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The Usage of the Microwave Crack Detector for Fatigue Cracks Detection

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Abstract

The work includes the description of fatigue cracks testing. The first tests were carried out with the help of microwave crack detector using the ultrasonic sound. The tests results proved the expectation. The equipment set "Remote Indicators Active Defects-2" (also RIAD-2) allows to perform remote detection of the active defects, occurring in the metal parts of the samples after cycle testing. The aftereffect with the duration time starting from several minutes and up to several hours was pinpointed for the first time. The successful results were achieved in the reactivation of inactive defects.

Keywords: defect, bending, microwave sensor

1. Introduction

The previous tests on the laboratory models of the microwave sensors used for the detection of the active defects in the metal samples allowed to begin the research, being of concern to the remote detection of the active defects. The earlier tests, performed on the tension testing machines showed the range of the microwave sensor capability by its fatigue failure load (see Gorbunov & Sutorikhin, 1999, 2010, 2012). The new tests results showed the possibility of determining the danger rating in the increasing fatigue stress.

The research objective is to determine the height of the valid signal functional relation (i.e. its spectral components) to the number of stress cycles and to find the activity duration (i.e. "memory" effects) after mechanical impact is finished.

The grave contradiction between the given efficiency of the testing ultrasonic sound (not more than 5 or 6 Watt) and the intercepted power of the spectral components (exceeds the indicated ultrasonic sound power for 45.5 dB or from 800 to 900 Watt), noticed by the authors makes the discovery basis (Sutorikhin, 2012). The unusual characteristic of the new phenomenon, which was detected while testing, resulted in the significant memory effect duration.

The laboratory equipment of the "RIAD-2" set. "RIAD-2" contains 1 generator of the ultrasound. The "RIAD-4" set (contains 2 generators of the ultrasound), designed and tuned during the previous testing stages proved its operational integrity, ability for the remote detection of the hidden faults as well as its compliance with the standards for the NDT remote inspection equipment.

The unusual phenomenon, on which the research is based, required some efforts to define the new criteria for certain physical parameters choose to stimulate the critical stresses represented as the heights of the valid signal spectral components. It is incidentally known, that the irreversible deformation while undergoing mechanical stress is always attended by the acoustic emission acts (Kostoglotov & Popov, 2002). The given crystalline deformation is often registered by the "counting rate" of the sound impulse, defining the defect activity rating.

There are certain modern methods for defining the fatigue rate of the steel samples (Bezlud'ko, Yolkina, & Solomakha, 2009), aluminium alloy samples (Tupikin, 2011). The three given branches (acoustic emission, coersive force measurement and thermoelectric method) obviously enrich the modern methods for metal fatigue capacity determination. In line with the new methods there are also the time-honoured, well-known ones, applied for fatigue capacity determination. These ones are based on the direct determination of the strength level (National State Standard 25.505-85, 1985). Such variations for the cyclic loading (such as extcompletion and squeezing or torsion) assume the fatigue degree evaluation by the resistance reduction level up to 50% from the original point. It should be noted, that the 50% resistance reduction expects the microcracks to appear. The ability of metal to resist the fatigue failure is known as sturdiness, while the strain, by which the damage is carried out, is called vibration strength (lektsii-po-soprotivleniyu-materialov/-krivaja-ustalosti-krivaja-vellera, 2002, http://matsopru.ru/lektsii-po-soprotivleniyu-materialov/183-krivaja-ustalosti-krivaja-vellera.html), approaches asymptotically to a certain extreme, known as fatigue limit. The subject resistance reduction is assumed to be attended by the exert force reduction. Whether the exert force remains the same, than the dependence diagram for the strength level from the number of the loading cycles resembles the ATAN function (Nmax- 3n)/ATAN(Nmax), in which Nmax is the number of full loadings (see Figure 1, X- number cycles (N), Y- the strength level, Y=F/F_0, F- effort, Nmax=14) while the damage occurred, and n is the number of loading cyces.

