

NDE - A KEY TO ENGINE ROTOR LIFE PREDICTION

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Abstract

A key ingredient in the establishment of safe life times for critical components is the means of reliably detecting flaws which may potentially exist. Although currently used NDE procedures are successful in detecting life limiting defects, the development of automated and computer aided NDE technology will permit even greater assurance of flight safety.

INTRODUCTION

The ability to predict and monitor the useful and safe lifetime of critical components in turbine engines is a current requirement. A key ingredient in the procedure for establishing the safe lifetimes for critical components is the means of reliably detecting potential flaws which may exist in these components. As evidenced by component performance, currently used flaw detection procedures are successfully screening out components with life limiting defects. New developments in nondestructive evaluation (NDE) technology now being made will permit the adoption of more strict flaw detection requirements thereby giving even greater assurance of flight safety. The primary key to this advance in NDE technology is the adoption of automation and/or computer aided techniques which will reduce or eliminate the dependence on human operators for the performance of NDE procedures. This paper will indicate how these gains are being made by showing how the sensitivity of inspection is operator dependent and by example show how the introduction of automation can permit significant improvements in inspection sensitivity.

A SIMPLE MODEL OF AN NDE SYSTEM

In the simplest case, an inspection system can be described by two distributions - a defect and a noise or false defect distribution, and by two quantities - the inspection threshold and the inspection uncertainty. The defect and noise distributions are simply the number of either present in a given population or the likelihood of occurrence for a given size defect (indication); both distributions are usually (but not always) monotonically decreasing functions with increasing defect size. The inspection threshold is the discrimination level or decision

point which is set to differentiate between defects (indications) of different sizes. A measure of how well a particular inspection system can make discriminations is the inspection uncertainty. For example, if a system were sorting a population of balls into boxes of white ones and boxes of black ones, there would be numerous black balls in the white box and white balls in the black box if the inspection uncertainty were large. If the inspection were perfect, with no uncertainty, there would be no alien balls in either box.

It is clear that for an inspection to perform satisfactorily, that is reliably, it must have a low inspection uncertainty at the inspection threshold of interest. Figure 1 shows schematically how the defect and noise distributions and the inspection threshold and uncertainty would appear in a typical case.

DETERMINATION OF INSPECTION UNCERTAINTY

It is a practical problem of much interest to determine the true proportion of defects of a given size that can be detected by an NDE system. In particular, one is usually most interested in the defect size where the probability of detection drops below some critical level. Current convention identifies reliable inspections as those where the probability of detection exceeds 90 percent at the inspection threshold of interest.

An exact determination of the probability of detection would require a full knowledge of the statistical description of the inspection system which only can be obtained by making an infinite number of measurements. The best one can do is to estimate the probability of detection and depending upon the procedure used, one can make this estimate with any degree of confidence. Current convention considers

estimates of the detection probability which have greater than 95 percent confidence level to be acceptable.

During the last five years, the measurement of inspection reliability has been one of the major interests of NDE practitioners. It has been found that proper measurements of inspection reliability are difficult, expensive and are, unfortunately, unique only to the specific application or case studied. To make proper measurement of inspection reliability, one must use: real flaws in real parts, representative inspectors, multiple sets of equipment, multiple reference standards and unbiased measurement techniques. The latter is most difficult of all. Despite the difficulties, measurements of minimum flaw sizes with 0.9 probability of detection at 95 percent confidence have been made for some specialized cases. Typical results are shown in Figure 2 which summarizes the evaluation of four different inspection procedures that were used to find cracks near a fillet in a round steel bar; as noted above these results apply only to this case. A detailed scrutiny of these results and others like them show that the chief contributor to the inspection uncertainty is the inspection operator. This is shown, for example, in Table I which compares the effectiveness of six different operators performing an eddy current inspection designed to detect small (0.015" long) cracks in a titanium component. Analysis of this and other similar experiments suggests that 75 percent or more of the source of inspection uncertainty is operator related. The message is clear - improved, more sensitive inspections may be had by reducing or eliminating the dependence on human inspection operators.

