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Transit Time Ultrasonic Flowmeters Stretch Their Application Reach

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Introduction

The idea of measuring fluid flow based on the difference in transit time with the flow versus against the flow dates back to the 1800s, and maybe even earlier. Practical implementations of this concept awaited modern electronics. In the pre-microprocessor days, say 1950s-1970s, it was already understood that even a perfect measurement of transit time in each direction along a tilted diameter path was not sufficient to determine flow to accuracy better than a few percent. Reason? *Uncertainty in flow profile.* By the mid- to late- 1970s, commercially available solutions included: (a) Clamp-on, diameter path, with meter factor corrections based on power law or pipe friction models; (b) midradius paths; (c) multipath quadrature integrations.

Generally speaking, ultrasonic flowmeters solved liquid flow problems first, then multiphase, then gas. Up to now, clamp-on has been most successful with all sorts of liquids and some multiphase fluids. But so far, for gases, clamp-on flow measurements have been demonstrated only in special circumstances like high pressure N_2 in steel pipe; ordinary air in plastic pipe; flow velocities within certain bounds.

Today's efforts in transit time flowmetering include areas such as multipath (off-diameter quadrature or midradii paths) for achieving high accuracy independent of profile. With clamp-on, one also seeks the highest accuracy attainable within the constraints of on- or near-diameter paths that can be utilized when the transducers are completely outside the pipe and no modification of the pipe wall is allowed. Between these two extremes, several compromise solutions exist where some degree of wall modification is accepted in exchange for improvement in accuracy or to achieve some other added value. Table 1 summarizes many of the paths chosen by different researchers or manufacturers who sought, and still seek, the true value of flow. Apart from improving accuracy and reducing cost, today's efforts are directed to expanding the scope of applications. This means, while it is important to know today's limits, it is also important to recognize that some of these limits might be overcome by better transducers, better signal processing, or their combination, optimized for a particular fluid and an important set of flow conditions.

There are many factors motivating the preference for ultrasonics over competing technologies. These include accuracy; rangeability; little or zero invasiveness; negligible pressure drop; linear response; bidirectional; easiest to retrofit when clamp-on is acceptable; hot tappable or spoolpiece solutions when clamp-on is not sufficient. Fast response, low cost (despite opinions expressed to the contrary without distinguishing among purchase price, installation cost and ongoing cost of ownership), no moving parts, versatility, portability, zero or minimal maintenance, and ruggedness are other features found in many of today's ultrasonic flowmeters. Naturally, no single model is likely to have all of the conceivably desirable attributes.

Discussion of Clamp-On, Wetted and Hybrid Approaches

In this short article we can only summarize a few key ideas. Details are found in the literature [1-11]. Figures 1-6 illustrate examples of clamp-on, wetted and hybrid approaches. An important limit "today" is high temperature. Buffer waveguides, however, have proven to be one practical way to extend transit time flowmetering concepts down to the cryogenic range (-200°C) and up to high temperature (500°C). Is 500°C the upper limit? That depends on the length and material of the buffer, together with other aspects of the proposed application.

For clamp-on, one of the important apparent limits is small pipe diameter. In the sixties, the lower *D* limit for steel pipe containing water was about 0.3 m (1 ft). It is now down to ~ ¼″ (~ 6 mm) for thin metal tubing. Superheated (270°C) water flow has been measured in Ø3″ schedule 40 steel blowdown pipes for over a year in a nuclear plant in the Northeast, and in Ø3″ pipes in a Belgium nuclear plant for over three years. A hot hydrocarbon liquid has been measured to 400º in France. Cryogenic flows were measured by clamp-on in Korea (Ø6″) and in Japan down to Ø2″. Again, these hot and cryo extremes were handled with long-handled OKS "hockey stick" transducers (Fig. 2a,b). These transducers include a standoff or buffer portion which projects radially outward from the pipe so the piezoelement can operate comfortably at ordinary temperature.

