Surface Flaw Testing of Weld Zone by Uniform Eddy Current Probe

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Abstract. In the here discussed presentation, the authors propose the applying of a new eddy current probe to non-destructive surface weld testing through the anticorrosion painting. The probe developed by the authors has a conspicuous feature of generating very little probe lift-off noise. The experimental results in the laboratory have indicated that so performed eddy current testing can pick-up longitudinal and transversal flaws in weld zones at a reasonable signal-to-noise ratio. Thus the authors deem the eddy current weld inspection using the new probe as a promising replacement magnetic particles testing.

Introduction

Weld zones need periodic in-service non-destructive surface inspection in order to maintain their reliability and safety in oil storage tanks, power plants, etc. Although magnetic particle testing has successfully been applied to the in-service inspection, the method suffers under the fact that it is very time-consuming and costs a lot because of the need of removing the anticorrosion painting at the surface of the weld zone and repainting afterwards. In contrast, eddy current testing is non-contact testing. If eddy current testing can be applied to the inspection of weld zones, the inspection can be conducted over the paint without removing the paint, thus reducing the inspection time. However, when a conventional surface coil is used in the eddy current testing, the testing is difficult because of the large noise generated at the weld zone. The noise at the weld zone is due to the change in electromagnetic characteristics and the change in the relative distance of the test material and test coil.

In recent years, eddy current probes with little noise have been developed, and they were tested for weld zone inspection [1][2]. When these probes were used, flaw detection at the surface of the weld zone could be achieved because the noise at the weld zone was little. However, in order to detect flaws at the weld zone, repeated probe scanning was necessary, thus the testing was time-consuming. In addition, it was necessary to change the direction of the probe, depending on the direction of the surface flaw of the weld zone. The authors have reported that when magnetic test materials such as steel were tested with the uniform eddy current probe without changing the direction of the probe, flaws parallel to the scanning direction could be detected by the change in eddy current, and the flaws perpendicular to the scanning direction could be detected by the change in magnetic flux [3][4]. Thus, the authors contemplated the application of the uniform eddy current probe to a single scan testing method that is usable above the paint of the weld zone, regardless of the direction of the flaw on the surface of the weld zone. Thus, the authors devised a structure for the uniform eddy current probe such that a single scan could detect flaws on the surface of the weld zone. That is, the authors devised a uniform eddy current probe consisting of a rectangular exciting coil, which is sufficiently longer than the weld width, and a rectangular detecting coil. It was confirmed that if the exciting coil winding is placed perpendicular to the direction of the welding and the probe scans in the direction of the welding, a longitudinal flaw parallel to the weld zone and a transversal flaw perpendicular to the weld zone can be detected. For the detection of a longitudinal flaw at the weld toe of the test material with weld reinforcement, it was confirmed that the SN ratio is improved by reforming the exciting coil winding of the uniform eddy current probe.

Surface Flaw Testing of the Weld Zone by the Uniform Eddy Current Probe

The structure of the uniform eddy current probe used for the detection of surface flaws with a single scan is shown in Figure 1. The uniform eddy current probe consists of a rectangular tangential exciting coil, which is longer than the weld width, and a long rectangular detecting coil. In order to detect a surface flaw of the weld zone with a single scan and with a small weld noise, scanning was conducted as follows. As shown in Figure 2, the exciting coil winding of the uniform eddy current probe was placed perpendicular to the direction of the welding, and the probe scanned over the weld zone in the direction of the welding. The case in which a transversal flaw is present at the weld zone is shown in Figure 2(a). Magnetic fluxes generated with the exciting coil current pass through the test material. However, if there is a transversal flaw at the weld zone, the magnetic flux flow is disturbed by the flaw, and the magnetic fluxes over the surface of the test material become disordered. Some of the disordered magnetic fluxes pass through the detecting coil, then an electromotive force is generated and a flaw signal is obtained. If a transversal flaw is located at the center of the detecting coil, the magnetic fluxes that pass through the detecting coil are balanced, and an electromotive force is not generated. If a flaw is located under the opposite side of detecting coil winding, a flaw signal of the opposite polarity is obtained.