AUTOMATION - THE OPPORTUNITY FOR IMPROVED NDE

There is a concerted effort in the NDE field to develop automation and computer aided inspection techniques. The expressed purpose of these efforts is to increase

Table I

Summary Of Operator Performance In A
High Resolution Eddy Current Inspection

| Operator | Misses/Trials |
|----------|---------------|
| 1 | 0/14 |
| 2 | 1/14 |
| 3 | 1/9 |
| 4 | 3/14 |
| 5 | 4/8 |
| 6 | 6/9 |

inspection sensitivity of the currently used effective inspection systems by increasing the probability of detection for small defects. This is illustrated in Fig. 3 which shows that a reduction in inspection uncertainty of an NDE system lowers the defect size where the probability of detection drops below 90 percent. This ability to detect smaller defects reliably is an improvement of inspection sensitivity.

There are many examples which could be used to demonstrate how the introduction of automation will permit improved NDE procedures but two which relate to turbine disks seem to be most appropriate.

COMPUTER AIDED INSPECTION OF NEAR NET SHAPE DISKS

Fabrication techniques are currently being developed to permit the manufacture of disks for gas turbine engines to shapes very close to their final shape. These near net shape techniques will permit considerable cost savings over the current techniques. To permit maximum cost savings, near net shape disk preforms must be only slightly larger than the final shape, thereby requiring improved resolution of defects near surfaces. In addition, increased sensitivity to smaller defects is required, since the new fabrication techniques will permit the use of advanced alloys. A primary cost saving in near net fabrication approaches is derived from the elimination of machining operations before ultrasonic inspection. Accordingly, the advanced inspection system must have the capability of contour following non-regular surfaces while still maintaining normalcy of the ultrasonic beam, since near net shapes will, as a rule, possess tapered and curved surfaces.

An ultrasonic inspection system for near net turbine disk shapes is currently under development at P&WA with the support of Air Force funding. This system is an

automated computer aided inspection system, Fig. 4. It has the ability to sense and contour follow disk shapes with as-processed surfaces, while requiring only a minimal pre-knowledge of the shape under inspection. It has high sensitivity ultrasonics that can resolve a $1/64$ flat bottomed hole (FBH) 0.050 from the surface.

The inspection system has been configured about a small mini-computer and is designed to minimize the dependence on human operators. Unlike conventional disk inspection systems, this new system can detect and record the presence of indications with sizes much smaller than those at the inspection threshold. This information can be ordered into distributions such as number vs. size, as shown in Fig. 5, which can be used to monitor the fabrication process or possibly eventually could be used to estimate the statistical lifetime of the part. Being computer aided, this inspection system can recall at any future time the detailed inspection records for any part if required in the event of a disk service problem. The system has also been designed to permit the use of selective or variable rejection criteria that can be tailored to the anticipated local stress levels in the component.

The eventual introduction of computer aided and automated technology into production inspection will permit a more detailed and sensitive inspection of turbine disks because it has eliminated the major sources of operator generated inspection sensitivity. In addition, it offers significant advantages over conventional approaches, since it can collect order and store information beyond that just required to make go-no-go decisions.

AUTOMATED BOLT AND TIEROD HOLE INSPECTION OF DISKS

Occasionally during the static ferris wheel testing of disks, eddy current inspection of bolt holes and tierod holes is occasionally performed along with the regular wink fluorescent penetrant inspection. A potential advantage of eddy current testing is that it can be performed in situ and does not require any dismantling of the test apparatus. Unfortunately, most conventional eddy current inspection being manual inspections have larger inspection uncertainties than wink penetrant inspections at the small defect sizes which are of interest in static testing. For example, Fig. 6 shows the results of a conventional manual eddy current inspection for axial cracks in two disk bolt holes. The figure shows the eddy current scans of the circumference of the hole at nine equally spaced locations through the hole. The presence of a crack would be indicated by rightward-going peaks as seen in scan #5 of hole #5 and on this basis both holes would be judged to be cracked. In fact, wink penetrant inspection shows hole #5 to contain a very small crack and hole #9 to be uncracked.

