

# THE ULTRASONIC SLIDE RULE

## Instructions for Use

### INTRODUCTION

The practice of ultrasonic inspection involves frequent calculations to obtain the data required in establishing testing procedures, for calibration, and during testing. These calculations are both time-consuming and a constant source of error, and so the SANDT Ultrasonic Slide Rule has been designed to provide the tester and inspector with a quick and accurate means of obtaining information commonly required.

The Rule provides facilities for calculating—

- Wavelength
- Beam spread
- Probe angle or angle of incidence
- Decibel relationships
- Near zone length
- Skip distance and slant range
- Flaw location in plan and depth
- Inch/metric conversion

Conventional slide rule arithmetical calculations can also be made on the rule.

The Ultrasonic Slide Rule will be found to be of great value in all applications of ultrasonic testing including the training of operators. It will be especially useful to those working in accordance with the **Recommendations for the Ultrasonic Testing of Butt Welds** published by the Institute of Welding.

### GENERAL DESCRIPTION

#### SCALE 'A' BEAM SPREAD

This is a scale of sines based on the formula—

$$\sin \theta = \frac{K \lambda}{D}$$

Values of K refer to reduction in sound pressure relative to the maximum at the axis of the beam and appear on Scale B.

- K = 0.56 50% reduction ( 6 dB)
- K = 1.08 90% reduction (20 dB)
- K = 1.22 Extreme edge of beam

A knowledge of expected beam spread is important in many aspects of ultrasonic testing, in particular during the establishment of a testing procedure, but the use of the Rule does not remove the need for precise beam calibration, as prescribed in the Institute's Recommendations.

In angle probes the calibrated value of  $\theta$  may not be in close agreement with the calculated value, depending on the geometry of the near field, especially in cases where the crystal is mounted on a Perspex shoe.

Normally a beam spread (half-angle  $\theta$ ) greater than about  $15^\circ$  is of no practical interest but the scale has been extended to  $90^\circ$  so that trainees can use it to solve problems involving Snell's Law.

With the cursor set to  $\theta$  the corresponding value of  $\sin \theta$  is read on Scale 'D'.

#### SCALE 'B' CRYSTAL DIAMETER

This scale covers crystal diameters from 1-50mm. In the case of rectangular crystals, guidance is contained in the instructions.

#### SCALE 'C' FREQUENCY

This scale reads from 100kc/s to 15Mc/s. In flaw detectors of continental origin these terms appear as kHz (kilo-Hertz) and MHz (mega-Hertz)).



Since Scales C and D can be used as conventional dimensionless scales for incidental calculations, three useful gauge marks are included in the left-hand portion of Scale 'C' namely 254, 490, and 550.

254 is for the conversion from or into metric units

$(\lambda \text{ for compressional waves}) \times 0.49 = \lambda \text{ for shear waves in aluminium}$

$(\lambda \text{ for compressional waves}) \times 0.55 = \lambda \text{ for shear waves in steel}$

### SCALE 'D' VELOCITY

The scale runs from 100m/s to 15,000m/s with gauge marks as follows for compressional waves—

Metres/Second	Medium
330	Air at 20°C.
1,250	Light mineral oil at 20°C.
1,483	Water at 20°C.
4,700	Grey C.I., copper, brass, bronze
5,900	Constructional steels
6,300	Aluminium

The values for air, water, steel, and aluminium are proven figures; the remainder are approximations. The speed of ultrasound in plastics materials (e.g. 'Perspex', 'Plexiglass') varies and is temperature-dependent. Working values lie between 2,680 and 2,730m/s.

### SCALE 'E' WAVELENGTH ( $\lambda$ )

The Scale reads from 0.6mm (10Mc/s in steel) to 50mm (80kc/s in concrete).

A gauge mark indicates the wavelength of a compressional wave in steel at  $2\frac{1}{2}$ Mc/s namely 2.36mm.

