TELKOMNIKA, Vol.12, No.3, September 2014, pp. 523~630
ISSN: 1693-6930, accredited A by DIKTI, Decree No: 58/DIKTI/Kep/2013
DOI: 10.12928/TELKOMNIKA.v12i3.96

Application Status of the Barkhausen Effect in Nondestructive Testing

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Abstract

Change of internal structure or internal defect in ferromagnetic materials can produce change in Barkhausen noise, and by using Barkhausen noise signal measurement, the quality and internal defects of the material can be judged. The nondestructive testing technology is based on the Barkhausen effect, it gets the attention because of its advantages, such as rapid, non-destructive, mensurable, mainly used to detect stress, hardness, grain size, grinding burn etc.. The research status of Barkhausen effect in nondestructive testing was reviewed. Its application situation was investigated that the nondestructive testing technology based on the Barkhausen effect on stress, hardness, grain size, grinding burn detection etc., and the relationship between the MBN signals and stress, hardness, grain size, grinding burn were showed.

Keywords: *Barkhausen noise, Barkhausen effect, stress, hardness, grinding burn*

1. Introduction

Barkhausen effect was found for the fist time in 1919, after years of research, today it developed into a nondestructive testing technology. The nondestructive testing technology based on Barkhausen effect is using the presence of magnetic signal caused by the exceptions or defects of the internal structure of materials to determine the damage degree of abnormalities and defects of the structure. It being mainly used for evaluating the quality and fatigue condition of the ferromagnetic materials, having the advantages of nondestructive, quantitative, reliable, fast, through the electric plating layer, large area detected, environmental protection and no harm to human body, the technology has significant application value in fields that including machinery, metallurgy, construction, aviation and aerospace, nuclear energy, transportation and other industries, as well as the geological exploration, safety testing, materials science and so on. Thus, the nondestructive testing technology based on the Barkhausen effect has become hot spot of the research.

2. The Barkhausen effect

In 1919, the German scientist Dr. Barkhausen found that the hysteresis loop of ferromagnetic materials is not perfectly smooth curve in the action of outside alternating magnetic field, and the matte part is enhanced in a step leap way, it can make the receiving coil that placed on the surface of the ferromagnetic materials to produce pulse signal and noise that will make a sound after being amplified by loudspeaker [1]. This phenomenon is called the Barkhausen effect and the noise is called MBN (Magnetic Barkhausen noise) [2], as shown in Figure 1.

Along with understanding of ferromagnetic materials, people found that there are a lot of magnetic domains segmented by magnetic domain wall inside the ferromagnetic materials, because of the internal magnetic domain sort in random but the magnetic offsets each other, macroscopically, the ferromagnetic materials have no magnetic. The magnetic domain would reorder in the direction the external magnetic field when the ferromagnetic materials placed in magnetic field, at this time, materials will show magnetic to the external. Ferromagnetic materials of inside space, defects such as dislocation and nonmetallic slag complicate the

Received March 27, 2014; Revised July 8, 2014; Accepted July 21, 2014

magnetic domain structure, and hinder the movement of domain wall. J. Pal'a and others have designed the experimental measurement system [3], as shown in Figure 2, the Barkhausen noise can be observed when applying parallel and perpendicular magnetic field to the stress direction. With the enhancement of external magnetic field, 90° and 180° domain wall (mainly the 180°) are going to happen irreversible movement in a jumping way, namely the Barkhausen Jump [4]. Due to the domain wall irreversible movement, friction and extrusion will happen between the adjacent magnetic domains, and this will cause magneto-acoustic emission, so the noise is appearing, that is Barkhausen noise. Because the magnetic characteristics is decided by internal microstructure of ferromagnetic materials, and displacement of the domain wall is sensitively influenced by micro structural change and surface stress distribution of materials, Barkhausen noise can reflect that interior microscopic structure change and stress conditions of metal material. Since the 1960s, researchers were using the MBN nondestructive testing to assess the ferromagnetic materials conditions of macrostructure, stress, grain size, fatigue etc.

