

Ultrasonic Flaw Detection Systems for Testing Rails in Iran Railways (RAI)

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Abstract

To have a safe and reliable railway system, nondestructive testing (NDT) methods are necessary to be implemented in order to avoid catastrophic failures. NDT methods also provide a powerful tool for proper maintenance of valuable railway system assets. Among various NDT methods, ultrasonic testing (UT) along with magnetic particle testing (MPT) and eddy current testing (ECT) play significant roles in testing rails, rail welds and other train parts and assemblies such as wheels, suspension system and bogie axles of rolling stocks. One of the vital sections of rail tracks are the weld joints for which two main methods of welding are currently being used in Iran railways (RAI); thermite welding and flash butt welding. Each of these methods has its own pros and cons. Penetrant testing (PT) along with UT are used to detect potential flaws in both the weld and rail. UT is used during construction of rails (at rail manufacturing site) and also during operation in certain time periods in order to detect internal cracks and any other flaws which might lead to a failure. In this paper, two ultrasonic flaw detectors currently used in RAI for inspecting rails are introduced. Results obtained from testing rails by these two flaw detectors are also briefly discussed.

Keywords: Nondestructive Testing, Ultrasonic Testing, Railways, Welding, Asset Management

Introduction

With increasing pace of technology advancement, the need for more accurate and faster methods of measuring characteristics of industrial components and detecting internal and external defects has become more urgent. One solution for these problems is the application of NDT methods, which can examine objects without affecting their future usefulness. Among various NDT methods, ultrasonic testing (UT) has shown to be quite effective. This is due to its unique and powerful features such as ability to detect surface and internal defects, high sensitivity and accuracy, reliability and safety, and ability to inspect objects just by having access to one side.

Because of high value of railway components and their vital role in safety of trains, along with unending interest in increasing the speed of the trains, application of NDT methods has become more and more important than any time before. One of the most critical parts of railway components are the rails which enable trains to move by providing a dependable surface for their wheels to roll. Along a rail line, the weld joints have the highest potential of development of flaws which can lead to the breakage of a rail [1]. Therefore, special care should be devoted to the inspection of rail welds in order to achieve a safe and reliable transportation service. One of the best methods for testing rails and rail joints is UT which can reveal internal defects at the head, the web and some sections of the rail foot.

Two main methods of welding are currently being used in Iran railways (RAI). These methods are: aluminothermic (thermite) welding and flash-butt welding. Narrow gap or enclosed arc welding is also sometimes used in RAI but the majority of current welds are either aluminothermic or flash-butt welds.

In aluminothermic welding, the weld section is filled with a molten steel produced through a chemical reaction between oxidized iron and metallic aluminum. The advantages of thermite welding are its simplicity and mobility. Therefore, it is mainly used in the field as a final step for installation of rails. The chemical process of this weld is govern by the following chemical process [2]:



Flash-butt welding is a completely automated process, therefore, labor skills do not directly affect the quality of the final welding. Because of its automated process, flash-butt welding has high level of quality and productivity. Two types of equipment are available for this method of welding; the plant flash-butt welder machine which uses large equipment with hydraulic systems and mobile flash-butt welder which is a miniaturized model of the plant flash-butt welder usually used in the field [1].

In some welding processes, defects such as cracks, porosity, slags, and lack of fusion (LOF) may occur and cause rail failure [3].

Monitoring the growth of cracks before they reach their critical length, especially those which are exposed to fatigue forces or are in corrosive environments, is very important. Therefore, regular inspection of rails and welds is required to make sure that cracks have not reached their critical length which leads to failure. For this purpose, RAI uses UT devices. In this paper, an overview of the previous work done for inspecting rails in tracks of RAI is reviewed and some results are described and discussed. Additionally, the current UT inspection devices at RAI are introduced.

Ultrasonic Flaw Detector of Rails

The first ultrasonic flaw detector for manual rail inspection in RAI was DIO562-2CH made by STARMANS. This is a two-channel flaw detector whose channels can be used independently at the same time. In Figure 1, the DIO562-2CH and its screen are shown. Three probes are used for inspecting rails. One transmitter/receiver normal probe and two 4 MHz, 70° angle beam probes; one along the movement direction and the other one in the opposite direction (forward and backward). Angle beam probes are used to detect transverse flaws in head of rails. As this walking stick is moved along the rail surface, the three probes simultaneously inspect different parts of the rail or welding section. Water is used as the couplant through a water tank which directs the water into the space between the probes and rail.