Currently, P&WA is developing automated eddy current inspection techniques for the evaluation of holes. One approach being used, shown in Fig. 7, places the eddy current sensing device on the tip of a small rotating probe which is automatically indexed through the hole. Inspection information is recorded on a strip chart such that the results of each circumferential scan sequentially follows the previous one. The results of evaluations of holes 5 and 9 using this automatic system are compared with the manual scans and wink penetrant results in Fig. 8. In the automatic system, the circumferential scans are spaced 0.02" apart and the presence of a crack is indicated by an upward peak; the results of the hand scans shown in Fig. 6 have been linked sequentially in Fig. 8 for comparative purposes.

Figure 8 shows that unlike the manual inspection, the automatic inspection properly distinguishes the cracked hole from the uncracked one. In addition to identifying the crack, the automatic inspection indicates that the crack has some structure and that it has variable depth along its length. The use of other displays and analysis techniques with automatic eddy current inspection, Fig. 9, will eventually permit a quantitative determination of crack length and depth, something which is not possible using wick penetrant inspection. Again, this example demonstrates how the inspection sensitivity of a current inspection can be improved using automation techniques.

CONCLUSION

Improvement in flight safety is a continuing goal and a key to establishing flight safety is the reliable inspection of rotating components for potential defects. The development of new automated and computer aided NDE techniques will permit increased flight safety margins by improving the reliability of already reliable and effective NDE procedures.

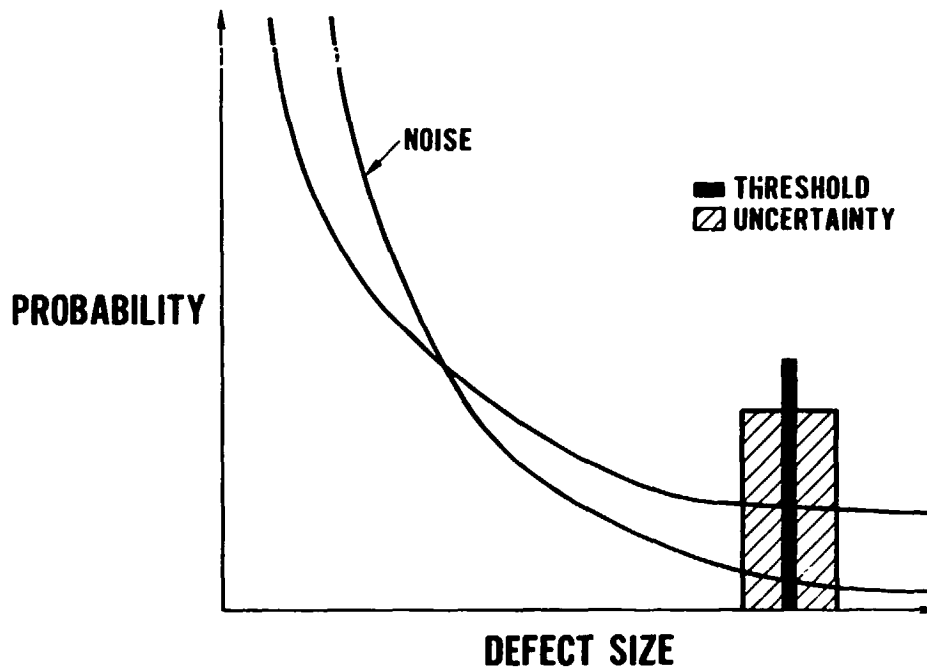
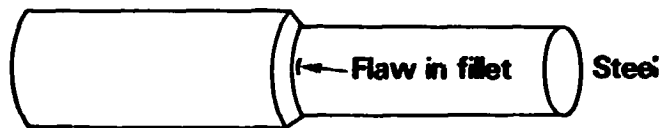


Figure 1 - The defect distribution for typical inspection. The noise distribution is low at the inspection threshold, signifying a practical signal to noise ratio. On the average the inspection threshold has the value indicated, however for a specific application of the inspection the actual inspection threshold lies somewhere in the band of inspection uncertainty.

