Main Index

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DYNAMIC VERIFICATION OF COMPACT (PISTON) PROVER REPEATABILITY

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DYNAMIC VERIFICATION
OF
COMPACT (PISTON) PROVER REPEATABILITY

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SUMMARY

The main method of establishing (piston) prover repeatability is by observing waterdraw calibration repeatability. However, being an essentially static exercise, the waterdraw procedure will not reveal any ill effects on performance introduced during normal cyclic use at realistic flow rates. Testing dynamically against devices with a better proven performance is not an option, as few, if any, exist.

To provide a better test, and thus allow higher confidence to be placed in the performance of piston provers, a test was outlined by the OIML in its doc. no. 7, employing two standard turbine meters in series with the prover being tested.

This paper explains the statistical method used and the reason it works in theory. The development of numeric acceptance criteria is described, in addition to the qualified evaluation of result chart presentations that have been used exclusively with this test method earlier. Finally, some experiences and typical results from an actual test (on a 24" Brooks Compact Prover) are presented.

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1 INTRODUCTION

The on- and offshore industrial markets have exhibited growing acceptance of compact, or piston, provers as both primary and supplementary calibration devices in fiscal metering systems. This has led to a requirement for better, but still practical methods for verification of the performance of these devices.

The testing normally used provides directly verifiable figures for up- and downstream volume repeatability, but only an indication that the dynamic performance is equally good.

Accordingly, the OIML in its doc. no. 7 has outlined a new kind of test, using statistics not only to evaluate the data, but to generate the quantity evaluated. This method allows the use of standard equipment to evaluate a device with a better repeatability.

As we shall see, the use of statistics-based testing requires that acceptance criteria not be put in absolute terms.

2 CURRENT TESTING PRACTICE

Standard testing encompasses:

- Leak check
- Waterdraw calibration
- Dynamic testing against a conventional prover

The leak check is a static exercise, performed by manually moving the piston to a designated number of positions along the (water filled) cylinder, shutting in- and outlet valves, then applying a force to the piston (the Brooks Compact Prover [BCP] uses its plenum spring pressure) while monitoring piston movement. Zero movement confirms both seal integrity and cylinder roundness.

The waterdraw calibration uses automatic start and stop circuitry to precisely transfer the downstream (and/or upstream) cylinder volume of water to a calibrated volume standard. Repeatability is determined by repeating the exercise a designated number of times.

While no proof of the claimed repeatability (0.01 %) is achieved, the final test against the conventional prover at least shows that there is no gross deviation from the performance predicted by the static tests performed. The result from this exercise is customarily expressed as a "total spread" encompassing repeatabilities from the compact prover, the transfer meter and the conventional prover. This, at best, gives a reasonable assurance that the compact prover is performing to specification.

3 OIML TEST DESCRIPTION

Two standard turbine meters with a range extending to or above the maximum for the prover on test are installed in series with the prover.

It is assumed that the two turbine meters are installed in such a way that they do not influence each other in any way; i.e. any variation in **actual** meter factor when running at a fixed flow rate is due to the inherent repeatability limits of that meter, and is not affected by the presence of the other meter, and vice versa. This means that deviations from the mean meter factor will vary **randomly and independently** in sign and magnitude within the meter repeatability specification.

The above assumtion means that the covariance (equation 1) of the actual meter factors will be zero when **n** (the number of observations) approaches infinity. Even with "large" but finite **n**, this may be assumed with sufficient accuracy.

Now, when the meter factors are simultaneously determined (at a certain flow rate) with the prover, the deviations from the mean meter factors will be composed of one part due to the meters' repeatabilities, and one part due to the prover repeatability, with the latter component contributing the same percentage to both deviations. Since we have just established that the meter repeatabilities will not contribute to the covariance, we may see the calculated covariance as a measure of prover performance.

When selecting turbine meters for this duty, standard specification repeatability criteria must be met. Too large turbine meter repeatability figures are unacceptable

$$cov(k_1, k_2) = \frac{1}{n-1} \sum_{1}^{n} (k_{11} - \bar{k}_1) \; (k_{21} - \bar{k}_2)$$

k_1 : k-factor meter #1
k_2 : k-factor meter #2
n : number of tests

Equation 1

because they tend to "mask" the effect of the prover, both in chart observation and calculation based evaluation (see below).

4 RESULT EVALUATION

4.1 XY CHART OBSERVATION

This method does not really require that any statistical methods be applied to the data. When the meter factor deviations for meters #1 (X) and #2 (Y) are plotted in an XY diagram, a pattern appears that can be used for evaluation of the prover performance as follows:

Little or no contribution from prover	-	Majority of points evenly distributed within rectangle defined by the two turbine meter repeatabilities.
Prover contributes	-	Points stretch out along the line defined by X=Y, moving beyond the rectangle defined above.
Difference between meter repeatabilities is large	-	Points stretch out along the X or Y axis.

If turbine meter repeatabilities are more or less the same, the emerging pattern will be reasonably regular, and the listed changes due to prover effects will be easily visible. As discussed above, "bad" turbine meters will tend to obscure the pattern, but this is easily detectable from the individual meter factor results and thus avoidable.

