

NEW APPROACH TO FATIGUE DAMAGE EVALUATION VIA BARKHAUSEN NOISE

Vengrinovich V.L, Busco V.N., Institute of applied physics, Minsk, Belarus.

The report relates to the field of material Non Destructive Evaluation (NDE), namely to the fatigue damage NDE, considering also the complexity of fatigue phenomena and alternative approach to fatigue damage assessment.

The fundamental approach to the conventional fatigue damage NDE via various physical characteristics like conductivity, permeability, Barkhausen noise (BN), optical or x-ray reflection, etc. is based on fitting the corresponding measured values of these parameters to calibration diagram, preliminary acquired experimentally by variation the number of cycles. Unfortunately the prediction of fatigue damage, going this way, is frequently useless mainly due to three reasons: 1) fatigue is too complicated phenomena to have the monotonic calibration diagram. E.g. fatigue degradation is usually defined ambiguously via magnetic characteristics; 2) the irrelevant material characteristics like microstructure, residual plastic deformation, surface condition, etc. are usually mask the influence of structure variations provided by fatigue; 3) the fatigue, particularly at early stages, is commonly associated with changes in fine sub microstructure, characterized by behavior of vacations, dislocations, micro cavities, glide lines, etc., while the micro structure variations, provided by fatigue, are usually negligible, similarly to measured physical characteristics associated with them. Therefore the way to fatigue characterization via absolute values of measured parameters should be complemented and elaborated. Last time there appeared several reports [1-3] on volatility behavior of BN parameters due to fatigue damage. This report is resulted from experimental study of spatial non uniformity of BN behavior in surface space and in depth in the specimens under investigation.

The cycling experiments were provided with the intermediate-alloy steel 40Cr (0,4%C and 1% Cr), low carbon soft steel ST3 and high strength martensite-ageing alloy VNS-2. The specimens (in the fig.1, right) were cycled by bending until crack appearance. The measurements were done with the BN analyzer "INTROSCAN". Scanning along the specimen across specimen's neck were done with the sensor which measurement area was about 1mm². The scanning results for intermediate-alloy steel 40Cr are shown in the fig. 1.

