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PERFORMANCE OF CLAMP ON ULTRASONIC FLOWMETER PIPELINE LEAK DETECTION SYSTEMS

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PERFORMANCE OF CLAMP-ON ULTRASONIC FLOWMETER PIPELINE LEAK DETECTION SYSTEMS

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1. INTRODUCTION

Recent enhanced awareness of the environmental, safety and financial consequences of the release of petroleum and derivative petroleum products from pipelines, has made development of an effective and readily implementable pipeline leak detection system essential. It is not surprising that the pipeline industry's first attempt to implement leak detection was based on software systems, using data from meters already installed in existing pipelines. However, considering that these conventional intrusive meters were usually specified for purposes other than leak detection, in these cases the performance obtained falls short of the level needed to protect both the environment and the financial interests of the industry.

Accordingly, there is an incentive for instrument manufacturers to create, and the industry to actively consider, new types of leak detection systems that are more effective in performance, and more affordable in cost. It is essential that the meters on which these systems are based provide the short term calibration stability required for fast detection of leaks, as well as the long term stability normally required over the time period of complete batches, as required for custody transfer. In addition, they must be logistically compatible with the reality that leak detection systems must be installed on a vast network of already existing pipelines, without requiring the pipelines to shut down operation for leak detector installation. Perhaps as important, the preferred leak detection system will not demand that pipeline operators change their normal operating procedures.

Fortunately, the modern clamp-on transit-time ultrasonic flowmeter meets the criteria for such a leak detection system in every way, as is detailed in the body of this paper. In addition, this type of meter is not new to the industry, having been in pipeline service for the petroleum industry in various forms for almost 20 years.

However, the key to the improved performance of the clamp-on transit-time meter in leak detection service is its ability to continuously identify the type and condition of the liquid in the pipeline, and thereby assure the correct calibration of the system at all times. This is important since it is well known that the liquid characteristics of crude oils can vary substantially, not only from batch to batch, but also even within each batch. This 'dynamic calibration' overcomes the short term variation of conventional turbine and PD meters, whose calibration is established only periodically by proving runs conducted only for a small percentage of each batch. In other words, these meters 'see' as to provings, only part of each batch, if provings are conducted for each one.

Use of these detected liquid properties is not limited to aiding leak detection performance. Sensing these properties also permits the transit-time leak detection system to provide interface detection, batch tracking, and liquid quality monitoring. Therefore the transit-time flowmeter-based leak detection system can pay back its cost through its ability to provide improved efficiency of pipeline operations and replacement of maintenance prone intrusive meters.

The basis for the benefits of the transit-time leak detection system lie in the performance and operating parameters of the ultrasonic meter itself. Since there are substantial differences in the design and performance of transit-time ultrasonic meters produced by different manufacturers, the user should examine the characteristics of the selected system's flowmeter to ensure that it includes:

1) Intrinsically high accuracy
2) Stable calibration over a wide range of liquid conditions
3) High flow detection sensitivity, even at zero flow
4) High flow rangeability and linearity, including bi-directionality
5) High reliability, requiring little or no maintenance
6) Installs easily without requiring shutdown of operations
7) Low installed cost, as compared to standard intrusive meters
8) Resistance to wear, or change of calibration through use
9) Fast response, able detect leaks in seconds
10) Capability of monitoring long pipeline segments
11) Ruggedness under actual site environmental conditions
12) Accuracy in multi-product pipelines
13) Detects and compensates for free gas
14) Empty pipe detection
15) Immune to corrosive or abrasive liquids
16) No pressure drop, to save pumping energy costs
17) Compatibility with many different types of nondescript liquids
18) Capable of installation near bends and elbows
19) Minimal operating power, for remote area operation
20) Has provision for optimizing calibration for actual site conditions

These characteristics are intrinsic to the clamp-on transit-time system, as described in the body of this paper, below, as presented follows:

- Principle of Operation
- Application Requirements
- Functions & Output Data
- Performance Parameters
- Installation Logistics
- Description of the Leak Detection System
- Performance of the Leak Detection System

2. Principle of Operation

The principle of operation of the clamp-on transit-time flowmeter is described in conjunction with Figure 1. Shown is the high precision system that uses the patented Wide Beam clamp-on transducer.

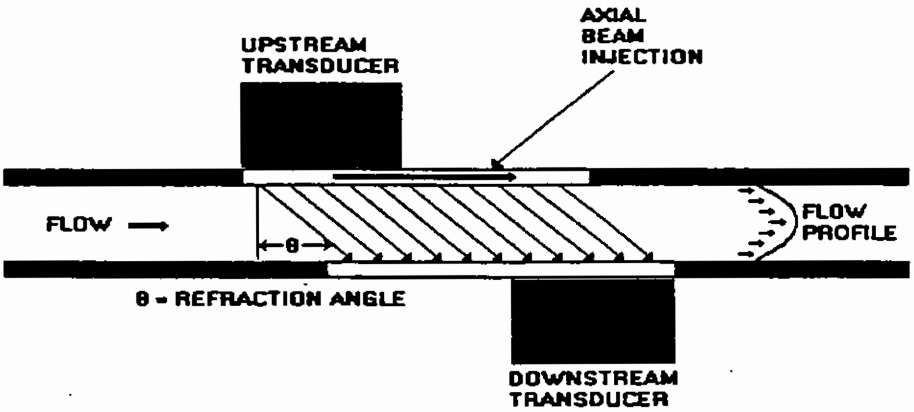

Figure 1: Wide Beam Transit-Time Principle

As shown, the Wide Beam transducer excites a natural *acoustic waveguide* mode of the pipe so as to induce a sonic wave which travels axially down the pipe wall. As it travels it '*rains*' sonic energy through the liquid in the form of a wide beam. This beam arrives at the far wall and travels down toward the receive transducer, where it is collected. Note that Figure 1 shows what is called 'Direct' transducer mounting. An alternate 'Reflect' mounting is available, in which both transducers are mounted on the same side of the pipe.

The advantage of the Wide Beam is that the angle of refraction of the beam is a function of the liquid sonic propagation velocity, which varies from about 600 meters per second for very light compressed gasses, to about 1500 meter per second for heavy crude oils. The wide beam assures that no matter what liquid is in the pipe, and what its refraction angle is, the beam will still *cover* the receive transducer and permit continuous operation of the system. In fact, this meter can operate on sequential batches of compressed gas, followed by oil, without requiring any human intervention or readjustment.

Sonic energy is injected alternately in the 'downstream' and 'upstream' directions. When sent upstream, the travel time required to reach the opposite transducer is longer than when sent downstream, proportional to the actual flow velocity. Thus the meter's ability to measure the flow rate is based on measurement of this time difference.

