NON-DESTRUCTIVE TESTING OF RAILS IN CASE OF GUIDED WAVES USE

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Abstract: The report represents the results of the researches in the field of ultrasound propagation in rails and gives the characteristics of the device for rails flaw detection. This device allows detecting the perpendicular cracks in rails, the square of which exceeds 10% from the section square of rail's head, web or base. As a sender and receiver of ultrasound the device uses the line array of probes with dry point contact (DPC). The distance for detecting the butt-end of the rail achieves 50 m from the place, where the array contacts the rail.

Introduction: The problem of flaw detection for rails is very up-to-date now. At the present time for these purposes services use flaw detector cars, which allow making a continuous speedy rails testing in railways, and different specialized handheld flaw detectors. The low spatial exactness of readings, received by flaw detector car, does not allow quickly finding the supposedly defective part of rail, which should be after that tested with handheld flaw detectors to estimate kind and admissibility of the detected defect. Usually this search is made with the mechanized equipment that is rolled manually tens of kilometers along the rails. Much easier and more quickly this search can be done with the device that provides a distance detection of defects in rails without scanning.

Already in the first half of the 1980s a low-frequency flaw detector "POISK-4" for a distance detection of defects in rails, based on the guided wave ultrasound propagation with the filling frequency of about 100 kHz [1, 2] was developed in the Scientific-Research Institute of Bridges "Leningrad Institute of Railway Transport" (now University of Transport Communications, St-Petersburg (PGUPS)). The testing was made by echo-pulse method with the single angle piezo-probe, which the operator put on the side of the railhead or on the web or on each pen base of the rail. Using the digital indicator the operator detected the distance from the probe to the nearest defect in the tested part of the rail. To achieve the acoustic contact the tough coupling liquid was used. In 1987 - 1988 a significant consignment of such devices was produced.

The progress in development of ultrasonic low-frequency probes and antenna arrays on the base of such probes leaded to the development of the similar equipment, but with the significantly better technical characteristics in comparison with its prototype. One of its most important advantages is the dry acoustic contact at testing.

The waveguide characteristic of the long solid body, and in particular, of rail becomes apparent when cross sizes of the body are commensurable to the wave length. When the cross sizes of such body less then the wave length it behaves as a waveguide. Any acoustic excitation appearing in the body propagates in this case along the body in two directions, as a bar waves (Pochhammer waves). The break in material homogeneity of waveguide or changes in its cross-section reflect the part of wave energy in the opposite direction. The delay time of the reflected signal, its intensity are the information parameters at testing the long objects with wave guided echo-pulse method.

The more difficult is the form of waveguide cross-section, then the more waves types are appearing in it at the same pulse excitation. The steel rail is rather a difficult waveguide, in which many types of waves can propagate. In the work [4] is shown, that only at the frequencies of up to 15 kHz the number of appearing wave types achieves 10. On the higher frequencies the number is growing with the frequency. In most cases it is better to use the lowest types of waves: modes of zero- or the first order, the ultrasound dispersion of which is minimal. The waves of these types are the most stabile to the variability of propagation conditions, have smaller attenuation level with the distance and, what is most important, basing on their signals it is possible to detect the distance to the reflectors with the highest exactness.

The rail in general consists of three acoustically connected waveguides: head, web and base. As they have different forms and sizes of cross-sections, then it is obvious, that the parameters of waves that can propagate in them are significantly different. That's why at searching the defects in different parts of rail the main characteristics of the flaw detector should also vary. The adjustment of these characteristics can be easily made, if the flaw detector is based on the antenna array with directivity characteristic controlled by the program and with the possibility of changing the sending pulse parameters in rather a wide range. To the last requirement fully conform the ultrasonic low-frequency short-pulse probes with dry point contact [3], which should be used as an elements of antenna array of the flaw detector.

The present work is devoted to the researches of the main characteristics of ultrasonic signals, propagating in the rails, to the choice of the parameters and algorithm of flaw detector's operation for testing rails with waveguide echo-pulse method.

Results: The series of experiments were made to research the propagation of pulse acoustic signals in rails. As senders and receivers of ultrasound were used the probes with dry point contact and with shear vibrations of their wear tips [3] relatively to their axis. The use of these kind of probes and not of their analogues with the longitudinal vibrations allows researching the bigger quantity of waves sending and reception variants in different parts of rails and on different surfaces. Thus, for example, with this probe it is easy to send a SH wave in the rail's web, propagating along the rail. The probe with longitudinal vibration doesn't allow doing it. The conversion coefficient's frequency range for these probes at the level of 0.7 lies approximately in the range of 15 - 80 kHz, that means that the relative band achieves 130%. Due to these characteristics the duration of the sending pulses can be 1 – 1.5 oscillation periods.

