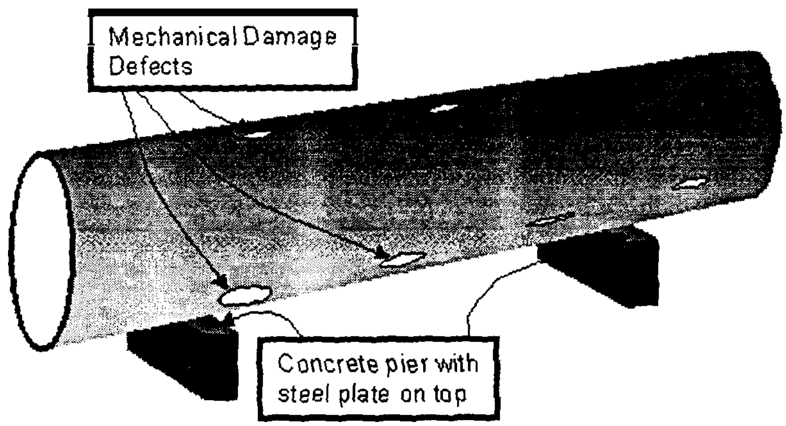
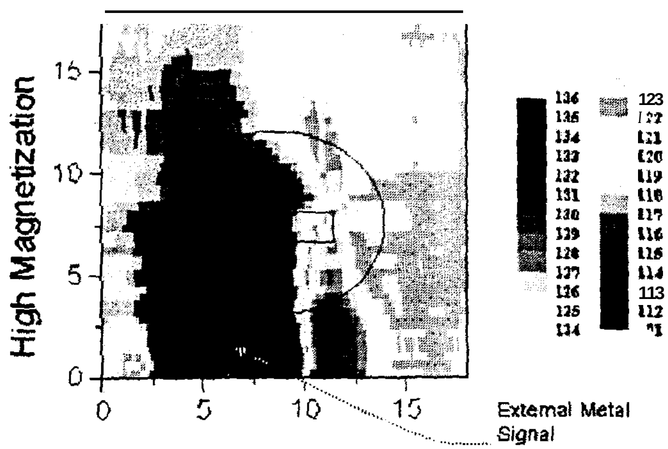
## Example - Decoupling with External Metal



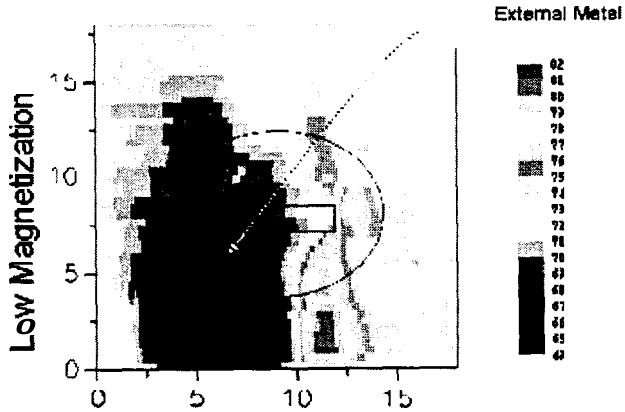

The testing at the Pioeline Simulation Facility posed an inspection challenge that illustrates the power *of* the multiple magnetization approach and the decoupling theory. The replaceable sections of the flow loop are placed on concrete piers. Each pier has a permanent steel cap to protect **the** concrete. These steel caps produce *a* magnetic signal that obscures defects near the **supports.**

The nominal dimensions of the steel caps are 6 inches **by** 24 inches **by** 1/4 inch thick. During the tests, **one** of the mechanical damage defects was located near the pier.

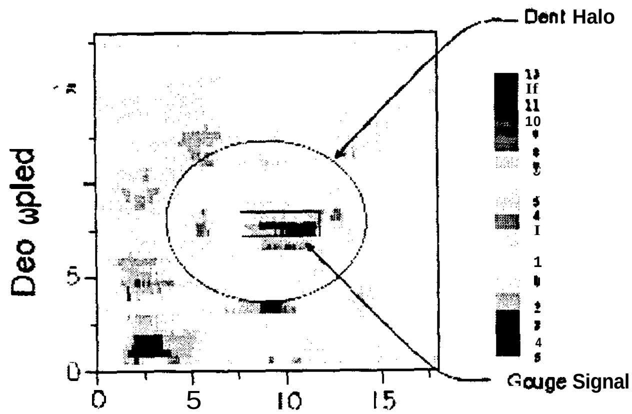
The plot at right **shows** data acquired at **a** high magnetization level, The circled region corresponds to a dent near the support; the rectangle corresponds to a gouge in the dent. The center of the gouge **is** approximately **4** inches *from* the edge of the the steel plate in the circumferential direction. In the axial direction, the gouge partially overlaps the steel plate. The dark blue signal is the magnetic reponse to the steel plate.



The plot at right shows data acquired at a low magnetization level. Again, the signal shows the large decrease in measured magnetic field (blue) associated with external metal. .



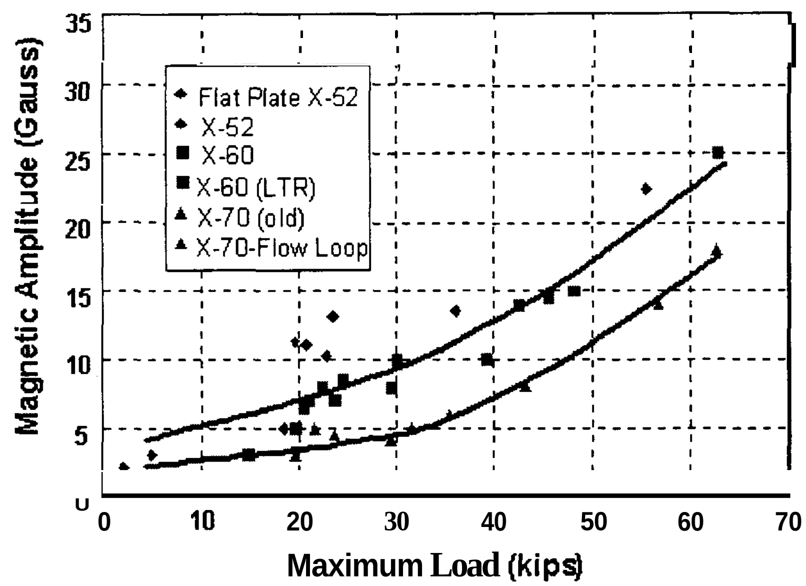

The decoupled signal, where the high magnetization signal is scaled and subtracted from the **low** magnetization signal, is shown at right. Decoupling removes the signal due to the extra metal and allows the dent halo and gouge signal to be visible.




Decoupling removes the signal due to the steel plate because extra metal is a geometric feature. That is, the signal due to extra metal is present at all magnetization levels.