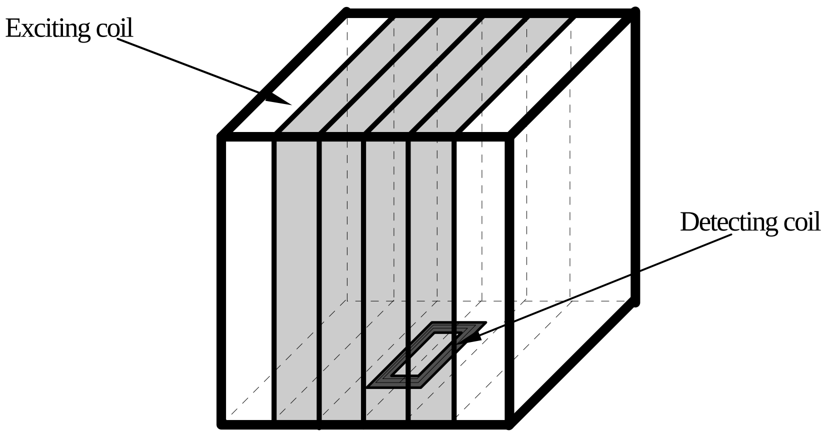
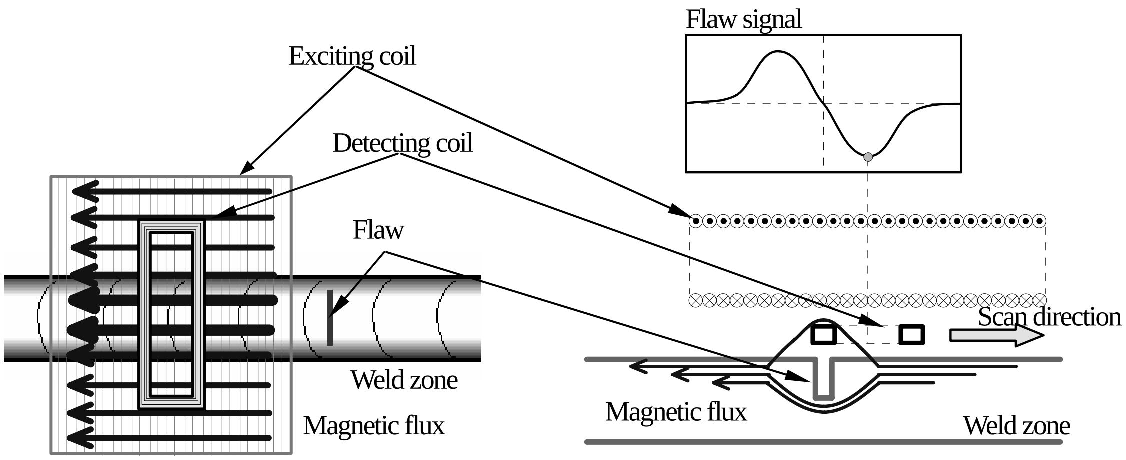
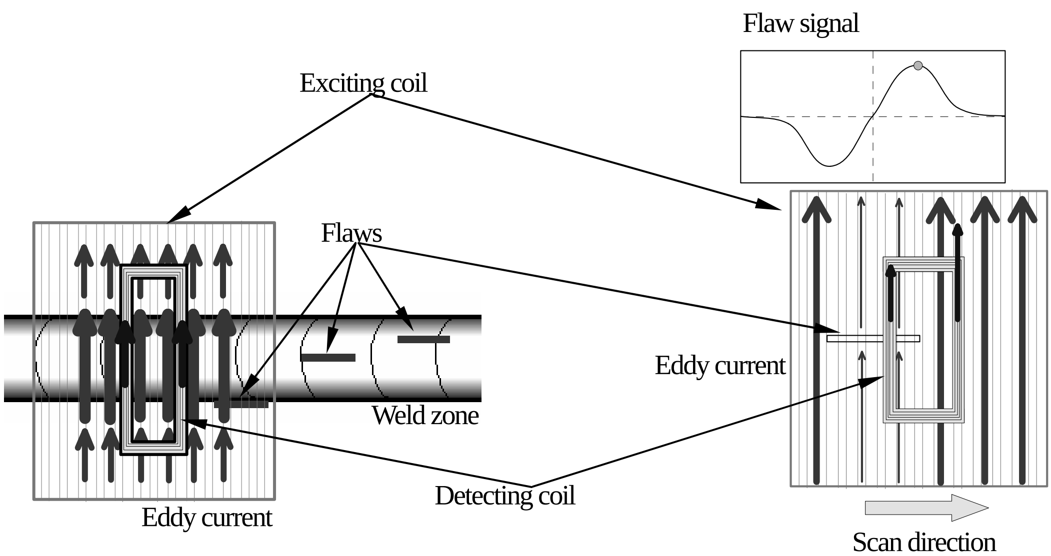