During the researches was ascertain, that the maximums of signal frequency spectrums, propagating in the head, web and base of the rail as a bar waves are different and lying in the frequency range of about 20 - 60 kHz. When increasing the distance of signal propagation in a rail from meters to tens of meters, these maximums start moving to the area of low frequencies. This can be explained by the stronger attenuation of the higher wave types in comparison with the lower wave types. At sending the short ultrasonic pulses (1 – 1.5 periods) there are the chaotic oscillation appearing unavoidable in the rail with the sent pulse's spectrum, which do not propagate along the rail and attenuate relatively slowly, creating the noises at signal reception.

On the figure 1 is represented the signal's oscillogram, received by the sounding method when the sending and receiving probes were put on the driving surface of rail at the distance of 1500 mm from each other. The sending probe was excited by the rectangular pulse of 5 μs duration. The vibration vector of both probes was directed perpendicular to the rail's axis. It is seen, that the initial part of the signal, in the range of 480 – 560 μs contains more low frequency oscillations, then the other part of oscillogram, where the time moments are more then 600 μs. The spectrum of these oscillations, calculated in the interval 480 - 560 μs, has the maximum at the frequency of 32 kHz. The spectrum of oscillations, calculated in the interval of 600 - 1000 μs has the

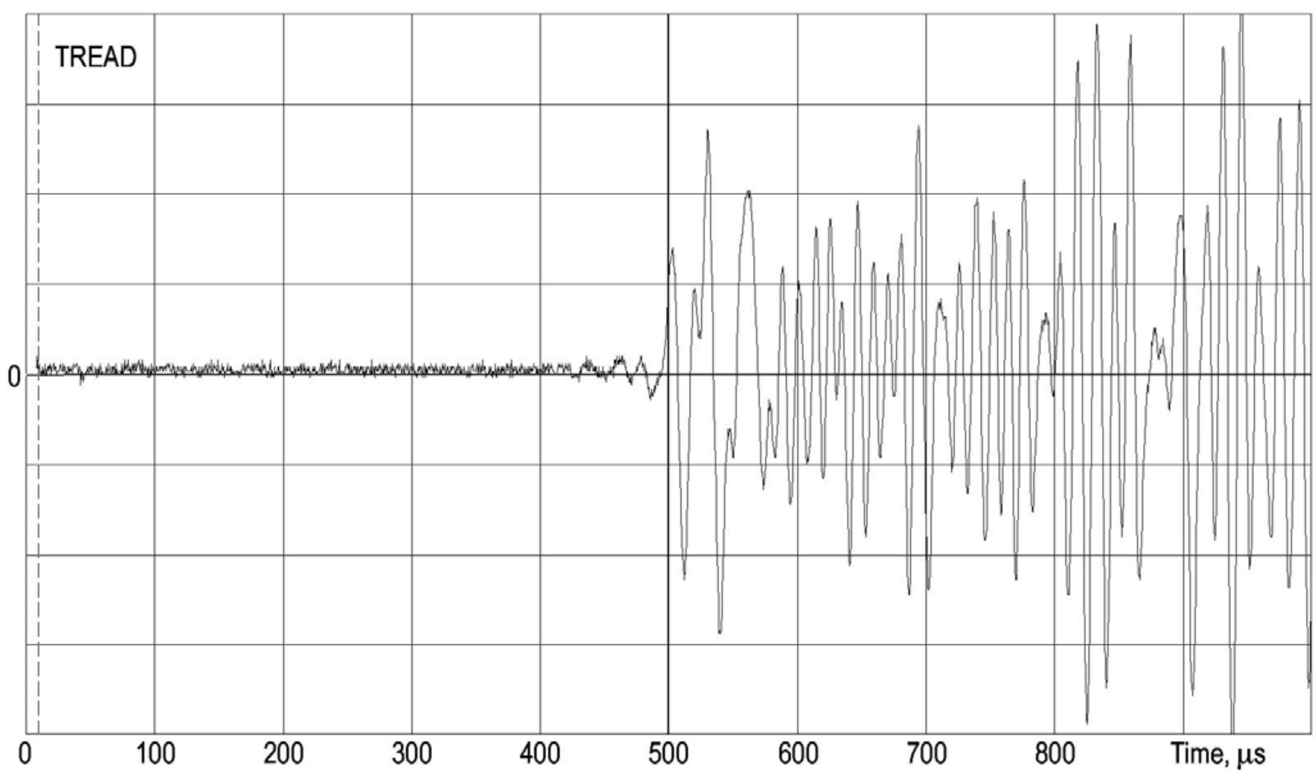

Figure 1. Signal oscillogram, received at sounding of rail along the driving surface at the base of 1500 mm