Note that the meter also measures the actual time required for the beam to travel across the pipe, and thus it can measure the actual sonic propagation velocity of the liquid. The sonic velocity of the liquid is a function of its density, and therefore the transit-time meter can identify then correlate to the API number of the liquid in the pipe at all times, with a resolution of 1 part in over 200,000. Since the meter takes approximately 1000 measurements per second, it is always aware of what liquid is in the pipe. It can therefore detect the interface between different batches of liquid, and can detect the presence of water in oil.

Since the presence of free gas 'scatters' the sonic beam to some degree, it affects the amplitude of the received sonic signal. This is very useful in that it permits the detection of 'Aeration' the term applied to the presence of free gas, whether included in the source product, or derived from depressurization or cavitation. A numeric value is assigned to the degree of aeration, which is reported as output data.

If a pipe empties, the sonic beam is completely interrupted. This loss of signal is monitored by the meter which issues an Empty Alarm if such a condition occurs.

3. APPLICATION REQUIREMENTS

3.1 PIPE & LIQUID SONIC PROPERTIES

The Clamp-on Transit-time Ultrasonic meter is among the most widely applicable of all flowmeter types. This is because the only thing that is required for operation is that the pipe wall be sonically conductive, and that the liquid also be sonically conductive. All common pipe materials are sonically conductive, as are all liquids.

3.2 STRAIGHT RUN REQUIREMENTS

Most flowmeters require installation with at least 10 diameters upstream, and 5 diameters downstream, straight run. In addition, some flowmeters require upstream straighteners to defeat swirl effects. While substantial straight run, and avoidance of swirl, are desirable for any flowmeter, in the pipeline industry accessible pipe is frequently of limited length, and often severely populated with bends and elbows.

Fortunately, where long straight runs are simply not available, mounting directly adjacent to bends and elbows is permitted for clamp-on transit-time flowmeter transducers. This is because the process of optimization reveals any calibration effects due to these conditions, and permits them to be counteracted at all flow rates, and for all liquids, even if of highly variable viscosity. This process also reduces the need for frequent proving, since the behavior of a given type of liquid is 'remembered' and the correct calibration is automatically installed. In addition, the fact that the transducers are clamp-on permits the installer to try several different locations, and simply select the one which shows the minimum evidence of flow profile distortion.

Where flow profile is severely aberrated due to nearby bends and elbows, or intrusive elements such as pumps and valves, it is recommended that a multi-path transducer installation be employed to average out the profile distortions. They are available in dual, triple or four path models. In general, dual path systems are sufficient for all but the most severely distorted profile conditions. In addition, the use of a transducer mount configuration where the transducers receive a reflection of the transmit signal (Reflect mode) completely eliminates any error due to non-axial flow. Swirl, other than its effect in flattening the flow profile, has absolutely no effect on clamp-on flowmeter calibration.

3.3 TRANSDUCER MOUNTING LOCATION ENVIRONMENT

Clamp-on transit-time transducers are available for any conceivable environment. They can be installed above or below ground, and can be installed under water. In addition, transducers of this type are capable of operation at very high and low temperatures, such as at 450°F in nuclear power plants, and as installed on the Trans-Alaska Pipeline.

3.4 VIBRATION

Clamp-on transit-time transducers are completely immune to vibration, other than the need to use the appropriate mounting accessory.

4. Functions & Output Data Provided

Once per minute, clamp-on transit-time site stations provide the master station with the following data:

- Flow Rate (Average over the last minute for each path)
- Flow Total
- Liquid Temperature
- Ambient Temperature
- Liquid Sonic Properties:
  - Sonic Propagation Velocity, Vs
  - Sonic Signal Strength, Valc
  - Liquid Aeration, Vaer
- Timed-Stamped Maximum Rate of Change of Vs
- Site Station Diagnostic Data:
  - Empty Pipe Alarm
  - Flow Direction
  - Operation Fault
  - Aeration Alarm

In addition to providing data to the leak detector master station, each site station is capable of providing local site control, flow rate alarms and empty pipe alarms, etc.. The same data as is provided to the master station can be fed to the pipeline SCADA system in parallel. Output data is available in every standard data format, such as 4 to 20 mA, 0 to 10 Volts, and RS-232.

5. Performance Parameters

It is surprising to some that the performance parameters of the clamp-on transit-time meter are superior to those of the conventional intrusive flowmeters, since there is an intuitive 'feeling' that something that is in actual contact with the liquid 'must' be superior to a meter whose sensing is non-intrusive. However, when one considers that the intrusive meter calibration suffers from wear, coulomb and viscous friction, and residual flow profile distortion, it becomes fairly obvious that the intrusive meter derives its reputation for accuracy primarily from periodic proving, and prover repeatability.

When proving is done at least once for a batch of uniform product, and the flow rates and other conditions remain stable, the accuracy obtained for the total batch volume can be excellent. However, on many occasions, batches of product are not uniform, and flow rates and liquid temperatures can vary significantly. Under these conditions, unless proving is done frequently, the calibration factor obtained for infrequent proving will not provide accurate meter factors.

In addition, it is essential to recognize that periodic proving is quite adequate for custody transfer purposes. However, periodic proving of leak detection meters is not adequate. This is because the accuracy of a batch is determined on the scale of many hours or even days. The accuracy of a leak detection system must be maintained for periods as short as 1 minute, to assure detection of a leak in the fastest possible time, and to avoid false alarms which defeat operator confidence in the system. Periodic proving, no matter how precise at the time it is performed, cannot protect a conventional intrusive meter leak detection system from inaccuracy at the 1 and 5 minute interval level, since batches of product are frequently non-uniform, and physical constraints prevent such frequent cycling.

On the other hand, the clamp-on transit-time leak detection system identifies the product once per minute. Even a small batch non-uniformity cannot escape detection. And through the process of optimization, subsequently described in detail, the correct meter calibration factor is always provided.

The performance parameters and functions provided by the clamp-on transit-time site station include:

PERFORMANCE PARAMETERS	
Flow Range	From 0 to ±60 ft/sec flow velocity (bi-directional)
Flow Sensitivity	0.001 ft/sec at any flow rate, including zero
Liquid & Ambient Temperature Accuracy	0.1 °F
Calibration Repeatability	0.02 to 0.1%
Reynold's Number	From 1 to 10^9
Flow Change Bandwidth	10 Hz
Flow Slew Rate	80 ft/sec^2
Temperature Rating	- Flow Computer from -40° to +155°F - Transducers from - 80° to +450°F
Safety Ratings	Class 1, Div 1 & Div 2; NEMA 4X & NEMA 7
Site Station Power Requirement	15 watts
Interface Detection Resolution	1 part in 200,000

FUNCTIONS

- Built-in Datalogger with Site Identification and Time Stamp
- 9600 Baud, RS-232 I/O Serial Data Communication
- Built-in Diagnostics alerts user to liquid/system conditions
- Built-in Pig detection