What about low density fluids like air, natural gas or steam? These are not yet within the province of clamp-on. *Wetted* transducers, however, already measure air and steam flow in hundreds of applications. Wetted transducers, in the multipath flowmeters of several manufacturers, also measure natural gas, with an accuracy of 0.5% being typical. This accuracy is typically achieved by weighting measurements obtained over several paths (three to six, for example). "Experience" allows manufacturers to reduce errors or uncertainties, to the extent there is relevant data available on the piping and the fluid. CEM applications [8] of wetted transducers demonstrate the use of ultrasound to measure hot nasty gases flowing at Mach 0.1 in smokestacks having diameters of 3 to 15 m (~ 10 to 50 ft).

Clamp-on accuracy *claimed* for liquid applications sometimes reaches ± 0.5%, but if one examines the sources of uncertainty one is led to conclude that, just as for *any* flowmeter, the conditions for which the claim is valid need to be carefully examined. Compared to clamp-on, claims for flowmeters using wetted transducers are more easily verified by calibration at an independent lab. However, one must take into account the increase in uncertainty when an accepted calibrated meter is installed in the field and operates under conditions different than when calibrated.

Natural gas custody transfer applications, solved by multipath flowmeter manufacturers including Daniel and Instrumet, is a good example where ultrasound is becoming, perhaps has already become, the meter of choice because of its years of essentially drift-free performance, high accuracy, wide turndown ratio, and lower cost resulting from that wide turndown ratio, compared to an orifice station. A new spoolpiece multipath design, developed jointly by RMG and Panametrics, is shown in Fig. 4. Depending on the accuracy spec, simpler versions derived from this three-plane Chebyshev solution may suffice.

Flare gas applications (Fig. 3), comprising over 1000 installations since 1984, represent another example of reliable service over years, along with a multiparameter feature: average *MW* (molecular weight) and mass flowrate outputs derived from the sound speed, after routine compensation for temperature and pressure. Flare gas installations are often hot-tapped, in contrast to the usual multipath spoolpieces used in the natural gas custody transfer cases, e.g. Fig. 6.

Steam is an emerging application in the sense that only a few hundred such applications are in service so far. Of these, a few have been running for about five years. To handle the highest temperatures of steam, as well as other gases that are processed up to about 500°C, fiberacoustic bundle waveguides have proven effective in hundreds of installations since about 1995. The first were in The Netherlands at a Shell refinery, where the pressures reached 209 bar in some cases. Originally used only in gases, they are now used in liquids and in two-phase applications like intermittently-flashing cryogenic situations.

Clamp-on is by far the most common use of transit time ultrasonics in industrial (e.g. chem plant) flowmeter applications. Simple plastic wedges like those used in NDT angle beam testing usually suffice. One of the largest applications for clamp-on is in *large diameter pipes* for measuring the flow of water or other liquids where cost is reduced significantly in comparison to any solution requiring a spoolpiece. Reason: the cost of a clamp-on system is fairly independent of pipe diameter. Buffers extend applications down to –200°C in pipes of Ø2″, and up to superheated water and hot hydrocarbon liquids, 260 to 360°C so far. Molten salt applications, which occur in some cases up to roughly 750°C, might be solvable with a longer-handled OKS transducer. The thin buffer developed and proven in the –200°C to +360°C portion of temperature extremes (Fig. 2 a,b) is also finding other possible applications. One of these possibilities is sea bottom, where the weld-on transducer would be exposed to pressures on the order of 68 MPa (10,000 psig). Another possibility is a hybrid multipath spoolpiece notched internally and externally, controlling the paths to lie in quadrature planes analogous to multipath wetted transducer spoolpieces. But now the transducer can be removed at any time since it is not part of the presssure boundary (Fig. 6). Still another is clamp-on swirl sensing, similar to Fig. 1b.

Conclusions

- Clamp-on, wetted and hybrid solutions exist for many fluid flow situations: air, gas, steam, all sorts of liquids, standard atmosphere, hazardous environment, etc. The envelope of applications is being extended to broader ranges of flow, conduit size, fluids and measuring requirements.
- Temperature extremes (cryo or very hot), beyond the range of housed transducers, can be handled by buffering the piezoelectric transducers that generate or detect compressional or shear waves. This has extended clamp-on and wetted transducer applications down to cryogenic levels, -200°C, and up to 400°C for clamp-on, and 500°C for wetted buffers, so far.
- A spoolpiece offers advantages of calibration, path control, and precise placement of transducers. These transducers are usually wetted but they can be clamp-on, at least for liquids. Multipaths, especially off-diameter paths, are utilized in high-accuracy equipment intended for applications where the flow profile is not known very well. Accuracies of multipath flowmeters are typically ½% or better, if properly installed and used in their intended range.
- Multiparameter output from the "ultrasonic flowmeter" often includes flow velocity V plus one or more of: volumetric flow rate Q, sound speed c, gas average molecular weight (MW), density (ρ), mass flowrate (M_F). Less often, but certainly possible with transmission (contrapropagation) flowmeters for ideal gases or pure liquids, would be the reporting of temperature T averaged over the path used to obtain V.