# Details on Predicting Maximum Indentor Loads

The decoupled signals for 32 mechanical damage defects were examined using the linear test rig. Peak-to-peak amplitudes were measured and compared to the measured maximum indentor load used to create the defects for indentor load from 5 to 80 thousand pounds. The relationship shows a significant degree of scatter. As a result, methods were investigated to reduce the scatter. Results showed that much more accurate estimates of maximum indentor load could be made if the yield strength of the material is known.




Predicted Indentor Loads

A vertical load of about 10 thousand pounds (kips) is required to produce a decoupled signal amplitude that is greater than 3 gauss. This value represents a lower limit to MFL's ability to detect magnetic deformation. For MFL signals with amplitudes less than 3 gauss, the decoupling method was ineffective because noise levels were of the same order as the resulting signals. Defects that produce signals this small include some surface scratches.

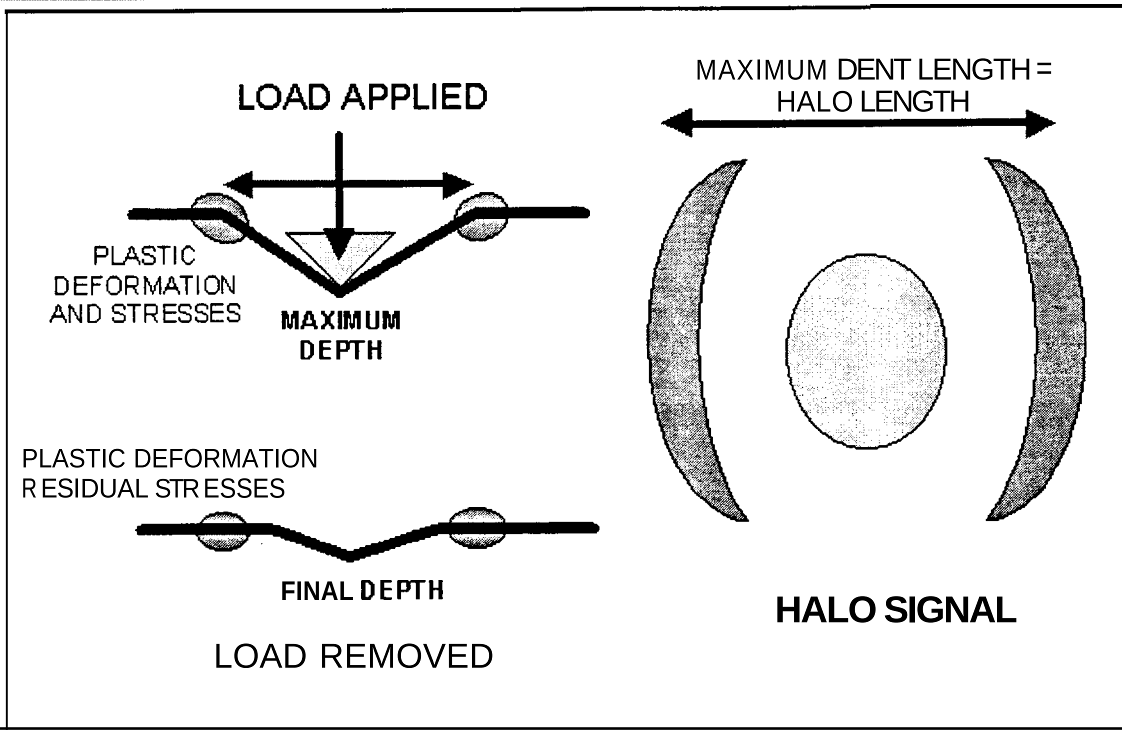
## Details on Rerounding and Predicting the Maximum Dent Depth

After denting, a pipeline will reround due to internal pressure. During the denting process, a maximum dent depth is reached, and at this point, the dent has a maximum surface extent. When the load is removed, the dent rerounds due to internal pipeline pressure. During the tests conducted in this program, rerounding as high as 80 percent occurred.

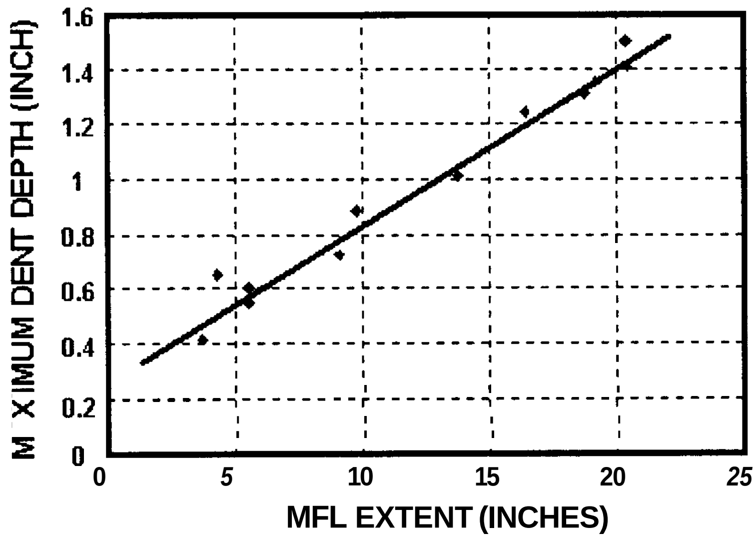
Because of the denting and rerounding process, residual stresses and plastic deformation arise at the outer edge of the maximum dent length. These stresses give rise to a small amount of magnetic deformation in the rerounded area. Data from Task 1 were used to determine if the maximum dent depth can be estimated from a "halo" signal around a defect.

The halo signal is caused by a ring of magnetic deformation that surrounds defects that have been rerounded from internal pipe pressure. This deformation is typically largest at the maximum dent length. The signal is visible at the low magnetization level, and it can be apparent in the high and decoupled MFL signals.

Because of the process used to produce mechanical damage, the halo length and the maximum dent depth were expected to be related. ***So,*** the maximum dent depth can be estimated from the halo length. Assuming the residual dent depth can be measured, the amount of rerounding can be easily determined.




Halo Concept



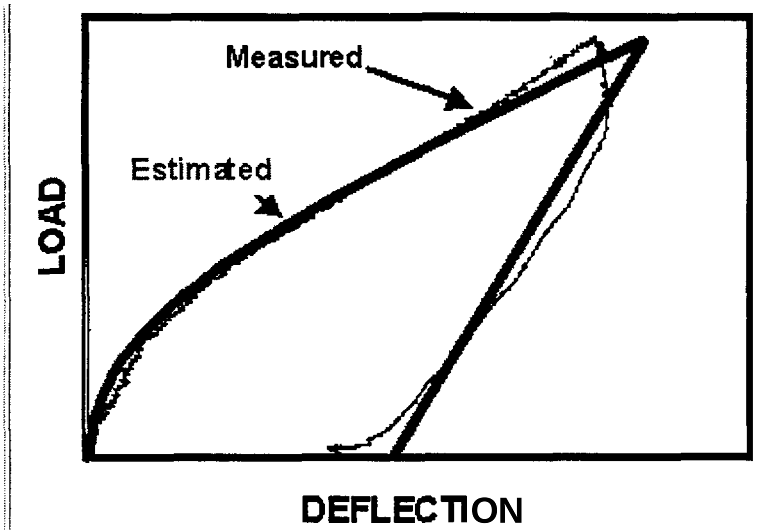

Halo Relationship

## Details on Recreating the Load-Deflection Curve and Predicting the Absorbed Energy

A method was developed to estimate the energy absorbed during the mechanical damage process. This method is based on a recreation of the load-deflection curve for the damage process. The method predicts the inward pipe displacement as a function of the radial indentor load as a function of the maximum indentor load, maximum dent depth, and residual dent depth.

