

Manual of Petroleum Measurement Standards Chapter 4—Proving Systems

Section 6—Pulse Interpolation

SECOND EDITION, MAY 1999

ERRATA, APRIL 2007

REAFFIRMED, OCTOBER 2013



AMERICAN PETROLEUM INSTITUTE

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Section 6—Pulse Interpolation

Measurement Coordination

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FOREWORD

Chapter 4 of the *Manual of Petroleum Measurement Standards* was prepared as a guide for the design, installation, calibration, and operation of meter proving systems commonly used by the majority of petroleum operators. The devices and practices covered in this chapter may not be applicable to all liquid hydrocarbons under all operating conditions. Other types of proving devices that are not covered in this chapter may be appropriate for use if agreed upon by the parties involved.

The information contained in this edition of Chapter 4 supersedes the information contained in the previous edition (First Edition, May 1978), which is no longer in print. It also supersedes the information on proving systems contained in API Standard 1101, *Measurement of Petroleum Liquid Hydrocarbons by Positive Displacement Meter* (First Edition, 1960); API Standard 2531, *Mechanical Displacement Meter Provers*; API Standard 2533, *Metering Viscous Hydrocarbons*; and API Standard 2534, *Measurement of Liquid Hydrocarbons by Turbine-Meter Systems*, which are no longer in print.

This publication is primarily intended for use in the United States and is related to the standards, specifications, and procedures of the National Bureau of Standards and Technology (NIST). When the information provided herein is used in other countries, the specifications and procedures of the appropriate national standards organizations may apply. Where appropriate, other test codes and procedures for checking pressure and electrical equipment may be used.

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MPMS Chapter 4 now contains the following sections:

- Section 1, "Introduction"
- Section 2, "Conventional Pipe Provers"
- Section 3, "Small Volume Provers"
- Section 4, "Tank Provers"
- Section 5, "Master-Meter Provers"
- Section 6, "Pulse Interpolation"
- Section 7, "Field-Standard Test Measures"
- Section 8, "Operation of Proving Systems"
- Section 9, "Calibration of Provers"

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Suggested revisions are invited and should be submitted to the general manager of the Upstream Segment, American Petroleum Institute, 1220 L Street, N.W., Washington, D.C. 20005.

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Chapter 4—Proving Systems

Section 6—Pulse Interpolation

0 Introduction

To prove meters that have pulsed outputs, a minimum number of pulses must be collected during the proving period. The prover volume or the number of pulses that a flowmeter can produce per unit volume of throughput is often limited by design considerations. Under these conditions it is necessary to increase the readout discrimination of the flowmeter pulses to achieve an uncertainty of 0.01%.

The electronic signal from a flowmeter can be treated so that interpolation between adjacent pulses can occur. The technique of improving the discrimination of a flowmeter's output is known as pulse interpolation. Although pulse-interpolation techniques were originally intended for use with small volume provers, they can also be applied to other proving devices.

The pulse-interpolation method known as double-chronometry, described in this chapter, is an established technique used in proving flowmeters. As other methods of pulse interpolation become accepted industry practice, they should receive equal consideration, provided that they can meet the established verification tests and specifications described in this publication.

1 Scope

This chapter describes how the double-chronometry method of pulse interpolation, including system operating requirements and equipment testing, is applied to meter proving.

2 Definitions

2.1 detector signal: A contact closure change or other signal that starts or stops a prover counter or timer and defines the calibrated volume of the prover.

2.2 double-chronometry: A pulse interpolation technique used to increase the readout discrimination level of flowmeter pulses detected between prover detector signals. This is accomplished by resolving these pulses into a whole number of pulses plus a fractional part of a pulse using two high speed timers and associated gating logic, controlled by the detector signals and the flowmeter pulses.

2.3 flowmeter discrimination: A measure of the smallest increment of change in the pulses per unit volume of the volume being measured.

2.4 frequency: The number of repetitions, or cycles, of a periodic signal (for example, pulses, alternating voltage, or current) occurring in a 1-second time period. The number of repetitions, or cycles, that occur in a 1-second period is expressed in hertz.

2.5 meter pulse continuity: The deviation of the inter-pulse period of a flowmeter expressed as a percentage of a full pulse period.