Figure 1 Structure of the uniform eddy current probe used for the detection of weld surface flaws with a single scan.

The case in which a longitudinal flaw is present at the weld zone is shown in Figure 2(b). The direction of the induced eddy current in the test material is in the same direction under the vicinity of the exciting coil winding. Therefore, the eddy current flows perpendicularly to the weld zone. The longitudinal flaw and the eddy current are orthogonal, and the eddy current is disturbed by the flaw. Thus, the magnetic fluxes are disordered, an electromotive force is generated in the detecting coil, and a flaw signal is obtained. If a longitudinal flaw is located at the center of the detecting coil, the eddy current flow is symmetrical around the axis that passes through the center of the detecting coil and is perpendicular to the weld zone. Then, the magnetic fluxes that pass through the detecting coil are balanced, and an electromotive force is not generated. If a flaw is located under the opposite side of detecting coil winding, a flaw signal of opposite polarity is obtained because the winding of the detecting coil is reversed.



(a) detection of transversal flaws perpendicular to the weld zone by magnetic fluxes.

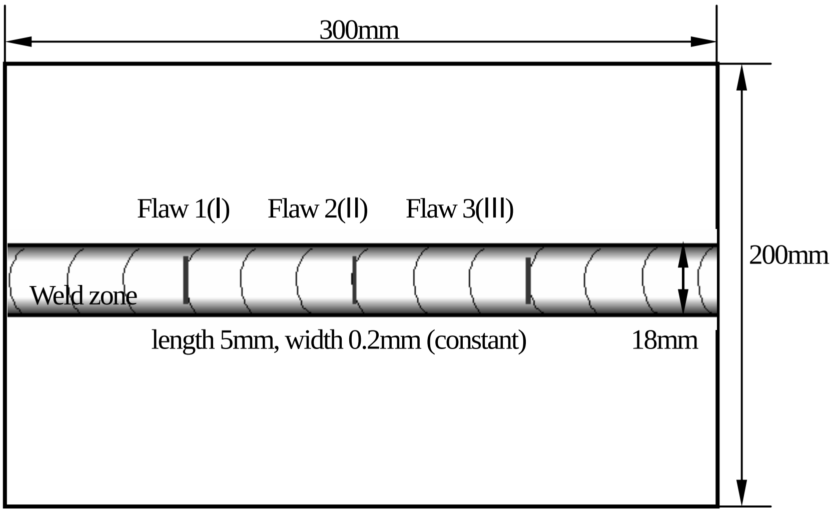


(b) detection of longitudinal flaws parallel to the weld zone by eddy currents.

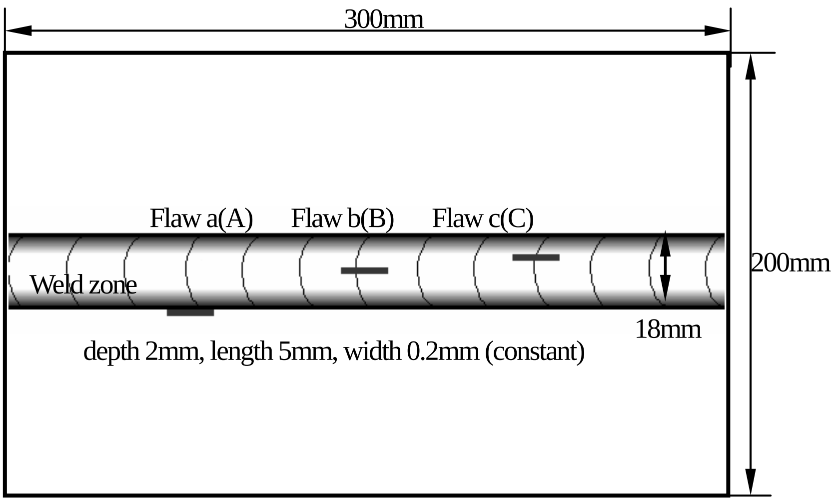
Figure 2 Surface flaw testing of the weld zone by the uniform eddy current probe.

