# The Analysis of Spectrum on the Barkhausen Noise of Hysteresis Loops on Neutron Irradiated Material

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## Abstract

In relation to a non-destructive evaluation of irradiation damages, the changes in the hysteresis loop and Barkhausen noise amplitude and the harmonics frequency due to a neutron irradiation were measured and evaluated. The Mn-Mo-Ni low alloy steel of RPV was irradiated to a neutron fluence of $2.3\times10^{19}$ n/㎠ (E≥1 MeV) at 288℃. The saturation magnetization of neutron irradiated metal did not change. The neutron irradiation caused the coercivity to increase, whereas susceptibility to decrease. The amplitude of Barkhausen noise parameters associated with the domain wall motion were decreased by a neutron irradiation. The spectrum of Barkhausen noise is analysed with an applied frequency of 4 Hz and 8 Hz, sampling time of 50 $\mu$ sec and 20 $\mu$ sec. The harmonic frequency shows 4 Hz, 8 Hz, 12 Hz and 16 Hz reflected from an unirradiated specimen. On the contrary, the harmonic frequency disappeared on the irradiated specimen. In addition to the amplitude, the harmonic frequency of Barkhausen noise is taken into accounts as a promising tool for monitoring the irradiation induced degradation of the reactor materials such as a SA508 of PWR-RPV steel and a $Zr_4$ of HANARO-CNH.


## Ⅰ. Introduction

The Monitoring of the irradiation induced degradation of light water RPV(reactor pressure vessel) and research reactor HANARO-CNH(cold neutron hole) is of a primary concern to operating nuclear reactors in relation to the safety and the prediction of a life time. The degradation known as embrittlement has long been evaluated by using approved models and guidelines together with mechanical tests, such as Charpy impact tests and tensile tests through reactor surveillance programs1,2. Results from the models and surveillance program, however, do not always provide enough accurate informations regarding the exact materials conditions about reactors. Further problem regarding the current surveillance program can be realized in limited number for the basis of life extension.

Recently, several attempts have been made to utilize the measurements of magnetic parameter as a nondestructive testing method for examining the material state of reactor under operation[3,4,5,6,7]. These investigations are based on the idea that microstructural changes due to irradiation inherently affect the magnetic domain wall movement and consequently affect the nature and magnitude of magnetic parameters[8]. Until now, most of these examinations have been performed to explore interrelationship among the changes in the material and mechanical parameters such as grain size, microstructure, hardness, tensile properties and fracture toughness, etc. and magnetic parameters like Barkhausen noise and hysteresis loop due to irradiation.[9]

In the present work, the changes and magnetic parameters related to Barkhausen noise amplitude, Barkhausen noise harmonics frequency and hysteresis loop parameters due to neutron irradiation were measured and analyzed to investigate the interrelationship between these parameters on RPV steel. Results showed a possibility that magnetic measurement may be used for the nondestructive evaluation of material degradation.

## Ⅱ. Experiment

Materials used in the present study were obtained from a surveillance test of operating reactor in Korea and the chemical composition is shown in table 1. The total accumulated fluence was $2.3\times10^{19}$ n/㎠(E≥1 MeV). The saturation magnetization, coercivity and susceptibility were measured by vibrating sample magnetometer. To

Table 1. Chemical composition(wt%) of SA508 Class 3 RPV steel.

| Element | C | Mn | P | S | Si | Ni |
|---|---|---|---|---|---|---|
| Base | 0.155 | 1.28 | 0.006 | 0.005 | 0.168 | 0.712 |
| Element | Mo | Cr | Cu | Al | Co | Fe |
| Base | 0.484 | 0.171 | 0.063 | 0.011 | 0.012 | Bal. |