2.6 nonrotating meter: Any metering device for which the meter pulse output is not derived from mechanical rotation as driven by the flowing stream. For example, vortex shedding, venturi tubes, orifice plates, sonic nozzles, and ultrasonic and electromagnetic flowmeters are metering devices for which the output is derived from some characteristic other than rotation that is proportional to flow rate.

2.7 pulse period: The reciprocal of pulse frequency, i.e., a pulse frequency of 2 hertz, is equal to a pulse period of $1/2$ seconds.

2.8 pulse generator: An electronic device that can be programmed to output voltage pulses of a precise frequency or time period.

2.9 pulse interpolation: Any of the various techniques by which the whole number of meter pulses is counted between two events (such as detector switch closures); any remaining fraction of a pulse between the two events is calculated.

2.10 rotating meter: Any metering device for which the meter pulse output is derived from mechanical rotation as driven by the flowing stream. For example, turbine and positive displacement meters are those metering devices for which the output is derived from the continuous angular displacement of a flow-driven member.

2.11 signal-to-noise ratio: The ratio of the magnitude of the electrical signal to that of the electrical noise.

3 References

The current editions of the following standards are cited in this chapter:

API

MPMS Chapter 4, Proving Systems Section 3, "Small Volume Provers"

Chapter 5, Metering Section 4, "Instrumentation and Auxiliary Equipment for Liquid Hydrocarbon Metering Systems", Section 5, "Security and Fidelity of Pulse Data"

4 Double-Chronometry Pulse Interpolation

Double-chronometry pulse interpolation requires counting the total integer (whole) number of flowmeter pulses, N_m ,

generated during the proving run and measuring the time intervals, T_1 and T_2 . T_1 is the time interval between the first flowmeter pulse after the first detector signal and the first flowmeter pulse after the last detector signal. T_2 is the time interval between the first and last detector signals.

The pulse counters, or timers, are started and stopped by the signals from the prover detector or detectors. The time intervals T_1 , corresponding to N_m pulses, and T_2 , corresponding to the interpolated number of pulses (N_I), are measured by an accurate clock. The interpolated pulse count is given as follows:

$$N_I = N_m (T_2/T_1)$$

The use of double-chronometry in meter proving requires that the discrimination of the time intervals T_1 and T_2 be better than $\pm 0.01\%$. The time periods T_1 and T_2 shall therefore be at least 20,000 times greater than the reference period T_c of the clock that is used to measure the time intervals. The clock frequency F_c must be high enough to ensure that both the T_1 and T_2 timers accumulate at least 20,000 clock pulses during the prove operation. This is not difficult to achieve, as current electronics technology used for pulse interpolation typically uses clock frequencies in the megahertz range.

4.1 CONDITIONS OF USE

The conditions described in 4.1.1 through 4.1.3 apply to double-chronometry pulse interpolation as described in this chapter.

4.1.1 The interpolated number of pulses, N_I , will not be a whole number. N_I is therefore rounded off as described in *MPMS* Chapter 12.2, Part 3.

4.1.2 Pulse-interpolation methods are based on the assumptions that actual flow rate does not change substantially during the period between successive meter pulses, and each pulse represents the same volume. To maintain the validity of these assumptions, short period fluctuations in the flow rate during the proving operation shall be minimized.

4.1.3 Because pulse interpolation equipment contains high speed counters and timers, it is important that equipment be installed in accordance with the manufacturer's installation instructions, thereby minimizing the risk of counting spurious pulses caused by electrical interference occurring during the proving operation. The signal-to-noise ratio of the total system shall be adequately high to ensure that typical levels of electrical interference are rejected. Refer to Chapter 5.4, Chapter 5.5, and other sections of Chapter 4 for more details.

