Ya=-58.295 dBVrms

POWER SPEC1

-50.0

1Avg 0%Ovlp Hann 0v1

0 Hz

CERAMIC-OIL

-150

Yb=-43.059 dBVrms
POWER SPEC2

-30.0

1Avg 0%Ovlp Hann 0v2

0 Hz

CERAMIC-OIL

-110

Fxd Y 0 Hz

Top Trace: Ceramic Specimen Oil Core Filtered Input Frequency-Space
Bottom Trace: Ceramic Specimen Oil Core Un-filtered Input Page: 199
Ch. 1 = 50.00 mvolts/div  Offset = 0.000 volts
Timebase = 25.0 ms/div  Delay = 0.00000 s
Memory 1 = 50.00 mvolts/div Offset = 0.000 volts
Timebase = 25.0 ms/div Delay = 0.00000 s
Memory 2 = 50.00 mvolts/div Offset = 0.000 volts
Timebase = 25.0 ms/div Delay = 0.00000 s
Memory 3 = 50.00 mvolts/div Offset = 0.000 volts
Timebase = 25.0 ms/div Delay = 0.00000 s
Memory 4 = 50.00 mvolts/div Offset = 0.000 volts
Timebase = 25.0 ms/div Delay = 0.00000 s

Ch. 1 Parameters Freq. = 260.325 Hz
Rise Time = 11.7939 ms + Width = 2.02051 ms
Fall Time = 319.765 us Preshoot = 112.5 mvolts
P-P Volts = 300.0 mvolts Overshoot = 112.5 mvolts
Trace: Ceramic Specimen  Dutycycle = 52.59 %
Sand/Oil Core

Four Trace Overlay in Time-Space

Page: 200
Ch. 1 = 200.0 mvolts/div  
Ch. 2 = 1.000 volts/div  
Timebase = 25.0 ms/div  
Ch. 2 Parameters  
Freq. = 80.5544 Hz  
Rise Time = 251.832 us  
Fall Time = 329.007 us  
P-P Volts = 2.656 volts  

Offset = 0.000 volts  
Timebase = 25.0 ms/div  
Rise Time = 251.832 us  
Fall Time = 329.007 us  
P-P Volts = 2.656 volts  

Offset = 0.000 volts  
Delay = 0.00000 s  
Period = 12.4140 ms  
- Width = 363.053 us  
Overshoot = 0.000 volts  
Dutycycle = 97.07 %  

Top Trace: Ceramic Specimen  
Bottom Trace: Ceramic Specimen  
Filtered Input  
Un-filtered Input  
Page: 201
X = 40 Hz
Y = -57.789 dBVRms

POWER SPEC1

Y = -42.803 dBVRms

POWER SPEC2

Top Trace: Ceramic Specimen, Sand/Oil Core, Filtered Input, Frequency-Space
Bottom Trace: Ceramic Specimen, Sand/Oil Core, Un-filtered Input
Timebase = 25.0 ms/div
Memory 1 = 75.00 mvolts/div
Timebase = 25.0 ms/div
Memory 2 = 75.00 mvolts/div
Timebase = 25.0 ms/div
Memory 3 = 75.00 mvolts/div
Timebase = 25.0 ms/div
Memory 4 = 75.00 mvolts/div

Mem 1 Parameters
Freq. = 78.6676 Hz
Rise Time = 4.64185 ms
Fall Time = 1.03479 ms
P-P Volts = 424.2 mvolts

Filtered Input
Four Trace Overlay in Time-Space
Page: 203
Top Trace: Ceramic Specimen      Lead Shot/Oil Core      Filtered Input    
Bottom Trace: Ceramic Specimen    Lead Shot/Oil Core     Un-filtered Input  
Page: 204
X = 40 Hz
Ya = -59.612 dBVrms

POWER SPEC1
-50.0 dB

1Avg 0% overlap Hann

Yb = -44.686 dBVrms

POWER SPEC2
-30.0 dB

1Avg 0% overlap Hann

Fxd Y

Top Trace: Ceramic Specimen
Bottom Trace: Ceramic Specimen

Lead Shot/Oil Core

Filtered Input

Un-filtered Input

Frequency-Space

Page: 205
Timebase = 25.0 ms/div
Memory 1 = 100.0 mvolts/div
Timebase = 25.0 ms/div
Memory 2 = 100.0 mvolts/div
Timebase = 25.0 ms/div
Memory 3 = 100.0 mvolts/div
Timebase = 25.0 ms/div
Memory 4 = 100.0 mvolts/div
Mem 1 Parameters
Rise Time = 37.1352 ms
Fall Time = -36.7623 ms
P-P Volts = 700.1 mvolts
Freq. = 139.718 Hz
+ Width = 455.826 us
- Width = 6.70147 ms
Preshoot = 275.0 mvolts
RMS Volts = 121.7 mvolts
Overshoot = 0.000 volts
Dutycycle = 6.368 %
Trace:
Granite Specimen
Air Core
Filttered Input
Four Trace Overlay in Time-Space
Page: 206
Ch. 1 = 200.0 mvolts/div
Ch. 2 = 1.000 volts/div
Timebase = 25.0 ms/div

