

# **EXAMINATION 2013 / 2014**

## **AHOLIADAU 2013 / 2014**

# **EXAM**

### **FACULTY OF APPLIED DESIGN AND ENGINEERING**

**NAME OF COURSE/PROGRAMME:** MSc in Non-destructive Testing & Evaluation

**YEAR OR LEVEL:** Level 7

**NAME OF MODULE/UNIT/EXAM PAPER:** Ultrasonic Methods

**MODULE NO:** M7X00731

**DATE OF EXAMINATION:** 14/05/2014

#### **EXAMINATION TIMES:**

**START TIME:** 9.00am

**FINISH TIME:** 11.00 am

**TIME ALLOWED:** 2hrs

#### **INSTRUCTIONS TO CANDIDATES:**

Answer all questions.

Formulae and Material Properties on last two pages

### Question 1. Total Marks - 10

For a single element rectangular ultrasonic crystal, show that the field distribution in the far field can be given as:

$$A(\theta) = a_0 d \frac{\sin(\alpha)}{\alpha}$$

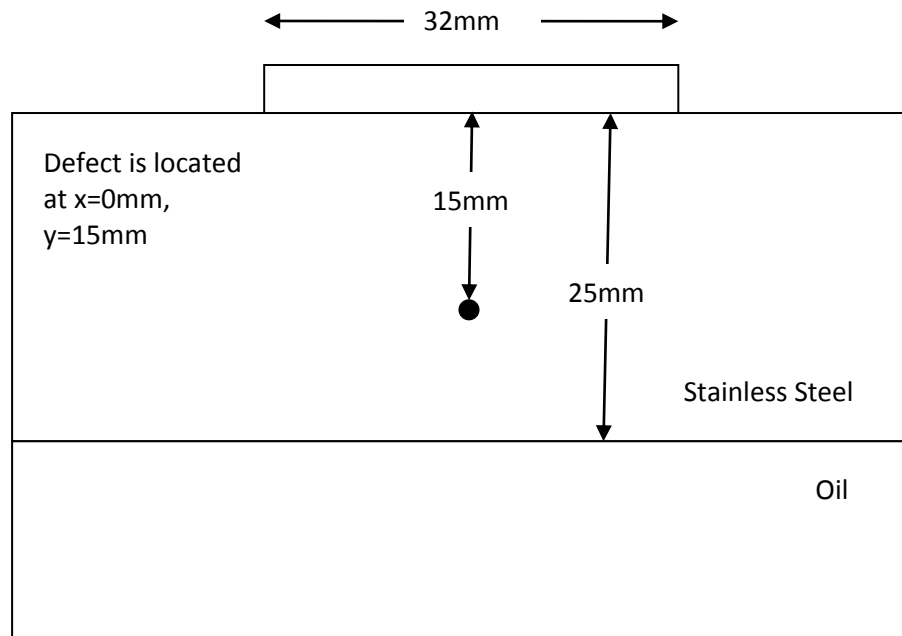
Where  $a_0$  is the ray amplitude,  $\alpha = k \frac{d}{2} \sin(\theta)$  where  $k$  is the wave number ( $2\pi/\lambda$ ) and  $d$  is the aperture width. **(10 marks)**

### Question 2. Total Marks – 16

- What do we mean by the term 'Q' factor and how is it used with regards an ultrasonic probe specification. **(2 marks)**
- For a 10mm diameter PZT crystal of thickness 0.6mm, and given that the compression wave velocity for PZT is 3000m/s, determine the crystals near field distance when transmitting into Perspex. **(4 marks)**
- If the crystal in Q2.b) is in direct contact with a mild steel surface, calculate the theoretical absolute ultrasonic beam width for the crystal at a thickness in mild steel of 45mm. **(4 marks)**
- If a suitable Perspex delay line were to be used determine the change in -6dB half beam spread angle at a Perspex/mild steel interface. **(4 marks)**
- For an ultrasonic probe with a 'Q' factor of 1.5 and wavelength of 0.987mm in water, estimate its centre frequency and spectral bandwidth. State the upper and lower frequency values that would have been used in its initial determination. **(2 marks)**