The procedure for estimating the load deflection curve is as follows:

- Determine maximum vertical load from the amplitude of the decoupled signal
- Determine the maximum dent depth from the halo signal
- Measure the residual dent depth using a caliper tool or other method
- Assume the initial slope of the load-displacement curve is the same as the unloading portion
- Based on the above, estimate the full shape of the load-deflection curve.



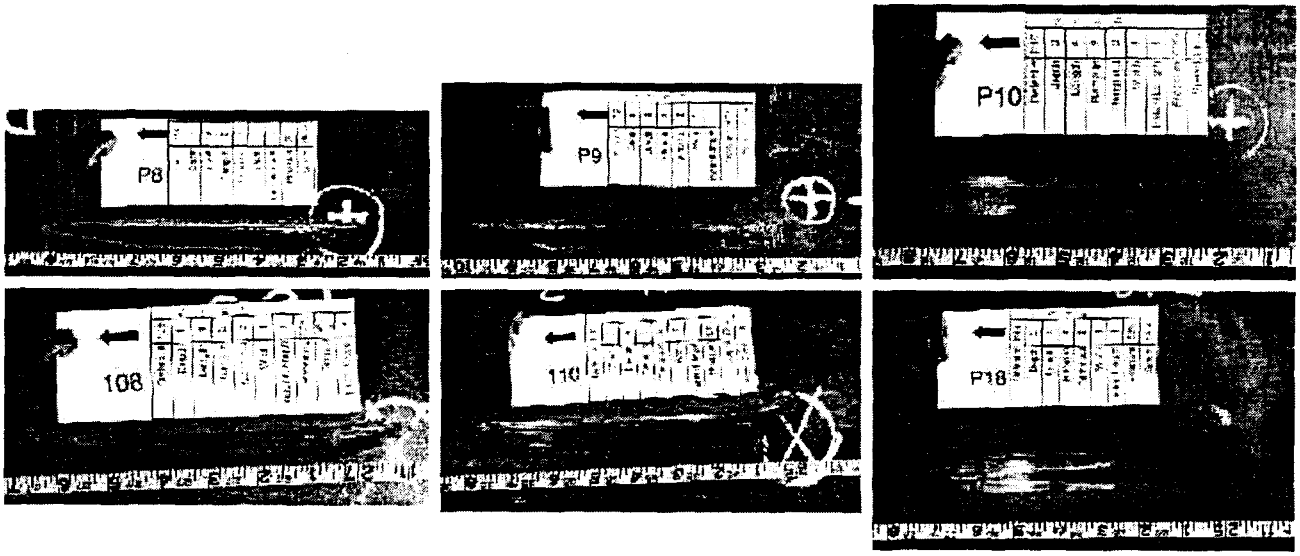
Load Deflection Curve

## Effects of Dent Depth

The effects of dent depth can be seen by comparing six defects with similar geometries but different values of dent depth. Each of the following defects is six inches long, with a two-inch ramp in, flat bottom, and ramp out. All were installed at a slow speed. For the first three cases, the defects were installed with no lubricant between the pipe and the indentor. For the second three cases, lubricant was used.

- Defect P8 (dry): 1 percent deep
- Defect P9 (dry): 2 percent deep
- Defect P10 (dry): 3 percent deep
- Defect 108 (lubricated): 1 percent deep
- Defect 110 (lubricated): 2 percent deep
- Defect P18 (lubricated): 3 percent deep

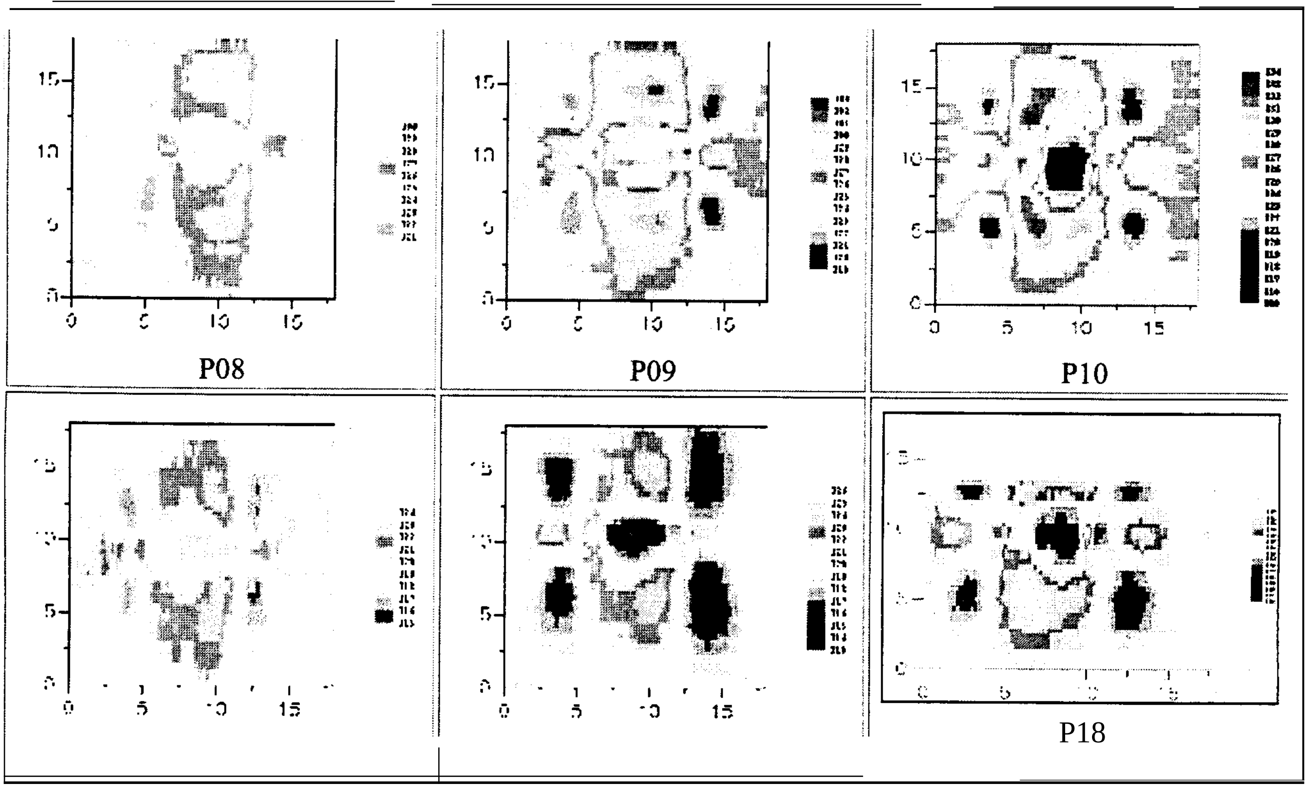
<u>Appearances</u>




The appearances of the lubricated and nonlubricated defects are largely similar at shallow depths. As depth increases, the nonlubricated defects show chatter marks, where the indentor stopped and started as it moved along the pipe.