Ch. 2 Parameters
Freq. = 333.660 Hz
Period = 2.99706 ms

Rise Time = 404.687 us
Width = 1.13797 ms
- Width = 1.85909 ms

Fall Time = 783.070 ms
Preshoot = 0.000 volts
Overshoot = 0.000 volts

P-P Volts = 2.687 volts
RMS Volts = 1.217 volts

Dutycycle = 37.96 %

Top Trace: Granite Specimen Air Core Filtered Input Time-Space
Bottom Trace: Granite Specimen Air Core Un-filtered Input

Page: 207
Timebase = 25.0 ms/div
Memory 1 = 100.0 mvolts/div
Timebase = 25.0 ms/div
Memory 2 = 100.0 mvolts/div
Timebase = 25.0 ms/div
Memory 3 = 100.0 mvolts/div
Timebase = 25.0 ms/div
Memory 4 = 100.0 mvolts/div
Timebase = 25.0 ms/div
Mem 3 Parameters
Rise Time = -2.86227 ms
Fall Time = 4.99932 ms
P-P Volts = 425.0 mvolts
Delay = 0.00000 s
Offset = 0.00000 s
Delay = 0.00000 s
Offset = 0.00000 s
Delay = 0.00000 s
Offset = 0.00000 s
Delay = 0.00000 s
Offset = 0.00000 s
Delay = 0.00000 s
Offset = 0.00000 s
Delay = 0.00000 s
Offset = 0.00000 s
Delay = 0.00000 s
Offset = 0.00000 s
Freq. = 179.370 Hz
Width = 2.44944 ms
Preshoot = 0.000 volts
Overshoot = 0.000 volts
RMS Volts = 127.2 mvolts
Dutycycle = 43.93 %

Trace: Granite Specimen Sand Core Filtered Input
Four Trace Overlay in Time-Space
Ch. 1 = 200.0 mvolts/div
Ch. 2 = 1.000 volts/div
Timebase = 25.0 ms/div
Ch. 2 Parameters
Freq. = 249.832 Hz
Period = 4.00269 ms
Rise Time = 400.017 us
Width = 2.00269 ms
Fall Time = 400.017 us
Preshoot = 0.000 volts
P-P Volts = 2.937 volts
RMS Volts = 1.458 volts
Offset = 0.000 volts
Delay = 0.00000 s
Overshoot = 0.000 volts
Dutycycle = 50.03%

Top Trace: Granite Specimen Sand Core Filtered Input Time-Space
Bottom Trace: Granite Specimen Sand Core Un-filtered Input

Page: 210
X = 121.25 Hz
Y_a = -64.056 dBVrms

POWER SPEC1
-30.0 dB

GRANITE-SAND

POWER SPEC2
-30.0 dB

Granite Specimen
Granite Specimen
Sand Core
Sand Core
Filtered Input
Un-filtered Input
Frequency-Space
**Trace: Granite Specimen**  
Rise Time = 1.43359 ms  
Fall Time = 6.42154 ms  
P-P Volts = 425.0 mvolts  
Freq. = 233.646 Hz  
Delay = 0.00000 s  
Offset = 0.00000 s  
Period = 4.27998 ms  
Dutycycle = 56.85%  

**Trace: Lead Shot Core**  
Rise Time = 1.43339 ms  
Fall Time = 6.42154 ms  
P-P Volts = 425.0 mvolts  
Freq. = 233.646 Hz  
Delay = 0.00000 s  
Offset = 0.00000 s  
Period = 4.27998 ms  
Dutycycle = 56.85%  

**Filtered Input**  
Trace:  
Rise Time = 1.43359 ms  
Fall Time = 6.42154 ms  
P-P Volts = 425.0 mvolts  
Freq. = 233.646 Hz  
Delay = 0.00000 s  
Offset = 0.00000 s  
Period = 4.27998 ms  
Dutycycle = 56.85%  

Four Trace Overlay in Time-Space
Ch. 1 = 200.0 mvolts/div
Ch. 2 = 1.000 volts/div
Timebase = 25.0 ms/div
Ch. 2 Parameters
Freq. = 238.799 Hz
Period = 4.18763 ms
Rise Time = 487.294 us
+ Width = 1.64732 ms
- Width = 2.54031 ms
Fall Time = 252.165 us
Preshoot = 0.000 volts
Overshoot = 1.062 volts
P-P Volts = 2.875 volts
RMS Volts = 1.290 volts
Dutycycle = 39.33%

Top Trace: Granite Specimen Lead Shot Core Filtrered Input Time-Space
Bottom Trace: Granite Specimen Lead Shot Core Un-filtered Input
Timebase = 25.0 ms/div
Memory 1 = 100.0 mvolts/div
Timebase = 25.0 ms/div
Memory 2 = 100.0 mvolts/div
Timebase = 25.0 ms/div
Memory 3 = 100.0 mvolts/div
Timebase = 25.0 ms/div
Memory 4 = 100.0 mvolts/div

Mem 2 Parameters
Rise Time = 794.414 us
Fall Time = 809.003 us
P-P Volts = 500.0 mvolts

