Magnetic Noise Measurements

Flux leakage signals from mechanical damage defects are small when compared to signals from typical metal **loss** defects. Many noise sources are associated with pipeline inspection that could obscure the signal from mechanical damage defects. Noise sources include:

- Data recording system noise from sensors, cabling and amplifiers, and data storage (either on analog tape or digital recording system)
- Sensor lift-off noise (i.e., variation in the separation between the pipe and the sensor)
- Noise due to magnetic property variations in the pipe steel

Repeated runs in both the flow loop and the pull rig were used to help sort, identify, and quantify the noise types.

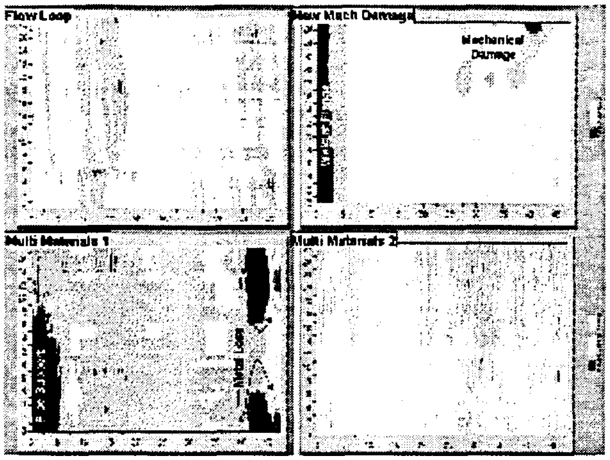
Data Recording Noise. Data recording noise occurs randomly and is a function of the design of the sensors and data handling systems. Data recording occurs independent of pipeline position and in different locations with respect to pipeline features such as welds, branches, and valves. By comparing data taken at different times under the same conditions, recording noise levels can be estimated.

For the test equipment used in this program, the system was designed to produce a very low noise level. In air, the equipment has a noise level of 0.2 to 0.5 gauss, depending on the specific sensor and data recording module in use. In a pipeline, which provides electromagnetic shielding, the levels are less than 0.2 to 0.5 gauss. This compares to a typical MFL system, which has a data recording noise level between 0.5 and 2.0 gauss in a pipeline.

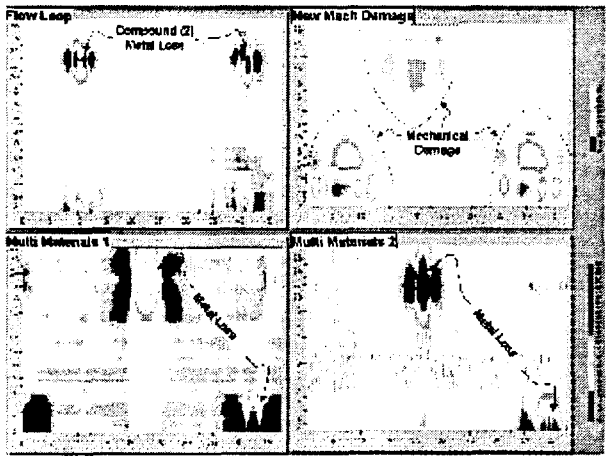
Lift-off Noise. Sensor lift-off is caused by debris, scale, and oxidation deposits. These conditions raise and lower the sensor with respect to the pipe wall, on which the sensor slides. In the tests conducted under this program, the MFL tool, with its stiff brushes and strong magnets, efficiently cleans the pipeline - repeated passes polish the inside of the pipe, reducing and nearly eliminating changes in the flux leakage signal due to lift-off in the main body of the pipe. Measured sensor lift-off noise was on the order of 0.2 gauss, as indicated by a small but general increase in signal level after the remanent magnetization effects had subsided. Noise due to sensor lift-off in commercial inspection tools in operating pipelines can be much greater, approaching several gauss.

Magnetic Property Variation Noise. The final noise source, magnetic property variations, is caused by variations in grain size, residual stresses, alloying elements. The noise levels are very pipe material dependent, and the variations measured in this program ranged from a few tenths *of* a gauss to over 5 gauss.