4.2 FLOWMETER OPERATING REQUIREMENTS

The flowmeter that is being proved and is providing the pulses for the pulse-interpolation system shall meet the following requirements:

- If the pulse repetition rate at constant flow rate cannot be maintained within the limits given in *MPMS* Chapter 4.3, then the flowmeter can be used with a pulse-interpolation system only at a lower overall accuracy level. In this case, a revised calibration accuracy evaluated or multiple runs with averaging techniques.
- The meter pulse continuity in rotating flowmeters should be in accordance with *MPMS* Chapter 4.3. The generated flowmeter pulse can be observed by an oscilloscope, whose time base is set to a minimum of one full cycle, to verify meter pulse continuity of the flowmeter.
- The repeatability of nonrotating flowmeters will be a function of the rate of change in pulse frequency at a constant flow rate. To apply pulse-interpolation techniques to nonrotating flowmeters, the meter pulse continuity of the flowmeter should be in accordance with *MPMS* Chapter 4.3 to maintain the calibration accuracy.
- The size and shape of the signal generated by the flow meter should be suitable for presentation to the pulse-interpolation system. If necessary, the signal should undergo amplification and shaping before it enters the pulse-interpolation system.

5 Electronic Equipment Testing

The proper operation of pulse interpolation electronics is crucial to accurate meter proving. A functional field test of the total system should be performed periodically to ensure that the equipment is performing correctly. This may simply be a hand calculation verifying that the equipment correctly calculates the interpolated pulses per 4, or if need be, a complete certification test as described in 7 if a problem is suspected.

6 Functional Operations Test Requirements

Normal industry practice is to use a microprocessor based prover computer to provide the pulse interpolation functions. The prover computer should provide diagnostic data displays or printed data reports which show the value of all parameters and variables necessary to verify proper operation of the system by hand calculation. These parameters and variables include, but are not limited to, timers T_1 and T_2 , the number of whole flowmeter pulses N_m and the calculated interpolated pulses N_I .

Using the diagnostic displays provided, the unit should be functionally tested by performing a sequence of prove runs and analyzing the displayed or printed results.

7 Certification Test

Certification tests should be performed by the prover computer manufacturer prior shipment of the equipment, and if necessary, by the user on a scheduled basis, or as mutually

agreed upon by all interested parties. The certification tests provided in this chapter do not preclude the use of other tests that may be performed on an actual field installation.

A block diagram of the certification test equipment is provided in Figure A-2.

An adjustable, certified, and traceable pulse generator with an output uncertainty equal to or less than 0.001% is installed that provides an output signal of frequency F'_m , simulating a flowmeter pulse train. This signal is connected to the flowmeter input of the prover flow computer.

A second adjustable, certified, and traceable pulse generator with an output uncertainty equal to or less than 0.001% is installed that provides an output pulse signal separated by time period T'_2 , simulating the detector switch signals. This signal is connected to the detector switch inputs of the prover computer.

The pulse interpolation function is more critical when there are fewer flowmeter pulses collected between the detector switches. Set the output frequency of the first generator to produce a frequency equal to the flowmeter that has the lowest number of pulses per unit volume to be proved with the equipment, at the highest proving flowrate expected.

The pulse interpolation function is also more critical when there are fewer clock pulses collected between the detector switches. Set the pulse period of the second generator to provide a volume time, T'_2 , equal to that which would be produced by the prover detectors at the fastest proving flowrate expected.

Example: A small volume prover with a waterdraw volume of 0.81225 barrels will be used to prove a turbine meter (K Factor 1000 pulses per barrel) at a maximum of 3000 barrels per hour.

Volume time T_2 for 0.81225 barrels at 3000 barrels per hour:

$$= 3600 \times 0.81225 / 3000$$

$$T_2 = 0.9747$$

Flowmeter frequency F_m produced by flowmeter (K Factor 1000) at 3000 barrels per hour:

$$= 3000 \times 1000 / 3600$$

$$F'_m = 833.33333 \text{ hertz.}$$

The calculated interpolated flowmeter pulses N_I are simply the simulated flowmeter frequency F'_m times the simulated volume time T'_2 .

$$= 833.33333 \times 0.9747$$

$$N_I = 812.2491$$

Verify the actual results displayed or printed by the prover computer under test, ensuring that they are within $\pm 0.01\%$ of the calculated value.

It is possible to select a simulation frequency F'_m above whose pulse period is an exact multiple of time period T'_2 , thereby synchronizing the simulated flowmeter pulses and detector signals. If this is the case, it will be necessary to modify either the simulated flowmeter frequency F'_m , or the simulated detector switch period T'_2 slightly to ensure that the interpolated pulses will include a fractional part of a pulse.

