Smith Meter® Turbine Meter
A Smart Preamplifier for Real-Time Turbine Meter Diagnostics
Technical Paper

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Introduction

A new, dual-purpose device for turbine meters, which functions as a traditional signal preamplifier and accomplishes real-time performance diagnostics, is now available. This smart preamplifier (patent pending) utilizes high-speed microprocessor technology to continuously monitor and analyze the rotation of a turbine meter rotor. Continuous monitoring allows the device to detect rotational anomalies that can lead to erroneous measurements as they occur. The smart preamplifier works on liquid or gas turbine meters that use a variable reluctance pickup coil for signal generation. This paper will discuss the technology and capabilities of the smart preamplifier.

To simplify this discussion, it is assumed that the signal generated will be via a non-rimmed rotor. Thus, the term "blade" is used throughout. However, all discussions relevant to signal generation are also true for a rimmed rotor using either buttons or slots for signal generation.

Background

The following brief review of how signals are generated from the operation of a typical turbine meter will facilitate appreciation of the technology utilized in the smart preamplifier. A reluctance pickup coil consists of a permanent magnet producing a flux field that passes through a coil near its tip and into the housing where the rotor is mounted. Rotor blades made of a magnetically-permeable material pass in front of the pickup coil causing an elongation of the flux field. As this change in the flux field takes place, a voltage signal is generated in the coil (Figure 1). The amplitude of the voltage signal is determined by the velocity of the blades as they pass the pickup. Frequency is determined by the speed of the rotor.

Under optimum conditions, the turbine meter is a precision instrument for accurate measurement of liquids or gases for custody transfer purposes. Although the turbine meter is, by nature, an inference measurement device (throughput is determined from the rotational velocity of the rotor), its turndown, linearity, and repeatability make it suitable for a number of critical applications.

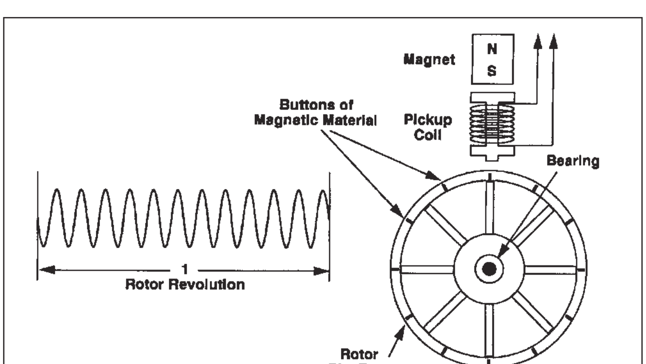

Figure 1—Turbine Meter Signal Generation

A properly-operating turbine meter, using a reluctance pickup coil, will produce a dynamic signature similar to the sine-wave shown in Figure 2. "Properly-operating" here refers to a turbine meter that has been manufactured with consistent spacing from blade-to-blade, with good bearings, and is in use under stable flow conditions with reasonable pressures at either side of the flanges. The sine-wave is extremely stable and repetitive from blade-to-blade; and, for any one given rotation of the turbine rotor to the next, the elapsed time will be consistent under constant flow conditions.

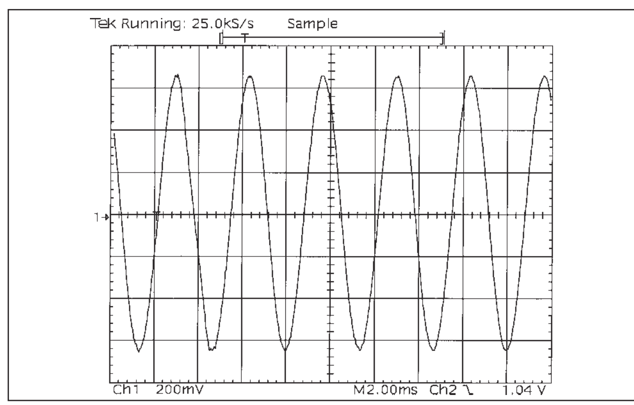

Figure 2—Typical Turbine Meter Reluctance Pickup Coil Signal

In typical applications, a preamplifier is used to condition the pulse pickup signal to prevent the possibility of erroneous electrical noise being injected into the transmission line. The result is a square wave voltage signal of constant amplitude regardless of the product flow rate through the turbine meter.

Hardware

The smart preamplifier performs this same function of signal amplification in addition to diagnostic analysis. The device is separated into two distinct functional blocks: a diagnostic microprocessor and a preamplifier.

The preamplifier has a differential input for optimum noise rejection, discrete power supply input (separate from the microprocessor power input), optical isolation from the diagnostic microprocessor, and a "push-pull" output driver that can either sink or source current into the receiving device (allowing for maximum flexibility in connecting to external devices). This means that there is no effect on the operation of the preamplifier from the microprocessor side of the smart preamplifier.

