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# Ultrasonic Flaw Detection Systems in Testing Rails of Iran Railway (RAI)

## Abstract
For having a safe and reliable railway system, using Nondestructive Testing (NDT) methods is a critical process with which a great number of catastrophic accidents can be prevented. Additionally, NDE methods will provide a powerful tool for proper maintenance of valuable railway system assets. Among all of the NDE methods, Ultrasonic Testing (UT) beside Magnetic Particle Testing (MPT) and Eddy Current Testing (ECT) plays significant role in testing rails, rail welds and other relevant parts and assemblies like wheels, suspension and bogie axles of locomotives. One of the vital sections of rail tracks is welded section. Nowadays three methods of welding are used in Iran railway (RAI) tracks for joining rails: thermite welding, flash butt welding, and narrow gap welding each of which has its own prose and cons. Penetrate Testing (PT) along with UT are used to detect potential flaws in both welds and tracks. Moreover, UT is used both before installing rails (at rail manufacturing site) and during operation in defined periods in order to detect internal cracks and any other flaws which will lead to failure of rail. In this paper, a brief overview of the methods of rail welding will be expressed and two ultrasonic flaw detector used in RAI for inspecting rails and welding will be introduced.

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

## Introduction
With increasing peace of advancements in technologies, the need for more accurate and faster methods for measuring characteristics of parts and finding any internal and external unfavorable defects is more required. The solution for these problems is using NDE methods. Among all of the NDE methods, UT, because of its unique and powerful features like its ability to detect internal defects and high penetration power has fulfilled the need of different industries one of which is railways.

Nowadays, high expense of rail components and their vital role in safe running, coupled with the desire of authorities to increase the speed of the trains and having heavier haul freight, using NDE methods become more necessary and important than before. One of the most critical part of rail tracks are rails which enable trains to move by providing a dependable surface for their wheels to roll. Moreover, along rails, weld joint sections with an offset known as Heat Affected Zone (HAZ) are more potential of flaws which will cause rails to break [1]. Therefore, special care should be given for inspecting different aspects of weld to achieve safety transportation service and highly reliable rail welds. 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 section of the foot of rails.

Three forms of welding are currently used in Iran railway (RAI): 1) Aluminothermic (thermite) welding, 2) Flash-butt welding, and 3) narrow gap welding. The narrow gap welding has recently been added to railway system; therefore, majority of the current welds are Aluminothermic and Flash-butt welding.

In Aluminothermic welding, 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 fields as a final step for installing rails. The chemical process of this welding is govern by equation (1) [2]:

$$\mathrm{Fe_2O_3 + 2\,Al \rightarrow Al_2O_3 + 2Fe + 850\ kj} \qquad (1)$$

Flash-butt welding is a completely automated process, so labor skills do not directly affect the quality of the final welding. Because of its automated process, this welding has high level of quality and productivity. Two kinds of these welding are available: The plant flash-butt machine using large equipment with hydraulic systems and mobile flash-butt welder which is a miniaturized model of the plant flash-butt and is used in field in order to join rails [1].

In welding process, some of the standard criteria are ignored and as a result during operation some defects like cracks, porosity, lamination, and Lack of Fusion (LOF) will occur and cause rail failure [3].

Monitoring growth of cracks before reaching their critical length, specially those that are exposed to fatigue forces or are in corrosive environments, is very important, so rails should be replaced before they are broken. Therefore, regular inspection of rails and weld is required to make sure cracks have not reached their critical length and rail break is prevented. For reaching that goal in RAI, ultrasonic testing devices have been used to apply preventive actions, enhance safety level, and reduce the risk of accident. In this paper, an overview of the previous work done for inspecting rails of RAI is reviewed and some sample tests are exposed and discussed. Additionally, the current inspection devices of ultrasonic testing is 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 which can use its channels independently at the same time. In Figure 1, the flaw detector and its screen is shown. Three probes are used for inspecting rails. One Transmitter /Receiver normal probe and two 4 MHz, 70° angle probes (one along the movement and the other one against it). Angle beam probes are used to detect transverse flaws in head of rails. As this walking stick is moved across the rail surface, three probes are simultaneously inspecting the different part of the rail or welding section. Water is used as couplant in inspection process and it is filled into the blue tank shown in Figure 1 and is directed to the space between 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 Ø5 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 Ø10 mm SDHs are located in depth of 70 mm, 90 mm and 110 mm with a 80mm space between them. In Figure 2, the manufactured calibration block is shown.