6. INSTALLATION LOGISTICS

Installation of a clamp-on transit-time flowmeter is quite simple, taking from 1/2 to 1 1/2 hours. It generally follows the procedure below:

a) Installation site selection based on site survey, with a portable clamp-on transit-time flowmeter to check actual flow characteristics of several candidate transducer locations, or from site drawings, a particular location is selected. The preferences will be for as much straight run as convenient, in combination with avoidance of location immediately downstream of cavitation sources.

b) Identify pipe outer diameter, material and wall thickness

c) Install mounting tracks plus flow and temperature transducers.

d) Mount flow computer and connect cables to transducers

e) Start up flow computer, and then set initial adjustments

f) Check basic flow operation of installed meter.

g) Print out Site Setup and System Diagnostic parameters for future reference

7. Clamp-On Transit-Time Leak Detection System Description

Since substantial literature describing the clamp-on transit-time leak detection system in great detail is available, this paper will, in the interests of space, limit itself to a broad description of the system. Additional information can be obtained by writing or calling the author:

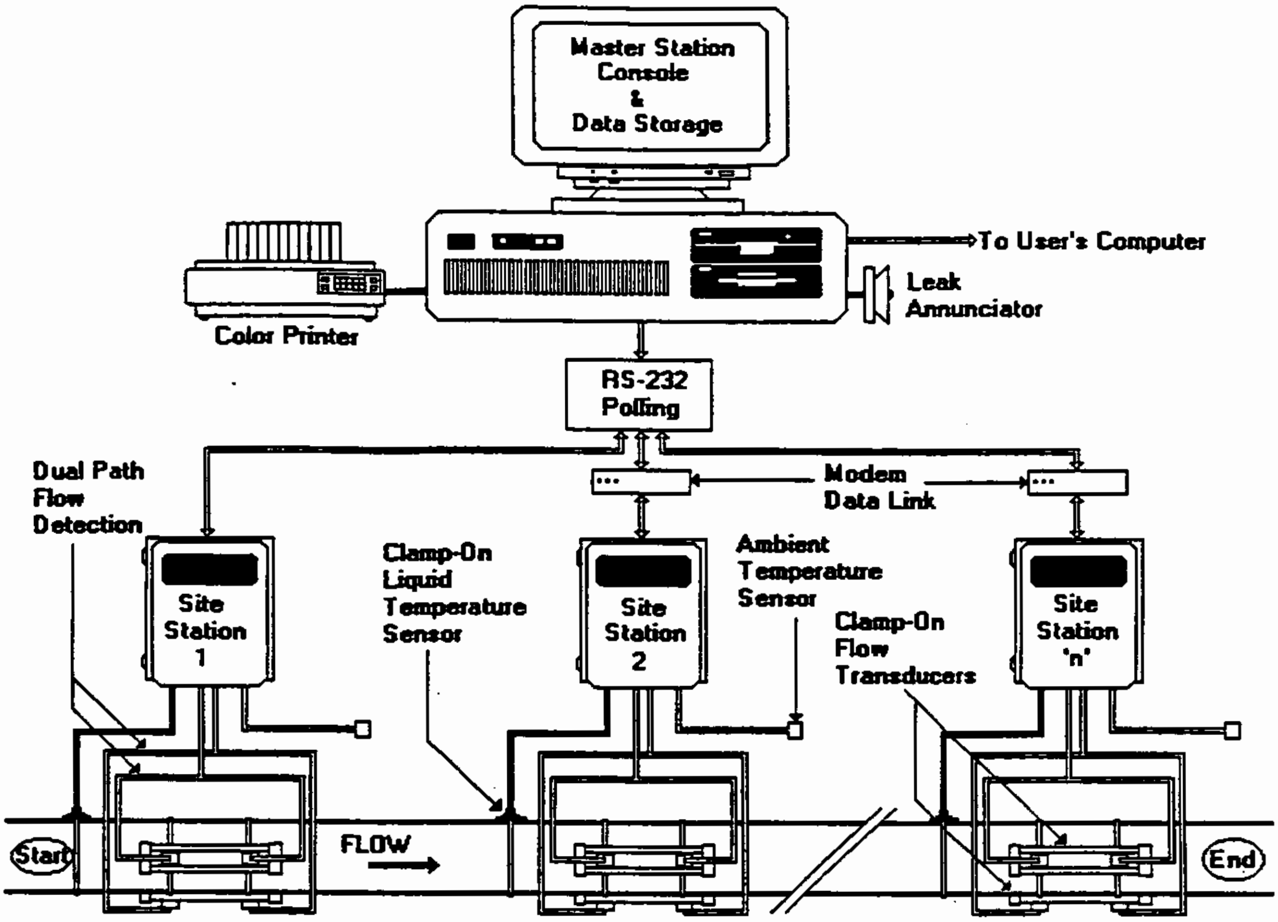

Figure 2: Transit-Time Leak Detection System Schematic

Referring to Figure 2, it is seen that the clamp-on transit-time leak detection system consists of a number of site stations, installed at various distances from each other along the pipeline. The separation between site stations is chosen dependent on the risk factor of the intervening segment. The maximum segment length recommended is about 30 miles, although test cases involving segments over 100 miles have been successful.

As shown, each site station includes a single, dual or triple path clamp-on transit-time flow computer, plus clamp-on temperature sensors to measure both the liquid and ambient temperature, as required by the type of system specified. Also included at each site station is communication equipment, for either phone line, radio or satellite communication, as required.

The master station is also equipped with a communication port. the master station is the control center of the system, and processes all incoming data to provide both alarms and pipeline operations data, dependent on which type of system has been specified. The master station also archives all incoming data into daily data files, which can subsequently be analyzed to permit system optimization, and to provide a playback capability in order to show due diligence, when necessary.

Master stations are available to handle any and all pipeline configurations, so that expensive and time consuming custom leak detection system design is avoided. Instead, provision is made for the actual physical configuration of any pipeline to be described in a generic topology file, which is prepared for installation into the master station. Thus the master station interprets all site station data by referring to the topology file, which tells the standard master station operating system how to handle this data to provide for accurate and reliable leak detection performance.

The master station polls all site stations once per minute simultaneously. Some models can handle as many as 64 site stations, which can be on any number of independent individual pipeline systems as desired, up to the capacity of the master station. Upon receipt of the data, it proceeds to compute the temperature and line pack corrected volume balance for each segment of each pipeline registered. It also computes a number of additional factors which are useful in determining the validity of a leak alarm, such as the current application and equipment operating conditions. It also computes data useful for management of the pipeline, such as interface detection, batch tracking, liquid type identification, liquid quality determination, pig detection and many other important factors.

At the completion of this computation, which takes less than one minute, The master station publishes all computed data. If there is a breach of one of four leak detection thresholds, for 1, 5, 15 and 60 minute periods, the leak alarm is activated, generating both audible and visible alarms. Up to this point, the system need not be actively monitored, unless its many operations management screens, such as those for interface detection or batch tracking, are utilized for pipeline management.

