A Program for 3D Simulation of Signals for Ultrasonic Testing of Specimens

A. A. Markov, V. V. Mosyagin, and M. V. Keskinov
OAO Radioavionika, St. Petersburg, Russia
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Abstract—Optimization of the parameters of schemes using multichannel ultrasonic flaw detectors for sonic testing of rails (sonic test schemes), as well as development of algorithms for processing test signals, are considered. The efficiency of the RAIL-3D computer code proposed for the 3D simulation of the propagation and formation of echo signals during ultrasonic testing is tested by comparing real signals and simulation results for a CB-2 calibration block. The comparison is performed for the complex conditions under which rails are tested. The code can also be used for simulating signals of ultrasonic nondestructive testing in other metal products.

1. BACKGROUND INFORMATION: MAIN PROBLEMS

Significant changes have been observed recently in nondestructive testing of track rails in situ [1]. Flaw detecting railcars and motor-rail cars with on-board computers may concurrently conduct both ultrasonic and magnetic testing [2]. Detachable flaw-detection carts of a new generation that are equipped with built-in microprocessors provide continuous recording of signals for all test channels [3, 4].

To ensure reliable detection of flaws with different orientations in rails, ultrasonic vibrations are inputted from a railhead’s roll surface at different angles. A set of angle and normal piezoelectric probes (PEPs) installed in the search system of a flaw-detection device creates a so-called sonic test scheme for rail cross sections. Up to ten different sonic test schemes are currently used in mobile and detachable devices for the detection of flaws in rails. These schemes, which differ in the number of used PEPs and the methods applied for ultrasonic testing, are characterized by different potential technological efficiencies [5].

The most advanced sonic test schemes are based on original probes that apply the newly developed mirror through-transmission method to detect flaws in rails. The probes create a two-beam directivity characteristic [6, 7]. As a result of implementation of the new methods, the number of fractures induced by flaws in rails has been decreased significantly.

However, some problems in NDT of rails remain unresolved. In addition, some test parameters need to be detailed and adjusted. The following is a list of urgent tasks in NDT of rails:

1. Analysis of available schemes for sonic testing of rail cross sections in order to obtain information about potential capacities for detecting flaws and optimization of the parameters of the testing schemes' elements for the further increase of the efficiency of rail testing.
2. Development of concepts and algorithms for recognition of signals in the background of noise and reflexes from structural reflectors to automate the process of decoding test signals.

Awareness of disadvantages of sonic test schemes (for example, their dead zones, i.e., areas in a rail that are fully or partly missed by a particular sonic test scheme) allows improvement of the situation in the future by amending the available schemes or developing new ones and, thus positively affecting the test efficiency and railway safety.

In general, the efficiency of a test device depends on the correct choice of the number, angle, geometric position, and operating mode of the ultrasonic probes used. Determination of the optimum values for a search system’s parameters that might increase the efficiency of rail testing is an important but currently unresolved problem of ultrasonic testing.

During ultrasonic testing of rails, flaw-detector railcars and motor-rail cars record test signals in a continuous mode along the entire length of a tested track. Concurrently, they record coordinates of the signals, thereby enabling referencing of the detected flaws to the track. Interpretation of test results by means of checking all test parameters on a computer display for each millimeter of a track is labor-intensive and tedious. An operator performing this job not only needs to be highly trained but also must concentrate and be attentive.
As a result of gradual replacement of outdated detachable two-line flaw-detection devices with new devices equipped with recorders operating in a continuous mode, the workload of a flaw-detection operator in charge of viewing and analyzing recorded information will increase significantly. Therefore, the occurrence of errors will also increase. This situation may be resolved by implementing automatic interpretation of test signals. However, creation of algorithms for the automatic interpretation of test signals meets certain problems: the wide variety of known flaws [8], contamination of test signals with noises and groups of signals (packets) from structural discontinuities present in a rail, and constantly changing test conditions [2].

2. VERSIONS OF THE SOLUTION TO THE PROBLEM

Different methods are applied to solve the problems listed above.

1. In a real experiment, it is possible to receive signals from physical models or real flaws with known parameters. The aforementioned problems may be solved with the use of such signals because they contain information that can be used for assessing both the efficiency of a particular sonic test scheme and the reflecting properties of different flaws. At the same time, the data collected in a series of real experiments are not statistically uniform; i.e., when analyzing such data, it is impossible to take into account a number of factors affecting the final result: random variations of the acoustic contact, the wear rate of a rail and deviations of its geometric characteristics from nominal values, fluctuations of the reflective properties of a rail and its flaws, and inaccuracies in the geometry of specific ultrasonic probes and in the installation (centering) of a search system.

Moreover, preparation and performance of a series of real experiments, including creation of physical models of flaws, require large investments and time.

2. A theoretical calculation based on exact or approximate (empirical) formulas. Calculations based on an exact theory are very complicated and time-consuming.

Approximate calculations that involve a number of simplifying assumptions are more efficient. These may include approximating a piezoelectric probe’s directivity characteristic with simple functions [9], using a rail with a simplified shape, disregarding a number of insignificant factors, etc.

Theoretical calculations provide a solution to the aforementioned problems. However, it is obvious that the calculations should be repeated for each new search system or configuration of a rail; therefore, this approach involves great effort even in the case when the approximations described above are made.

3. Computer simulation based on a mathematical model makes it possible to automate calculation procedures. The time-consuming development of a mathematical model is only performed once at the design stage. The created mathematical model is used as a basis for the development of the algorithms implemented in the form of a computer code. Whenever the parameters of a search system or a rail’s configuration (type) change, the calculations are made automatically. This approach to the solution of the aforementioned problems was used because it enables a significant amount of calculations to be made during a short time, while the required accuracy is ensured.

The currently available computer simulation programs [10] feature a number of shortcomings and no longer meet the requirements set for them. In these programs, an individual mathematical model is used for each channel of a search system. The model describes physical processes developing within a single channel; moreover, channel-specific algorithms are applied. These limitations automatically restrict a program’s applicability to the set of channels that are available now. Normally, the existing programs can only synthesize signals for a particular type of a flaw detector, thus preventing their usage for optimization of sound-test schemes, comparative analysis of test devices, or development of new devices.

Moreover, the earlier developed means of computer simulation involve a number of functional limitations: probes cannot be mounted on other surfaces of a rail (the side edge of a railhead or a rail foot’s wing), the number of probes and their types are limited, some parameters (PEPs) may not be varied, etc. These programs have been developed to eventually produce signal models as A and/or B scans. However, presentation of test-signal models in the form of scans of such types is not sufficient for solving the problems listed above.

3. A PROGRAM FOR 3D SIMULATION OF ULTRASONIC TEST SIGNALS

The efficiency of an applied scheme of sonic tests may be assessed in a graphic way using diagrams of sonic testing of a rail’s cross section. The proposed diagram makes it possible to assess the potential capacity of a selected sonic test scheme in terms of the probability of detecting a flaw in different areas of the tested specimen.