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Gas and Liquid Ultrasonic Transducer Technology
– Latest developments and what it means for Diagnostics

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1. INTRODUCTION

Ultrasonic flow meters continue to gain recognition in the oil and gas industry worldwide. Since the first multipath gas ultrasonic meters were introduced in the early 1990's they have now become the preferred technology for most custody transfer and non-custody transfer installations on all 5 continents.

Liquid ultrasonic meters were introduced a few years later and have yet to receive the same full acceptance as gas ultrasonic meters. Probably the major hurdle, and a key difference between the usage of gas and liquid flow meters, is the onsite proving normally done for liquid meters. In line proving of ultrasonic flow meters is not as easy as we have come accustomed to using traditional technologies like Positive Displacement (PD) meters and turbine meters. However, the ultrasonic meters applicability is growing and the constant evolution of the technology is indeed helping.

The advances in electronics, signal processing and especially ultrasonic meter software have made possible certain developments in ultrasonic transducers. This has shown that to optimize performance in all the different conditions where gas and liquid ultrasonic meters are now being applied, one transducer to fit all applications will no longer provide the industry with the best solutions.

This paper will address some of the challenges provided, detail key specific issues that needed to be resolved, and describe solutions to the challenges.

The second part of the paper will take the next step and explain what these solutions have done for the signal processing in ultrasonic meters and how this in turn opens up new possibilities in ultrasonic meter diagnostics. It will detail how these possibilities now makes it possible to further close the gap between diagnostic and meter performance – which may be the last "holy grail" of the ultrasonic meter development.

The last part will discuss how the diagnostics information together with all the valuable flow information can be used to assess the results from a flow calibration and the validity on site. Possibly this information can also be used to evaluate the uncertainty of flow calibration facilities caused by varying conditions. Such varying conditions can in certain cases lead to unnecessary failed tests of good meters – which are costly and time consuming.

2. TRANSDUCER TECHNOLOGY – THE ORIGIN AND ITS LIMITATIONS

When ultrasonic gas meters were introduced in the early 1990s the technology obviously was limited to the transducer and electronics technology available at the time. For electronics that meant three major limitations compared to where the technology is today:

1. AD conversion and sampling – limited AD conversion and sampling, resulting in the use of only key signal information like the timing of zero crossings, signal amplitudes, gain levels etc.
2. Memory – obviously limited the amount of information which could be stored and used for signal processing, and also later used for longer term diagnostics and trending
3. Processing power – limiting the amount of data analysis that could be done. This of course was also limited by the amount of signal information available.

On the transducer side the core technology used in all gas and liquid ultrasonic meters, the piezo ceramic crystals were available, but several other aspects of transducer design and the effects of their design in the widest range of applications were limited.

2.1 The Origins - Gas

As described in an earlier paper from the SEA Workshop in 2006 [1], The piezo ceramic, or piezo electric elements are very sensitive and relatively fragile so they are in one way or another isolated from the process in which they are installed. This may be done for example by placing these piezo ceramic elements inside a metal transducer housing which is sufficiently solid to withstand the pressures in question. This method reduced cracking and bonding challenges at high pressures and wide temperature ranges, which were experienced with other types of transducer constructions. The most used alternate solution was to mould a piece of epoxy around the piezo directly, and use the epoxy not only as an acoustic matching layer but also as the insulator to the process conditions.

For the FMC MPU series gas flow meters transducer, titanium was chosen as the housing material due to e.g. its advantageous corrosive, chemical and mechanical properties, and its acoustic impedance being rather close to the acoustic impedance of the piezoceramic element (cf. Fig. 2), which reduces the signal loss due to the unavoidable impedance mismatch between the transducer and the gas.

With the electronics and the signal processing available in the late eighties/early nineties, piezoelectric transducers encapsulated in titanium without employing any matching layer, was not so relevant for use in ultrasonic gas flow meters. To increase the coupling to the gas and the signal level, as well as to improve the acoustic properties of the transducer (bandwidth, directivity, etc.), an acoustic impedance matching layer was used.

Fig. 1 – Photograph of titanium encapsulated transducers with and without an epoxy front

Piezoceramics (typical)	32 Mrayl
Titanium	27 Mrayl
Epoxy (typical)	3 Mrayl
Natural gas @ 100 bar	0.04 Mrayl
Air (@ 1 atm., room temp.)	0.0004 Mrayl

Fig. 2 – Typical acoustic impedances of some materials and gases (examples).

2.1.1 Wet Gas – an Issue

Epoxy is a polymer, i.e. chemically bound hydrocarbons in a three-dimensional crystal structure, and as such it will be dissolved by solvents. One common component in hydrocarbon formations is hydrogen sulphide, or H_2S. When present in normal dry natural gas, H_2S is quite benign to epoxies, and ultrasonic meters can maintain performance over many years with concentrations of tens or hundreds of parts per million. However, in a wet gas application, especially if water is present, the H_2S can dissolve in such aqueous solutions producing a weak acid (pH7 down to pH3, or sometimes lower). This acid will over time affect any epoxy and start to break it down. This will of course affect the performance of any ultrasonic gas flow meter with epoxy based transducers.