As detailed in the additional available literature, a complete description of the many data screens are provided. Suffice it to say, master stations can produce a substantial amount of very useful data, all of it presented in both graphics and numeric data screen formats. These are displayed by simply depressing an appropriate master station 'hot key'. The screens are organized in a sequence so that the system operator can quickly determine which segment of the pipeline generated the leak alarm. Many of these screens are of multi-graph type, which permits the inspection of as many as four different data items simultaneously. The operator, or user designated staff, can then easily associate various cause and effect relationships, so as to quickly make a decision as to the validity of the leak alarm.

In addition, communication links to the leak detection system supplier's headquarters permit experienced system engineers to assist in diagnosis of leak conditions.

In order to avoid false alarms, the system should include an automatic application condition monitoring function. If deteriorated liquid or other operating conditions are responsible for a leak alarm, there is an automatic readjustment of the alarm threshold to avoid the false alarm. However, such a condition will also trigger the leak warning so as to alert the operating staff of the potential of an as yet undeclared leak alarm. In addition, the process of optimization further ensures against the generation of false alarms, while also enabling the setting of the minimum possible alarm threshold.

7.1 LINE PACK & THERMAL EXPANSION/CONTRACTION DETECTION

The clamp-on transit-time flowmeter automatically detects both line pack and, for systems in which temperature gradients are expected, it also determines the effect of liquid and pipeline expansion or contraction, so as to preclude either false alarms, or failure to detect a leak.

a) Line Pack Detection

The clamp-on transit-time leak detector has a unique advantage in the detection of line pack, or unpack. This is because compression of the liquid, as in line pack, also increases the liquid density. This increase in density is sensed as a sudden increase in Vs, the liquid's sonic propagation velocity. Thus, by correlating the increase in flow rate with the increase in Vs, it is easy to confirm that the current segment volume imbalance is due to line pack, and not a leak, thus preventing the declaration of a false leak alarm.

However, during the process of optimization, a determination is made as to the amount of liquid which is normally packed in each pipeline segment under various flow conditions. Using this data, the leak detection system is able to sense if the actual liquid unbalance, during line pack events, is within the historical limit. If it exceeds this limit, as if the pipeline leaked during the line pack event, the system will immediately declare a leak alarm.

b) Correction for Thermal Expansion or Contraction

The clamp-on transit-time leak detector senses both the liquid and ambient temperature at each site station. It uses this data, in combination with the thermal model of the pipeline, contained in the master station topology file, to compute the temperature of the liquid and pipe wall at 100 points between site stations. This is done for all pipeline segments once per minute. These temperatures are used to compute the incremental expansion or contraction of both the liquid and the pipeline for each segment registered in the master station. This volumetric data is either added to, or subtracted from, the measured segment volume imbalance, so as to prevent either a false alarm, or masking a true alarm condition.

Assuring that the thermal model of the pipeline is working properly is relatively simple. One of the points whose temperature is computed is at the next site station, where actual measurement of the liquid temperature is being made. If the parameters of the thermal model were not correct, the computed and measured temperatures would not coincide. If they do not coincide at first, the process of optimization determines the correct thermal model operating parameters to achieve coincidence. Since both the computed and measured temperatures are presented on one screen, the operator can easily confirm that the thermal model is operating properly.

7.2 INTERFACE DETECTION

Interface detection is frequently performed by sampling the product in the pipeline periodically, and physically measuring its density. Alternatively, expensive and maintenance prone densitometers are used. But, note that Vs, the sonic propagation velocity of the liquid, is a function of liquid density. The clamp-on transit-time flowmeter can sense the change in Vs, and thereby density, with considerably more sensitivity than conventional densitometers.

The clamp-on transit-time leak detection system uses this Vs data, in combination with the measured liquid temperature, to compute the 'sonic signature' of each liquid. This uniquely identifies the liquid, enabling computation of its current density, and its density at 60°F.

This leads directly to the API number determination. Both the sonic signature and API number of the batch are plotted as a function of time. These screens are available for real time interface detection, and the data is also made available as a local output from each site station.

7.3 BATCH TRACKING

Since the clamp-on transit-time leak detection system can identify the liquid in the pipe at all times, and has full knowledge of the time history of flow rates, it is a relatively straightforward matter to compute the location of all batch interfaces within each pipeline segment. Marking the interfaces between batches also permits the system to compute the actual standard volume of each batch. Thus data screens are available to show the actual volume of each batch, where the interfaces are at any given time, and to predict the arrival time of all batches at their next target site station.

7.4 CUSTODY TRANSFER

Clearly, the entire batch tracking function available from clamp-on transit-time leak detection systems is based on the ability of this ultrasonic flowmeter to identify each batch of liquid, its density and API number. It is already well established that clamp-on transit-time meters can be volumetrically proved, using the conventional API proving method. The only question which remains to determine its candidacy for custody transfer service is to establish its long and short term calibration stability. Tests of this type have shown excellent conformance to batches measured by conventional turbine and PD meters, with repeatability to better than 0.04% in actual field trials.

Referring back to the previously described parameters, the clamp-on transit-time flowmeter performance could be superior to conventional intrusive meters. For example, it has greater flow rangeability, being both completely linear and bi-directional, from minus to plus 60 feet per second. It has greater sensitivity, 0.001 foot per second, at all flow rates, even at zero flow, at which conventional meters do not operate. It has no change of calibration due to friction, wear or aging, since it is entirely non-intrusive, and uses only drift free digital computation.

This system senses the type of liquid in the pipe continuously, and therefore can instantly and continuously adjust its calibration to previously optimized parameters. Conventional meters are limited to infrequent periodic proving, which cannot maintain calibration as the product parameters may vary from those present during the proving cycle.

While volumetric accuracy is important, so is the assurance that the product whose custody is being transferred is of the grade specified, and is free from contamination by water, free gas, or by non-specified product. The transit time meter's sonic signature confirms product type and grade continuously, and the site station diagnostics instantly identify the presence of both water and free gas.

Substantial data has been obtained to confirm that the clamp-on transit-time meter has the potential to provide custody transfer capability. It is expected that as more industry experience is gained with this type of system, a formal evaluation of this potential will develop, with acceptance as a standard after sufficient data has been obtained. However, users of the transit-time leak detector system will have an opportunity to compare its performance against their conventional meters, since these systems can be operated in parallel with existing meters.

7.5 LEAK LOCATION

Finding that a leak condition exists, and terminating flow so that injury to people and the environment is prevented or minimized, is the primary requirement that society places on our industry. But, in the real world, locating the source of the leak quickly, so that remedial action can be taken immediately, is what is necessary to be able to continue operations at the earliest possible time. Since the terrain through which pipelines pass is frequently populated, it is essential that the actual location of the leak be identified as precisely as possible. Uncertain 'poking around', with the resultant loss of public confidence, is becoming intolerable.