8 Manufacturer's Certification Tests

Certification tests should be performed at a number of simulated conditions. These conditions should encompass the prover device's range of prover volume times, T_2 , and flowmeter pulse frequencies, F_m . The manufacturer must provide, on request, a test certificate detailing the maximum and minimum values of prover volume time, T_2 , and flowmeter frequency, F_m , that the equipment is designed to accept.

If the pulse-interpolation electronics are tested and verified using the equipment and procedures shown, they can be used during a flowmeter proving operation with confidence that they will contribute an uncertainty of less than $\pm 0.01\%$ to the overall uncertainty of the proving operations within the pulse-signal-frequency range tested.

APPENDIX A—PULSE-INTERPOLATION CALCULATIONS

A.1 General

The double-chronometry method of pulse interpolation is described in 4. Figure A-1 is a diagram of the electrical signals required for the technique. The technique provides the numerical data required to resolve a fractional portion of a single whole flowmeter pulse. Double-chronometry pulse interpolation requires using the following three electrical counters: $CTR-N_m$ to count whole flowmeter pulses, $CTR-T_1$ to count the time required to accumulate the whole flowmeter pulses, and $CTR-T_2$ to count the time between detector signals, which define the displaced prover volume.

The double-chronometry technique reduces the total number of whole flowmeter pulses normally required for the displaced volume to fewer than 10,000 to achieve a discrimination uncertainty of 0.02% ($\pm 0.01\%$ of the average) for a proof run.

The required time/pulse discrimination guidelines are presented in 4 and shall be used in conjunction with a prover designed in accordance with the sizing parameters described in *MPMS* Chapter 4.3.

The examples given in A.2, which conform to the guidelines in 4, each represent a single case of defined data and are not necessarily representative of all available pulse-interpolation methods.

A.2 Examples

A.2.1 EXAMPLE 1—INTERPOLATED PULSE CALCULATION

The following data are given:

F_c = clock frequency used to measure the time intervals, in hertz $> (20,000/N_1)F_m$

F_m = flowmeter pulse output frequency (the maximum value for analysis), in hertz
= 520

N_m = total number of whole flowmeter pulses
= 200 ($CTR-N_m$)

N_1 = number of interpolated flowmeter pulses
= $(T_2/T_1)N_m$

T_1 = time interval counted for the whole flowmeter pulses (N) in seconds
= 2.43914 ($CTR-T_1$)

T_2 = time interval between the first and second volume detector signals (that is, the displaced

prover volume), in seconds
= 2.43917 ($CTR-T_2$)

If the required pulse-interpolation uncertainty is better than $\pm 0.01\%$, then

$$\begin{aligned} 100,000 &> (20,000/200 \text{ pulses})(520 \text{ hertz}) \\ &> (100)(520) \\ &> 52,000 \end{aligned}$$

Note: The period of the clock is the reciprocal of the frequency, $T = 1/F$. The period of 1 clock pulse is therefore $1/100,000$ hertz, or 0.00001 second. The discrimination of the clock is $0.00001/2.43914$, or 0.0004%. The requirement for the value of F_c and the discrimination requirement in 4.6.2 are therefore satisfied.

To calculate the interpolated pulses,

$$\begin{aligned} N_1 &= (2.43917 / 2.43914)(200) \\ &= (1.00001)(200) \\ &= 200.002 \end{aligned}$$

A.2.2 EXAMPLE 2—CERTIFICATION CALCULATION

Using equipment as shown in Figure A-2, the following data applies:

Simulated data:

F'_m = pulse frequency of generator number one simulating meter pulses, in hertz
= 233.000

T'_2 = pulse period of generator number two simulating detector signals, in seconds
= 1.666667

Observed data at prover computer being tested:

N_m = number of whole flowmeter pulses
= 388

T_1 = number of clock pulses accumulated during whole flowmeter counts N_m
= 166,523

T_2 = number of clock pulses accumulated during simulated prove volume
= 166,666

Note that both timers T_1 and T_2 accumulated $> 20,000$ clock pulses, satisfying the discrimination requirement detailed in 4.6.2.

