TRANSFER OF POD PERFORMANCE CAPABILITIES FROM SIMPLE SHAPES TO COMPLEX SHAPES

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INTRODUCTION

The demand for quantified nondestructive evaluation (NDE) has increased significantly with increasing use of damage tolerance in engineering design and acceptance. The metric that has been developed to quantify NDE capabilities and to provide a method of data exchange is the probability of detection (POD). Generation of a characteristic POD curve requires: (1) passing a statistically significant number of representative flaws through and NDE procedure; (2) the flaw distribution must be near the expected NDE detection threshold; (3) flaws located in representative materials, geometries and surface conditions; (4) systematic control of NDE procedures; and (5) documentation of the results of application [1-3].

Fatigue cracks in simple test specimens are frequently used as the test artifacts. Fatigue cracks have been determined to be representative of severe detection conditions and are relatively inexpensive to produce. A large database has been generated for NDE capabilities of relatively simple specimens [4]. Simple test specimen geometries may not be representative of the NDE challenges in a complex structure or system and methodologies for transfer of the measured capability to complex shapes are required. Substantial progress in predictive modeling of NDE signal response has been made and confidence in such models will result fewer required measurements to validate performance of a new NDE procedure or application. Since comparative response using physical artifacts is the primary basis for most NDE "calibration" comparative response measurements may logically be used to both validate model predictions and to provide a basis for transferring reference POD measurements from simple specimens to more complex applications. This paper describes such methodology and the rationale for transfer based on repetitive measurements on "calibration" artifacts. Since the method is based on quantified NDE measurements, it is applicable only to those procedures which produce a quantified, scalar output such as those obtained in eddy current and ultrasonic methods.

"CALIBRATION" USING REFERENCE ARTIFACTS

The objective of a calibration procedure is to provide a baseline for reproducibility and repeatability for measurements made. NDE instrument "calibration" generally consists of setting instrument gain to produce a specified signal from a slot or hole artifact of a

Review of Progress in Quantitative Nondestructive Evaluation, Vol. 18
Edited by Thompson and Chimenti, Kluwer Academic/Plenum Publishers, 1999

specified size. Good practice involves a secondary check to assess the linearity (functional reproducibility) of response from artifacts of a size that bounds the size range of flaws to be detected by the procedure. Further, one or more signal to noise measurements are recommended for response characterization and added confidence in reproducibility of the instrument set-up. For purposes of discussion, we will assume that "calibration"/reference artifacts are a series of slots of increasing size, that have been induced in a flat plate specimens of the same material properties and thickness as the test object to be inspected.

Slots are economical to produce with available technology and are commonly specified in establishing and applying NDE procedures used in crack detection. In addition, slots may be induced in large structures and complex shapes that would be difficult to crack for purposes of determining crack detection capabilities (POD). The response from a slot is not, however equivalent to the response for a crack (in most cases) and the capability for crack detection must be determined experimentally [5]. A crack detection threshold that has been carefully established in simple specimens (often flat plate) may then be transferred to a more complex shape by comparison of relative responses to slots in simple and complex specimens and by then adjusting the signal discrimination threshold to the equivalent signal to noise response.

Figure 1 shows typical response distributions for repetitive measurements on a slot and crack of equal size. The decision to identify a signal response as a crack is dependent on the capability to discriminate signal from noise. The differences in signal and noise responses are thus bounded by the upper limit of the noise distribution and the lower limit of the signal distribution as shown by the dashed lines. The applied discrimination/acceptance criteria level is the value between the bounds that is the basis of a flaw call out.

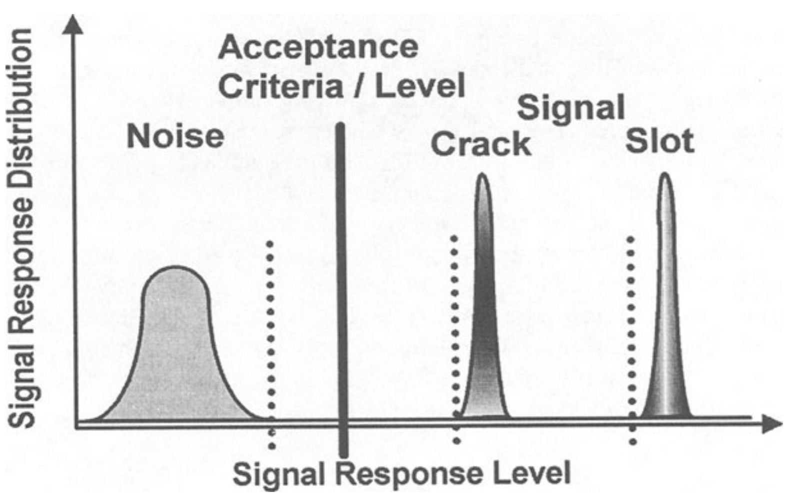

Figure 1. Comparative responses from a crack and a slot of equal size.

