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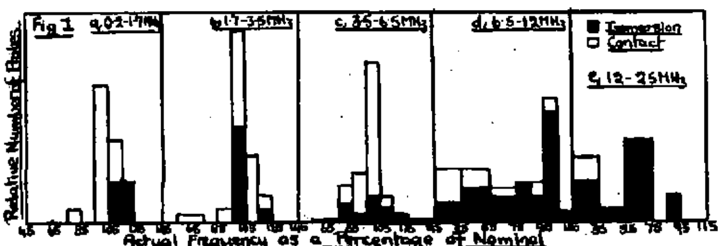
ULTRASONICS IN INDUSTRY SESSION.

Ultrasonic Probe Standardisation

M.G. Silk and B.H. Lidington

Introduction

The purpose of the present paper is to consider some of the factors which influence the performance of ultrasonic probes. It has been shown that the reproducibility in performance between probes of the same specification may require some considerable recalibration of ultrasonic systems when it is necessary to replace the transducer. A number of valid techniques such as the use of test blocks and the D.G.S. diagram are in use which enable this calibration to be made and which eliminate a lot of the uncertainty inherent in probe replacement. It remains conceivable however that quite gross transducer malfunctions may not be brought out by present calibration techniques. In addition it would result in a considerable saving of effort if transducers were sufficiently standardised to enable recalibration to be reduced to a bare minimum. It is hoped that the present paper represents a step towards the achievement of such standardisation by identifying some of the important factors contributing to transducer variation and considering the effect of such variations on the present methods of probe characterisation and on finding and sizing defects.



Some attempt is made at defining acceptable limits but it is recognised that the individual ultrasonic application will dictate the acceptable variation. The conclusions are supported by experimental data on probe variability obtained at the NDT Centre at Harwell[1]. This analysis suffers from certain limitations in probe sample selection[1] but may be regarded as a reasonable first estimate of the variability of probe characteristics after some period of use. Four areas of possible probe malfunctions are considered in this report which appear to represent the most common and most serious types of defect.

Probe Frequency Variations

The natural frequency of the transducer is the most fundamental and potentially the most easily measured of the important probe parameters. Manufacturers typically quote a variation of ± 10% in frequency of new probes and it would be unreasonable to expect much greater accuracy from batch construction at present. This suggests that few probes will have natural frequencies more than 10% from nominal. The survey of reference 1 may be used to estimate the variation in frequency after some use.

From a sample of 154 probes of known nominal frequency the histograms above were obtained showing the probe frequency deviations as a percentage of nominal frequency for each of five arbitrary frequency ranges - Fig. 1. For the three lowest frequency groups there is a clear tendency for the nominal and actual frequency of the probe to coincide. The magnitude of the variation is not unreasonable although the number of probes more than 10% out of specification was 33 out of a sample of 104. The situation is worse when the nominally higher frequency probes are considered, reflecting the greater difficulties of probe construction at these frequencies. Here no less than 38 probes our of a sample of 50 were found to have natural frequencies great than 10% from nominal. Unless the initial distribution in frequency is much worse than has been assumed these figures must represent a substantial deterioration in probe properties with use. The former possibility is reasonably likely since it is difficult see any reason to keep probe frequencies within a 10% tolerance fo most general ultrasonic applications. Thus users may well accept probes well out of specification. For probes of frequency 15MHz and greater the tolerance on frequency is not normally quoted as ± 10% and it would certainly be difficult to hold this accuracy.

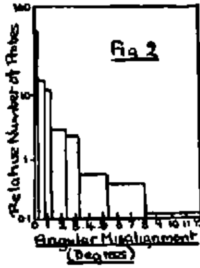
A substantial number of the probes tested (23%) were found to respond at two frequencies. In some cases the second frequency was a harmonic of the primary frequency but this was not generally the case. The frequencies could not be analysed with sufficient accuracy to assess whether they were completely unrelated or represent two different modes of vibration in the crystal. In th case of one contact probe studied the two frequency response disappeared when it was placed in contact with steel representing normal usage. This appears to be an isolated effect. In neithe the frequency distribution nor the presence of second frequencies was the distribution of contact and immersion probes statistically different.