One of the most important benefits of the transit-time flowmeter is its ability to keep track of the different types of liquids in the pipeline at the time that a leak is discovered. This permits an exact 'triangulation' to be made of the pressure waves that emanate from the source of the leak to each segment's adjacent site stations. As a result of this capability, transit-time based leak detection systems show the promise of being able to place the source of even very small leaks to within meters of their actual location. In addition, advanced leak detection systems of this type have the ability to detect and warn of the development of even pin-hole sized leaks.

7.6 PIG DETECTION

Unlike conventional intrusive meter based systems, the clamp-on transit-time leak detector is a full bore system. Accordingly, no expensive bypass piping is needed to shunt pigs around the site stations.

In addition, the pig will interrupt the sonic beam as it passes through the site station. The site station is programmed to interpret the interruption duration, from the then current signal conditions, as detection of a pig. At the next polling, this pig detection alarm is transmitted to the master station, where the time of passage is displayed. This pig detection alarm is also available for local display at each site station.

The clamp-on transit-time leak detection system can be procured for leak detection service only, or can be upgraded to also serve as a pipeline management system when purchased, or at any time thereafter.

8. Field Performance of Installed Transit-Time Leak Detection Systems

Clamp-on transit-time leak detection systems have been in operation in the field for several years. Over this period, substantial data has been obtained in a variety of crude and product applications which substantiate the performance predicted by the specification parameters of the system. The data presented below is actual field data, obtained from the archived data files automatically saved by each system. The types of service from which these files were obtained include:

a) *A 22 inch interstate crude pipeline, handling as many as 15 different types of crude. Segment lengths are from 30 to over 100 miles*

b) *A bi-directional 12 inch pipeline, between a refinery and a tank farm, handling extremely viscous liquids.*

c) *An 8 inch pipeline handling aviation fuel in Arctic environment, covering a length of over 70 miles.*

d) *A 36 inch pipeline, handling many grades of crude, and crossing an Alpine mountain range.*

Among the examples shown below are:

Figure 3:	**A leak test performed under blocked Line conditions**
Figure 4:	**A leak test performed under high rate flow conditions**
Figure 5:	**Interface detection on a multi-product pipeline**
Figure 6:	**Batch tracking on a multi-product pipeline**
Figure 7:	**Liquid quality monitoring in refinery delivery application**
Figure 8:	**Liquid data screen identifying liquid data and condition**
Figure 9:	**Diagnostic screen showing site station operating conditions**

8.1 BLOCKED LINE LEAK DETECTION

Direct detection of leaks in a blocked line by the volume balance method requires that the flow meter operate with high sensitivity under zero flow conditions. This attribute of the clamp-on transit-time flowmeter is illustrated by Figure 3.

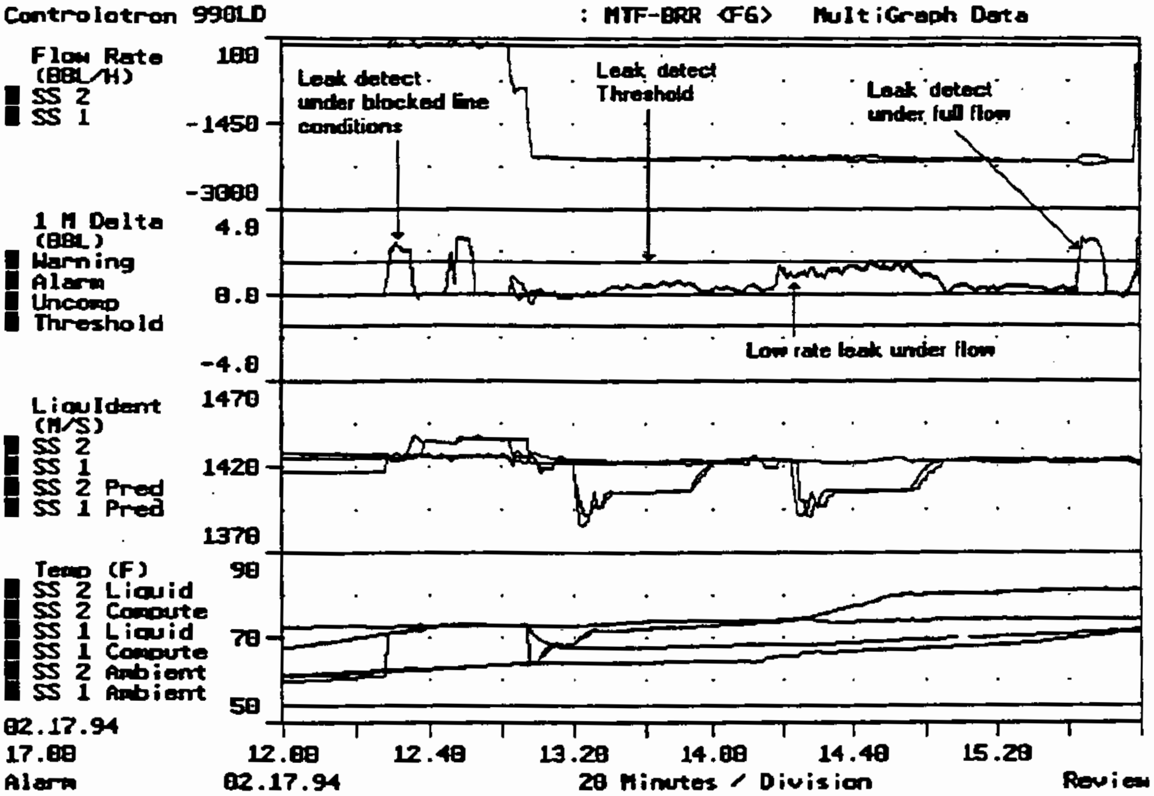

Figure 3: Leak test under blocked line condition

As shown, this is a multi-graph screen produced by the master station for a 12-inch line flowing highly viscous product. The upper trace shows the flow rates for each of the two site stations bounding the segment. As can be seen, the flow is effectively zero from 12:20 on February 17, to a little after 13:00 hours. A leak of around 2 BPM, lasting around 7 to 10 minutes, was provoked on two occasions; at 12:27 and again at 12:43. This leak was driven by line head pressure only. As shown on the second trace, which shows the segment volume imbalance for a 1 minute integration period (1 minute delta), both leak events passed through the leak alarm threshold, set to 1.5 barrels, and triggered the alarm within 1 minute. Also shown on this multi-graph screen are the Liquident sonic signature values, and the computed and measured temperatures of the liquid, and the ambient temperature, at each site station.