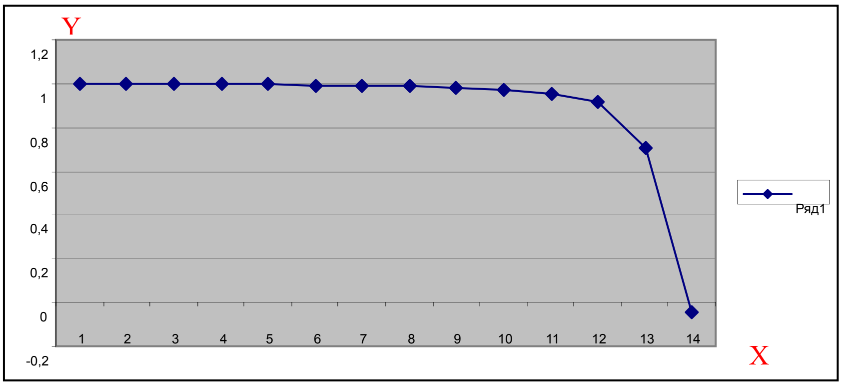


Figure 1. The Normalized level to toughness as function of the number of the cycles load

The significant strength level reduction for 20% or 25% occurs already by the number of cycles, approaching to the extreme (90%). Such significant loading exceeding 90% cycles are obviously very dangerous. Thus it is required to stop the mechanical stress when 10% or 20% strength reduction is seen. According to the test data (Kuzmin, Prokhorov, & Borisov, 1998), even the 10% strength level reduction results in microcracks occuring. The test data received by our group prove the microcracks to be attended by the registration of the spectral components of the ultrasonic sound frequency in the repelled microwave field. The valid signal exceeds the noise level for 4 or 5 dB.

This condition, called the enrichment of the repelled microwave signal range while microcracks occur is the new phenomenon in physics, a discovery able to change the known possibilities for the remote detection of the metal fatigue.

2. The Main Part

The authors initially suggested that the process of the stepwise mechanical stress should result in the fatigue stress accumulation, and valid signal height increase (Kuzmin, Prokhorov, & Borisov, 1998; Kostoglotov & Popov, 2002). However, while testing the first gagging (included 3 samples made of one plate with the dimensions of 500 × 85 × 4 mm supplied with the fixed console, divided in its end surface in three parts with the dimensions of 150 × 14 × 4 mm on the end surface) proved the level of the valid signal to increase significantly by crack occurring (see Figure 2). The unit steps of the spectral components while measured between the completion cycles (including 20 or 40 cycles) are insignificant and thus were registered by the devices given (such as spectrum analyzer SK4-59, analogue-to-digital converter AKTAKOM) poorly.

The working distance between the duct aperture plane and the samples surface was selected on condition of receiving the maximum proportion of the combination signal/noise and reached the point of 75 or 110 mm.

