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STATISTICAL ANALYSIS OF ULTRASONIC REFLECTOR RESPONSE

MIHALJEVIC, M[orana]; MARKUCIC, D[amir] & STEPANIC, J[osip]

Abstract: *The sensitivity of ultrasonic testing system depends on many factors that should be adequately selected for precise reflector characterization. In this paper several factors were analyzed in order to show how their interactions influence variability of results. We utilized two-level three-factor design of experiments. The three factors selected and varied were probe frequency bandwidth, probe response damping and pulse energy. The experiment design enabled us to determine which factor and which interaction has the most significant influence on the reflector size evaluation. The underlying ultrasonic technique was the pulse echo technique in which the differences in gain between infinite reflector and disc reflector (DELTA) were determined. The bandwidth was revealed as the most influential among the three factors considered.*
Key words: *ultrasonic reflector response, statistical analysis, design of experiment*

1. INTRODUCTION

The accuracy and reliability of any ultrasonic testing depends on calibration procedure and sensitivity settings. When the ultrasonic pulse echo method is used the sensitivity is defined as the amplitude of the signal related to the minimal detectable disc reflector (Krstelj, 2003).

Modern quality assurance requires verification of system setting that should be used for reliable flaw size evaluation. Among numerous flaw types, cracks are one of the most dangerous types that are sometimes extremely difficult to detect and to be sized. Ultrasonic testing is regularly used in many in-service inspections in which the crack size evaluation is the main criterion for component integrity assessment. In that sense, all influential factors should be set or kept in the range of values for which they do not degrade significantly capability of selected methods.

Therefore, the aim of this study was to extract and rank the parameters that can significantly affect the reliability of ultrasonic testing results. Our research showed that the factor *bandwidth* has the largest impact when experimental determination of ultrasonic sensitivity is applied to disc reflector the cross-section of which falls within the ultrasonic beam.

This paper is a contribution to improvement of a pulse-echo, contact ultrasonic technique, which is regularly used in non-destructive testing of constructions. The approach is limited to contact ultrasonic techniques.

2. SELECTING AND DEFINING THE RESEARCH PROBLEM

A series of preparatory experiments was conducted in order to extract the most influential factors on reflector size evaluation. Investigation showed that the factors that are expected to be prevailingly influential are: *bandwidth*, *damping* and *energy*. The experiments have been performed using ultrasonic probes with nominal frequency of 4MHz that differ in frequency bandwidth (factor *bandwidth*); K4G [70% bandwidth] and G4N [100% bandwidth]. Second factor is instrument setting - probe response *damping* - set to 50Ω and 1000Ω. Third factor is pulse *energy* in respect of high and low settings corresponding to the magnitudes of 135V and 332V respectfully, and determined by oscilloscope. As several factors are of interest in an experiment, a factorial experimental design is used. Since two-levels were attributed to all factors, 2^k factorial design of the experiments was applied (k = 3 factors) with each of the factors considered as a numerical variable (Winer, 1962).

Measurements were conducted on a steel specimen with disc reflector put on distance of 90 mm (Fig. 1.). Selected depth of reflector was due to the ultrasonic beam geometry, specifically focus distance (Gilardoni, 1981). One of the basic parameters of ultrasonic beam is a near field length (*N*) and a focal diameter (FB6). For selected probes the values are *N* = 88 mm, FB6 = 2.9 ± 0.1mm (K4G).

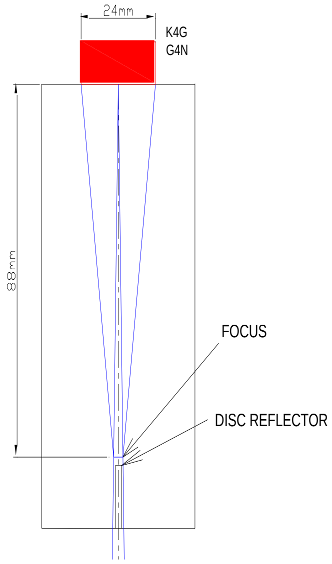

Fig. 1. Ultrasonic beam geometry and specimen with a disc reflector

Consequently, a disc reflector having diameter of 2 mm is completely within the ultrasonic beam (Krstelj, 2003).

3. RESULTS AND ANALYSIS

The analysis of variance (ANOVA) for selected factorial model was conducted using the software package Design Expert 7.1.5 in order to investigate whether some factor affects the result or not and to determine influences of their interaction. According to the obtained results the selected model of experiment is significant (Douglas, 2001) (Fig. 2.).

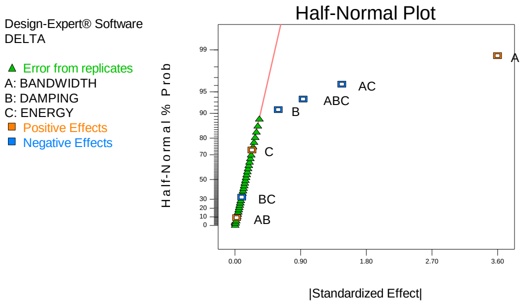

Fig. 2. Half-Normal plot of effects

Two factors (A and B) and two interactions (AC and ABC) that are significantly away from the red line in Figure 2 have significant impact onto experimental results that is reflector sizing (*DELTA response*). According to the statistical analysis the most influential factor is *bandwidth* (in Figure 2.: variable A) while factor *damping* is also significant but its effect is relatively small (in Figure 2.: variable B). Factor *energy* clearly causes the change of amplitudes of responses but it does not affect reflector sizing (in Figure 2.: variable C). Interactions of factors *bandwidth – energy* (AC) and *bandwidth – damping – energy* (ABC) are also significant.