To illustrate, the magnetic property variations noise for four pipe materials are shown at right. Each color change signifies a 2 gauss change in the flux leakage signal. The noise levels vary in both amplitude and frequency. The upper right material, in which the majority of defects were installed for this program, has the least amount of noise (Note that the figure shows data taken near a flange and mechanical damage defect, which are not noise sources). The upper left material (flow loop pipe) has a repetitive band of noise, slightly off from the circumferential direction. Two other pipe materials (used in the GRI multiple materials metal-loss defect sets), were included for comparison. The lower left material is relatively quiet, not unlike the upper right material. The lower right material has a high frequency noise component.

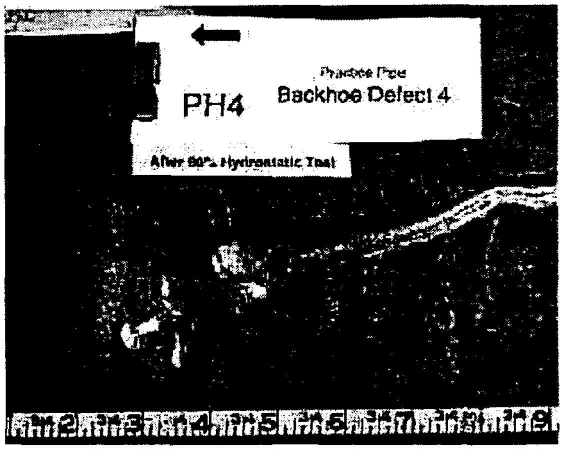


The figure at right compares the material property noise to typical mechanical damage defect signals. For each of these pipe materials, the defect signals shown are greater than the noise level. Most of the defect signals are from metal **loss,** which generally produces a large magnetic signal. **A** mechanical damage signal is shown in the upper right plot. The signal in this plot is easily seen in this material, but it would be somewhat obscurred in some lower right or upper left materials.

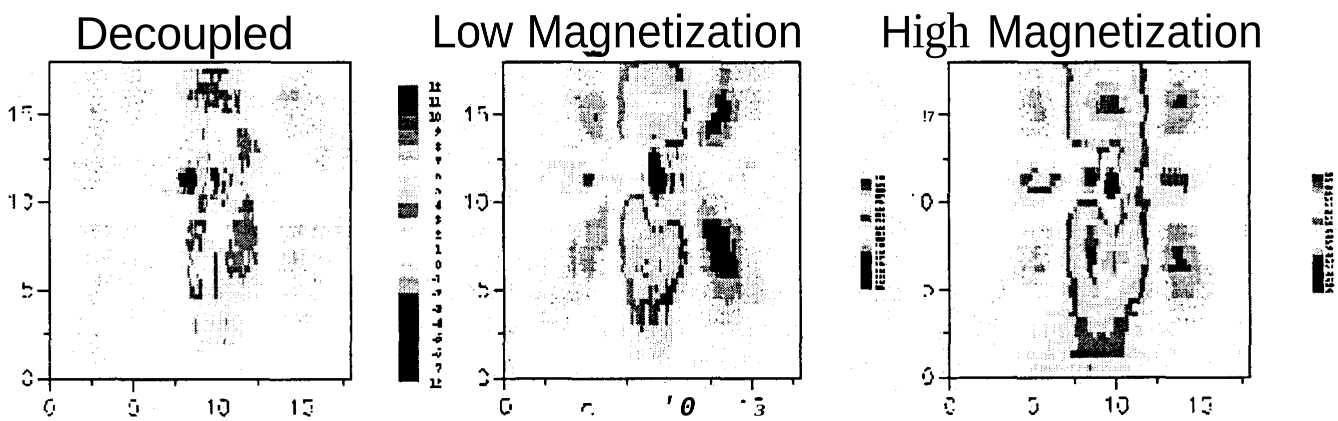


Comparisons Between Fabricated and Backhoe Defects

Defects made with the dent and gouge machine were compared to defects created by a backhoe to verify that the fabricated defects were realistic in appearance and inspection signals. Five defects were made with a with a rubber-tired backhoe, a John Deere M300 that weighs approximately 8000 pounds, as part of Defect Set #4. Two were hard strikes on the pipe, similar to those that might occur when a backhoe operator tried to break through a hard layer or rock. The other three were scrapes as might occur when a backhoe works parallel to the pipe.