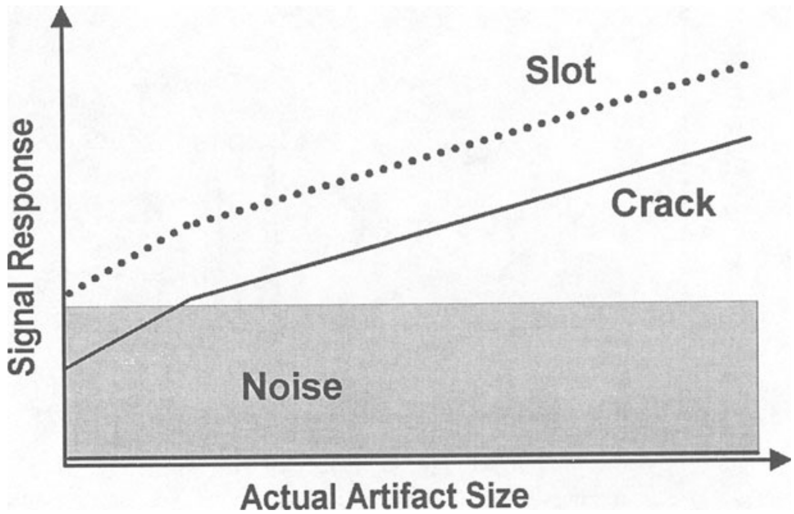

Figure 2. Relative signal response for cracks and slots of varying size.

It is important to note that the noise response is not electronic noise that is familiar in other applications, but is signal response due to surface roughness, grain scatter, etc. that are inherent to the NDE measurements on the test object in the absence of a flaw. The relationship between the flaw and slot responses is important since transfer to a complex structure is achieved by using that simple relationship; the relative responses of equivalent size slots in the simple specimen and the complex part; and by maintaining equivalency of the slot signal to noise response for the complex part. A typical plot lower limit of the repetitive signal response from cracks and slots is shown schematically in Fig. 2.

A quantitative NDE response relationship may then be experimentally generated using equivalent size slots in both flat plate and complex specimen configurations and equivalent size cracks in simple (flat plate) specimens. Transfer of the respective slot and crack responses is then a similar procedure to that used for initial procedure set-up/"calibration". The simple ratio calculation is as follows:

$$\ln\left(\text{Crack Response } (C)\right) = \frac{\ln \text{Slot } a(C)}{\ln \text{Slot } a(F)}\left(\text{Crack Response } (F)\right)$$

$$\ln\left(\text{Crack Response}(C_{o\rightarrow n})\right) = K \ln\left(\text{Crack Response } (F_{o\rightarrow n})\right) \qquad (1)$$

where C is the complex shape, and
F is the flat plate respectively.

Figure 3 shows a calculated crack response distribution that may be generated from the corresponding slot and flat plate crack responses. The calculated crack and slot responses may also be provided by predictive modeling of the specific measurement process once the model has been validated and confidence in output has been established.

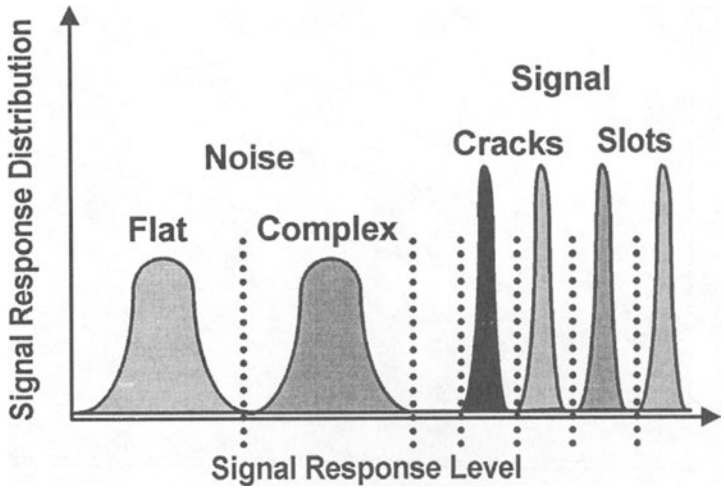

Figure 3. The calculated relative response for a single size crack in a complex shape is shown in solid black.