Figure 2. The manufactured calibration block

Using the introduced inspection system, internal defects located in head, web, and some sections of foot, which is in front of the web, can be detected. The normal probe can almost inspect the entire high of the rail beneath 5 mm depth. This probe usually detect horizontal cracks. Angle beam probes cover the volume beneath 10 mm depth from head until the bound of head and web. These probes are mainly used to detect transverse cracks.

The ultrasonic testing device has three gates. One of the gates is set for the back wall echo of the normal echo. 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 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 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 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 schism of this flaw detector system is shown in Figure 3. Additionally, this flaw detector makes it possible to test all switches elements and to detect all defects [4].

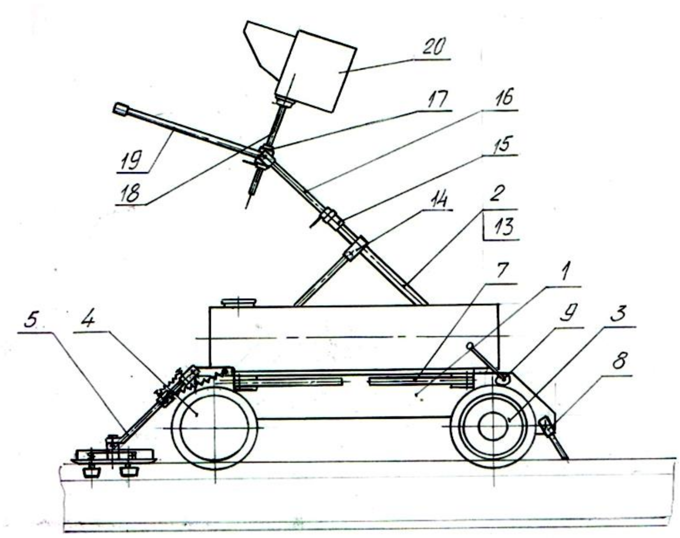


Figure 3. The schism of the USDS2-73MR ultrasonic rail flaw detector

To detect inner rail defects of various directions, several UT techniques are implemented in this flaw detector. This flaw detector system has two probe unites each of which contains 13 probes at different positions. The normal transmitter and receiver 4 MHz probe, detects vertical 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 the refracted angle of $58^{\circ}$ (turned over by $34^{\circ}$ relative to the longitudinal axis in the gage side) make it possible to detect transverse defects of various directions relative to the vertical plane.

Two angle beam 2.5 MHz, single crystal probes with the refracted angle $70^{\circ}$ (directed along the longitudinal rail axis) are used to make it possible to detect transverse surface cracks of 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 the refracted angle $45^{\circ}$ (directed along the longitudinal rail axis) are used. For reliable detection of cracks in bolt holes, probes have a wide direction pattern. This allows, simultaneously with the signal from the hole, watching the signal from a possible crack situated mainly at an angle of $45^{\circ}$, including the one that does not go beyond the hole projection. The technique also makes it possible to detect transverse surface cracks in the base, except for the defects situated in the bolt holes area. Such defects are not usually detected by the normal probe. To detect defects of various directions, two probes are implemented that are directed along and against the trolley movement. Base scheme of complete rails testing of one of the probe unites is shown in Figure 4.

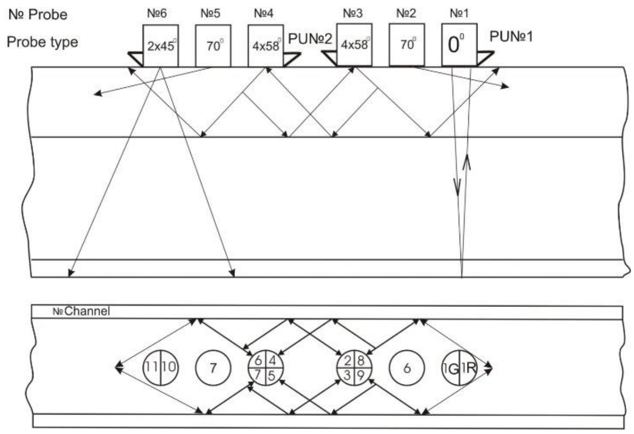


Figure 4. Base scheme of complete rails testing

Finally, the testing area which this detector system can cover is shown in Figure 5.

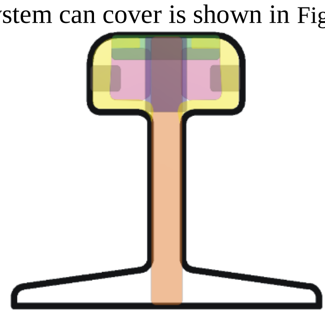

Figure 5. Testing area of the flaw detector system

**Results and discussion**

By testing 25 km of the rails, defects like crack, porosity, lamination, lack of fusion, and break in rail, thermite welding and flash-butt welding were detected. Additionally, all of the defects were inspected another time using manual ultrasonic device in order to verify and characterize the defects. In Figure 6 and Figure 7, sample signals obtained from defects detected in rails and the relevant section of the rail are shown and in Figure 8 and Figure 9, two samples of detected defects in flash-butt welding and the relevant rail sections are shown.

