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AN INTRODUCTION TO ULTRASONIC WHEEL PROBES

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The ultrasonic wheel probe, also known as a “roller search unit”, is an old form of ultrasonic transducer assembly that has been around in one form or another since at least the early 1950s. With the advent of new materials and new transducer types such as phased array transducers there has been a recent resurgence of interest in wheel probes and similar transducer assemblies.

WHAT IS AN ULTRASONIC WHEEL PROBE?

A wheel probe is an ultrasonic transducer assembly that allows rolling contact of a transducer over a surface. The transducer assembly is “scanned” over the surface in a more or less straight line. An outer part of the assembly rotates, allowing the wheel to roll over the surface, while an inner part of the assembly holds the ultrasonic transducer(s) at fixed angles relative to the surface. In a wheel probe housing a phased array transducer the mechanical support for the transducer will be fixed, even though the angle may be scanned electronically.

One type of wheel probe uses a fluid filled polymer bladder to surround the transducer assembly. This bladder is usually shaped in the form of a small tyre attached to the rotating part of the wheel and which rotates as the wheel is scanned over the surface. The tyre may be made from polyurethane, silicone, or some more specialized material with improved ultrasonic and mechanical properties. This type of wheel probe can be called a “fluid filled wheel probe”.

Another type of wheel probe uses a solid rotor which rotates around an inner stator (i.e. the axle assembly) which does not rotate. The stator holds the transducer(s) in a fixed position. The rotor may be made from a material with relatively low ultrasonic attenuation such as acrylic plastic and covered with a thin compliant material such as polyurethane or silicone. However, some “solid” style wheel probes use hard contact with the test surface. This type of wheel probe can be called a “solid core wheel probe”.

Ultrasonic wheel probes generally need couplant to be used between the wheel and the test surface to allow effective ultrasonic transmission but the amount of couplant used is significantly less than that required when using bubblers or squirters (jet probes). Some wheel probes use tyres made from “dry coupling” materials and may be used in some circumstances without couplant at all, although coupling efficiency may be reduced significantly.

Wheel probes allow scanning at speeds greater than are possible with manual scanning of ultrasonic transducers and the coupling is more uniform. In ultrasonic rail flaw detection, for example, properly designed ultrasonic wheel probes can be used at speeds in excess of 60 kph.

PARTS OF AN ULTRASONIC WHEEL PROBE.

Figure 1 shows the main parts of a fluid filled ultrasonic wheel probe. The caliper is a bracket which supports the wheel probe allowing it to be mounted, but it does not have to be a separate assembly. If a separate caliper is used, the mounting plate of the caliper is usually used for attaching the wheel assembly to another mechanical assembly, e.g. for attaching a small wheel probe to a tank crawler. In industrial applications mechanical slides may be attached to the mounting plate allowing the position of the wheel probe to be adjusted.

It is necessary to get electrical access to the transducers housed inside the wheel probe. This is usually through the axle of the wheel. Electronic connectors can be fitted onto the end of the axle, or the transducer cable(s) may be routed directly to the ultrasonic instrumentation.

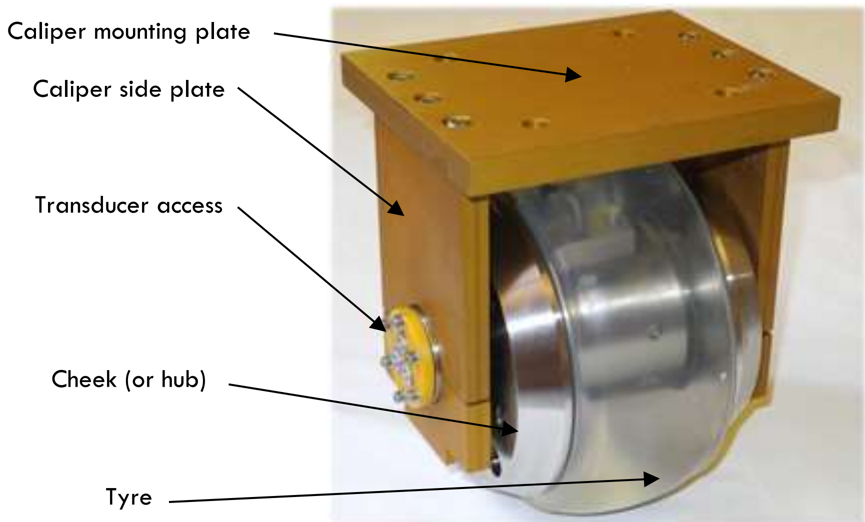


FIGURE 1: PARTS OF A WHEEL PROBE - 1

Fluid filled wheel probes usually need two valves: one for introducing the filling fluid into the wheel, and one for letting trapped air escape. The filling valve can be located in a cheek or in one end of the axle assembly. The bleed valve is usually located in a cheek. The idea is to fill the wheel with fluid and to make sure that no air is trapped in the wheel. Trapped air interferes with ultrasonic transmission within the wheel.

