ज्ञान ज्योति से मार्गदर्शन

To Beam As A Beacon of Knowledge

USFD TESTING OF RAILS AND WELDS

August 2019

INDIAN RAILWAYS INSTITUTE OF CIVIL ENGINEERING,

PUNE 411001

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FOREWORD TO SECOND EDITION

The book on 'USFD testing of rails and welds' was originally published in September 2013 by Shri Pradeep Kumar Garg, the then Sr. Professor, IRICEN. The book has been again now corrected and updated as per latest correction slips on various provisions of USFD manual by Shri P K Garg, CE/TM, Central Railway.

Shri Vineet Gupta, Sr. Professor Bridges, IRICEN has done proof reading of the book.

I hope that the book will be found useful by the field engineers involved in track maintenance and USFD testing of rails.

The suggestions for improvement are welcome.

Ajay Goyal
Director
IRICEN, Pune

Pune
August 2019

PREFACE

The need for detection of internal defects in rails and welds to avoid in-service rail and weld failures can not be over-emphasized. The detection of defects is done using ultrasonic flaw detection (USFD) and Indian Railways have been using this technique for decades. However, for proper understanding and implementation of the technique, the absence of a comprehensive book on the subject has always been felt. The present book on USFD Testing of Rails and Welds will fill this gap.

The author of the book Shri Pradeep Kumar Garg has been associated with the subject in Research Designs & Standards Organisation (RDSO) during his posting as Director (Track Machines) and subsequently in IRICEN as Senior Professor (Track). He has profound understanding of the subject and apart from the theoretical aspects he has covered the practical aspects also in this book. The book covers the internal defects in rails and welds, the basic theory of wave propagation and its application to flaw detection, ultrasonic equipments in use and the salient features of USFD manual. However, the book is not meant as an alternative to the USFD manual but will help in understanding its various provisions.

A good coverage has been given to the advancements in this field on other railway systems such as use of wheel probes and vehicular based systems. It is felt that there is an urgent need of switching over to vehicle-based systems for ultrasonic testing on Indian Railways.

It is hoped that the book will prove immensely useful for field engineers on Indian Railways working in the field of track maintenance in general and for those involved in USFD testing in particular.

C. P. Tayal
DIRECTOR

ACKNOWLEDGEMENTS

The need for a comprehensive book covering the theory and the practical aspects of ultrasonic testing of rails and welds was being felt since long. The knowledge of the field engineers in flaw detection by ultrasonic technique as applied to rails and welds is limited resulting in poor implementation of this technique. The provisions of USFD manual published by RDSO and interpretation of signal patterns obtained on the monitor of USFD machine during testing can seldom be understood by the field engineers in absence of clear understanding of the theory.

While working as Director (Track Machines) RDSO, I was given the project of procurement of two SPURT cars from an Israel based firm M/S Scan Masters. This led to my interest and study on the subject. Of course, the understanding started with attending a 3-days special course on USFD in IRICEN in December 2004. I am thankful to the concerned faculty on the subject in IRICEN in providing me the basic understanding of the subject. Lot of learning also came by attending the numerous trial runs made by the Scan Master's engineers on the new cars on Southern Railway. Subsequently I was also the convener of a study team appointed by Railway Board who was assigned the task of recommending the system of ultrasonic flaw detection in rails on Indian Railways. Later on during my posting as Senior Professor(Track) in IRICEN, I opted for teaching this subject out of my interest. The queries raised by the trainee officers led to further reading and learning.

I have tried to keep the language and explanation of the concepts simple so that these can be understood even by supervisors and junior scale officers who may not have any prior knowledge of USFD system. The basic understanding of the various types of internal defects arising in rails and welds has also been given in the initial part of the book.

I am grateful to Shri Naresh Lalawani Senior Professor (Bridges), who has been a great source of motivation to me in IRICEN, for going through the complete book and providing his valuable suggestions in making the subject matter more lucid and easily understandable for the readers.

I am also thankful to IRICEN Director Shri C. P. Tayal for his encouragement and guidance in writing this book. Last but not the least, I am thankful to IRICEN staff in helping me at various stages in bringing out the printed version of the book.

I hope that the book will be useful for maintenance field engineers at every level right from supervisors to officers including those working in USFD testing directly. In spite of all the efforts, some mistake in the first edition of the book might be there. It will be a great help if the mistakes and suggestions are conveyed to me through email at pkgarg@iricen.gov.in OR pkgarg99@hotmail.com.

Pradeep Kumar Garg

Sr. Professor (Track-II)

IRICEN, Pune

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CHAPTER 1

INTRODUCTION

Indian Railways is considered as the lifeline of the nation. It fulfills vital transport necessity and large number of people travel daily on its network. The safety of the traffic is to be given paramount importance on a railway system. Lots of advancements have taken place in track infrastructure and better track maintenance practices have been evolved to improve the reliability of the system. The noteworthy among these are the conversion of free rails into long welded rails, use of pre-stressed concrete sleepers, mechanization of track maintenance, improvements in the rail manufacturing technology, improvements in the rolling stocks etc. The track structure today is sturdier and the track parameters are better maintained. This has certainly reduced the risk of accidents due to rail wheel interaction. However, discontinuity caused due to rail/ weld breakage is an area of concern for track maintenance engineers.

Any defect in the rail or any material which may lead to fracture or breakage is called a flaw or a defect. The development of flaws in rails is inevitable. The two main reasons for occurrence of flaws are the inherent defects in the rails generated during manufacturing and fatigue of rails due to passage of traffic. The inherent weak spots or inherent defects in the rails such as non-metallic inclusions, hydrogen flakes, rolling marks, guide marks etc. at the manufacturing stage pose a threat in the form of rail breakages. The inherent defects can be taken care of by improving the rail metallurgy and the process of rail rolling during the manufacturing stage. On the other hand the defects due to fatigue in the rail during service will depend on the residual stresses in the rails, magnitude of the rail stresses and the number of load cycles.

Defects may also occur due to incorrect handling of rails and excessive thermal stresses due to large variation in rail temperature with respect to stress free temperature. The weld joints in the rails, especially the Alumino Thermit (AT) welds are the weak links, drawing lot of attention of track maintenance engineers. With the increase in the axle loads and the speeds of the trains, the rail stresses are increasing which in turn is likely to result in high defect generation rate in the rails.

It is essential that detection of flaws be carried out well in advance so that timely preventive action can be taken to avoid in-service breakage. This assumes importance as the consequences of in service failures may sometimes be disastrous.

Different types of Non-Destructive testing techniques presently available are

- Visual Inspection
- Dye Penetrant testing
- Magnetic particle Testing
- Radiography
- Eddy Current Testing
- Ultrasonic Testing

Apart from the visual inspection, ultrasonic testing has been considered to be the most effective means of ensuring the soundness of the rails and welds world over due to its versatility, accuracy, sensitivity, overall economy and flaw detection capabilities. Ultrasonic technique is having advantage of its high penetration power, estimation of severity of defect, feasibility of automation, scanning at high speed and requirement of access from one surface only. The use of the other techniques such as eddy current system for detection of surface defects, flaw detection using magnetic flux leakage, rail inspection using electro-magnetic acoustic transducers, rail inspection using alternating current field measurement, inspection using ultrasonic phased array are also in practice on limited scale on some railway systems. Some of these techniques are still in developmental stage.

Indian Railways, depend primarily on ultrasonic technique for reliable flaw detection. The ultrasonic testing of rails and welds is being used on Indian Railways for more than five decades. Testing procedures are continually being modified to suit the requirements of the newer kinds of flaws being noticed. For example, the detection of gauge face corner defects was started in 2005 by providing 70^0 gauge face side probe.

USFD technique is successfully being used world over for the detection of internal flaws in the rails and welds. However, there are certain apprehensions about the capability of this technique on Indian railways. The reasons for this are more of administrative in nature rather than technical. The testing on Indian Railways is being carried out manually using hand testing equipment that brings in lot of subjectivity to the process. The results of testing thus depend upon the knowledge and sincerity of the USFD operator apart from the reliability of the equipment. The knowledge of track maintenance engineers is also one of the important issues that need to be addressed on our system. Without the complete and clear understanding of the technique in the minds of supervisors and officers, the doubts about its efficacy are natural. Understanding of the subject will expel most of the doubts regarding the capability and the limitations of the technique. Understanding the provisions of the manual is difficult without a clear understanding of the principles of USFD testing. The principles used for flaw detection are quite simple and use the basic physics. This book is being written to elucidate the principles of USFD testing including its inherent limitations. Provisions of manual have been touched upon as are required for the sake of completeness. This book should not be looked as the commentary on the manual. For flaw marking and classification, Manual of Ultrasonic testing of Rails and Welds with its latest correction slips should be referred to.

■ ■ ■

CHAPTER 2

DEFECTS IN RAILS AND WELDS

Defects develop in rails as well as welds either as surface defects or as internal defects. Two main reasons for the development of defects in the rails/welds are -

1. the defects generated during the process of manufacturing of rails and welds and
2. the defects developed during the service due to high stresses imparted by the moving wheels.

Appropriate actions need to be taken at the manufacturing stage to improve the rail metallurgy as also the process of rolling of rails to avoid the inherent defects.

Similarly, in case of welds, care is to be taken during execution stage to get a sound weld.

The surface defects can be seen visually during the routine inspections and do not require any special technique for their detection. These include head checks, spalling, shelling, wheel burns, squats, cupped welds, high welds, misaligned joints, low joints, hogged rail ends, bettered rail ends, corrugations etc.

The internal defects cannot be seen during routine track inspections and special non-destructive technique is to be used for their detection. We will discuss the internal defects in detail in this chapter.

2.1 Internal Defects in Rails and Welds

It is the internal defects, which need to be detected using ultrasonic testing for taking timely action to prevent in-service failures. These defects can be broadly classified as below:

1. Horizontal defects
2. Transverse defects
3. Gauge face corner defects
4. Longitudinal vertical defects
5. Bolt hole cracks.

In addition to these, there are certain defects which are specific to alumino thermic weld. These are:

1. Half moon defects
2. Porosity or blow holes
3. Lack of fusion
4. Slag inclusion

The defects in the rail are named as per their orientation i.e. the plane in which they lie - horizontal or vertical and their direction of propagation - longitudinal (i.e. along the length of the rail) or transverse (i.e. along the cross section of the rail). The planes are depicted in Fig. 2.1. So a defect growing along the cross section of the rail will be named as transverse defect while a vertical flaw growing along the rail axis will be named as vertical longitudinal flaw.

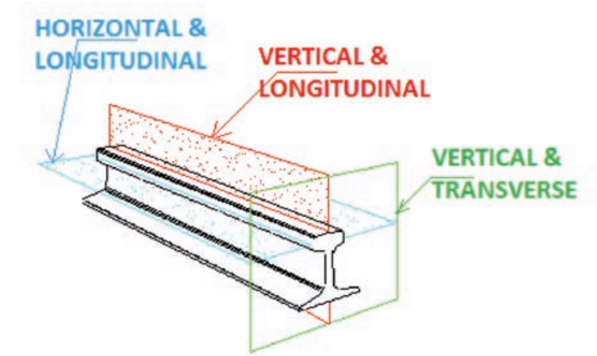

Fig. 2.1 – Different Planes for Nomenclature of Flaws

Let us discuss these defects and the probes used for their detection. Probes are used for generation of ultrasonic waves and we will learn about the probes in chapter 4 in this book.

2.2 Horizontal Defects (HF):

These defects are horizontal and longitudinal i.e. they grow along the axis of the rail. They can develop in the head of the rail, at the head-web junction or at web-foot junction of the rail. High vertical stresses, high residual stresses and inclusions in the rails are responsible for initiation of these defects. These cracks can be easily detected using 0^0 probe during USFD testing. Fig. 2.2 is the schematic diagram showing horizontal flaws in different locations in rail. Fig. 2.3 shows a horizontal defect in the web of the rail through an AT weld.

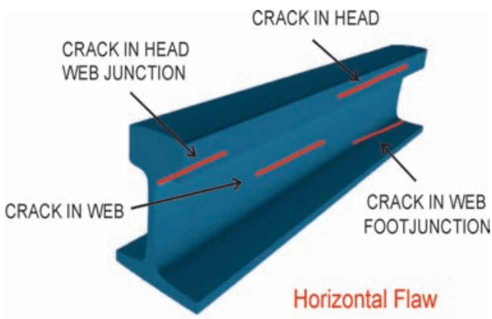

Fig. 2.2 – Schematic Diagram for Horizontal Flaw

Fig. 2.3 – Horizontal Flaw in Web through Weld

2.3 Longitudinal Vertical Flaw (LVF):

As the name suggests, these flaws are in vertical plane and run parallel to the longitudinal axis of the rail as shown in Fig. 2.4 and 2.5. These are caused by presence of non-metallic inclusions, poor maintenance of joints and high dynamic stresses. These defects cannot be easily detected in early stages by USFD due to their unfavourable orientation. These can be detected by 0^0 probe when grown up or by 45^0 tandem rig used on the side of the rail head.

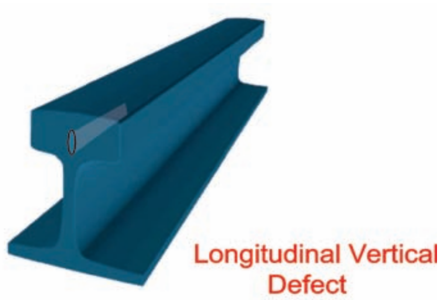

Fig. 2.4 – Schematic Diagram for Longitudinal Vertical Flaw

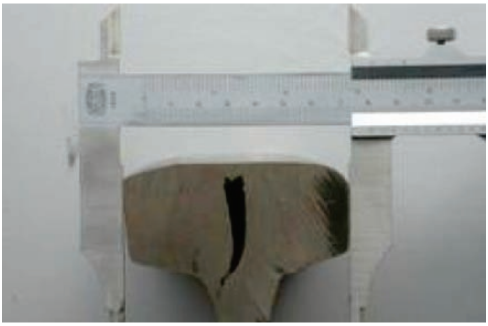

Fig. 2.5 – Longitudinal Vertical Flaw in Rail Head

2.4 Transverse Flaws in Rail Head (TF):

These flaws grow along the transverse plane i.e. along the cross section of the rail and their growth along the rail axis is quite small. These are mostly in the shape of a kidney when fully grown and hence, also known as kidney defects. They are generally inclined at an angle of 18-23^0 to vertical plane and can be detected by 70^0 probe by USFD. Hydrogen accumulation and non-metallic inclusion coupled with high stresses are the main cause of this type of defect. A Transverse or kidney flaw is shown in Fig. 2.6.

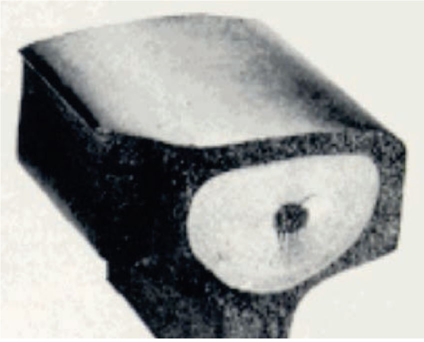

Fig. 2.6 – Transverse or Kidney Defect in Rail Head

2.5 Gauge Face Corner Flaw (GFC):

These are also transverse flaws in the rail head but are located towards the gauge face side instead of located centrally. Transverse defects can originate from the central part in the rail or from the gauge face corner depending upon the point of contact between rail & wheel and stresses generated due to rail wheel interaction. When the flaws get generated near to the center of the rail, 70^0 central probe can detect them. But when they originate from the gauge face corner, 70^0 central probe is not amenable for their detection and we use additional 70^0 probes which are shifted towards the gauge face. Such flaws are termed as gauge face corner flaws. A gauge face corner flaw is shown in Fig. 2.7.

Fig. 2.7 – Gauge Face Corner Defect in Rail Head

Fig. 2.8 – Bolt Hole Crack in Rail

2.6 Bolt Hole Cracks:

These flaws originate from the edges of bolt holes (provided for fish plated joints) in the web of the rail as shown in Fig. 2.8. The typical growth of these cracks is diagonal in star pattern. Hence these are also called star cracks. Earlier 37^0 probe was provided for detection of these defects. 37^0 probe was replaced with 70^0 shifted probe in 2005 for detection of GFC. Now bolt hole cracks are detected using 0^0 probe only. We use the principle of loss of backwall echo of 0^0 probe for their detection.

2.7 Defects Specific to Alumino Thermit Welds

AT welding is a casting process which is carried out in-situ. The quality control at site is not as stringent as in the plant and non-availability of adequate block is another main reason of comprise with quality. Due to shortage of time, field units tend to adopt short cuts. There are some specific defects which develop in Alumino Thermit welds. These are described below.

2.7.1 Half Moon Defect

AT welding was done using two piece mould as shown in Fig. 2.9. In some cases the molten metal leakage causes formation of fin at the bottom of the weld (under the foot of rail). A fin marked with red arrow can be seen in Fig. 2.10. This fin can be felt by moving bare hand under the weld. This particular defect develops due to stress concentration due to this fin.

Fig. 2.9 – Two Piece Mould for Welding

Fig. 2.10 – Half Moon Defect in AT Weld

Fins would not be there in new welds as all new AT welds are being made using three piece moulds where a separate single piece is used at the bottom of the weld avoiding formation of joint at the center. This will avoid the fin and the half moon defects to a large extent.

2.7.2 Porosity

Porosity develops in the weld due to ingress of moisture or some gases entrapped within the weld body. The sources for the moisture are the dampness in portion or dampness in pre-fabricated mould, excessive water in luting sand, ingress of rain water etc. The blow holes are there in the weld body and are sometimes visible on the surface also. A porous weld is shown in Fig. 2.11.

Fig. 2.11 – Porosity or Blow Holes in AT Weld

Fig. 2.12 – Slag Inclusion in AT Weld

2.7.3 Slag Inclusion

Slag is the unwanted molten metal which may find its way into the body of the weld and may result into a weak weld. The reasons for this could be early tapping or not giving sufficient time for the slag to separate out from the metal. The colour and texture of the slag is different than the weld metal as shown in Fig. 2.12. This type of defect is taken care of by use of auto thimble which avoids early tapping.

2.7.4 Lack of Fusion

Another defect which may result in the failure of a weld is lack of fusion. This may occur due to insufficient heat to bring proper fusion. The reason for insufficient heat in the weld joint could be inadequate pre-heating, more gap at the joint, delay in tapping of molten metal into the joint etc. An AT weld with lack of fusion is shown in Fig. 2.13. This type of defect will also be minimised by use of auto thimble.

Fig. 2.13 – Lack of Fusion in AT Weld

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CHAPTER 3

PRINCIPLES OF USFD TESTING

In USFD testing, we use ultrasonic waves for flaw detection. Wave is a disturbance in a medium, which transmits the energy from one place to another through the medium or without the medium. Waves can be broadly classified into two types - the electro-magnetic waves and the mechanical waves. Light waves, radio waves, X-rays, α-rays etc. are the examples of electromagnetic waves while sound waves are mechanical waves. Electro-magnetic waves do not require any medium for their propagation, whereas mechanical waves necessarily require a medium for their propagation. The velocity of the mechanical waves is dependent on the properties of the medium in which they are travelling.

The vibrations, when cyclic in nature are classified according to their frequency i.e. the number of cycles per second. The sound waves are classified as sonic, sub-sonic and ultrasonic based on their frequencies.

3.1 Ultrasonic Waves

The frequency of sonic waves ranges from 20 cycles per second (also called Hertz denoted by Hz) to 20,000 Hz. Subsonic waves are the sound waves of frequency less than 20 Hz and ultrasonic waves are those having frequency of vibrations more than 20,000 Hz.

It is only the sonic range, which is audible to the human ear. We cannot sense the subsonic and ultrasonic waves. Ultrasonic waves are not of very uncommon occurrence in nature and have assumed great importance in recent years because of their unique properties, which have been applied to many fields of engineering and one of the most popular use of ultrasonic waves, has been in the non-destructive testing of materials.

3.2 Classification of Waves

A sound wave can be transmitted through any material, which is having elastic properties. Every material is composed of small particles that are inter-connected and vibrate about their equilibrium position. The speed of propagation of sound waves depends upon the elastic properties and density of the medium in which they are travelling. The velocity of sound waves in solids is more than that in liquids and gases.

Depending upon the direction of the particle vibration with respect to direction of propagation of wave, the ultrasonic waves are categorized into following three types –

1) Longitudinal Waves
2) Transverse Waves
3) Surface Waves

3.2.1 Longitudinal Waves

Longitudinal waves are the waves in which the oscillation of the particles of the medium is in the direction of propagation of wave (as shown in Fig. 3.1). The particles of a medium when imparted with energy, start vibrating with higher amplitude and transfer part of their energy to the adjoining mass particles. The process continues and the energy transfer takes place from one location to another in the form of longitudinal waves. The wave transmits itself by generating alternate zones of compression (where particles come closer) and rarefaction (where particle go farther apart). These waves are also termed as compression waves or pressure waves.

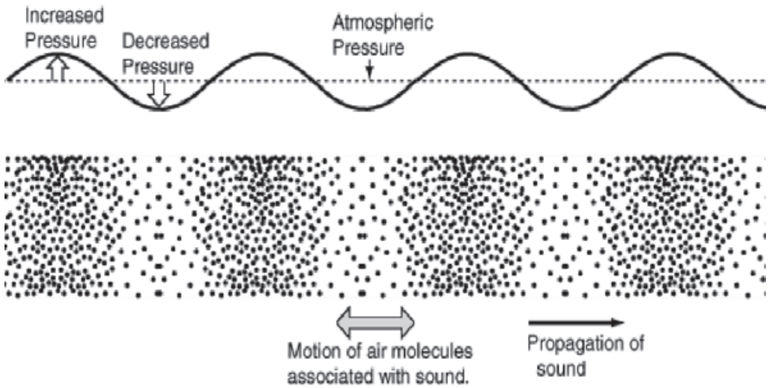


Fig. 3.1 – Longitudinal Waves in a Medium

The longitudinal waves can travel through solids, liquids and gases and their velocity is constant in a given material. In dense materials the inter-molecular distance is smaller, therefore the energy transfer and the wave propagation, is faster. That is why velocity of longitudinal waves is more in denser materials than in lighter materials.