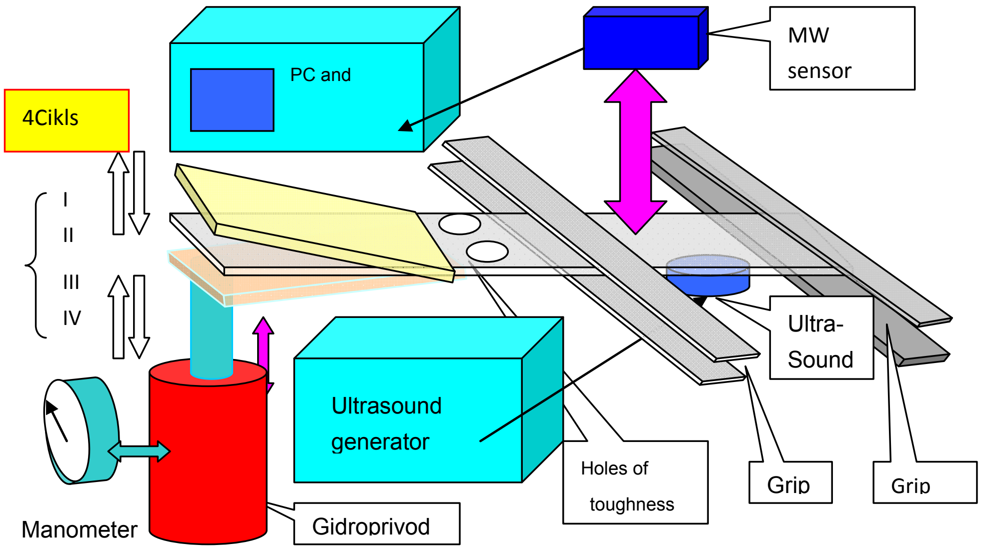


Figure 2. Structured scheme of the experiment

The proportion control was carried out with the help of the known current rate of the phase-lock detector for the microwave sensor. The detector current was determined by the previous testing performed with the help of the active defects simulator.

The spectrum diagrams (see Picture 3) show, that the valid signal rate increased for 5.1 dB after the cracks occurred (with the completion strength reduction for 20 or 25%). The initial valid signal rate with the noise equaled 11 dB, after the crack occurred it became 16.1 dB. Thus the difference equals 5.1 dB.

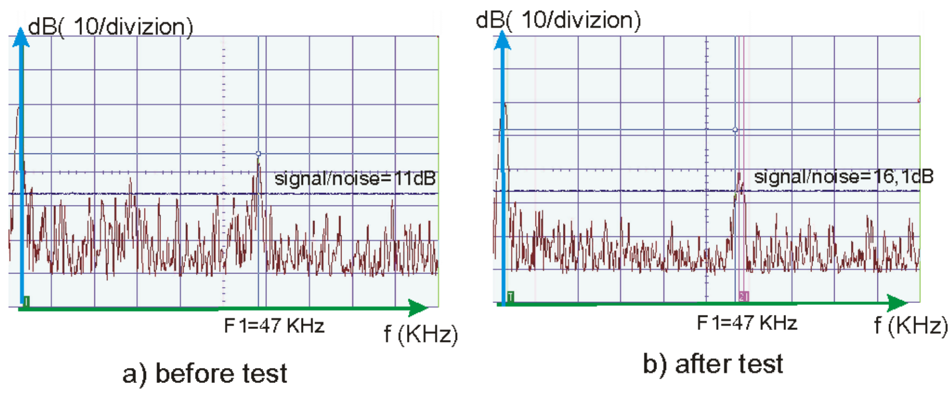


Figure 3. Spectral recordings show the begining (a) and the completion (b) of the test

The testing spectral recordings of the output signal by the certain number of load cycles can show the increase of the valid signal by a crack occurring (the increased rate equals 6.5 dB) (see Picture 4). The increased signal rate while 20 cycles were carried out (equal 3 dB) is occasional. Such occasionally increased signal rate fitsi its short increased height with its later lowering, which is common for the acoustic emission signals (Ivanov, Bykov, & Ryabov, 1985; Kostoglotov & Popov, 2002).

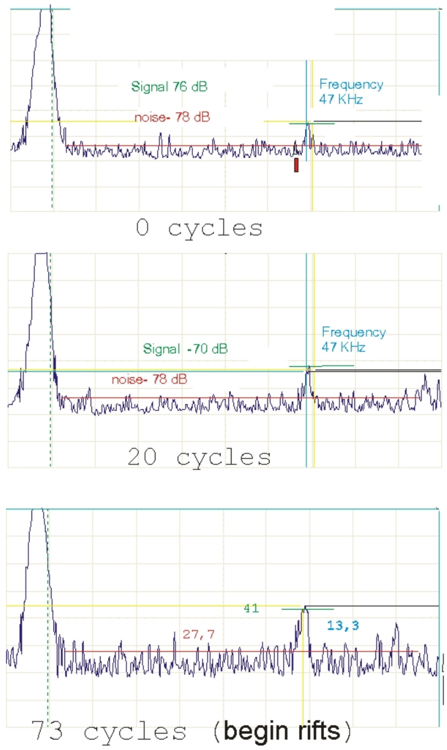
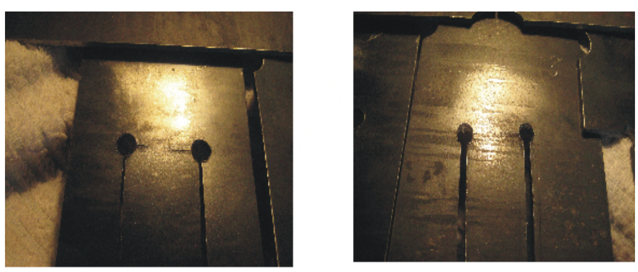


