Application of Eddy Current Array Technology to Surface Inspection

Jean-François BUREAU 1, Robert C WARD 1, Alexandre JULIEN 2

1 GE Inspection Technologies, 50 Industrial Park Road, Lewistown, PA, USA 
17044; Phone: +1 450-530-4286, Fax +1 717 242-2626; e-mail: jeanfrancois.bureau@ge.com, e-mail: robert_ward@ge.com.

2 GE Inspection Technologies, 68 chemin des Ormeaux, Limonest, France; Phone: +33 (0) 620 161 527; e-mail: Alexandre.julien@ge.com

Abstract

Eddy Current array technology is becoming a more viable and important option in surface testing of conductive materials. The demand for solving applications with ecologically-greener, cleaner, faster, documentable and more repeatable technology has increased with greater accessibility to eddy current arrays. This paper discusses various criteria for evaluating a potential Eddy Current Array applications, some of the development steps in designing an Eddy Current Array probe and where the technology is evolving.

Keywords: Eddy Current Array (ECA), Flexible-circuit Eddy Current array (FLX ECA), Probability of Detection (POD).

1. Introduction

Eddy Current is a common Non-Destructive Testing (NDT) technique for surface inspection of conductive materials. The technology requires the development of probes with specific coil size, frequency, defect orientation requirements, etc. therefore many thousands of probe designs have been developed for users of the technology. Although these probes can vary extensively the number of coils and resulting data channels tends to remain constant at less than five and most often will result in one or two Eddy Current data channels. This is exclusive of multiple frequencies injected simultaneously into a particular coil. This is mostly driven by simplicity of operation and limits of typical Eddy Current instruments, most of which range from one to four channels. This channel limitation can create challenges for some inspections as follows:

- The probability of detection (POD) of an indication. It is difficult to insure that small, low-channel-count probes in manual applications adequately cover the surface to result in a high POD.

- The time required to inspect a large surface area. Because of the limited footprint of low-channel-count probes the inspection of large surface areas can be long, tedious and not cost effective.

Approximately 15 years ago, with the advancement in high-speed, lower-cost computer technology and electronics, Eddy Current Array probes have started to be utilized to solve these challenges. This paper will explain some of the elements of what array probes are, how they work and where they are good candidates to replace standard Eddy Current or other surface inspection techniques.
2. Eddy Current Array Probes

One of the most significant evolutions in Eddy Current sensor technology in recent years has been the development and use of the Eddy Current Array probe.

Figure 1: Example of simple Eddy Current array vs. a single-channel pencil probe

The inspection of large surfaces is problematic due to the low POD for the defects of interest if the inspection is done manually or by the complexity and cost associated with a probe scanner and fixture. Inspection times can be long and often costly, or present a bottleneck in a production environment. Visual surface techniques such as dye penetrant, fluorescent penetrant or magnetic particle require development time, can mean production of chemical wastes and provide data that can only be recorded by photograph. In many cases the quality of the test is highly operator-dependent. Eddy Current Array technology increases productivity and detection capabilities for surface inspection by reading multiple sensors through a multiplexing sequence allowing coverage of a wide surface in a single pass. The data can be stored and processed digitally improving quality, documentation and repeatability, while reducing operator dependency. When compared to manual single-channel Eddy Current inspection, Eddy Current Arrays provide dramatically increased POD for defects-of-interest, due to known surface coverage, sensitivity, and resolution.
3. **Pros and cons**
Eddy Current Arrays are subject to the normal strengths and weaknesses of standard Eddy Current technology. The difference is the number of coils read and data points generated which can range into the hundreds in an array. The physics remain the same and will not work on non-conductive material.

### 3.1 **Pros**
- Best suited for inspection of large surface areas and surface-breaking indications.
- Fast, one pass can cover a wide area, typically up to 4 inches for 0.060” coils and could be much higher with larger coils.
- Better confidence in results due to the known sensitivity of the coils and their overlap which improves resolution.
- Simpler to analyze as the results can be presented as a C-scan image which also allows for use of advanced image processing tools including overlay with volumetric inspection data.
- Can be design to fit complex shape.
- Complex firing and reading sequence pattern can be achieved by the multiplexing electronics.
- Ecologically green, no chemical waste.
- Reduce need of complex robotics.
- Very repeatable results, less operator-dependent than many surface techniques.

### 3.2 **Cons**
- Usually application specific and can be limited to specific areas or geometries.
- Software setup complexity for initial setup as compared to other techniques.
- Solving an application usually requires more development than with a pencil probe.
- Lower sampling rate due to multiplexing.
- Higher initial investment cost.

4. **Application evaluation**
Important to selecting any eddy probe is a proper evaluation of the application, especially for Eddy Current Arrays. Like any other technology it has its advantages and limits and each of them must be weighed carefully to be successful. A good evaluation should take as a minimum the following points in consideration.

