MULTIPLE REGRESSION FOOTPRINTING OF METER FACTORS

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SUMMARY

This paper shows how multiple linear regression techniques were used to predict meter factors from historical data.

Some details from differing meter types are shown and interpretation of the results is discussed.

The results of the successful application of the method, during an extensive period of meter prover breakdown are presented.

It is shown how "footprinting" of turbine meters could be used as a means of real time measurement monitoring and control.

Notation

a, b, c, d	Regression Constants	-
MF	Meter Factor	-
Y	Calculated Meter Factor	-
F	Flow Rate	m3/hr
Rho	Density	kg/m3
T	Temperature	^oC
P	Pressure	bar g
R^2	Correlation Coefficient	-
X	Standard Error of Y Estimate	-

1.0 INTRODUCTION

The regular proving of turbine meters, at custody transfer and fiscal metering stations, is a legal requirement incumbent upon us (1). For those of us in an industry which produces and transports high value products, it makes good commercial sense to monitor and control our assets.

Various industry standards (2, 3, 4) outline how turbine meter performance may be monitored. The choice of method adopted is normally left open to the individual.

As a multi oil field operator, with a large number of metering stations, a large amount of meter proving data can be amassed.

Nowadays, within most major companies, desk top computers are readily available. Having access to such machines, with their pre-packaged programmes, data handling and graphing capabilities, means that the measurement engineer has the opportunity to study data in detail.

The author initially set out to ascertain whether meter proving frequencies were being optimised on two measurement stations. In general we are expected to prove our meters when fluid parameter changes (flow, temperature, pressure, density) are likely to cause a change in meter factor (MF) by 0.1%.

It was clear to the author that whilst the effects of flowrate on meter factors were understood by station operators, the effects of changes in combinations of fluid parameters were not fully understood.

The prediction of the results of such effects was a requirement of the exercise, in order to ascertain when meter proving was required. Also in order to judge whether meter proving was being optimised, real time meter factor prediction was thought preferable.

This paper shows how multiple linear regression techniques were used to "foot print" turbine meters from historical data. The results from two differing types of turbine meter are presented and interpretation of the results is discussed. The results of the successful application of the method, to an extensive breakdown period of a meter prover are also presented. It is shown how the method could be used, in some cases, as a means of real time measurement monitoring and control.

2.0 MULTIPLE LINEAR REGRESSION

The first aim of the regression analysis is to provide estimates of the dependent variable (meter factor) from values of the independent variables (flowrate (F), temperature (T), pressure (P), density (Rho)) The output of the regression in this case takes the form of a linear best fit using a least squares method.

The algorithm used in this study for calculating meter factors was:

$$Y = C + (a \times F) + (b \times T) + (c \times P) + (d \times Rho) \qquad (1)$$

Where C, a, b, c, d are regression constants and Y = calculated meter factor.

The second aim of the regression analysis is to obtain measures of the error involved in using the regression line as a basis of estimation. The value of the error is expressed in X, the standard error of the Y estimate.

The standard error of the Y estimate is an estimate of the deviation around the true but unknown population regression line and may be interpreted as a standard deviation.

The third aim, correlation analysis, is to obtain a measure of the degree of association or correlation between the dependent and independent variables. A measure of that strength is the coefficient of correlation R^2.

In order to carry out the study, a number of simplifying assumptions were made, these being:-

- a linear relationship existed between the dependent variable (meter factor) and the independent variables (flowrate, temperature, pressure, density)
- the turbine meters were being operated in their linear flow range
- no meter drift had occurred during the compilation of the data base
- no outliers existed in the data.

From the multiple regression outputs, meter performance was predicted. For each meter 40 to 50 previous proves were used to compile the data base using the regression fit algorithm and real time fluid conditions, meter proving requirements were judged by comparing the actual meter factor in use to that of the calculated meter factor.

3.0 METER FOOT PRINT RESULTS

Two stations were studied, one with 6 inch turbine meters installed, the other with 10 inch heliflu meters installed. The range of conditions encountered by the meters are shown in Figure 1.

3.1 Meter Station A Results

3.1.1 Meter No. 1

Meter No. 1 had been installed for 5 months at the start of the study, the total throughput being 2 x 10^6 m^3.

From the statistical analysis in Figure 2 it can be seen there was a high degree of correlation ($R^2 = 0.94$) between the meter factors and the fluid parameters. This is also reflected in the low standard error estimate (x). The compilation of the data base took place over a period of 3 months. In applying the regression data to this period the difference between the actual meter factors and the calculated meter factors is in the region of <0.04%.

Calculated values were produced for all subsequent meter proves over a further 3 months period. Graphs of meter factor and calculated meter factor versus time are shown in Figures 4 and 5. The calculated meter factor showed a high level of agreement with the actual meter factors for a period of 2 months after the initial data base compilation.