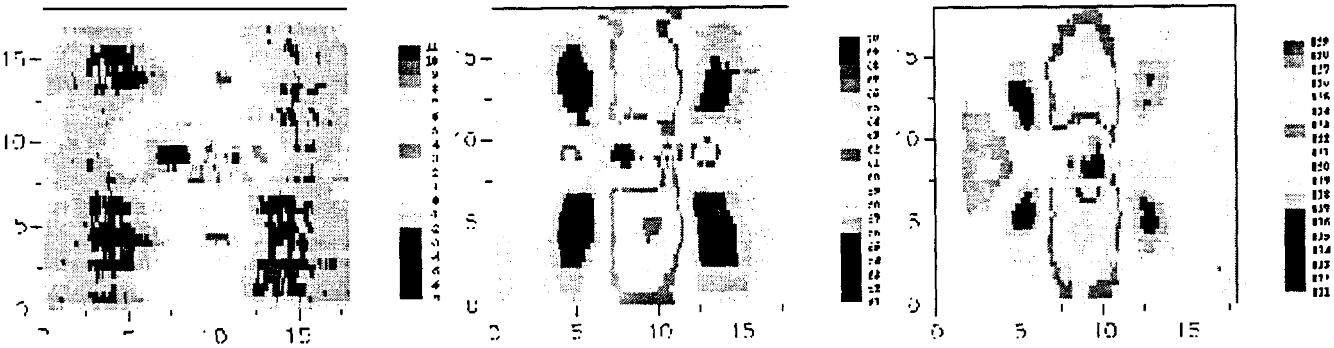


One of the hard strikes to the pipe is shown at right. In this case, the defect shows two distinct hits, where the backhoe bucket bounced after initial contact. The defect contains denting, displaced metal, and cracking as detected by magnetic particle inspection. The flux leakage image of this defect is shown below.



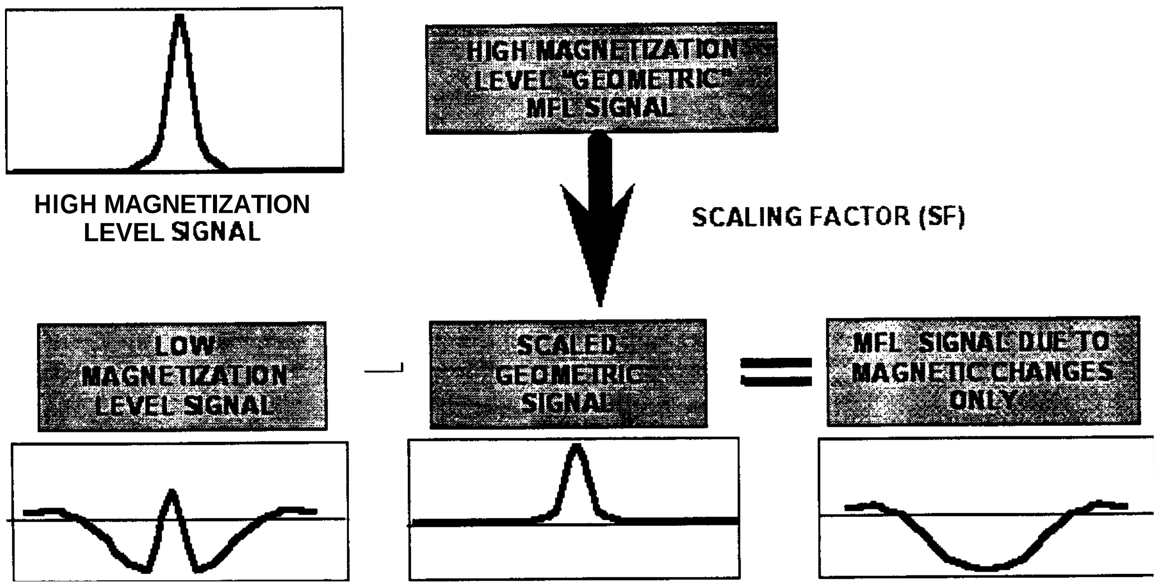
For comparison, the following flux leakage map **is** for a 2-percent deep 4-inch long (1-inch ramp in / 2-inch bottom / 1-inch ramp out) defect:

Decoupled Low Magnetization High Magnetization



Many of the same signal features exist, including four blue areas along the diagonals and yellow/orange areas above and below the defect. The major difference **is** due to the fact that the backhoe defect **is** one-half the length of the machine-made defect. **As** a consequence, the peaks and valleys in the center signal overlap and are difficult to isolate.