Experimental Methods

The exciting coil for the uniform eddy current probe used in the experiment had a width of 30 mm, length of 60 mm, height of 45 mm, and it was a single winding. The detecting coil had a width of 4 mm, length of 40 mm, and the winding cross-section is 1x1 mm^2. The test material was a SM490A steel plate with 10 mm thickness and with a weld zone of about 18 mm in width. Two types of material with polished weld reinforcement and material with 2 mm high weld reinforcement are used. On both materials, slits with a length of 5 mm, width of 0.2 mm, and depths of 1.0, 2.0, and 3.0 mm are machined by electro discharge machining. The locations and sizes of flaws perpendicular to the weld zone (transversal flaws) are shown in Figure 3(a), and those flaws parallel to the weld zone (longitudinal flaws) are shown in Figure 3(b). The test frequency is 20 kHz so that the signal amplitude for the longitudinal flaw and the signal amplitude for the transversal flaw would be comparable. In order to simulate the anticorrosion painting, a non-conducting acrylic plate is sandwiched between the probe and the test material. The relative distance between the probe and the test material is set at 3 mm by considering the weld reinforcement height of the weld zone.



(a) Test material with transversal flaws.



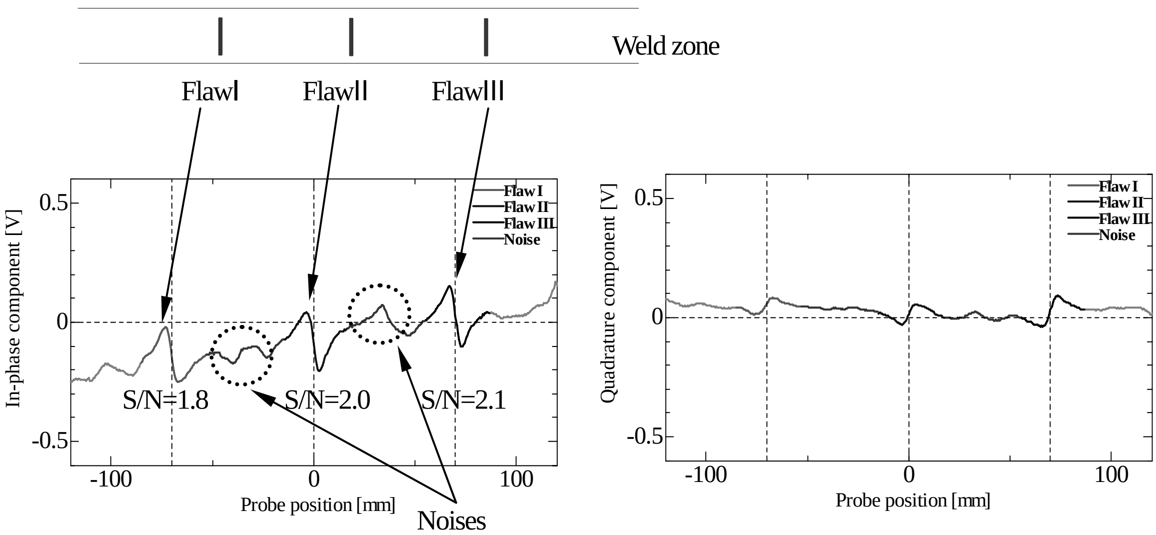
b) Test material with longitudinal flaws.

Figure 3 Test materials and flaw sizes used in the experiment.