The microprocessor used in the smart preamplifier is a Motorola 68332. Its primary function is to capture information pertaining to the sine-wave through the use of high-speed chronometry. This data is stored in tables that are used to perform the diagnostic calculations.

Theory of Operation

The smart preamplifier uses a processing cycle that consists of three distinct elements:

1. Collect and store data.
2. Analyze the collected data.
3. Post the results to historical files, output switches, and communications.

A formatted data table for a turbine meter with an eight-bladed rotor assembly lends itself easily to analysis for the purpose of explaining the operating principles of the smart preamplifier (Figure 3).

1= 3065	9= 3065	17= 3062	25= 3066	33= 3064
2= 3054	10= 3050	18= 3055	26= 3058	34= 3054
3= 3050	11= 3064	19= 3053	27= 3052	35= 3052
4= 3060	12= 3064	20= 3064	28= 3062	36= 3059
5= 3057	13= 3061	21= 3064	29= 3054	37= 3049
6= 3067	14= 3063	22= 3065	30= 3065	38= 3063
7= 3066	15= 3056	23= 3063	31= 3063	39= 3056
8= 3055	16= 3055	24= 3059	32= 3055	40= 3054

Figure 3—Example Data Table for Turbine Meter Chronometer

Collection

Information is collected by the microprocessor and arranged so that the data is presented based on the number of blades on the turbine rotor. The columns represent one complete rotation of the turbine rotor and the rows represent the same blade at the start of each new cycle of the rotor. Five revolutions of the rotor are shown. Note that the microprocessor collects identical data tables for the rising portion of the sine wave (that part of the sine wave that is above the zero crossing line) and falling portion of the sine wave (that part of the sine wave that is below the zero crossing line).

Depending on the number of pickup coils being used, the smart preamplifier will perform this data collection for both an “A” pickup coil and a “B” pickup coil. Data is collected and stored in data tables for the “A” pickup coil “high” data, the “A” pickup coil “low” data, the “B” pickup coil “high” data, and the “B” pickup coil “low” data. For simplicity, only one of the data collection tables will be used for discussion purposes as the concept is the same for all four data collection tables. For this paper, only 40 data collection values per table will be presented.

A four-inch turbine meter with an eight-bladed rotor, a K-factor of 25 pulses per gallon (6.6 pulses per litre), operating at 720 gpm will have a data collection table similar to the one shown in Figure 3. The first column down the left-hand side of the table shows chronometer times for the eight blades. Each individual blade has its own count value specific to this rotor at this flow rate. The first row (across the top) shows the same blade relative to itself for five consecutive revolutions of the rotor. The consistency of the count values is dependent on the flow profile of the system (uniform pump pressure, valve modulation, etc.).

The first column represents one complete revolution of the rotor assembly. The blade-to-blade spacing, as evidenced by looking at the count values collected for each row of the highlighted column, is fairly symmetrical. The flow profile must be extremely stable in order to achieve the test results indicated.

Analysis

Numerical analysis can now be performed on the data collection tables. The first point to be analyzed is blade-to-blade spacing which affects meter linearity. It is calculated for each rotation of the rotor by monitoring the total count time of each column. The fact that the second column repeats with numbers similar to the first column indicates that the rotor is turning with a fair degree of consistency. Notice that the third and fourth columns are also fairly uniform when compared to the first column. This is a further indication that the rotor velocity is constant.

Analysis of the first row of data presented shows the count data collected for the same blade over five consecutive revolutions of the rotor. This data is utilized to verify repeatability and the stability of the rotor velocity. However, merely utilizing row data against itself does not provide for an adequate analysis of what is happening between the rotor velocity, blade position, and bearing wear.

A change in the angle of the blades of a turbine meter rotor will have the effect of either increasing or decreasing the rotor velocity for a given liquid velocity. The blade angle of each blade of the rotor remains constant unless debris of substantial size and weight pass through the meter. Should any type of debris become lodged on the rotor, or actually cause a change in the blade angle through impact on the rotor, the smart preamplifier will detect this change and provide an alarm indication. This alarm can be used to alert the operator that conditions have changed and proving may be required.

However, since changes in blade positioning may only affect linearity of the meter, proving must be accomplished at more than one flow rate to determine if there has been a shift in the meter linearity curve.

Blade/Linearity maximum errors are detected by comparing the column average to the row average and displaying the highest error. Average and worst case values are calculated based on the wave-form rise and fall time chronometer values. Additionally, since this type of data is available for both the high-going part of the sine wave and the low-going part of the sine wave, the microprocessor numerically combines the worst case value calculated from the high-going data collection table with the worst case value calculated from the low-going data collection table. “AVG” Blade/Linearity is calculated utilizing a standard deviation equation. This is accomplished on the row average.