2.1.2 Crude Oil and Condensate – Another Issue

Unfortunately, it is not only the commonly known aggressive components (like H_2S) that will cause problems for epoxy based transducers in the oil and gas industry. A number of the heavier hydrocarbon molecules, often designated the C_6+ components in gas/oil compositions, are actually epoxy solvents as well. It is in particular the components in the Aromatic series which will attack epoxies and eventually dissolve them. These constitute Benzene (C_6H_6), Toluene ($C_6H_5CH_3$), Ethyl benzene ($C_6H_5C_2H_5$) and Xylene ($C_6H_4(CH_3)_2$), - the so called BTEX components.

As solvents, not only will these components react with the surface of any epoxy, but will be absorbed by the epoxy and change the structure and behaviour also from within. This of course may strongly affect the performance of the ultrasonic gas flow meter.

Fig. 3 shows a diagonal cut through an MPU transducer matching layer which has been exposed to Aromatic components over a 4-6 months period. One can clearly see how the original "fresh" epoxy (the darker section in the middle) has been affected and absorbed the fluid it has been exposed to along its edges (the “whiter” area).

Fig. 3 – Diagonal cut through an MPU transducer matching layer which has been exposed to Aromatic components.

2.1.3 And Finally – Size and Ultrasonic Noise

In addition to the critical process issues of chemical resistance and pressure and temperature conditions the first meters on the market utilized a “one transducer fits all” strategy. Basically that meant transducers of one size, and as a result one size piezo with one resonance frequency. The standard size transducers meant that there was a limit to how small the meters could be made with full path designs.

There were two major issues causing this:
1 – Simply the problem of fitting all the transducers with its mounting hardware on a small piece of pipe.
2 – The influence on accuracy caused by the disproportionately large cavities which was a result of the “large” diameter transducers in a small piece of pipe.

In the 2000s several manufacturers launched two or more different size transducers to overcome the two issues above, and also to try and improve their meters’ capabilities in dealing with another issue encountered in many installations around the world – ultrasonic noise.

All gas ultrasonic transducers operate in the kHz range. Several companies introduced different transducers that operate at fairly discrete frequencies from 100 kHz up to roughly 350 kHz. This indeed helped address the size issues, as smaller diameter transducers can be made when using piezos that operate at higher frequencies. However, their ability to compensate for or deal with the ultrasonic noise most often created by control valves was highly overrated. Noise spectrums taken from such installations have show that it has a fairly broad range that certainly covers the range used by the USMs on the market.

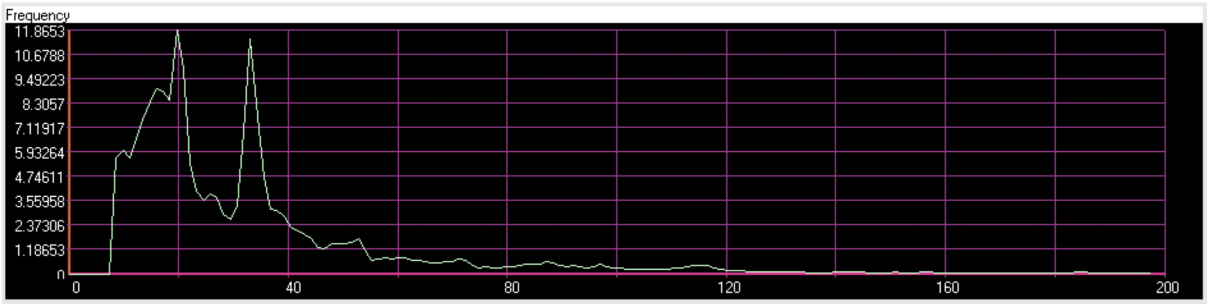

Fig. 4 – Noise frequency spectrum measured after a control valve at Saudi Arabia Pump Station 3 (Saipem) with a microphone.

2.1.4 What Needed to Change?

Even if the transducer is the heart of any ultrasonic flow meter, as with the human body, no part can exist on its own and the whole system has to be "in tune" and in shape to achieve optimum performance. The developments in both electronics and signal processing have been vital in the further evolution of ultrasonic meters – but, the transducer technology had to evolve as well.

To do that, all the key parameters of transducer performance had to be addressed – individually and collectively to define the desired range and weight of each parameter to find the best solution for that meter design. Among these parameters are:

Temperature	Drift in performance over operational range
Pressure	Calibration (yes/no)
Flow/velocity range	Bandwidth
Directivity	Sensitivity
Gas quality (dry/wet/CO_2/H_2S/C_6+)	Zero point offset (Delta T)
Meter dimension (size)	Lifespan
Transducer size (diameter)	Acoustic matching

Fig. 5 – Parameters affecting the design and performance of USM gas transducers

2.2 Gas Solutions

As discussed above the first step taken by several manufacturers was to offer different size transducers. This immediately addressed the size and cavity distortion and turbulence issues. Different sizes also meant different frequencies, but the noise issues were not really resolved by this step.

Acoustic impedance matching using layers of epoxy around or in front of the transducers are also about to become a thing of the past. Transducer designs have been able to increase sensitivity, matched with improved signal processing, enough to compensate for the loss of the approximately 30 dB signal gain provided by an epoxy matching layer. This has left one issue remaining for some manufacturers though – the inability to cope with very low pressures – commonly referred to as pressures below 10 bar.