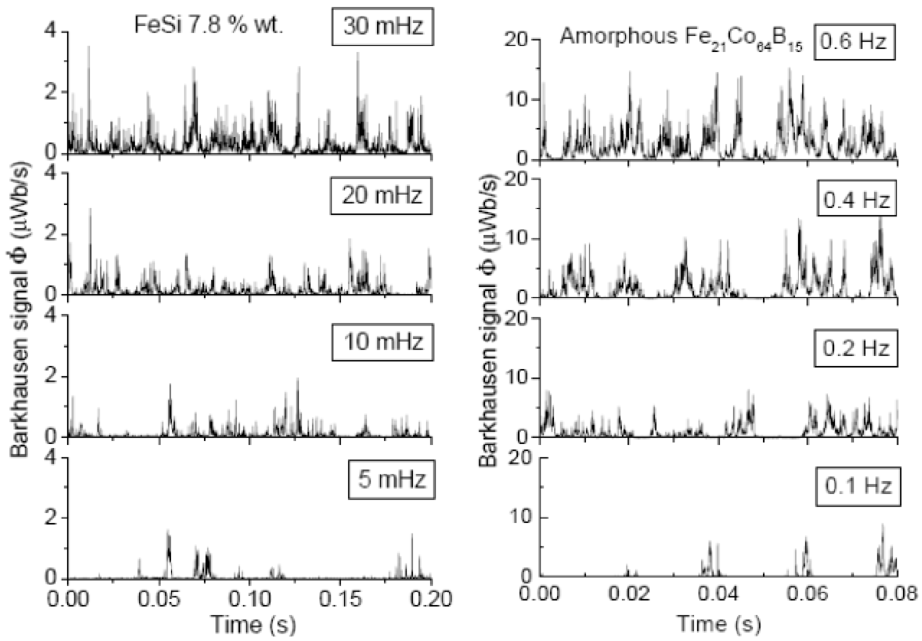

Figure 1. Time sequences of Barkhausen noise measured in a polycrystalline FeSi 7.8 % wt. ribbon (left) and an amorphous Fe21Co64B15 under moderate tensile stress (right). The labels indicate the frequency of the applied field [2]

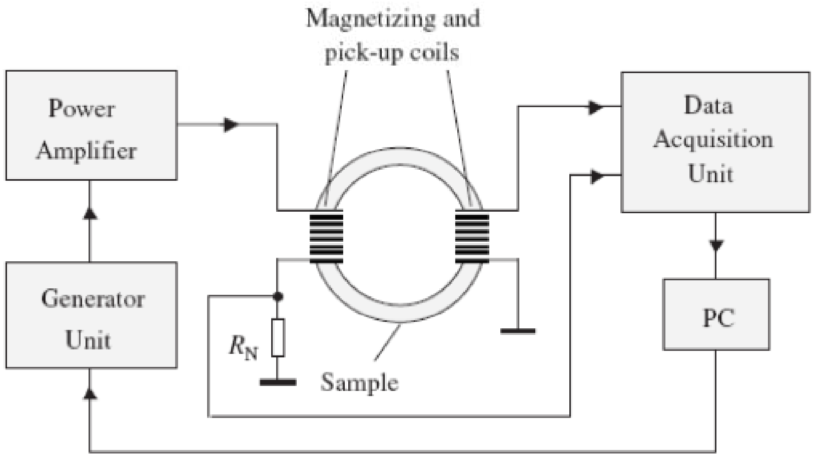

Figure 2. Sketch of the measuring system [3]

3. The application status of Barkhausen effect in nondestructive testing

3.1. Stress testing

The research on that nondestructive testing technology for detecting stress distribution and the size of the residual stress based on Barkhausen effect has been in-depth. In 1987, Kirsti Tiitto etc. used the Barkhausen effect to measure residual stress in ferromagnetic materials, and obtained good consistency by comparing with hole-drilling stress method and X ray methods [5]. It was also proved the feasibility of MBN measuring the residual stress. C. G. Stefanita etc. had analyzed the principle of MBN testing technology setting out from the micro theory, and researched after material bending the relationship between material stress condition of plastic deformation and elastic deformation and MBN signal. As shown in Figure 5, it's the relationship between stress condition of the plastic deformation and MBN signal, the two curves in the figure are respectively measuring result of detection head that parallel and perpendicular to the direction of stress [6].

Durin G etc. found that there is certain relation between noise and stress (strain), namely noise increases with the increase of strain, reduces with the increase of stress, since they combined with the power spectrum analysis and statistical analysis, from the perspective of signal analysis and processing [7]. S. Desvaux etc. have the MBN testing technology applied to the M50 steel stress testing [8], they found that distribution and size in surface residual stress of the annular M50 steel have certain linear relationship with MBN signal spectrum, and compared to the measuring result of the X ray in diffraction, both have good consistency, as shown in Figure 6.