maximum at the frequency of 75 kHz. The signal propagation velocity, recalculated by the front delay time (the time of 495 μs) is equal to 3090 m/s (error ± 10 m/s). The represented oscillogram illustrates the approximate levels relation of useful signals (with the frequencies of 30 kHz), propagating along the rail's head as a bar wave, and of signal feedthrough (with the frequencies of 75 kHz), appearing in the rail's head at sending the wideband signal in it.

To get the directed along the rail sending and reception bar waves and to increase the signal/noise relation at the echo-signals reception from rail the linear equidistant antenna array, consisting of 12 probes, analogue to the ones, used in the previous trials, was developed. This number of array's elements provides rather high relations of signal levels in the chosen direction and opposite one. The step between the elements in the array is equal to 20 mm, that makes the compromise between the length of the array and the attenuation level of noise oscillations in rail. The vibration vector of all the elements is perpendicular to the array's aperture. The summation of the received signals realizations from all the array's elements with the determined time shift relatively to each other provides the one-side directivity of antenna array. To improve the signal/noise relation the summarized realization is affected to the band filtration, distinguishing the signal's spectrum, typical to the tested rail part (head or web or base).

On the figure 2 a, b are represented the proceeded with the band filters summarized realizations of echo-signals from the rail's butt-end at the distance between the array and the butt-end of 5 and 20 meters accordingly. The array was put on the tread of rail. The elements of the array were disturbed by the rectangular pulses of 5 μs duration. On the figure 3 a, b (accordingly) are represented the modules of spectrum densities of echo-signals' summarized realizations at the band filters input (picked out by black line – at output). From the figure 2 it is evident, that the noises from the stray oscillations in rail are in general lay in the range of 0 – 2.5 ms. The relations of pick meanings of echo-signals from the butt-end to the effective meanings of noise, preceding the echo-signal, in these realizations exceed 30 dB. The figure 3 illustrates the tendency of maximum's moving in useful signals frequency spectrum in the direction to low frequencies at the increase of the distance to the reflector.

The figure 4 shows the summarized realization of echo-signals from the models of defect in the rail's head. The horizontal axis on it is divided in distance meters to the reflectors. The models of defects were on the distance of 1.5 and 2 m from the antenna array. They were the transversal saw cuts in the rail's head with the square of 11.5% and 10% (accordingly) from the square of rail's cross-section. On the distance of 2.5 meters from the array places a free butt-end of the rail. The strange, from the first view, correlation of the signals' amplitudes from the models of defects (the stronger signal was received from the smaller defect) can be explained, that at the distance of about 1 meter from the antenna array the bar waves in the rail's head hasn't been fully form yet. The relatively weak signal from the rail's butt-end in comparison with the signals from the saw cuts can be explained with their shading influence.

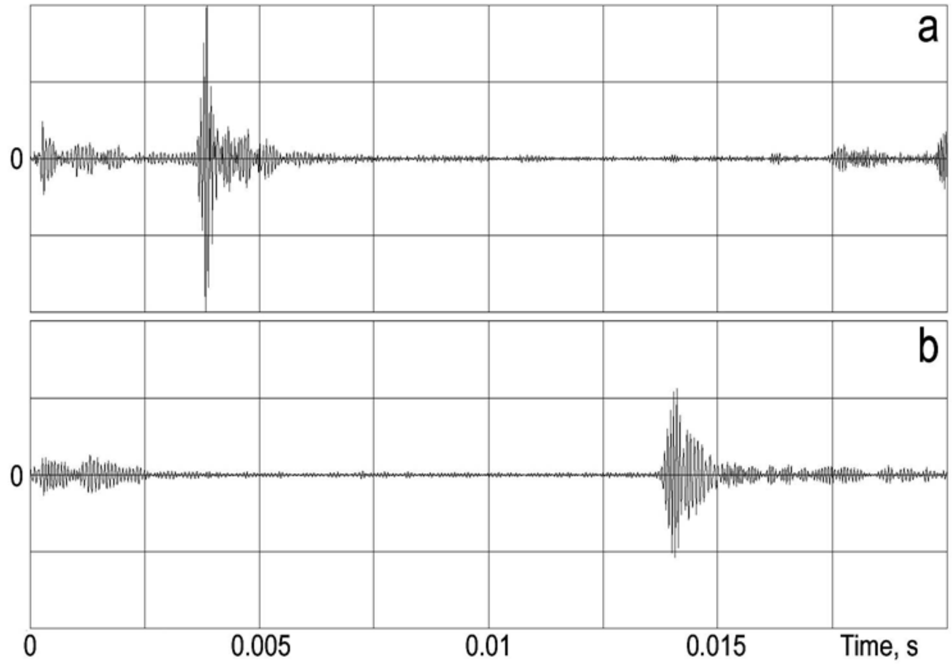

Figure 2. Echo-signals from the rail's butt-end at the distances between the array and the butt-end of 5 m (a) and 20 m (b)