The level of agreement confirmed the validity of the large point meter factor shifts seen with this meter (0.1 - 0.3%). These shifts can be generally traced to simultaneous changes in temperature, $\pm$ 10°C and density, $\pm$ 10 kg/m^3. The degree of agreement was not expected in view of the co-dependence of these two parameters (viscosity).

In the final month of the study the meter performance deteriorates up to the point where the meter is shut in. However, whilst the level of agreement of the calculated meter factors deteriorates, the foot-print continues to mirror how the meter factor changes in line with fluid parameter changes.

3.1.2 Meter No.2

This meter had been installed for one month at the start of the study, with a total throughput of 250 x 10^3 m3. Once again, the data base compilation took place over a 3 month period.

The statistical analysis shows a lower correlation ($R^2 = 0.52$) than that of meter No. 1. However the standard error is of the same magnitude although the value is slightly higher at 0.0004.

The agreement between actual and calculated meter factors is generally very good, being about 0.03%. There are some points where this increases to >0.1%; there were no obvious reasons from the data base why these excursions in values should occur.

Almost immediately after the data base compilation, the meter failed and was taken off line.

3.1.3 Meter No.3

This meter was newly installed and was put on line when meter no. 2 showed signs of failure.

The data base of 50 proves for this meter was collected over a period of six weeks, the increased proving frequency being due to the meter being new.

From the regression analysis in Figure 2 we see a reasonable correlation coefficient value of $R^2 = 0.73$. Agreement of actual meter factor and calculated meter factor is generally better than 0.03%.

There are a couple of occasions when the calculated meter factors differ from the actual by up to 0.16%. However, these can be attributed to extremes of flow rate (138/598 m^3/hr) when compared to the bulk of the data.

This highlights the dangers of using predicted meter factors where data is sparse, or where extrapolation beyond the data base parameters is to be considered.

However, despite the large single point shifts in meter factor (0.3 - 0.6%), Figure 5, the meter performance follows that as predicted by the regression analysis.

The calculated meter factors continued to correlate well, up to and beyond the end of the study period.

3.2 Meter Station B Results

3.2.1 Meter No. 1

The major feature of this station was the varied flowrate. Meter No. 1 and No. 2 were subjected to less fluctuations in temperature and pressure than those of Station A.

From the statistical analysis in Figure 3 we see that the correlation coefficient is of a value 0.53. Despite the low correlation value, the agreement between actual and predicted meter factors was excellent, generally being less than <0.02%.

Also of note is that the standard error of the Y estimate (0.0002) is in line with those values of Station A meters where better correlation values were obtained.

Agreement between actual and calculated meter factors continued to be good until the final two weeks of the study; at which time the agreement drifted out to 0.14%. (Figure 6).

However it should be noted that the meter had been previously shut in for a period of 3 weeks. Also, the crude export water content increased tenfold (0.1 - 1.0%). It is not usual to record water content at the time of meter proving. As meter 2 did not exhibit a similar drift it is possible that the meter inlet header had some effect on water distribution in the system.

3.2.2 Meter No. 2

With meter No. 2 we see from the statistical analysis the opposite results to those of Stream 1.

In this case the correlation coefficient is of higher value, however, the level of agreement between actual and predicted meter factors is about 0.05%.

Whilst there were no obvious reasons for the poorer agreement, clues may be gleaned from the values of the pressure regression constant and the standard error value of this coefficient.

The pressure coefficient value is quite high, indicating the meter may be sensitive to pressure effects. Such effects may be due to upstream conditions emanating from the strainer flow straightener or even the inlet header itself.

Once again we must be cautious in taking the regression analysis on face value, as the addition of other factors to the regression analysis can, and does on occasion, alter the magnitude and sign of the coefficient values.

3.2.3 Meter No.3

This meter had been on line for only two weeks at the end of the study period, as only 9 meter proves had been carried out, no evaluation of the meter took place.

4.0 <u>PROVER OUTAGE</u>

In 1989, Shell Expro's North Cormorant installation's meter prover suffered damage to its internal lining, resulting in the meter prover being out of service for 8 weeks.

Loss of the prover raised some difficult operational and accounting problems. The North Cormorant platform is used to process commingled Eider and North Cormorant fluids. As the Eider field production was measured at source, the North Cormorant production was accounted for by difference from the total metered export quantities.

It is considered by the Department Of Energy Gas and Oil Measurement Branch, to be "good oil field practice" to maintain last proved flow rates and conditions when meters are unable to be proved.

To comply with such requirements would have placed restrictions on the Eider field development and been impractical in view of the combined field processing.

Shell Expro's approach to the problem was to use calculated meter factors based on multiple regression footprints of the meters.