The effect of interaction between variables is illustrated graphically in several ways. The first one (Fig.3.) reveal**s** that different DELTA response (and consecutive reflector sizing) is obtained by changing the level of factors *bandwidth* and *energy*.

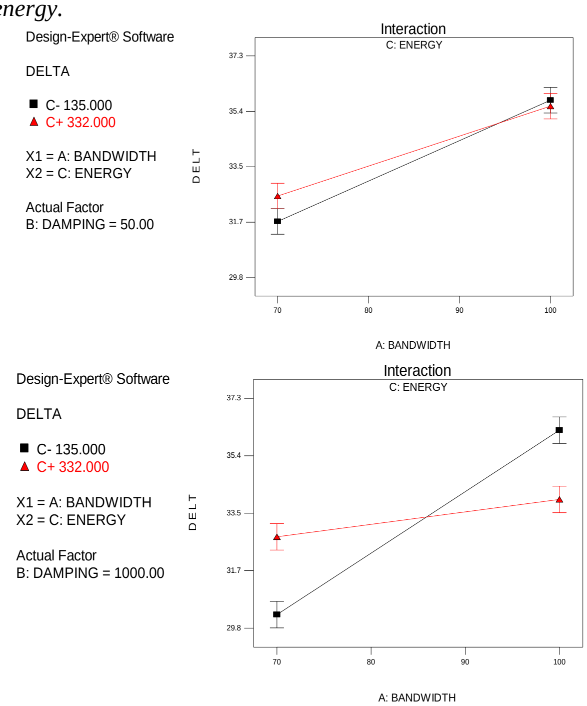

Fig. 3. Interaction between factors *bandwidth* and *energy*

The largest DELTA response is achieved using probe with narrower frequency spectrum and with the highest setting of factor *damping* (1000 Ω), while keeping the pulse *energy* on the lowest level at the same time.

Difference of DELTA response between two pulse *energy* levels (135 V and 332 V) is larger for *damping* setting on 1000 Ω in comparison with *damping* setting on 50 Ω.

Considering DELTA response at lower pulse *energy* level and using lower *bandwidth* (70%), it decreases at *damping* setting on 1000 Ω in comparison with *damping* setting on 50 Ω. This effect does not occur and DELTA response remains almost the same while using higher *bandwidth* (100%) regardless of *damping* setting.

The same effect occurs at higher pulse *energy* level using higher *bandwidth* (100%) - DELTA response decreases at *damping* setting on 1000 Ω in comparison with *damping* setting on 50 Ω. Again, this effect does not occur and DELTA response remains almost the same while using lower *bandwidth* (70%) regardless of *damping* setting.

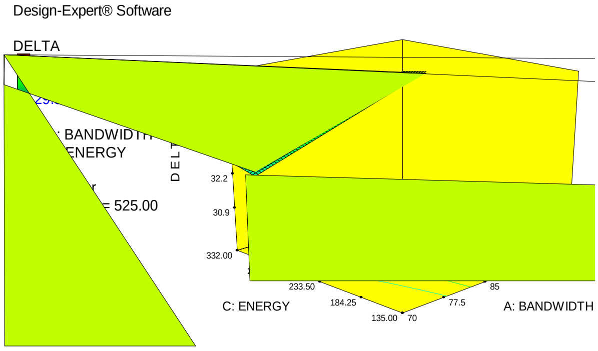

Fig. 4. Three-dimensional surface plot of the results

The results of experiment are further presented in the three-dimensional surface plot (Fig. 4.). This plot shows the relationship of the interaction between factors *bandwidth* and *energy*. It is obvious that interaction between these factors exists as the response function is a curved surface.

4. CONCLUSION

In this paper we analyzed three factors (*bandwidth*, *damping* and *energy*) on ultrasonic reflector response. Factorial design of experiments is a suitable way to characterise interactions among variables thus it was performed to investigate the effect of calibration settings on the disc reflector response. The results of conducted experiments point to the significance of ultrasonic system settings onto the estimation of the reflector size.

The most significant influence has the frequency bandwidth of the used ultrasonic probe, hereby factor *bandwidth*. In that sense, the probes with broadband frequency spectrum produce less reliable response for reflector sizing. Interaction between factors *bandwidth – energy* is also significant and is more prominent when factor *damping* is increased. With smaller probe response damping the interaction *bandwidth-energy* is of lesser importance.

In our further research the experiment using the probes with different nominal frequencies and probe diameter is going to be conducted. All results will be analysed according to the same experimental design in order to investigate whether the impact of factors on reflector sizing is significant or not.

Our research belongs to development of ultrasonic techniques in non-destructive testing

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