#### 4.1 **Type of inspection**
Knowing more about the type of inspection and its environment will help better understand the requirements and design the appropriate solution. If the solution is meant to be used in an industrial environment or part of a manufacturing process, it will most likely have to be ruggedized, automated or semi-automated. If intended for a clean research lab environment, the requirements will be quite different.

#### 4.2 **User profile**
As with the inspection environment, knowing the user profile is very important. A
knowledgeable user that understands all the variable and details of the system might want to have access to all its settings and software menus for optimization. Conversely, if the user is a machine operator in a production environment with minimal or very limited NDT knowledge, a system that is as simple and straight-forward to use should be recommended.

4.3 **Complexity of surface geometry**
Array probes can typically be made to fit specific geometries and can be flexible when using film sensor technology. 3D-geometries can present a serious challenge. One of the big drivers for using array probes is to replace existing visual techniques such as magnetic particle or penetrant methods and careful consideration must be taken of the original specification and any codes requirements. Replacing a magnetic-particle technique for a specific wide-surface area may appear straight forward. However, if the original specification calls for 100% of the part’s surface to be inspected and/or if the part has very complex-shaped geometry, covering 100% with Eddy Current may prove to be unrealistic or cost ineffective.

4.4 **Material**
The type of material to be inspected will help determine the most suitable probe frequency. The lower the frequency, the more array probes are limited due to the multiplexing of its coils. Less multiplexing results in fewer coils and less coverage.

4.5 **Flaw size to be detected**
Flaw size and orientation will be very important to help determine the right configuration or coil design to use. If the orientation of the indication is known, an orientation-sensitive design could be used such as a differential coil or two pancake coils next to one another. This information will also be used to determine the coil overlap necessary to meet the minimum detection requirement.

4.6 **Time constraint**
Inspection time is one of the biggest advantages of array probes since they cover significantly more area in a single pass making the inspection of large surface areas much quicker. Knowing the inspection time requirement will help determine the size of the array and making it more cost effective.

5. **Pitfall/misconceptions**

- Make sure that the added complexity of the array solution does not override its advantages. Array probe is not always the right solution.
- Using an array doesn’t mean you shouldn’t also use a pencil probe. The Eddy Current array can be used as a fast screening tool. Once an indication is found it is easy to re-inspect with a pencil or conventional probe for further investigation as needed.
6. Development steps

The development efforts for new applications can vary significantly depending on the complexity and amount of research needed. In general, it follows these steps:

6.1 Feasibility study
A feasibility study is the most important step of any new array probe development. Although an experienced designer can determine the candidacy of an application with a basic description of the requirements, unknown details are often problematic. The feasibility study consists of gathering all necessary information of the application such as detection requirements, environment, samples, test blocks, etc. This is followed by an exploratory phase where various candidate coil designs are tried as single channels, even if there is good confidence of what the final design should be. This ensures that all aspects of an application are considered and that an unforeseen, better solution isn’t missed. Note that these tests are always conducted using a single-channel configuration since the final array is nothing more than a multitude of the same coil or channel in results should be similar. Care must be taken when doing the evaluation of the results from the feasibility study. The most common error is to look solely at the signal-to-noise ratio to determine the coil’s design to use and although that may sound intuitively correct this may have adverse effects on other aspects of the probe design. A cross-wound coil typically gives very good signal-to-noise ratio because of its self-nulling characteristic, but it would also increase the cost of the probe because of its increased manufacturing complexity. The best evaluation usually compares multiple criteria with appropriate importance weighting. Criteria include defect detection in all orientations, sensitivity vs. lift-off, coil manufacturing, flexible arrays, costs, etc.

6.2 Type of coil
There are many configurations of coils which can be used to make an array probe: Absolute bridge, differential bridge, absolute transmit-receive, differential transmit-receive, cross-wound and more. This is usually determined at the feasibility step along with its size, based on the flaw size to be detected.

6.3 Array design
Once the coil type and size are determined it can be made into an array. The array design will consist of the mechanical housing, the coil’s layout and wiring. This is where the multiplexing comes into play. The coils in the probe are not read simultaneously but rather in a sequential pattern also referred as the firing/reading sequence.
The pattern will be determined by the coil configuration used, which may require that a coil be used as a driver in one time increment and be used as a receiver in the next so that different flaw orientations are covered. This sequence is then repeated in parallel for another group of coils in the probe, always making sure that the closest coil driven simultaneously is far enough to avoid cross talk. Below is an example of a basic sequence where the coils in Time 1 are driven and read simultaneously than Time 2 and so on until all time increments have been done and start over again.

![Figure 2: Basic coil configuration sequence](image)

7. Conclusions

Eddy current array technology is a great NDT tool to improve speed and quality of inspection compared to single-channel eddy current or enhanced-visual techniques for surface breaking indications. However, much like any other tool, it is only as good as what it was made for to do. The very first step before selecting a solution is to have a complete understanding of the application and the desired outcome. This will help pursue the right solution and avoid unnecessary spending for suboptimum or inadequate tools.