On presentation of the evidence to the Department Of Energy that this method was equivalent to "good oil field practice", they gave a statement of "no objection" to its use.

We were able to continue export virtually without restriction accommodating the increasing flows from the Eider field.

The value to Shell Expro of the additional crude produced from Eider during the prover outage was approximately £10 Million.

4.1 Method

Initial meter footprints were produced for the meters. The regression constants were used to produce calculated meter factors from the export fluid conditions prevalent during the prover outage.

Totaliser readings were noted each time a new calculated meter factor was used. The meter factors in use were updated daily, or when export conditions varied by more than present values. Process conditions were recorded each time a new meter factor was used.

After reinstatement and calibration of the prover loop, extensive meter proving was carried out. Footprints for the meters were obtained and compared to those previous to the prover outage.

4.2 Results

The initial meter footprint gave good agreement between actual and calculated meter factor values, in line with that of the initial study (0.03 - 0.05%). After recalibration of the prover loop the agreement had deteriorated to about 0.3%. (Figure 7). The post calibration footprints showed good agreement between actual and calculated meter factors.

By combination of both footprint data bases, (Figure 8) we were able to show that the meter shifts were due to changes in fluid density (Figure 9), which were outside the range of the pre prover outage regression data base.

The new regression constants obtained from the combined pre and post prover outage data, showed that the respective meters would react to the density changes in the manner observed. Also, using conventional data sorting of meter factor and density, the graphs produced supported the regression data.

Having ascertained an assignable cause to the meter "drift", new meter factors were calculated for the whole of the prover outage period. Adjustment factors were applied to the metered quantities to obtain revised export totals.

5.0 ONLINE MONITORING

Where computerised process monitoring equipment is installed, it is possible to utilise the trending capabilities to monitor meter factors on a real time basis.

By entering into the computer the linear regression constants for the meter footprint, it is possible to calculate a meter factor for the current fluid conditions.

Where an actual meter factor can be automatically or manually entered onto a trend the operator is able to compare and see how the calculated meter factor is responding to changes in process conditions.

One such display, which the author has used in practice, is shown in Figure 10. It can be seen that, given action limits on the variance between actual and calculated meter factors, an effective means of measurement control may be possible.

6.0 CONCLUSIONS

Using a simple model and off the shelf computer facilities, the author was able to carry out an effective study of turbine meter performance.

The multiple linear regression techniques used proved to be of great commercial benefit to Shell Expro when one of its meter provers was damaged. The approximate value of the additional crude produced being £10 Million.

The approach was received in a positive manner by the Department Of Energy as compatible with "good oil field practice". As Operators, we may in the future, be expected to do more with our measurement data than we probably do now and additional parameters may require to be monitored during meter proving operations.

Given further study, based on sound statistics, multiple regression analysis of meter factor data may offer more insight into the validity of individual meter proves than some of the statistical control techniques currently in use.

Where demonstrated applicable, footprinting of turbine meters can form the basis of an effective real time measurement monitoring tool.

REFERENCES

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2. PETROLEUM MEASUREMENT STANDARDS, Chapter 5 - Metering, Section 3 Turbine Meters.

3. PETROLEUM MEASUREMENT MANUAL, Part 10 - Meter Proving, Section 1 Field Guide to Proving Meters with a Pipe Prover.

4. PETROLEUM MEASUREMENT STANDARDS, Interim Chapter 13, Measurement Control Charts and Statistical Methods for Petroleum Metering Systems.

Parameter	STATION A	STATION B
Nominal design rate	60 - 660 m3/hr	200 - 2200 m3/hr
Flowrate	160 - 590 m3/hr	500 - 1600 m3/hr
Temperature	40 - 55 deg C	25 - 35 deg C
Pressure	18 - 35 bar g	10 - 15 bar g
Density	810 - 823 kg/m3	795 - 815 kg/m3
Water content	0 - 5%	0 - 5%