Flowchart of Decoupling Procedure



Additional Details on Decoupling

To improve the ability to reliably detect, classify, and size mechanical damage defects, Battelle developed a multiple magnetization level analysis methodology as part of this project. The approach requires two magnetizing levels: a low level for detecting magnetic deformation and a high level for detecting geometric deformation. Classifying and determining the severity of the damage requires additional signal processing. The measured signals must be decoupled into their geometric and magnetic components. Once decoupled, unique signatures of different types of damage become more readily apparent.

The decoupling procedure developed under this project works as follows. The MFL signal taken at a low magnetization level contains information on both the magnetic and geometric deformation. At high magnetizing fields, the MFL signal contains information on the geometric deformation only. The geometric or high-magnetization level signal is "scaled" to the lower magnetization level. This scaled signal is then subtracted from the low level signal. The result is a signal that reflects the magnetic deformation only. This signal is referred to as the decoupled signal.

Scaling

Scaling requires specific knowledge of how the geometric component of an MFL signal changes with magnetization level. Generally, the signal changes its amplitude and shape. The shape change can be viewed as a non-uniform amplitude change across the signal. For example, the center of the signal may have a greater amplitude change than the ends of the signal, giving rise to the change in shape.

The bias or background magnetization level is subtracted out of the geometric signal before being multiplied by the scaling function. The scaling function returns the scaled geometric signal without a bias. The scaled geometric signal without bias is subtracted from the measured mixed MFL signal without bias to yield the decoupled signal.

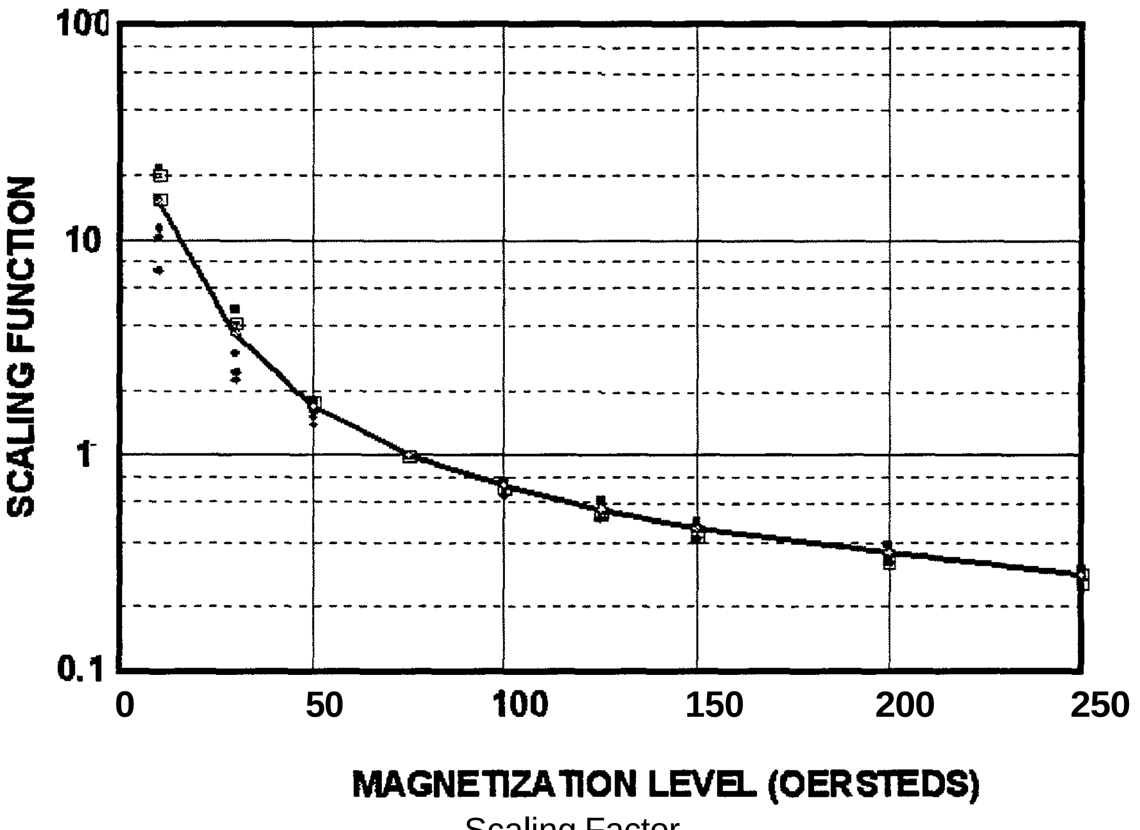
As a first approximation, the scaling function was taken to be independent of spatial coordinates. For the geometries studied, the results show that the signal shape does not appreciably change the shape function. That is, the amplitude scaling is roughly uniform over the whole signal. Therefore, we assumed the scaling function was a scalar. This approximation is very good for dent depths less than 0.75 inch and gouges less than 10 percent deep. The approximation works reasonably well for dent depths between 0.75 and 1.00 inches deep and gouges up to 20 percent deep, but it becomes less exact for deeper dents and gouges.