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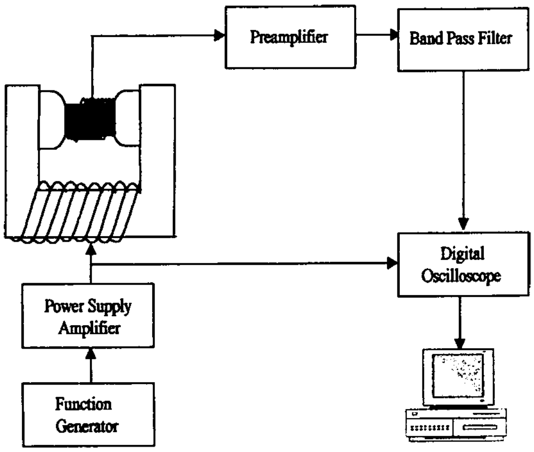


Figure 1. Block diagram of Barkhausen noise measurement equipment.

minimize demagnetizing field effect, specimens were made in 3mm diameter disk. The block diagram for the Barkhausen noise parameters is shown in figure 1. An U-shaped ferrite magnet core was used to magnetize the specimen. The electromagnet was placed along the length of the specimen. A magnetic field was applied to the specimen by supplying a sinusoidal current of 4 Hz, 8 Hz to the electromagnet. An encircling sensing coil wound around the specimen was used to measure the magnetic induction in the specimen. The Barkhausen noise signal detected by the pick-up coil was amplified. The measured data were processed by a computer via a storage digital oscilloscope.

## Ⅲ. Results and discussion

### 3.1 Effect of neutron irradiation in magnetic parameters

Figure 2 shows the comparison of the hysteresis loop for base metal before and after the irradiation. After neutron irradiation, specimen' s hysteresis loop showed a clockwise rotation relative to that of unirradiated specimen. This means a reduction of relative susceptibility. The susceptibility of base metal decreases 50%. It is believed that the decrease of susceptibility comes from the interference of domain walls with the defects, such as strain, inclusions, lattice imperfection, or small amount of impurities. The saturation magnetization is known to be insensitive to structure in the sense that it does not depend on the details of fine structure[10].Therefore, saturation magnetization didn' t show any change due to neutron irradiation and showed

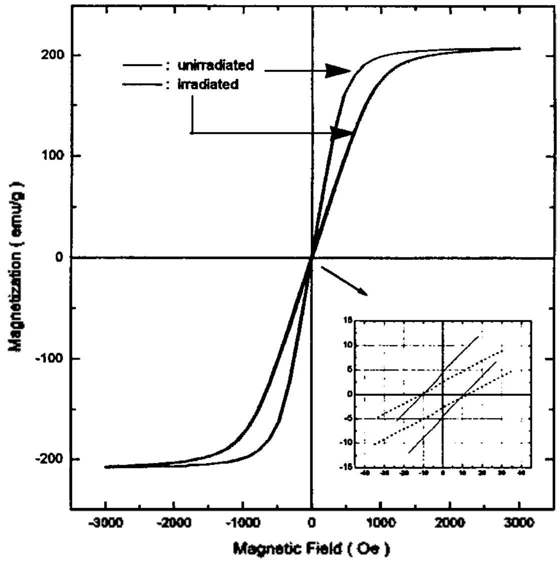


Figure 2. Comparison of hysteresis loops for unirradiated and neutron irradiated base metal with does of 2.3 x 1019 n/cm2.

constant saturation magnetization of about 208 emu/g. The coercivity of base metal showed an increase from 8.8 Oe to 11.9 Oe. The coercivity can be explained by using the equation of Gyorgy et al [11]. According to the equation, the coercivity can be expressed as :

$$H_c = \frac{4S(AK)^{1/2}}{(M_s t)} \quad (1)$$

where S is function of the size and density of precipitates, A is the exchange constant, K is the anisotropy constant, Ms is the saturation magnetization and t is the thickness. When A, K, $M_s$ and t are known to be variables in the equation above, coercivity is able to be determined from the size and density of precipitates. Therefore, the formation of defect and the second phase due to a neutron irradiation bring in an increase of the coercivity. Same results were revealed in the work of Narayan[9] that the size and shape of the second phase grain affect magnetic field and, in particular, coercivity in high strength and low alloy iron. Magnetic properties are summarized in Table 2.