| | | |
|--------------|-------|---------------------|
| MPI | ----- | 0.06 to 0.08 |
| Ultrasonic | ----- | 0.06 to 0.07 |
| Eddy current | ----- | 0.10 to 0.12 |
| FPI | ----- | 0.14 to 0.16 |



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Figure 2 - The results of the measurement of minimum size crack near a fillet in a steel bar with 0.9 probability of detection at 95 percent confidence. The crack lengths are given in inches. It should be emphasized that these results apply only to this special case and that other inspection systems in other applications will have different minimum detectable flaws.

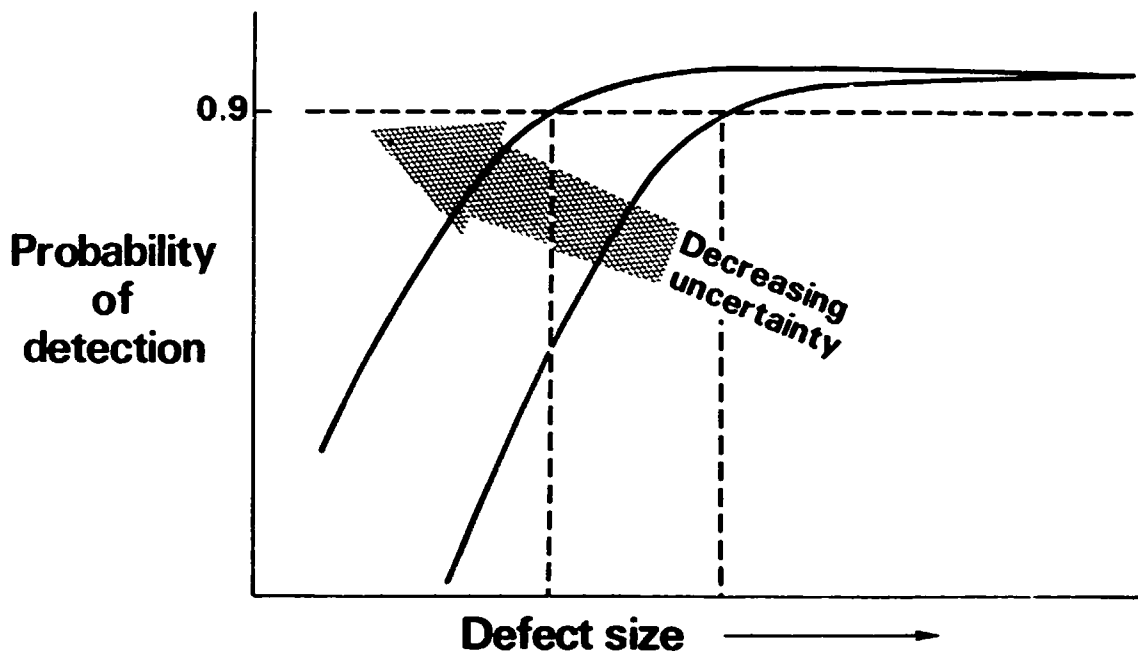


Figure 3. - The probability of detection at 95 percent confidence for different defect sizes for a typical NDE system. As the inspection uncertainty is reduced, the minimum reliably detectable defect decreases in size, and the reliability of detection at a given size increases.



Figure 4. - The computer aided ultrasonic inspection system for near net shape disk. This system will permit more sensitive inspection of turbine disks during production.