A tonpilz design transducer is fairly simple and has high sensitivity even without matching layer. It does not need any gluing in its active parts. This is also called a stacked transducer, because of multiple piezo rings working in a push-pull configuration. The frequency properties are decided by the diameter of the piezo rings and the masses in the head and tail. A tonpilz transducer can be made broadband by proper dampening. Below is a schematic diagram of a tonpilz transducer in its simplest form [3]:

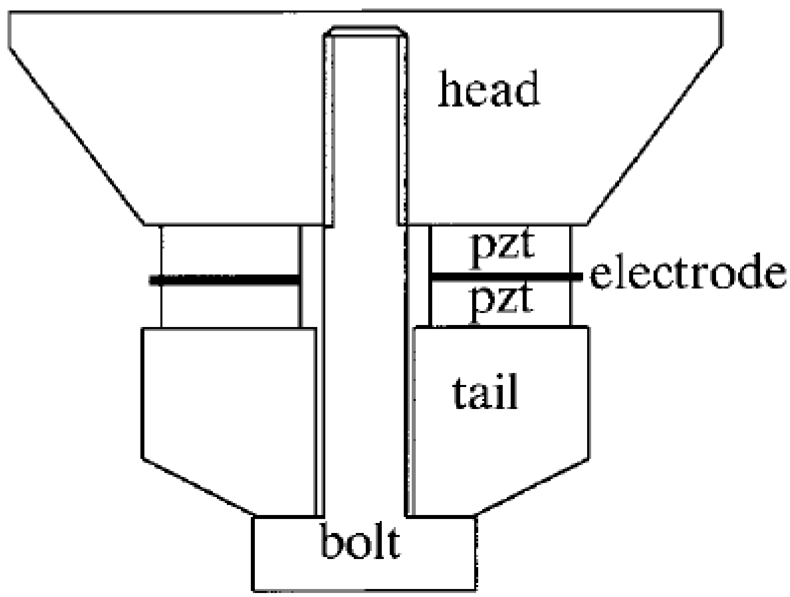

Fig. 6 – Schematic diagram of a tonpilz transducer.

In other words the solution in gas has been to overcome some of the problems with improved technology and design, and to solve some of them by offering different size and type transducers for the different applications.

2.3 Liquid Solutions

For liquid USMs the situation was quite a bit easier, for two main reasons:

1 – The development started quite a number of years after the gas meters, as such they could benefit a lot from the work and knowledge already out there.
2 – Transmitting ultrasonic energy into a liquid from a piezo ceramic element fully contained in a metal housing is a lot easier due to the closer acoustic impedance compatibility between the metal and the higher density liquid.

The choice of frequency is a compromise between the wish for a high frequency to give good time accuracy vs. the wish for a low frequency to get the signal through the medium.

There is also a relation between diameter of the transducer and the frequency. To go down in frequency, you need a larger transducer diameter. That is with traditional design. However with a tonpilz design you can push the frequency down by adding mass to the resonators, and still be able to keep a small diameter. Going up in diameter has many disadvantages:

1. The directivity is narrower because of interference patterns.
2. Larger cavities
3. Less defined path

The operational frequencies for liquid transducers typically run around 1 MHz but do vary from around 500 kHz up to 2 MHZ depending on the application.

Fig. 7 – Typical liquid USM transducers with titanium body/well

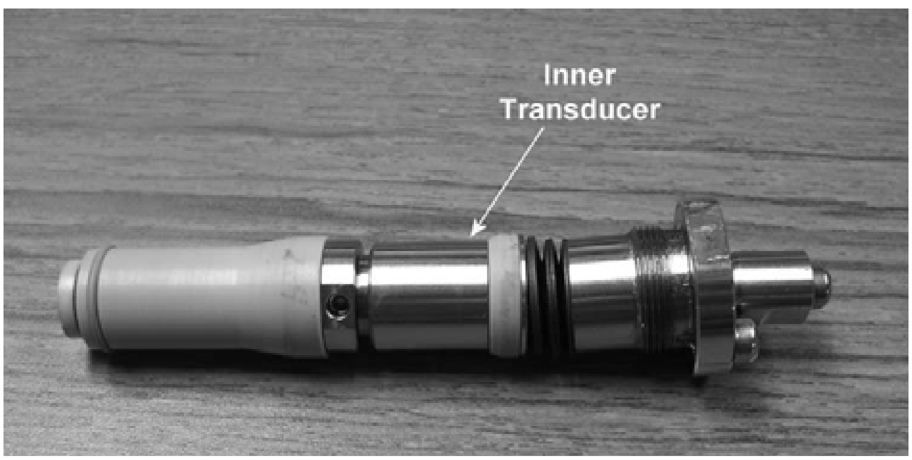

Fig. 8 – Typical liquid USM inner transducer

Other than size the two main issues or challenging situations for liquid transducer design have been:

1 – Viscosity
2 – LNG

High viscosity, or low Reynolds number applications, typically Reynolds number below 10.000 where the fluid enters the transitional area between laminar and turbulent flow, has probably been and still remains the key liquid transducer issue. To address this manufacturers have resorted to one of the solutions from the gas applications discussed above. To ensure signal transmission thru the higher viscosity fluids the transducers transmit with lower frequencies, down to approx. 500 kHz.