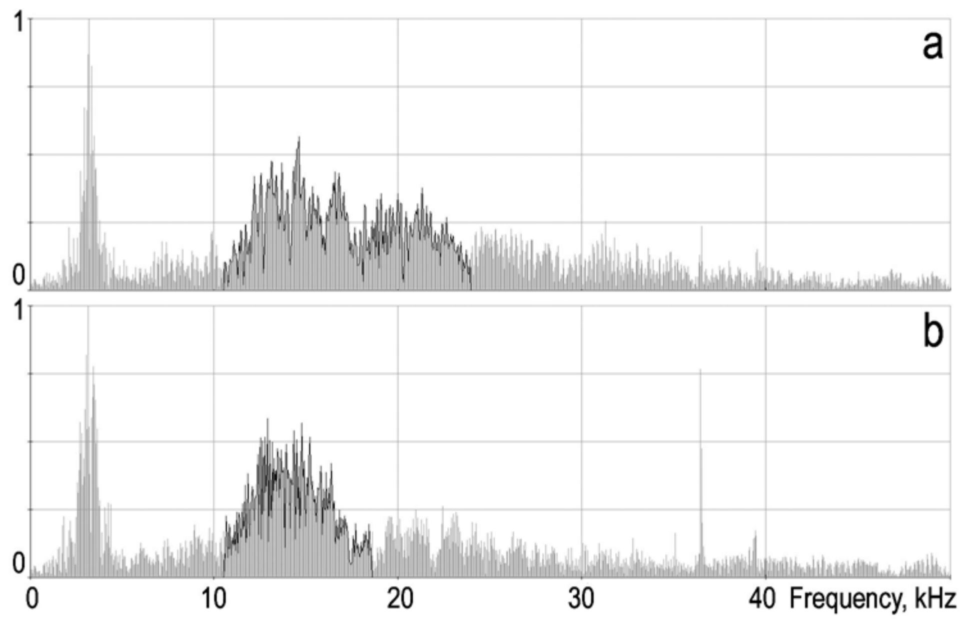

Figure 3. Spectrum density modules of signal summarizes realizations in rail at the distances between the array and the butt-end of 5 m (a) and 20 m (b)

As a result of these experiments was developed the ultrasonic flaw detector AKR1224 for rail testing with waveguide echo-pulse method. The device consists of electronic unit with the graphical display and 12-elements antenna array. The electronic unit by its functions is analogue to the electronic units of usual ultrasonic flaw detectors of wide application. Its difference is in the algorithm of received signals proceeding and in the band of reception track, enveloping the sound and ultrasonic frequencies. The antenna array besides the sending-receiving elements has the controlling element and the signal preamplifier. During the testing the array is put along the rail on the part, which is objected for controlling. On the screen the image of signals in rectified and RF- form is displayed. The direction of testing is set through the program. The signal screening in both directions at the same time is possible. The main application of the device is testing both separate rail and railways. The figure 5 illustrates the photo of the working moment of rail testing with AKR1224 device. There is also given the photo of antenna array.