A second approximation was made that the scaling function is a function of magnetization level only. Here, the magnetization level includes both the level from and the level to which the signals are being scaled. Figure 2 shows the approximate scaling factor as a function of the magnetizing level for the defects modeled, where all signals were scaled to a magnetizing force of 70 Oersteds. With the approximations, the scaling function can be written as a scalar function dependent only on the magnetization levels:

$$SF(LML,\ HML) \cong A(LML)\ e^{-a\,(LML)\,HML}$$

where A and ***a*** are functions of the low magnetization level.

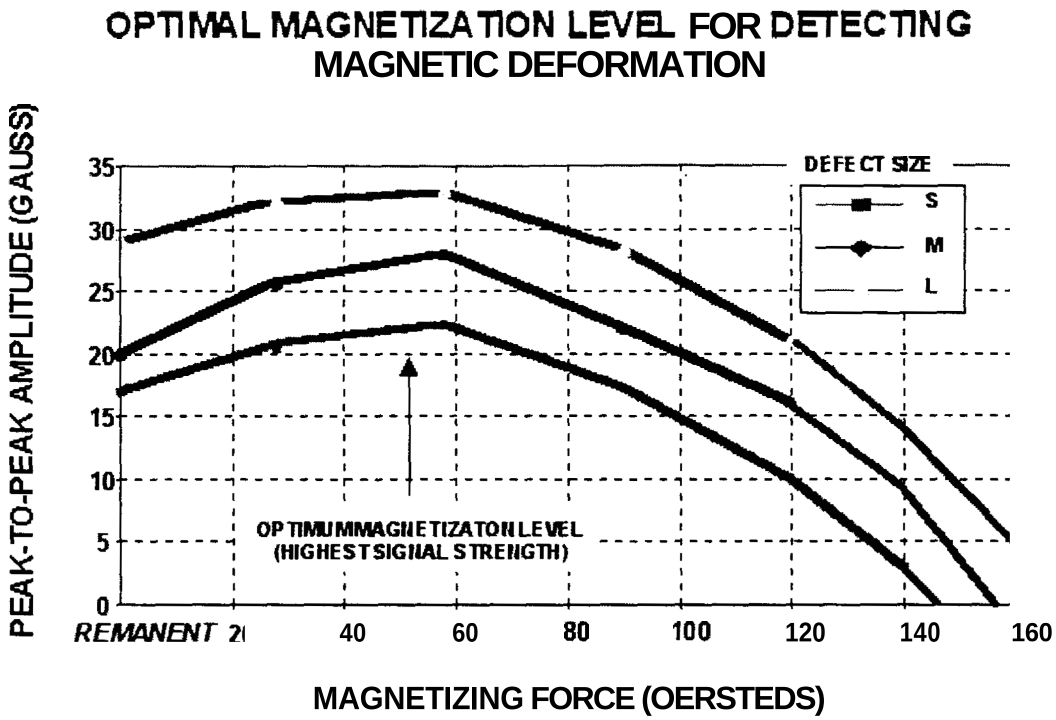
This scaling factor worked well on most defects studied. It provides a signal that can be used to reveal cold working where cold work has occurred and no cold work where there is none. Some defects, such as surface scratches, where signal amplitudes are small (e.g., under 5 gauss), have problems due to noise, as discussed later. Magnetic noise found in most pipe is on the order of 2 to 3 gauss making classification and decoupling difficult.