LNG is another situation altogether – here the challenge is the extremely low temperatures required to keep the gas liquid - the cryogenic temperatures of approx. -160°C or -256°F. Manufacturers have solved this in one of two ways:
1 – Design special transducers that can operate at these low temperatures
2 – Insulate the transducers from the very cold fluid using some form of a waveguide to transmit the ultrasonic energy into the flow. This to ensure the transducer design can remain the same as the transducer will be exposed to temperatures within their normal operating range.

2.4 What Possibilities Has This Resulted In?

Again we are not talking about the individual components as much as the whole system for the purpose of this paper. And it is the combined developments in transducer technology, electronics and signal processing that has finally made it possible to make a major push towards resolving what may be the last holy grail of ultrasonic measurement – to link the diagnostics to the performance of the ultrasonic meter.

With that said, this step would not be possible without the increased performance in today's transducers – especially with the parameters like bandwidth, sensitivity and directivity.

Now, to also further increase the value of diagnostics – with the advanced transducers a few new and very important/useful diagnostics features are possible:
1 - Real time impedance measurement to detect any build-up on transducer
2 - Create special diagnostic signals for advanced self diagnostics of the system and components in the system,
3 - To diagnose what is in the pipe, or should not have been in the pipe – without the need for any extra diagnostics paths.

It is essentially the increased bandwidth in the next generation transducers which provides more data to work with for diagnostics. A single frequency, or very narrow band, transducer is not very interesting for frequency sweeps, and does not provide that much useful diagnostics information.

For each transducer pair, there are 3 different frequency sweeps that can be made:

1. Impedance of transducer A
2. Impedance of transducer B
3. Transfer function of complete pair including the medium.

The impedance plots are not influenced directly from the medium in the pipe. However what is in the close proximity of the transducer front can influence the impedance curve. This can be used for detecting build-up on single transducers.

The impedance plot is also an excellent tool to detect changes in the transducer itself, because it is not dependant on what is in the pipe.

3. SIGNAL PROCESSING AND DIAGNOSTICS – THE NEXT LEVEL

The signal processing in ultrasonic meters today have two main tasks:

1 – To define the signal sent, and to process the received signal in order to be able to utilize the information in as adverse conditions as possible, and create quality measurement as a result.
2 – To utilize the information in the received signal also for diagnostics purposes.

Traditionally the electronics and signal processing have made a lot of data available to the world outside of the ultrasonic meter. The meters have done this with only certain internal self diagnostics functions being implemented. This has left most of the real evaluation and decision making to either an external diagnostics program/software or the actual user/operator – and in many cases, even to the manufacturer.

The next generation in diagnostics will move the decision process from the user or often manufacturer, via the external software (like WinScreen) down into the meter itself. In other words, Condition Based Monitoring taken to the next level.

Why do we consider this the correct step? The feedback from the industry is that you, the manufacturers, are the experts, you and your meter should know what the issue is, and we don't have time to evaluate a lot of alarms and to try and decide what to do about them.

We then asked ourselves – what is it we all really want from our ultrasonic meters? And we distilled it down to the following:

We want to know if something is wrong, what is wrong, why/how did it happen, what do we need to do to fix it – and the ultimate – what is the effect on my measurement??

3.1 The Key – Neural Networks (Patent Pending)

In the past manufacturers have continuously improved the diagnostics capabilities of their ultrasonic meters, but this has almost exclusively been done using predetermined logical equations and calculations versus defined limits to mimic the human ability to interpret all the results. With the amount of data constantly being produced by today's modern ultrasonic flow meters this quickly becomes inefficient and in the end basically impossible.

The only solution we have found is to utilize a system which is able to monitor all the variables, store information indefinitely and perform the complex analysis and evaluation in real time – all the time. And today there is only one system capable of doing this – an Artificial Neural Network, or simply NN for Neural Network.

3.1.1 Neural Networks – What are They?

We want to have the meter to evaluate a lot of data that is produced by the meter.
An artificial neural network introduces the element of intelligence, or Artificial Intelligence, into the meter.
A neural network can be trained to find patterns in data even when the input is not clear.
The neural network consist of highly interconnected processing elements (neurons) working together to solve a certain problem. The neural network will learn by examples. Given a large set of input data sets and the desired output for each data set, the training of the network will adjust the network to mimic the behavior from the examples [2].

From WIKIPEDIA: An **artificial neural network (ANN)**, usually called neural network (NN), is a mathematical model or computational model that is inspired by the structure and/or functional aspects of biological neural networks. A neural network consists of an interconnected group of artificial neurons, and it processes information using a connectionist approach to computation. In most cases an ANN is an adaptive system that changes its structure based on external or internal information that flows through the network during the learning phase. Modern neural networks are non-linear statistical data modeling tools. They are usually used to model complex relationships between inputs and outputs or to find patterns in data.

Below is sample of a simple neural network structure (other structures are possible).