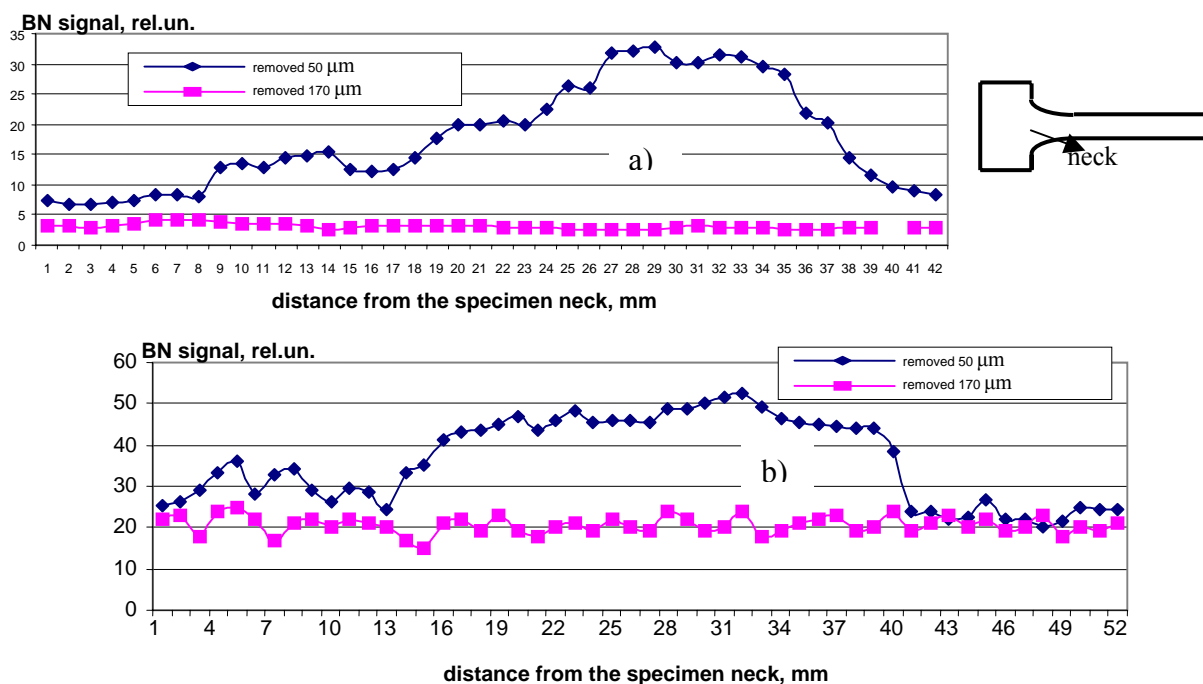


Fig.1. BN signal distribution in the fatigue zone after removal of 50 and 170 μm relatively after cycling of the: a) martensite-ageing steel VNS-2 and 2) intermediate-alloy steel 40Cr

Each pair of scans on a) and b) diagrams corresponds to two undersurface layers: respectively 50 and 170 μm depth. The measurements were done after electro polishing removal of respective layers from the specimen surface. Therefore 50 μm depth corresponds to the layer close to surface while 170 μm depth corresponds to the ground material. The results, from one side, clearly show the growth of an average signal value due to fatigue damage, and, from the other side, they reveal the growth of the spatial non uniformity in the damaged layer.

The growth of the spatial non uniformity is also illustrated by the BN signal distribution with depth resolution shown in the fig.2 respectively before cycling (0), after 18000 and 40000 cycles.

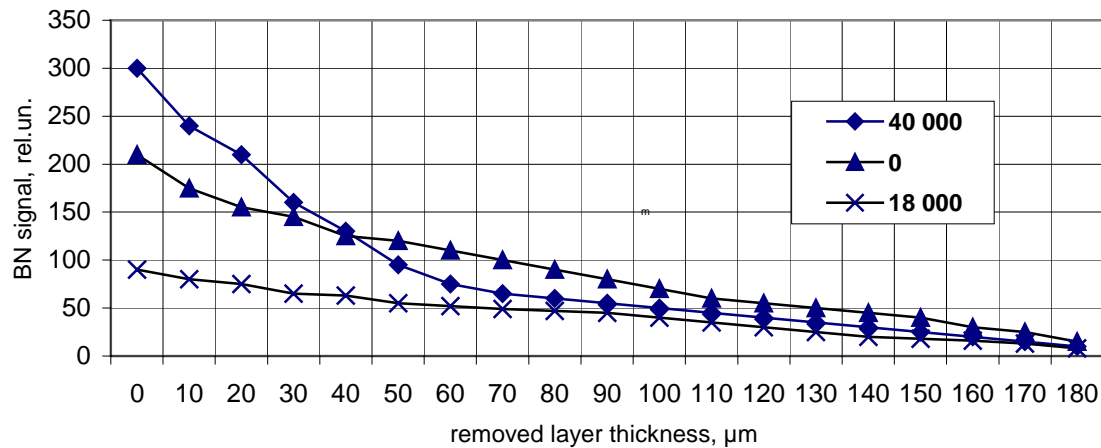


Fig.2. BN signal value vs removed layer thickness after cycling of the martensite-ageing alloy VNS-2

The step-by-step removal of surface layers was provided by electro polishing. After each layer removal from the surface of the fatigue damaged specimen scanning measurements of BN signal were done. The scanned results confirmed the ambiguous correlation between magnetic parameter and number of cycles (fig.3).