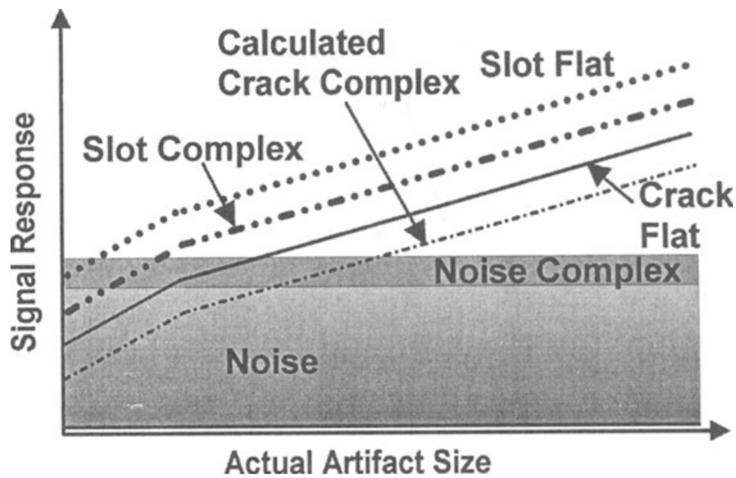

Figure 4. Calculated relative response from a crack in a complex shape.

Oncc a relationship between responses to slots and cracks is established, a continuous function may be plotted in the form shown in Figure 4. This is the same response required in use of the a/â method used in POD generation (Response and actual crack size are plotted as logarithmic function - ln/ln) [6].

PROBABILITY OF DETECTION (POD) ADJUSTMENT

The probability of detection for a given inspection procedure is dependent on the signal response and on the acceptance criteria applied to the signal responses generated. The acceptance criteria is established at a point where the signal can be discriminated from the noise response (signal to noise characteristic--see Figure 1). The POD established for the complex shape inspection must therefor be adjusted to provide the same signal/noise

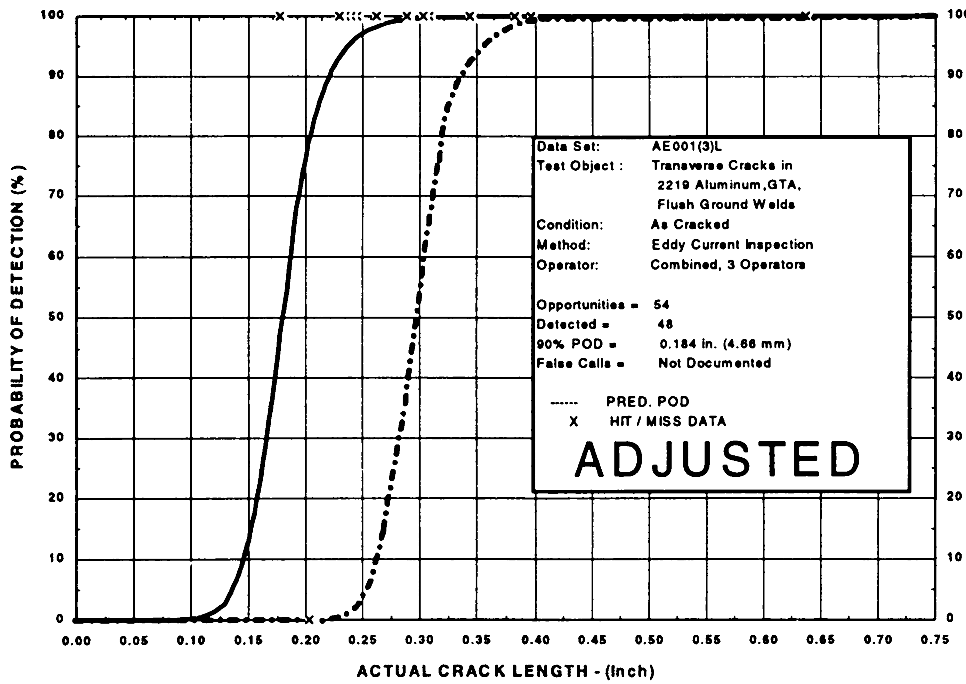

Figure 5. Relative POD curve for the flat plate case and the adjusted curve for the complex shape case using equivalent threshold discrimination level criteria.