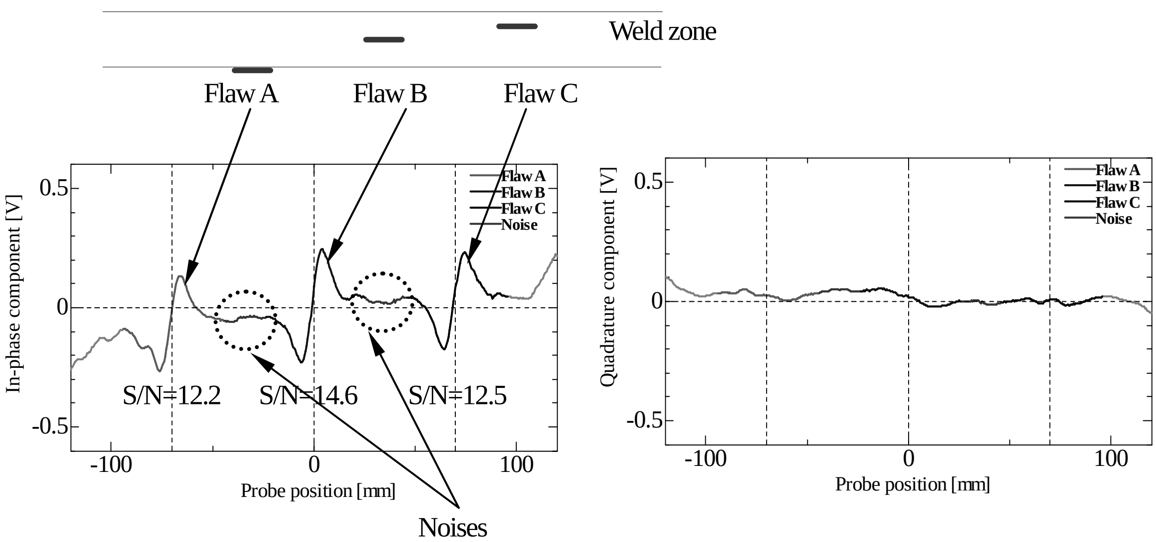
Experimental Results

1.1 Surface Flaw Testing of the Weld Zone with Polished Weld Reinforcement

Flaw signals obtained by scanning in the direction of the weld zone are shown in Figure 4. Figure 4(a) shows the flaw signals for the transversal flaws with respect to the probe position. Figure 4(b) shows the flaw signals for the longitudinal flaws with respect to the probe position. The SN ratios shown in the figure are calculated from the flaw signals and the noise where there are no flaws. Both transversal flaws and longitudinal flaws can be detected with high SN ratios with a single scan. For the transversal flaws, the signal amplitude varies depending on the different flaw depth. For the same depth of longitudinal flaws, similar signal amplitudes are detected regardless of the flaw location with respect to the weld zone.



(a) Flaw signal waves for transversal flaws.

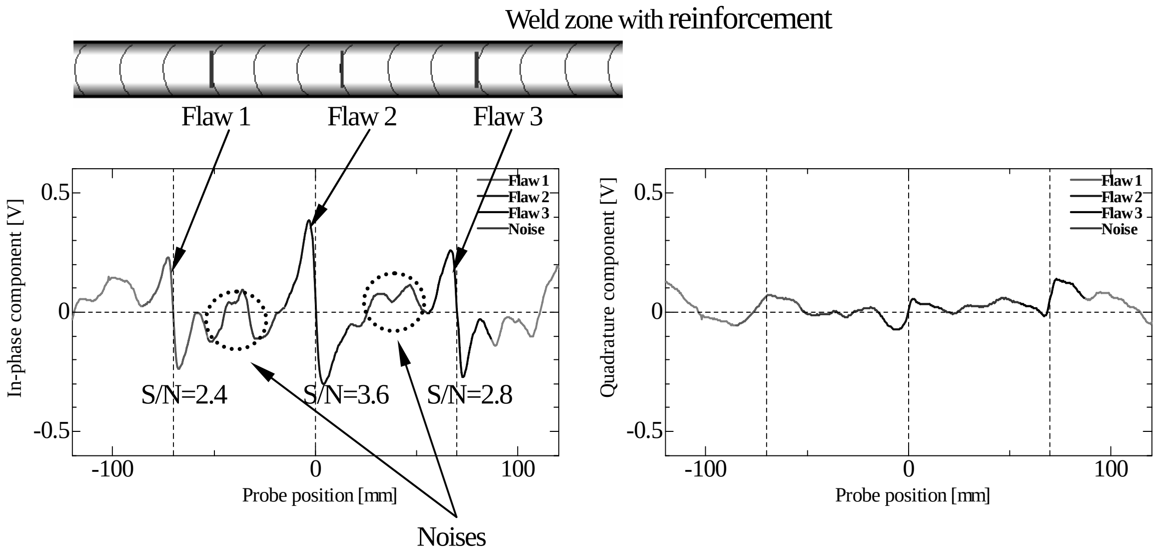


(b) Flaw signal waves for longitudinal flaws.