Solid core wheel probes require a very precise and close fit between the rotor and stator sections. The very fine cavity formed is usually filled with light oil such as silicone oil to exclude air.

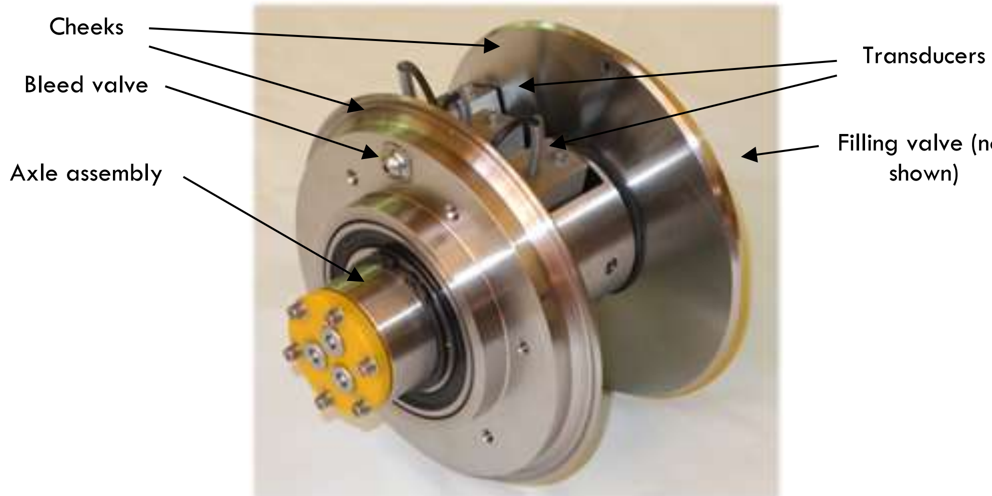


FIGURE 2: PARTS OF A WHEEL PROBE – 2

The names of wheel probe parts may vary between different manufacturers but the functions are essentially similar.

USING ULTRASONIC WHEEL PROBES.

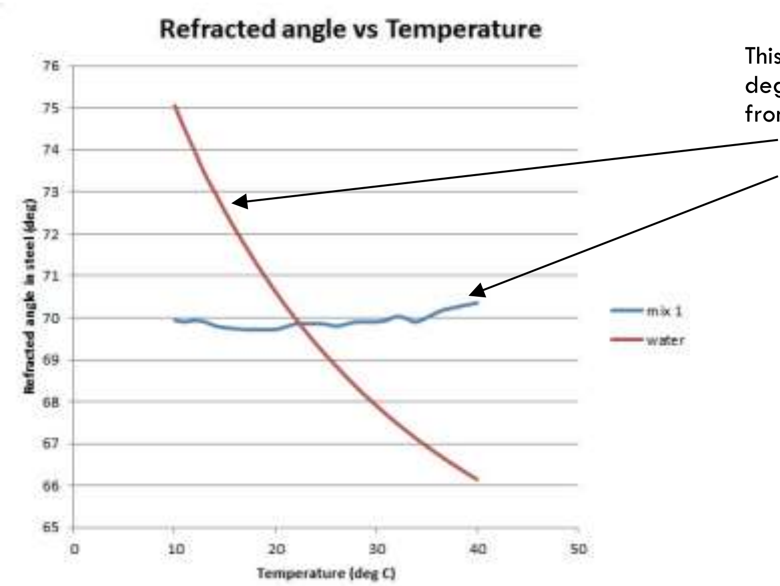
Ultrasonic wheel probes are typically used in NDT applications where the amount or location of coverage required is not practical for manual inspection. They are also used where the use of ultrasonic couplant must be minimized. They are typically used for

- ultrasonic rail flaw detection
- ultrasonic inspection of railway wagon wheels
- ultrasonic inspection of long products
- automated ultrasonic thickness testing
- corrosion mapping
- inspection of composite parts for delamination
- end area inspection of oilfield drill pipes
- ultrasonic tube and pipe inspection
- conveyor belt inspection

In applications such as thickness testing and delamination detection the wheel probe typically employs a single 0 degree probe and the data is displayed in A scan or B scan format. A wheel probe for corrosion mapping might use a single 0 degree probe or a phased array probe configured for linear scans allowing data collection for a C scan display.