### Question 3. Total Marks – 14

- A 32 element 2.5MHz array probe with an element pitch of 1mm is used to inspect a stainless steel pipe carrying a hydrocarbon (oil) product. The 'static' B-Scan image created by the probe uses an aperture size of 4 elements. Using the fraunhofer 'far-field' approximation, produce a normalised directivity graph for the specified aperture. **(6 marks)**
- Using the directivity function as determined in part a) along with relevant calculations, provide a scaled illustration of the B-scan image that would be observed using this probe in the presence of the defect as indicated in the following figure. Assume an aperture width of 4 elements and a scan resolution of 1 element. **(6 marks)**
- Estimate the reflection coefficient for the stainless steel/product interface and determine the percentage energy transmitted into the product. **(2 marks)**



**Question 4. Total Marks - 20**

A TOFD inspection system is to be used to inspect a mild steel weld with a nominal wall thickness of 75mm. It has already been decided that  $60^\circ$  compression probes with a centre frequency of 2.5MHz are to be utilised along with a probe separation distance of 100mm.

- Disregarding wedge delays and using probe index points only, determine the approximate arrival times for the lateral and back wall signals. **(4 marks)**
- If the transmit pulse length is assumed to be 2 cycles at the probe centre frequency, what would be the minimum theoretical depth from the weld surface that near surface indications could be resolved. **(4 marks)**
- Develop and sketch a TOFD depth/arrival time correlation curve for the TOFD configuration described previously. Use the basic TOFD assumption that defect signals are assumed to originate centrally between the probe pair, and use at least 5 equally spaced depth values. Mark on the illustration the theoretical minimum depth value calculated previously, and comment on the depth resolution characteristics of the technique. **(12 marks)**

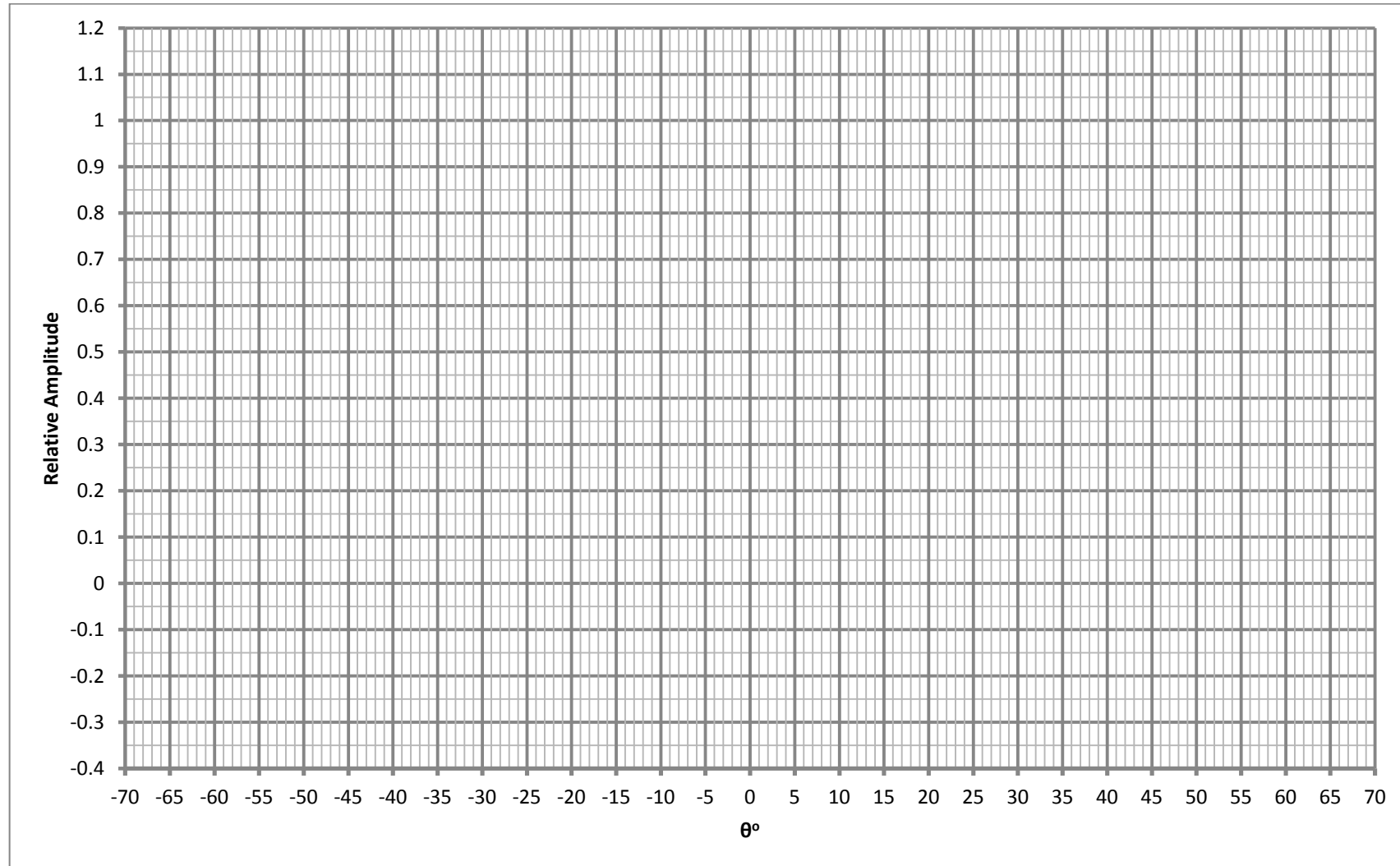
## Material Properties.