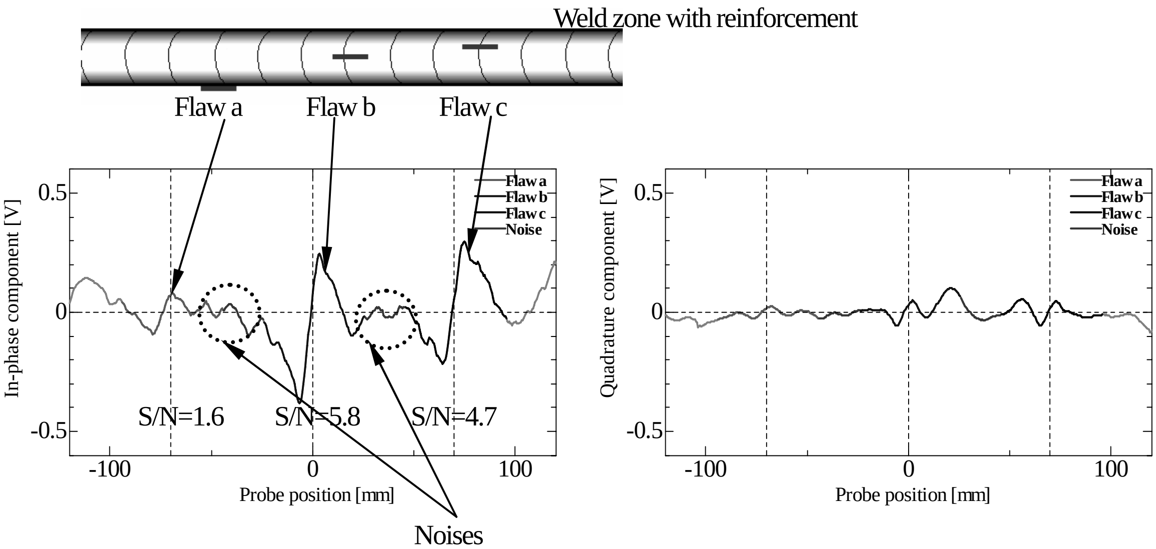
Figure 4 Flaw signals obtained by scanning a uniform eddy current probe to the direction of the weld zone.

1.2 Surface Flaw Testing of the Weld Zone with Weld Reinforcement

Flaw signals obtained by scanning over the weld zone with the weld reinforcement are shown in Figure 5. Figure 5(a) shows the flaw signals for transversal flaws with respect to the probe position. Figure 5(b) shows the flaw signals for longitudinal flaws with respect to the probe position. The SN ratios shown in the figure are calculated from the flaw signals and the noise where there are no flaws. Both transversal flaws and longitudinal flaws can be effectively detected with little noise due to the weld zone. For the transversal flaws, the signal amplitude varies depending on the different flaw depths. For the same depth of longitudinal flaws, large signal amplitudes are obtained, except for the flaws at the weld toe. For the flaws at the weld toe, the signal amplitude is small since the probe lift-off is large because of the weld reinforcement height at the weld zone. Therefore, in the detection of a longitudinal flaw at the toe of the weld zone, the exciting coil winding of the uniform eddy current probe was reformed.



(a) Flaw signal wave for transversal flaws.



(b) Flaw signal waves for longitudinal flaws.

Figure 5 Flaw signals obtained by scanning a uniform eddy current probe to the direction of the weld zone.

At the toe of the weld zone with the weld reinforcement, the authors considered that the induced eddy current is small because the distance between the probe and the test material is large. Thus, the structure of the uniform eddy current probe is reformed so that the induced eddy current at the weld toe would be large by allowing multi-layer winding at the both side of exciting coil winding with respect to the weld zone. The flaw test results are shown in Figure 6. Compared with Figure 5(b), a longitudinal flaw (flaw a) at the weld toe is detected with a high SN ratio.