Sound waves travelling through air are longitudinal waves. The waves generated by striking a tuning fork against a rubber pad are also another example of longitudinal waves (Fig. 3.2).

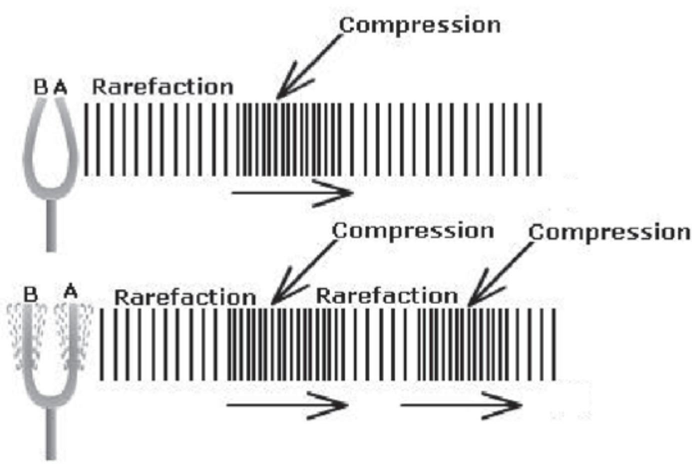


Fig. 3.2 – Longitudinal Waves Generated by Tuning Fork

3.2.2 Transverse Waves

When the vibration of the particles is in a direction perpendicular to wave propagation (as shown in Fig. 3.3), the wave generated is termed as transverse wave. This is also known as Shear Wave because the energy transfer between two particles takes place by the shear movement between these two planes. When a particle is going upwards, it drags the adjacent particles also upwards due to shear strength and when the particle is going downwards, it takes the adjacent particles also downwards along with it. This sets in a wave motion in the medium. It is therefore necessary that the medium should have shear strength for propagation of these waves. That is why transverse waves cannot propagate through liquids and gaseous mediums since these mediums do not possess any shear strength. Thus transverse waves can travel only through solids. However, these waves can travel on the surface of a liquid also due to surface tension. The wave travels by formation of crests (high points) and troughs (low points). The distance between two adjacent crests or two adjacent troughs is called wavelength.

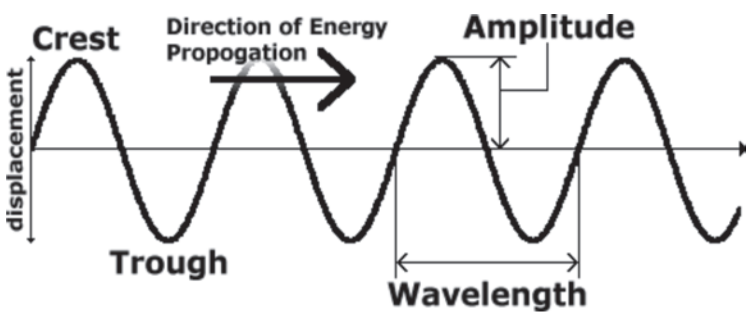


Fig. 3.3 – Transverse Waves in a Medium

If we tie one end of a string with a hook in the wall and wave the other end up & down, transverse waves start travelling in the string (Fig. 3.4). The wave propagates along the length of the string while the vibration of the particles is perpendicular to the length.

Fig. 3.4 – Transverse Wave in a Rope

Similarly waves generated on the surface of still water by throwing a stone into it are also transverse waves. The waves propagate radially outwards on the water surface. If we keep a cork on the water, it dances up and down at same place. This is another example of particles of the medium vibrating perpendicular to the direction of wave propagation.

3.2.3 Surface Waves

These waves propagate over the surface of the material only. This consists of both longitudinal and transverse type particle movement. There are different types of surface waves like Lamb wave, Rayleigh wave etc. Since these waves travel only on the surface of the material, they are not used for testing the internal defects in the material.

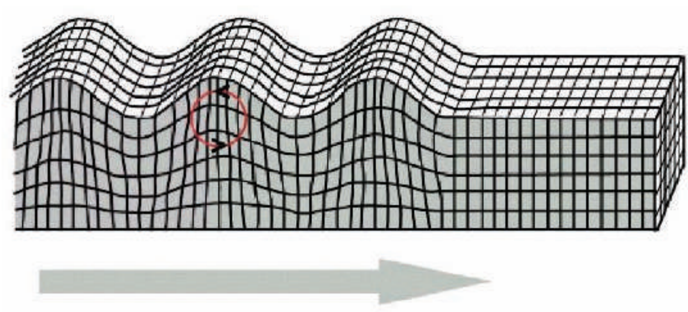


Fig. 3.5 – Surface Waves in a Material

3.3 Wave Velocity

The velocity of a particular type of wave say longitudinal wave will remain the same in a particular medium but will be different in another medium. For example, velocity of longitudinal waves (sound waves) in air is 330 m/s while their velocity in steel is 5900 m/s. The velocity of the wave 'v', its frequency 'f' and wavelength 'λ' are correlated as -

$$v = f * \lambda \text{ ------- } (eq^{n}\ 3.1)$$

We can’t change the velocity of a wave in a medium. But we can choose the frequency of its wave and that will affect its wavelength. Higher the frequency, the lower will be the wavelength and vice versa.

The velocity of different kind of waves is different in the same medium. For example, in steel the velocity of the longitudinal waves is 5900 m/s while the velocity of transverse waves is 3230 m/s.

The velocity of longitudinal waves is approximately double the velocity of transverse waves in a given medium.

For steel, the ratio of velocity of longitudinal waves to that of transverse waves is 1.82. The velocities of the longitudinal and transverse waves in few materials of interest to us are given in Table 3.1.

Table 3.1 - Velocities of Waves in Different Mediums

Medium	**Velocity (in m/sec.)**	
	Longitudinal Waves	**Transverse Waves**
Steel	5900	3230
Perspex	2730	1430
Water	1480	Can't travel
Air	330	Can't travel

Prespex is the material which is provided at the face of a probe to protect the piezo-electric crystal. We will learn more about it in Chapter 4.

3.4 Propagation of Sound Waves

3.4.1 Reflection & Refraction

When a sound wave reaches the boundary of two media, part of the energy comes back in the first medium as reflected wave and part energy goes in the second medium as refracted wave.

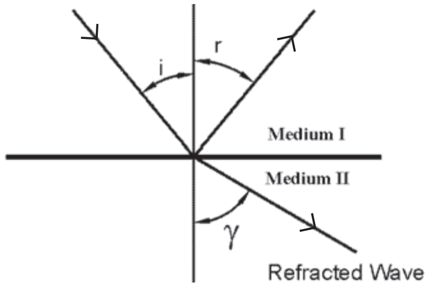


Fig.3.6 – Reflection & Refraction

The reflected and the refracted waves follow two principles. The first principle states that the incident wave, the reflected or the refracted wave and the normal lie in the same plane. As per the second principle reflection as well as refraction follow the Snell's Law which states that the ratio of sines of angles of incidence (i) and reflection (r) or refraction (γ) is equivalent to the ratio of the velocities of incident wave (v_i) and the reflected (v_r) or the refracted (v_2) waves. Mathematically we can write,

for reflected wave -

$$\frac{\sin i}{\sin r} = \frac{v_1}{v_r} \text{ ---- (eq}^n \text{ 3.2)}$$

and for refracted wave -

$$\frac{\sin i}{\sin \gamma} = \frac{v_1}{v_2} \text{ ------- (eq}^n \text{ 3.3)}$$

The incident and the reflected waves travel in the same medium and if the type of the wave is also same (say both are longitudinal or both are transverse), then $v_1 = v_r$.

Hence, from equation 3.2,

$$\frac{\sin i}{\sin r} = 1 \text{ ------- (eq}^n \text{ 3.4)}$$

i.e. $i = r$

The refracted wave travels in the second medium and gets deviated from its path into the second medium at an angle γ, which is lower or higher than the angle of incidence depending upon whether the sound velocity in the second medium is lower or higher than the velocity in the first medium.

If $v_2 > v_1$, then $\sin\gamma > \sin i$ i.e. $\gamma > i$. This implies that the refracted wave will deflect away from the normal in medium 2 if its velocity in medium 2 is higher.

The transducer used for the testing has a prespex sheet on its face and it is kept over the rail for flaw detection. So in our case, medium 1 is prespex and medium 2 is steel. For longitudinal wave, v_1 = 2730 m/s and v_2 = 5900 m/s. So the refracted wave will get diverted away from the normal.

3.4.2 Transformation or Mode Conversion

This phenomenon is observed in case of transmission of sound waves from one medium to another at an angle other than normal. Part of an incident longitudinal wave after striking at the boundary of two media gets transformed into transverse wave, whereas remaining part continues as longitudinal wave. This happens due to redistribution of energy at the boundary. After striking at the boundary, some of the medium particles continue to vibrate in the direction of propagation of the wave while others start vibrating perpendicular to the direction of propagation. Thus there will be two reflected waves and two refracted waves – one longitudinal and the other transverse. The phenomenon of transformation or mode conversion is observed in both types of waves - longitudinal as well as transverse. This is shown for longitudinal wave in Fig. 3.7.

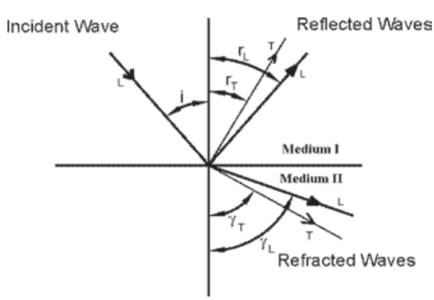


Fig. 3.7 – Transformation or Mode Conversion

It may be noted here that no transformation takes place if the wave is coming in the direction of normal. It means that an incoming longitudinal wave in the direction of normal will go in the second medium also as longitudinal wave without transformation.

The basic principle of ultrasonic testing is that the ultrasonic wave travelling in medium 2 will get reflected after hitting a flaw. The reflected energy is picked up by the probe and the flaw gets detected as shown in Fig. 3.8.

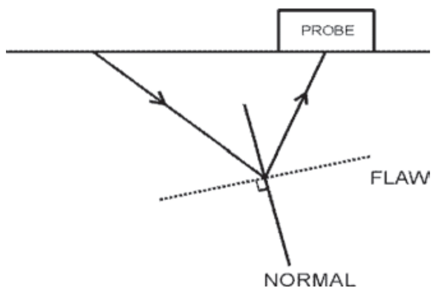


Fig. 3.8 – Detection of Flaw by Probe

So during testing, we are interested in waves travelling in medium 2 (i.e. rail steel) only. By applying the Snell's Law, we can calculate the angles of refraction for longitudinal and transverse waves depending upon the value of angle of incidence and the velocities of these waves in the two mediums, as given in equation 3.5 & 3.6.

$$\frac{\sin i}{\sin \gamma_L} = \frac{V_{L_1}}{V_{L_2}} \text{ ------- (eq}^n \text{ 3.5)}$$

$$\frac{\sin i}{\sin \gamma_T} = \frac{V_{L_1}}{V_{T_2}} \text{ ------- (eq}^n \text{ 3.6)}$$

Where γ_L and γ_T are the angles of refraction for longitudinal and transverse waves respectively. V_{L_1} & V_{L_2} ,, are the velocities of longitudinal waves and V_{T_1} & V_{T_2} are the velocities of transverse waves in medium 1 & medium 2 (refer Fig. 3.7).

As brought out earlier, the first medium in our case is prespex and the second medium is steel. Therefore,

v_{L_1} = 2730 m/s

v_{T_1} = 1430 m/s

v_{L_2} = 5900 m/s

v_{T_2} = 3230 m/s

We can substitute these values on R.H.S. in equations 3.5 & 3.6. We find that -

Since $v_{L_2} > v_{L_1}$, so $\gamma_L > i$.

and, $v_{T_2} > v_{L_1}$, so $\gamma_T > i$.

Also, $v_{L_2} > v_{T_2}$, so $\gamma_L > \gamma_T$.

It means that both refracted waves are diverted away from normal in medium 2 and the refracted longitudinal wave is diverted farther away from the normal as compared to refracted transverse wave.

Now, instead of one, two waves (longitudinal & transverse) are travelling in medium 2, they will strike the flaw at different times due to difference in their velocities and will also be received by the probe at different times as shown in Fig. 3.9. This will create confusion in testing process.

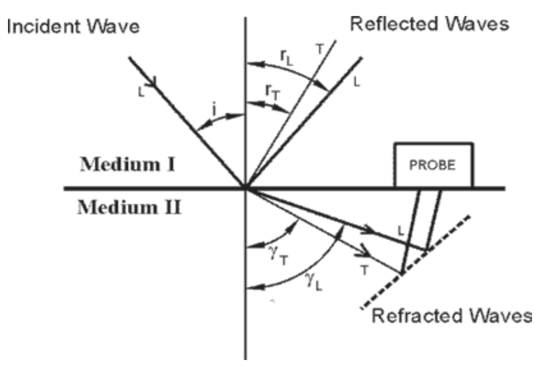


Fig. 3.9 – Sketch Depicting Confusion in Flaw Detection Due to Two Waves in Medium 2

The confusion arises because two waves reflected by the flaw will be received by the probe at different times due to difference in their velocities and operator will not be able to make out whether the received energy has come from two different flaws or the same flaw has reflected them for two different waves. So for proper testing, one of these waves needs to be eliminated. This is achieved by applying the concept of 'total internal reflection' as explained below.

3.4.3 Total Internal Reflection and First Critical Angle

Let us consider the reflection and refraction again as shown in Fig. 3.10. Due to trasformation, we have two refracted waves - longitudinal wave AB and transverse wave AC. As seen earlier, $\gamma_L > \gamma_T > i$ since. $V_{L_2} > V_{T_2} > V_{L_1}$.

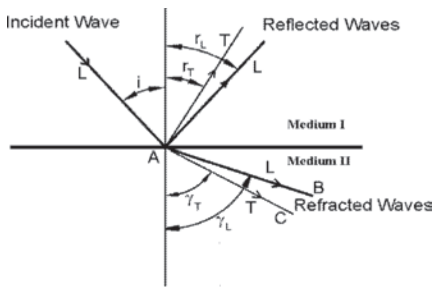


Fig. 3.10 - Refracted Waves

If i is increased, both γ_L and γ_T will increase. If we go on increasing i, there will be a particular value of i for which γ_L will become 90^0 (while γ_T will still be less than 90^0). That means the longitudinal wave AB will not be refracted and will become a surface wave. This phenomenon is called 'total internal reflection' and this value of i is called 'first critical angle'. The value of first critical angle i_{C_1} can be calculated from the equation 3.7 by substituting $\gamma_L = 90^0$, $V_{L_1} = 2730$m/s & $V_{L_2} = 5900$ m/s for perspex – steel combination.

$$\frac{\sin i_{C_1}}{\sin \gamma_L} = \frac{V_{L_1}}{V_{L_2}} \quad \text{----- (eq}^n \text{ 3.7)}$$

We get $i_{C_1} = 27.5^0$. It implies that, if we keep angle of incidence 27.5^0 or more, the longitudinal wave AB will become a surface wave and only transverse wave AC will travel in medium 2 (i.e. steel) as shown in Fig. 3.11.

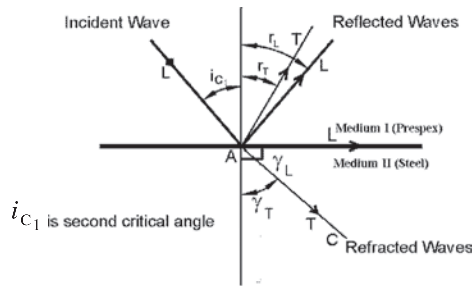


Fig. 3.11 – Total Internal Reflection

Substituting i_{C_1} = 27.5^0, V_{T_2} = 3230m/s & V_{L_1} = 2730 m/s in equation 3.8,

$$\frac{\sin i_{C_1}}{\sin \gamma_T} = \frac{V_{L_1}}{V_{T_2}} \quad \text{------} \quad (\text{ eq}^n \; 3.8)$$

we get γ_T= 33.1^0.

3.4.4 Second Critical Angle

If we keep on increasing angle i further, there will be another value of i for which γ_T will also become 90^0 i.e. the transverse wave will also become a surface wave. This value of i is called 'second critical angle' i_{C_2} and this is shown in Fig. 3.12.

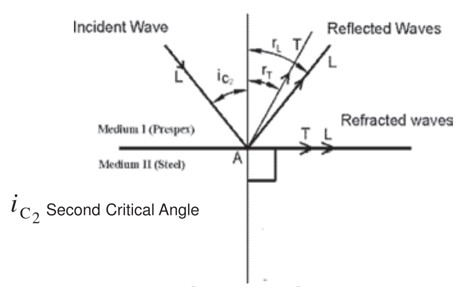


Fig. 3.12 – Second Critical Angle

In this case no wave will travel in medium 2 and the testing will not be possible. So, value of i should be less than i_{C_2}.

i_{C_2} can be calculated from equation 3.9 by substituting γ_T = 90^0, V_{L_1} = 2730m/s & V_{T_2} = 3230 m/s.

$$\frac{\sin i_{C_2}}{\sin \gamma_T} = \frac{V_{L_1}}{V_{T_2}} \quad \text{---- (eq}^n \text{ 3.9)}$$

We get i_{C_2} = 57.7^0. So we design the angular probes to keep i more than i_{C_1} but less than i_{C_2} i.e. between 27.5^0 & 57.7^0 for USFD testing of rails.

Here it is important to point out that the **probe angle** is not the angle of incidence but it is the angle of refraction i.e. the angle at which the wave enters the steel after refraction from the boundary between the prespex and steel. So the probe angle can vary between 33.3^0 & 90^0 from these criteria. **All angular probes utilize the transverse waves for the testing** of flaws in the material since longitudinal waves are eliminated by total internal reflection.

The phenomenon of transformation takes place only when the incident wave is coming in a direction other than normal. So in case of normal probe, the transformation does not occur and the longitudinal wave travels in medium 2 also as longitudinal wave. Hence **normal probe utilizes the longitudinal wave for the testing of flaws.**

3.5 Attenuation

The intensity of a wave decreases as it progresses into a medium and this is known as attenuation. This happens due to loss of energy by absorption and scattering. That is why the sound is not audible after a certain distance, which depends upon the intensity, frequency as well as the type of medium. Attenuation or loss of sonic energy is due to following phenomenon.

3.5.1 Absorption

Some sound energy gets absorbed in the medium as it travels through it. The absorption is at the boundary as well as in the medium.

3.5.2 Scattering

Scattering of the ultrasonic wave results if the material is not strictly homogeneous. Wherever there is non- homogeneity leading to changes in the densities, scattering of ultrasonic waves takes place resulting into loss of energy.

The more the losses, the lesser will be the amount of the reflected energy available to the transducer for the detection of the flaw. So the losses need to be minimized. The energy/intensity of a wave 'I' after travelling a distance 'd' is related to its initial energy/intensity 'I_0'as

$$I = I_0 e^{-\alpha d} \text{ ------ (eq}^n \text{ 3.10)}$$

where α is a constant known as coefficient of attenuation. Greater the value of α, more will be the losses and the lesser will be the intensity of the wave after travelling a distance d. α depends upon the frequency and the average grain size of the material. Typically, for ultrasonic testing of rails/ welds, α may be defined as

$$\alpha = k\,D^3 / \lambda^4 \text{ ------ (eq}^n \text{ 3.11)}$$

where 'k' is a constant, 'D' is average grain size of the material being tested and 'λ' is the wavelength of the waves being used for testing. The equation can also be written in terms of frequency 'f' and velocity 'v' as below.

$$\alpha = k\,D^3 f^4 / v^4 \text{ ----- (eq}^n \text{ 3.12)}$$

It is clear from the above equation that attenuation is directly proportional to the fourth power of frequency and the third power of average grain size. This means that for higher frequencies, the penetration of the sound in a medium becomes poor due to higher losses.

For testing, normal probe uses longitudinal waves (because there is no transformation) while all angular probes use shear waves (because of transformation and total internal reflection of longitudinal waves). We know that the velocity of shear waves is approximately half the velocity of longitudinal waves in a given medium. It means in a given medium, the coefficient of attenuation for angular probe will be 16 times higher as compared to normal probe (as per equation 3.12), which will result in higher loss of energy making the detection of flaws difficult by an angular probe. Therefore, to reduce the losses, **the frequency of crystal in angular probes is kept half of the frequency of that in the normal probe.** This will keep the ratio v/f almost the same. That is why during testing by trolley the normal probe used is having 4MHz frequency while all angular probes have 2MHz frequency.

If we consider the test medium, two different media are encountered during the testing by trolley viz. rail and AT welds. While rails are having fine-grained structure, AT welds being cast steel material have coarser grain size. It means that the value of 'D' will be much higher for AT welds as compared to rails. This will result in more attenuation in AT welds as compared to rail steel (as per equation 3.12). If we have two small defects of same size – one in AT weld and the other in rail, the reflected energy received by the transducer from the defect in AT weld will be much less as compared to that from the defect in the rail. It means that the same defect in the rail may get detected while the one in the weld may remain undetected. To take care of this, **there is a procedure for separate hand testing of AT welds using normal probe of 2MHz frequency (instead of 4 MHz used on trolley) to reduce the losses.** It is essential to bring out that there are other reasons also for separate hand testing of welds such as testing of flange of the weld, detection of half moon defect, detection of porosity etc., which cannot be done by machine probing.