8.2 LEAK DETECTION AT HIGH FLOW RATE CONDITIONS

A high flow rate leak was created on the same pipeline as described previously, as shown on Figure 3. The flow rate was set to approximately -2000 barrels-per-hour (this is a bidirectional line). At 15:42 a 2 BPM leak was created, the same rate as instituted earlier when the line was blocked. As may be seen on the second trace, the 1 Minute Delta, the alarm threshold was crossed in 1 minute. In all respects, detection of the leak at high flow rate was identical to its detection under blocked line conditions.

Note that at 14:20 a leak smaller than the 1 minute alarm threshold was created. As shown on Figure 4, the MultiGraph Delta screen, the second trace, for the 5 minute integration period, detected the leak within two minutes.

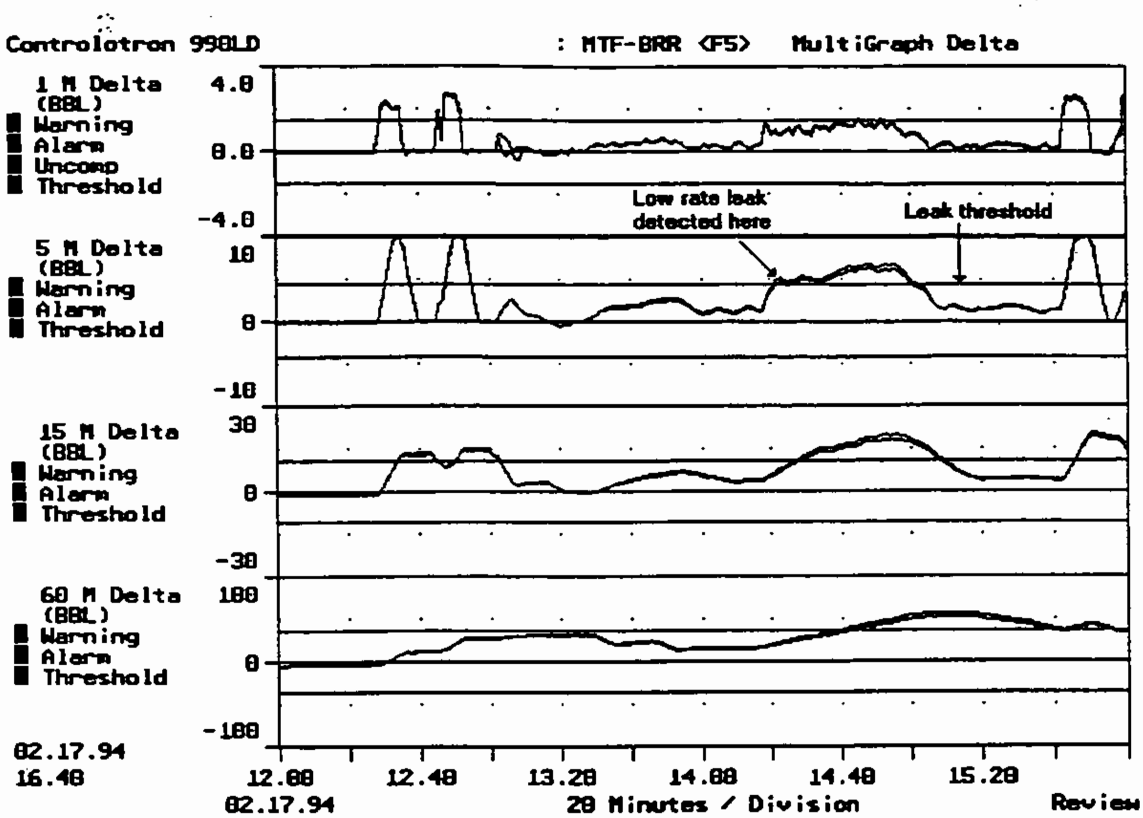

Figure 4: Leak test under high rate flow condition

8.3 INTERFACE DETECTION & BATCH SIGNATURE ON A CRUDE PIPELINE

The sonic signature graph shown as Figure 5 was obtained by monitoring flow on a 22-inch pipeline, for a segment of over 100 miles. Liquldent is the 'sonic signature' of the different batches of crude which flow, and is directly related to liquid density.

As may be seen, each batch flowing down the pipeline generates a characteristic sonic signature shape, dependent on the variation of product within the Batch. As may be seen, these shapes are essentially identical as each batch passes first one site station, and then the next site station down the line. Also clearly visible are the interfaces between the batches.

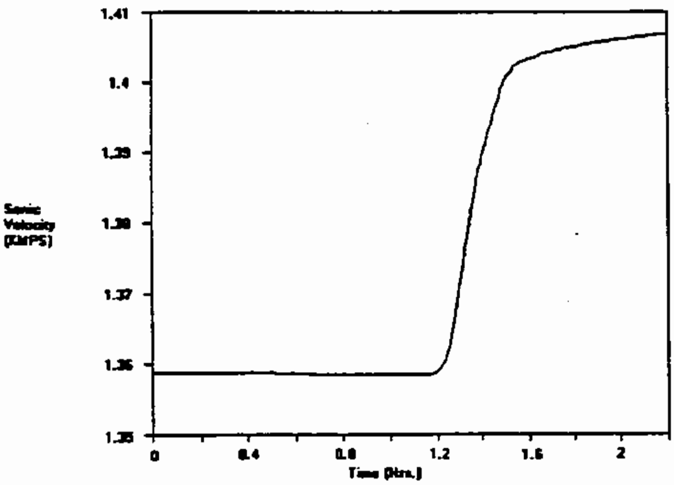

Figure 5: Interface detection on multi-product pipeline

The distinctive and easily recognizable batch signature shapes on the screen enable pipeline operators to cut each batch as it arrives at the terminal. As shown below, the system also provides a batch tracking screen which predicts the arrival time of each batch at the next site station, and also identifies the materials API number, and its volume at the standard temperature of 60°F.

8.4 BATCH TRACKING

Consistent with the clamp-on transit-time system's ability to visualize the flow of batches down a pipeline, is its ability to quantify the batch volume, and its position in the pipeline numerically. Figure 6 shows a typical batch tracking screen produced by the master station. As shown, it provides a listing of all batches still in the pipeline, indicating the standard volume of each batch, its average API number and the estimated time of arrival of its leading Interface at the next site station. These values (times, BBLs, etc.) are automatically re-computed as rates change.