Wheel probes for rail flaw detection, drill pipe end area inspection, and similar applications often have to generate a mix of compression and shear wave beams in the test item. They can employ multiple transducers and require very precise machining of the transducer supports to minimize errors in the transducer mounting angles. In particular, wheel probes used for generating ultrasonic beams at angles in the test item must be filled with a special fluid that has minimal variation of ultrasonic velocity with temperature; otherwise the refracted angle of the beam in the test piece will also vary with temperature. There are certain mixtures of fluids with water that provide the minimal temperature variation.

Precise ratios of water mixed with either ethylene glycol or glycerol (glycerine) are commonly used, although mixtures of water with various alcohols could also be used. However, once a wheel is designed for a particular fluid mixture, only that mixture should be used. Wheel probe fluid mixtures are not interchangeable.



This figure shows the variation of a 70 degree shear wave in steel generated from a wheel probe:

1. Filled with distilled water
2. Filled with a fluid mix for minimal velocity variation with temperature

FIGURE 3: TEMPERATURE VARIATION OF 70 DEGREE SHEAR WAVES IN STEEL

COUPLING OF WHEEL PROBES

Most wheel probes require couplant between the tyre and the test piece surface. Even “dry coupled” wheel probes benefit from the use of couplant.

The couplant excludes air from between the tyre and test piece surfaces. Trapped air provides a very large impedance mismatch which does not allow efficient transmission of the ultrasonic pulses from the wheel to the test material. When air is excluded and the tyre and test surface are in intimate contact, ultrasonic transmission is greatly improved.

The couplant may be water, and it may be applied as a fine spray or wiped onto the tyre or test piece surface. Stronger spays of couplant have the benefit of cleaning dust of the test surface and flooding small depressions in the surface. Fine sprays are adequate for surfaces in good condition.

Dry coupling makes use of special polymers for making the tyres. One type of “dry coupling” tyre makes use of hydrophilic (“water loving”) polymers. These polymers absorb water and become soft and flexible when hydrated. An example is the sort of polymer used for contact lenses. When hydrated, these polymers transmit ultrasonic up to quite high frequencies (> 5 MHz) very well and exude a small amount of water, sufficient to allow efficient transmission into the test piece. While having good ultrasonic properties, hydrophilic polymers may lack suitable mechanical properties for widespread wheel probe use. Also, their properties change as the polymer dries out.

Some proprietary polymer blends have been created which allow efficient dry coupling. Some off the shelf or simply modified silicones also allow dry coupling in some limited circumstances, but these are generally not as good as the proprietary or the hydrophilic polymers.

A downside of dry coupling is the propensity of the tyres to pick up dust and dirt, reducing efficiency of the ultrasonic transmission.

Wheel probes for heavy duty use in applications like ultrasonic rail flaw detection use polyurethane tyres. Other polymer materials are not tough enough for such use. Polyurethanes can have high wear resistance and high tear resistance, and some have ultrasonic transmission properties useful up to 5 MHz. These heavy duty polyurethane tyres are not suitable for dry coupling and always need couplant.

DEPLOYMENT OF ULTRASONIC TRANSDUCERS WITHIN THE WHEEL PROBE.

Traditionally transducers were located inside wheel probes with a significant standoff of the transducer from the interface with the test material. This distance is called the “water path length”.

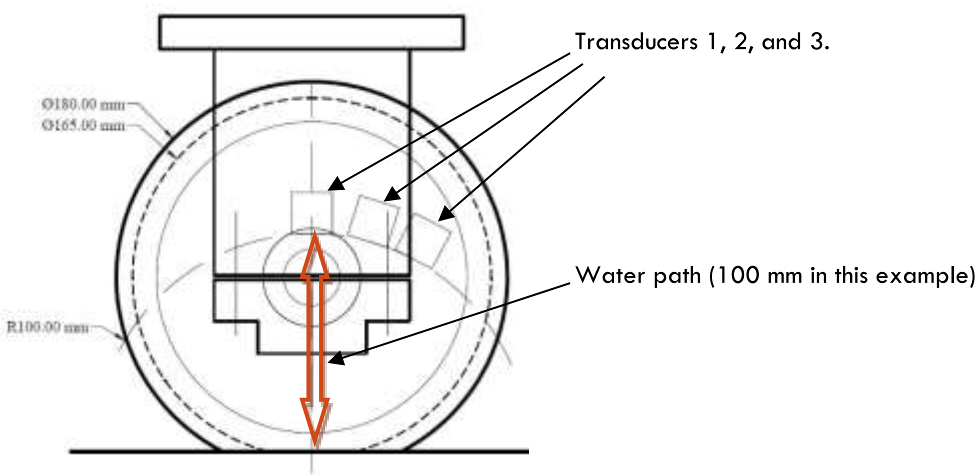


FIGURE 4: WATER PATH

In Figure 4, three transducers are shown: a 0 degree transducer and two transducers producing shear waves in the test material. Each transducer face is the same distance from the entry point (i.e. the “index point” of the sound beam entry into the test material. In this example, the water path length is 100 mm, but it could be more or less, depending on the application.