discrimination as that used for the flat plate case. This may be accomplished by simple determination of equivalent signal response at the threshold POD level or a new POD curve may be generated using the signal response data and the equivalent relative acceptance threshold. The equivalent response procedure is a variance of that described as "equivalent reflectivity" by other workers [7,8]. It is important that care and rigor in making measurements be exercised to link NDE performance capability (POD) using this method. A typical adjusted POD curve is shown schematically in Figure 5.

CAUTIONS

Rigor in application of the method described is required and documentation of each data acquisition and calculation step is necessary for both process control and for future re-validation. Further: (1) cracks and slots must be reproducible and must be representative of the conditions under which the measurement and evaluations are to be applied; (2) physical measurements of slots and cracks must be traceable to established measurement standards; (3) all measurements must be made using the same procedure that is intended for the application; (4) crack to crack variance is not transferred and is assumed to be equal to the variance found in the flat test specimens; (5) variances in part stress state and crack orientation are not transferred and must be addressed by the mode of application of the NDE procedure; and (6) human factors variables are not accounted for by this data generation and analysis method and must be addressed separately.

Particular care must be taken in generating equivalent slots in materials that are degraded by local heating during the slotting (electrodischarge machine, laser or saw cut) process. Alloy steels and age hardenable aluminum alloys are known to be particularly sensitive to the slotting process. It is recommended that slot generation procedures be assessed to assure that the same size slot produces and equal and functionally equal responses in flat plate specimens, before slotting the test specimens to be used for POD adjustment.

SUMMARY

An experimental procedure is described for transferring nondestructive evaluation (NDE) procedure performance (probability of detection - POD) capabilities, that have been validated on simple specimens, to complex configurations found in field applications. The method is useful in both procedures applications to complex inspection objects and in validating predictive model outputs that may be used in applications to similar complex shapes. The method is based and is an extension of procedures used is routine "calibration"/set-up of inspection procedures.

Users are cautioned that the methods cannot be applied in a cook book manner, but require a thorough understanding of NDE procedures, procedure characteristics, limitations and boundary conditions for application. Particular care and attention must be used in producing and characterizing "calibration"/reference slotting procedures and output before attempts are made to generate equivalent response data. The link and integration of the method with predictive measurement response models is a desirable feature for broad procedure applications.

REFERENCES:

1. P. Berens, "NDE Reliability Data Analysis", in Metals Handbook, 9th Edition, Vol.17, p 689, ASM International, 1989.
2. W. D. Rummel et al, "Recommended Practice for a Demonstration of Nondestructive Evaluation Reliability on Aircraft Production Part", Materials Evaluation, 40, p 922, 1982.
3. W. D. Rummel, G. L. Hardy & T. D. Cooper," Applications of NDE Reliability to Systems, in Metals Handbook, 9th Edition, Vol.17, p 674, ASM International, 1989.
4. NDE Capabilities Data Book, 3rd Edition, DB-2, 1997, available through NTIAC, (512) 263-2106.
5. Ward D. Rummel, "Considerations for Quantitative NDE and NDE Reliability Improvement, Review of Progress in Quantitative Nondestructive Evaluation, Vol., 2A, p. 19, 1983, Plenum Press, New York.
6. A. P. Berens, op cit.
7. R. H. Burkel, D. J. Sturges, R. S. Gilmore and W. T. Tucker, "Effective Reflectivity: POD Methodology for Ultrasonic Inspection, Paper presented to the 1995 Fall Conference of the American Society for Nondestructive Testing, Dallas, Texas.
8. Olav Forli, et al, "Guidelines for replacing NDE techniques with one another, NT Report 300, NORTEST, P.O. Box 116, FIN-02151 ESPOO, Finland, 1995.