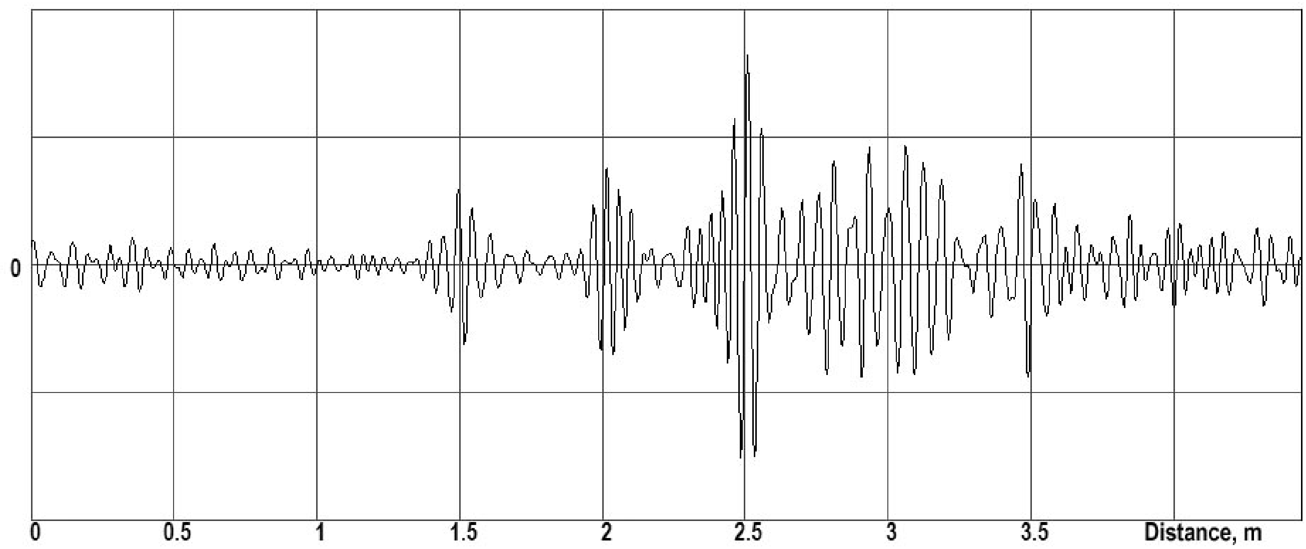

Figure 4. Echo-signals from the model of defects in rail's head

Figure 5. Rail testing. Antenna array

The main characteristics of AKR 1224

Maximal tested distance	50 m
Dead zone at detection of rail's butt-end	not more then 0.5 m
Distance counting discreteness	0.01 m
The duration of work from accumulator	not less then 8 hours
Operation temperature range	– 20 ÷ + 45° C
Sizes of electronic unit	245 x 120 x 50 mm
Sizes of antenna array	258 x 92 x 39 mm
Weight of electronic unit	770 g
Weight of antenna array	850 g

Discussion: The possibility of the equipment, based on the waveguide echo-pulse methods, easily to register the reflectors much smaller then the wavelength, can be explained with the commensurable with the wave length transversal sizes of the wave guide, through the section of which goes the whole spring of ultrasonic waves energy. It is almost impossible to register such small reflectors with the usual pulse-echo method on the volume waves. Moreover, the less the transversal sizes of the waveguide then the wavelength are, the more the intensity of the reflected signal depends on the relation of reflectors sizes to cross sizes of the waveguide and not to the wave length. At the group wave velocity in the rail's head of about 3000 m/s the signal wavelength at the frequency of 30 kHz is 100 mm. The drilling with the size of 10% from the cross-section square does not exceed in the linear sizes 1/3 of the wavelength. Still the echo-signal amplitude from it is only in 3 - 5 times less then from the butt-end, which reflects the whole energy of the signal.

The experiments have shown that on the separate rail when the distance to the reflector increases on 10 m, the echo-signal amplitude reduces approximately on 2 – 2.5 dB. That's why at the distance of 50 m to the rail's butt-end when it is detected, the relation signal/noise is expected to be not less then 20 dB. The signal level from the 10% saw cut in the rail's head at the same distance should on 6 - 10 dB exceed the noise level. That means that this kind of defect still can be detected. However in the rails, laid in railways, the ultrasound attenuation will become higher with the growth of distance. The noise level should also be higher because of the additional signal reflections from the places of rail/sleeper connection. This demands the additional researches.

The perpendicular orientation of elements' vibration to the aperture of the antenna array provides the sending and reception of torsion waves in tubes and of SH waves in plates, which propagate along the aperture of antenna array. The rating value of directivity diagram for the developed antenna array in sending and reception modes for SH waves in plates doesn't exceed 40 grades at the frequency of 80 kHz. Therefore the developed flaw detector may also be applicable for testing of tubes, bands and even lists.

Conclusions: The researchers came to the following conclusions:

1. For rail testing with guided wave echo-method it is perspective to use the linear antenna array of low-frequency short pulses ultrasonic probes with DPC. This antenna array has a good possibility of electronic adaptation to the parameters of wave propagation in different parts of rails and other long testing objects.

2. The operation signal frequencies for testing rail's head, web and base and their propagation velocities are different and before testing of a specific rail part it is necessary to choose the corresponding adjustment configuration.

3. The developed flaw detector provides the efficient search of defects in rails without scanning them with the 10 cm exactness of defect localization.

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