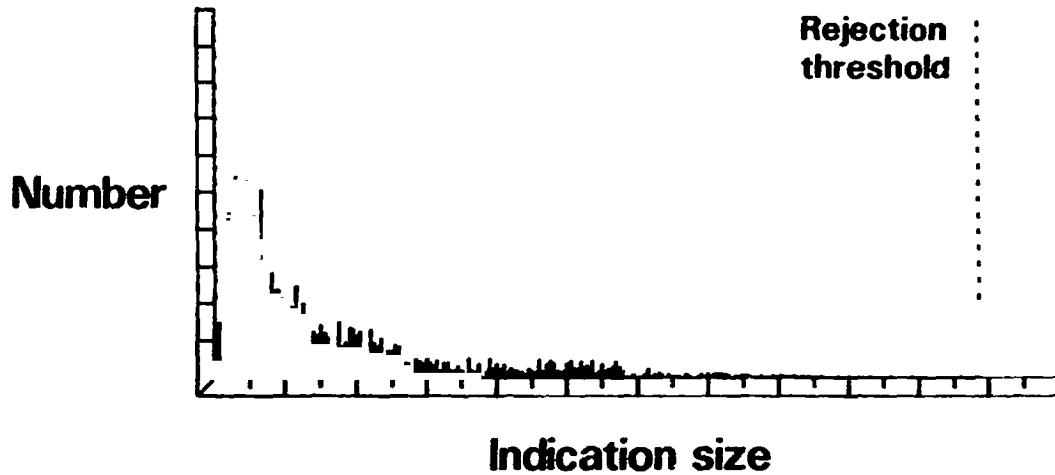


Figure 5. - A summary plot of the number of indications vs indication size for an ultrasonic inspection of a disk using a computer aided inspection system.

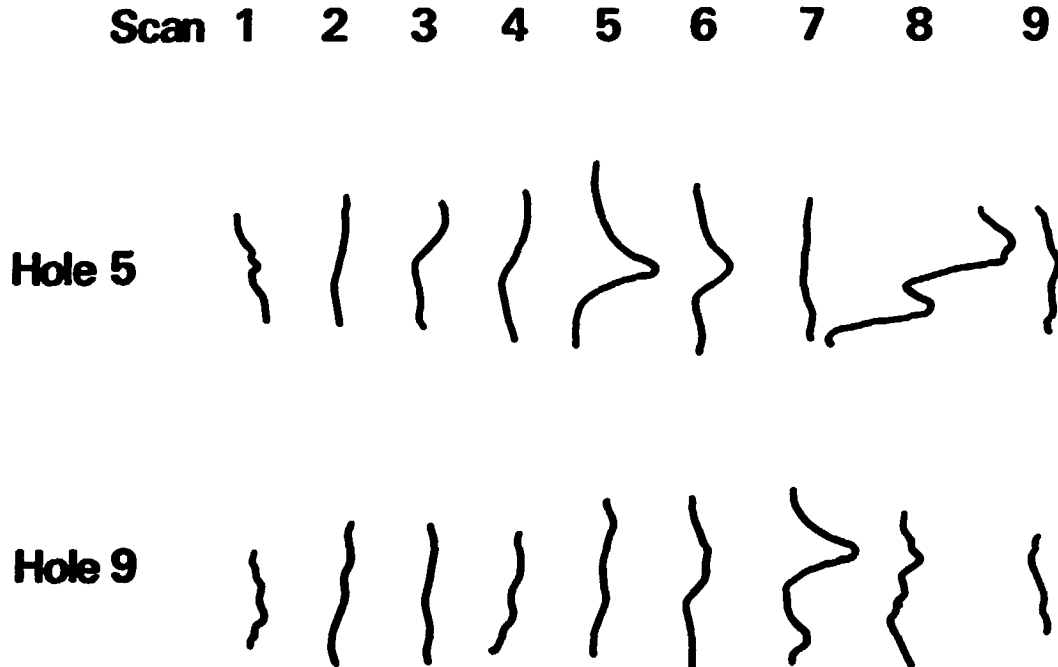


Figure 6. - The results of a conventional manual eddy current inspection of bolt holes. The eddy current scans the circumference of the hole at 9 equally spaced (0.1" apart) locations. A rightward peak as in scan no. 5 of hole 5 indicates a crack. Although the results show both holes to be cracked only hole 5 is cracked.



Figure 7. - An apparatus for automatically eddy current scanning a hole. The eddy current probe rotates while it continuously indexes into the hole.