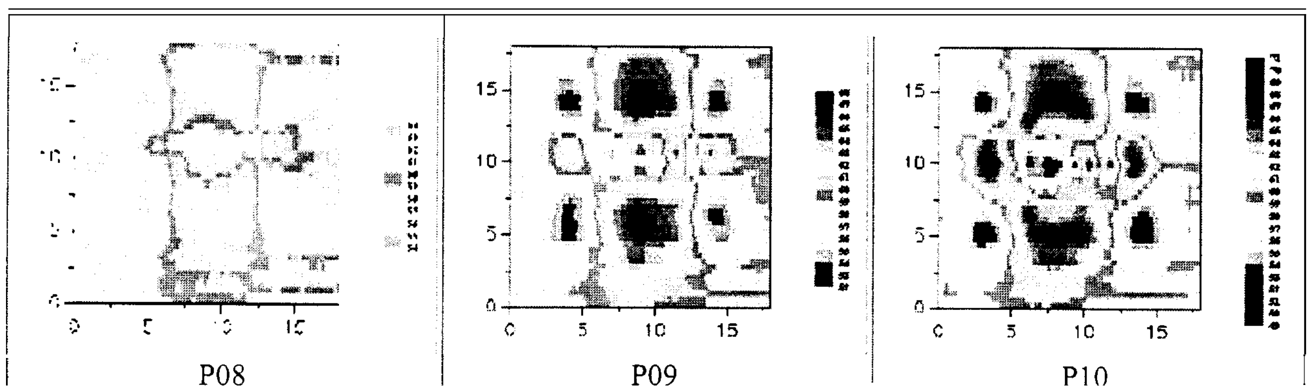
As dent depth increases, the gouges begin to show "wagon tracks" or ridges along each side. These tracks are most pronounced in the center of the gouge length.

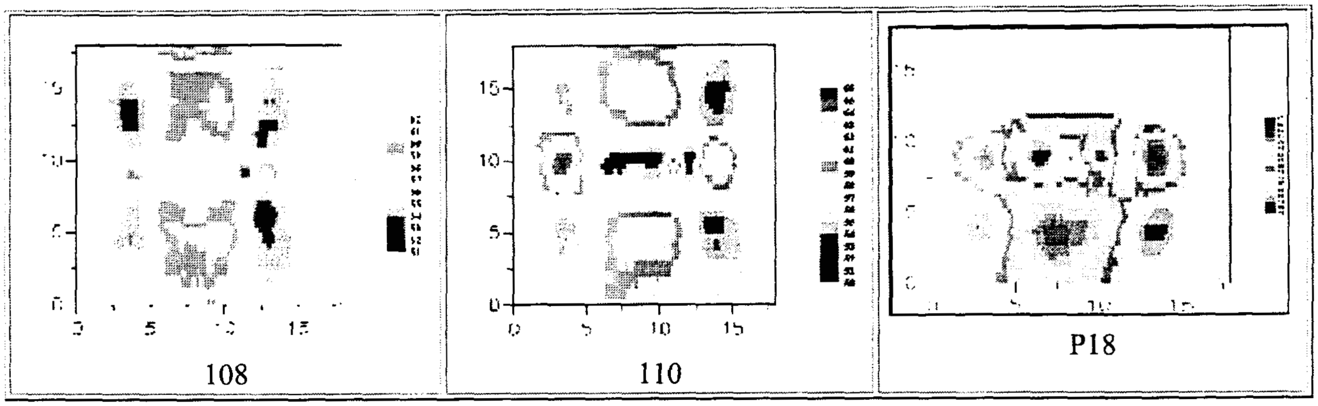
High Magnetization Level Signals




**As** expected, the high magnetization signals increase in magnitude as the dent depth increases. The signals appear more distinct for the cases where the indentor was not lubricated.