4.2 COVARIANCE CRITERION

As discussed, the covariance between meter factors can be seen as a measure of prover performance. In order to calculate a covariance limit and determine other criteria to apply to the value calculated, and also to determine other test parameters, some simulation is required. During preparations for the testing mentioned in 6. below, such simulation was carried out as follows:

- The number of tests (single-pass runs) required to achieve a result sufficiently n -> ∞ was initially determined simply as the maximum number of runs per test that could be tolerated, given a reasonable time frame to complete the tests. Testing was considered necessary at 1/1, 2/3 and 1/3 of the maximum prover flow rate, and the desired number of tests at each flow rate was approximately 6. The number of passes arrived at from these requirements was 40, and this was used in all subsequent work.

- A test simulation (a spreadsheet) was developed with the following key assumptions:
    - the turbine meter factor deviations are random numbers, with a uniform probability distribution over the range of the quoted meter specification (typical repeatability +/- 0,02 %)
    - the prover contribution to meter factor deviation is a random number, applied equally to both k-factors, with a uniform probability distribution over the range of the quoted prover specification (typical repeatability +/- 0,01 %)
- Thereafter, approximately 1,000 complete tests were simulated, and the results were used to create a probability distribution profile for the covariance.

5 ACCEPTANCE CRITERIA

The covariance distribution found above was inspected, and a limit value that would statistically allow 2/3 of tests to pass was selected. It was felt that this would discriminate better than using a maximum value with a 100% pass requirement.

Comparison of the actual calculated covariance with the above limit yields a PASS/FAIL result for each 40-run test. In order for the complete test suite to be considered PASSED, at least 2/3 of tests at each flow rate must PASS.

However, being based on an averaging calculation, this criterion does not guarantee that every value is within the specified limit, and does not catch situations where an initially "perfect" prover deteriorates towards the end of a test, but not enough to bring the average out of bounds. Individual turbine meter deterioration should be caught by the prover, but to further safeguard against these possible problems, an additional criterion was introduced, using the XY diagram: a predominant number of the plotted points for any 40-run test, shall be located within a square described by:

$$|x| < a$$
$$|y| < a$$

where **a** is the straight sum of maximum deviations [%] for meter and prover.

6 EXPERIENCES AND PRACTICAL CONSIDERATIONS

Our immediate interest in the method and its use was prompted by a delivery of a 24" BCP to a Norwegian onshore site. The Norwegian Weights & Measures Directorate (Direktoratet for Måleteknikk, *DFM*) wanted an OIML test to be performed during the FAT.

Earlier implementations of the OIML test had been based primarily on evaluation by observation of the XY-charts as described above. On this occasion, the DFM felt (and the manufacturer concurred) that as far as possible, objective criteria should be used. This would allow a more uniform approach to evaluation in the future, would be more in line with tradition, and would finally be more acceptable to those writing contracts including such testing. Hence the calculation and simulation exercises described above.

During testing, the following points were noted and should be observed:

- The proviso that the turbine meter factors are independent is *not* to be taken lightly. Care should be taken when installing the temporary meter runs. Any flexible or corrugated tubing should be smooth inside; noticeable meter repeatability effects were seen with a corrugated tubing section upstream of turbine meter #1.
- Because of the fairly large amounts of data that need to be handled (possibly manually, depending on the prover electronics used), it is useful to have a spreadsheet or other system ready for immediate evaluation during testing.

7 SAMPLE RESULTS

For the particular installation mentioned above, the following data applies:

Prover (BCP) repeatability:	+/-0.01 %
Meter (Brooks) repeatability:	+/-0.02 %
Prover capacity:	1,589 m^3/h

Acceptance criterion from simulation:

- For each flow rate, approx. **2/3** of the performed tests shall result in a calculated covariance less than **4.3E-09.**

Acceptance criterion from chart inspection:

- For each test, a predominant number of the plotted points shall be located within the square described by:

  $|x| < 3.0E-04$
  $|y| < 3.0E-04$

Results:

LOW FLOW
Number of tests : 6
Number passed : 4
XY diagram check : Accepted
Test suite result : **PASSED**

MEDIUM FLOW
Number of tests : 6
Number passed : 5
XY diagram check : Accepted
Test suite result : **PASSED**

HIGH FLOW

Number of tests : 7
Number passed : 5
XY diagram check : Accepted
Test suite result : **PASSED**

OIML TEST RESULT: PASSED

After the test series had been completed, time was left to allow some further experiments. We therefore ran two test series where a variable error was introduced by generating a variable leak through a vent valve at the BCP. The main object of this was to make sure that the test method would actually catch the errors it should reveal according to theory.

The charts generated did indeed show the characteristic stretch along the X=Y line, and the covariances calculated exceeded the limit set.

ACKNOWLEDGEMENT

All work related to testing and development of acceptance criteria has been carried out in direct cooperation with or under the supervision of mr. Kristen Hellerud, DFM, Norway.

16.10.95

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.