Figure 4. The change of the valid signal completion on the number of cycles

The spectral recordings represented here (see Figures 3, 4) refer to the single-frequency excitation with the rates of 47 kHz and 80 volt. The average increase rate for such signals from the testing beginning and until the cracks occur is equal to 6.5 or 8 dB. The number of the completions before cracks occur also varies from 70 and up to 180, what follows the artificial difference of strength in the completion point. Both samples No. 1 and No. 2 (see Figure 5) vary in their strength (where the second sample has a track of 1.2 or 1.5 mm deep)) in its expected damage area, which resulted in the number of cycles reduction. The crack length in the sample No. 1 equals to 3 and 6 mm due to the fact, that the first sample undergone the completion exceeding the required standard. The second sample has the tracks of 1 or 2 mm deep.

The testing with the impact of the bifrequency ultrasonic sound signal were carried out in compliance with the rate equal to 47 and 107 kHz.



a) b)

Figure 5. Sample after the testing completion, a- sample1, b - a sample 2

Such a bi-harmonic signal of the same heights of 80 or 90 volt was indicated at the testing beginning with a controlling piezoelectric hydrophone.

The several bendings performed (which made 50 or 68 times), made it possible to detect the subtractive spectral components (see Figure 6). Their occurrence matched the cracking with the depth no more than 1 mm and the 10 or 15% efforts level decrease.

The spread spectrum included both original and new components. The frequency of 60 kHz is obviously a difference frequency (as follows: 107-47=60). It was fully unapplicable in the spectrum of the monitoring ultrasonic sound receiver after crack occurrence. The occurrence of the other components complies with the stated nonlinear conversions, occurring on the metal surface, but it also requires further analysis.

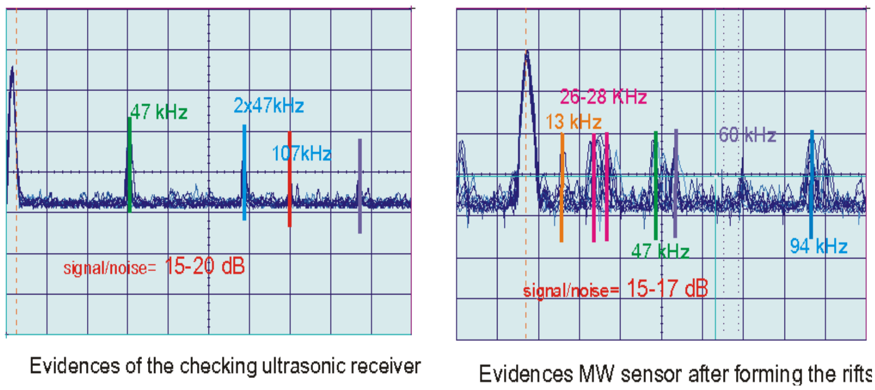


Figure 6. The spectral recording influenced by the bi-harmonic signal

The testing of the limited number (equal to 5) of the first type samples and was replenished with the second type samples (equal to 4). The testing was continued with the help of the improved RIAD-4 set. The set included the microwave sensor, 2 ultrasonic generators with the intensifier, conversion device, reinforcing agent (for the spectral signal transfer to the audio-frequency range with the valid signal referring to the frequency of 6.1 or 6.23 kHz), and a PC like “Aspire One” with “Sound Forge.5” software. Such configuration results in significant cost reduction without the working parameters worsening considering their responsivity and durability.

