# Detection of Cracks at Welds in Steel Tubing Using Flux Focusing Electromagnetic Probe

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## Introduction

The inspection of weldments in critical pressure vessel joints is a major concern in the nuclear power industry. Corrosive environments can speed the fatigue process and access to the critical area is often limited. Eddy current techniques have begun to be used to help overcome these obstacles [1]. As direct contact and couplants are not required, remote areas can be inspected by simply snaking an eddy current coil into the intake tube of the vessel. The drawback of the eddy current method has been the high sensitivity to small changes in the conductivity and permeability of the test piece which are known to vary at weldments [1]. The flaw detection mechanism of the flux focusing electromagnetic probe can help alleviate these difficulties and provide a unique capability for detecting longitudinal fatigue cracks in critical tube structures.

The Flux Focusing Electromagnetic Flaw Detector, originally invented for the detection of fatigue and corrosion damage in aluminum plates [2-3], has been adapted for use in testing steel tubing for longitudinal fatigue cracks. The modified design allows for the probe to be placed axisymmetrically into the tubing, inducing eddy currents in the tube wall. The pickup coil of the probe is fixed slightly below the primary windings and is rotated 90° so that its axis is normal to the tube wall. The magnetic flux of the primary coil is focused through the use of ferromagnetic material so that in the absence of fatigue damage there will be no flux linkage with the pickup coil. The presence of a longitudinal fatigue crack will cause the eddy currents induced in the tube wall to flow around the flaw and directly under the pickup coil. The magnetic field associated with these currents will then link the pickup coil and an unambiguous increase in the output voltage of the probe will be measured. The use of the flux focusing electromagnetic probe is especially suited for the detection of flaws originating at or near tube welds. The probe is shown to discriminate against signals due solely to the weld joint so that flaw signals are not hidden in the background in these locations. Experimental and finite element modeling results are presented for the flaw detection capabilities of the probe in stainless steel tubes.

## Probe Design and Operating Characteristics

Fig. 1 displays the probe design and finite element modeling results for the magnetic flux and induced eddy current density when the probe, operating at 240 kHz, is placed in an unflawed tube. The mode of operation is very similar to that of the self nulling flaw detector for surface crack detection as explained elsewhere [2-4]. The main design change is in the rotation of the pickup coil so that its axis is normal to the tube wall. As seen in fig. 1, there is no flux linkage with the pickup when unflawed material is inspected. When the probe passes a longitudinal fatigue crack at the inner surface of the tube wall the induced eddy currents in the tube wall will be forced to flow around the flaw. The magnetic field associated with these currents will then link the pickup coil and an emf will be generated across the pickup coil leads. The design and resulting flaw detection mechanism of the probe make it relatively insensitive to circumferential discontinuities, such as a butt joint or weld bead.

## Experimental Results

In order to test the operation of the probe an experimental sample was fabricated. A pressure vessel and intake tubes were simulated by welding two 9.5 mm ID tubes of 2.5 mm wall thickness into 9.5 mm through holes in a 25 mm thick block. A 0.25 mm wide EDM notch was then cut 3.175 mm long and 1.57 mm deep into the stainless steel block beginning at the weldment of one of the tubes, the other remaining unflawed. All materials used in the sample were stainless steel 316.

Fig. 2 shows the output voltage of the probe, operating at 240 kHz, as it is scanned past the welds in both the unflawed and EDM notched tubes. The large peak in the output voltage of the notched tube clearly identifies the damage. As a comparison with conventional eddy current techniques, the results of testing the same two tubes with a 600 kHz differential eddy current probe are also displayed in fig. 2. Although the effect of the EDM notch can be seen in the

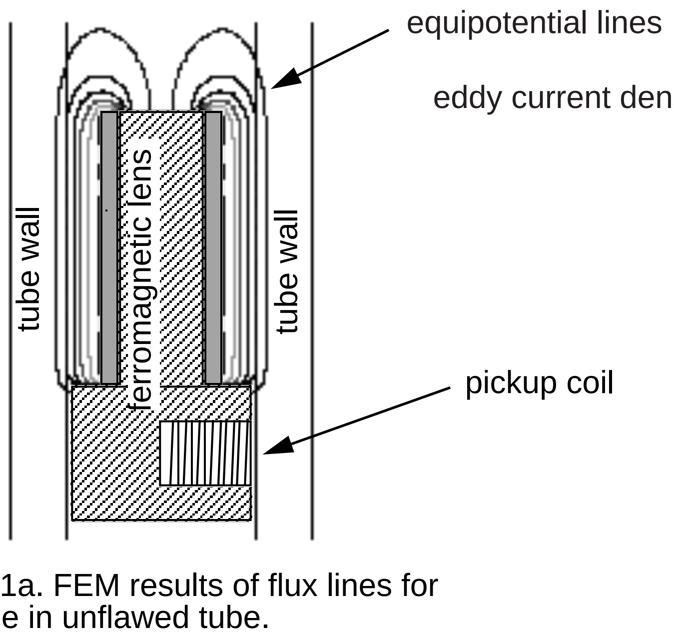

Fig. 1a. FEM results of flux lines for probe in unflawed tube.