Comparison of results:

N'_1 = calculated interpolated pulses based on certified pulse generators,

$$= F'_m \times T'_2$$

$$= 233 \times 1.666667$$

$$= 388.33341$$

The certification test agreement required between N'_1 and N_1 , is better than $\pm 0.01\%$. then

$$(N'_1 - N_1)/N'_1 < 0.0001$$

N_1 = calculated interpolated pulses based on prover computer observations,

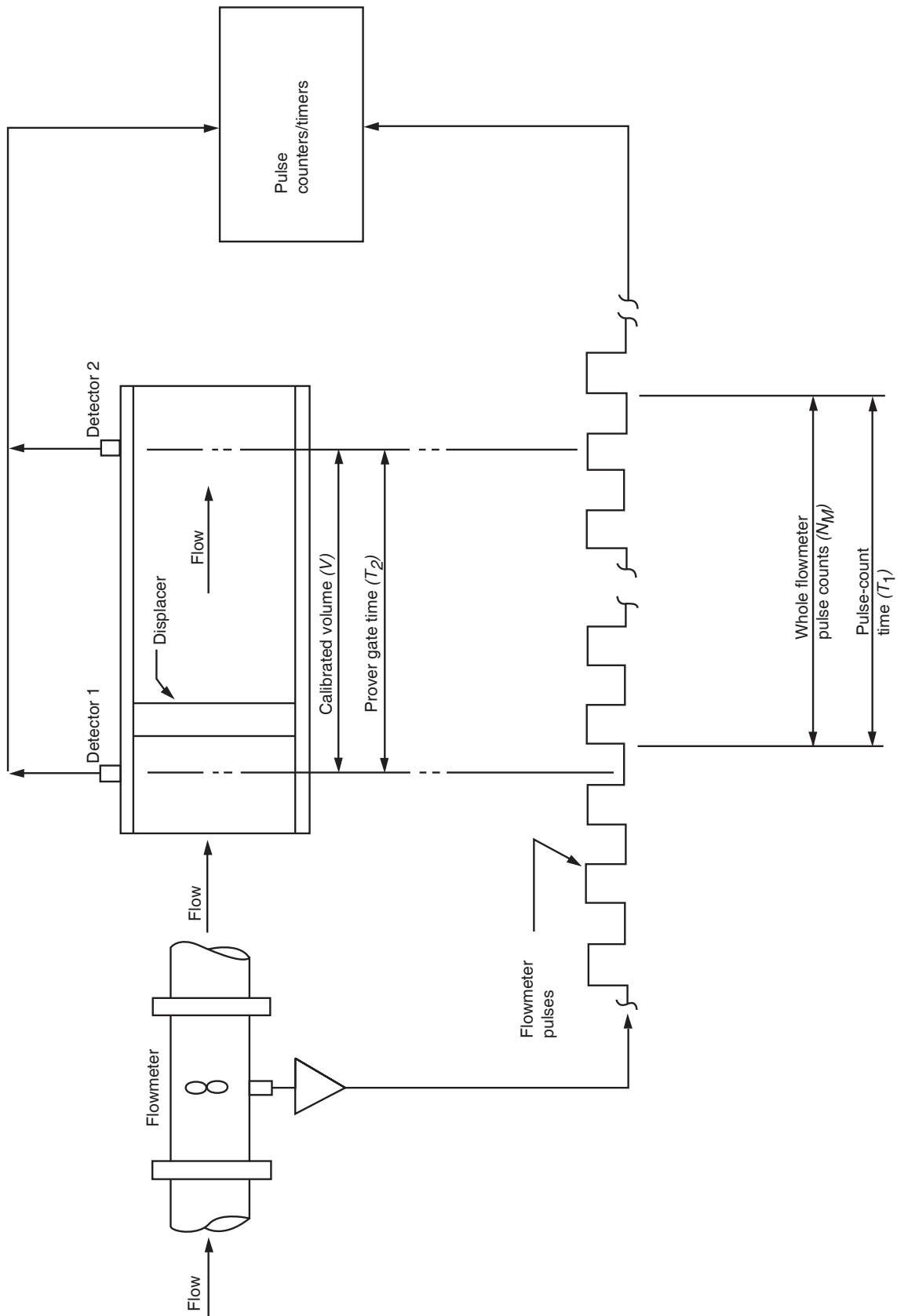
$$(388.33341 - 388.33319) / 388.33341 = 0.0000005$$

$$= N_m (T_2/T_1)$$

$$= 388 \times 166666/166523$$

$$= 388.33319$$

The test device results agree with calculated results based on traceable pulse generator data within 0.00005%. The certification test run is acceptable.