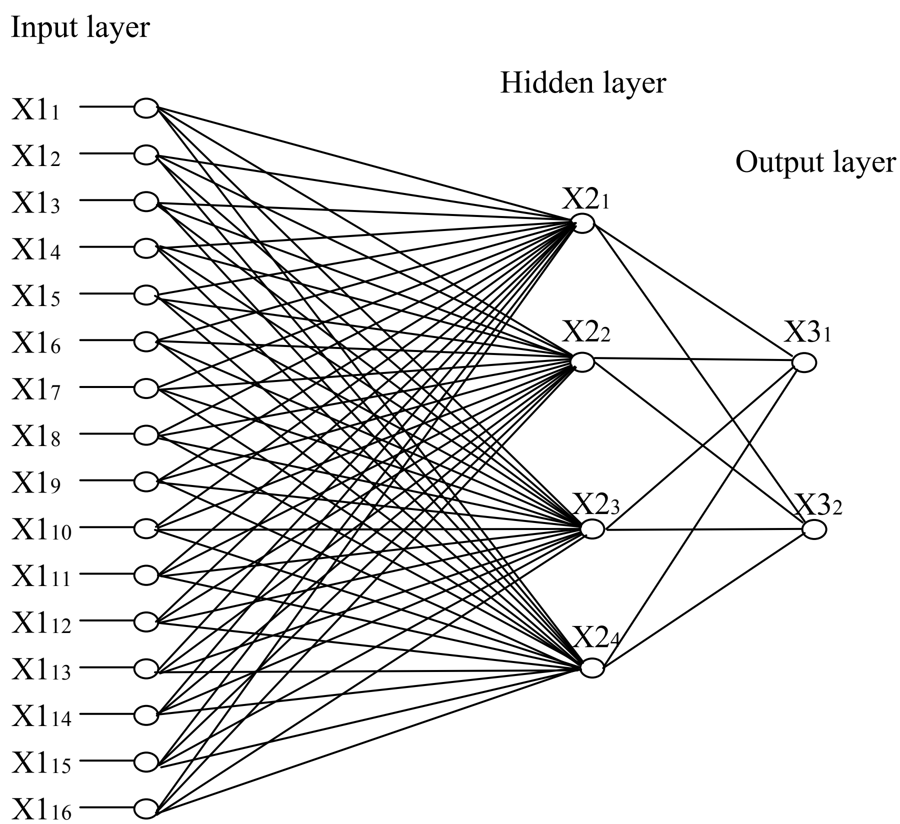

Fig. 9 – A simple neural network structure

The input layer (X1) has only passive nodes. The data are just forwarded to the next layer (X2), the hidden layer. The nodes in the hidden layer and the output layer (X3) are active. They modify each input data with a weight and apply some sort of nonlinear function, normally a sigmoid function. The output of the output layer will hopefully show results that resemble the output when the network was trained.

The active nodes functionality is shown below. The inputs are multiplied with weights and summed before being passed through the sigmoid function. This multiply and accumulate structure can be done very efficient on modern processors with DSP functionality.

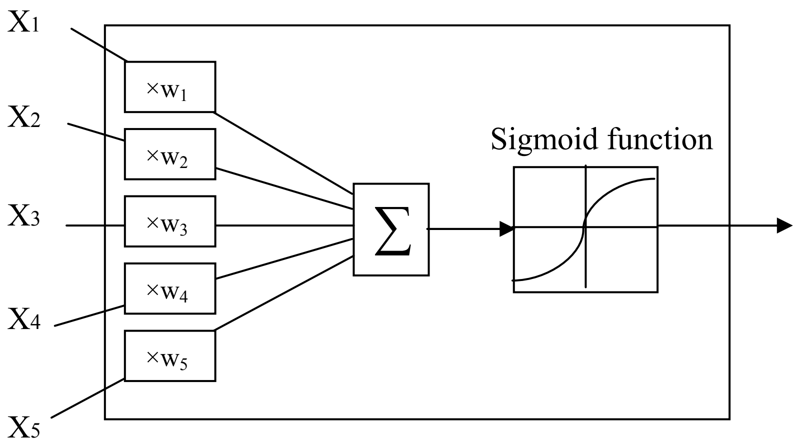

Fig. 10 – The multiply and accumulate sigmoid function structure

The sigmoid function is what makes the neural network different from other signal processing methods like correlation, filters etc. The sigmoid function is not linear, and makes NN able to solve not only linear problems, but also non linear problems.

The other main difference is the training of the NN. This is done in an iterative process. You present several data sets and corresponding desired output to the algorithms, and the training process, will find the weights that will resemble this behavior as close as possible.

3.1.2 Neural Networks in Ultrasonic Flow Meters

The set of weights will tell the neural network what to do and what to look for. The algorithm stays the same. Another set of weights, and the network will look for something else.
The training of the neural network can be based on logged information from meters installed all over the world. Some logs where meters are working perfectly, and other logs where meters have problems.

Below is a simplified sample of a neural network. The real implementation would contain a lot more inputs.