The reduction in frequency of hand held probes reduces the loss and helps in better detection of flaws. One may wonder as to why do we not reduce the frequency of probes further from the existing frequency of 4MHz or 2MHz to reduce the losses. This is because of another limitation. **The minimum size of the detectable defect is approximately half the wavelength.** If we reduce the frequency, wavelength will increase which in turn will increase the size of the minimum detectable defect making the detection of the small size defects difficult. Therefore, we can't reduce the frequency as per our wish and a balance has to be struck between the minimum size of the detectable defect and the loss of energy.

3.6 Acoustic Impedance

Acoustic impedance is the property of the medium which determines its affinity for a wave. The acoustic impedance of a medium is defined as the product of the density of the medium ρ and the velocity of the wave in the medium v. It is denoted by 'Z'.

$$Z = \rho\, v \text{ --------- } (eq^n\ 3.13)$$

The more the value of 'Z', the more is the tendency of the medium to attract the wave.

We know that after striking at the boundary of the two media, part energy of the waves comes back in the first medium as reflected wave and part energy goes to the second medium as refracted wave. The distribution of the energy between reflected and the refracted wave will depend upon the relative values of the acoustic impedances of the two media. The ratio of the reflected energy to the total energy of the wave is known as 'Reflective index' and is defined as –

$$R = \left(\frac{z_1 - z_2}{z_1 + z_2} \right)^2 \text{ --------- } (eq^n \ 3.14)$$

Where z_1 & z_2 are the acoustic impedances of medium 1 & medium 2 respectively.

If the values of z_1 & z_2 are almost the same, R = 0 i.e. there will be no reflection and all the energy will go to medium 2. On the other hand if z_1 is far far greater than z_2, R=1 i.e. there will be 100% reflection at the boundary.

The acoustic impedances of some of the materials used in USFD testing are given in table 3.2.

Table 3.2– Acoustic Impedances of Different Materials

Material	**Acoustic Impedance**
Steel	4.68
Air	0.0004
Water	0.149
Machine Oil	0.150
Prespex	0.320

The acoustic impedance of air is very less as compared to other materials. Therefore, for Steel & air or prespex & air boundaries, there will be complete reflection and no energy will pass through air. So whenever, ultrasonic wave meets air as boundary or a flaw (also air), the energy gets completely reflected making it possible to detect the flaw.

For water & steel boundary, R = 0.88 i.e. there will be 88% reflection and only 12% of the energy will pass to the steel. Similarly, for prespex & water boundary, R = 0.13 i.e. 87% of the energy will go into water.

3.7 Use of Couplant for Ultrasonic Testing

When we keep the probe on the surface of the testing material say rail, there will be a thin film of air between the probe and the rail top surface which will act as a third medium. The first reflection & refraction will occur at the boundary between the prespex and air. The ratio between reflected and the refracted energy will depend upon the acoustic impedances of prespex and air. The acoustic impedance for prespex is 0.32 and that of air is 0.0004. Due to vast difference between the two acoustic impedances, reflection coefficient will be nearly 1 and all the energy will be reflected back from the boundary. No ultrasonic energy will enter into the rail (through air) and the testing will not be possible. It is therefore necessary to expel the air film between the probe and the rail by the use of a couplant (Fig. 3.13). If we do not use a couplant, testing will not be possible.

Water is used as a couplant during USFD testing of rails by trolley. Water makes a good couplant since it is cheap, easily available, flowable and does not contaminate the rail top. However, grease makes a better couplant due to its viscosity. USFD manual prescribes the use of soft grease (RDSO Specification No. WD-17-MISC.-92 or WD-24-MISC.-2004) during calibration and hand testing of welds. So, we use water as couplant during through testing of rails & welds and soft grease as a couplant during calibration and hand testing of welds.

In fact, a third medium is introduced with the use of water or grease. The effect of this water layer is again to cause reflection and refraction at the boundary depending upon the relative acoustic impedance values of different media. On analyzing, we find that only 1.44% energy comes back to transducer after reflection from the discontinuity and the rest is lost due to reflection and refractions from various boundaries as explained in Fig. 3.14. In fact, there will be further losses due to attenuation and the actual energy received will be still less.

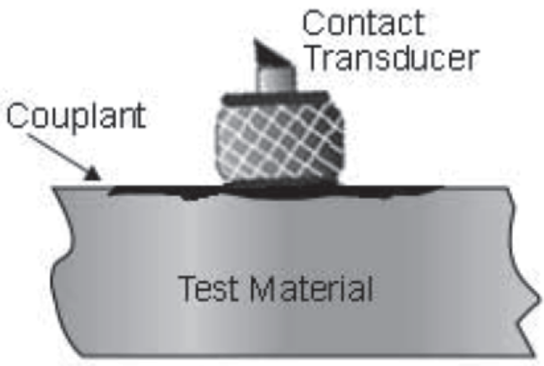


Fig. 3.13 – Use of Couplant Between Probe & Test Piece

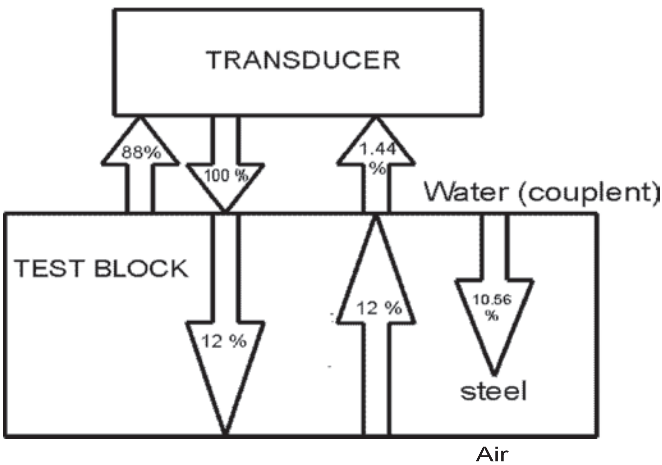


Fig. 3.14 – Energy Received Back by Probe

3.7.1 Effect of couplant on angle of refraction in steel

One may be wondering that with the introduction of a third medium as water, the assumptions made so far regarding the boundary between prespex and steel will get vitiated. In fact, it doesn't. This can be explained with the help of Fig. 3.15.

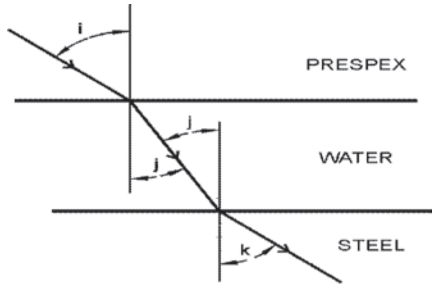


Fig. 3.15 – Effect of water layer

If v_p, v_w & v_s are the velocities of a wave in prespex, water & steel respectively, we have –

$$\frac{\sin i}{\sin j} = \frac{v_p}{v_w} \text{ ----- (eq}^{n}\text{ 3.15)}$$

$$\frac{\sin j}{\sin k} = \frac{v_w}{v_s} \text{ ------- (eq}^{n}\text{ 3.16)}$$

Multiplying the two equations, we get –

$$\frac{\sin i}{\sin k} = \frac{v_p}{v_s} \text{ -------- (eq}^{n}\text{ 3.17)}$$

This is the same equation as applicable to boundary between prespex & steel without water layer in between. Thus water layer does not make any difference as far as the angles of incidence and refraction between prespex & steel is concerned. Hence, the theory of wave propagation discussed so far without considering water layer holds good.

3.8 Detectable Flaw Sizes

The detectable size of the flaw depends upon the wavelength of the ultrasonic wave 'λ'. Normally a flaw size of $\lambda/2$ is reliably detectable. Since the velocity of a particular wave in a medium is constant, a higher frequency wave will have a lesser wavelength (λ = v/f). If we use transverse waves, (the velocity of which is almost half of that of longitudinal wave in the same medium) for the same frequency, the wavelength of this transverse wave will be almost 50%, thereby reducing the minimum detectable size of flaw by 50%. While testing by trolley, we use normal probe (using longitudinal wave) 4MHz frequency and 70^0 probe (using transverse wave) 2MHz frequency. As the velocity becomes half, we reduce the frequency also to half to keep the wavelength same. This gives a detectable flaw size as 0.8 mm. So theoretically, it is possible to detect the flaws more than 0.8mm with the present probes on trolley. This happens when the flaw is most favourabley oriented to the ultrasonic beam and all the energy strikes the flaw normally. In practice, this does not happen and the size of the flaws detected is much larger.

3.9 Use of Probes of Different Angles

The detection of flaws by USFD is based on the principle that the USFD waves after reflection from a flaw should be received back by the probe. As per the principle of reflection, we know that the ultrasonic waves after reflection will return to the probe only when they fall perpendicular to the flaw. In this situation, angle of incidence as well as angle of reflection will be zero (Fig. 3.16). If the waves fall on the flaw at an angle other than normal, angle of incidence will not be zero. Since angle of reflection is same as the angle of incidence, the reflected wave will not return back on the incidence path and energy will not be picked-up by the probe and the flaw will remain undetected (Fig. 3.16). To detect this flaw, we have to use a probe which sends the wave at an angle. The probability of flaw detection is higher when the wave hits the flaw normal to it as shown in Fig. 3.17. It implies that for a horizontal defect, the beam path should be vertical i.e. we should use a 0^0 or normal probe. Similarly for a defect inclined at 30^0 from the vertical, we should use a 60^0 probe and so on. Therefore **we need to use probes of different angles for detection of different defects at different orientations (or angles).**

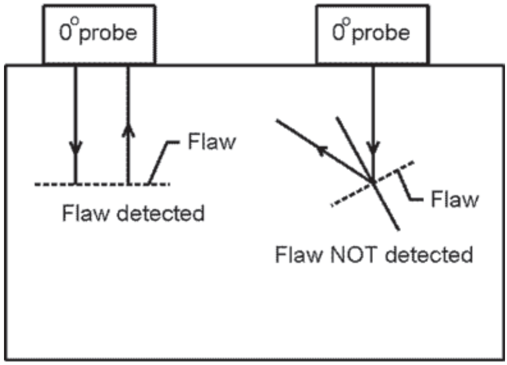


Fig. 3.16 – Flaw Detection by Normal Probe

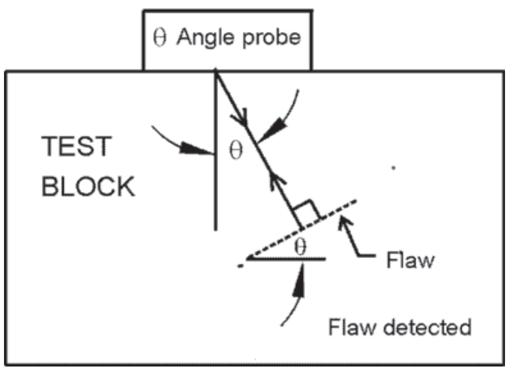


Fig. 3.17 – Flaw Detection by Angular Probe

3.9.1 Use of Probes of 0^0 & 70^0 angles

As explained earlier, we need to use probes of different angles for detection of defects at different orientations. Theoretically the flaw may be oriented in any direction, so we should have number of angular probes for the detection of all probable flaws. But we have limitation of number of channels in USFD testing machine and only limited number of probes can be provided with the machine. It is therefore prudent to take care of the most probable flaws in the rails and welds. The common types of flaws have been explained in chapter 2. 0^0 probe is used for the detection of horizontal flaws, bolt hole cracks and longitudinal vertical flaws. To take care of transverse flaws, we use 70^0 probes. It has been seen by experience that most of the transverse flaws are inclined at an angle of 14-24^0 from the vertical and therefore 70^0 probe has been found to be effective in detection of these flaws. A 70^0 probe, by virtue of its crystal size will scan only the central portion of the rail head while moving at the center of the rail head. Hence, gauge face corner flaws initiating from the corner will not be detected by 70^0 central probe. We therefore, use 70^0 shifted gauge face probe for detection of these flaws. Similarly, 70^0 non-gauge face probes are used for detection of flaws initiating from non gauge face corner. In shifted probes, we physically shift the probe towards the gauge face or non-gauge face of the rail with respect to the centre of rail head. Thus almost entire area of rail head is covered by three sets of 70^0 probes. We will learn about the area covered by different probes in chapter 5.

So far we have discussed the detection of plane flaws. Actually, this is only a concept for understanding. In actual practice no flaw is perfectly planar. If we observe under a microscope, the flaw will always be zigzag having number of reflecting surfaces. Some of these will be more prominent than others. Thus, if the probe angle is little different, some of the facets of the flaw will still reflect the energy in a direction favourable for the detection by the probe. Thus 70^0 probe not only detect the flaws inclined at 20^0 from the vertical but also the flaws inclined within a range close to 20^0. So bigger size disoriented flaws can be detected but the smaller flaws may not reflect sufficient energy back to the probe for their detection. Theoretically, we can detect flaws up to 0.8mm if most favourably oriented.

We used to have 37^0 probe for detection of bolt hole cracks earlier. In 2005, a conscious decision was taken to remove 37^0 probe to make space for 70^0 GF probe. The possibility of bolt hole cracks has now reduced due to reduction in fish plated joints. Also, we can still detect these defects using 0^0 probe. On the other hand, the population of gauge face corner defects has increased considerably and it became necessary to detect these defects for safety. Hence 70^0 GF probe was added.

3.10 Use of Angular Probes in Pairs

Angular probes are always used in pair i.e. forward and backward probes. This is easy to understand. Let's take a defect inclined at 20^0 from vertical as shown in Fig. 3.18. We use a 70^0 probe for detection of this flaw. 70^0 probe will send the beam which will fall normal to the flaw and the reflected wave will return back to the transducer, thus making the flaw detection possible. Now take a situation where the flaw is oriented at 20^0 from the vertical but in the other direction as shown in diagram below. The beam coming from the 70^0 probe will now fall on the flaw at an angle other than normal and the reflected beam will not return to the probe and the flaw detection will not be possible. To detect this type of flaw, we should send the beam to the flaw from the other direction. This will require the machine to be reversed and run in that direction. This will double the work of testing. To avoid this, we use another 70^0 probe that will send the beam in backward direction. The logic holds good for all angular flaws. Hence all angular probes are used in pairs.

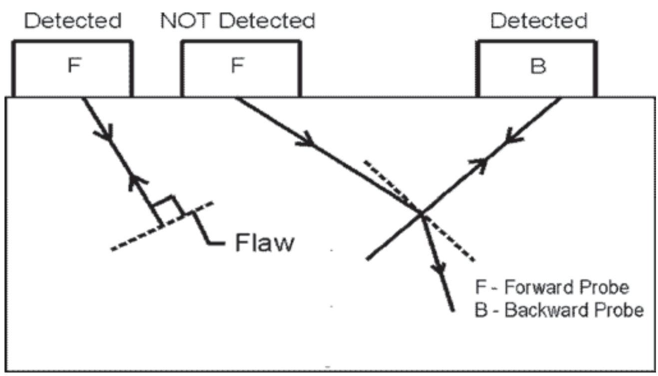


Fig. 3.18 – Angular Probes in Pair

Now we are conversant with the principles of flaw detection by USFD technique. In the next chapters, we will understand the use of these principles for detection of actual flaws in rails and welds.

■ ■ ■

CHAPTER 4

GENERATION OF ULTRASONIC WAVES AND EQUIPMENTS

4.1 Generation of Ultrasonic Waves

Though the ultrasonic waves are generated by mechanical means in a number of real life examples, the frequency range of these waves is limited to narrow band. They are also not generated in a controlled beam form. Therefore, most engineering applications depend upon the electro-acoustic methods for production of ultrasonic waves. The ultrasonic generators are termed as Electro-acoustic Transducers because these convert electrical energy into sonic energy.

The method used for generation of ultrasonic waves for the purpose of nondestructive testing is mainly based on Piezo-Electric Principles.

4.2 Piezo Electric Generators

There are certain crystals in nature, which have a peculiar property of developing opposite electric charges on their two faces, on application of mechanical compression or tension. The amount of developed charges depends upon the amount of applied tension/compression. Similarly these crystals convert electrical energy into mechanical energy. This property of such crystals is known as Piezo (synonym for pressure) electric property and therefore, these crystals are named as Piezo Electric crystals.

The Piezo Electric Crystals are of two types.

(a) Natural Crystals

(b) Artificial Crystals

Quartz and Tourmaline are the examples of natural crystals while Barium Titanate, Lead Zirconate Titanate (PZT), Lithium Sulphate etc. are the examples of artificial crystals. PZT is the genrally used in the transducers for ultrasonic testing.

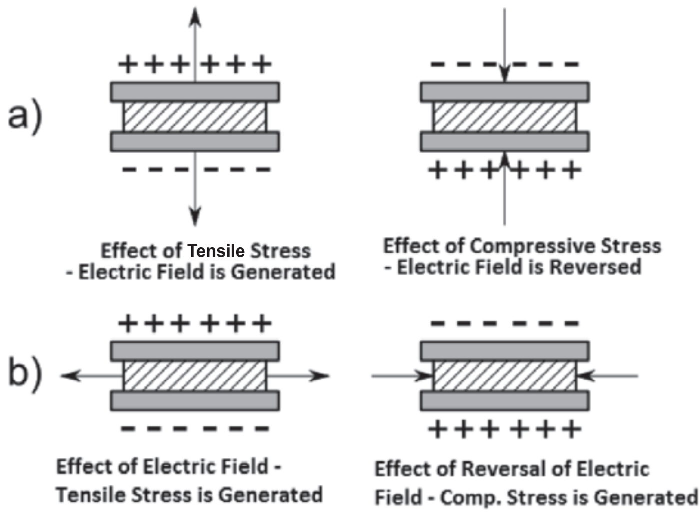


Fig. 4.1 – Piezo-Electric Effect

For producing ultrasonic waves, we apply certain potential difference at an alternating frequency, reversing the nature of potential difference, which creates the compressive and tensile strains in the crystal and makes it to vibrate at quite a large frequency depending upon the thickness and the elastic properties of the material of the crystal. These high frequency ultrasonic waves pass through the material being tested. After returning from the boundary between two dissimilar materials or a reflector (such as flaw) these waves are received back by the crystal and the crystal converts these mechanical waves into electric energy. Thus we give some potential difference to the crystal and measure the potential difference on return.

The frequency of vibration of the crystal is inversely proportional to the thickness of the crystal and because of various limitations; a workable range of 100 KHz to 15 MHz can be produced using Piezo-Electric Crystal.

4.3 Probe or Transducer

The vibrations of the crystals are directly transmitted to the medium in the form of ultrasonic waves. These crystals are mounted in housing with suitable damping material and this entire assembly with metallic housing is known as a PROBE or a TRANSDUCER. The crystal can transmit the ultrasonic waves and receive them back.

Probes can be single crystal or double crystal. In single crystal probe, same crystal is used as transmitter as well as receiver while in double crystal probe, there are two crystals – one works as a transmitter and the other as a receiver. Both the crystals in double crystal probes are exactly identical and any one of them can be used as a transmitter or a receiver. 0° probe is double crystal probe while all other angular probes used in testing of rails and welds are single crystal probes.

Depending upon the angle at which the waves are transmitted into the test specimen, the probes are classified as below.

4.3.1 Normal Probe

This probe generates longitudinal waves and transmits them into the specimen at zero angle of incidence, i.e. normal to the plane of application. The frequency of this probe is 4 MHz for rail testing and 2MHz for hand testing of AT welds. These are double crystal probes.

4.3.2 Angular Probes

These Probes transmit waves in the specimen, at a pre-decided angle. The angle of incidence is so designed so as to cause the transmitted wave in steel to travel at a particular angle. For that purpose the Perspex Wedge is used and the crystal is glued to the wedge, so that it generates waves to fall on the foot of the wedge at an angle. All angular probes used for rail/weld testing are 2 MHz frequency.

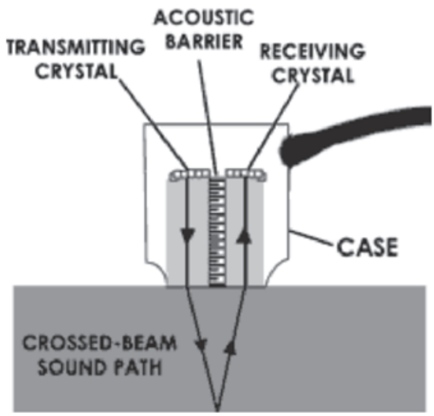


Fig. 4.2 – Normal Probe

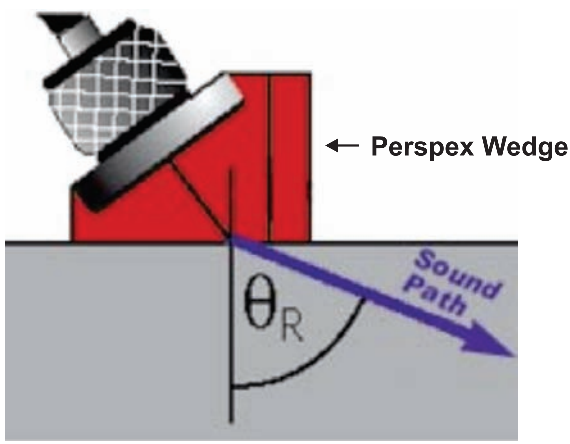


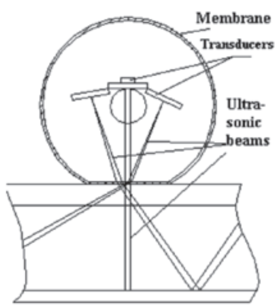
Fig. 4.3 – Angular Probe

4.4 Sliding Probes and Wheel Probes

There are primarily two technologies available for testing namely wheel probe and sliding probes. A brief comparison of the two technologies is presented below:

4.4.1 Wheel Probes

In the wheel probes, membrane of polyurethane filled with fluid is used. The transducers are mounted within the probe wheel. The structure of a wheel probe is shown below:



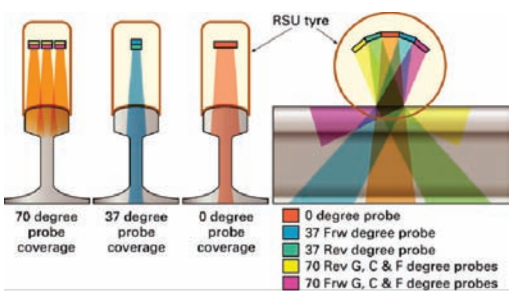


Fig. 4.4 – Structure of a Wheel Probe

4.4.2 Sliding Probes

It is the oldest technology used in the rail mounted rail testing cars in which the various transducers are mounted on a probe beam which slides over the rail surface while testing of rails.