The spectral recordings of the output signal in this case were received during the 2 second period via Fourier quick transformation programs (Sound Forge.5). The Figure 6 shows the unapplicable valid signal in the spectrum before testing the second steel samples (the general sample possesses the dimensions of 500 × 85 × 5 mm and is divided on its end surface into 3 samples with the dimensions of 150 × 18 × 5 mm). The spectral recording represented on the Figure 7 refers to the testing beginning with the second end surface sample of the second variant. The spectral recording represented on the Figure 8 shows the valid signal occurrence with the frequency of 4 or 5 dB or 6.221 kHz after 28 cycles were completed.

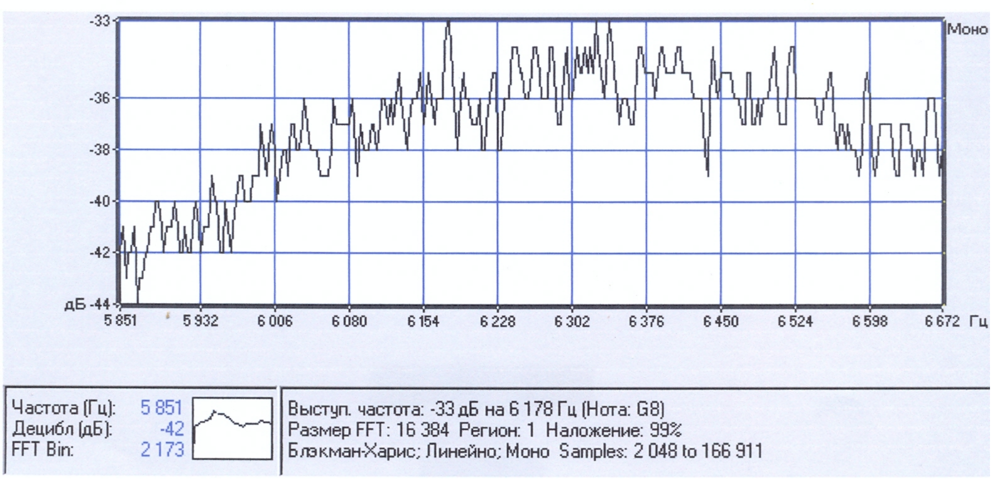


Figure 7. The testing beginning for the second sample of the second variant

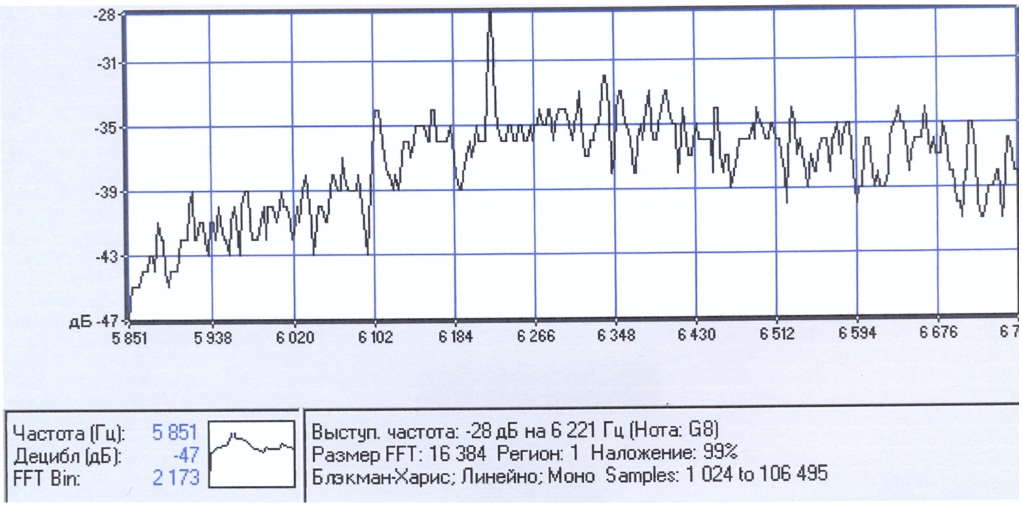


Figure 8. The appearance of rifts with the reduction of 29% effort

While testing it was noted, that the rate of the valid signals measured remain for some time after the mechanical stresses are completed. The memory time for activity of the the faukts detected varied from 6 to 7 hours (for the second series samples with the depth of 5 mm), and up to 10 or 12 hours (for the first series samples with the depth of 4 mm). The measurement period was chosen uneven. The pause lasted for 10 minutes the first 2 hours running and later it lasted for 30 minutes during the в next proving time. The valid signal rate reduction for 3 dB was chosen as the standard for further testing abortion. The testing ultrasonic sound was applied only during the measurements and lasted for 2 or 3 seconds.

3. Test Data

Due to the complete absence of the theoretical foundation the reaseach activiteies performed are of experimental character.

Both well-known works of the foreign and Russian scientists dedicated to the metal fatigue failure contain no information disconfirmating the results of the reseacr activities performed (Ivanov, Bykov, & Ryabov, 1985; Guidebook on Non-Destructive Testing of Concrete Structures Iaea, Vienna, 2002). There's no any information on the possibility of remote indicating and measuring the parametres of the initial damage process in standard environment with the help of the microwave field. The laboratory employees are currently testing the ways for activity regenerating. Such reactivation process became manageable due to the thermal shock application. The method of thermal shock, suggested by our employee, Brichkov S. A. will be described in our later works.