Acknowledgments

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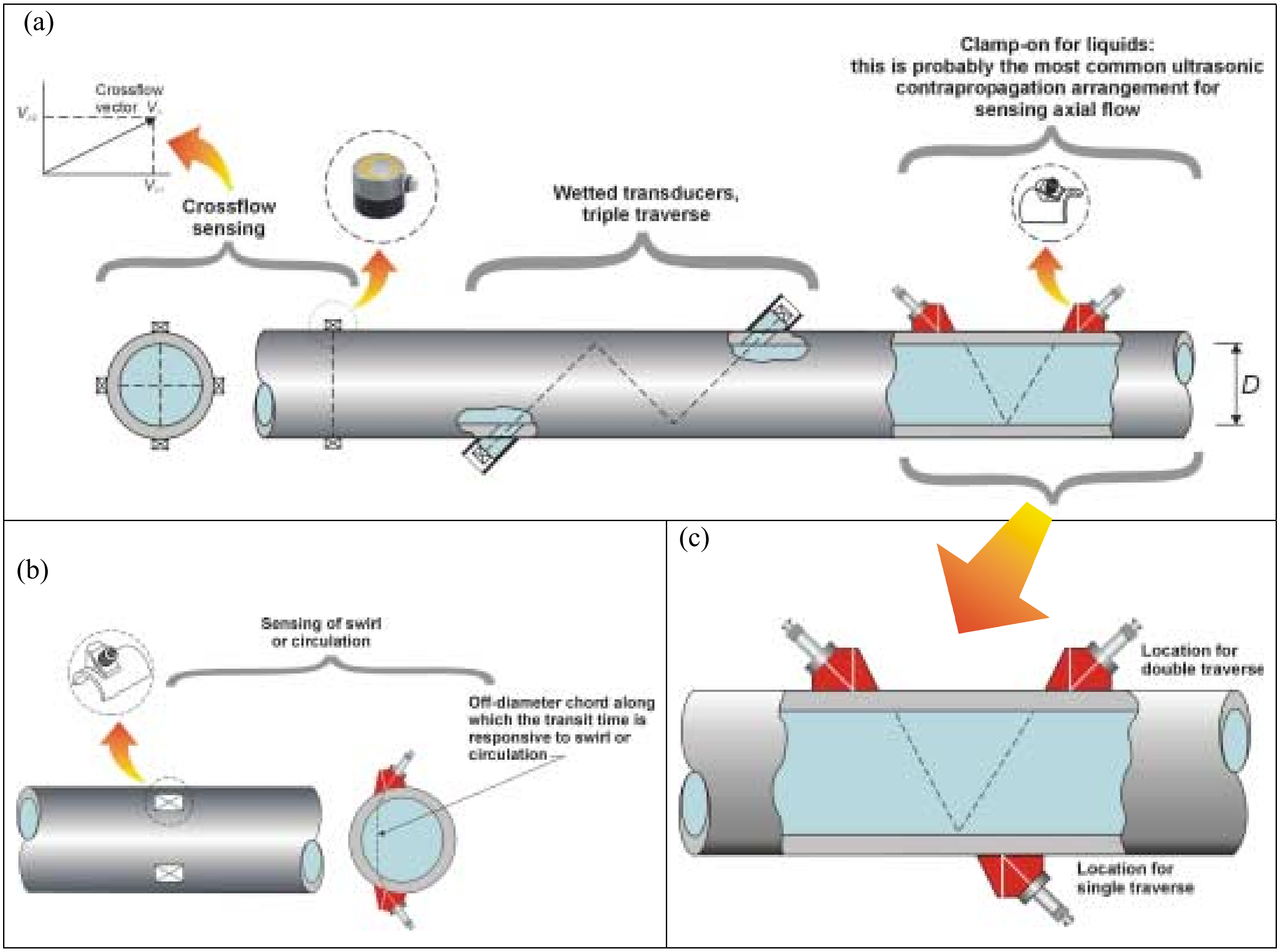