Table 2. Magnetic parameters of base metal.

| Material | | Hysteresis loop | | | Barkhausen Noise | | |
|---|---|---|---|---|---|---|---|
| | | Ms (emu/g) | Susceptibility | Hc (Oe) | BN amplitude | BN voltage | BN energy |
| Base metal | Unirr. | 207. | 1 | 8.8 | | | 3913 |
| | Irr. | 207.4 | 0.50 | 11.9 | | | 2411 |

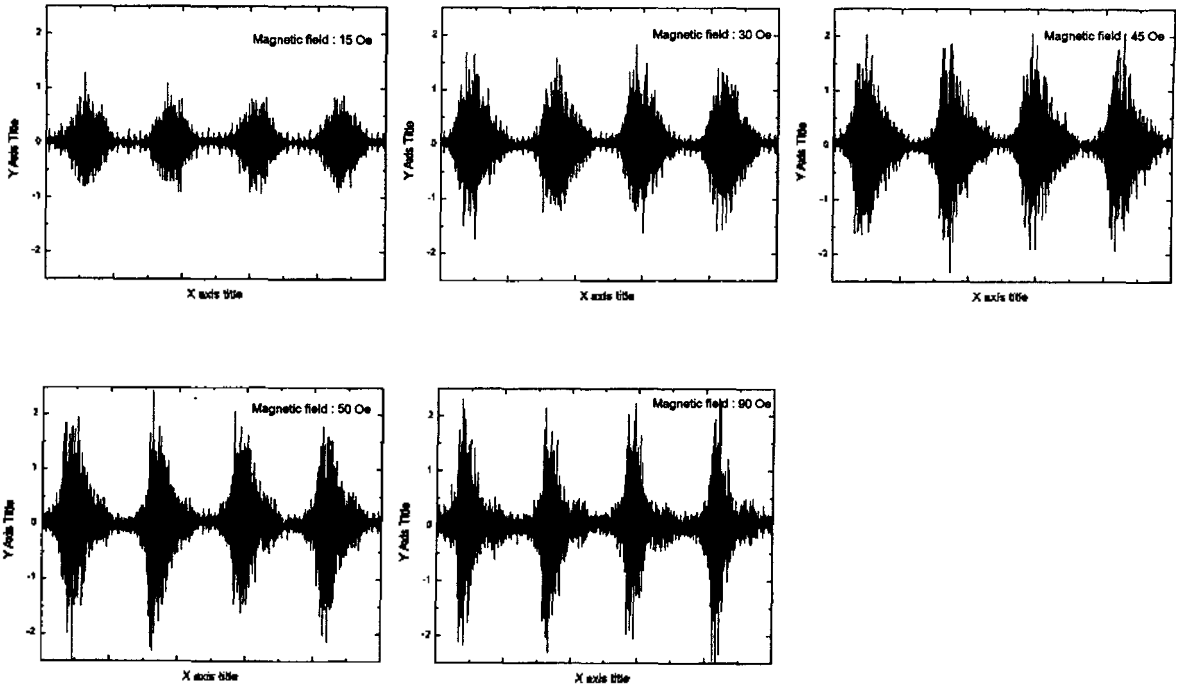


Figure 3. The dependence of magnetic Barkhausen waveforms on the magnetic field on irradiated base metal.