It is necessary to take into account the time delay introduced by the water path length when designing system timing for wheel probe applications

- in order to prevent cross-talk between the different ultrasonic transducers,
- to allow proper timing for setting up timing gates, and
- to prevent “phantom echoes” from incorrect PRF selection.

Some wheel probes designs do not use a water path. The transducers are placed directly onto the inside surface of the wheel probe tyre and spring loaded with a weak spring to maintain contact. The wheels still need filling with a fluid to provide lubrication between the transducer face(s) and the tyre. In this case light oil may be better for filling the wheel than a water based fluid mixture for minimal temperature variation.

It is necessary to take into account the internal configuration of ultrasonic wheel probes. The presence of internal reflectors (e.g. other transducers facing in the opposite direction) may introduce “internal echoes” that limit the performance of the wheel probe by limiting the echo capture times available before interference from these echoes occurs.

Fluid filled wheel probes generally use single element or phased array transducers, or a combination of both. Solid core wheel probes can be constructed to operate like a rolling twin crystal probe.

CALIBRATION OF WHEEL PROBES.

It is essential for wheel probes that generate shear waves in test materials to be calibrated correctly. Calibration must establish any deviations from the intended refracted angles in the test materials, and also deviations in the designed index points of the various transducers in the wheel.

Calibration errors can arise from

- incorrect mixing of the filling fluid:
    - the wrong mix ratio
        - gives the wrong refracted angles
        - makes the refracted angle temperature sensitive
    - additives such as anti-corrosion agents may not have not been characterized for their effects on the temperature coefficient of ultrasonic velocity
- machining errors
- not designing the transducer angles to the correct wheel probe fluid ultrasonic velocity
    - Snell's Law applies, and the correct ultrasonic velocities must be used to achieve the correct refracted angles

Errors accumulate, and the effect of the ultrasonic velocities in metals and other solids being higher than the velocity of the wheel probe fluid is to amplify any errors further. For example, in ultrasonic rail flaw detection, commonly used shear wave beams in the rail are angled at 70 degrees and 38 degrees. If the accumulated errors are such that the refracted 70 degree beam is actually closer to 75 degrees, the proportion of surface wave generated on the rail surface will increase and more false positive indications will arise from rail grinding marks.

The 38 degree beam is used to detect cracking around bolt holes in rail. There is a critical angle at 33.2 degrees in steel for the wheel probe fluid recommend by NTS Ultrasonics. As the refracted angle deviates from 38 degrees towards 33.2 degrees due to mechanical errors or thermal variation in wheel probe fluid velocity, the shear wave amplitude rapidly decreases towards 0 at the critical angle.

Errors for shear waves in steel (vel = 3.23 mm/us)	**Error**
Angle error to produce 75 degrees instead of 70 degrees	0.86 degrees
Angle error to produce 33.2 degrees instead of 38 degrees	2.07 degrees
Error in fluid velocity to produce 75 degrees instead of 70 degrees	0.044 mm/us
Error in fluid velocity to produce 33.2 degrees instead of 38 degrees	0.204 mm/us

FIGURE 5: WHEEL PROBE CALIBRATION ERRORS

As can be seen from Figure 5, some quite small machining or velocity errors can result in significant refracted angle errors in steel that will have an impact on wheel probe performance.

Traditional wheel probe calibration ("zeroing") for wheel probes with transducers for producing refracted shear waves tends to ignore calibration of the shear wave probe angles and only calibrates the 0 degree probe, if one is present in the wheel. This is unsatisfactory as the 0 degree probe is less sensitive to angle and velocity errors than the shear wave probes.