The frequency variability of probe crystals is basically determined by the degree to which the crystal dimensions can be held to a tolerance. For lower frequency probes the variability from this source could probably be held to ± 10% if necessary although there is some evidence that it may be greater than this. Where the higher frequency probes are concerned the crystals are much thinner and more fragile and the frequency variation may be greater with a tendency to leave the crystal slightly oversize. Other reasons for frequency variations are to be found in the difficulties associated with the attachment of electrical connections, provision of damping etc. Any such attachment can, if not carefully matched, load the crystal and modify its frequency response. High frequency crystals are likely to be much more susceptable in this respect and, since the effect of these mechanisms will be a frequency reduction, the markedly skew distributions found for high frequency probes may be significant.

As regards the appearance of two frequencies it is probable that, where these frequencies are unrelated the mechanism is to be found in a broken crystal or a crystal with a major dead region. Broken crystals have been reported elsewhere[2] and the case cited where the effect disappeared when used in a contact mode could well indicate a crystal break. Other cases of apparently unrelated frequencies could arise from two vibration modes being excited and would occasionally be expected from fortuitous dimension configurations. It is easy to explain the presence of harmonics of course but difficult to see why they should not occur in every undamped probe.

Variations in Pulse Shape

An experimental arrangement to determine the natural frequency of the probe will also give information on the length and shape of the transducer response. This information is available from reference 1 both in terms of actual elapsed time and in terms of the number of cycles of vibration emitted. A significant difference between the responses of contact and immersion probes was observed in both respects, the former ringing for longer times and for a greater number of complete cycles. There was a tendency for most transducers to ring for only a few cycles approximating the 'ideal' transducer although of course this is an over simplification and in many applications probes which ring for a substantial number of cycles are acceptable.



A number of probes examined did not show the normal pure exponential decay of pulse amplitude. In these cases there was either a long almost constant amplitude tail to the pulse or else the probe began to ring again after the apparent end of the pulse. This latter class includes a few probes assumed earlier to be examples of two frequency response[1]. In all some 15% of probes behaved in either of these ways and, although the amplitude in the tail of the pulse was small it is likely that sufficient power is radiated to affect experimental work.

The only significant factor affecting the pulse shape is the amount of damping present in the probe. This is the cause of the marked difference in the responses of immersion and contact probes since the latter are damped partly by the contact surface and are thus underdamped in the experimental situation.

The variations in the decay of the pulse are probably attributable to interference effects similar to those common in the near field of the probe. One burst of vibration is superceded by another of the same frequency but out of phase and this seems to imply a more complex variation in the form of the probe beam with time than generally assumed. This may well warrant further study.

The Energy Output From the Probe

One of the most serious variations in normal usage in probes of the same nominâl specification is that of the energy output. Unfortunately due to the continued development of the probe scanning equipment it has not been possible to make any quantitative estimate of the energy output of the probes. However to give some limited idea of the variations of probe energy the beam plot results were divided into a crude sensitivity scale[1] which showed that some 6½% of the probes analysed appeared to give an anomalously low energy output.

The power radiated by a transducer is a function of its efficiency of electrical to mechanical energy conversion. The sensitivity of the transducer is conversly dependent on the efficiency of mechanical to electrical energy conversion. Since the probe beam plotter uses a reflection technique[1] the above results essentially represent an evaluation of the product of these conversion factors. In general the conversion efficiencies will be highly correlated and this is implicitly assumed in the above assessments. The physical factors which may be assumed to be effective in defining these conversion factors include poorly designed damping, crystal variations and dead areas and poor lead attachment etc.

Variations in the Character of the Beam

The probe beam plotter provides longitudinal and transverse scans of the ultrasonic beam which give a direct indication of its quality[1]. A poor quality beam may be considered to be one with such properties as a weak or hollow beam or interference from side lobes etc. As might be expected there is a significant correlation between poor beam quality and other types of probe malfunction.

A small fraction (4½%) of the probes studied showed evidence of the presence of a well developed secondary beam which often rivalled the primary beam in intensity. Usually only one such beam was present the other side lobes being reduced. The effect was most marked for focussed probes.

A very small number (1½%) of the probes studied had the axis of the main beam normal to the probe but apparently aysmmetrically placed with respect to the central axis of the probe. The extent of misalignment in all cases was between 0.4mm and 0.6mm so that this is unlikely to be a serious source of error in ultrasonic measurements.