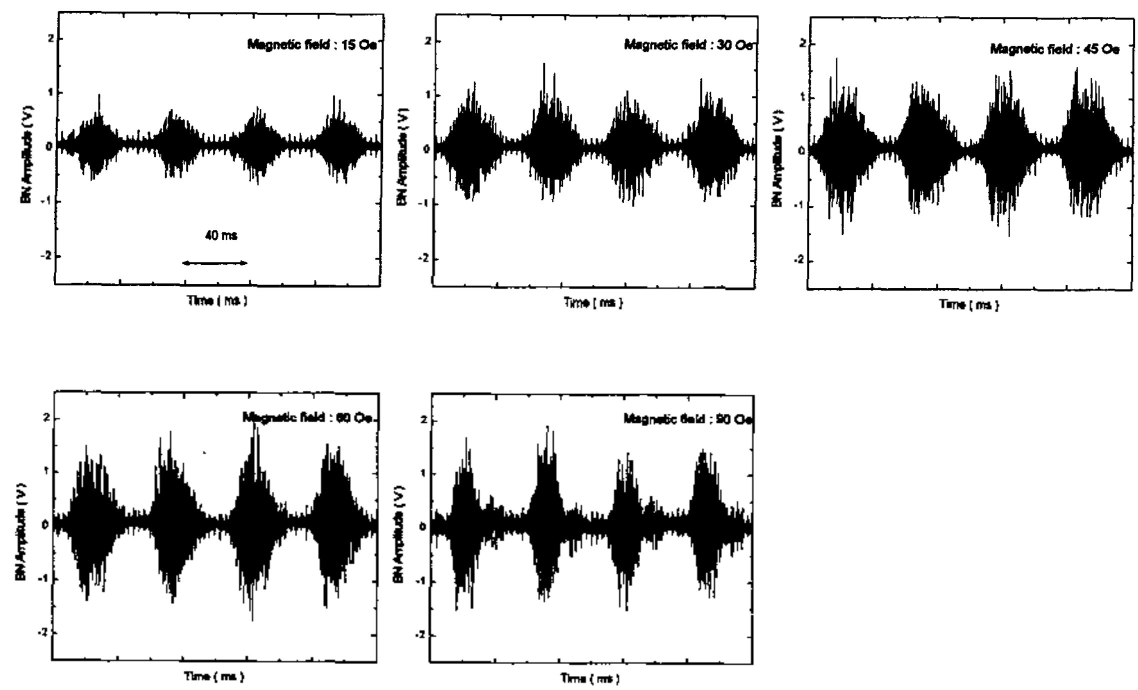


Figure 4. The dependence of magnetic Barkhausen waveforms on the magnetic field on irradiated base metal.

Figure 3 and 4 show a comparison of the Barkhausen noise waveforms before and after the irradiation for base metal with a magnetic field, 15, 30, 45, 60, and 90 Oe, respectively. The Barkhausen noise signals reflect the statistical nature of both the number of event and individual pulse height via the degree of overlapping in the detector coil, in which the individual pulse is signified by the irreversible wall motion. Generally, it is known as Barkhausen noise amplitude decreases when the motion of domain wall is impeded by a retarding force. Therefore, the decrease of Barkhausen noise amplitude in neutron irradiated specimen is attributed to the hindrance of the domain wall induced by defect clusters. Figure 5 show a comparison of the Barkhausen noise waveforms before and after the irradiation for base metal with a magnetic field, 4Hz.

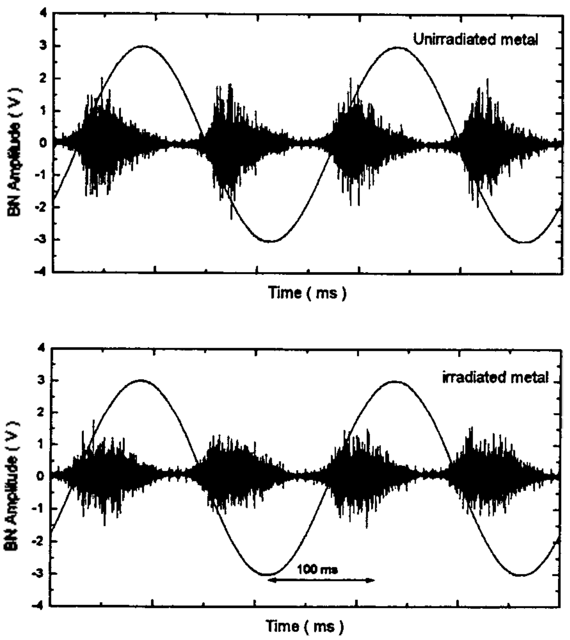


Figure 5. Magnetic Barkhausen waveforms of base metals at a 45 Oe magnetizing field and 4 Hz.