### SCALES 'F', 'G' AND 'H'

This group of scales is used for calculating angles of incidence and refraction in aluminium, steel, and Perspex. They are for guidance when designing or repairing angle probes or when a probe designed for steel must be used on aluminium and vice versa. They are based on a velocity of 2,730m/s for compressional waves in Perspex.

The gauge mark at  $\alpha = 27\frac{1}{2}^\circ$  on the shear wave Scale 'F' indicates the first critical angle of incidence in the Perspex shoe of a high-angle probe beyond which shear waves appear in a steel workpiece. (For aluminium the figure is  $25\frac{1}{2}^\circ$ .)

Scale 'G' relates to low-angle probes (compressional waves) and ends at an angle of refraction  $\beta$  of  $20^\circ$ , which is the advisable limit for steel. Beyond  $20^\circ$  the appearance of a shear wave component of increasing strength is to be expected. This of course could produce misleading parasitic echoes.

A general warning is appropriate here concerning calculations which directly involve Snell's Law. Users of this rule should avoid assumptions based upon close similarity between the wave velocities in which they may be interested, e.g. glass, nickel, porcelain, quartz, and those for aluminium or steel.

The same applies to the use of the sine scale 'A' in such calculations.

The existence or otherwise of any given wave mode is determined by other physical constants as well as velocity and reference should first be made to an authoritative text.

### SCALE 'I' DECIBELS

This scale permits signal heights to be compared in terms of decibels and is based on the formula—

$$\frac{\text{Echo signal } h'}{\text{Echo signal } h''} = 20 \cdot \log_{10} \frac{h'}{h''} \text{ decibels}$$

(amplitude ratio) equivalent to (power ratio)

### SCALES 'J', 'K' AND 'L'

These scales give the length of the near field N for a piston source transmitting into an extended medium. Where two successive media are involved and the calculated field extends into the second medium, the 'excess' length must be increased or decreased in



inverse ratio to the respective wavelength in order to determine the resultant effective length.

For this and other reasons the calculated value of  $N$  is necessarily a first approximation but even so the figure is an essential guide to the choice of probes, particularly for short-range work as in weld testing or immersion testing.

### SCALES 'M', 'N' AND 'O'

As shown in the sketch opposite Scale  $N$  these scales relate the known angle of refraction or probe angle to the half-skip probe position and slant range for a given thickness of workpiece. Scale  $N$  may be used for calculations in both inch and metric units and for unlimited value of  $t$ ,  $R$ , and  $S$ .

Alternatively they may be used to relate observed slant range to calculated flaw depth and plan position for a given probe angle.

Although the sketch illustrates a welded joint, these scales are of course applicable to any application of shear wave testing to determine flaw position.

### CONVERSION INCH/METRIC

The last scale of all, for conversion into or from metric units, is unlettered and self-explanatory.

## INSTRUCTIONS

### 1. To determine wavelength ( $\lambda$ )

Set cursor to sound velocity in the material to be tested on Scale  $D$ , making sure that you are using the velocity appropriate to the mode of propagation (compressional, shear etc.), and bring frequency on Scale  $C$  to cursor.

Bring cursor to left hand unity on Scale  $C$  and read wavelength against cursor on Scale  $E$ . For practical testing, the degree of precision readable from the scale is adequate. However, if a more precise value is required up to 6mm, wavelength may be read off on Scale  $D$ .

#### EXAMPLES—

- (1) Material to be tested = constructional steel  
Frequency: 4 Mc/s  
Type of wave: compressional  
Velocity of sound, compressional wave = 5,900m/s

Set cursor to gauge mark  $5.9 \times 10^3$  m/s on Scale  $D$ . Bring 4 Mc/s on Scale  $C$  to cursor. Set cursor to left hand unity on Scale  $C$  and read off wavelength on Scale  $E$ . The value, to the nearest place of decimals, is 1.5mm.