Controlotron 990LD <F4> Batch/Liquid Status

Pipeline: MUP **Date/Time: 03:28:94 19.55**

Batch/Tag		Date/Time		Avg API	BBL	Mins
0019	DOMSWT	3.28.94	17:37	30.2	20560	714
0018	CSTLMIX	3.28.94	12:12	25.2	38001	460
0017	NIGRIAN	3.28.94	07:34	20.3	39222	198
0016	CSTLMIX	3.28.94	05.42	25.2	17232	83
0015	DOMSWT	3.28.94	04:04	30.1	15662	3
0014	CSTLMIX	3.28.94	02:12	25.2	16304	1018
0013	NIGRIAN	3.27.94	23:55	20.3	21258	876
0012	CSTLMIX	3.27.94	22:42	25.2	10553	805
0011	DOMSWT	3.27.94	16:25	30.1	51941	458
0010	CSTLMIX	3.27.94	14:02	25.2	22220	310
0009	NIGRIAN	3.27.94	13:01	12.9	9164	248
0008	EXTSOUR	3.27.94	10:15	28.5	21233	0

Figure 6: Batch tracking on a multi-product pipeline

8.5 LIQUID QUALITY MONITOR

Custody transfer is based strictly on proved volume transfer. Liquid quality is usually checked by sampling, which is available as reported data only after a batch has been delivered. In terms of value, liquid quality is certainly as important as liquid quantity in determining the value of the product which is being transferred. In this regard, the real time liquid quality monitor provided by the master station can be an important revenue producer.

Figure 7 shows the flow of processed product from a refinery to a tank farm. Note the characteristic 'bump' which appears on the sonic signature trace coincident with the initiation of flow. A short time later this bump arrives at the tank farm. This bump is water, which collected at the bottom of the holding tank at the refinery during the time that the batch was being processed. Its identification as water enables this contamination to be cut out of the batch prior to its being sent to its holding tank at the tank farm.

8.6 LIQUID DATA SCREEN

Of great value in the operation of a pipeline is information which shows the actual liquid in the pipeline, as opposed to the presumed liquid based on the 'name' of the product. The liquid data Screen, shown if Figure 8, identifies the actual sonic signature value, the Reynolds number under current flow conditions, the liquid viscosity and the liquid API number. As may be seen on a typical crude oil plot, the sonic signature is quite variable, indicating non-homogeneity. It is relatively easy to see how proving conventional intrusive flowmeters only once per batch (if that often with crude oil) could lead to erroneous batch totals caused by the normally unrecognized variability of liquid properties.