| Material<br>Units         | Velocity<br>(C)<br>m/s x 10 <sup>3</sup> | Velocity<br>(S)<br>m/s x 10 <sup>3</sup> | Density<br>kg/m <sup>3</sup> | Acoustic<br>Impedance |
|---------------------------|------------------------------------------|------------------------------------------|------------------------------|-----------------------|
| Air                       | 0.33                                     | -                                        | 1.2                          | 0.0004                |
| Aluminium                 | 6.40                                     | 3.13                                     | 2700                         | 17.3                  |
| Barium Titanate A         | 5.26                                     | -                                        | 5700                         | 30.0                  |
| Barium Titanate B         | 5.53                                     |                                          | 5700                         | 31.5                  |
| Beryllium                 | 12.89                                    | 8.88                                     | 1800                         | 23.2                  |
| Brass                     | 4.37                                     | 2.10                                     | 8450                         | 37.0                  |
| Cast Iron                 | 3.5 to 5.6                               | 2.2 to 3.2                               | 7200                         | 25 to 40              |
| Copper                    | 4.76                                     | 2.33                                     | 8930                         | 42.5                  |
| Glass (Crown)             | 5.66                                     | 3.42                                     | 3000                         | 17.4                  |
| Gold                      | 3.24                                     | 1.20                                     | 19300                        | 63.0                  |
| Iron                      | 5.96                                     | 3.22                                     | 7850                         | 46.8                  |
| Lead                      | 2.40                                     | 0.79                                     | 11300                        | 27.2                  |
| Lead Niobate              | 2.76                                     | -                                        | 5800                         | 16.0                  |
| Lead Zirconate Titanate A | 3.00                                     | -                                        | 7600                         | 22.8                  |
| Lead Zirconate Titanate B | 3.00                                     | -                                        | 7500                         | 22.5                  |
| Lithium Sulphae           | 5.45                                     | -                                        | 2060                         | 11.2                  |
| Magnesium                 | 5.74                                     | 3.08                                     | 1720                         | 9.90                  |
| Mercury                   | 1.45                                     | -                                        | 13550                        | 19.6                  |
| Molybdenum                | 6.25                                     | 3.35                                     | 10200                        | 63.7                  |
| Nickel                    | 5.48                                     | 2.99                                     | 8850                         | 48.5                  |
| Oil                       | 1.44                                     | -                                        | 900                          | 1.3                   |
| Perspex                   | 2.68                                     | 1.32                                     | 1200                         | 3.2                   |
| Platinum                  | 3.96                                     | 1.67                                     | 21400                        | 85.0                  |
| Polystyrene               | 2.35                                     | 1.12                                     | 1060                         | 2.5                   |
| Steel (Mild)              | 5.96                                     | 3.24                                     | 7850                         | 46.7                  |
| Steel (Stainless)         | 5.74                                     | 3.13                                     | 7800                         | 44.8                  |
| Silver                    | 3.70                                     | 1.70                                     | 10500                        | 36.9                  |
| Tin                       | 3.38                                     | 1.61                                     | 7300                         | 24.7                  |
| Titanium                  | 5.99                                     | 3.12                                     | 4500                         | 27.0                  |
| Tungsten                  | 5.17                                     | 2.88                                     | 19300                        | 100.0                 |
| Tungsten-Araldite         | 2.06                                     | -                                        | 10500                        | 21.65                 |
| Tungsten-Carbide          | 6.65                                     | 3.98                                     | 10000 to 15000               | 66.5 to 98.5          |
| Uranium                   | 3.37                                     | 2.02                                     | 18700                        | 63                    |
| Water                     | 1.48                                     | -                                        | 1000                         | 1.48                  |
| Zinc                      | 4.17                                     | 2.48                                     | 7100                         | 29.6                  |
| Zirconium                 | 4.65                                     | 2.30                                     | 6400                         | 29.8                  |