Scaling Factor

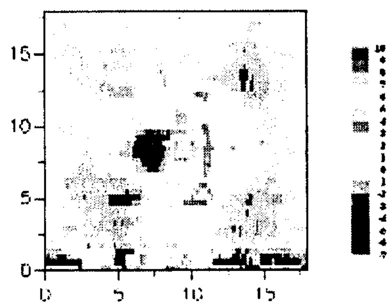
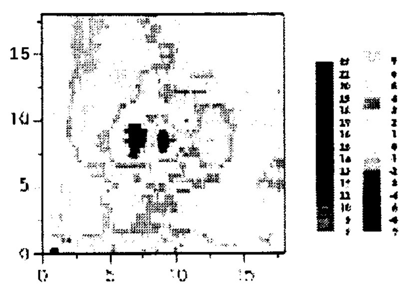
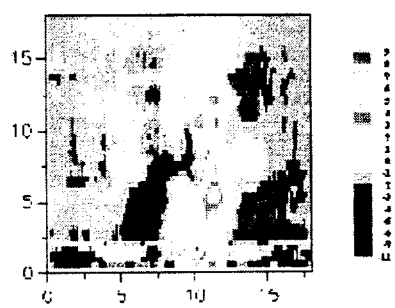
For more information on decoupling, refer to The Feasibility of Magnetic Flux Leakage In-Line Inspection as a Method to Detect and Characterize Mechanical Damage.

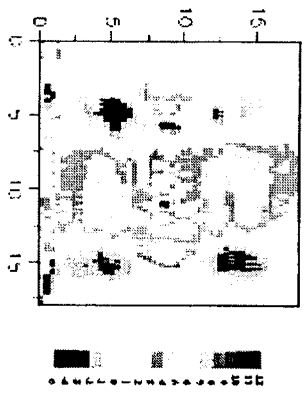
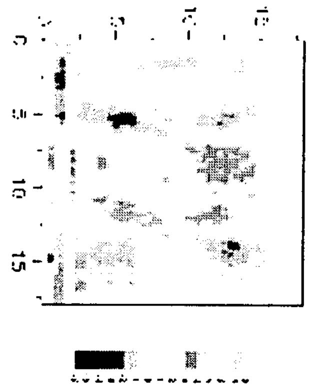
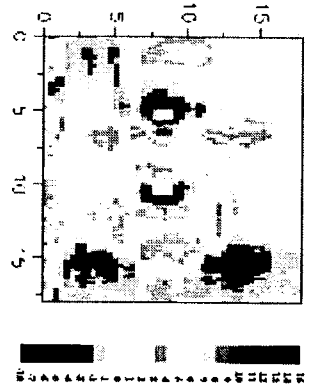
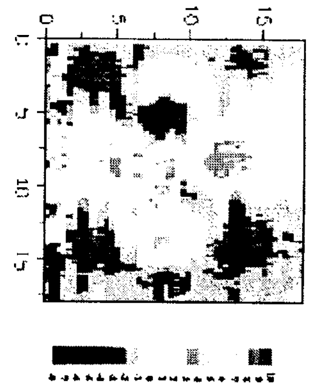
Graph *of* Optimal Magnetization Level

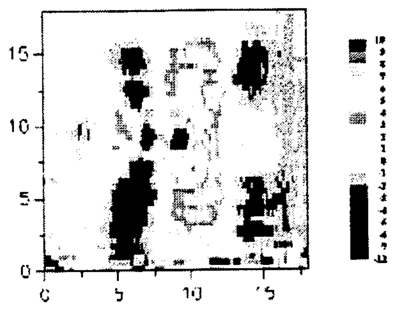
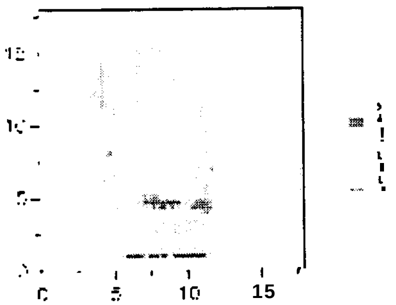
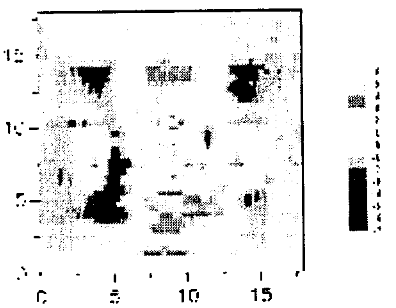
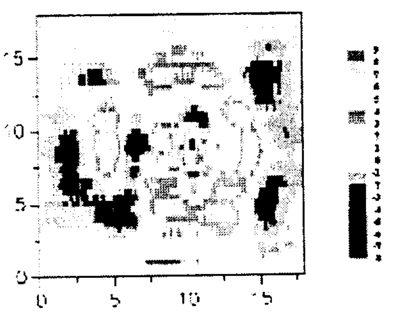