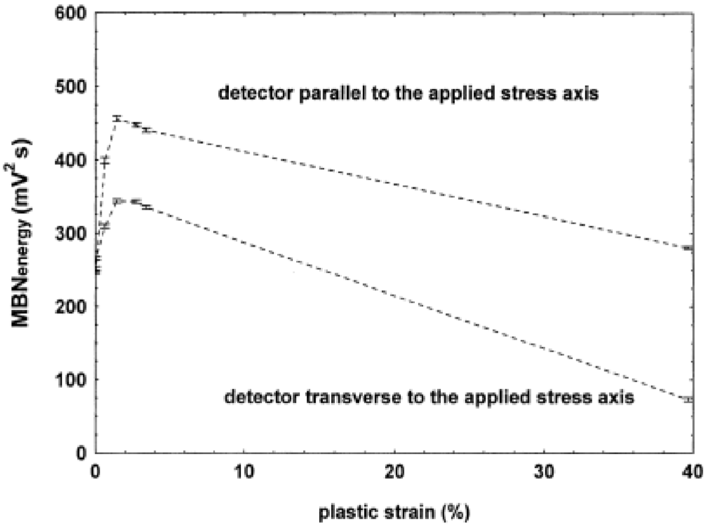

Figure 5. Relationship between stress condition of the plastic deformation and MBN signal [6]

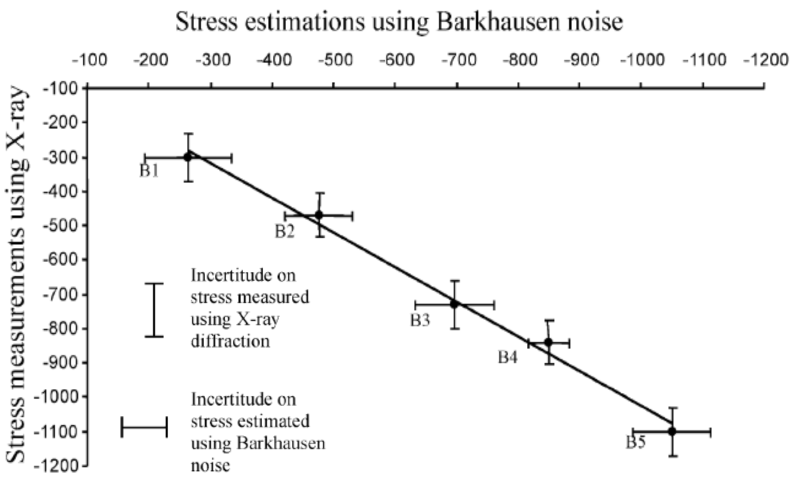

Figure 6. The measured surface residual stress of the annular M50 steel by X-ray diffraction versus surface residual stress estimated of the annular M50 steel by Barkhausen noise [8]

Aki Sorsa etc. used the characteristic value of the MBN signal (half peak width, peak position, crest factor, coercive force, remained magnetic) to build the mathematical model of forecast material hardness and stress [9]. T. Inaguma etc. used MBN technology to evaluate steel stress condition in different carbon content, also gave the curve about relationship between stress of the mild steel with Carbon content 0.1% - 0.5% and the Barkhausen noise [10]. O. Kypris etc. used MBN technology to evaluate the stress under different depth [11], they had stress calculation method of different depth by stress piezoelectric checking.

To evaluating stress condition using MBN for steel pieces of the plane was proposed by Ma xianyao who has given the relationship between MBN extremer and stress [12]. Multifunction magnetic elasticity instrument was developed to detect residual stress by Mu Xiangrong etc. [13]. Weld residual stress detector based on MBN technology was developed by Qi xin etc., which can precisely detect the stress distribution of welds and the value of the residual stress, and the MBN signal calibration curve was drawn[14]-[16]. They obtained the result that the distribution of the weld residual stress is approximate with symmetry and gave the mathematical model of Barkhausen noise. Juan Chen made the Barkhausen detection sensor that was used to detect the internal stress of ferromagnetic materials [17]. Yu Shisheng and Qi xin etc. have been committed to the rail longitudinal temperature stress research, developed rail longitudinal temperature stress detector, and carried on the test at the scene of the rail and inspected the health of the rail [18]-[22]. Chen Ligong etc. studied steel welding part in the changes of MBN noise before heat treatment or after [23]-[24]. They have analyzed power spectrum for the MBN noise signal, and found that before or after heat treatment, with the decreasing of weld residual stress that the MBN signal level is on the decline. Tang Dedong etc. researched the temperature influence mechanism of the flexible cable force sensor and designed a differential structure to realize temperature compensation [25].

3.2. Testing of hardness and grain size

Ranjan, R etc. have used the Barkhausen effect to decide the grain size of nickel and decarburized steel [26]. They had obtained the relation between grain size and both acoustic Barkhausen signal(AB) and magnetic Barkhausen signal(MB) by designing the measurement device of MBN grain size, namely in nickel, both AB and MB signal decrease with increasing grain size, in decarburized steel,however, AB and MB signals increase with increasing grain size. P. Zerovnik etc. was used the Barkhausen effect to measuring the size of steel and the result showing that the noise increases with the increase of hardness [27]. Charles H. etc. used the Barkhausen testing method to detect the microstructure of nuclear reactor ferroalloys (HT-9) for three different process of heat treatment [28]. This proved that the main loop coercive force and remnant magnetization are proportional to the hardness, and MSN signal is proportional to the hardness. P. Zerovnik etc. evaluated microstructure, hardness and surface stress of the material surface hardening layer by using the Barkhausen noise [29]. It was found that changes of energy input in the specimen surface layer affected the microstructure variation and, consequently, microhardness and the residual stress.