Figure 1. Walking stick ultrasonic testing device

For calibrating probes and the ultrasonic testing system, a 500 mm rail section is used and four artificial flaws, side drilled hole (SDH), at different positions are drilled. The first $\text{\O}5$ mm SDH is located in 15 mm depth from the head surface of the rail and is 160 mm away from the side of the rail block. Other three $\text{\O}10$ mm SDH's are located in depths of 70 mm, 90 mm and 110 mm with a 80 mm horizontal distance between them, see Figure 2.



Figure 2. The calibration block with defined defects

Using the DIO562-2CH inspection system, internal defects located in head, web, and foot/web section, can be detected. The normal probe can almost inspect the entire height of the rail for flaws having a depth greater than 5 mm. This probe detects horizontal cracks. Angle beam probes cover the volume beneath a depth of 10 mm from head to the surface of intersection of head and web. These probes are mainly used for detecting transverse cracks.

The ultrasonic testing device has three gates. One of the gates is set for the back wall echo of the normal probe. At the calibration stage, the back wall echo is set to 100% Full Screen High (FSH). Whenever there are defects on the path of the ultrasound, the probes are not well positioned on the rail, or there is not enough and appropriate couplant, the back wall echo will decline and as a result this gate would alarm an error. Two other gates are set accordingly and whenever any echo of the defects appeared on the screen, the ultrasonic device will start alarming showing the defect. When a defect is detected, that position, at the rail surface, is marked by a specific color and then it is inspected manually in order to measure the defect accurately.

Another flaw detector system used in railway tracks of Iran is USDS2-73MR which is a trolley, double rail flaw detector system with the capability of testing both rails of the railway track at a same time for defects detection along the running surface and entire rail section excluding the rail foot flanges, and also is intended for conformity testing of separate rail section using manual probes. The schematic of USDS2-73MR is shown in Figure 3. This flaw detector makes it possible to test all parts of a rail and to detect all possible defects [4].

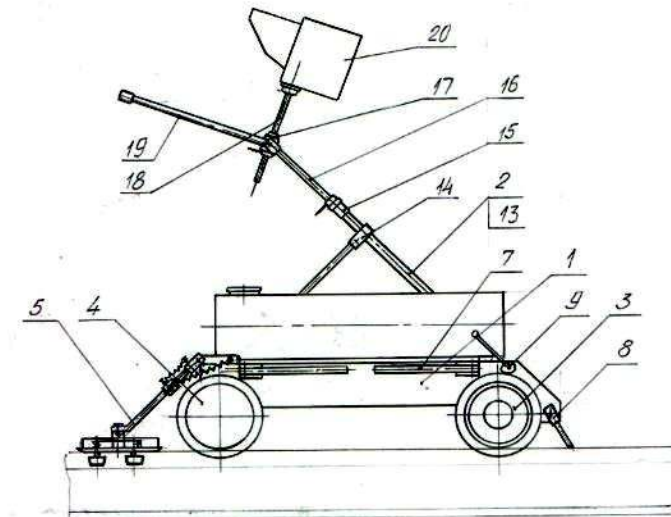


Figure 3. The schematic of USDS2-73MR ultrasonic rail flaw detector

To detect inner rail defects of various directions, several UT techniques are implemented in this flaw detector. This flaw detector system has two probe units each of which contains 13 probes at different positions. The normal transmitter and receiver 4 MHz probe, detects horizontal cracks in the base and in the web situated mainly along the rail axis, and also cracks in the bolt holes. Additionally, it can control acoustic coupling loss and searching system positioning. Eight angle beam 2.5 MHz, single crystal probes with refracted angle of 58° (turned over by 34° relative to the longitudinal axis in the gage side) make it possible to detect transverse defects in various directions relative to the vertical plane.

Two angle beam 2.5 MHz, single crystal probes with an angle of 70° (directed along the longitudinal rail axis) are used to make it possible to detect transverse surface cracks in various directions relative to the vertical plane, including the ones that develop under horizontal separations at the distance of no more than 50 mm from the beginning of separation in the direction of testing by the probes.

For testing the whole rails cross-section in the web projection, including bolt holes, two angle beam single crystal probes with an angle of 45° (directed along the longitudinal rail axis) are used. For reliable detection of cracks in bolt holes, probes have a wide direction pattern. This allows watching the signal from a possible crack situated mainly at an angle of 45° , including the one that does not go beyond the hole projection. The technique also makes it possible to detect transverse surface cracks in the web/base area. Such defects are not usually detected by the normal probe. To detect defects in various directions, two probes are implemented that are directed along and against the trolley movement. The main scheme for complete rails testing of one of the probe units is shown in Figure 4.

