Technical Abstract
Advanced discontinuity detection topics for engine valves

Valve Head Fillet Inspection Overview

Equipment Setup
The equipment setup in this study used a Resonic bench-top valve-scanning unit modified with a second axis of motion for valve rotation (Figure 1). Sensors consisted of a pair of SH wave EMAT pencil probes with an identical form factor as those found in testing at USEV. 9 samples of large engine valves were obtained for this test. 7 were defect free and 2 had visible surface defects on the underside of the head. Images of the two defects can be found in Figure 4 on page 3.

During the test valves were oriented vertically with valve face gently clamped in a small 3-jaw lathe chuck. Pencil probes were precisely positioned on the back of the valve head by vertical actuation. Testing was done with .005 to .010 in. liftoff between sensor faces and valve surfaces while the valve rotated at 60 RPM. A more detailed view of the sensor and part orientation can be seen in the diagrams in Figure 5.

Data Collection
With a spinning engine valve the data collection approach used here is quite similar to valve stem mapping. But instead of traversing the length of the stem, data was recorded over a single 360-degree rotation of the valve. And instead of constructing a “point-by-point” stem profile with dynamic part failure criteria, we used a more general approach with a single resonance amplitude failure criterion for the entire head scan. Thus the starting angular position of the valve head is not important to the test.

A valve head profile consists of 190 amplitude data points collected over a single 360-degree, 1 second long scan. The data for all 9 valves is presented in the following chart.

![Figure 1. ARIS bench-top valve scanning system](image)

![Figure 2. Peak amplitude plots of 9 scanned valve heads](image)
Results
Individual amplitude scan profiles are generally flat from start to finish except for those of samples 8 and 9 which show dramatic fluctuations which correspond to the presence of significant surface defects on the fillet. This change in amplitude profile is the most significant indicator of defects that has been identified so far and will preliminarily serve as the basis for a head inspection procedure.

It is worth noting up front that there is some variation in the overall strength or amplitude values between the scans of different valves. For instance, the resonance profile of valve 3 is significantly higher than valve 6 even though they are the same part type. The causes of this observed difference could be many-fold but are likely related variation in either the physical part holding or the grain/density/stress characteristics of the material. It is notable, however, that the two valve samples with surface defects, valves 8 and 9, have the lowest overall amplitudes in the entire set. These overall amplitude and resonance signal strength issues can be ignored for now since they will not affect the ability to detect defects.

Detection Mechanism
Similar to testing valve stems we can construct a calibration set of good valves and a failure threshold that accounts for all the acceptable amplitude variation in defect free valves. Here we aligned all the scan profiles and selected a threshold using standard deviations that passed all the good parts while failing both bad parts.

In the chart below, same as in the test, where the amplitude profile of a part crosses outside the acceptance threshold represented by the blue area, the part is rejected.

![Failure thresholds with 2 valve head profiles](image)

**Figure 3.** Failure thresholds with 2 valve head profiles

Here the defect indications in the normalized amplitude profiles tend to have both high amplitude “peaks” and low amplitude “drop-outs” in the same detection event. As in the case of Valve 9 there are not three separate defects but one single defect with signal “trapping” effects at the beginning and end of the defect and signal “damping” or attenuation effects in the middle of the feature. This is both expected and desirable.
Detection Limitations

The defects seen above from the current set of valve samples are what we consider to be quite large. Valve 9 contains the larger of the two defects and in its resonance amplitude profile the defect can be seen in the plots in Figure 2 to affect about 40 degrees of the full 360-degree scan or about 20 out of 190 data points. The smaller defect in Valve 8 could be about half that size affecting roughly 20 degrees or 10 data points out of 190.

Since there are no verifiable defects in the sample set that are significantly smaller we don’t fully know what the test sensitivity will be, though we are confident that it will be high. We also don’t have any sample defects that are located farther up the fillet nearer the stem. Overall, this lack of formal evidence in detecting a wider range of defect types makes it difficult to speak with specificity about test resolution and also what the tradeoffs of increased rotational speeds might be.
Figure 5. Sensor and test fixture diagrams