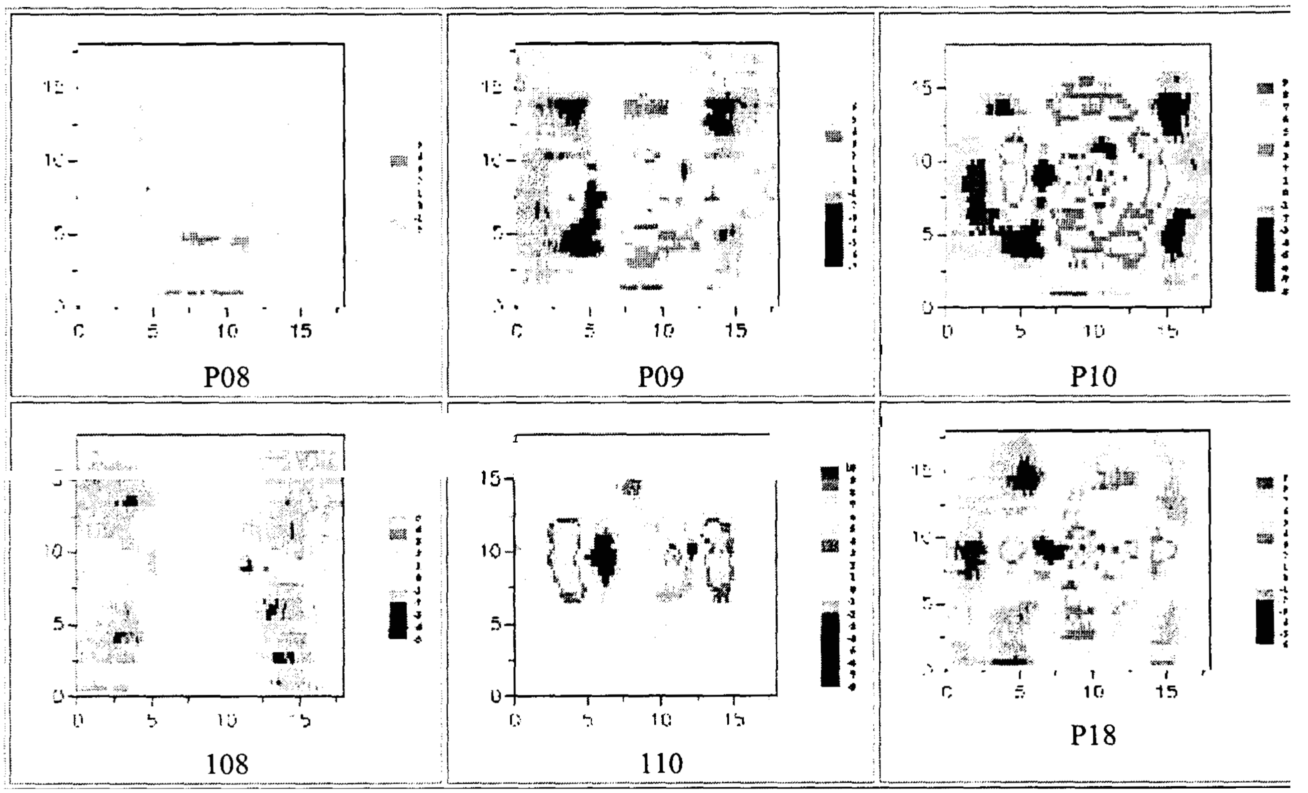
Low Magnetization Signals






The same trends appear in the low magnetization level signals as were seen in high magnetization signals. Again, the signals appear more distinct for the cases where the indentor was not lubricated.

<u>Decoupled Signals</u>




The decoupled signals also have a similar general pattern, with deeper and nonlubricated defects having greater magnitudes. The reround halo can be clearly seen in both 3 percent defects. The decoupled signal for the deepest nonlubricated defect (Defect P10) shows distinct end signals where the gouge started and stopped.

Summary

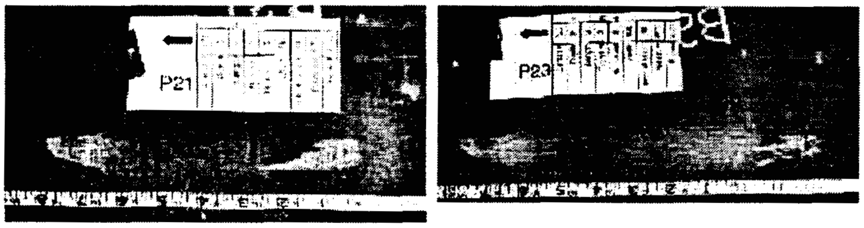
The general trend of increasing signal magnitude iwth increasing depth depth is an encouraging trend that will be helpful for defect characterization.

## Effects of Dent Length

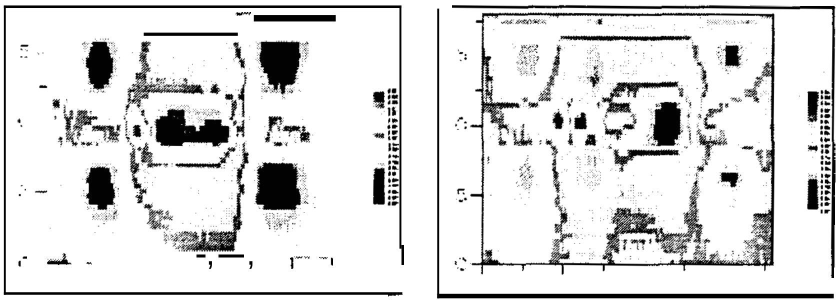
The effects of dent length can be seen by comparing two defects with similar geometries but different lengths. Each of the defects three percent deep, with a two inch ramp in and ramp out. Both were installed at a slow speed.

- Defect P21 (short): 8 inch overall length **(4** inch flat bottom)
- Defect P23 (long): 10 inch overall length (6 inch flat bottom)

Appearances



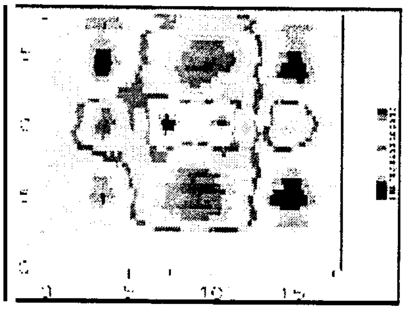

High Magnetization Level Signals



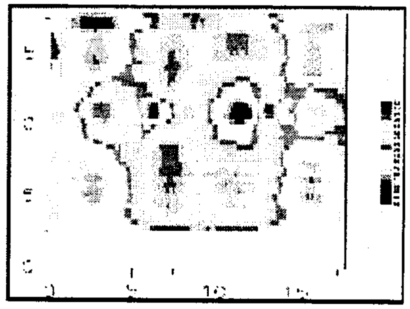
P21 P23

As expected, the high magnetization level signals increase in strength and distinctness as the dent length increases.

Low Magnetization Level Signals



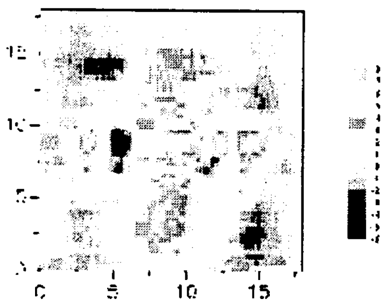
P21



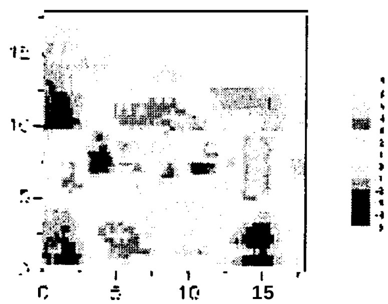
P23

The low magnetization level signals show a similar trend to that seen at the high magnetization level. In addition, the signal in and around the gouge appears to have more information content, with distinct peaks and valleys.

Decoupled Signals



P21



P23

For the largest dent length, a halo begins to appear around the decoupled signals.