It should be noted, that the variant suggested is able to detect the initial occurrence of the dangerous defects without previous state study of the object unlike the other known methods for the deterioration level detection. The area of the assumed or expected damage is not required to be detected. The whole metal object surface, able to repel the microwave field can inform the researcher about active defects occurrence (i.e. cracks, layering, bad rivertting, bad electrical link etc.). The application of the testing ultrasonic signal is required for active defects detection and can be performed by the lazer thermal ray (http://www2.warwick.ac.uk/fac/sci/physics/research/r/, 2011; Blodgett & Baldwi, 2006). Then the assumed method of the NDT controlling becomes completely remote. Thus we consider the research activities performed to play a significant role both for theory and practice despite their poor theoretical foundation (Vasilyev & Lyuboshitz, 1994). It is also assumed, that the application of the phenomenon discovered would allow to accumulate the information sufficient for further theoretical research. The authors emphasize the fact, that the registered spectral components of the testing ultrasonic sound remain after the loading completion during a long period of time (starting with several dozens of seconds and up to several hours) unlike the acoustic emission signals. This new condition allows to detect the dangerous or active defects, thus resulting in the fatigue capacity measurement with no information on the sample state before testing, which is a significant advantage toward the old known methods, requiring the information on the previous resistance parameters.

4. Conclusion

The work performed proved the service full capability of the both sets RIAD-2 and RIAD-4. The steel samples testing proved the possibility of the remote initial damage registration by analyzing the frequency content of the microwave field repelled with the frequency of 33 and 10 GHz. The testing proved the new possibilities of the NDT controlling for the qualification inspection of the wheels and rails considering railway service. The improved variant of the RIAD-4 set, installed in the railroad haul can detect the cracks in the raiway wheels, the failure turn of the wheel hub in relation to the axle. The testing ultrasonic signal can be transferred via rail in the wheel contacting point. The performed testing on the special stage of engineering department in Novosibirsk proved such possibilities by experiment. We render our thanks to Plotnikov S. V. for his invaluable help during these testings. It should be noted, that the major part of the field research was financed by the federal relief programme for small enerprises "START-10" under Polyakov S. G. guidance.

The results achieved proved the complete practical productivity of the remote active defects indicator model (RIAD-2, RIAD-4) for researching and testing the metal samples. The possibility of remote detection of the dangerous defects after mechanical stress was also proved.

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