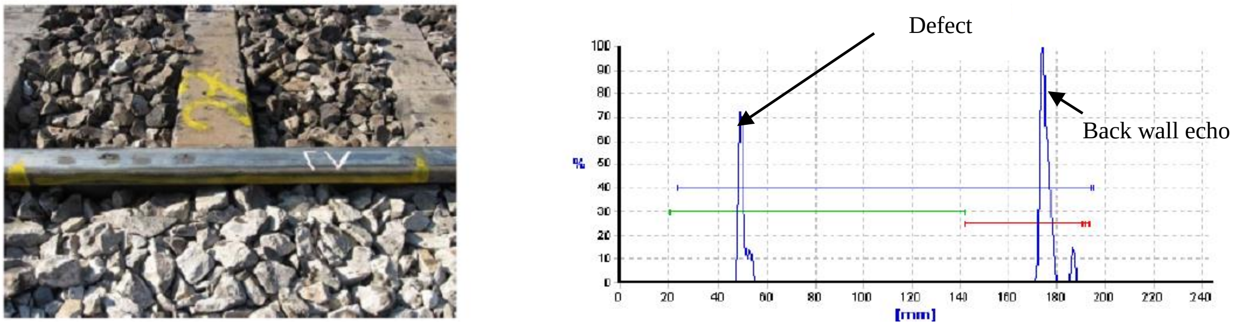


Figure 6. Lamination in rail in 49mm depth with 300 length

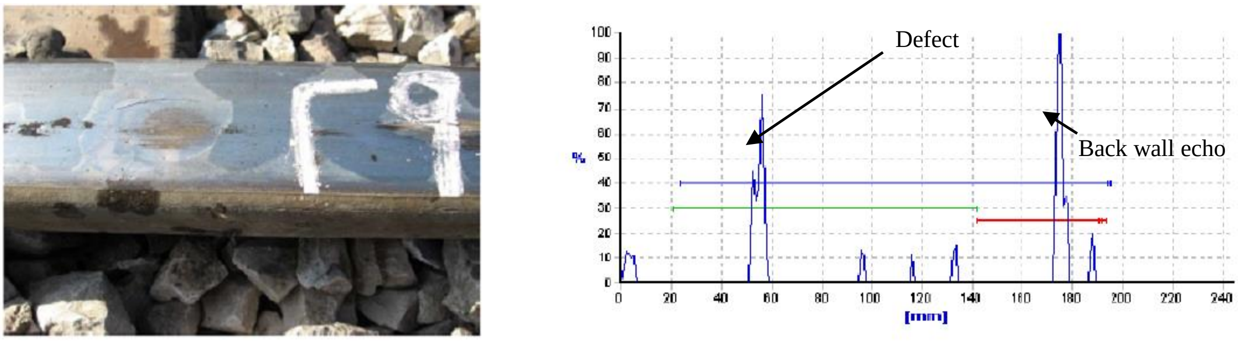


Figure 7. Lamination in rail in 57 mm depth

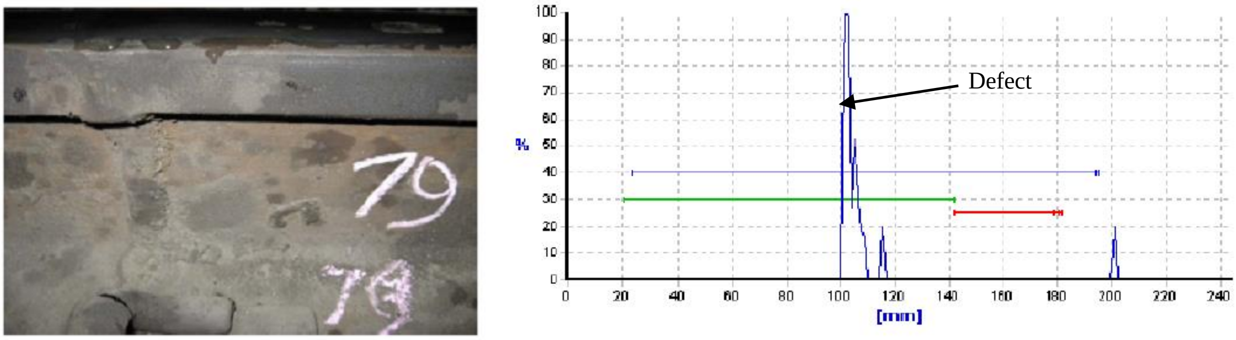


Figure 8. Crack in flash-butt welding in 101 mm depth

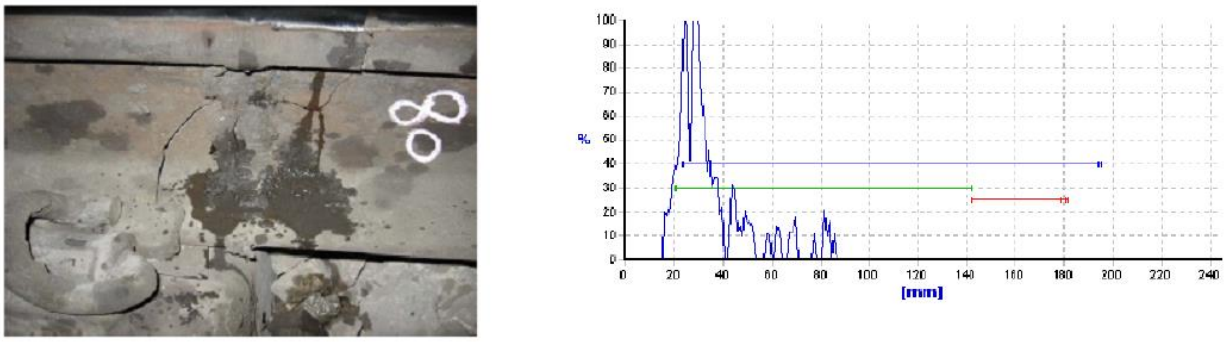


Figure 9. Rail break in flash-butt welding

According to the obtained statistical results from defects in rail, thermite welding and flash-butt welding, 1.6 % of defects are break, 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 this distribution of defects is shown.

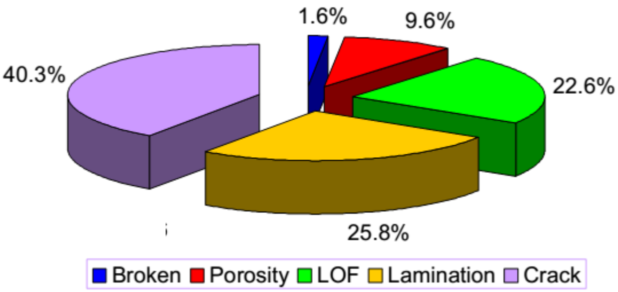


Figure 10. The distribution of different kind of detected defects

The detected defects have been analyzed in another form too. 26.6% of defects occurred in rails, 22.6% occurred in thermite welding and 50.8% were accord in flash-butt welding. The pie chart of these statistics is shown in Figure 11.

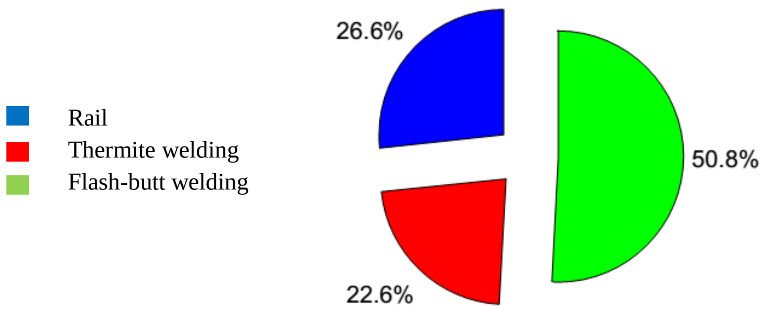


Figure 11. The distribution of the situation of defects

By inspecting the rails and welding, the sections containing dangerous defects like break, cracks, and porosities were replaced by new rail section and other ones which did not reach their critical size, were kept under consideration and were inspected regularly.

## Conclusions

As the time passes, the desire to move trails faster and safer grows with higher peace. Although testing rails might be a small portion of railways industry, it plays a crucially important role in safety and asset maintenance. Thanks to the advancements of NDE methods, testing and monitoring condition of rails have become possible and will help the authorities to acquire their goal of having faster and safer running. Iranian railways, like all of the modern railways in the world today, have been implementing different NDE methods to test and evaluate the condition of rails and other relevant components in rail industry and in this paper, two ultrasonic flaw detector devices were introduced. However, there is a need for more advanced and faster flaw detector machines with which 10000 km rail track will be more often monitored and less shut down will be imposed to rail track.

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