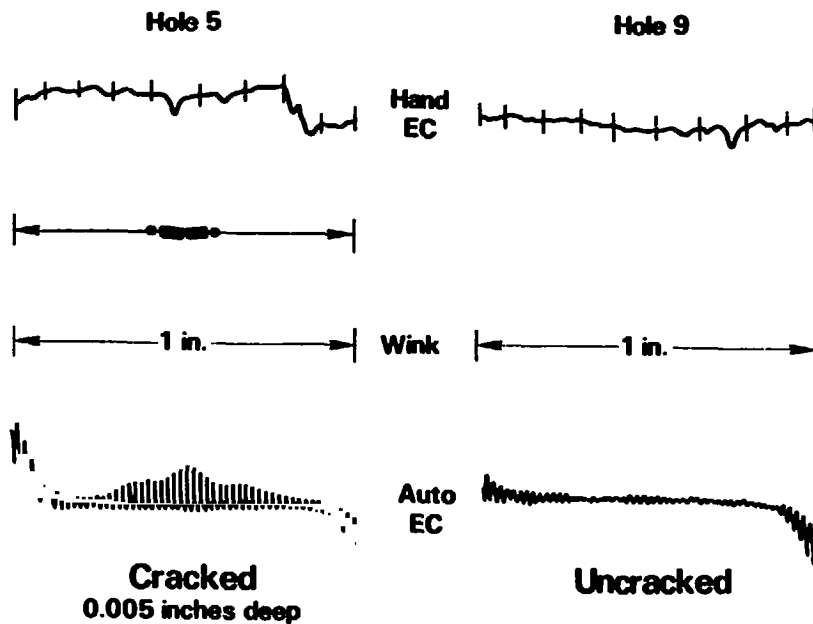


Figure 8. - The comparison of the inspection of two holes using manual eddy current wink penetrant and automatic eddy current techniques. The automatic correctly distinguishes between the cracked and uncracked hole. The scans of figure 6 have been linked for comparison.

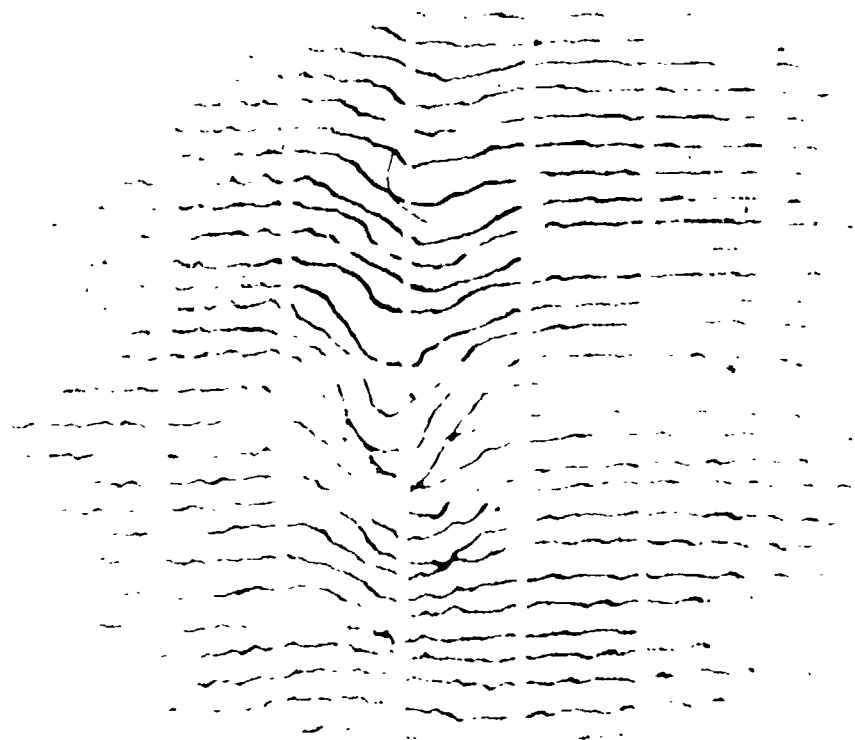


Figure 9. - A two dimensional presentation of the results of an automated eddy current inspection.