## Formulae

|                                                                                                                                                                                                                                                                                                 |                                                                                                                                                                                                                                             |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Snell's Law:</b> $\frac{\sin i}{V_1} = \frac{\sin r}{V_1} = \frac{\sin R}{V_2}$                                                                                                                                                                                                              | <b>Reflected Energy Equation:</b> $RE = \frac{Z_1 - Z_2}{Z_1 + Z_2} \times 100\%$                                                                                                                                                           |
| <b>Ultrasonic Beam Formulae:</b> $NF = \frac{d^2}{4\lambda}$ <p>Where:<br/>NF = Near Field Distance<br/>d = Crystal diameter or aperture width<br/><math>\lambda</math> = wavelength</p>                                                                                                        | <b>Far Field Approximation:</b> $A(\theta) = \frac{\sin(\alpha)}{\alpha}$ <p>Where</p> $\alpha = k \frac{d}{2} \sin(\theta)$ <p><math>K</math> is the wave number (<math>2\pi/\lambda</math>) and <math>d</math> is the aperture width.</p> |
| $\sin \frac{\theta}{2} = \frac{1.22\lambda}{D}$ Defines the absolute edge<br><br>$\sin \frac{\theta}{2} = \frac{0.56\lambda}{D}$ Defines the 6 dB edge                                                                                                                                          | $\sin \frac{\theta}{2} = \frac{1.08\lambda}{D}$ Defines the 20 dB edge                                                                                                                                                                      |
| <b>Q Factor</b> $Q = \frac{f_0}{f_2 - f_1}$ <p>Where:<br/><math>f_0</math> = the centre frequency<br/><math>f_2</math> = the upper -6dB frequency<br/><math>f_1</math> = the lower -6dB frequency</p>                                                                                           |                                                                                                                                                                                                                                             |
| <b>Frequency thickness crystal constant:</b> $f \times t = V/2$ <p>Where,</p> <ul style="list-style-type: none"> <li><math>f</math> = desired frequency</li> <li><math>t</math> = crystal thickness, and</li> <li><math>V</math> = compression wave velocity in the crystal material</li> </ul> |                                                                                                                                                                                                                                             |

Q3. a)



Q3. b)