Summary

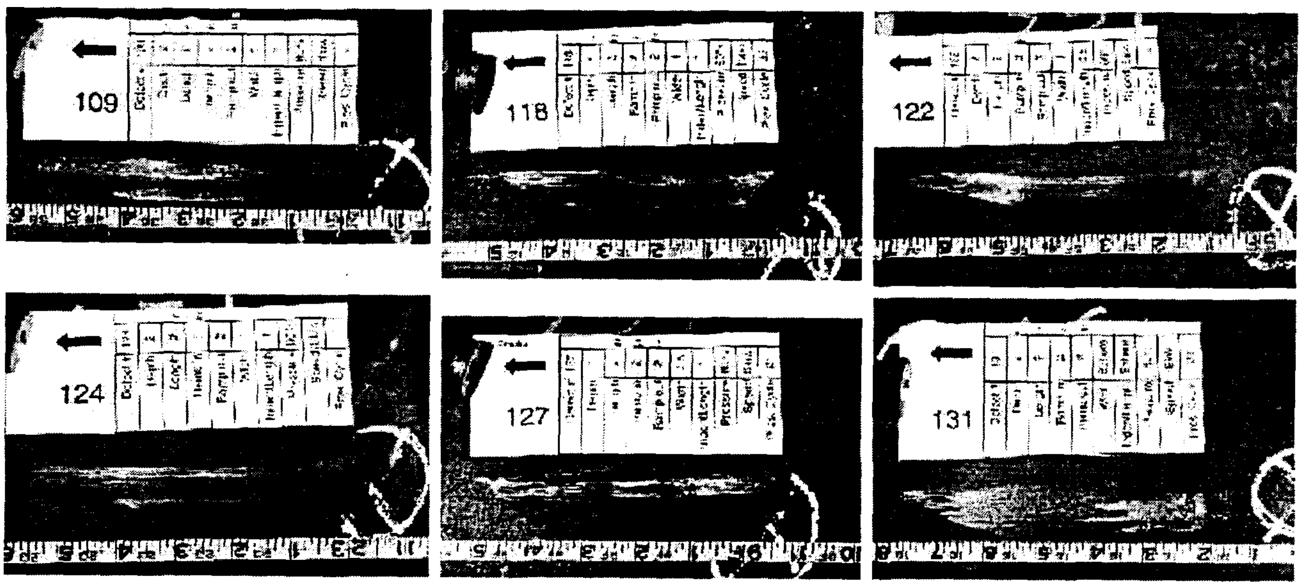
In summary, the signal strength relates strongly to dent length. For short defects, the signal features overlap and are difficult to isolate for analysis. For defects over *two* to three inches long, the overlap decreases and the signals become more suitable for analysis.

## Effects *of* Indentor Shape

The effects of indentor shape can be seen by comparing the following six defects in which the indentor was varied. Each defect is 2 percent deep and six inches long. The ramp in, ramp out, and flat bottom lengths were two inches.

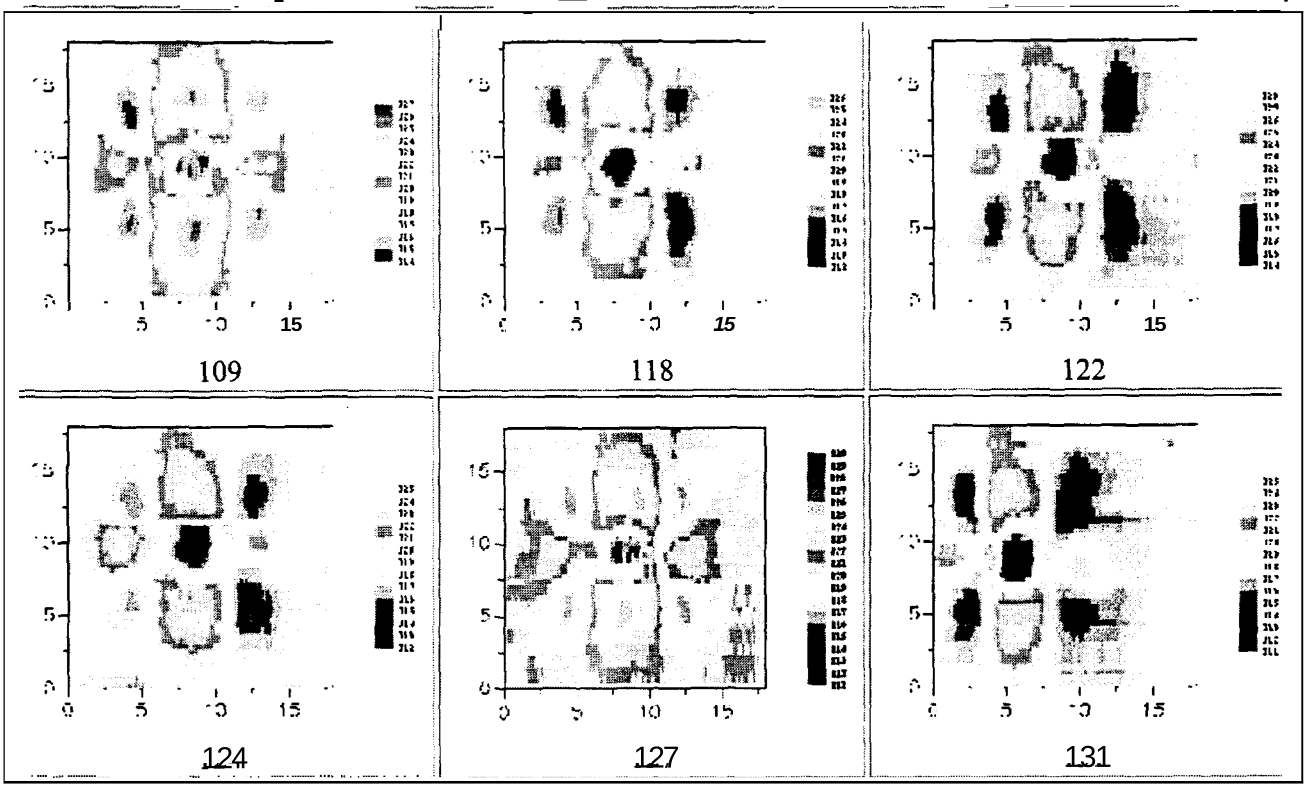
- Defect 109: 1 inch by 1 inch indentor; slow installation speed
- Defect 118: same indentor, fast installation speed
- Defect 122: 1 inch wide by 1/2 inch long indentor; slow installation speed
- Defect 124: duplicate of 109
- Defect 127: 1/2 inch wide by 1 inch long indentor; slow installation speed
- Defect 131: 4-inch spherical ball; slow installation speed

<u>Appearances</u>




The appearances of Defects 109 (base case), 118 (faster installation), and 124 (repeated defect) are nearly identical, indicating that the installation procedure was repeatable and speed does not have a significant affect on appearance. Defect 122 (short indentor) is similar in appearance with more definite edges, indicating that indentor length has a minor effect of appearance. Defect 127 (narrow indentor) looks more narrow and deeper, and Defect 131 (spherical indentor) has a gouge-like appearance at the defect start (right hand side). ***So,*** indentor width has a significant affect.