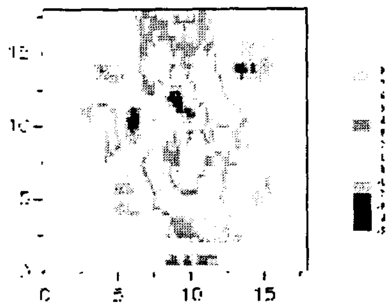
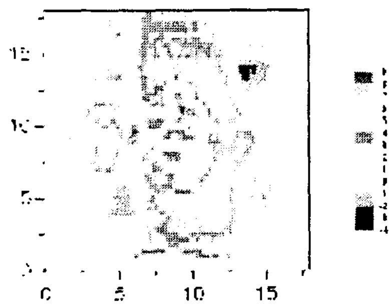
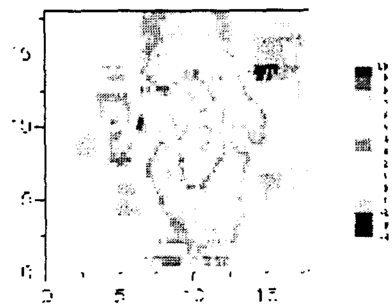
Defect Set 4 - Practice Defects
Decoupled Data

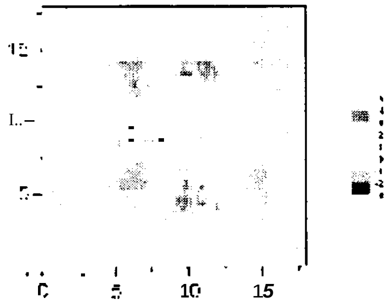
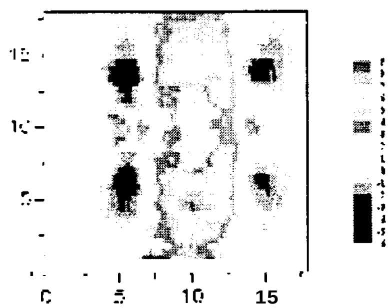
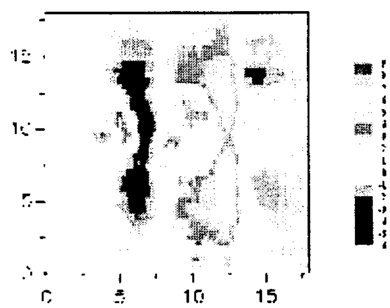
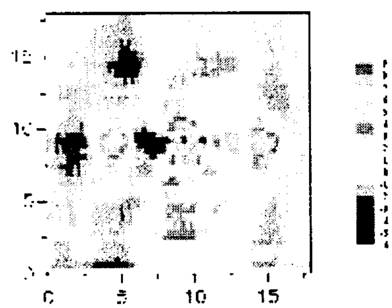
This defect set was used in the pull rig. Clicking on the defect number will link to a page with all MFL data, as well as photographs and load-deflection-time plots. For a layout map of the defects, click here. For a description of the variables included in this table, see the legend at the bottom of this page.