- (2) Material to be tested = constructional steel  
Frequency: 10 Mc/s  
Type of wave: compressional  
Velocity of sound, compressional wave = 5,900m/s

Set cursor to  $5.9 \times 10^3$  m/s on Scale  $D$ . Bring 10 Mc/s on Scale  $C$  to cursor. Note that left hand unity on Scale  $C$  is now off scale so set cursor to middle unity. The wavelength on Scale  $E$  is read off as 5.9 but as the middle unity is being used, the wavelength will be one tenth of this, i.e. 0.59mm.

### 2. To determine beam spread

Obtain wavelength as in 1 above. Set cursor to wavelength on Scale  $E$  and bring the appropriate value of  $K$  (see page 1) on Scale  $B$  in line with cursor. Set cursor to crystal diameter on Scale  $B$  and read off half-angle  $\theta$  of beam spread on Scale  $A$ .

EXAMPLE— Material to be tested: Constructional steel  
Frequency: 4Mc/s  
Crystal diameter: 15mm

It is required to calculate the beam spread at the beam boundary as defined in the Institute's Recommendations, i.e.—20dB on beam axis echo signal height;  $K = 1.08$  in this case.



Wavelength found as in 1 on page 3 = 1.5mm

Set cursor to 1.5mm on Scale E and bring  $K = 1.08$  on Scale B to cursor. Set cursor to 15mm on Scale B and read off  $6.2^\circ$  on Scale A. This is the half-angle so that beam spread is  $12.4^\circ$ .

Note: If the crystal is rectangular, the cross-section of the beam will be an ellipse. The appropriate major and minor axes will be obtained by using the large and small dimensions respectively of the crystal as 'diameter' on the rule.

### 3. Probe angle and angle of incidence

Scales F, G, and H provide means of calculating, for probes with Perspex shoes, the angle of refraction  $\beta$  (probe angle) for compressional and shear waves in steel or aluminium, from the angle of incidence  $\alpha$  in the Perspex, or vice-versa. In addition, direct conversion between probe angles in steel and aluminium may be carried out.

- (i) To find angle of incidence required in Perspex to give specified probe angle.

- (a) Shear wave in material under test.

Set cursor to left hand (red)  $\beta$  on Scale H. Bring desired probe angle on Scale F to cursor. Set cursor to left hand (red)  $\alpha$  on Scale H (steel or aluminium as appropriate) and read off required angle of incidence in Perspex on Scale F.

EXAMPLE— Material to be tested: Steel

Probe angle required:  $45^\circ$

Set cursor to left-hand  $\beta$  on Scale H. Bring  $45^\circ$  on Scale F to cursor. Set cursor to left hand  $\alpha$  St. and read off angle of incidence required in Perspex as  $36.6^\circ$  on Scale F.

- (b) Compressional wave in material under test.

Set cursor to right hand (green)  $\beta$  on Scale H. Bring desired probe angle on Scale G to cursor. Set cursor to right hand  $\alpha$  Al or  $\alpha$  St. on Scale H, and read off angle of incidence required in Perspex on Scale G.

EXAMPLE— Material to be tested: aluminium

Probe angle required:  $17.5^\circ$

Set cursor to right-hand  $\beta$  on Scale H. Bring  $17.5^\circ$  on Scale G to cursor. Set cursor to right-hand  $\alpha$  Al on Scale H and read off angle of incidence required in Perspex as  $7.5^\circ$  on Scale G.

- (ii) To find probe angle in aluminium when the value in steel is known.

Set cursor to appropriate  $\beta$  mark on Scale H (red for shear, green for compressional). Bring known probe angle on Scale F or G to cursor. Set cursor to  $\alpha$  St. and read off angle of incidence on Scale F or G as appropriate.

Set cursor to  $\alpha$  Al and bring angle of incidence to cursor. Set cursor to  $\beta$  mark and read off probe angle in aluminium against cursor on Scale F or G as appropriate.