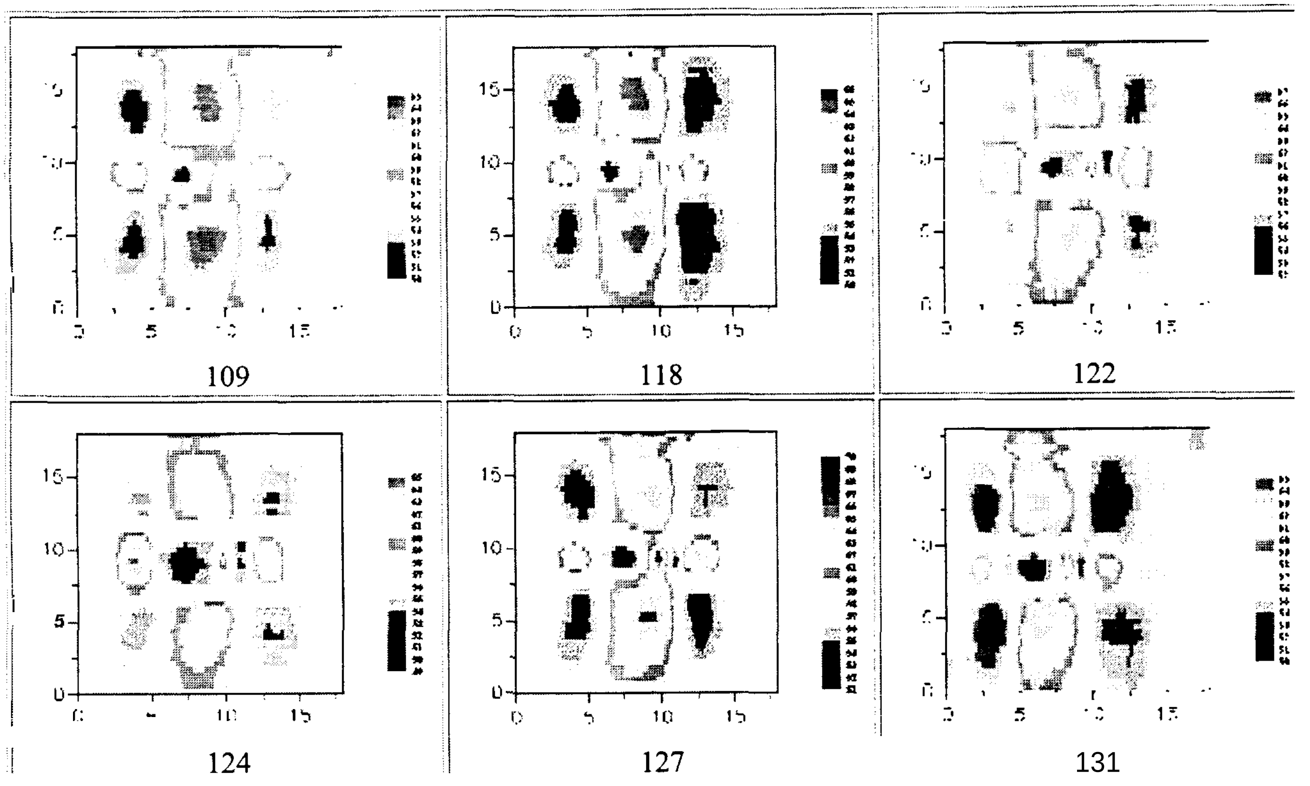
## High Magnetization Level Signals




The high magnetization signals all have a similar general pattern. Each has a drop in magnetic signal (blue) at the center and on the diagonals, and an increase in signal (yellow and orange) above, below, and to the right and left of the defect.

There is not a strong variation in signal as a result of indentor shape. The range of signal variation for nominally identical defects can be seen by comparing defects 109 and **124.** (Note that the baseline or background signal for each defect can vary slightly, causing a one or two color shift in the plots.) The signals for defects 118, 122, 127, and 131 are within this range of signal variation, with one exception. Defect 127, which was made with a narrow indentor, shows a peak to the right of center where the gouge began.

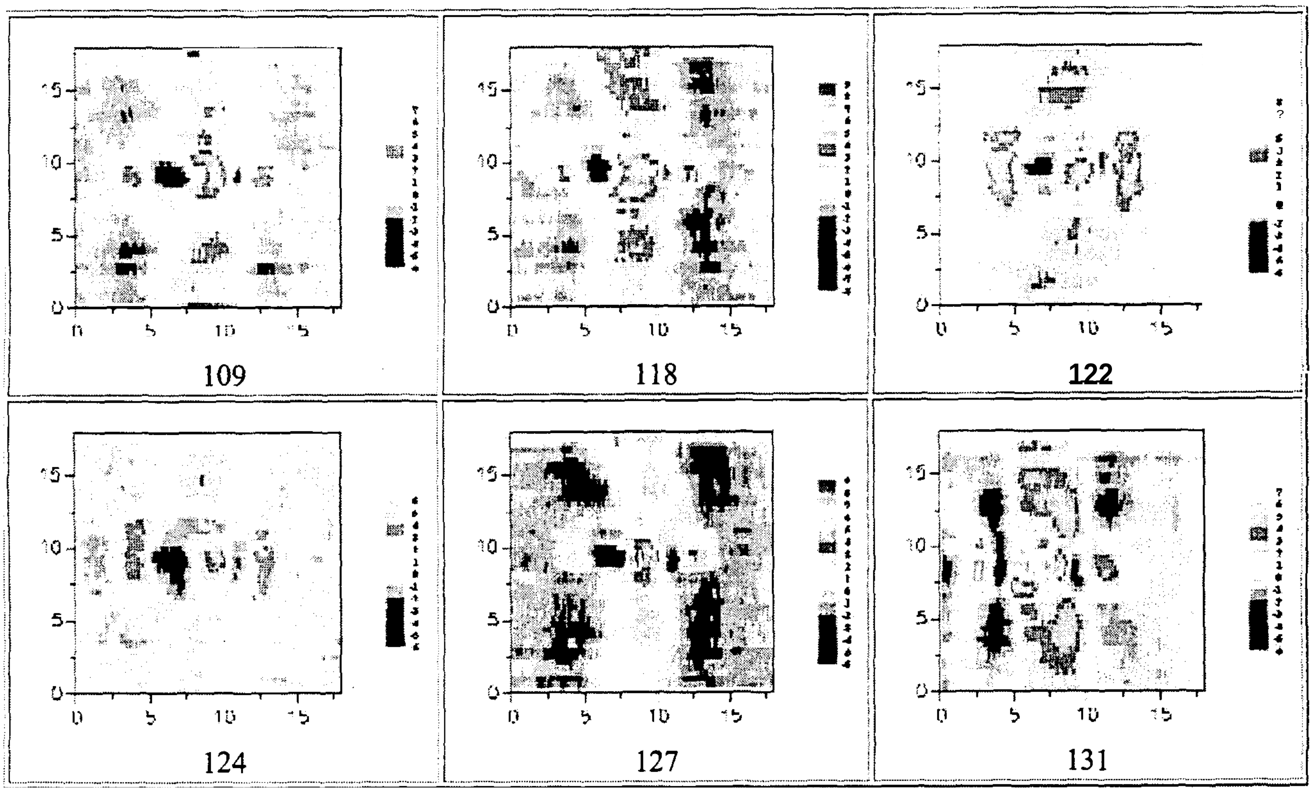
Low Maanetization Sianals




The low magnetization signals also have a similar pattern, with a decrease of magnetic signal (blue) on the diagonals as well as an increase (yellow and orange) in the circumferential direction and to the right and left of the defect center. The flux leakage down the center of the defect is both asymmetric and consistent. This flux leakage pattern is different and more complicated than the high magnetization signal pattern.