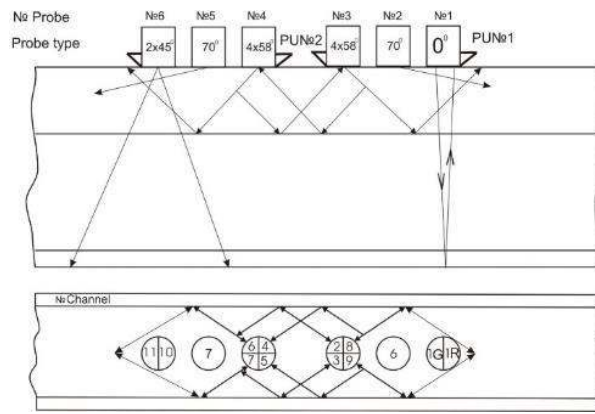


Figure 4. The main scheme of complete rails testing

The testing area which this detector system can cover is shown in Figure 5.

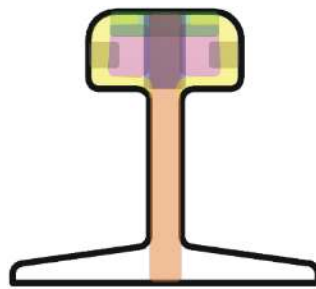


Figure 5. Testing area of the flaw detector system

Results and discussion

By testing 25 km of the rails in service, defects such as crack, porosity, lamination, lack of fusion, and break in rail, thermite welding and flash-butt welding were detected. All defects were also inspected by using a manual ultrasonic device in order to verify and characterize the defects. In Figure 6 and Figure 7, two signals obtained from defects detected in rails along with photos of their corresponding rail sections are shown. In Figure 8 and Figure 9, two examples of detected defects in flash-butt welding are shown.