The design physics for a turbine meter dictate that the velocity of the meter cannot change instantaneously (due to inertial effects of the rotor). Assuming that velocity will not play a part in two consecutive blade readings, each consecutive blade count value can be compared to the next count value for analysis purposes. Large deviations in these comparisons point to bearing problems.

Changes in rotor bearing friction will interfere with velocity measurement of the product. This is particularly pronounced with journal bearings running at speeds too slow to produce the film necessary for low friction. Turbine meters with journal bearings installed in the vertical position, with upward flow, experience significant bearing friction until the flow becomes sufficient to "float" the rotor off the upstream thrust bearing. In certain instances, deposits can form on the journal bearing that alter the friction. Varnish is a common deposit with gasoline service. Bearing deposits are particularly troublesome on liquid petroleum gas and anhydrous ammonia service. Assuming that the deposit formation is not uniform, meter performance will be affected and the smart preamplifier will detect changes in rotational velocity. This type of error will manifest itself during a prove as a repeatability problem with the meter.

Posting

Posting decisions are based on the data available from all data points for both the high-going and low-going portion of the sine wave. The microprocessor looks at the complete chart utilizing all results from the numerical analysis in an attempt to identify the most probable cause of a discrepancy, if any, and determine which alarm messages should be posted. Any current value that exceeds the desired "properly operating" signature will elicit some type of response from the smart preamplifier. A standard diagnostic data screen for a sine wave typified by the hypothetical "perfect turbine" would produce a computer DIAGNOSTIC UPDATE display screen similar to the one shown in Figure 4 on the DOS-compatible program supplied with the smart preamplifier. This reference signature can be determined automatically by the smart preamplifier or can be manually entered by the operator.

```
CUSTOMER          Smith Meter Inc.
METER             H5111                    BATCH AVG. GAL/HR     36102.13
FLOW DIRECTION -  FORWARD                  BATCH INST. GAL/HR    43050.00
BLADE COUNTS            8                  FREQUENCY                  298
METER FACTOR      1.00000                  K FACTOR                 25.00
LOCATION :        Houston, TX
   DATE           01/31/95       TIME      09:30:20      UNIT ID    1
START DATE        01/31/95       TIME      08:00:00      TICKET     1

BLADE/LINEARITY          CONSISTENCY              BEARING/REPEATABILITY
AVERAGE       1.02       INTEGRAL        0.26     AVERAGE            0.02
MAX           1.03       RATIO           0.49     MAX                0.26

ENTERED MAX ERROR VALUES
AVERAGE       2.50       INTEGRAL        1.00     AVERAGE            3.00
MAX           3.25       RATIO           2.00     MAX                4.00

TURBINE MIN.DIAG.FREQ.HZ        30         SENSITIVITY FACTOR SECONDS   10

Alarm :  Bent
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Figure 4—Diagnostic Update Screen From Computer Display

Alarm processing allows for indication of the most probable cause represented by the following phenomenon:

1. **No Problem** - Perfect signature, a properly-operating turbine meter.
2. **Bent Blade** - Perfect signature with a single distorted repetitive sine wave.
3. **Bad Bearing** - Perfect signature with a single distorted non-repetitive sine wave.
4. **Bearing Wear** - Distorted non-repetitive multiple wave signature.
5. **Debris on Rotor** - Good signature with repetitive frequency modulation.
6. **Cavitation** - Good signature with non-repetitive frequency modulation.

The processing cycle now repeats itself. Typically, this whole process of data collection, data analysis, and posting is completed in less than one second.

Example

For the purposes of illustration, a bent blade is an excellent example. What happens to the signature (sine wave) of a turbine meter when a blade becomes bent? The sine wave looks like the diagram shown in Figure 5. The numeric signature appears as shown in the data collection table of Figure 6. Note that this is the same data collection table used in the previous example, but with a bent blade.

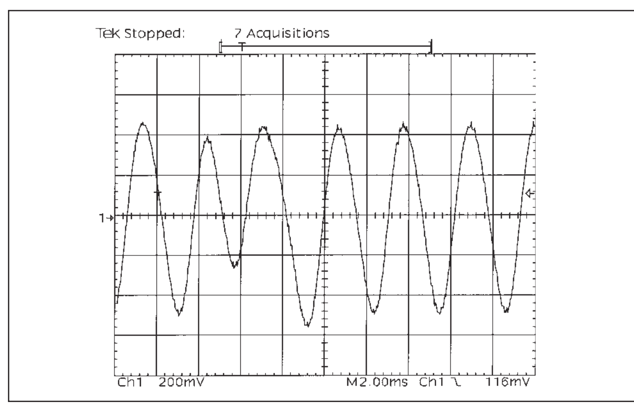

Figure 5—Signature From a Turbine Meter With a Bent Blade

1= 3065	9= 3065	17= 3062	25= 3066	33- 3064
2= 3154	**10= 3150**	**18= 3155**	**26= 3158**	**34= 3154**
3= 2950	**11= 2956**	**19= 2953**	**27= 2952**	**35= 2952**
4= 3060	12= 3064	20= 3064	28= 3062	36= 3059
5= 3057	13= 3061	21= 3064	29= 3054	37= 3049
6= 3067	14= 3063	22= 3065	30= 3065	38= 3063
7= 3066	15= 3056	23= 3063	31= 3063	39= 3056
8= 3055	16= 3055	24= 3059	32= 3055	40= 3054

Figure 6—Example Data Table for Turbine Meter With Bent Blade

The bent blade appears in the data collection table as a change in chronometer count value (could be positive or negative) with respect to its previous count value. The new value is repetitive at the same blade location, and can affect the count value of the numerical data before and after the location where the blade is bent. There is relatively little change in the velocity of the turbine rotor as the total travel time for one revolution of the rotor is almost the same as when the blade was not bent. This is because the bent blade does not affect the overall speed with which the rotor is turning, but rather affects sine-wave timing values on an individual blade-to-blade basis.

The corresponding DIAGNOSTIC UPDATE data screen on the computer appears as shown in Figure 7. Notice that the numbers for the data fields described as BLADE/LINEARITY have increased in value to the point that if the count value exceeds the time filter constant value, an alarm will be generated. Note that the BLADE/LINEARITY AVERAGE is the average of ALL blades for an entire data table, whereas, the MAX value is the same as calculated on the chart for the worst case deviation.