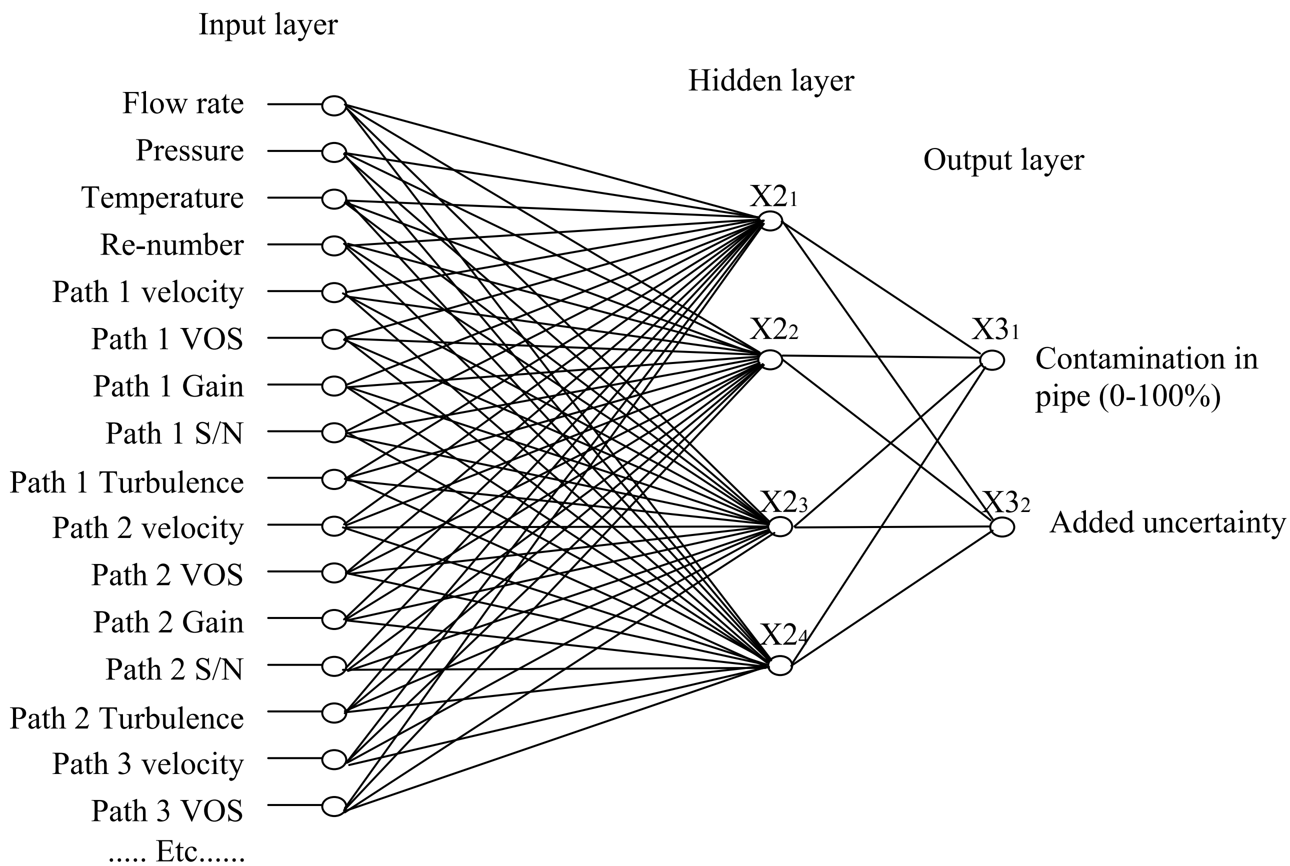

Fig. 11 – A simplified example of a USM neural network

The example is testing for contamination in the pipe. To test for something else, the algorithm and all inputs stays the same, but a different set of weights for layer X2 and X3 is used.

There will be one network for every diagnostic case. They have exactly the same structure, but the weights are different. There are a lot of calculations to be done, but these kinds of calculations can be done very efficient on newer processors with DSP functionality build in.