Li Qiang etc. designed the magneto elastic sensor and testing system based on Barkhausen effect to measure the grain size of the ferromagnetic materials, they found that the Barkhausen noisy signal increases with the increase of average grain diameter [30]. Tian Jianlong etc. designed the magneto elastic sensor and testing system based on Barkhausen effect for detecting 45#steel on line [31], the result showed that the Barkhausen noisy signal increases with the increase of hardness.

3.3. Quantitative analysis of grinding burn

Grinding burn is the result of energy being converted to heat in the production of workpiece. This heat is concentrated in the surface layers and may cause deleterious effects if not properly managed. Ceurter. Jeffrey S etc. put up using Barkhausen effect to evaluate the degree of grinding burns of gear and the acid corrosion acting as a reference, they set up a relation curve about magnetic parameters MP value and degree of grinding burn for one gear type on a motorcycle transmission gear system [32], as shown in Figure 7. Figure 7a is a correlation for the maximum MP values measured on all scans of a gear, while Figure 7b is a correlation for the difference between maximum and minimum MP values measured on all scans of a gear.

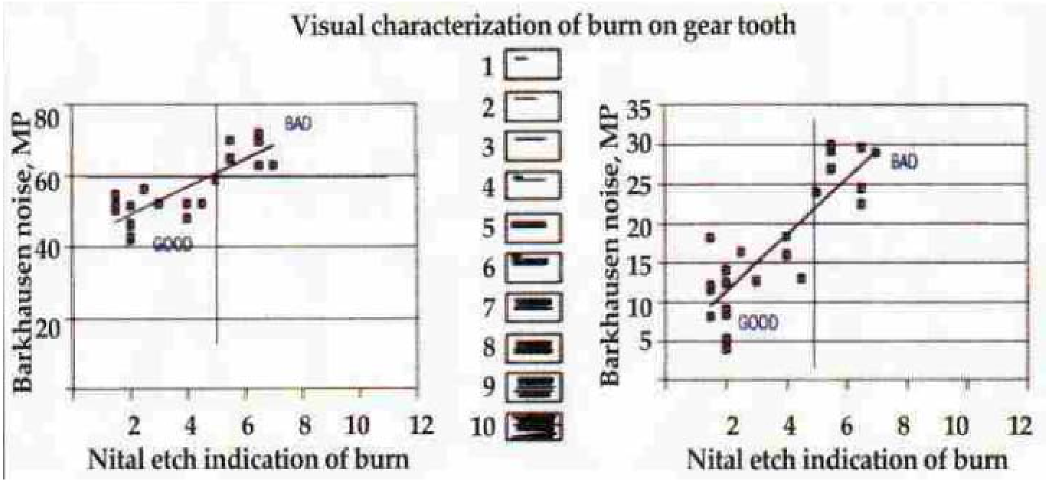

Figure 7. (a) Maximum MP correlation with nital etch. (b) Difference (Maximum Minimum) MP correlation with nital etch [32]

Kendrish S.J. and Siiriainen J. etc. used magnetic Barkhausen Noise Analysis(BNA) to evaluate change in microstructural properties [33],[34]. They got the qualitative results that correlate BNA test values to acid etch patterns/colors for the detection of retempering burn defects. Vaidhianathasamy M. etc. have made the MBN measurements on Marine Gears made with case-carburised En36 steel using three different methods, namely, High Frequency, Medium Frequency and Low Frequency MBN measurements [35]. They found that the grinding damage in different deep layers can be detected using different frequency MBN measurements, and the themal damage caused by grinding brun is clearly revealed by the shifting of the Low frequency MBN perk tolower magnetic field. Suvi Santa-aho and A. Sorsa et al. produced calibration samples for the Barkhausen noise methods with laser processing and optimized parameters for the laser processing [36],[37].

4. Conclusion

MBN applied in engineering is the inevitable trend of future development, while the development of testing equipment is the ultimate way to realize industrial application, thus MBN sensors and the whole equipment research and development will also be the focus of future research and development.

Above all, the following conclusions are drew:
(1) MBN signal increases with the increase of tensile stress, decreases with the increase of compressive stress.
(2) MBN signal increases with increasing hardness.
(3) MBN signal increases with increasing of burn degree.
(4) MBN signal begins to increase with the increase of the material that being tested carbon content, when increase to a certain extent, MBN signal decreases with the increase of the material that being tested carbon content.
(5) MBN signal attenuation degree will increase with the increase of the detection depth.

So the stress, hardness, grain size, grinding burn of ferromagnetic materials can be detected by using MBN signal.

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