FIG 1: Ultrasonic contrapropagation flow measurement at ordinary temperature utilizes upstream and downstream times-of-flight, each determined to high precision. The transducers may be wetted or clamp-on. Wetted transducers have been preferred over clamp-on if the fluid is of low density (gases), or if off-diameter nonrefracted multipaths along prescribed geometries are necessary to accurately deal with variable flow profiles and nonideal installation effects. Clamp-on has the advantages, for liquid flow, of easy installation, no holes, and the possibility of easily going from one pipe to another to obtain a flow survey. Sometimes it is possible to combine the features of clamp-on and wetted approaches in a "hybrid" spoolpiece (Fig. 6). The schematic associated with the left end of (a) symbolizes a clamp-on measurement of the crossflow velocity V_x. (b) Schematic representing clamp-on measurement of swirl or circulation. (c) Single- and double-traverse for clamp-on at ordinary temperatures. ©2000 Panametrics.

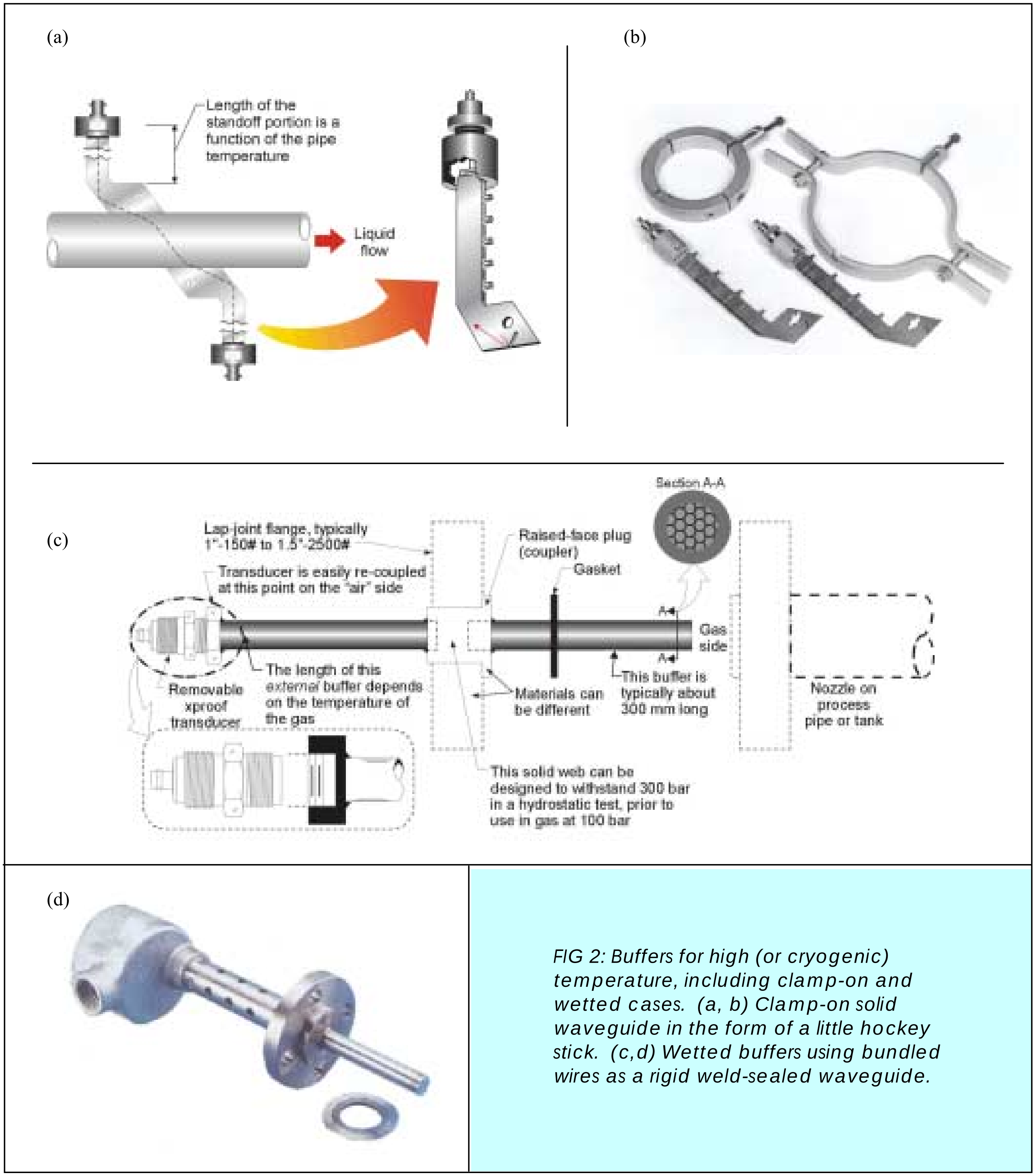

FIG 2: Buffers for high (or cryogenic) temperature, including clamp-on and wetted cases. (a, b) Clamp-on solid waveguide in the form of a little hockey stick. (c,d) Wetted buffers using bundled wires as a rigid weld-sealed waveguide.

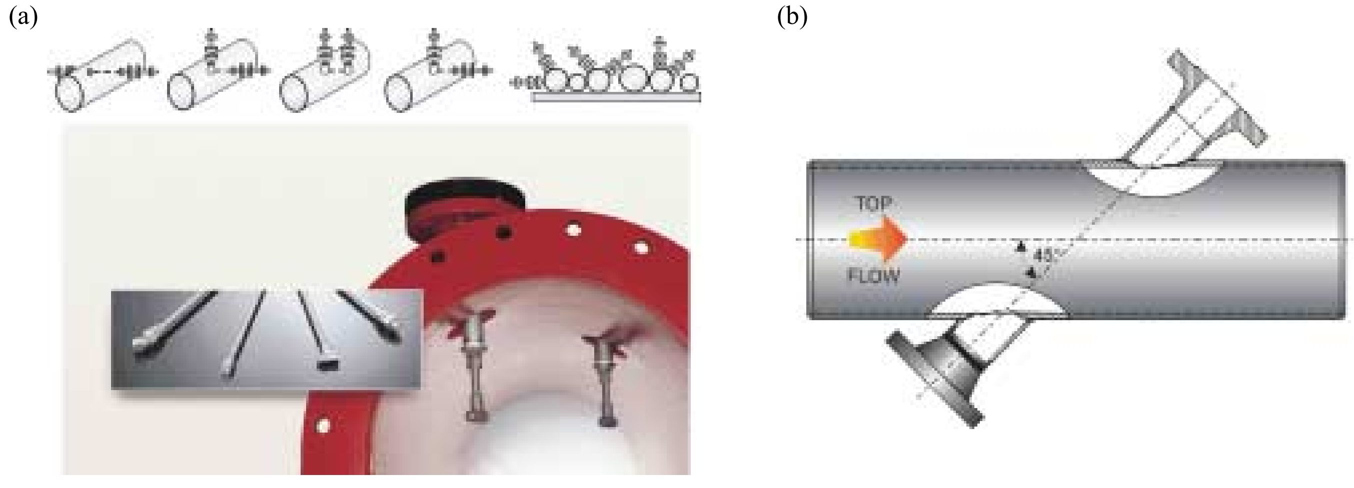

FIG 3: Flare gas applications use (a) hot-tapped solutions or (b) spoolpieces.

FIG 4: Multipath three-plane Chebyshev spoolpiece for high-accuracy custody transfer of natural gas, developed by RMG & Panametrics.