### 3.2 Spectrum analysis of Barkhausen noise[12)]

The spectrum analysis is a useful method for a sort of random noise embedded with a deterministic signal to extract a certain characteristics of the specimen. In orde to observe the harmonics frequency of the applied AC current, the spectrum analysis of the BN signal of specimen is performed This method is able to supply the charteristics of the harmonics frequency as well as the fundmental frequency. The spectrum of input signals is represented as the equation of (3-4).

$$\Phi(e^{j\omega}) = \sum_{-\infty}^{\infty} \phi(n) e^{-jn\omega} \qquad (3\text{-}4)$$

where $\phi(n)$ is the signal of time domain.

$\phi(n)$ is represented as the AC signal.

$$V_{in} = A\cos\omega t \qquad (3\text{-}5)$$

where $\omega = 2\pi f$.

In the experiment, frequency 4Hz, 8Hz and magnetic 45 Oe is adopted to meet the impedance-match. In case of 3 order model of harmonics, the output is depicted as below (3-6).

$$V_{out} = k_0 + k_2\frac{A^2}{2} + (k_1 A + \frac{3k_3A^3}{4})\cos\omega t$$

$$+(\frac{k_2A^2}{2})\cos 2\omega t(\frac{k_3A^3}{4})\cos 3\omega t \cdots \qquad (3\text{-}6)$$

, where $k_0 \sim k_3$ is harmonic parameter, $A^1 \sim A^3$ is amplitude.

The output spectrum involves the DC components, fundmental frequency and harmonics frequency. If $\omega_1, \omega_2$ the input signals exist, the equation is expressed as the below

$$\omega_{nm} = |n\omega_1 \pm m\omega_2| \qquad (3\text{-}8)$$

, where $n$ and $m$ results in $n+m \le 3$[12,13)]

The spectrum of Barkhausen noise is analysed with an applied frequency $\omega_1$=4 Hz , $\omega_1$=8 Hz of sampling time 50 $\mu$ sec, 20 $\mu$ sec. The spectrum of an applied magnetic field 4 Hz is plotted as figure 6 with the leakage phenomena. The leakage phenomena is resulting from the finite computation different from the equation 3-4[13)].

In case of $\omega_1$=4 Hz, the harmonic frequency shows at 4

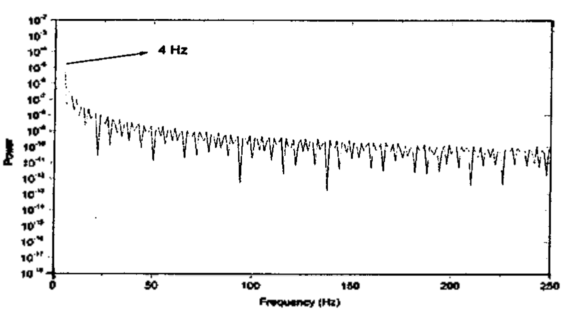


Figure 6. The peak frequency of an applied current with leakage phenomena.

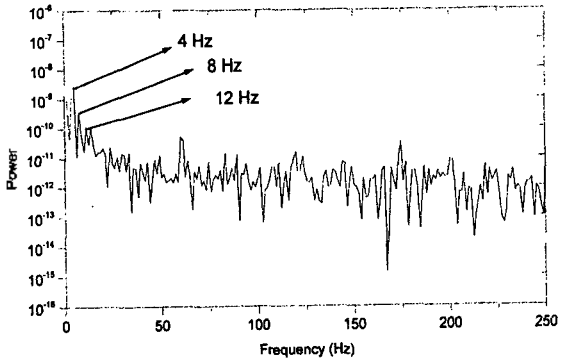


Figure 7. The harmonics frequency of an applied current 4Hz on the unirradiated base metal.