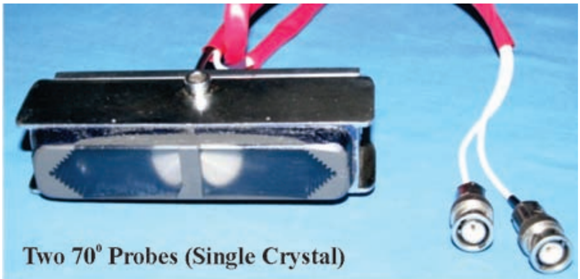


Fig. 4.5 - Sliding Probes

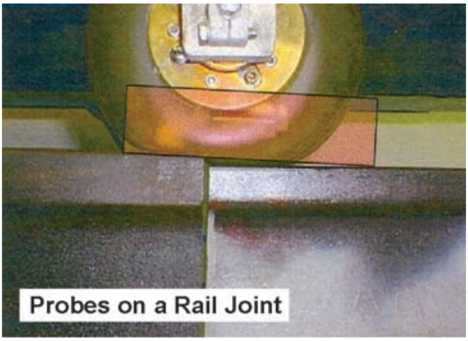
Thus the basic difference between the sliding probes and wheel probes is in the method of mounting of transducers for rail testing although the technology used for testing is similar. The comparison between these two techlogies is presented in table 4.1.

Table 4.1 – Comparison of Sliding & Wheel Probes

S.No.	Parameter	Sliding Probes	Wheel Probes
1	Construction	Transducers are mounted on a probe beam sliding over the rail top while testing.	Transducers are mounted within the probe wheel and the probes wheel roll on the rail top while testing.
2	Wear and tear of probe shoe	Due to direct sliding of probe on the rail, there is abrasion and the wear	Since there is no direct contact between probe and rail surface,

		of the material of the probe shoe. In worst cases, this may result in change in the effective angle of the probe.	the wear is limited to tire, which is also substantially low as compared to the sliding probes due to rolling action.
3	Acoustic Coupling	Due to rigidity, these probes may often loose contact with the rails in case of irregular rails surface, on rails joints and on poorly maint-ained tracks. Thus it is difficult to have reliable testing on rail joints.	Being flexible, these probes are able to negotiate the irregularities on the rail surface better and thus have better contact with the rail surface as compared to sliding probes. The testing on rail joints will be more reliable than sliding probes arrangement.
4	Requirement of couplant	Water is used as couplant and the water requirement is high ne-cessitating larger water tank capacity on board.	Water is used as couplant but the quantity of water required is much smaller as compared to sliding probes.
5	Defect Detection Pitch	Since the ultrasonic waves are generated near the rail, ultrasonic waves can be sent to rails immediately and next ultrasonic wave can be sent in a short time consequently comparatively smaller defect detection pitch can be achieved.	Since it takes long time for ultrasonic waves to penetrate in to the liquid in the tire, a long time is required to send the next ultrasonic wave, the defect detection pitch cannot be reduced without compromising speed of testing.
6	Speed of testing	Speed of testing on well maintained track is claimed to be high i.e. in the range of 80 – 100 kmph.	The speed of testing is limited to 40 – 50 kmph on well maintained track.
7	Cost	Structure of the probe	Structure of the probe and

		and its mounting arrangement is simple, thus it is less costly as compared to wheel probe.	its mounting arrangement is complicated, thus it is costly as compared to sliding probes.
8	Repair	Damage to probe mounting arrangement can be fixed quickly.	Damage to a tire cannot be fixed quickly.
9	Signal Attenuation	Since the distance traveled by ultrasonic rails to reach up to rail top is less, there is less attenuation of energy.	There is more attenuation since ultrasonic rails penetrate rubber tire.



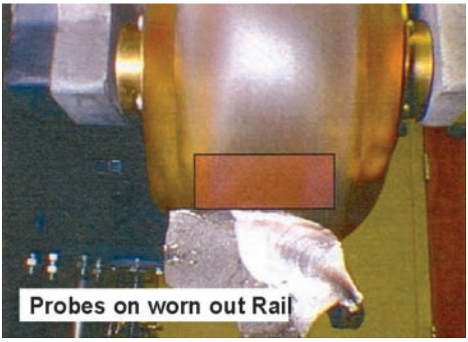


Fig. 4.6 – Negotiation of Wheel and Sliding Probes

4.5 Ultrasonic Rail Tester

A beginning of ultrasonic testing of rails on Indian Railways was made in early 1960s. The ultrasonic testers were procured from M/S KRAUTKRAMMER, West Germany. In 1974 ECIL developed the indigenous model which incorporated 37^0 probe in addition to 0^0 and 70^0 probes being used earlier. Of late few more manufacturers are in the field of manufacturing of the ultrasonic rail testers in India. The testing equipments are to be purchased only from the firms approved by RDSO. The list is available on RDSO website under 'Master list of approved vendors' circulated bi-annually by Quality Assurance (Mechanical) Directorate of RDSO.

4.5.1 Testing Equipments

On Indian railways USFD testing of rails is carried out using -

(a) Single Rail Tester (SRT) for through testing of rails & welds

(b) Double Rail Tester (DRT) for through testing of rails & welds

(c) Hand Testers for Weld testing

(d) Self Propelled Ultrasonic Rail Testing (SPURT) Car or Vehicle based Ultrasonic systems

Presently SRTs, DRTs and hand testers are being used for testing on Indian Railways but no SPURT car or vehicular based testing system is available. Indian Railway procured a SPURT car from M/S Matix, France in 1987. The car was self propelled and used to test the rails at 30kmph. However the over-reporting of defects by car was very high and hence it was not well accepted in the field. The car was condemned in 2003 after its service life was over. Efforts are on to reintroduce vehicular testing of rails and welds.

Fig. 4.7 – Single Rail Tester

Fig. 4.8 – Double Rail Tester

As per the current specifications, all new equipments being procured will be digital type having the facility of storing the signal pattern in the machine and downloading the same onto a computer. Procurement of USFD equipments are to be done only from the RDSO approved sources (as per latest list available on RDSO website). Maintenance spares are also to be procured along with machine from original equipment manufacturer. The codal life of USFD machine is eight years. However, the replacement of the equipment is done on condition basis. SRT is capable of Testing only one rail at a time while DRT can test both the rails of track simultaneously.

Both type of machines are provided with 7 probes for each rail

(i) 0° Normal (4 MHz)

(ii) 70° Center Forward (C F) (2 MHz)

(iii) 70° Center Backward (C B) (2MHz)

(iv) 70° Gauge Face Forward (G F) (2 MHz)

(v) 70° Gauge Face Backward (G B) (2MHz)

(vi) 70° Non-gauge Face Forward (NG F) (2 MHz)

(vii) 70° Non-gauge Face Backward (NG B) (2MHz)

Here 'B' stands for Backward, 'F' for Forward, 'G' for Gauge face side and 'NG' for non-gauge face side.

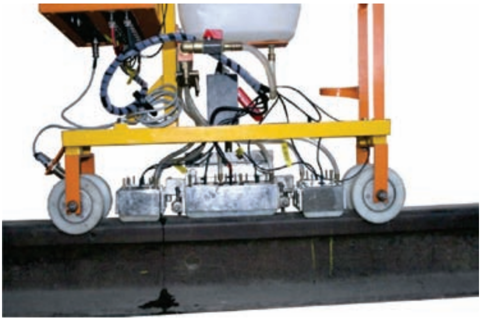


Fig. 4.9 – SRT Fitted with Probes

Normal probe (0°) is utilized for detecting horizontal defects situated in head, web or foot of rail and also bolt-hole cracks. Longitudinal vertical flaw is also detected using normal probe by side probing (to be done manually in case of doubt) or by scanning from top when the flaw has grown to sufficient size. 70° probe has been specifically provided for detecting defects in rail head, the most typical of which is the transverse fissure or kidney fracture. 70° GAUGE face probe is used to detect kidney defects originating from gauge face corner (GFC). Similarly, 70° NON-GAUGE face probe is used to detect transverse flaws originating from field side.

In the event of a bolt-hole crack, back echo shows reduction in amplitude even after passage of bolt-hole leading to detection of bolt-hole cracks. Thus the equipment works on the principle of back wall drop. It is also supported by separate audio alarm with distinctly different tone and LED display.

It is desirable to deploy DRT on LWR track only due to frequent misalignment of probes on fish plated track.

4.5.2 'B' Scan Type USFD machines

RDSO has issued specifications for Digital Ultrasonic Rail tester with coloured signals and Real A-Scan with continuous recordings of B-Scan storage facility. 'B' Scan display is the presentation of flaw in the cross section of test specimen. It is constructed from a series of A-Scan displays to indicate the location of the reflection in the test specimen. It makes the appreciation of the flaw, its location in the rail longitudinally as well as vertically convenient. A real time display of the reflections received from various probes is available to the operator while testing and in offline mode also to the user in the office. One can appreciate defect shape and size also with B Scan image.

The equipment will have facility to record A-Scan defect echo envelope in real time along with data setups as and when required by the operator and continuous B-Scan recording for different sliding/ wheel probes fitted on the trolley. The equipment shall be capable to display A-Scan and B-Scan simultaneously during single run of rail testing. The equipment shall be capable to display 7 different colours for signals/echoes of A-Scan and B-Scan for each of the 7 probes provided on the trolley. The equipment can record 200 nos. real time A-Scan defect echo envelope as and when required by the operator. The equipment can record continuous B-Scan of minimum 50 kms rail length corresponding to A-Scan echo crossing particular threshold value set by the operator.

The equipment shall also give the location stamping km/m/cm by digital encoder (odometer) and GPS (latitude and longitude) recordings. The stamping of time in synchronization with the satellite clock shall also be given.

The equipment shall have the facility of Offline re-creation of A-Scan echo envelope display from recorded B-Scan. The data can be downloaded to a USB drive directly.

4.5.3 Probes Used for Through Testing on Trolley

The probes used for testing of rails and welds by trolley are given in table 4.2.

Table 4.2 – Probes Used on Trolley

Probe Type	Frequency	No. of probes
Normal/ 0^0	4 MHz	One
70^0 Center	2 MHz	Two
70^0 Gauge Face	2 MHz	Two
70^0 Non-gauge Face	2 MHz	Two

4.5.4 Probes Used for Hand Testing of AT Welds

Probes used for Hand Testing of AT Welds are given in table 4.3.

Table 4.3 - Probes Used for Hand Testing of AT Welds

Probe Type	Frequency	No. of probes
Normal/ 0^0	2 MHz	One
70^0	2 MHz	One
45^0	2 MHz	One
70^0 SL (20^0 Side Looking)	2 MHz	Two (in pair)

It may be noted that during hand testing of welds, normal probe used is 2MHz frequency to compensate the enhanced losses due to larger grain size of weld as compared to rail. A Side looking probe is the one in which the crystal is rotated by 20^0 in horizontal plane.

In addition to this, 2 nos 45^0 2 MHz probes are used in tandem for detection of lack of fusion in AT welds. A test rig with two 45^0 Probes is used for detection of transverse flaws in rail head when rail top surface is having wheel burns or scabs.

4.6 Area Covered by Different Probes

The area of the rail covered by normal probe is indicated in Fig. 4.10 and that by angular probes is indicated in Fig. 4.11(a) & 4.11(b).

There is a dead zone of about 4mm from the rail top during scanning by normal probe since any defect echo coming from this region will get merged with the surface echo and the defect will not be detected.

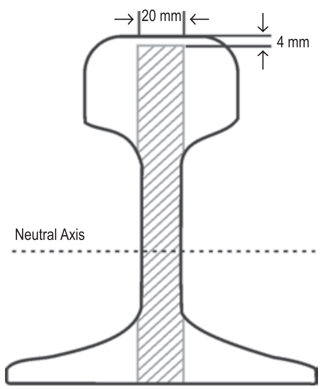


Fig. 4.10 – Area Covered by Normal (0^0) Probe

(For AT welds area below neutral axis remains untested)

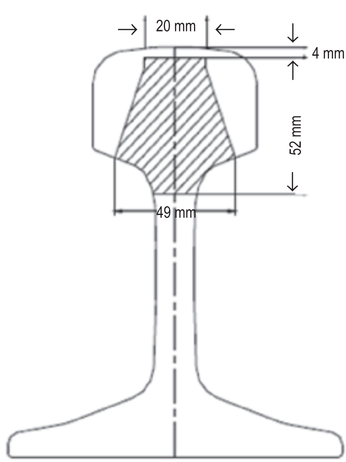


Fig. 4.11(a) – Area Covered by 70^0 Central Probe

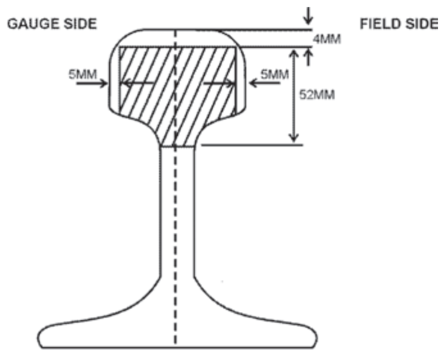


Fig. 4.11(b) – Area Covered by 70⁰ Probes in Equipment with Gauge Face Corner, Central and Field Corner Probes

During hand testing of AT weld, we use 70^0 2MHz probe for scanning rail flange. The area covered by this probe is shown in Fig. 4.12.

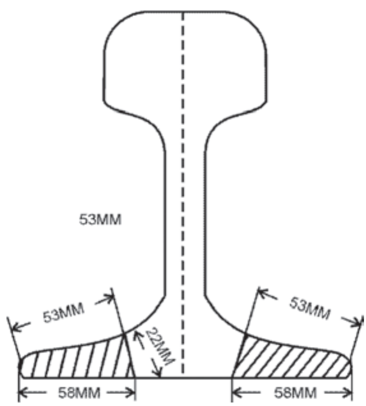


Fig 4.12

The signal received from the defects by any of the probes is indicated on the cathode ray tube (CRT) screen or LCD Screen provided on the equipment. A photograph of CRT screen is shown in Fig. 4.13. Photograph of LCD screen of a rail tester is shown in Fig. 4.14. In order to find out the origin of detection i.e. which probe has picked up the defect, provision for displaying the individual probe operation along with audio alarm/LED display has been made in the testing equipment.

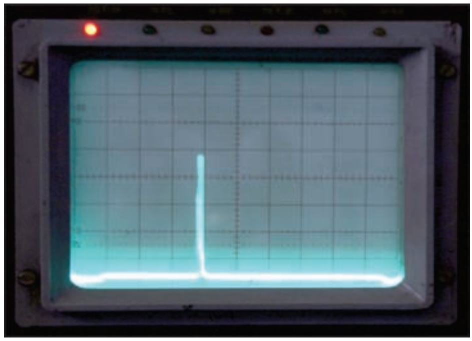


Fig. 4.13 – CRT Screen of a Rail Tester

Fig. 4.14 – LED Screen of a Rail Tester

Due to frequent misalignment of probes on the fish plated joints and limitations of detection of bolt hole cracks having unfavourable orientation and size, it is desirable to deploy only SRT for testing of the section other than LWR/CWR. DRT is having the advantage of giving higher progress and is to be deployed on LWR sections.

SRT is also useful for testing on curves with wider gauge and rails with high lateral wear.

Inspectors carrying out the ultrasonic testing of rails shall be trained by RDSO.

4.7 Maintenance and Repairs of Equipment

It is advisable to have AMC with the manufacturer of the equipment for its repair and maintenance after the guarantee period. The Railways should also develop departmental facilities for this purpose. Each Zonal Railway should create centralised depots for carrying out mechanical repairs and checking the characteristics of the equipment.

Characteristics of Ultrasonic Flaw Detection Equipment

The testing of the defects by ultrasonic equipment and transducers will be reliable only when the equipments are functioning properly. To check the proper functioning of the equipments, the characteristics of the equipment is checked at least once in a month as per the procedure given is IS:12666-1988. These characteristics are:

i) Linearity of time base of flaw detector

ii) Linearity of Amplification of flaw detector

iii) Penetrative power

iv) Resolving power

v) Probe Index

vi) Beam angle

In a month all parameters shall be checked with 0^0/2-2.5 MHz single crystal probe, as per IS:12666-88 or its latest version. The reader is advised to go through the IS code for detailed provisions in this respect.

In addition to this dead zone for the probe is also to be checked at the time of procurement.

■ ■ ■

CHAPTER 5

TESTING PROCEDURE AND FLAW MARKING

5.1 General Procedure for Flaw Detection

The principle used for detection of flaws using ultrasonic waves is simple. Ultrasonic wave (in fact, it is a beam) is sent into the material and the wave travels till it comes across a boundary with dissimilar material. The dissimilar material could be a flaw or the slag in AT weld or the edge of the rail. The ultrasonic energy gets reflected from this boundary. The amount of reflected energy will depend upon the acoustic impedances of the media on the two sides of the boundary and the direction of reflection will depend upon the angle of incidence of the beam. If the boundary is oriented in a way that it reflects the wave towards the probe, the probe senses the time taken and the amount of the reflected energy. This is seen as a signal on the CRT screen of the machine. The machine monitors the time taken by the ultrasonic wave from entry into the rail to coming back and the amount of the energy received back by the probe (this mechanical energy is converted into electric energy by the piezo-electric crystal in the probe). Thus, the machine sends a pulse and monitors the echo. Hence this technique is known as **'Pulse Echo Technique'.**

The horizontal axis of the screen is calibrated for the time taken by the ultrasonic wave from entering the rail to coming back after hitting a reflector in the rail which could be either the bottom of the rail (referred as backwall echo) or the defect in the rail (referred as defect echo). Since the velocity of the wave in the rail is known, we can get the distance from where the signal is received back. Thus we can get the location of the defect, if any, in the rail. This is explained in the diagram given below. Let us take a normal probe for simplicity. Time taken by the wave (T) to enter till coming back will be 2H/v, where H is the height of the rail and v is the velocity of the wave. So we get the reflected energy in the form of a signal after time 'T'. This signal is known as 'Backwall Echo'.

In case there is a horizontal defect at depth h from rail table, time taken will be t = 2h/v (Fig. 5.1(a)). Obviously, t < T. So if we get the reflected energy i.e. a signal at a time t < T, then there is a defect in the rail. Lesser the value of t, the smaller is the distance traveled and hence, the smaller is the distance of the defect from rail top. This signal from the defect is known as 'Defect Echo'.

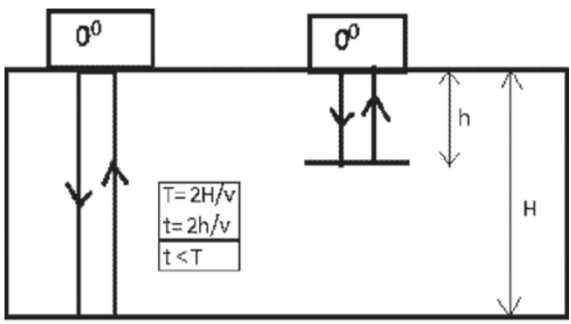


Fig. 5.1(a) – Flaw Detection Using 0^0 Probe

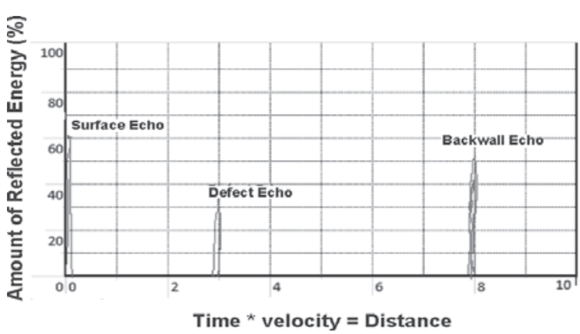


Fig. 5.1(b) – Signal Pattern on CRT Screen

The vertical axis of the screen is calibrated for the amount of the energy reflected by the defect in the rail. The bigger the discontinuity or the defect, the more will be the amount of the energy reflected. Thus by seeing the height of the signal received, we can estimate the severity of the defect. The signal pattern received by a horizontal flaw is shown in Fig. 5.1(b). We need to calibrate the machine before testing of rails. Let us now understand the procedure for the calibration of the machine.

5.2 Visual Inspection of USFD machine

The USFD operator needs to inspect the machine every day before start of the work to ensure that the various components of the machine are in working condition so as to have a trouble free testing. The items to be checked daily are given in Annexure – 'A'.