A more general example of beam misalignment was observed between the angle of the axis of the probe and the axis of the beam. The variation in alignment is shown in the form of a histogram in Fig. 2. There is no significant difference between immersion and contact probes in this respect and it is also clear that the majority of probes are aligned within $\frac{1}{2}^{\circ}$. On the other hand a significant minority of probes (9%) have a beam axis misalignment of greater than $2\frac{1}{2}^{\circ}$.

The quality of the beam may be affected by the response of the crystal which may have an apparently dead region where the power radiated is very much reduced. Conversly the appearance of strong side lobes and secondary beams may represent the presence of more efficient areas of the probe which radiate anomalously large quantities of power. The tendency for side lobe formation to occur more frequently in focussed probes thus could arise from non-uniformities in the crystal due to the machining of the concave face.

The alignment of the beam would most commonly be a function of the accuracy to which the crystal can be mounted in the transducer. This fits with the observation that most probes are aligned within $\frac{1}{2}^{\circ}$ and would also account for the smaller number of misalignments up to about 2°. Beyond (say) $2\frac{1}{2}^{\circ}$ it is unlikely that crystal misalignment is the cause since misalignments of this order would be apparent to the eye. One attractive explanation is that these cases represent side lobe production to the extent that the main beam is reduced and not readily visible. This however does not allow for the observation that there is no correlation between beam misalignment and focussed probes as there appears to be between side lobe formation and focussed probes. On the other hand attempts to ascribe misalignment to crystal defects are similarly difficult to reconcile with a lack of correlation with poor beam quality.

Other Calibration Methods

Probe calibration is usually carried out using test blocks and the D.G.S. diagram. The careful use of these can yield a lot of information on probe malfunctions but does not give the global picture of the nature of the beam that the beam plotter does. The amount of information that can be extracted from the use of test blocks is also very much a function of the insight of the observer.

Remembering that the beam may be misaligned with respect to more than one plane the angular misalignment of contact probes can be found to an accuracy probably better than 1^o using a suitable test block. The same block will yield information on the beam profile and, if used correctly, the beam quality and the presence of secondary beams can also be inferred although the information will be limited being based essentially on spot checks of the beam.

The relative energy output of probes can be readily established using test blocks enabling the recalibration of equipment on probe replacement. There can be very serious errors here if the fullest information on beam quality, profile, alignment and the presence of side lobes or secondary beams has not been ascertained.

The pulse shape and natural frequency of a probe are readily measured in principle. It is surprising however how many sets of ultrasonic equipment which rely on a step edge to shock the transducer do not have the facility of viewing the unrectified pulse. The pulse length can usually be displayed if only indirectly.

Effect of Malfunctions on Ultrasonic Measurements

The probe frequency governs the minimum size of flaw that can be detected and the transmission of sound through the medium.When the transducer is shocked into vibration the frequency will be the natural transducer frequency but if continuous wave or pulsed c.w. operation is required the effect will be seen as a loss of power. In general it seems doubtful whether a 10% tolerance is necessary but it is clear that if close frequency tolerances are required provision for regular frequency inspection is necessary.

The extent to which the beam parameters will affect ultrasonic measurements will depend almost entirely on how well the initial characterisation has been carried out. Clearly angular misalignment, power variations, beam character and the presence of side lobes could cause havoc with ultrasonic determinations if unsuspected and could cause serious error if only partially defined.

Conclusions

If a probe frequency limit of within 25% of nominal is taken only 3% of lower frequency probes will lie outside. At the same time 66% of the higher frequency groups remain outside this wide specification. The presence of two frequencies is also rather common and may often be unsuspected.

The pulse shape and length is clearly very variable reflecting the great difficulties in balancing good damping against power output. The survey has shown up a need for calibrating contact probes in a manner closer to their usual applications if excessive ringing is to be eliminated and has given an indication that the shape of the beam may vary more with time than originally expected. It does not seem realistic to attempt to define any close tolerances for pulse shape at present. The factors affecting beam quality, misalignment power etc. should be studied further with the eventual aim of eliminating effects which will always be time consuming to detect.

Finally it seems clear that over the next decade ultrasonic techniques of increasing sophistication will be required. Ultrasonics seems to be unlikely to achieve its full potential if over this period it is not possible to define all of the important parameters to close tolerances.

References

1. B.H. Lidington and M.G. Silk
   To be published.

2. B. Lambert
   Proceedings of Seminar on Significance of Weld Defects, London, Dec. 1971.