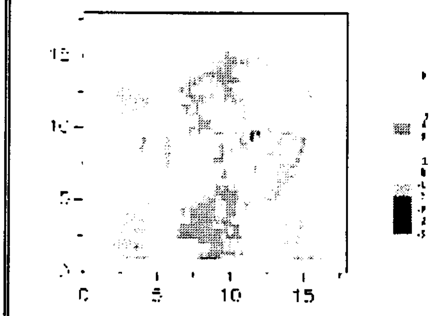
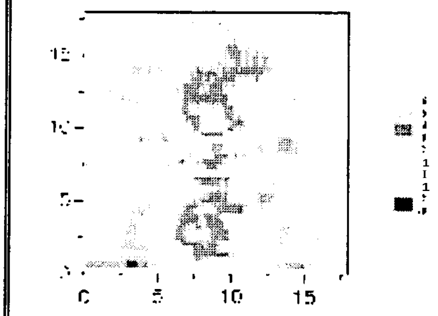
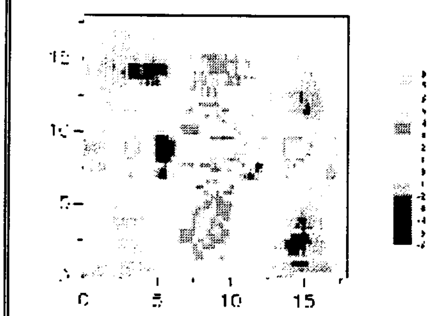
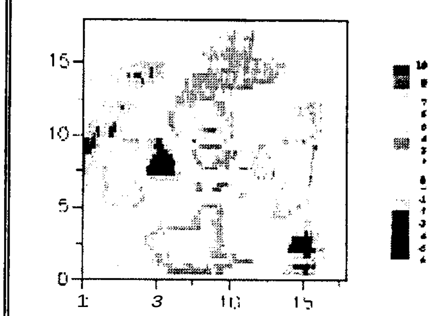
#	Decoupled MFL Signal	D	L	FB	RI	RO	IW	IL	P	S
P01		3	3	0	1	2	0%	0%	60%	S
P02		6	3	0	1	2	0%	0%	60%	S
P03		3	3	0	1	2	1	0.5	60%	S

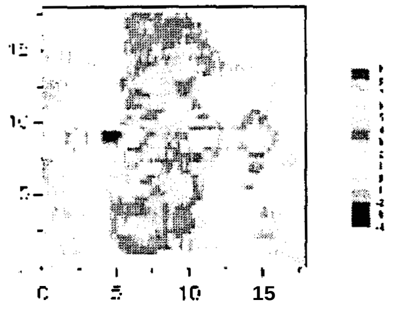
P06		2	8	4	2	2	1	0.5	60%	S
P05		1	8	4	2	2	1	0.5	60%	S
P04r		3	7	4	1	2	0% w/10%	0% w/10%	60%	S
P04		3	7	4	1	2	0% w/10%	0% w/10%	60%	S

P07		1	8	3	3	2	1	0.5	60%	S
P08		1	8	4	2	2	1	1	60%	S
P09		2	8	4	2	2	1	1	60%	S
P10		3	8	4	2	2	1	1	60%	S

P11		3	8	0	4	4	1	1	60%	S
P12		3	8	0	4	4	1	1	60%	S
P13		3	8	0	4	4	1	1	60%	S
P14		3	8	2	3	3	1	1	60%	S

P15		1	8	2	3	3	1	1	60%	Not F
P16		2	8	2	3	3	1	1	60%	Not F
P17		3	8	2	3	3	1	1	60%	F
P18		3	8	4	2	2	1	1	60%	S

P19		2	8	4	2	2	0%	0%	60%	S
P20		2	8	4	2	2	0%	0%	60%	S
P21		3	8	4	2	2	0%	0%	60%	S
P22		4	8	4	2	2	0%	0%	60%	S

P23		3	10	6	2	2	0%	0%	60%	S
P24		3	10	6	2	2	0%	0%	60%	F

Legend:

- # = Defect# is an arbitrary number identifying each defect
- D = Depth is the dent depth in percent of the diameter.
- L = Overall Length is the total length of the gouge in inches.
- FB = Flat Bottom Length is the length of the flat bottom portion of the gouge in inches.
- RI = Ramp In and RO = Ramp Out are the distances on either side of the flat bottom used to ramp the indentor into and out of the pipe (the overall gouge length is the sum of the flat bottom length and the ramp in and ramp out lengths).
- IW = Indentor Width and IL = Indentor Length are the footprint dimensions of the indentor in inches; where **x%** is shown, the indentor was a 4-inch sphere with a sharp protruding cutter that extended **x%** of the wall thickness.
- P = Pressure is the internal pipe pressure in percent of specified minimum yiemfl strength.
- S = Speed refers to the rate of axial movement of the indentor (S is 1 inch per second; **F** is 5 inches per second).