5.3 Calibration of the USFD Machine

As brought out earlier, in ultrasonic testing technique, time for the wave from entering the test piece till return is monitored. This is presented on the x-axis of the CRT monitor. The procedure for setting the x-axis for monitoring the time (converted to distance) is known as 'calibration'. The machine can monitor the time and not the distance. But for the user, distance of the reflector from the starting of the wave makes more sense than time. So the actual monitoring is done for the time and we convert it to distance during calibration process by multiplying the time with the velocity.

There are two types of the machines in use on Indian Railways - the analogue type and the digital type. As per the current specifications of USFD machine issued by RDSO, only digital testers are to be procured. So the analogue testers are on their way out but are still in use. The digital testers are easier to use and are capable of storing the signal pattern on the machine which can later be downloaded to a computer. We will understand the procedure of calibration for the analogue tester first. The calibration of digital tester is much simpler.

5.3.1 Calibration of Analogue Testing Equipment

In analogue tester, the calibration of the equipment is done using a steel block of size 50x50x60mm for through testing of rails and welds. As per USFD manual, x-axis is to be calibrated for 300mm distance for longitudinal waves. Fig. 5.2(b) shows the monitor of equipment. X-axis as well as Y-axis is divided in 10 divisions.

When we connect the normal probe to the machine, we start getting an echo on the screen. This is the machine echo. If we touch the probe with our finger, we can see this echo flickering. Now keep the normal probe on steel block as shown in Fig. 5.2(a). Whenever we are doing calibration or testing, it is understood that couplant is being used since without couplant there will be no signals.

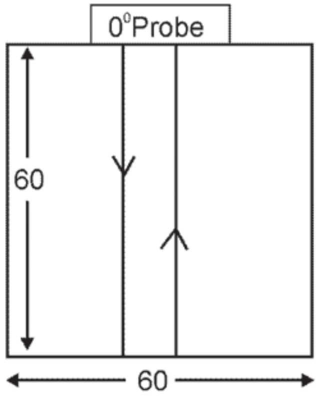


Fig. 5.2(a) – Calibration Block

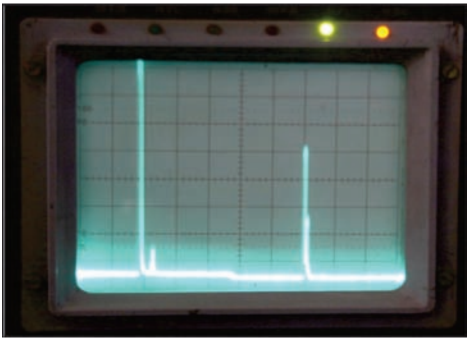


Fig. 5.2(b) – Signal Pattern for Calibration Block

Two more signals will appear on the screen. One echo is coming from the top of the block known as 'Surface Echo' and the other from the bottom of the block known as 'Backwall Echo'. Since the machine has not been calibrated yet, these echoes will appear randomly on the screen. The signal pattern may be as shown in Fig. 5.2(b) (or some other random pattern).

The distance between these echoes is the distance covered by the longitudinal wave from entering the block till coming back after reflection from the bottom of the block. This distance is 120mm since height of the block is 60mm. The manufacturer of the machine has built in a factor of 2 in the machine so that we need not count two paths for the wave i.e. for going to the reflector and coming back. This has been done for the simplicity to avoid the division by 2 every time to get the distance of the reflector from the rail surface. So instead of taking the distance between the echoes as 120mm, we will consider it only 60mm. Now there are 10 divisions on the x-axis of the machine and x-axis is to be calibrated for 300mm. it means that 10 divisions of the machine should represent 300mm i.e. each division should represent 30mm distance. The surface echo should come at '0' division as this is the starting point for entering the wave into the block. 60mm height of the block should be represented by 2 divisions i.e. distance between surface echo and backwall echo should be 2 divisions.

To bring the surface echo to '0' division, we use a control switch in the machine known as 'Delay control'. By operating this switch, the whole echo pattern moves on the x-axis either to the left or to the right. So we bring the surface echo at '0' by using the delay control. The signal pattern will now be as shown in Fig. 5.3.

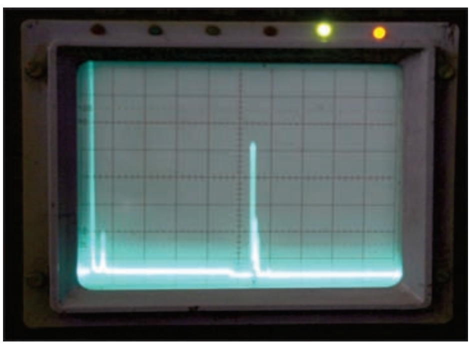


Fig. 5.3 – Signal Pattern with Surface Echo at 0 Division

Now we have to bring the backwall echo at 2nd division. For this we use 'Range control switch' in the machine. By operating the range control, the distance between the surface echo and the backwall echo changes. But in the process, the surface echo also gets disturbed from its '0' position. So we have to operate the 'Delay' and the 'Range' switches simultaneously so that the distance between the two echoes is changed to 2 divisions and at the same time, the surface echo is at ‘0’ division. The signal pattern after calibration would be as shown in Fig. 5.4.

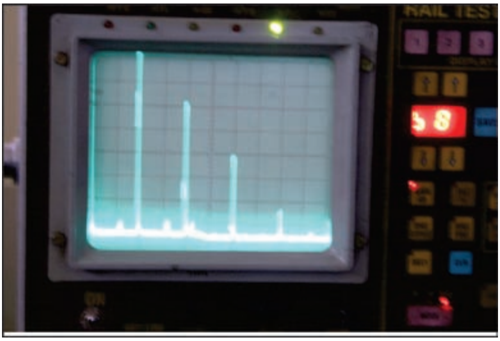
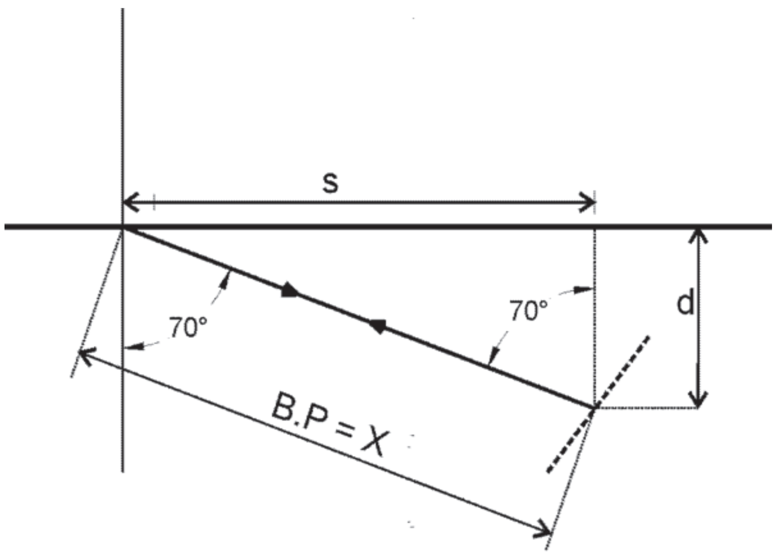


Fig. 5.4 – Signal Pattern with Backwall Echo at 2nd Division

In this position, the surface echo is at ‘0’, which is the starting point w.r.t. the top of the block. The backwall echo is at 2nd division. The distance between the two echoes i.e. 2 divisions is representing the height of the block i.e. 60mm. Hence 10 divisions of the machine are now representing 300mm. In fact, we will find that along with the backwall echo at 2nd division, we also get few more echoes appearing at 4th, 6th, 8th & 10th divisions as seen in Fig. 5.4. These are the multiples of the backwall echo. These appear due to the continuous reflection of energy from the top of the block, once the backwall echo reaches at the top of block. The reflected energy will again go to the bottom of block and get reflected from there to be received at the top by the probe producing another echo (the probe picks up the refracted energy from the top surface) at 4th division. Since the distance travelled by the wave is same, the echo will appear at an interval of 2 divisions. This process continues till the reflected energy becomes very feeble. It may also be noted that the heights of these multiple echoes go on reducing due to lesser and lesser energy being available after reflection and refraction from the top surface.

Since we have used normal probe for calibration, the time taken by the wave corresponds to longitudinal wave velocity. If we now keep the normal probe on a 52 kg rail (height 156mm), the backwall echo from the rail will appear at little away from 5th division. If we use the same calibration setting for an angular probe, which uses transverse wave for testing instead of longitudinal wave, the time taken by the transverse wave will be almost double (1.82 times to be exact) to cover the same distance in comparison to longitudinal waves. Thus the echo corresponding to 60mm distance covered by transverse wave will not appear at 2nd division but near 4th division (2*1.82 i.e. 3.6th division to be precise). This is the reason that we calibrate the machine for 300mm for the longitudinal wave in spite of the maximum rail height being only 172mm for 60kg rail in use on IR. 300mm distance for longitudinal wave will translate to 300/1.82 i.e. 164mm for transverse wave. This is due to the lesser velocity of transverse wave and consequently more time required to cover the same distance. To get the depth of flaw from rail top, we have to use simple trigonometry ($d = x * \cos 70^0$ as per Fig. 5.5). Corresponding to 164 mm beam path, depth will be $164 \cos 70^0$ i.e. 55mm. This is almost the same as the height of rail head. Therefore, 70^0 probe will detect the transverse defects only in rail head with this calibration settings.



$$d = x \cos 70^0$$
$$s = x \sin 70^0$$

Fig. 5.5 – Beam Path for Angular Probe

IIW V1 Block

This is a standard steel block as shown in Fig. 5.6 below. This block is used for calibration of digital rail tester and for checking the characteristics of USFD equipment.

Fig. 5.6 – Standard V1 Block

GATE

GATE is a threshold limit of certain signal height set within a particular rail depth as shown in Fig. 5.7 below. The details of any signal crossing the gate will be displayed on the screen of the machine.

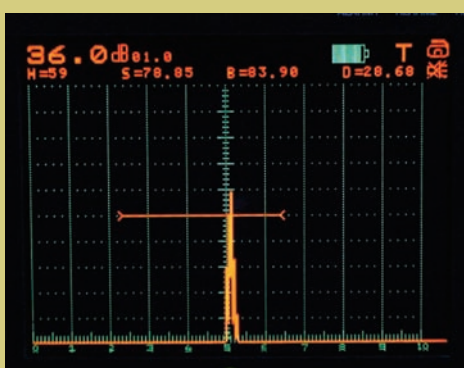


Fig. 5.7 – CRT Screen with a Gate

In this Figure, 'H' is the **Height**

'S' is the **Surface Distance**

'B' is the **Beam Path**

& 'D' is the **Depth**

5.3.2 Calibration of the Digital Equipment

The range calibration in digital SRT/DRT with multiplexure/ multichannel unit is to be undertaken as follows:

5.3.2.1 Calibration for 300 / 200 mm Longitudinal Wave using 0° Double Crystal Probe

i) Connect the 0° / 4 MHz Double Crystal probe to requisite channel given in multiplexure or in the unit itself.

ii) Select Mode T-R i.e. Double Crystal/Multichannel mode in Rail Tester having multiplexure. For multichannel unit, select the calibration set which is required to calibrate.

iii) Feed the required range i.e. 300mm for rail tester having multiplexure/ 200mm for multichannel rail tester.

iv) Put 0°Double Crystal probe on IIW(V1) Block after applying couplant at 100 mm width side.

v) Set Delay and Probe Zero (in unit having multiplexure) as per operational manual.

vi) Set first reflected peak at 3.3 div (if range is selected 300 mm) or at 5.0 (if range is selected 200 mm) using delay key provided in multiplexure or DELAY parameter provided in multichannel unit. Place Gate over it. Press measure 0 (in unit having multiplexure) and read the beam path, depth shall be 100 mm.

vii) Second reflected peak will appear at 6.7 & third peak at 10.0 (if range is selected 300 mm) or second peak at 10.0 (if range is selected 200 mm).

viii) If last peak is not at 10.0, velocity may be adjusted to set the last peak at 10.0 (if velocity control available) or by delay key on multiplexure.

ix) The equipment is calibrated for 300 /200mm longitudinal wave for 0° Double Crystal probe.

x) To verify the calibration put probe on top of rail head, the backwall peak position will be at 5.2 for 52 Kg. rail (Fig. 5.8) & at 5.7 for 60 Kg. rail (if range is selected 300 mm) or at 7.8 for 52Kg. rail & at 8.6 for 60 Kg. rail (if range is selected 200 mm).

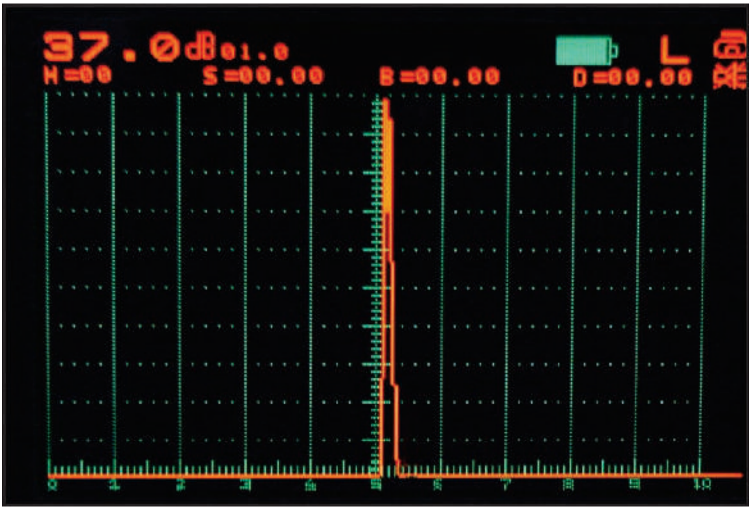


Fig. 5.8 – Back Wall Echo From 52 kg Rail With 300 mm Calibration

5.3.2.2 165 mm Direct Shear Wave Calibration for 70°/2 MHz Single Crystal Probe

i) Connect the 70°/ 2 MHz Single Crystal probe to requisite channel given in multiplexure or in the multichannel unit itself.

ii) Select Mode T-R i.e. Double Crystal mode for rail tester having multiplexure. For multichannel equipment, select the calibration set and channel required to calibrate.

iii) Feed range 300 mm for rail tester having multiplexure or 165 mm SW for multichannel unit.

iv) Set Delay and Probe Zero (in unit having multiplexure) as per operational manual.

v) Put 70°/2 MHz Single Crystal probe on IIW (V1) Block after applying couplant and direct the beam towards 100 mm curvature.

vi) Move the probe slightly to and fro to get maximum signal.

vii) Adjust the peak at 6.0 using delay key provided in multiplexure or DELAY parameter provided in multichannel unit.

viii) Place the gate over this peak, press measure 70 (in unit having multiplexure) and read the beam path. It shall be 100 mm.

ix) To verify the calibration, Direct the probe towards 25 mm curvature and maximize the peak.

x) Put the gate on this peak, the beam path shall be 25 mm.

xi) The equipment is calibrated for 165 mm shear wave.

Thus the digital equipment is calibrated for longitudinal as well as shear waves separately. We can directly get the beam path and the depth of the flaw with this equipment and no field calculations are necessary.

As per the current provisions of USFD manual, **the calibration is to be checked weekly by the operator.**

5.4 Sensitivity Setting

On y-axis of CRT screen, we monitor the intensity of the reflected energy received back by the probe. The process of calibration of 'Y' axis for reflected energy is called sensitivity setting.The more the energy received, the bigger is the flaw. This can be understood with the help of Fig. 5.9. In probe there is a crystal having some size. The crystal sends a beam of ultrasonic waves. Let us again take the case of a normal probe for simplicity. This beam will go unobstructed to the bottom of rail, if there is no defect and backwall echo of sufficient height is seen on the screen depending upon the gain used (Fig. 5.9(b)). In case there is a small defect, part beam will be obstructed by the defect resulting in lowering of backwall signal and generation of a defect echo as shown in Fig. 5.9(c). The bigger the defect, the more will be the energy obstructed by the flaw and hence bigger will be the defect echo. Thus the signal height of defect echo indirectly represents the relative sizes of the defects. In case the defect is big enough to block all the energy coming from the probe, a higher defect echo and no backwall echo (since no energy reaches to the bottom of the rail) is obtained. This is shown in Fig. 5.9(d).

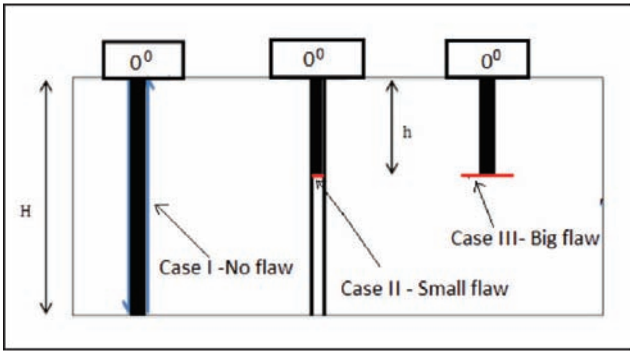


Fig. 5.9 (a) – Block with no Flaw, Small Flaw and Big Flaw

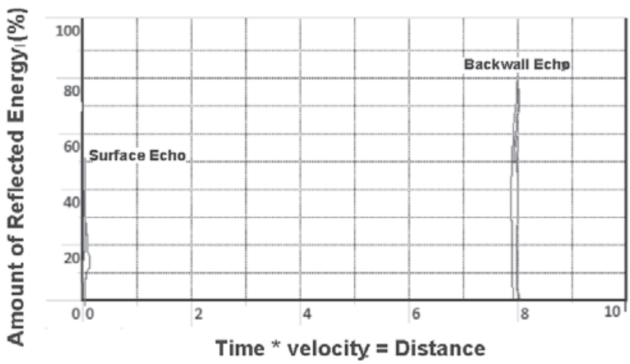


Fig. 5.9 (b) – Signal Pattern for no Flaw

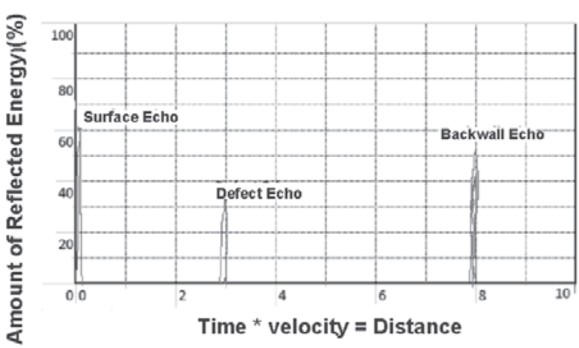


Fig. 5.9 (c) – Signal Pattern for Small Flaw

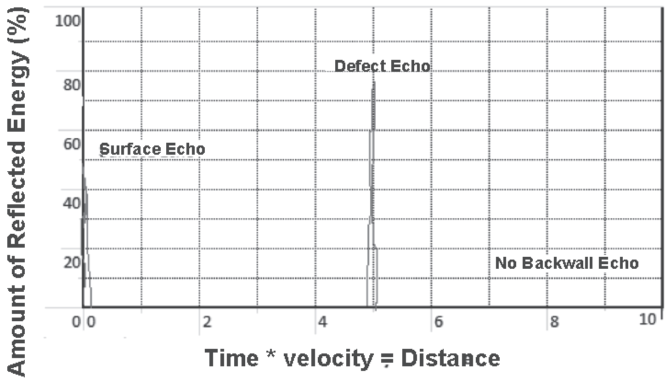


Fig. 5.9 (d) – Signal Pattern for Big Flaw

Since different defects are detectable by different types of probes, the sensitivity setting is carried out for each probe separately. For sensitivity setting of probes, simulated flaws of pre-decided sizes are created in a reference test rail piece. The signal heights with respect to these standard simulated flaws, is set to a level as given in USFD manual. The signal height is adjusted using the gain control switch in the machine. As an example let's assume that it is 60% of the screen height for a particular probe. Now with this sensitivity setting, the probe during testing in the field shows a signal of 80% height at a location. It means that the defect in the field at this location is bigger than the simulated defect. If the signal height is 30% then the defect in the field is smaller than the one created in the rail. Thus during testing, we come to know the size of the available defects with respect to those created in the standard test piece. Thus we do not get the absolute size of the flaw during testing.

As mentioned earlier, the sensitivity setting for each probe is to be done separately.

5.4.1 Sensitivity Setting for 0^0 Probe

For sensitivity setting of 0^0 probe, no simulated defect is created in the rail since the backwall is available for setting the signal height in this case. The normal probe is kept over the rail to be tested (i.e. 52kg or 60kg) and the acoustic barrier of the normal probe is set at right angle to the longitudinal direction of rail. The height of the backwall is adjusted to 100% of the screen height using the gain control (Fig. 5.10) and this is used as a reference for flaw marking.