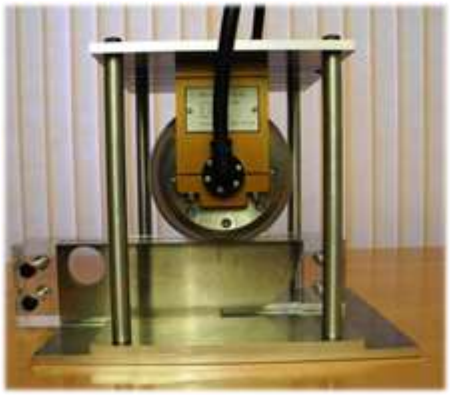


FIGURE 6: WHEEL PROBE CALIBRATION RIG

Figure 6 shows a simple calibration rig that allows use of an IIW calibration block to determine wheel probe refracted angles and index points.

WHEEL PROBES FROM NTS ULTRASONICS.

NTS Ultrasonics started off making wheel probes for heavy duty use, based on earlier experience gained from designing wheel probes for ultrasonic rail flaw detection. The basic heavy duty design is designated PL180 for a wheel probe of 180 mm diameter (when inflated with fluid) with a tough polyurethane tyre. The author of this document instigated the original 180 mm wheel probe design back in the 1980s, and it has since been adopted by all Australian manufacturers of rail flaw detection systems and has also used in Asia and North America. The PL180 wheel probes have customizable transducer configurations and can accept multiple single crystal transducers, including paintbrush style transducers. They are suitable for various railway, steel mill, and drill pipe end are inspections.

A variation on the basic PL180 design can accept single or multiple phased array transducers. Several versions have been built with one holding four PA transducers.

Conventional PL180 with cables fed through a conduit

Modified PL180 holding a single PA transducer

FIGURE 7: PL180 VARIATIONS

The NTS Ultrasonics wheel probe range has been expanded to include the RL70 wheel probe which has a 70 mm diameter when inflated with fluid. The RL70 is a single transducer wheel using a 0 degree probe intended mainly for corrosion mapping, thickness testing, and similar applications, but it is suitable for other NDT inspections as well. The tyre is made of a modified resin that offers good ultrasonic performance up to ultrasonic frequencies of 7.5 MHz. The tyre is not intended for dry coupling, but it will dry couple on some flat, clean surfaces.

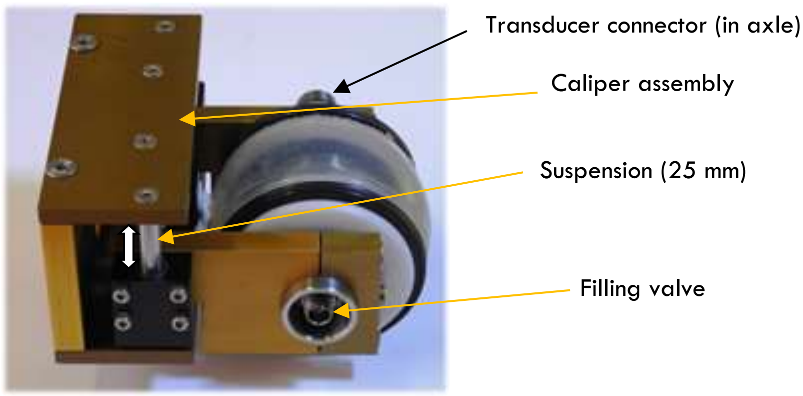


FIGURE 8: RL70 WHEEL PROBE WITH CALIPER WITH SUSPENSION

INSTRUMENTATION FOR ULTRASONIC WHEEL PROBES.

Electronic instruments for use with ultrasonic wheel probes are generally very similar to the instrumentation used in other areas of ultrasonic NDT, with the possible exception of the specialized systems design specifically for high speed ultrasonic rail flaw detection.

For single transducer ultrasonic wheel probes such as the RL70, standard single channel ultrasonic flaw detection equipment can be used. The main considerations are:

- Does the UT set have sufficient delay to cope with the water path delay?
  - The required delay could be in excess of 125 us for wheel probes with a 100 mm water path.
- Does the UT set have multiple gates with at least one gate that can be set as an interface gate with leading edge triggering and following gates set up for “interface following”?
  - Interface following is useful in situations where the water path length changes. The exact time of the interface echo is measured and following defect gates are synchronized to this interface. As the interface moves in time, the defects gates also move to keep a fixed timing relationship with the interface.

Multiple transducer wheel probes need multiple channels of electronics, usually one channel per transducer. However, it is not uncommon to combine two transducer outputs in parallel into a single channel of electronics. For example, in a simple rail flaw detection system, a 45 forward facing and 45 degree backward facing transducer may run in parallel through a single channel of electronics to save cost. In multi-transducer systems where speed of data collection is not important, it may also be acceptable to use a single channel of electronics connected to the wheel probe transducers through a multiplexer.

The same considerations apply for wheel probes containing phased array transducers. A single phased array transducer requires a single phased array channel of electronics.