EXAMPLE— Probe angle in steel:  $45^\circ$

This is shear wave propagation so that the red scales will be used. Set cursor to left-hand  $\beta$  mark on Scale H and bring  $45^\circ$  on Scale F to cursor. Set cursor to  $\alpha$  St. and read off  $36.6^\circ$  on Scale F. Set cursor to red  $\alpha$  Al and bring  $36.6^\circ$  on Scale F to cursor. Again set cursor to red  $\beta$  and read off probe angle in aluminium as  $42.2^\circ$  on Scale F.

Note: A similar procedure is followed to calculate probe angle in steel if the value is known in aluminium.

- (iii) To find probe angle when angle of incidence in Perspex is known.

Set cursor to appropriate  $\alpha$  gauge mark on Scale H. Bring angle of incidence on Scale F or G to cursor. Set cursor to appropriate  $\beta$  mark on Scale H and read off probe angle on Scale F or G.

EXAMPLE— Angle of incidence in Perspex:  $38^\circ$

Material to be tested: steel

Wave form in steel will be shear

Set cursor to red  $\alpha$  St. on Scale H and bring  $38^\circ$  on Scale F to cursor. Set cursor to red  $\beta$  mark on Scale H and read off probe angle as  $46.9^\circ$ , say  $47^\circ$  on Scale F.

#### 4. Decibel relationship

Scale I provides a direct conversion from the ratio of echo signal heights to dB or vice versa.

#### 5. Near Zone Length 'N'

Determine wavelength as in 1 on page 3. Set cursor to wavelength on Scale L and bring crystal diameter on Scale J to cursor. Set cursor to unity (arrowed) on Scale L and read off length of near zone against cursor on Scale K.

Note: (i) There are a number of formulae available for calculating 'N'. It will be found that the use of different formulae yields slightly differing values of 'N'. This is not however, important in relation to the practical utilisation of the near field.

(ii) In the case of a rectangular crystal, the theoretical determination of near zone length is difficult and it is recommended that for a safe approximation the major dimension be used for crystal diameter.

EXAMPLE— Wavelength: 1.5mm  
Crystal diameter: 15mm

Set cursor to 1.5mm on Scale L and bring 15mm on Scale J to cursor. Set cursor to unity on Scale L and read off near zone length as 37mm on Scale K.

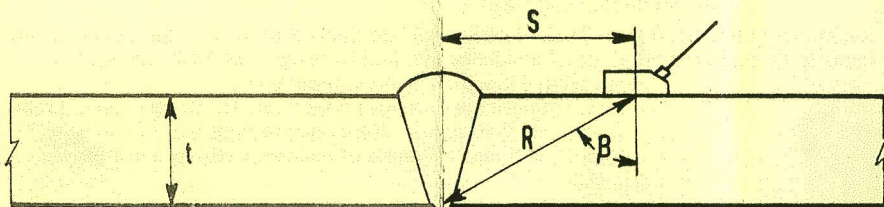


Fig. 1.

#### 6. Skip distance 2S and range R (see Fig. 1)

Set  $t$  on Scale N to arrow ( $45^\circ$  position) on Scale O. Read off half skip distance  $S$  on Scale N against known probe angle on Scale O. Read off slant range  $R$  on Scale N against known probe angle on Scale M.

EXAMPLE— Material thickness: 1.5in.  
Probe angle:  $60^\circ$

Set 1.5 on Scale N to arrow on Scale O.

Use cursor to read off half-skip distance as 2.6in. on Scale N against  $60^\circ$  on Scale O and slant range as 3in. against  $60^\circ$  on Scale M.

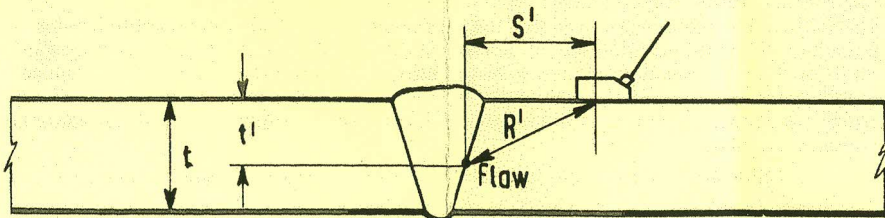


Fig. 2.  $R' < R$ ; required to find  $t'$  and  $S'$

#### 7. Flaw location

(i) When flaw range is less than slant range  $R$  (see Fig. 2). When maximum echo signal is obtained from flaw, read off flaw range  $R'$  from the screen of the flaw detector.