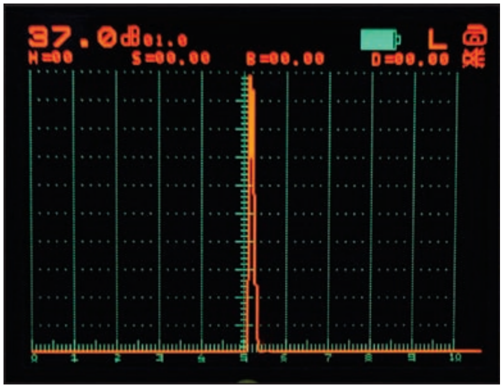
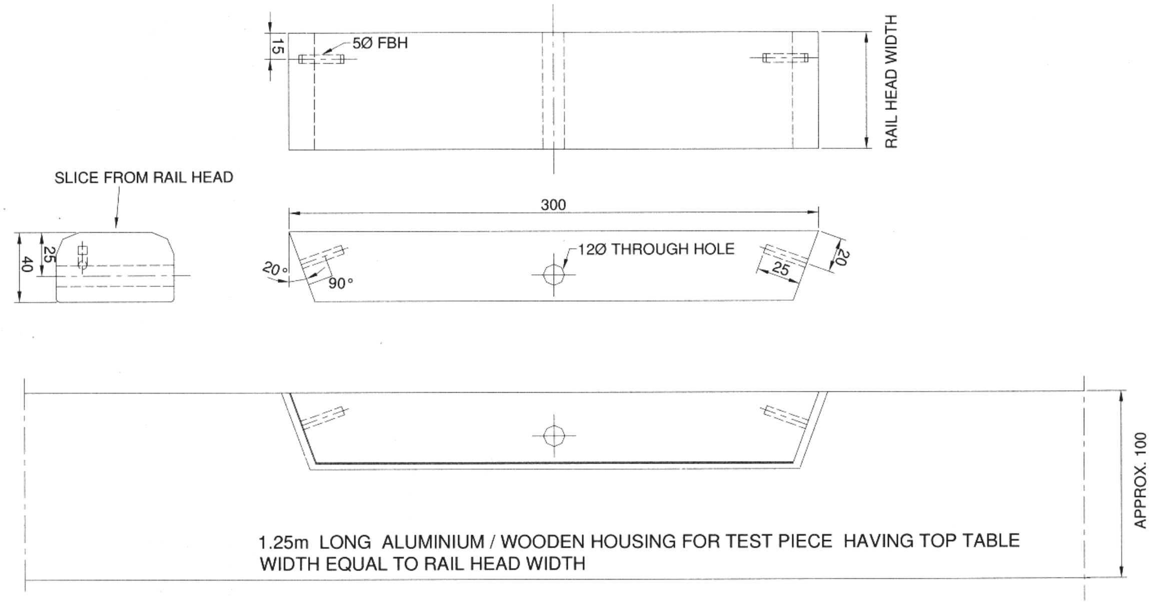


Fig. 5.10 – Sensitivity Setting for 0^0 Probe

5.4.2 Sensitivity Setting for 70^0 Central Probes

For sensitivity setting of 70^0 probes, a standard test piece as shown in the Fig. 5.11 is used.

This is a 300mm length rail piece having only the rail head. A 12mm dia hole is drilled at the centre of this piece at a depth of 25mm from rail top. This 12ϕ hole is used for sensitivity setting of 70^0 central probes. 70^0 central probe is kept on rail top directing the beam towards the hole. An echo is seen on the screen. The probe is moved to and fro to get the maximum height of the echo. Now the echo height is adjusted to 60% of the screen height using the gain control (Fig. 5.12). The process is repeated for both 70^0 central forward and backward probes.



1. The slice from rail head for sensitivity setting shall be from rail of same sectional weight which is to be tested (i.e. for testing on 60Kg/52Kg, 90R rails etc. the sensitivity testing piece shall be from 60Kg, 52Kg, 90R rails respectively).
2. In case of machines having provision of variable shift of gauge face probes following shall be ensured:

a) Maximum shift of probe shall be limited to the extant up to which there is no loss of acoustic coupling depending on rail top profile.
b) The sensitivity setting shall be done at the shift level with which actual testing is to be carried out.
c) The shift of probe shall not be altered during testing without fresh setting at altered shift .

Fig. 5.11- Sensitivity Setting Block for 70^0 2MHz (Centre and Gauge Face) Probes

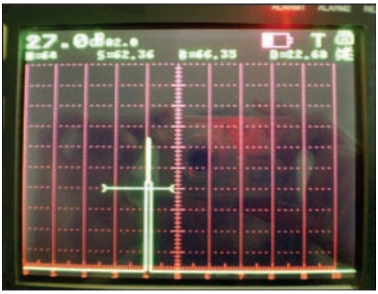


Fig. 5.12 – Sensitivity Setting for 70^0 Central Probe

5.4.3 Sensitivity Setting for 70^0 GF & NGF Probes

For sensitivity setting of 70^0 shifted probes i.e. GF & NGF, Forward & Backward probes, 5ϕ Flat Bottom Holes (FBH) at the ends of the test piece are used (Fig. 5.11). The test piece ends are cut at an angle of 20^0 from the vertical and then the holes are drilled. The holes are also not the ordinary holes made using a simple drill bit but they are Flat Bottom Hole (FBH) created using a special Electric Discharge Machine (EDM). This special arrangement is required to ensure that the beam from 70^0 probe falls normal to the surface of the hole (and not on a curved surface created by a normal drill bit). The 70^0 shifted probe is kept on rail top directing the beam towards the hole. Two echos are seen on the screen. The second echo (on right side) is coming after reflection from inclined rail end and the first echo is coming from the drilled FBH. For sensitivity setting, we will use the first echo.The probe is moved to and fro slowly to get the maximum height of this echo. Now the echo height is adjusted to 60% of the screen height using the gain control. The process is repeated for 70^0 shifted GF & NGF, forward and backward probes. The signal pattern is shown in Fig. 5.13.

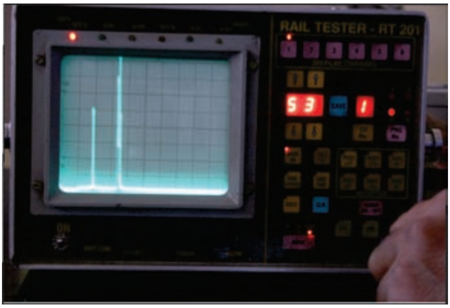


Fig. 5.13 – Sensitivity Setting for 70^0 Shifted Probe

5.4.4 45^0 probe (for locations having scabs/wheel burns)

At the location of wheel burns, scabs etc. on rail table, the detection of defects in the rail become difficult. To overcome this, we use 45^0 test rig on the side of rail head to detect the defects at such locations. Machine shall be calibrated for 165 mm range for shear wave on the rail of same sectional weight under test. The test rig shall be placed 20 mm below rail table on the side of rail head. The transmitter and receiver probe in the test rig shall be in opposite direction and shall be apart twice the rail head width. Peak obtained in receiver probe shall be adjusted to full scale height by gain setting. Testing of rails shall be done by keeping index mark of probe 20mm below rail table (Fig. 5.14 & 5.15).

Note: For 52Kg and 60Kg rails the peak of received signal shall appear at approximately 95mm (shear wave) and 103mm (shear wave) respectively.

The sensitivity setting of other probes i.e. 70^0 side looking probe etc. is done as per the procedure given in USFD manual.

5.4.5 As per the current provisions of USFD manual, **the sensitivity setting is to be checked once in 3 days.**

While testing on single line section and 'D' marked rails on double / multiple line section, additional gain of 10dB is to be employed for 70^0 Forward and 70^0 Backward probes..

However, when a defect signal is exhibited at a weld while testing with increased gain of 10 dB, the classification of defect with reference to Annexure-IIB using 70^0 probes shall be done based on signal pattern obtained after reducing the gain by 10 dB.

The non-reportable signals (i.e. below OBS/OBS(W) range) received by all types of 70^0 probes shall be marked as 'O' on the web of the rail.

5.5 Adjustment for Sensitivity Setting for Variation in Rail Temperature

Following procedure shall be used for adjustments in sensitivity setting of Ultrasonic Rail tester on account of variation in rail temperature before starting the testing of rails.

(a) Switch on the Ultrasonic rail tester and keep the equipment for two minutes for thermal acclimatization of the component of the equipment before starting the adjustment in sensitivity setting operation.

(b) In the morning at 8:00 hrs.

(i) Normal Probe: Set the sensitivity of the equipment as per para 5.3.1 above and note the gain required to setup the amplitude of the signal to 60% of full screen height.

(ii) Angle probe 70 degree (Forward and Backward): Set the sensitivity of the equipment as per para 5.3.2 above and note the gain required to set up the amplitude of the signal to 60% of full screen height.

(iii) Angle probe 70 degree GF & NGF (Forward and Backward): Set the sensitivity of the equipment as per para 5.3.3 above and note the gain required to set up the amplitude of the signal to 60% of full screen height.

(iv) Note the rail temperature.

(c) After setting the sensitivity of the probes, the ultrasonic rail tester shall be retained on the standard rail test piece in ON condition and the signal amplitude of individual probe set as per above procedure shall be checked on hourly basis. If the drop in the signal is observed then the drop shall be compensated by applying extra gain with use of gain control (dB). The height of signal amplitude is maintained to 60% of full screen height. Note the change in rail temperature from rail temperature at 8.00 Hrs. and corresponding extra gain used.

(d) Actual testing: During actual testing on the track, the gain set by the above procedure shall be maintained depending upon the time and rail temperature during testing. Any variation in the signal amplitude shall be compensated by giving measured extra gain (dB) as per step (c) above to carry out ultrasonic testing.

(e) Periodicity of setting the sensitivity: The above procedure for **sensitivity calibration against temperature variation shall be carried out at least once in a month.** The adjustments in sensitivity setting of ultrasonic equipment in respect of gain (dB) shall be employed accordingly.

5.6 Through Testing of Rails and Welds

Through testing of rails and welds is carried out using SRT & DRT as explained in chapter 4. Water is used as couplant during through testing. There are 7 probes (one 0^0 and six 70^0 probes) for testing each rail. Three pairs of 70^0 probes (F & B) are deployed for detection of transverse flaws in the rail head as explained in chapter 4. 0^0 probe is used to detect horizontal defects, longitudinal vertical defects and bolt hole cracks. The frequency of testing is kept as per para 6.1 of chapter 6.

In addition to these probes, 45^0 (2MHz) test rig consisting of two probes working as transmitter - receiver are used on the side of the rail head for scanning rail head area below wheel burns, scabs etc on rail table.

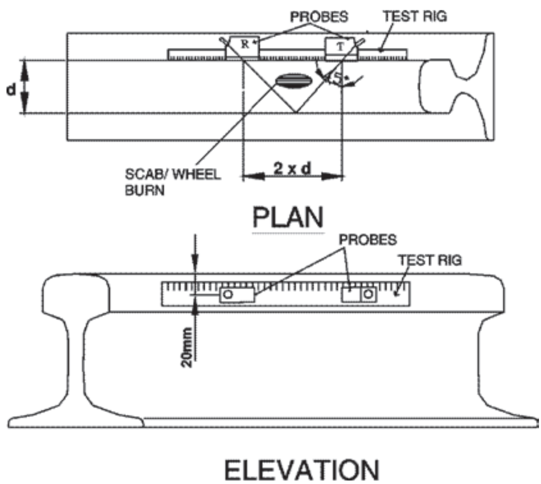


Fig. 5.14 : Sensitivity Setting/Testing with 45^0 Probe Using Test Ring (for locations having scabs/wheel burns)

Fig. 5.15 – Side Probing Using 45^0 Test Rig

5.7 Hand Testing of AT Welds

In addition to testing by trolley, Alumino Thermit Welds are also tested by hand scanning as per the frequency given in para 6.2 & 6.3 in chapter 6. The welded zone (rail head and flange) should be dressed properly after the execution of AT weld so as to facilitate proper and even placement of probes and to avoid emergence of spurious signals on the screen during testing.

Any joint showing any visible defect such as crack, blow hole etc. shall be declared defective.

For hand testing of welds, soft grease shall be used as couplant.

AT weld shall be hand tested using 0^0 2 MHz & 70^0 2MHz probes on rail head to detect cracks in head of weld joint and also porosity, blow hole, slag inclusion, lack of fusion in head and up-to mid web of AT welded joint. The standard test piece for sensitivity setting for 0^0 and 70^0 probes used at the rail top during hand testing of AT welds is shown in Fig. 5.16.

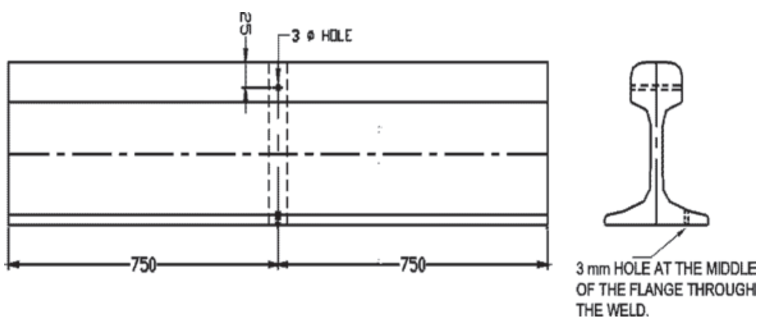


Fig. 5.16 – Standard A.T. Welded Rail Piece with Artificial Flaws for Sensitivity Setting of Ultrasonic Equipment to Examine A.T. Welds

45^0 2MHz probe on rail head shall be used to detect the clustered defects/ micro porosities and half moon shaped defect at the bottom of weld foot. The standard AT welded rail test piece is shown in Fig. 5.19. The testing with 45^0 & 70^0 probes on rail head shall be done as shown in Fig. 5.17

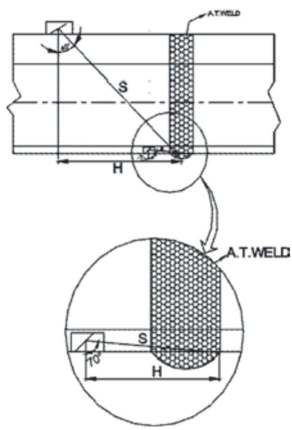


Fig. 5.17 – Testing of Bottom Flange of A.T. Welds using 70^0 and 45^0 Probes

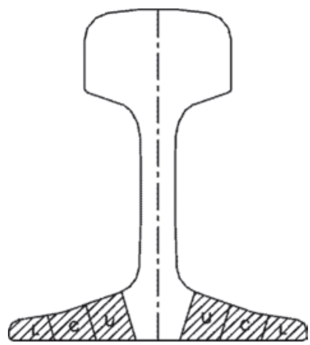


Fig. 5.18 – Sketch Showing the Location of Flange of Rail for Ultarsonic Testing with 70^0, 2MHz, (20mm, Circular or 20mm x 20mm Square Crystal) Angle Probe

Flange testing of AT weld shall be done using 70^0 2MHz probe for detecting lack of fusion, porosity, blow hole, slag inclusion etc. This is done by dividing the flange in lower, central and upper segments on either side of the weld as well as web of the rail as shown in Fig. 5.18.

The hand probing of weld foot will be done using a pair of 70^0 2MHz Side Looking probe for the detection of half moon shaped transverse defects (Fig. 5.19).

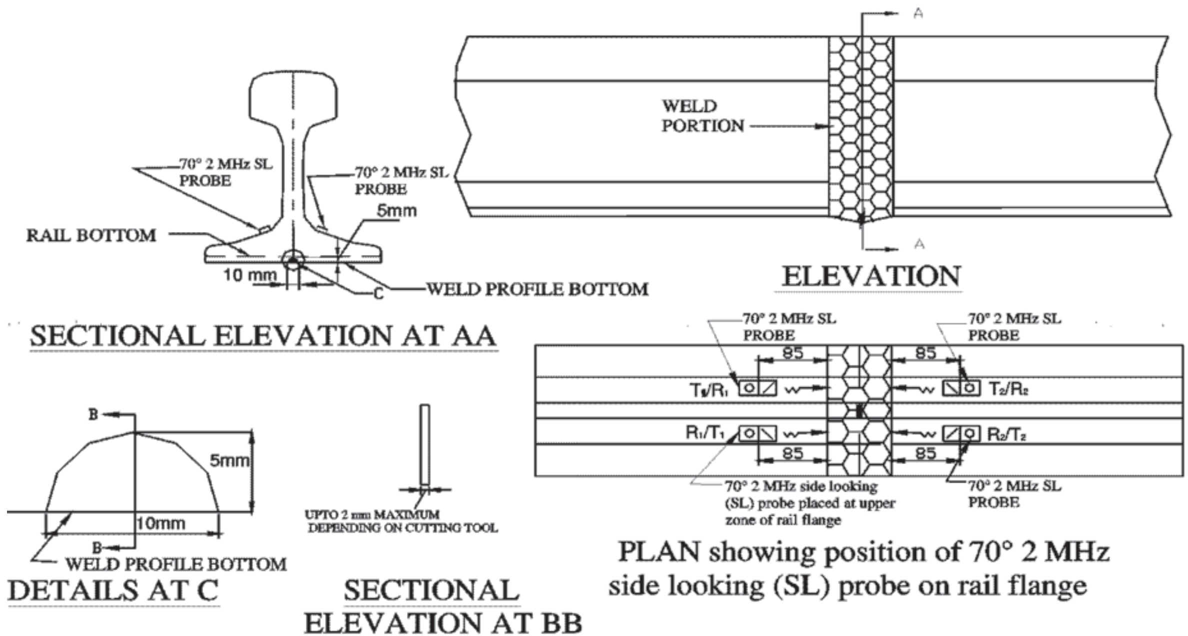


Fig. 5.19 – Standard A.T. Welded Rail Test Piece
(Half Moon Crack)

In addition to these, tandem probe rig scan on the rail table using 45^0 probes will be used to detect any vertically oriented defect like lack of fusion located at head-web junction, complete web and upto web foot junction area, web and foot region below web (Fig. 5.20 & 5.21).

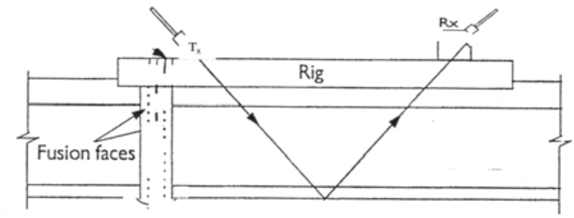


Fig. 5.20 (a) – Sensitivity Setting Using 45^0 Tandem Probe

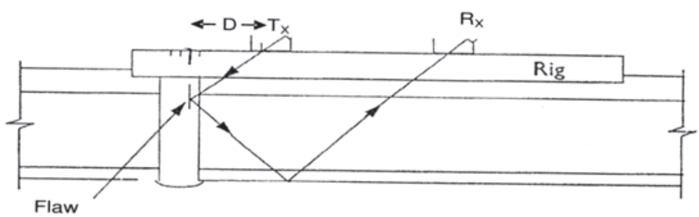


Fig. 5.20 (b) – AT Weld Testing Using 45^0 Tandem Probe

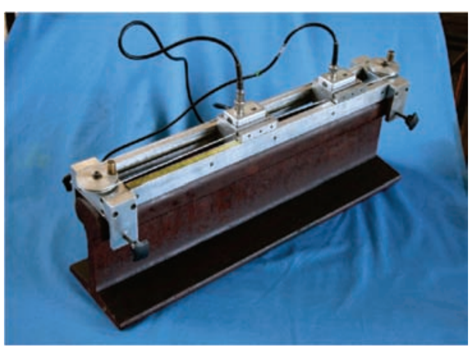


Fig. 5.21 – 45^0 Tandem Probes for AT Weld Testing

The calibration, sensitivity setting and testing of AT weld with various probes shall be done as per the provisions of USFD manual.

5.8 Testing of Other Types of Welds, SEJ etc.

Apart from the regular periodic through testing of rails and hand testing of AT welds, USFD testing is required for specific track components occasionally. The procedure for the same is not being discussed in this book. For specific applications such as testing of FB and GP welds, SEJs, worn out point and splice rails prior to reconditioning, rails required for fabrication of points & crossings, the procedure given in the USFD manual should be referred.

5.9 Flaw Marking and Classification

After the calibration and the sensitivity setting of the machine, the testing is carried out in the field. In case of a defect signal by a particular probe, the flaws are marked and classified as per the height and the spread of the signal as given in Annexure II of USFD manual. Annexure II-A details the flaw classification for rails and Annexure II-B for AT (Alumino Thermic)/FB (Flash Butt)/GP (Gas Pressure) welds. Broadly, the defects are classified during the through testing as below.

IMR & IMR(W) - IMR stands for 'Immediate Removal'. These are large size defects requiring urgent action including removal of the defective rail/weld from the track within certain period. The suffix 'W' is for the defect in weld. Any defect in rail within heat affected zone (HAZ) of weld is also treated as a weld defect.

OBS & OBS(W) - OBS stands for keeping under 'Observation'. These are small size defects which require action other than removal - generally to be kept under observation and supported by a ordinary/joggled fish plate.

DFWO & DFWR - During the hand testing of AT welds, defective welds are classified as DFWO & DFWR depending on the severity of the defects. The action to be taken for different defects will be discussed later in chapter 6.

The flaw marking by individual probe is not being discussed here, since it keeps changing as per the investigations and study done by RDSO from time to time and one needs to refer to the latest correction slips of the manual. However, it is worthwhile to mention here that the classification of the defect changes as per the severity of the location in the track also. For example an OBS defect in a normal track location may be classified as IMR if existing on the approach of a bridge or a tunnel or in the vicinity of fish-plated joint. We need to follow the provisions of the manual for classification. The action to be taken for various types of defect is discussed in chapter 6.

■ ■ ■

CHAPTER 6

PROVISIONS OF USFD MANUAL FOR TESTING

Manual for Ultrasonic Testing of Rails and Welds was last revised in 2012 incorporating nine correction slips issued till then. Four more correction slips have since been issued till August 2019. The manual contains various provisions of testing of rails and welds using ultrasonic technique on Indian Railways. The manual covers the various types of defects in brief, codification of the defects, probes to be used, frequency of the testing, testing procedure and flaw marking and also the action to be taken for various types of defects.

The manual also covers the ultrasonic procedure for special needs such as testing of SEJs, switches, rails for fabrication of points & crossings etc. It is advised to read the manual along with the latest correction slips to understand its various provisions. The present chapter highlights some of the important provisions of the manual and should not be considered as a replacement to the manual. The important provisions are discussed below.