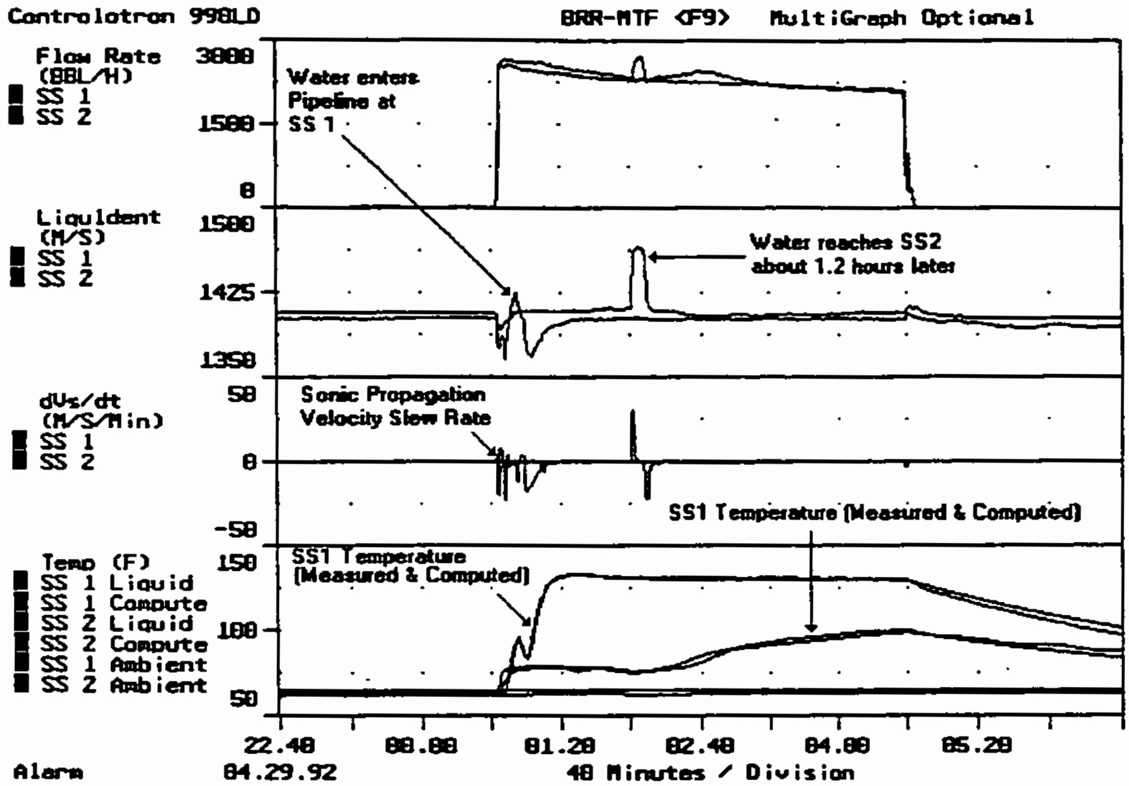

Figure 7: Liquid quality monitoring for refinery delivery

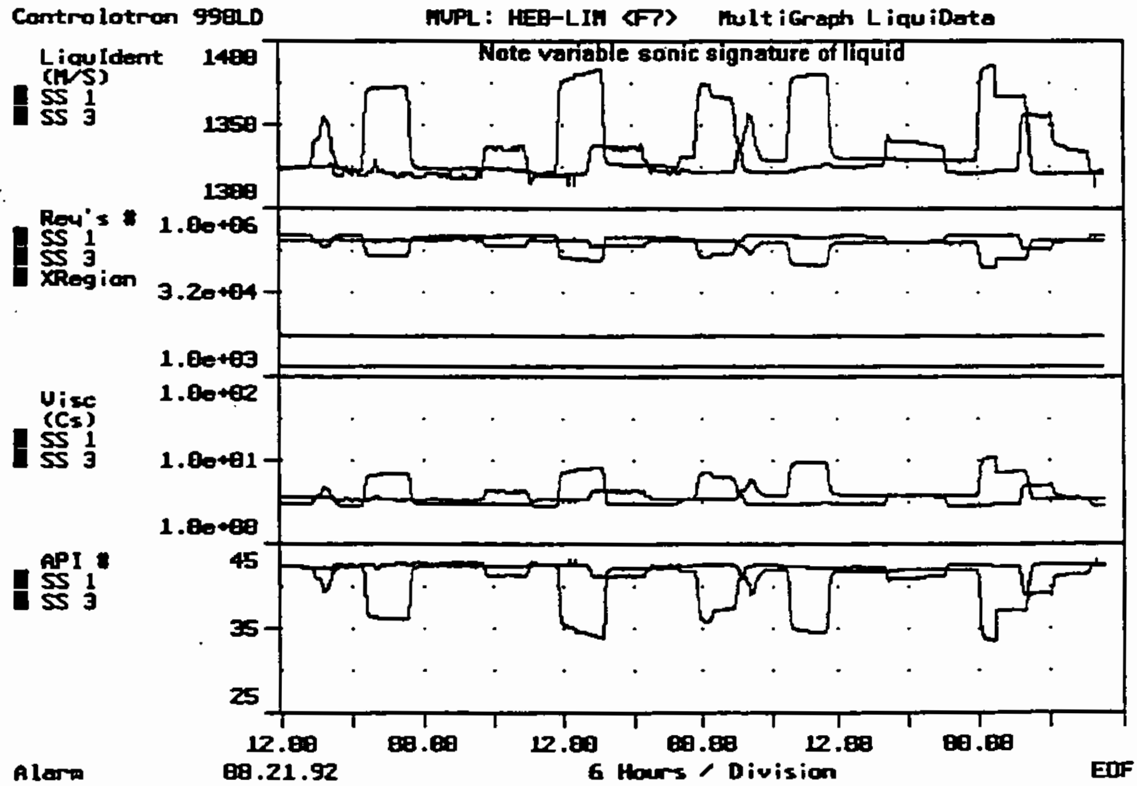

Figure 8: Liquid data 'sonic signature' screen

8.7 DIAGNOSTIC SCREEN

One substantial benefit provided by the clamp-on transit-time flowmeter is its ability to sense and report the condition of the meter itself, and of the liquid conditions at each site station. The diagnostic screen in Figure 9, updated once per minute, includes a variety of diagnostic data.

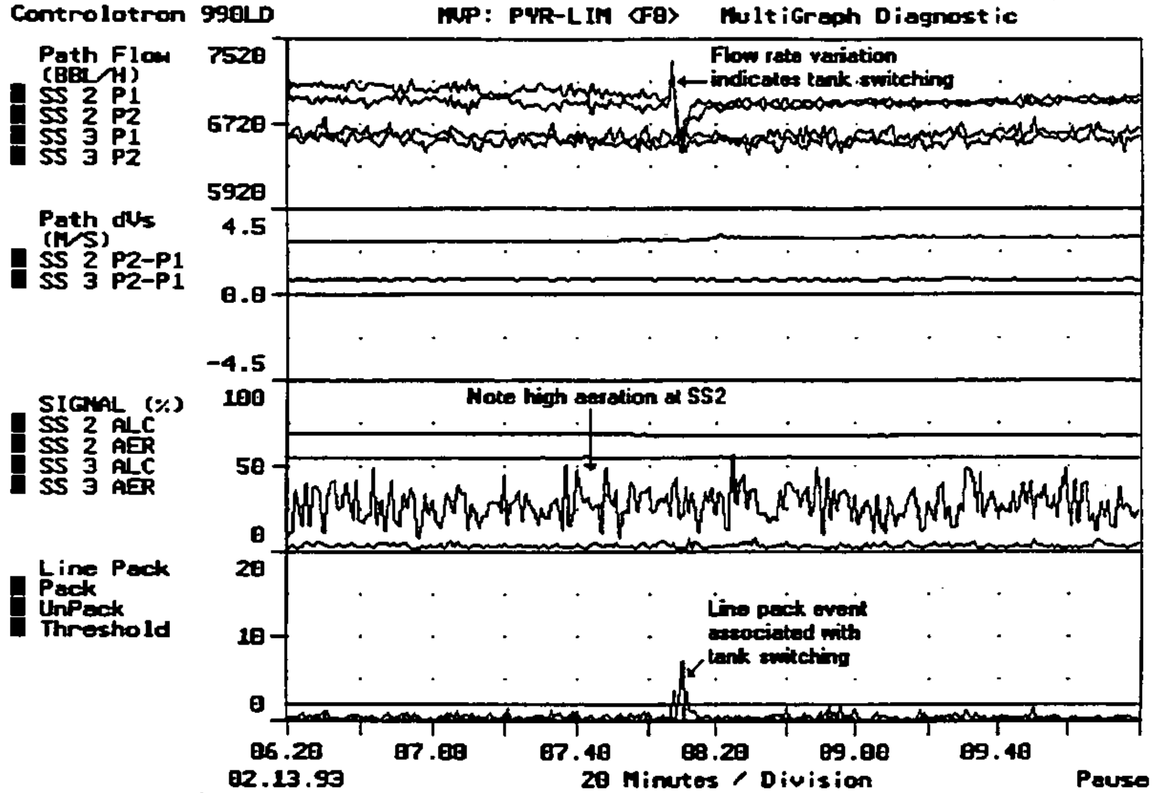

Figure 9: Diagnostics Screen

It shows the flow rate of each site station sensing path; in which a difference of rate is indicative of flow profile distortion. Any difference in displayed path sonic propagation velocity, Vs, is indicative of damage to a flow transducer.

The third trace shows the signal strength of the sonic beam, and as important, the amount of aeration being detected at each site station. This figure shows a substantial amount of aeration, which was later traced to a cavitation condition. This aeration would not have been identified by conventional intrusive flowmeters, and its net volume would have been counted as product, adversely affecting the transaction whose volume was being subject to custody transfer.

And finally, the line pack data shows exactly when a line pack or unpack event occurred, and its relative strength. In the event that any site station stopped operating, an immediate alarm is declared, and the offending site is identified on the master station screen which shows the pictorial of the pipeline installation.

9. SUMMARY & CONCLUSIONS

As shown, the clamp-on transit-time based leak detection system is a practical and field proven system for leak detection, and where applicable, for pipeline management. While not now approved for custody transfer, it has shown the performance capability to warrant its consideration for this important application.

It is significant that, due to its non-intrusive clamp-on technology, the effectivity of this system can be easily confirmed by site survey, even prior to purchase. At that time, sufficient data can be obtained to predict the leak detection performance that a fully installed system will provide on any pipeline. However, tests on all types of pipelines, flowing various grades of crudes and refined products, plus compressed and liquified gas, have been universally successful. It has proved compatible with a wide variety of pipeline environments, from tropical to arctic climates.

Unique among leak detection systems, those based on the clamp-on transit-time flowmeter provide a wide range of additional functions to pay back their cost. These added functions, such as interface detection, liquid quality monitoring, pig detection, etc., increase the efficiency of pipeline management and related activities, obviating the need for expensive alternative equipment, such as densitometers, viscometers, and maintenance prone intrusive flowmeters. Its performance has already proved successful on a variety of pipelines moving essentially every type of hydrocarbon liquid.

As such, the transit-time flowmeter based leak detection system is ready to provide the pipeline industry with a practical, affordable and quickly installed means of assuring the safety and integrity of pipeline operations.

References

[1] Paper presented at the North Sea Flow Measurement Workshop, a workshop arranged by NFOGM & TUV-NEL

Note that this reference was not part of the original paper, but has been added subsequently to make the paper searchable in Google Scholar.