Using the cursor, set reading  $R'$  on Scale M against the probe angle on Scale M and again using the cursor read off flaw depth from surface  $t'$  as 6 on Scale N against the arrow on Scale M.

Read off flaw position in plan  $S'$  (probe index to flaw distance) as S on Scale N against probe angle on Scale O.

EXAMPLE— Material thickness: 10cm  
Range reading from C.R.T.: 12cm  
Probe angle:  $60^\circ$

Bring 12 on Scale N against  $60^\circ$  on Scale M. Read off flaw depth as 6 cm against arrow, and plan position as 10.4cm against  $60^\circ$  on Scale O.

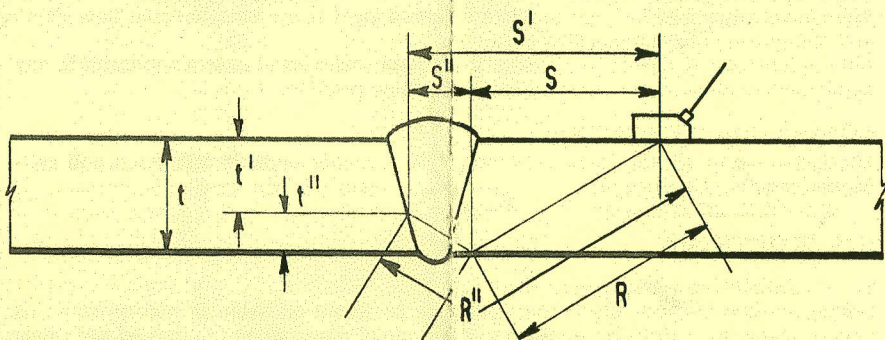


Fig. 3.  $R'' > R$ ; required to find  $t'$  and  $S'$

(ii) When flaw range is greater than slant range  $R$  (Fig. 3).

Subtract slant range  $R$  from range  $R''$ , read from the screen. Set dimension  $R'' - R$  on Scale N against probe angle on Scale M. Read off dimension  $t''$  as  $t$  on Scale N against arrow on Scale M. Flaw depth is then  $t - t''$ . Read off dimension  $S''$  on Scale N against probe angle on Scale O. Flaw position in plan is  $S + S''$ .

EXAMPLE— Material thickness  $t$ : 10cm  
Probe angle:  $60^\circ$   
Slant range  $R$ : 20cm  
Slat range  $R$ : 20cm  
Half skip distance  $S$ : 17.5cm } { These figures should be committed to memory during the test  
Observed range  $R''$  on screen: 25cm  
Set  $R'' - R = 5$ cm on Scale N against  $60^\circ$  on Scale M and read off  $t''$  as 2.5cm on Scale N against arrow on Scale M.  
Flaw depth ( $t - t''$ ) is  $10 - 2.5 = 7.5$ cm

Read off  $S''$  as 4.3cm against  $60^\circ$  on Scale O. Flaw position in plan ( $S + S''$ ) is  $17.4 + 4.3 = 21.7$ cm.

Note on Scales 'M', 'N' and 'O'

The accuracy of flaw location will be determined chiefly not by this Rule but by the care taken in equipment calibration and marking out the probe positions. Careful measurement of material thickness is also important.

## 8. Inch/metric and metric/inch conversions

A 5-in. scale is provided for this purpose. It will be found useful, for example, in converting inch units for material dimensions into metric and for converting flaw positions calculated in metric units into inches.

## 9. Conventional arithmetical calculations

Scales C and D may be used as conventional log scales for arithmetical calculations. For description of special gauge marks, see General Description which explains these fully.