6.1 Frequency of Through Testing of Rails & Welds

Safety against failures of rails in track depends upon the inspection frequency and the permissible (condemning) defect size. The inspection frequency and condemning defect sizes are related parameters. If the inspection frequency is high, the condemning defect size can be suitably increased. Increase in condemning defect size also enhances the reliability of inspection as probability of detection of larger size defects is high.

The rails are thoroughly checked ultrasonically for being defect free before they are dispatched from the steel plant. Since fatigue related defects take time to develop, probability of defects occurring in the rails during its initial service life is very less. Therefore, for new rails laid in the track, reduced frequency of testing is prescribed initially.

Whenever Rails are not tested in rail manufacturing plant, the test free period will not be applicable and the rail testing has to be done as per laid down periodicity right from the day of its laying in track.

6.1.1 Frequency of Testing of Rails and welds

The rails and welds will be periodically tested as per the frequency prescribed in the table 6.2.

However, after the initial USFD testing of rails in rail manufacturing plant, the subsequent USFD testing needs to be carried out at reduced frequency until the rails have undergone 15% of service life of GMT as given below.

Table 6.1 - Service Life of Rails on BG Track

Rail Section	**Service Life (GMT)**	
	72 UTS Rails	90 UTS Rails
60 kg	550	800
52 kg	350	525
90R	250	375

Rail testing during reduced frequency testing period is to be done using all probes as is being done during normal testing frequency period on passage of every 40 GMT traffic or eight years, whichever is earlier.

Table 6.2 - Frequency of Rail Testing

Route having	**GMT**	**Frequency**
All BG Routes	≤ 5	2 Years
	> 5 & ≤ 8	12 Months
	> 8 & ≤ 12	9 Months
	> 12 & ≤ 16	6 Months
	> 16 & ≤ 24	4 Months
	> 24 & ≤ 40	3 Months

	> 40 & ≤ 60	2 Months
	> 60 & ≤ 80	1.5 Months
	> 80	1 Month

The above table is based on the testing frequency **after every 8 GMT.**

6.2 Frequency of Hand Testing for AT Welds

6.2.1 Frequency for Conventional AT Welds

For old conventional AT welds Hand Testing will be done after passage of every 40 GMT or five years whichever is less.

6.2.2 Frequency for SKV Welds

For SKV welds, initial acceptance test will be done immediately after welding. A thermit weld shall be joggle fish plated with two clamps and supported on wooden block of size 300 x 450 mm till tested as good by USFD.

Thereafter, First periodic test will be undertaken after one year of welding and further testing will be done based on annual GMT of the section route GMT is given in table 6.3.

Table 6.3 - Frequency of Hand Testing for SKV Welds

Route having GMT	Frequency
> 80	1 Year
> 60 & ≤ 80	1.5 Years
> 45 & ≤ 60	2 Years
> 30 & ≤ 45	3 Years
> 15 & ≤ 30	4 Years
≤ 15	5 Years

6.2.3 Additional policy instruction on Ultrasonic testing of rails & welds (to be in force till 31.08.2020) (As a trial preventive measure to reduce numbers of rail failures during reduced testing frequency period and weld failures in initial period)

6.2.3.1 Frequency of USFD for all BG and MG routes shall be as under. For other sections, Chief Engineer of the railway may adopt a frequency at his discretion.

A	B	C	D
Route	**Routes having GMT**	**USFD Testing Frequency during the "Reduced freq-uency testing Period" once in**	**USFD Testing Freq-uency (Other than during the "Reduced frequency testing Period") once in**
ALL MG Routes	< 2.5	8 years	5 years
	2.5 - 5	4 years	3 years
	> 5	3 years	2 years
All BG Routes	≤ 5	4 years	2 years
	> 5 ≤ 8	30 months	12 months
	> 8 ≤ 12	20 months	9 months
	> 12 ≤ 16	15 months	6 months
	> 16 ≤ 24	10 months	4 months
	> 24 ≤ 40	6 months	3 months
	> 40 ≤ 60	4 months	2 months
	> 60 ≤ 80	3 months	1.5 months
	> 80	2 months	1 month

Frequency of USFD testing during reduced frequency testing period is broadly based on the criteria of :

a) Passage of every 20GMT traffic during reduced frequency testing period or

b) Eight (8) years, whichever is earlier

6.2.3.2 Frequency of testing of at welds by handprobing with probes listed in Para 8.15.2 of USFD Manual shall be as under

S. No.	Type of welds	Type of testing	Testing Schedule	
1	**Conventional AT weld**	Periodic test	Every 40 GMT or 5 years whichever is earlier	
2	**SKV weld**	Acceptance test	Immediately after welding	
3		Fist periodic test	20 GMT or 1year whichever is earlier	
		Further tests based on route GMT	**Routes having GMT**	**Frequecy**
4			> 80	1 year
5			> 60 ≤ 80	1.5 years
6			> 45 ≤ 60	2 years
7			> 30 ≤ 45	3 years
8			> 15 ≤ 30	4 years
9			0 -15	5 years

6.3 Other Related Provisions for rail and weld testing

6.3.1 In case of major bridges and bridge approaches (100 m either side) and in tunnels and tunnel approaches (100 m either side), the minimum frequency of testing shall be once in a year.

6.3.2 In case of unusually high weld failures or other abnormal reasons, Chief engineer may order testing of welds early as per the need.

6.3.3 The testing interval of USFD testing of defective AT welds should be reduced by 50% of normal testing interval as prescribed above i.e. the frequency prescribed in table 6.3 should be doubled.

6.3.4 Through Weld Renewal (TWR) should be planned after the welds have carried 50% of the stipulated GMT of rails.

6.3.5 More than one DFWO defects in the same weld shall be classified as DFWR.

6.3.6 Soft grease or oil shall be used for proper acoustic coupling instead of water for hand testing of AT welds. Operator should use the same couplant during setting the sensitivity and testing.

6.3.7 (a) Any defect or defect at any location which is detected by two or more probes are considered to be classified at OBS/OBSW based on peak pattern of individual probe, should be classified as IMR/IMRW and action shall be taken accordingly.

(b) In case two or more OBS/OBSW defects are located within a distance of 4.0meter from each other, such OBS/OBSW defects shall be classified as IMR/IMRW and action shall be taken accordingly..

6.4 Frequency of Testing for Other Welds

Flash Butt welds and Gas Pressure welds are to be tested immediately after creation and subsequently, during the through testing of rails. There is no requirement of hand testing of these welds afterwards. However, Chief Engineer may order hand probing of these welds in case of high failure rate of these types of welds in a section.

6.5 Classification of Rail/Welds Defects and Action to be Taken

The defective rails and welds after through testing are classified as IMR/IMR(W) or OBS/OBS(W). Suffix 'W' denotes a defect in the weld. Similarly, defective AT welds after hand testing are classified as DFWO or DFWR. The action to be taken for these defective rails and welds is given in table 6.4 and table 6.5.

Table 6.4 -Classification of Rail/Welds Defects and Action to be Taken

S. No	Classification	Painting on both faces of web of rail	Action to be taken	Interim Action
1	IMR/ IMR(W)	Three cross marks with red paint	The flawed portion should be replaced by sound tested rail piece of not less than 5.5 m length within 3 days of detection.	SE/JE(P.Way)/USFD shall impose speed restriction of 30 km/ h or stricter immediately and to be continued till flawed rail/weld is replaced. He should communi cate to sectional SE JE(P.Way) about the flaw location who shall ensure that clamped joggled fish plate is provided within 24 hrs.
2	OBS/ OBS(W)	One cross mark with red paint	The rail/weld to be provided with clamped joggled fish plate within 3 days. SE/JE(P.Way)/USFD to specifically record the observations of the location in his register in subsequent rounds of testing.	SE/JE(P.Way)/ USFD to advise Sectional SE/ JE(P.Way) within 24 hrs about the flaw location. Key man to watch during his daily patrolling till it is joggled fish plated.

Table 6.5 - Classification of AT Welds by Hand Testing and Action to be Taken

Classification	Painting in both faces of web	Action to be taken
Defective weld 'DFWO/ DFWR' with 0°/2 MHz, 70°/2 MHz, 45°/2 MHz or 70°/2 MHz SL probe, 45°/2 MHz Tandem Rig.	In case of DFWO, one circle with red paint. In case of DFWR, two cross with red paint.	**(i) For DFWO welds** a) SSE/JE(P.Way)/USFD shall impose speed restriction of 30 kmph or stricter immediately and communicate to sectional SSE/JE about the flaw location, who shall ensure the following : b) Protection of defective weld by joggled fish plates using minimum two tight clamps immediately with a speed restriction of 30 kmph. Speed restriction can be relaxed to normal after protection of DFWO weld by joggled fish plates with 2 far end tight bolts (one on each side) with champhering of holes, within 3 days. The joint is to be kept under observation. **ii) For DFWR welds** a) SSE/JE (P.Way) USFD shall impose speed restriction of 30kmph or stricter immediately and communicate to sectional SSE/JE about the flaw location who shall ensure the following: b) Protection of DFWR weld by joggled fish plates using minimum two tight clamps immediately. SR of 30 Kmph can be relaxed to normal after providing joggled fish plates with two far end tight bolts one on each side with champhering of holes. The DFWR weld shall be replaced within three months of detection. Adequate traffic block should be granted for removal of DFWR welds.In case of non-removal within three months, a speed restriction of 75 kmph for loaded goods train and 100 kmph for passenger train should be imposed.

Classification	Painting in both faces of web	Action to be taken
		(iii) In case of defective weld (DFWO/DFWR) on major bridges and bridge approaches (100 m either side) and in tunnels and tunnel approaches (100m either side), the following action shall be taken. a) SSE/JE (P.Way) USFD shall impose speed restriction of 30kmph or stricter immediately and to be continued till defective weld is replaced. He should communicate to sectional SSE/ JE about the flaw location who shall ensure the following: b) Protection of defective weld using clamped joggle fish plate within 24 hours. The defective weld shall be replaced within 3 days of detection.

Note : DFWR & DFWO found in "Initial Acceptance Test" shall be removed from track

6.5.1 An AT weld within the guarantee period of contract declared as defective (DFWO or DFWR) after initial USFD testing or subsequent testing shall not be allowed to remain in service. Such joints shall be cropped, re-welded and tested again. The re-welded joint shall undergo the same acceptance criteria again to ensure freedom from defects.

6.5.2 More than one DFWO defect in one weld shall be classified as DFWR.

6.6 Inspection of USFD Work by ADEN

As per the provisions of USFD manual, sectional ADEN should spend at least few hours (min two hours) each month during his routine trolley inspection with USFD team and cross check the working including accuracy of calibration, sensitivity setting and flaw marking.

The officer having technical control over the SE/JE (USFD) shall exercise regular checks once in between two successive half yearly maintenance schedule carried out in the maintenance depots.

6.7 Inspection of USFD Work by SSE/SE (P. Way)

There is no frequency of inspection prescribed for SSE/SE(P. Way) for USFD work. However, USFD manual specifies that SSE/SE(P. Way) should also associate themselves occasionally.

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CHAPTER 7

LIMITATIONS OF USFD TESTING

There are few limitations of the flaw detection by ultrasonic technique on Indian Railways. The limitations of flaw detection are not the limitations of the technology but the limitations as per testing arrangements under field conditions.

a) To detect the defect efficiently, ultrasonic beam is to be directed towards the flaw perpendicularly, otherwise, the reflected beam may not be received by the receiver crystal, resulting in absence/reduction in amplitude of flaw signal in the CRT. However, in actual practice no flaw is perfectly in one plane. The cracks normally have a zig-zag surface if seen under a microscope and those with favourably oriented facets will reflect energy towards the probe leading to flaw detection. However, smaller flaws may remain undetected in this case

b) The existence of flaw in a region which is not penetrated by the incident ultrasonic beam remains undetected. Due to this, defects in the flange of the rail are never detected during through testing.

c) The orientation of the flaw being unfavorable to the incident ultrasonic beam, e.g. vertical longitudinal flaws, remnant of piping, bolt-hole cracks unfavorably placed near joints can't be detected.

d) For detection of bolt hole cracks, 37^0 probes are ideal. This is because the cracks emanating from bolt holes are generally oblique and propagate in the zig-zag manner. However, the present SRT/DRT machines have not been provided with 37^0 probes due to limitation of number of channels and detection of bolt hole cracks is accomplished by normal probe. These cracks are detectable by 0^0 probe since they obstruct the path of sound waves and lead to drop/loss of back wall echo. However, the reliability of detection will not be as good as with 37^0 probe. If the cracks are so located that they are unable to be scanned by 0^0 probes due to smaller size or orientation, such cracks may not be detected in initial stages of their development.

e) The ultrasonic probes used in the rail testers have a frequency of 4MHz (longitudinal wave) and 2MHz (transverse waves). Therefore, cracks lesser than 0.8mm size cannot be detected by the present arrangement.

f) Defects within 4 mm from the top of the rail surface cannot be detected as this is the dead zone of the probe. Any signal arising within the dead zone will get merged with the surface echo and can't be interpreted for a defect echo. Also, a defect located within 5mm from the corner of rail cannot be detected by 70^0 and 45^0 probes.

g) If the top table of rails has rust, pitting, scabs, wheel burns, battering, hogging of rail ends etc., detection becomes difficult and unreliable because of improper contact. A special arrangement using 45^0 test rig to be used on the side of rail head has been developed for scanning of rail head in these conditions.

h) The USFD trolley has been designed to operate under normal conditions of gauge. In the event of dimensional variations in the gauge and also at sharp curves it is possible that the probes are not properly contacting the rail surface. This is indicated by loss of backwall echo or also by alarm provided in DRTs for backwall drop. Wherever it is not possible to ensure proper acoustic coupling due to these reasons, testing by hand probing or by single rail tester may be resorted to. Acoustic coupling needs to be ensured under all circumstances to detect the flaws.

I) Testing with 45^0 test rig is effective when the sides of rail head are nearly vertical. In case of badly worn faces of rail head the quality of results may get affected.

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CHAPTER 8

VEHICULAR ULTRASONIC TESTING

The present system of manual testing of USFD is having number of limitations. It is desired to test the track using vehicle based testing systems. There are numerous advantages of vehicular testing systems. These are discussed in brief.

8.1 Limitations of Manual USFD Testing

8.1.1 The present system is very strenuous for the operator and is highly dependent on the knowledge, skills and dedication of the USFD operator. Thus, the testing practically becomes subjective to an extent and person specific.

8.1.2 The progress of testing is very slow. Therefore, keeping large fleet of equipment and trained personnel becomes essential.

8.1.3 Any change in the hardware or the testing procedure take lot of time to percolate to the grass root level and for actual implementation. Modifications to a large number of geographically spread out equipment and the re-training of supervisors as per new procedures are major issues.

8.1.4 Since manual testing is carried out without traffic blocks, the portability of the equipment is the prime requirement to lift it off the track on the face of an incoming train. This limits the capability of the machine for providing additional channel as well as on board micro-processor.

8.1.5 The analogue machines are not having the facility of storing the data. The specifications of the digital machines provide for capturing the limited number of signal patterns. The data storage capacity of the equipment is limited since on board micro-processors can't be provided as explained in para 8.1.4 above. So it is not possible to capture all the run data for further processing. The isolated captured images cannot be converted into a systematic database for decision making.

8.1.6 The present frequency of testing based on GMT does not take into account the factors like axle load, age of the rails and welds etc. which are crucial for the flaw growth.

8.2 Vehicular USFD Testing

Vehicular USFD testing can overcome most of the limitations of manual testing. In vehicular testing, the transducers are provided on a separate testing trolley (Fig. 8.1) which is having separate small size wheels. In non-testing mode, the testing trolley is up and locked. For testing the trolley is lowered on the track.Some of these vehicles are self propelled while others require a separate power for their operation. The testing speed may vary from 30kmph to 80kmph depending upon the design of the testing car and the condition of the track.

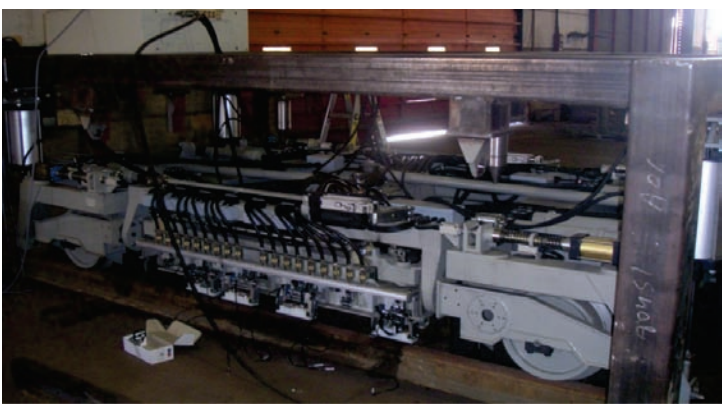

Fig. 8.1 – A Typical USFD Testing Trolley

The vehicle is provided with on board computers and all signals captured by the transducers are sent to the computer. The operator sitting in the control unit in the vehicle can see the signals picked up by different probes and ensure proper functioning of the system. A typical workstation of the testing car is shown in Fig. 8.2. The manual testers provide the 'A' scan image of the defects which are one dimensional. Most of these systems provide 'B' scan as well as

'A' scan image. ‘B’ scan image gives the two dimensional view of the rail wherein a moving scan of about 200 m length is shown continuously on the screen during the run. ‘A’ scan image can also be displayed wherever desired by the operator. A software is installed on the car which can analyse the captured data as per the requirements of the client and produce a list of the suspected defects along with their locations. Such systems are in use on most of the other railway networks in the world.

Fig. 8.2 – Work Station of a Vehicular Testing System

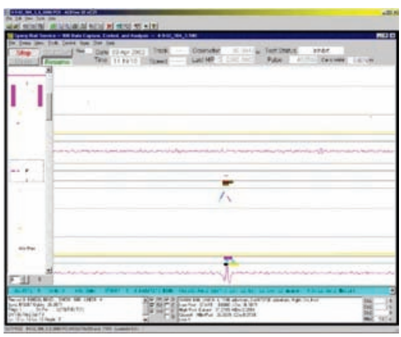

Fig. 8.3 – A Typical ‘B’ Scan View During Rail Testing

After getting the list of the suspected defects, confirmatory testing at the new suspected defects locations is carried out using manual systems. This is necessary since the vehicle running at higher speed will pick up lot of noise also along with the defects. So the actual defects need to be segregated based on the confirmatory manual testing.

The vehicle based system maintains a database of the defects and compares the run to run defect growth. Thus the defect growth rate can be studied for various types of the defects in different sections.

This will help in rationalizing the decision making in respect of frequency of testing, minimum sizes of the flaws to be detected and condemnable sizes of different type of flaws etc. Proper management of the flaw is possible only after having an objective system of testing, creating a systemized database and analyzing it with the help of proven software for decision making. Manual system cannot be designed to have such facilities without losing their portability requirement.

8.3 Vehicular Testing on Indian Railways

On Indian Railways, there is no vehicular USFD system at present. IR purchased a Self Propelled Ultrasonic Rail Testing car from M/s. Matix, France in 1987. The vehicle tested the rails till 2004 but IR could never gain confidence on operation and maintenance and the testing by this vehicle. Manual testing continued even in those sections where vehicle tested the rails. There were many reasons for this lack of confidence in the test results by this car. These are discussed below.

8.3.1 IR could not get proper support from the manufacturer for the maintenance of the car. In fact, the firm stopped the maintenance of the car after 2-3 years of supply.

8.3.2 Due to complicated internal procedures and technological obsolescence of the system, the Annual Maintenance contract could not be procured for longer duration.

8.3.3 The vehicle and the engine of the car were imported and it was very difficult for RDSO personnel to maintain the same in-house due to lack of expertise on this system. Getting the spares for the components was also a major problem.

8.3.4 Difficulties were also experienced in the operation of the car since the crew available on various zonal Railways had no experience of running of a different type of vehicle.

8.3.5 One complaint of the field engineers was that the machine tended to over report the defects. The over reporting of the defects was very high and the validation of the suspected defects in follow up manual testing was only about 10%.

8.3.6 The system of calibration and reporting of defects was changed by RDSO due to adoption of need based testing concept. This required major changes from the laid down testing procedures of the car which were initially set as per the conventional testing concept. The IR staff was not experienced for bringing about the required changes in the car. The manufacturer support was not available by this time.

8.3.7 The firm from which the car was procured winded up their business and was merged with another firm M/s Speno International Ltd.

8.3.8 The testing speed of the car was only 30 kmph due to which the Divisions were reluctant to give path to the car for testing. This resulted failure to adhere to the advance testing program and in poor progress of the car.

8.3.9 It was not possible to get the scheduled overhauling done in any workshop of IR due to lack of expertise in maintenance of such a system.

The car was condemned in 2003 after it met with an accident.

RDSO tried to procure two more testing cars from M/s Scanmaster, Israel in 2005. But the cars offered could not meet the technical specifications. A committee of officers nominated by Railway Board went into the various aspects of vehicular testing and the systems in use on different railways so as to suggest the further course of action for Indian railways. In 2007, the committee recommended to fix a performance based service contract by vehicular testing.

8.4 The Road Ahead

The vehicular testing systems have proved to be successful in timely detection of the defects and bringing down the in-service failures of the rails and welds significantly. There is a need to adopt the vehicular testing system on Indian Railways also. It will help us in objective testing of rails & welds, to create a defects database, analyse the data and study the defect growth rate. We can then rationalise minimum size of the defects, condemnable size of the defects and frequency of testing under various traffic and track conditions.