The dependence of BN signal over removed layer thickness until reaching the ground material displays strong signal reduction while moving off the next surface layer (fig.2). It is interesting that the behavior of BN signal in the immediate undersurface region is ambiguous. At the early fatigue stages the signal is dropping while at the later stages it increases. Thus just before crack appearance at 40000 cycles the BN signal value on the surface increases in times. But the main conclusion is that the difference between BN value on the surface and under the damaged layer increases for about one order. This result is in qualitative compliance with well known fatigue

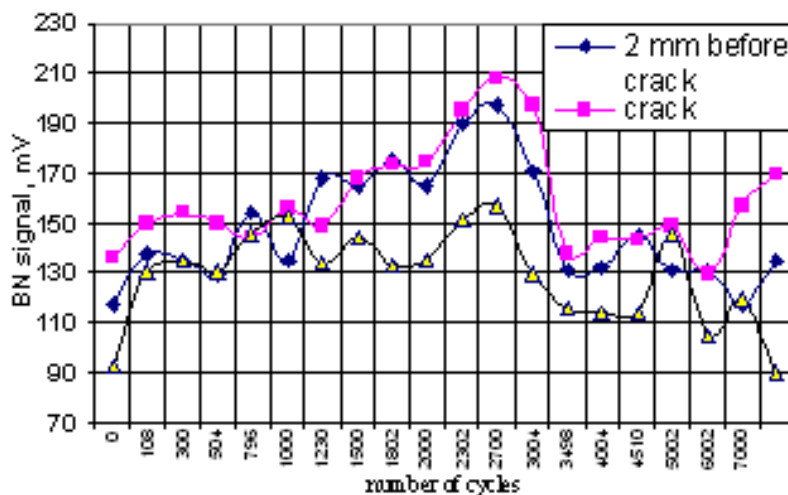


Fig.3. Initial part of the dependence of BN signal over number of cycles for intermediate-alloy steel 40Cr

damage origination from the surface layer. The ambiguous dependence of BN signal over number of cycles for intermediate-alloy steel 40Cr is clear from fig.3 for three positions of sensor location relatively to the crack initiated by fatigue.

It is seen that after approximately 3000 cycles the BN signal increases, what indicates softening and loss of

strength of the intermediate-alloy steel in the quenched state. From the other hand the behavior of BN signal via number of cycles in the soft low carbon steel is different: the sequential cycling at its initial stage causes the decrease of BN signal what indicates the strengthening effect. The resultant diagram of low carbon soft St3 cycling is shown in the fig.4, having in mind that cycling was continued until crack development and sample collapse.