```
CUSTOMER        Smith Meter Inc.
METER      H5111                            BATCH AVG.  GAL/HR      36102.13
FLOW DIRECTION -  FORWARD                   BATCH INST. GAL/HR      43050.00
BLADE COUNTS            8                   FREQUENCY                    298
METER FACTOR      1.00000                   K FACTOR                  25.00
LOCATION  :     Houston, TX
      DATE      01/31/95          TIME   10:25:50        UNIT ID       1
START DATE      01/31/95          TIME   08:00:00        TICKET        1

BLADE/LINEARITY             CONSISTENCY                  BEARING/REPEATABILITY
AVERAGE          7.02       INTEGRAL           0.46      AVERAGE            0.12
MAX             12.88       RATIO              0.89      MAX                0.29

ENTERED MAX ERROR VALUES
AVERAGE         2.50        INTEGRAL           1.00      AVERAGE            3.00
MAX             3.25        RATIO              2.00      MAX                4.00

TURBINE MIN.DIAG.FREQ.HZ         30      SENSITIVITY FACTOR SECONDS   10

Alarm :       None
```

Figure 7—Diagnostic Update Screen for Turbine Meter With Bent Blade

Applications

The smart preamplifier can be utilized on any turbine meter where immediate diagnostics can enhance measurement accuracy. Applications include, but are not limited to: pipeline, loading racks, refinery, blending, and gas measurement.

Installation

Physical installation of the smart preamplifier is similar to traditional preamplifiers (where NEC and applicable local codes apply). The user-friendly application program makes configuration and operation a relatively easy task.

Conclusion

In conclusion, the smart preamplifier is a critical improvement in custody measurement and metering accuracy. Traditionally, a turbine meter is proved on a periodic basis against a known volume to determine its repeatability and meter factor. Careful monitoring of line balance confirms measurement accuracy. If any of these factors are out of tolerance or change unexpectedly, the source of the error must be found and corrected. This task could be very extensive and time consuming.

Proving only detects turbine meter problems after they occur. Intermittent problems, such as those related to specific pump operation, may never be detected by proving. Measurement accuracy is significantly enhanced when turbine meter problems are detected as they happen.

The smart preamplifier provides the operator with the current turbine meter signature. The signature shows the turbine rotor machining deviations and rotational characteristic variations. When the current signature exceeds the programmed tolerance, a date- and time-stamped record is recorded in the historical alarm file. The operator will be signaled by a switch contact or through the communications link that an error has been detected, allowing for immediate diagnostics to prevent measurement inaccuracies.

The key benefit of a smart preamplifier is the ability to achieve immediate diagnosis of operational anomalies. Smart preamplifier users realize real-time detection of problems, providing the opportunity they need to correct potentially costly situations.The end result is a savings in time, money, and effort—all ingredients of optimum system operation.

Acknowledgment

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