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Annexure 'A'

Precautions to be Taken by the Operator for Testing

Before undertaking the testing of the rails and welds, the operator has to ensure that the equipment is in good fettle and properly calibrated. He has to take the necessary precautions so as to get the reliable testing results. The operator has to carry-out visual inspection of the machine and ensure its calibration and sensitivity setting as per the provisions of the manual. The precautions to be taken by the operator are elaborated below.

BEFORE TESTING

1. Check the battery condition as indicated by the voltage needle of USFD equipment (or ascertain the voltage with the help of a Voltmeter). Only fully charged batteries are to be used during testing.

2. Check proper functioning of all controls of electronic unit i.e. depth range, gain, reject etc.

3. Check proper functioning of trolley and probes.

4. Check junction box, water outlet, probe cable contact and ensure smooth movement of trolley wheels.

5. Maintain proper gap between probing face and probe shoe (0.2 mm). Check with the help of a feeler gauge.

6. Check probe alignment by keeping the rail tester on the rail.

7. Calibrate the instrument weekly as per the procedure.

8. Set the equipment for proper sensitivity once in three days.

9. The ultrasonic equipment shall be checked for its characteristics at least once in a month. The characteristics of ultrasonic equipment are checked as per IS:12666-1988.

DURING TESTING

1. Conduct test as given in USFD manual issued by RDSO.

2. Maintain proper alignment of all the probes during testing, otherwise false echoes may appear.

3. Ensure adequate supply of water for coupling.

4. Check proper functioning of 70^0 probes by touching the probe bottom with fingers. Noise pattern i.e. random flickering of the signal should appear on the screen.

5. Look out for the back echo corresponding to normal probe throughout the testing since back echo shall generally be present for full screen height if there is no defect in rail.

6. Lift your machine at crossings/change of rail table height at joints to protect the probes.

7. Mark the location found defective as per classification.

AFTER TESTING

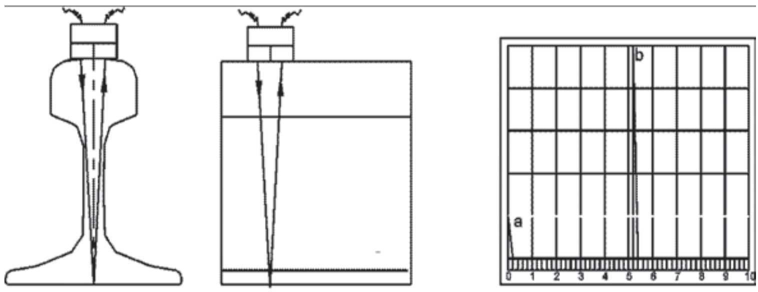
1. Maintain proper record of testing, observation, echo pattern, amplitude whenever a defect is noticed.

2. Keep the battery for charging after day's work.

Annexure 'B'

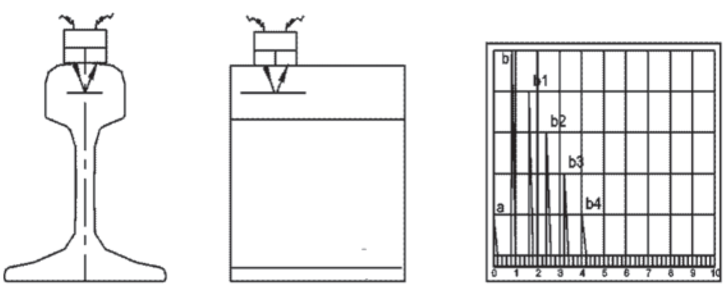
Typical Signal Patterns in Different Conditions

The signal patterns on the USFD tester screen in various conditions of rails and welds are given in USFD manual. The same are reproduced below to get a better insight and understanding of the subjects. The reader should draw and match the signal patterns for different conditions of rails.



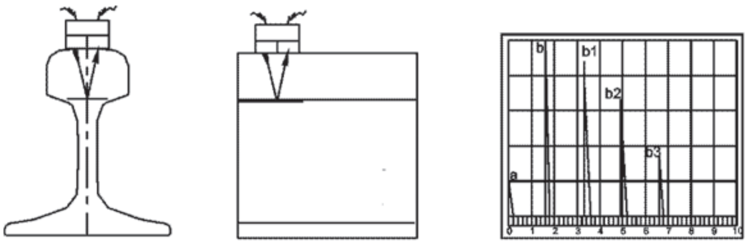
a - Surface Echo
b - Back Echo

Fig : Rail Without Flaw (0^0 Probe)



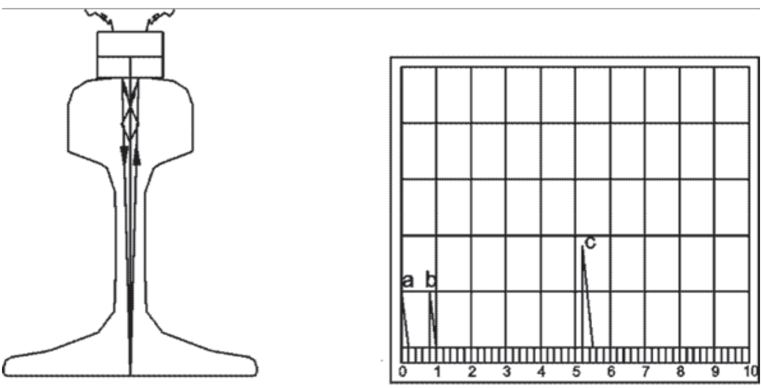
a - Surface Echo
b - Flaw Echo
b1, b2 ... Multiple Flaw Echoes

Fig : Longitudinal Horizontal Split In Head Region (Type 112 & 212, 0^0 Probe)



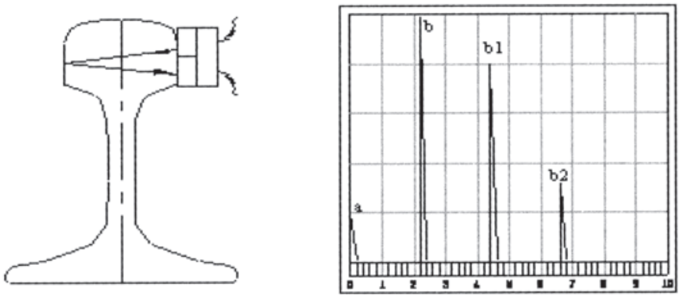
a - Surface Echo
b - Flaw Echo
b1, b2 ... Multiple Flaw Echoes

Fig : Longitudinal Horizontal Split In Head Web Junction (Type 1321 & 2321, 0^0 Probe)



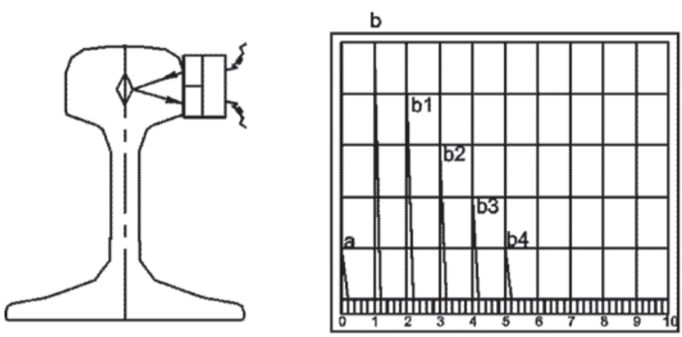
a - Surface Echo
b - Flaw Echo
c - Suppressed Back Echo

Fig : Vertical Longitudinal Split In Head (Type 113 & 213, 0^0 Probe)



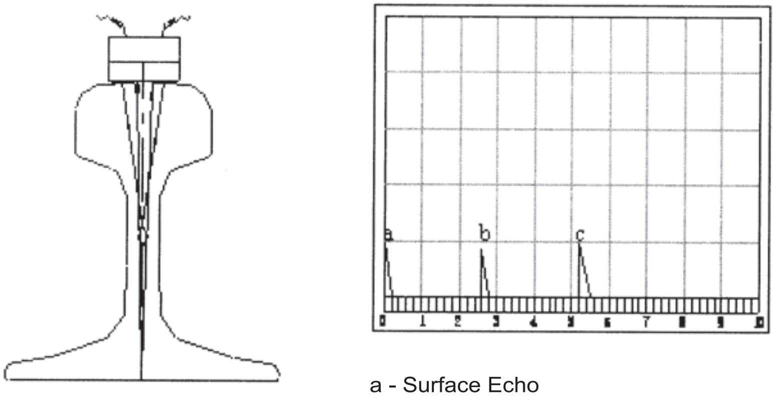
a - Surface Echo
b - Back Echo
b1, b2 ... Multiple Back Echoes

Fig : Side Probing of Rail Head, Without Flaw



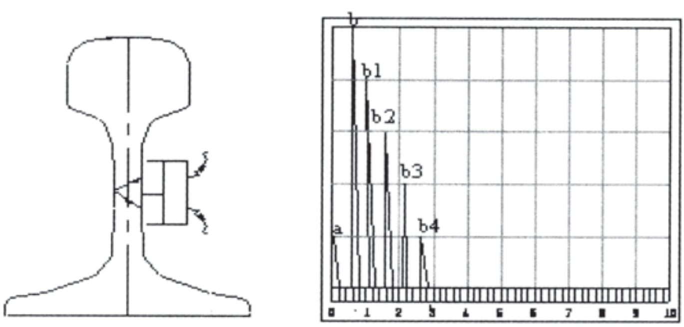
a - Surface Echo
b - Flaw Echo
b1, b2 ... Multiple Flaw Echoes

Fig : Vertical Longitudinal Split In Head (0^0 Side Probing)



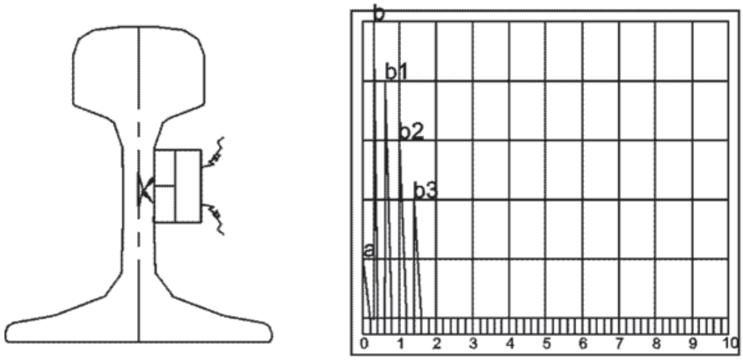
a - Surface Echo
b - Flaw Echo
c - Suppressed Back Echo

Fig : Vertical Longitudinal Split In Web
(Type 133 & 233-0^0 Probe)



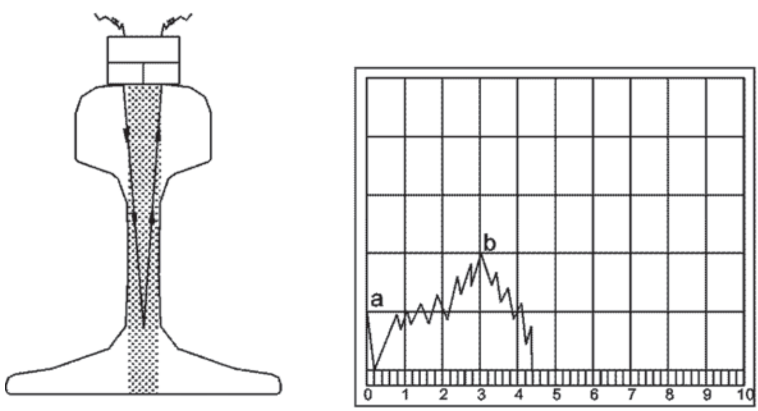
a - Surface Echo
b - Back Echo
b1, b2 ... Multiple Back Echoes

Fig : Side Probing of Rail Web, Without Defect



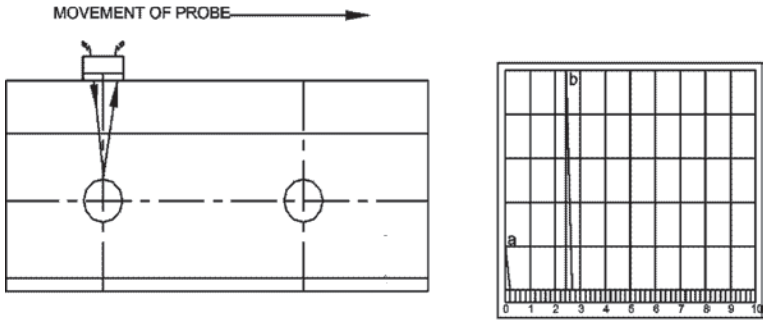
a - Surface Echo
b - Flaw Echo
b1, b2 ... Multiple Flaw Echoes

Fig : Vertical Longitudinal Split in Web (0^0 Side Probing)



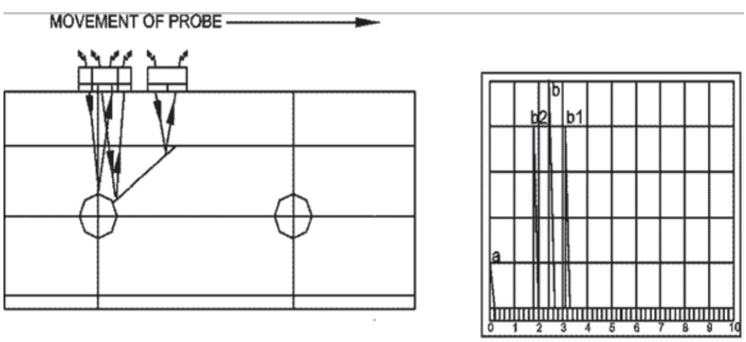
a - Surface Echo
b - Flaw Echo (Grassy Peak Pattern)

Fig : Segregation (0^0 Probe)



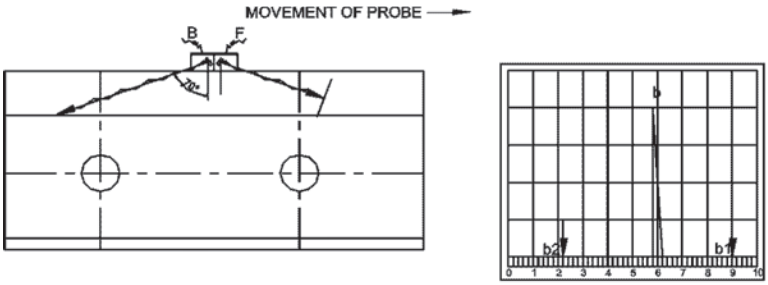
a - Surface Echo
b - Bolt Hole Echo

Fig : Bolt Hole Without Crack (0^0 Probe)



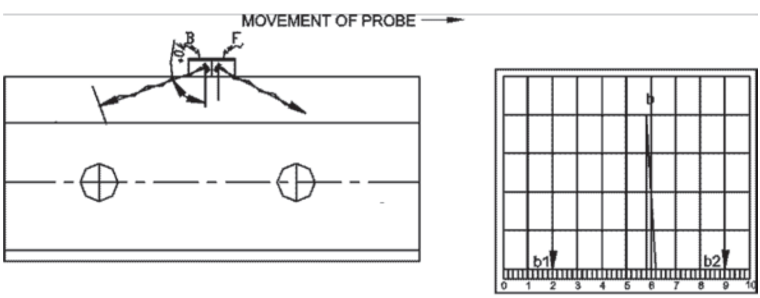
a - Surface Echo
b - Bolt Hole Echo
b1 & b2 - Shifting Flaw Echoes

Fig : Bolt Hole With Crack (Type 135, 235, 0^0 Probe)



b - Flaw Echo At Maximum Amplitude
b1 - Flaw Echo Starts Appearing From Here
b2 - Flaw Echo Vanishes Here

Fig : Transverse Defect
(Type 111, 211, 70^0, 2 MHz Forward Probe)



b - Flaw Echo At Maximum Amplitude
b1 - Flaw Echo Starts Appearing From Here
b2 - Flaw Echo Vanishes Here

Fig : Transverse Defect
(Type 111, 211, 70^0, 2 MHz Backward Probe)

Annexure 'C'

Explanation of Terms Used in USFD Scanning

A-scan Display

A cathode-ray tube display or presentation in which the travel time of the ultrasonic pulse is represented along the X-axis and the pulse amplitude is represented along Y-axis.

Angle Probe

A contact probe from which the main lobe of wave propagates at any angle, other than 0° or 90°, to the normal to the tangent plane to the surface at the place where the probe is positioned.

Attenuator or Gain Control

An instrumented control by which the amplitude of an ultrasonic signal can be adjusted by calibrated increments.

B-Scan Display

A cathode ray tube display or presentation in which the X-axis represents the probe position along the scan line and the Y-axis represents the travel time of the ultrasonic pulse. This shows the apparent size and position of reflectors in the test piece on a cross-sectional plane which is normal to the test surface and contains the beam axis of the probe during a single line scan.

Contact Scanning

Scanning carried out by means of an ultrasonic probe (or probes) in contact with the body under examination through a very thin layer of couplant.

Couplant

A liquid or semi-solid medium interposed between the probe and the object under examination to enhance the transmission of ultrasonic energy between them. Synonymous terms are Coupling Film and Coupling Medium.

Critical Angle

The angle of incidence of a beam of ultrasound on to an interface at which one of the refracted wave modes has an angle of refraction of 90^{0}.

Dead Zone

The region in a material adjoining the surface of entry from which no direct echoes from discontinuities can be detected due to the characteristics of the ultrasonic equipment and probe in association with the material under test and its surface condition.

Decibel

A unit used to express the magnitude of a change in the amplitude of an ultrasonic signal, defined by the equation, $dB = 20 \log_{10} (A1/A2)$, where A1 and A2 are the amplitudes of the ultrasonic signals 1 and 2, respectively.

Delay

A cathode ray tube control that is used to shift the initial part of the time scale laterally. Synonymous terms are Delayed Time Base Sweep and Zero Shift.

Distance and Amplitude Correction

Change in amplification of ultrasonic signals to provide equal amplitude from equal area reflectors at different distances. Synonymous terms are Time Compensated Gain and Swept Gain.

Double Probe Technique

An ultrasonic testing technique involving the use of one probe for transmission and other for reception.

Echo

A distinct pulse of ultrasonic energy reflected from any surface or discontinuity. Its display on cathode ray tube is usually a rectified pulse.

Flat Bottomed Hole

A cylindrical blind hole with a flat bottom, the flat bottom surface being used as the ultrasonic reflector.

Flaw Echo

Echo from an imperfection in an object under examination.

FSH

Abbreviation for Full Screen Height, equivalent to maximum height of the cathode ray tube display or range of the vertical scale.

Gate

An electronic means of monitoring a selected region of the cathode ray tube display of an ultrasonic flaw detector.

Grass

Spatially random signals arising from the reflection of ultrasonic waves from grain boundaries and/or microscopic reflectors in a material. Synonymous term is Hash.

Mode

The vibration patterns of waves.

Mode Conversion

The process by which a wave of a given mode of propagation is caused to generate waves of other modes by refraction or reflection at a surface or boundary. Synonymous terms are Mode Transformation and Wave Transformation.

Multiple Echo

The repeated reflection of an ultrasonic pulse between two or more surfaces or discontinuities in a body.

Multiplexer

A device for electrically connecting probes to various channels in sequence.

Noise

Any undesired signal (acoustic or electrical) that tends to interfere with the reception, interpretation or processing of the desired signal.

Normal Probe

A probe from which waves emerge at 90^0 to the contact surface.

Probe

An electromechanical device, usually incorporating one or more ultrasonic transducers, and functioning as a generator and/or receiver of ultrasonic waves. Synonymous term is Search Unit.

Pulse

A packet of waves of short duration.

Pulse Echo Technique

A technique in which the transmission of ultrasonic waves is done in pulses and the quality of the material is assessed by the reflection of pulses from discontinuities or back surface.

Range

The maximum ultrasonic path length that may be displayed on the cathode ray tube at a given time base setting. Synonymous terms are Depth Range and Time Base Range.

Reflector

An interface at which an ultrasonic beam encounters a change in acoustic impedance and at which at least a part of the ultrasonic energy is reflected.

Rejection

See Suppression

Scattering

Energy reflected in a random way by small reflectors such as grain boundaries, irregular shaped defects, etc, in the path of a beam of ultrasonic waves.

Skip Distance

For a beam of shear waves entering a body, that distance measured over the surface of the body between the probe index and the point where the beam axis impinges on the same surface after a single reflection from the opposite surface.

Suppression

The reduction of grass by the elimination of all signals below a predetermined amplitude. Synonymous term is Rejection.

Surface Noise

Unwanted signals at very short range, produced by ultrasonic waves being reflected within the coupling film and from irregularities of the surface.

Surface Wave

An ultrasonic wave which propagates on the surface of a body.

Sweep

Uniform and repetitive movement of electronic beam across the horizontal axis of the CRT screen.

Tandem Technique

An angle beam ultrasonic testing involving the use of two separate probes; one probe being used to transmit the ultrasonic energy into a body and the other being positioned so as to receive the reflected or re-directed energy from a discontinuity. It is used to detect vertically oriented flaws in thick material. In variation of the technique, more than two probes may be used.

Threshold

The minimum signal amplitude that is regarded as significant in a particular ultrasonic examination.

Transducer

An electro acoustical device for converting electrical energy into acoustical energy and vice-versa.

Ultrasonic Frequency

Any frequency of vibration greater than the range of audibility of the human ear, generally taken as greater than 20 kHZ.

Ultrasonic Wave

A disturbance (mechanical vibration) which travels through a material at ultrasonic frequencies by virtue of the elastic properties of that material.

Wheel Probe

A device housing one or more probes inside a liquid filled tire. The rolling contact area provides the coupling between the probes and test sample.

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