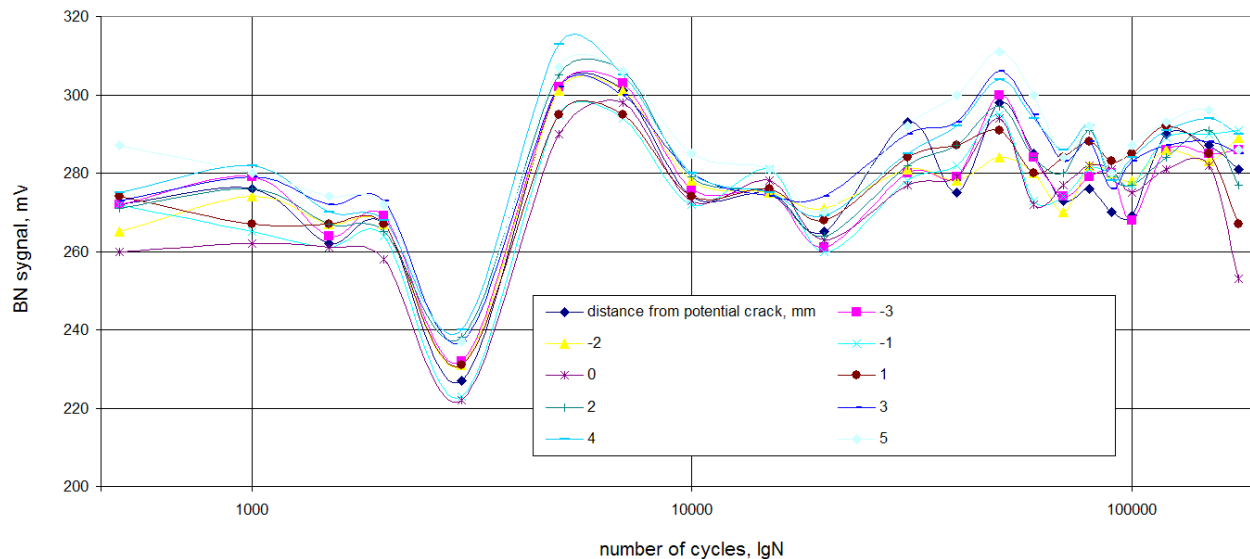


Fig.4. BN signal distribution changes via number of cycles variation during fatigue test of low carbon steel St3 in a crack zone at various distances from potential crack. FBC is 20 kHz.

The microstructural investigation charges these changes to the first stage of fatigue associated, in its turn, with the appearance of Luder's lines and glide planes. In high strength material it causes softening while in soft materials – strengthening effects respectively.

The full diagram also represents several stages of metal behavior during cycling, about five. In any case the multiple meaning of the curves does not give any chance to distinguish between them for non destructive testing purposes. This only means that stages of softening and strengthening during cycling are interchanged. The reliable result for this purpose is that in soft steels the stage characterized by the appearance of Luder's lines and glide planes as well as pre crack stage are interfaced with material softening. The other conclusion follows from the observed similarity of curves behavior for the BN signal measurements at different distances from the potential crack location. This means that the investigated area nearby the crack zone behaves similarly to the crack location itself. From fig.1 it follows that a “damaged crack zone” is usually quite large. This is also seen from fig.5, which shows the BN signal in steel St3 profile across the crack zone after various number of cycles. Therefore the critical cycles, where the profile is mostly distinguished in crack zone and out of it respectively, appear at the first and the last stage of fatigue damage respectively. Thus not the BN value itself but the BN profile “volatility” nearby the crack zone is important as a criterion of fatigue damage. The effect is emphasized at two stages: Luder's lines and glide planes, from one hand, and the stage just before crack appearance, from the other.

It could be predicted, that irreversible part of magnetic permeability (it is usually associated with BN activity) would have the similar behavior in the “crack zone”. Then it is clear that if one would measure the gradient value of the irreversible permeability across a crack zone its sign change within the profile could be observed. This easy predictable fact is probably the origin of the well known speculations, unreasonably called “magnetic memory” in an uncontrolled earth magnetic field.

The size of the present article don't give the opportunity to display all details of described experiments, but one important should be mentioned. This touches upon the frequency range of Barkhausen noise used in experiments, namely frequency band center (FBC). Those used in our experiments were 20, 50 and 100 kHz respectively. Two last higher FBC (50 and 100 kHz),

providing smaller penetration depths, namely approximately 0,2 and 0,1 mm respectively, for this low carbon steel, were unable to distinguish between different fatigue stages and different zones location. Those distinguishes became perceptible only at the FBC 20 kHz – minimal possible by the applied equipment. Corresponding penetration depth was about 0,5 mm. The results clearly point out that main micro structure changes during fatigue start up not at the surface itself, but in the undersurface layers. Though, observed differences in the behavior of surface and undersurface layers respectively are in compliance with the direct experimental results on BN measurements at different layers shown in the fig.2. It outcomes then that the “volatility” parameter has decisive