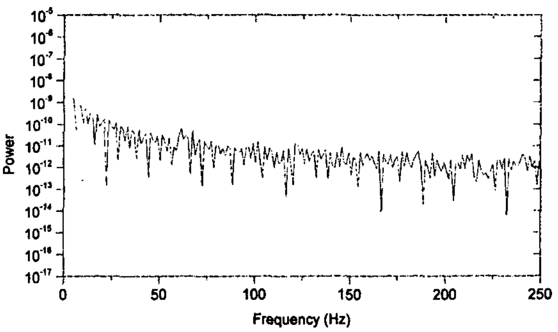


Figure 8. The non-harmonics frequency of an applied current 4Hz on the irradiated base metal.

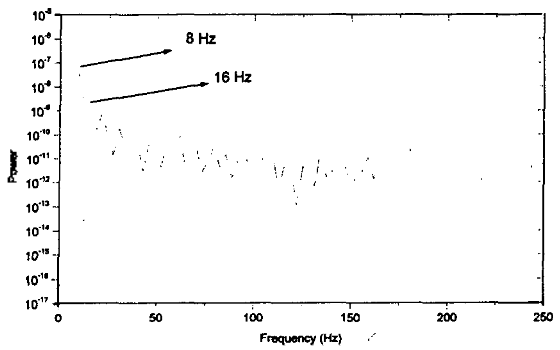


Figure 9. The harmonics frequency of an applied current 8Hz on the unirradiated base metal.

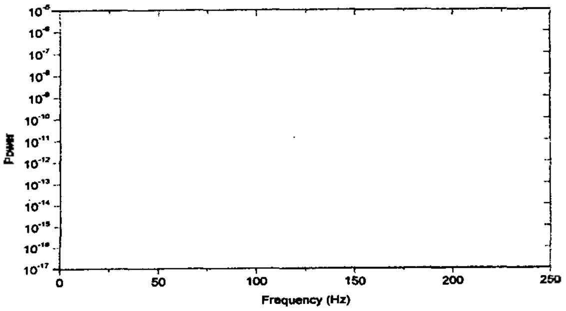


Figure 10. The non-harmonics frequency of an applied current 8Hz on the irradiated base metal.

Hz, 8 Hz and 12 Hz dominantly reflected from an unirradiation specimen in figure 7. In case of 8 Hz, the harmonic frequencies are showen at 8 Hz, 16 Hz dominantly echoed from the unirradiation specimen in figure 9. The harmonic frequency, however, disappeared on the irradiation specimen possibly due to the hindrance of the domain wall induced by the defect clusters in figures 8, 10[8,9].. The analysis of the harmonic frequency is a useful tool for the monitoring degradation induced by the irradiation.

## Ⅳ. Conclusions

Irradiation effects of neutron irradiated Mn-Mo-Ni low alloy steel were measured and compared using magnetic measurements. The saturation magnetization of neutron irradiated samples did not change. The neutron irradiation caused the coercivity to increase, whereas susceptibility to decrease. Barkhausen noise parameters associated with the domain wall motion were decreased by neutron irradiation. Barkhausen noise energy and susceptibility have increased while coercivity have decreased. The harmonic frequenies show at 4 Hz, 8 Hz and 12 Hz reflected from an unirradiation specimen. The harmonic frequencies, however, disappeared on the an irradiation specimen due to the hindrance of the domain wall induced by the defect clusters. The harmonic frequency can be a useful tool for the monitoring degradation induced by the irradiation. The results suggest that the magnetic measurements may be used as a promising nondestructive evaluation method in monitoring degradation of the reactor material such as a SA-508 of PWR-RPV steel and a $Zr_4$ H ANARO-CNH due to a neutron irradiation.

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