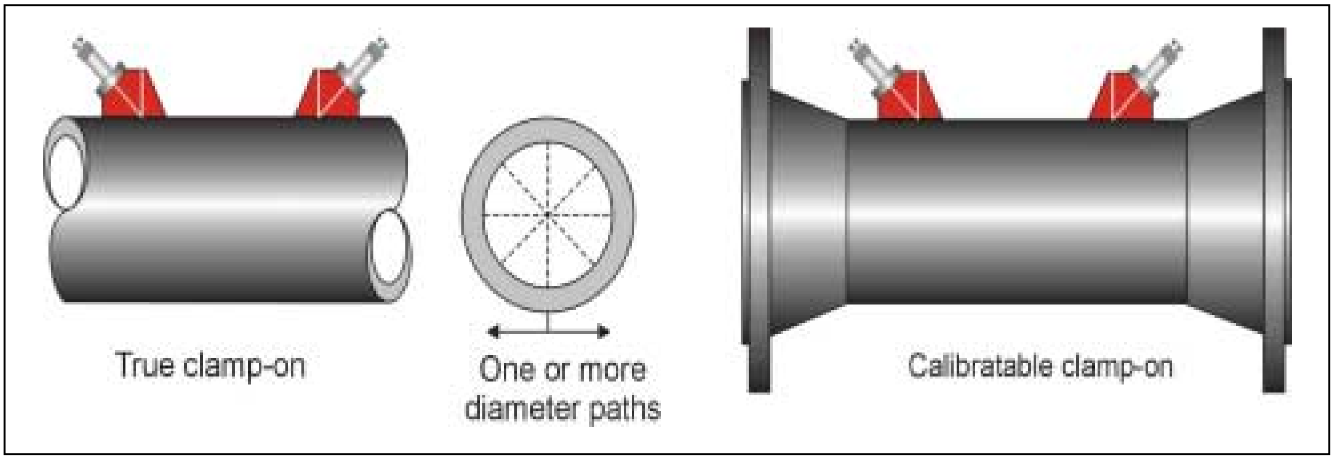

FIG 5: Clamp-on diameter paths on an undisturbed pipe and on a spoolpiece. More diameter paths generally give higher accuracy but still do not permit quadrature integration methods to be used.

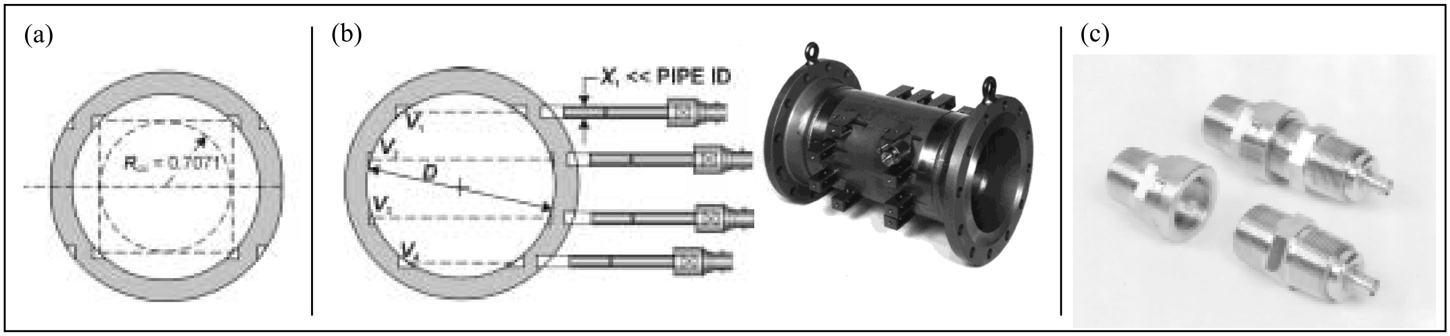

FIG 6: Hybrids are compromises that combine the characteristics of clamp-on and wetted methods. The three- and four-path hybrid spoolpieces in (a) and (b), respectively, are notched so paths correspond to traditional quadrature multipath solutions. These calibratable no-holes multipath R&D spoolpieces use the ***thin*** *blade-like character of 2-MHz OKS transducers of Fig. 2(a), to interrogate across narrow, off-diameter well defined regions without the usual ports. (a) Three-plane Chebyshev schematic. (b) Schematic and implementation in a Ø10" prototype* ($ID = 254$ mm), *with four paths* ***reflecting*** *in traditional parallel GC planes. The volumetric flow rate is* $Q = 0.138(V_1 + V_4) + 0.362\ (V_2 + V_3)]\pi D^2/4$. *In the photo, yokes are welded over each transducer site. (c) Pan-Adapta® precision plugs accommodate removable transducers, while providing the controlled paths associated with wetted transducers. The plug gets wet, but the transducer stays dry, like a clamp-on sensor.*