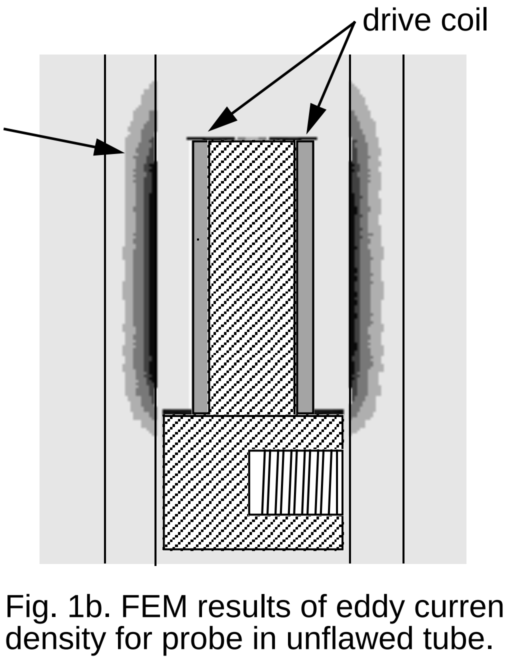

Fig. 1b. FEM results of eddy current density for probe in unflawed tube.

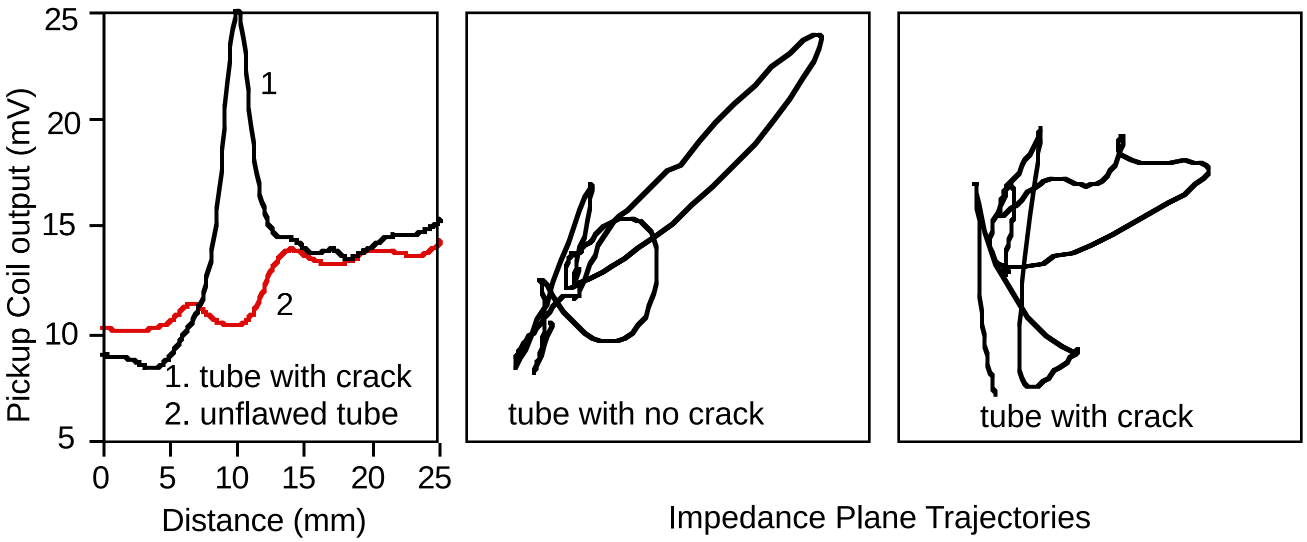

Fig. 2 Experimental results for flawed and unflawed tubes.

impedance plane trajectories, the signals are much more complicated than those recorded with the flux focusing probe. The flaw signal could easily be missed behind the signal due to the weldment.

## Summary

The flux focusing electromagnetic probe has been used to detect surface breaking EDM notches in stainless steel tubing. The flaw detection mechanism of the probe highlights longitudinal fatigue cracks while remaining relatively insensitive to circumferential discontinuities and small changes in conductivity and permeability associated with weld regions. The unambiguous flaw signal of the probe may help to increase the detectability of longitudinal fatigue cracks at or near weldments in critical pressure vessel tubes.

## References

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