Again, the range of signal variation for identical defects can be seen by comparing defects 109 and 124. Aside from some scaling differences, the signals are similar. The variation of defects 118, 122, 127, and 131 are within this range of signal variation. Again, defect 127 shows a slightly stronger peak right of center, where the gouge began.

## Decoupled




The decoupled signals show more differences than either the high or low magnetization level signals. Still, the differences are not large. Subtle differences in signal shape are apparent between several of the defects, but the meaning of these differences is not understood.

Defect 127 has the most significant gouge, and it contains cracks. The decoupled signal does not appear markedly different than the others. Defect 131, which was made with a spherical indentor, shows a broader and more widespread signal. This is consistent with the application of forces over a large area during denting.

## Summary

Indentor shape and footprint affect the normal and shearing forces applied to a pipe during denting and gouging. Consequently, they should affect the degree of damage to the steel and the defect severity.

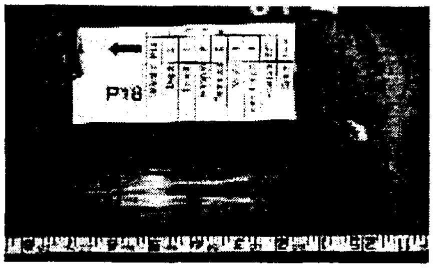
The basic signal features used to detect and identify gouges and rerounding are present in the defects studied in this program, but there was not a strong correlation between indentor shape and signal features. Some differences in signals could be seen as a result of using narrow indentors, and there were weak differences in the decoupled signal when a ball indentor was used. These might provide the basis for more advanced signal processing techniques.

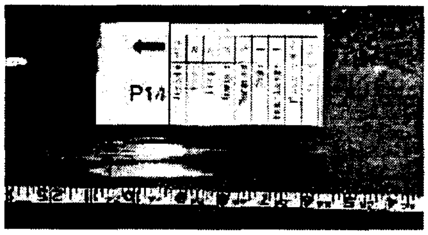
## Effects of Ramp In and Ramp Out

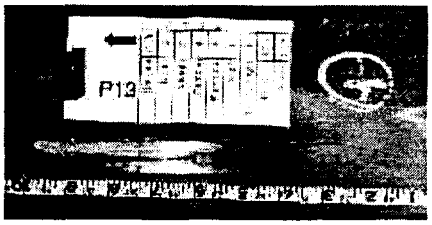
The effects of sharpness at which the defect was installed can be seen by comparing defects with similar geometries but different values for ramp in and ramp out. Each of the following defects is 3 percent deep, six inches long, and was installed at a slow speed. The ramp in, ramp out, and flat bottom lengths vary.

- Defect P18 (sharp entry angle): 2-inch ramp in; 4-inch flat bottom; 2-inch ramp out
- Defect P14 (moderate engry angle): 3-inch ramp in; 2-inch flat bottom; 3-inch ramp out
- Defect P13 (**low** entry angle): 4-inch ramp in; 0-inch flat bottom; 4-inch ramp out

Appearances





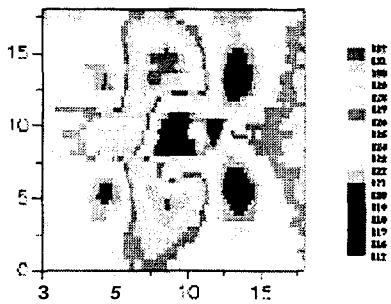



The defect appearances are similar.

High Magnetization Level Signals

**P18**

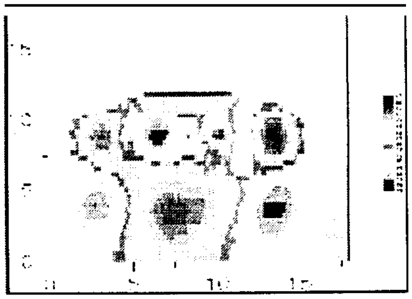

**P14**



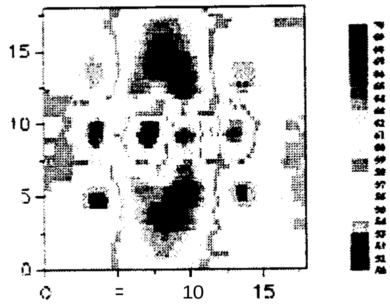

P13

The high magnetization level signals for Defect P18 show distinct peaks before and after either end of the gouge. As the entry and exit angle of the defect increased, these peaks moved in, decreasing their separation.

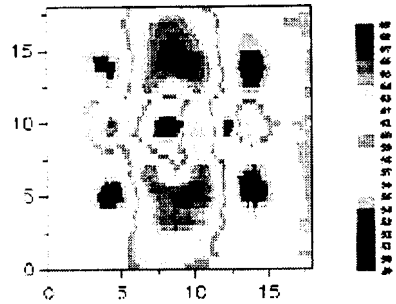
## Low Magnetization Level Signals



P18



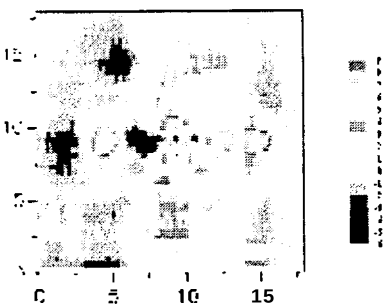
**P14**



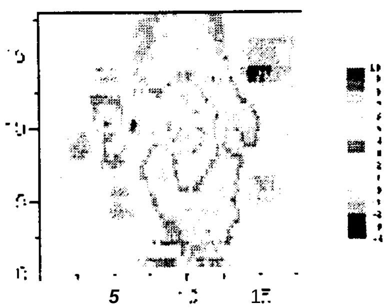
P13

The low magnetization level signals show a similar trend to that seen at the high magnetization level: the separation between the leading and trailing peaks appears related to the entry and exit angle of the indentor. In addition, the signals above and below the gouge appear stronger for the defects with a more shallow entry and exit.

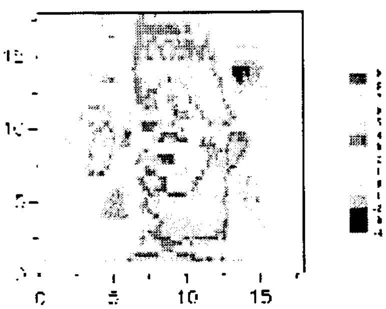
## Decoupled Signals



P18



P14



P13

The decoupled signals are stronger for the cases where the entry and exit angle is more shallow.

## Summary

In summary, there are differences in signals due to ramp in and ramp out. These differences appear in the high, low, and decoupled signals and may provide an opportunity for further analysis to determine defect features.