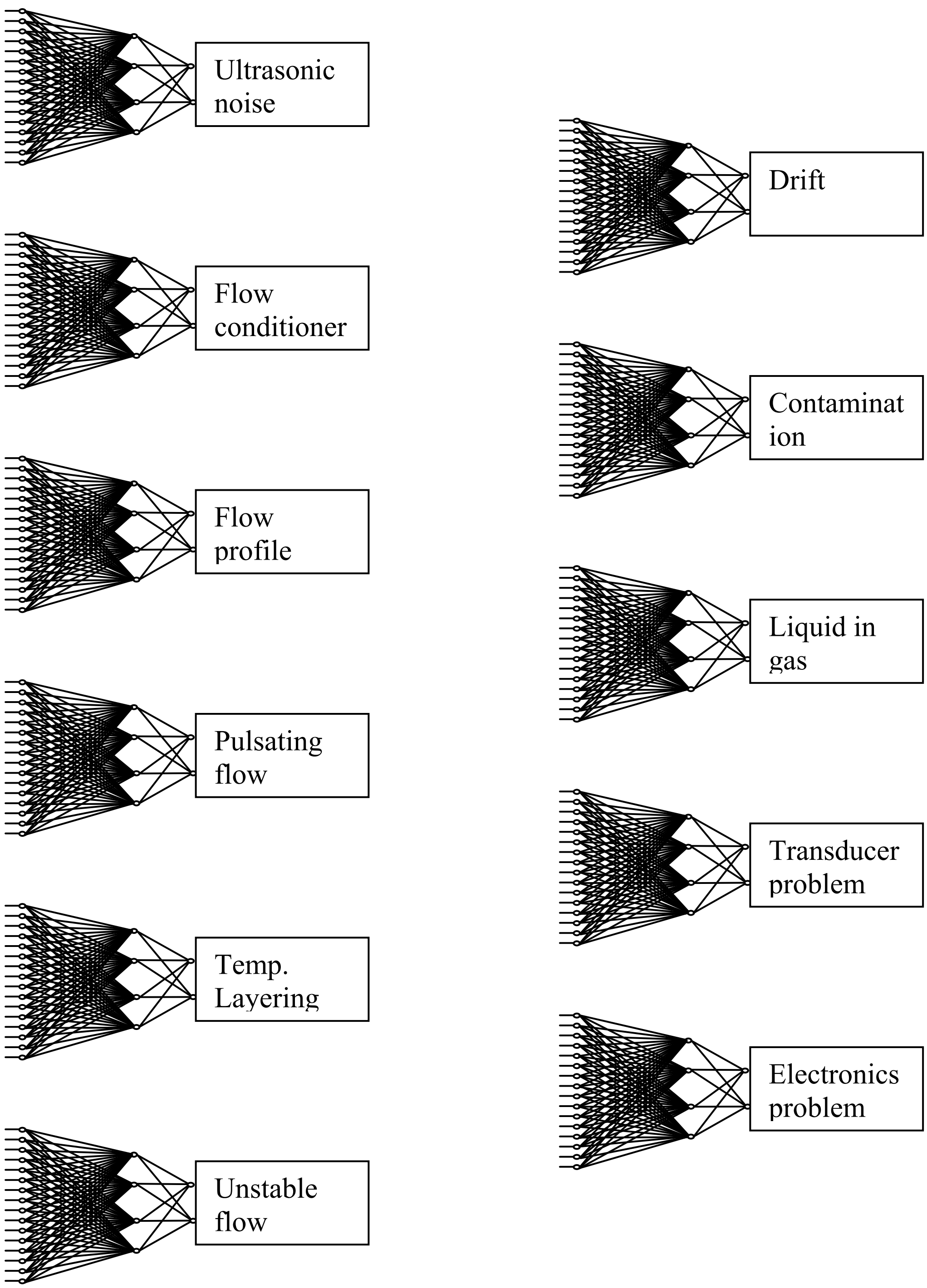

Fig. 12 – Examples of NNs for the different diagnostics features

3.2 Time – The Last Parameter – Diagnostics in TRUE 3D

With the constant developments in computer electronics memory is now small and relatively cheap compared to just a few years ago. This has made it possible to now store much larger amounts of data in the local ultrasonic meter electronics, and not have to rely on external computers and separate diagnostics programs to perform real diagnostics over time.

In other words, the third dimension to diagnostics – Time – can now be added, and the result is that we now can finally approach the ultimate goal as described in chapter 4. This also means that true Condition Based Monitoring, or CBM, can be achieved.

All the real time logged data will be used to extract key trend data. These data will be fed into the NN. The neural network will then be able to react on changes over time.

The NN can be updated to improve performance of the diagnostics. Using data from meters in the field, both functional ones, and especially meters with problems, we can continuously optimize the NN to detect problems, and to determine the resulting effects. The data from the meters can be sent back to the manufacturer through log files, service visits and even through online connection. The constantly improving Neural Network can be updated in every meter on an annual basis for example.

The NN will constantly improve – in fact the more meters you buy and put into use the better your meters will get!!

4. NEURAL NETWORKS – 3D DIAGNOSTICS

With Neural Networks, all the components they use as inputs, and the final dimension of time we can truly say that built-in real time diagnostics has arrived. For the first time all the processing, data storage, analyzing, real time diagnostics and trending over time is handled internally in the meters themselves.

4.1. What Are We Looking For?

The whole point with the next level of diagnostics is not to look at the normal alarm cases like "gain high" or "signal low". These are just symptoms that something is wrong. What we are after is the underlying reason.

Examples of these reasons can be:

1. Ultrasonic noise (from valves / pressure drops)
2. Object trapped in flow conditioner
3. Flow profile issues/changes (ie. protruding gasket.)
4. Pulsating flow (from compressors, etc...)
5. Temperature layering in the pipe at low flow
6. Unstable flow.
    a. Flow rate
    b. Temperature
    c. Pressure
    d. Density
    e. Viscosity
7. Drift
    a. Transducer delay/detection point
    b. Transducer sensitivity
8. Build-up of contamination
    a. On the transducer front. What transducer(s) to clean.
    b. Contamination in the spool
9. Liquid in the gas (gas meters)
10. Gas in the liquid (liquid meters)
11. Water in the liquid (liquid meters)
12. Internal transducer problem. What transducer to replace
13. Electronics/cables problem. What component to replace.

Getting information like this directly would be of great help for end users that are operating the meter and the systems these meters are in.

4.2 The Ultimate Goal – Added Uncertainty

Finally then, with these developments in transducer technology, in electronics and especially with the next level of signal processing – we can take the final step and get to the ultimate goal as mentioned in section 3.

Using Neural Networks to process all the diagnostic information available in our ultrasonic flow meters, including time, the meters can now point to the real source of the problem, instead of giving an alarm on the symptoms only – which has been the norm for every ultrasonic meter on the market up until now.