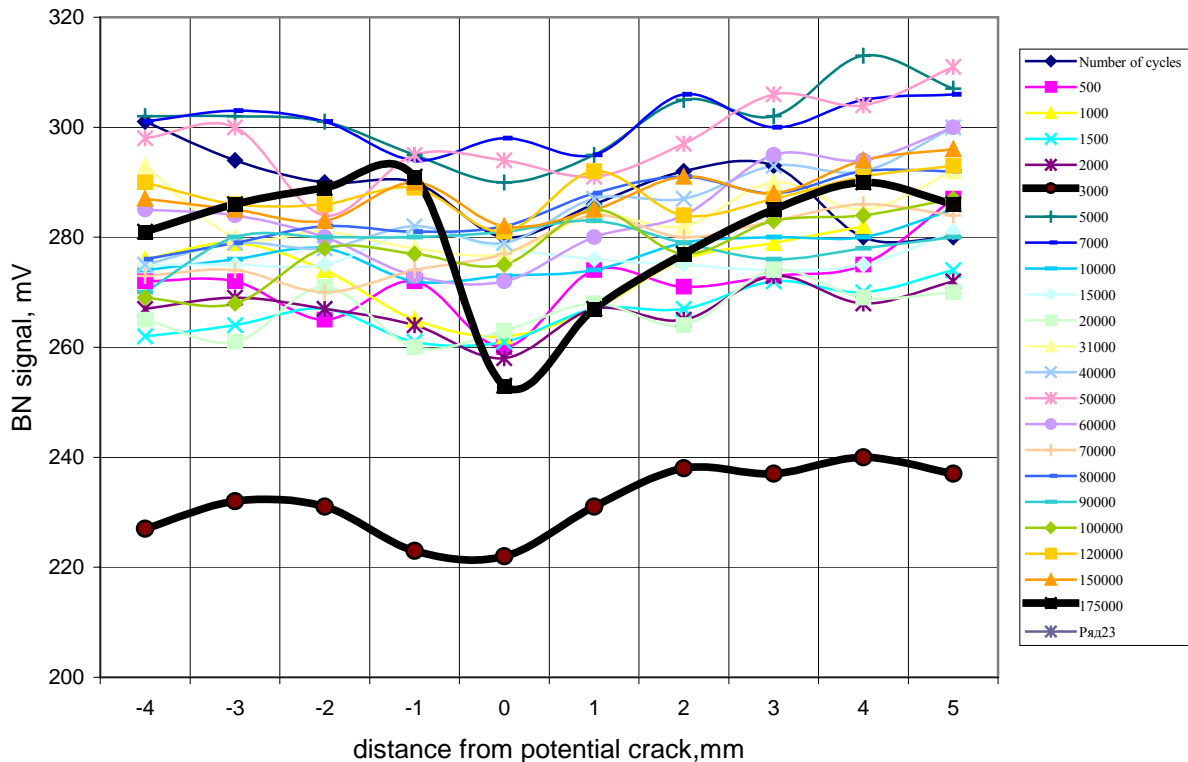


Fig.1. BN signal distribution in the surface within the fatigue zone after different number (right) of fatigue cycles. It is seen that only at the first stage of fatigue and just before the crack appearance (heavy lines) the crack zone becomes clearly distinguished.

meaning in the stage of fatigue damage estimate.

Finally the report stresses on the need to reset the approach to fatigue damage NDE using the parameters of non uniformity and “volatility” of BN signal, rather than its absolute values.

References:

- [1] J. Schreiber, U. Cikalova, and Ye. Vertyagina. Use of the fractal nature of spatial and temporal response behavior for materials damage characterization. Proceedings of the Sixth International Conference on Low Cycle Fatigue P.D. Portella, T. Beck, and M. Okazaki eds., DVM, Berlin, Special Issue, pp. 655-660.
- [2] V.Filinov, A.Filinova. Mechanical stress testing in steels by using magnetic and magneto acoustic effects. J-I “Testing and Diagnostics”, №2, 2007, pp. 41-44.
- [3] V.Vengrinovich, V.Busko and A.Dovgyallo. Spatial non uniformity as a new criterion to estimate residual life time of machine parts. Proceedings of the III Int. Congress on theoretical and applied mechanics “Mechanics-2007”. 16-18 Oct. 2007 г., ed. By M.Vysotski, Minsk, pp. 282-288.