Freq. = 237.929 Hz
+ Width = 2.56467 ms
Preshoot = 200.0 mvolts
RMS Volts = 164.5 mvolts

Delay = 0.00000 s
Offset = 0.00000 s
Delay = 0.00000 s
Offset = 0.00000 s
Delay = 0.00000 s
Offset = 0.00000 s
Delay = 0.00000 s
Offset = 0.00000 s
Period = 4.20294 ms
- Width = 1.63827 ms
Overshoot = 0.000 volts
Dutycycle = 61.02 %

Trace: Granite Specimen Oil Core

Four Trace Overlay in Time-Space
Ch. 1 = 200.0 mvolts/div
Ch. 2 = 1.000 volts/div
Timebase = 25.0 ms/div
Ch. 2 Parameters
Freq. = 250.000 Hz
Period = 4.00000 ms
Rise Time = 408.898 us
- Width = 2.00000 ms
Fall Time = 408.898 us
Preshoot = 0.000 volts
P-P Volts = 2.875 volts
RMS Volts = 1.398 volts
Dutycycle = 50.00%
Offset = 0.000 volts
Delay = 0.00000 s

Top Trace: Granite Specimen Oil Core Filtered Input Time-Space
Bottom Trace: Granite Specimen Oil Core Un-filtered Input

Page: 216
X = 121.25 Hz
Ya = -65.182 dB

POWER SPEC1

-30.0 dB

rms V^2

-110

Fx d Y 0 Hz

GRANITE-OIL

POWER SPEC2

-30.0 dB

rms V^2

-110

Fx d Y 0 Hz

GRANITE-OIL

Top Trace:
Granite Specimen
Oil Core
Filtrered Input
Frequency-Space

Bottom Trace:
Granite Specimen
Oil Core
Un-filtered Input
Page: 217
Ch. 1 = 200.0 mvolts/div
Ch. 2 = 1.000 volts/div
Timebase = 25.0 ms/div
Ch. 2 Parameters
Freq. = 250.000 Hz
Period = 4.00000 ms
Delay = 0.00000 s
Rise Time = 404.427 us
Width = 2.00556 ms
- Width = 1.99444 ms
Fall Time = 404.427 us
Preshoot = 0.000 volts
Overshoot = 0.000 volts
P-P Volts = 2.843 volts
RMS Volts = 1.398 volts
Dutycycle = 50.13 %

Top Trace: Granite Specimen  Sand/Oil Core  Filtered Input  Time-Space
Bottom Trace: Granite Specimen  Sand/Oil Core  Un-filtered Input
X = 121.25 Hz
Ya = -68.448 dBVrms

POWER SPEC1

-40.0

dB

rms

V^2

-120

Fxd Y 0 Hz

GRANITE-SAND-OIL

500

1Avg 0%Ovlp Hann

0v1

Yb = -55.19 dBVrms

POWER SPEC2

-40.0

dB

rms

V^2

-120

Fxd Y 0 Hz

GRANITE-SAND-OIL

500

1Avg 0%Ovlp Hann

0v2

Granite Specimen

Sand/Oil Core

Filtered Input

Frequency-Space

Granite Specimen

Sand/Oil Core

Un-filtered Input

Page: 220
Timebase = 25.0 ms/div
Memory 1 = 100.0 mvolts/div
Timebase = 25.0 ms/div
Memory 2 = 100.0 mvolts/div
Timebase = 25.0 ms/div
Memory 3 = 100.0 mvolts/div
Timebase = 25.0 ms/div
Memory 4 = 100.0 mvolts/div
Mem 4 Parameters
Rise Time = 1.27027 ms
Fall Time = 5.43169 ms
P-P Volts = 475.0 mvolts
Freq. = 250.159 Hz
+ Width = 2.15911 ms
Preshoot = 0.000 volts
RMS Volts = 159.5 mvolts
Delay = 0.00000 s
Offset = 0.00000 s
Delay = 0.00000 s
Offset = 0.00000 s
Delay = 0.00000 s
Offset = 0.00000 s
Delay = 3.99746 ms
Period = 1.83836 ms
Overshoot = 0.000 volts
Dutycycle = 54.01 %
Trace: Granite Specimen  Lead Shot/Oil Core  Filtered Input
Four Trace Overlay in Time-Space
Page: 221
Ch. 1 = 200.0 mvolts/div
Ch. 2 = 1.000 volts/div
Timebase = 25.0 ms/div
Ch. 2 Parameters
Rise Time = 404.404 us
Fall Time = 810.203 us
P-P Volts = 2.875 volts
Freq. = 239.842 Hz
+ Width = 2.00000 ms
- Width = 2.16941 ms
Preshoot = 0.000 volts
Overshoot = 0.000 volts
RMS Volts = 1.342 volts
Dutycycle = 47.96 %

Top Trace: Granite Specimen
Bottom Trace: Granite Specimen

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$X = 121.25 \text{ Hz}$

$Y_a = -63.032 \text{ dB Vrms}$

$Y_b = -49.855 \text{ dB Vrms}$

Top Trace:
Granite Specimen
Granite Specimen

Bottom Trace:
Granite Specimen
Granite Specimen

Frequency-Space

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