With that in place, knowing the real source of the problem – there is only one more step that is required to make the ultrasonic meter as close to the "perfect" technology as possible:

What is the meter's uncertainty in this condition?

Every ultrasonic meter is delivered and installed with a certain base uncertainty. For multipath meters installed in custody transfer applications this is typically 0,5% if the meters are not flow calibrated, and 0,1% with respect to the flow calibration facility if they have been flow calibrated.

With all the information in the Neural Network our FMC meters will now be able to provide an additional uncertainty number – logically called ADDED UNCERTAINTY. This is the additional uncertainty in the meter output which is caused by any problem, or any combination of problems with the meter or the flow condition.

With this final step one can say that ultrasonic flow meters have gone full circle:
Our meters can identify and alarm on the symptoms that something is wrong, they can identify what the problem actually is, and they can indicate how much the problem, or problems, are affecting the performance of the meters.

That means operators now have the tools available to not only automate much of the decision making process regarding alarms in ultrasonic meters, but more importantly the "threat level" of each alarm situation. Each situation can be properly assessed and the correct decision can be made immediately as to what action is required. That being decisions like continue to flow with a reduced uncertainty, when to intervene, do we need to shut down this line right now, what type of human intervention is required, what to target, what parts to order, the urgency of the intervention, does it require a recalibration and so on.

In other words – you now have the knowledge and the information to take the optimum and most efficient decision for you and your system – at all times.

5. FROM FLOW CALIBRATION TO THE FIELD

Flow calibrations at certified facilities are used almost universally for gas ultrasonic flow meters. Certainly for meters intended to be used in custody transfer applications, but also increasingly to ensure optimum performance from meters used in other applications. As you take a meter from the calibration facility and place it into the field there are essentially two things that determine the value of this calibration:

1 – The accuracy of the calibration itself – meaning how well the calibration was executed to reflect the true performance of the meter under test (MUT)
2 – The applicability of the flow situation at the calibration versus the flow situation in the filed

In the past most manufacturers have more or less accepted the first item above, as long as nothing is obviously wrong. For the second item they have been using the profile factors or “fingerprint” values from their ultrasonic meters to determine if the flow situation is “close enough” for the flow calibration to be considered relevant.

With the new level of diagnostics we can make that evaluation with much higher degree of confidence.

5.1 The Calibration Itself

Assuming that the reference meter system at a flow calibration facility is within specifications, there are a few key parameters that determine how good a flow calibration is when an ultrasonic meter is placed into the system:

Flow stability	Line and ambient temperature matching
Pressure stability	Functional reference meters
Temperature stability	Correct reference meters being used
Volume between the reference meters and the MUT, aka. Line Packing	

Fig. 13 – Parameters affecting the quality of a flow calibration

The ultrasonic meter with NN will utilize all the diagnostic information to assess how the flow calibration facility is behaving at any given time. And it will of course utilize the same system in normal operation.

What can a meter say about the quality of a calibration?

- Flow profile and turbulence – can detect unstable profile, protruding gaskets
- VOS profile – detect non stable P and/or T, or density/gas composition changes
- SNR – noisy valves or other noise sources – not very likely though
- Object trapped in flow conditioner
- Pulsating flow (from compressors, etc...)
- Temperature layering in the pipe at low flow
- Unstable flow.
    - Flow rate

- Temperature
- Pressure
- Density
- Viscosity

Based on the above output the NN will then determine not only what the problem is directly and provide that information, but more importantly it will also provide the most important number – the **added uncertainty** caused by the underlying problem.

With that the manufacturer, user, approval agency or weights and measurement official can evaluate the results and better determine the quality of the calibration, if the calibration can be accepted, and what steps, if any, should be taken when the meter is installed in the field.

5.2 From Calibration to the Field

With the information shown in chapter 5.1, and the "normal" meter DNA information like VOS profile, gain relations and flow profile, we have the most effective method to ensure that the meter has not change between flow calibration and final installation.

Again the NN will notify the operator if there are problems on the field installation, and provide details of what the problem is. Of course also here, arguably the most important number will be the **added uncertainty** that is the result of whatever problem is present.
If the NN is flagging an issue, this should be corrected regardless if it is flow calibration or field installation.

6. CONCLUSIONS

The developments in transducers, electronics and signal processing over the past decade now have made true internal Condition Based Monitoring in ultrasonic meters possible.

With the latest broad band transducer technology and electronics development a number of new important diagnostics parameters are available, like impedance analysis, which in turn results in improved meter diagnostics.

By using Neural Networks we can take the two last steps in Condition Based Monitoring which have been absent so far:
1 – We can determine the root cause of the problem, not only the symptoms
2 - And we can finally reach the ultimate goal – using the internal meter diagnostics to determine the effect on the meter output of any error or change in the meter conditions.

The Added Uncertainty is the holy grail of ultrasonics – and we believe we have found it!

This most valuable development will both improve the efficiency of any meter installation in the field, ensuring that operators can make the best decisions at any time regarding the operations of their meters and metering systems. And also to help ensure that the important, time consuming and costly flow calibrations are providing the expected return on investment.

FMC expect to install the first meters with this system implemented in 2012 and expect to be able to present actual field experiences and results at the 2013 NSFMW.

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