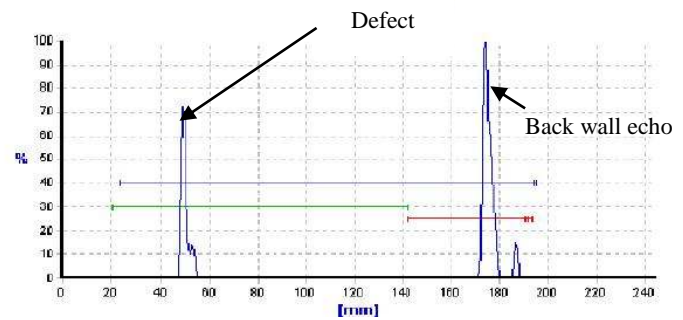


Figure 6. Lamination in rail in 49 mm depth with 300 mm length

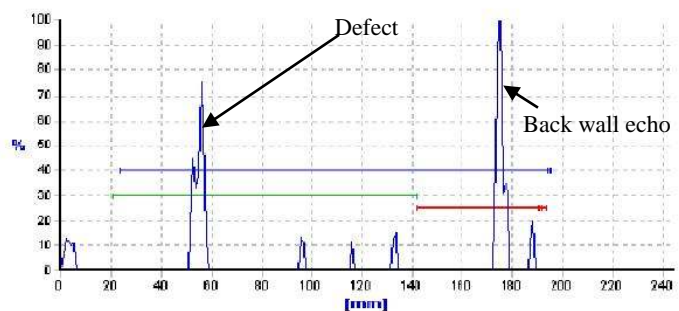


Figure 7. Lamination in rail in 57 mm depth

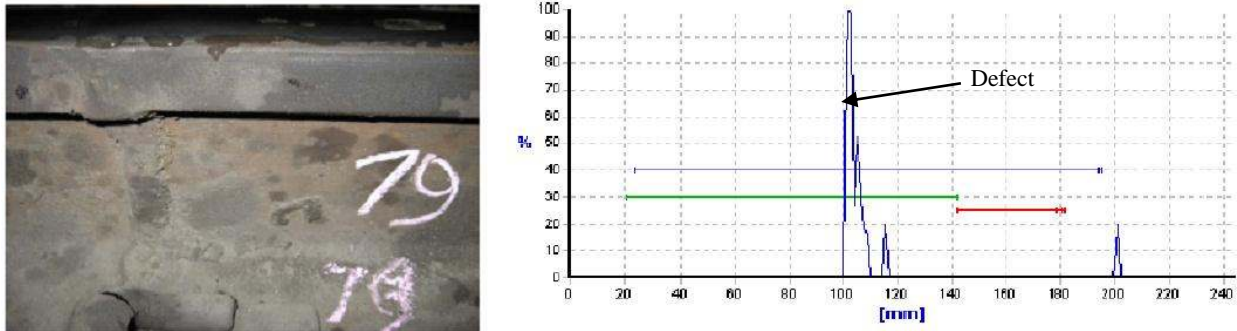


Figure 8. Crack in flash-butt welding in 101 mm depth

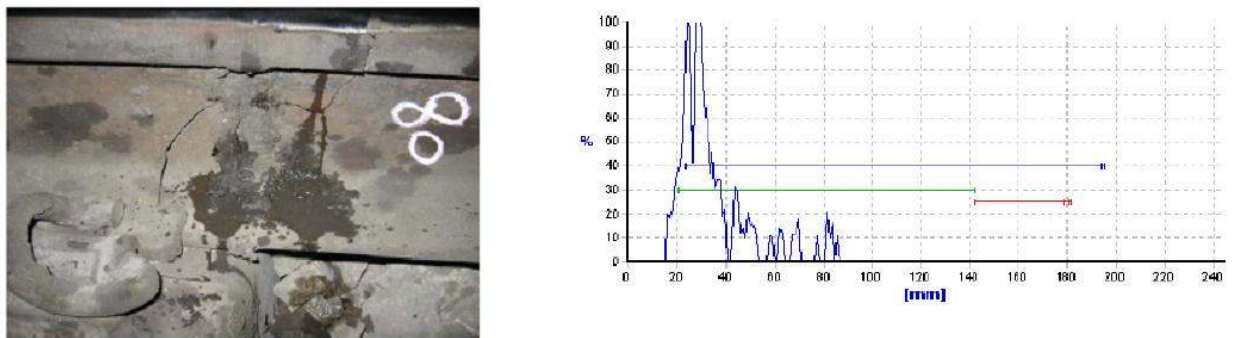


Figure 9. Rail break in flash-butt welding

According to the obtained statistical results from defects in rail, thermite and flash-butt welds, 1.6 % of defects are breakage, 9.6% are porosity, 22.6% are lack of fusion, 25.8% are lamination and 40.3% are cracks. In Figure 10, the pie chart of defects is shown.

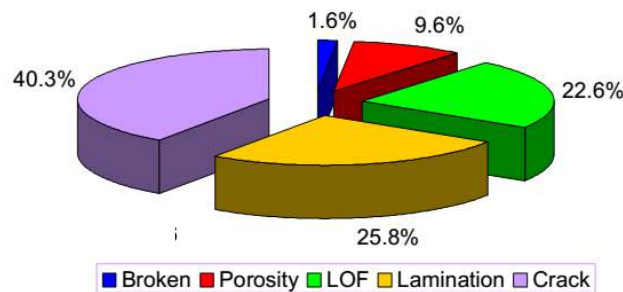


Figure 10. The distribution of different kind of detected defects

The detected defects have been analyzed by other means too. 26.6% of defects occurred in rails, 22.6% occurred in thermite welds and 50.8% occurred in flash-butt welds. The pie chart of these statistics is shown in Figure 11.

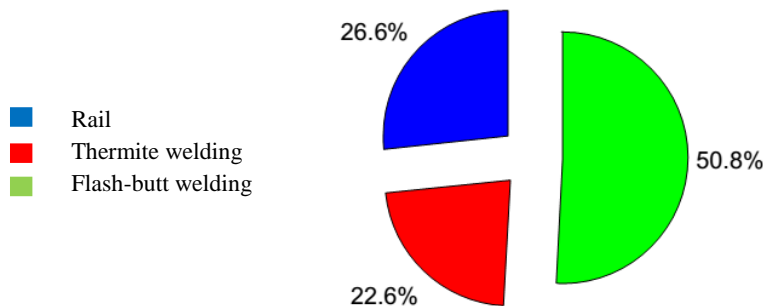


Figure 11. The distribution of defects

According to these results, half of the detected defects were in flash-butt welding; however, theoretically flash-butt welding is supposed to have better quality and productivity compared to other welding methods. The rate of the defects

in flash-butt welding at other rail tracks of RAI is lower than the showed results. Therefore, the welding process and machines in the inspected rail track were not appropriate or the required parameters were not set accurately.

By inspecting the rails and welding, the sections containing dangerous defects like break, cracks, and porosities were replaced by new rail sections and other ones which did not reach their critical size, were kept under regular surveillance. Moreover, the welding processes were checked and modified and new maintenance strategies were introduced.

Conclusions

As time passes, the desire for having faster and safer trains grows rapidly. Although nondestructive testing of in-service rails might be a small portion of railways industry, it plays a very important role in safety and reliability of railway transportation. Thanks to the advancements of NDT methods, testing and condition monitoring of rails have become much easier and more reliable and helps the authorities acquire their goal of having faster and safer trains. Iran railways (RAI), like all of the other modern railway companies around the world, have been implementing different NDT methods to test and evaluate the condition of rails and other relevant components in rail industry. In this paper, two ultrasonic flaw detecting devices which are currently being used in RAI were introduced. There is definitely a need for more advanced and faster flaw detecting machines with which more than 12000 km of Iranian main rail network could be regularly tested.

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