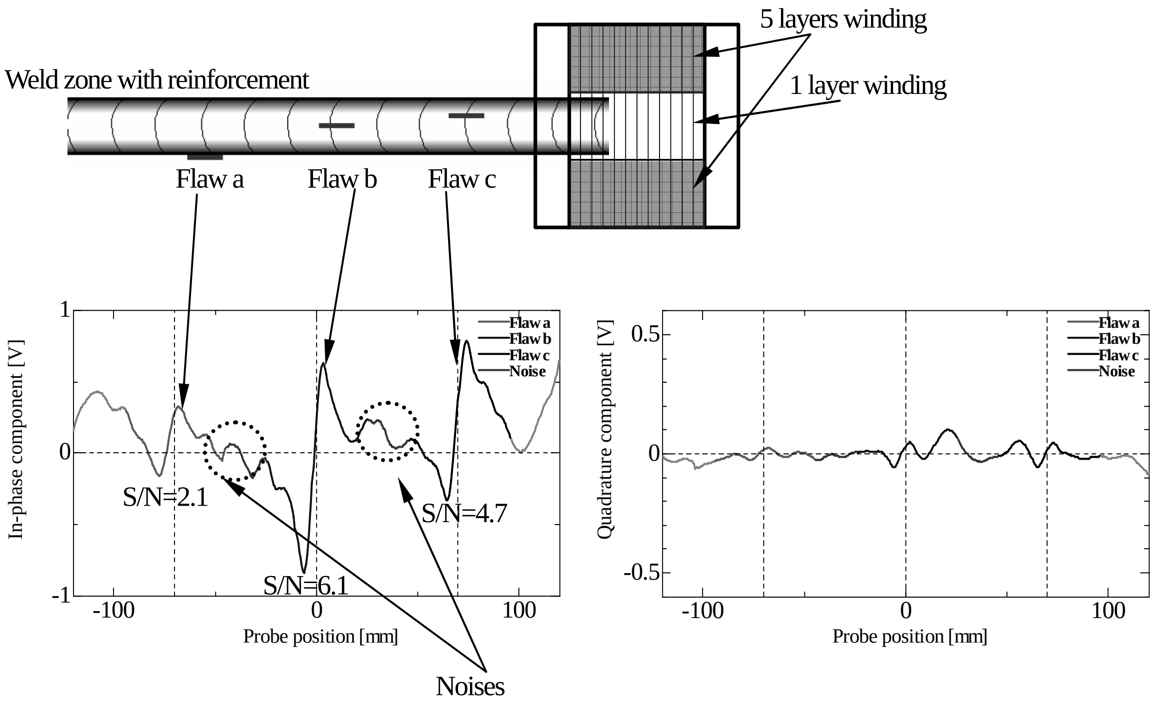


Figure 6 Results of a uniform eddy current probe with multi-layer winding at the both side of exciting coil winding with respect to the weld zone.

Summary

Surface flaw testing of the weld zone with a uniform eddy current probe is investigated and the following result is confirmed.

(1) A uniform eddy current probe consists of a rectangular exciting coil, which is longer than the weld width, and a long rectangular detecting coil. When scanning with the uniform eddy current probe so that the exciting coil winding is perpendicular to the direction of the weld zone, longitudinal flaws and transversal flaws can be detected with a single scan. Longitudinal flaws can be detected by the change in the eddy current, and transversal flaws can be detected by the change in the magnetic flux.

(2) For flaws of the weld zone with polished weld reinforcement, signals with approximately the same amplitude can be detected regardless of the location of weld flaws.

(3) At the weld zone with weld reinforcement, the distance between the probe and the test material becomes large at the weld toe because of the weld reinforcement. Thus, the signal amplitude for a longitudinal flaw at the weld toe is small, and the SN ratio is small.

However, the SN ratio can be improved by reforming the structure of the probe. Reforming the probe proposed by the authors can be achieved by applying a multi-layer winding to both side of the exciting coil and strengthening the induced eddy current.

In the future, the authors will investigate the effects of different test frequencies and probe sizes. In addition, the authors will conduct a further detailed investigation concerning the flaw evaluation.

References

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