Note: The interpolated number of pulses N_1 is equal to $N_M(T_2/T_1)$

Figure A-1—Double-Chronometry Timing Diagram

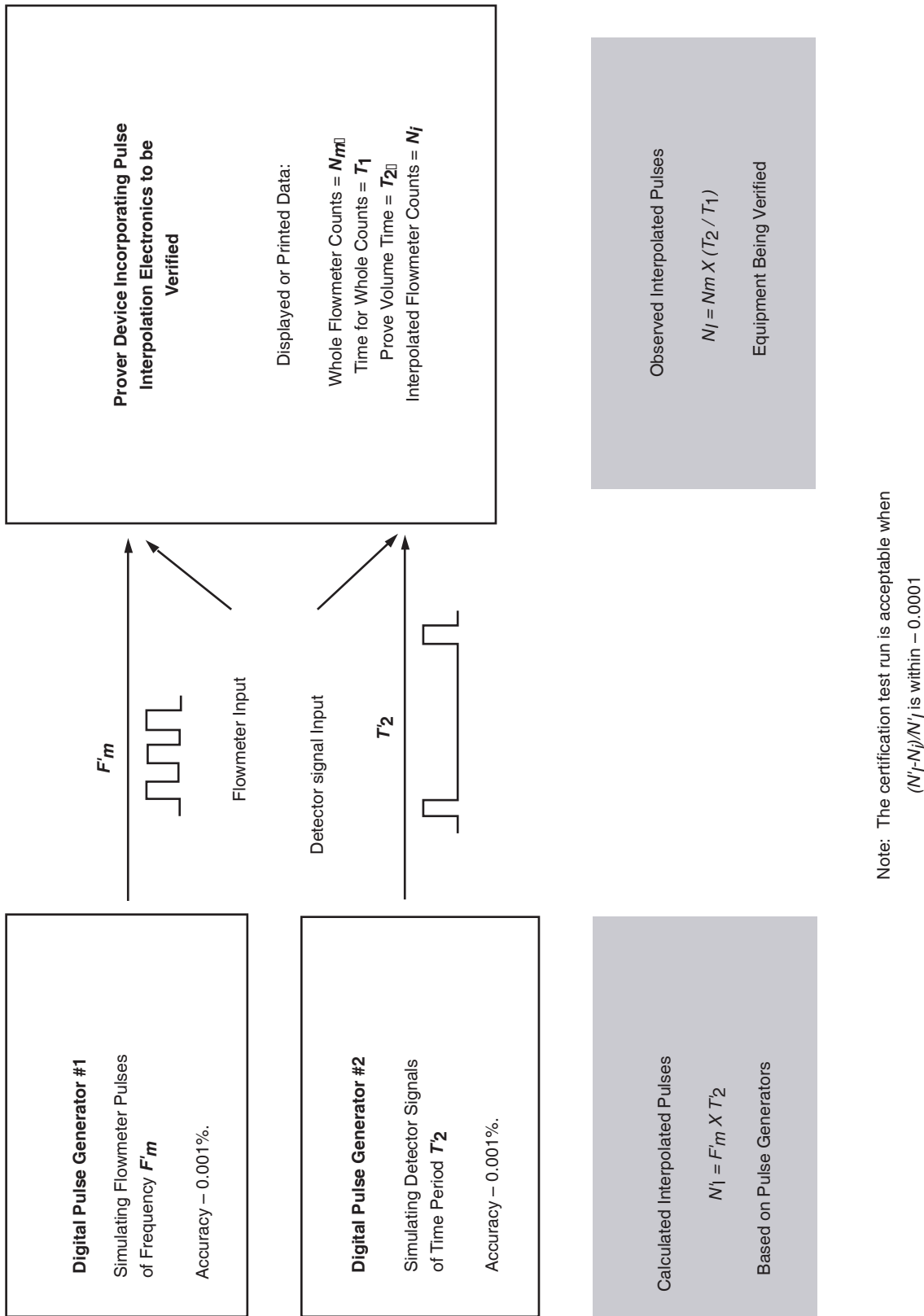


Figure A-2—Certification Test Equipment for Double-Chronometry Pulse Interpolation Systems

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Page 3, the equation at the bottom of the first column should read:

$$= 3600 \times 0.81225/3000$$

$$T_2 = 0.9747$$

Page 3, the equation in the second paragraph in the second column should read:

$$= 833.33333 \times 0.9747$$

$$N_I = 812.2491$$

Page 5, **A.2.1 EXAMPLE 1—INTERPOLATED PULSE CALCULATION**

Remove the punctuation at the end of each line, it should read as follows:

The following data are given:

$$F_c = \text{clock frequency used to measure the time intervals, in hertz} > (20,000/N_I)F_m$$

$$F_m = \text{flowmeter pulse output frequency (the maximum value for analysis), in hertz} \\ = 520$$

$$N_m = \text{total number of whole flowmeter pulses} \\ = 200 \text{ (CTR-}N_m\text{)}$$

$$N_I = \text{number of interpolated flowmeter pulses} \\ = (T_2/T_1)N_m$$

$$T_1 = \text{time interval counted for the whole flowmeter pulses (}N\text{) in seconds} \\ = 2.43914 \text{ (CTR-}T_1\text{)}$$

$$T_2 = \text{time interval between the first and second volume detector signals (that is, the} \\ \text{displaced prover volume), in seconds} \\ = 2.43917 \text{ (CTR-}T_2\text{)}$$

If the required pulse-interpolation uncertainty is better than $\pm 0.01\%$, then

$$100,000 > (20,000/200 \text{ pulses})(520 \text{ hertz}) \\ > (100)(520) \\ > 52,000$$

Note: The period of the clock is the reciprocal of the frequency, $T = 1/f$. The period of 1 clock pulse is therefore $1/100,000$ hertz, or 0.00001 second. The discrimination of the clock is $0.00001/2.43914$, or 0.0004%. The requirement for the value of F_c and the discrimination requirement in 4.6.2 are therefore satisfied.

To calculate the interpolated pulses

$$N_I = (2.43917 / 2.43914)(200) \\ = (1.00001)(200) \\ = 200.002$$

Page 5, **A.2.2 EXAMPLE 2—CERTIFICATION CALCULATION**

Remove the punctuation at the end of each line, it should read as follows:

Using equipment as shown in Figure A-2, the following data applies:

Simulated data:

$$\begin{aligned} F'_m &= \text{pulse frequency of generator number one simulating meter pulses, in hertz} \\ &= 233.000 \end{aligned}$$

$$\begin{aligned} T'_2 &= \text{pulse period of generator number two simulating detector signals, in seconds} \\ &= 1.666667 \end{aligned}$$

Observed data at prover computer being tested:

$$\begin{aligned} N_m &= \text{number of whole flowmeter pulses} \\ &= 388 \end{aligned}$$

$$\begin{aligned} T_1 &= \text{number of clock pulses accumulated during whole flowmeter counts } N_m \\ &= 166,523 \end{aligned}$$

$$\begin{aligned} T_2 &= \text{number of clock pulses accumulated during simulated prove volume} \\ &= 166,666 \end{aligned}$$

Note that both timers T_1 and T_2 accumulated $> 20,000$ clock pulses, satisfying the discrimination requirement detailed in 4.6.2.

Comparison of results:

$$\begin{aligned} N'_1 &= \text{calculated interpolated pulses based on certified pulse generators,} \\ &= F'_m \times T'_2 \\ &= 233 \times 1.666667 \\ &= 388.33341 \end{aligned}$$

$$\begin{aligned} N_1 &= \text{calculated interpolated pulses based on prover computer observations,} \\ &= N_m (T_2/T_1) \\ &= 388 \times 166666/166523 \\ &= 388.33319 \end{aligned}$$



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