Fig.1 Range of Meter Operating Conditions

Fig.2 STATION A REGRESSION OUTPUTS

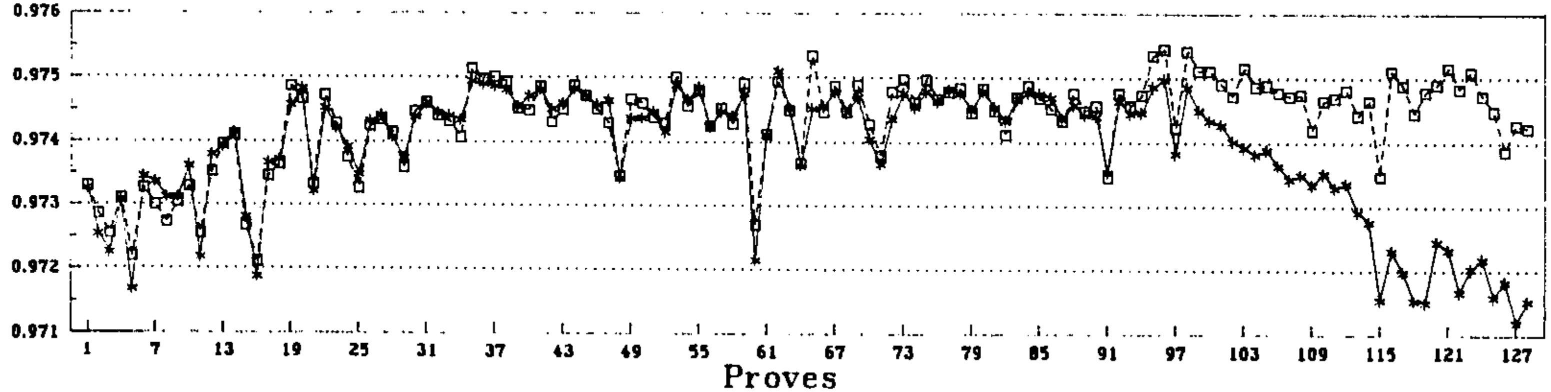
Regression output	Meter No.1	Meter No.2	Meter No.3
Constant	0.94638	0.97655	0.92418
Flow Coeff.	0.00014	5.15000E-05	0.00014
Temp.Coeff.	1.93000E-05	1.95000E-05	0.00026
Press.Coef.f	1.42000E-05	6.20000E-06	2.30000E-05
Dens.Coeff.	7.70000E-06	7.17000E-05	9.70000E-05
R^2	0.94300	0.51700	0.73100
(X) Std Error of Y estimate	0.00021	0.00043	0.00056
No. of Observations	50	50	50

Fig.3 STATION B REGRESSION OUTPUTS

Regression output	Meter No.1	Meter No.2	
Constant	1.00654	0.93756	
Flow Coeff.	6.00000E-07	4.10000E-06	
Temp.Coeff.	9.30000E-05	6.65000E-05	
Press.Coef.f	3.60000E-05	0.00013	
Dens.Coeff.	2.00000E-05	7.00000E-06	
R^2	0.54000	0.64300	
(X) Std Error of Y estimate	0.00023	0.00043	
No. of Observations	50	40	

Meter No.1

Meter factor Actual and Calculated Meter factor vs Time

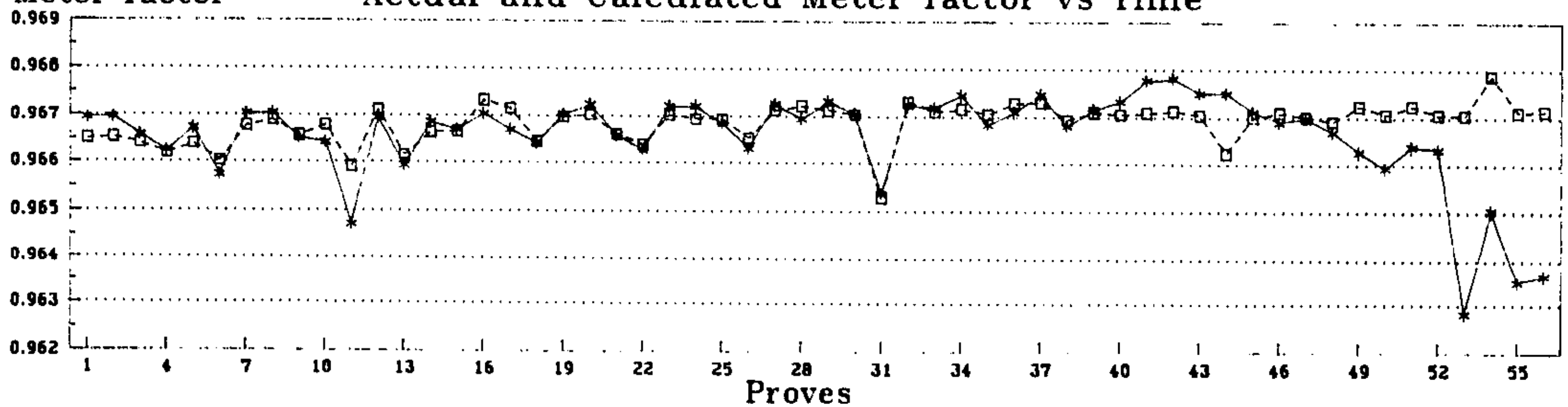


Jan–June

meter factor –*– calculated meter factor –[]–

Meter No.2

Meter factor Actual and Calculated Meter factor vs Time



Jan–March

meter factor –*– calculated meter factor –[]–

Fig.4 STATION A RESULTS

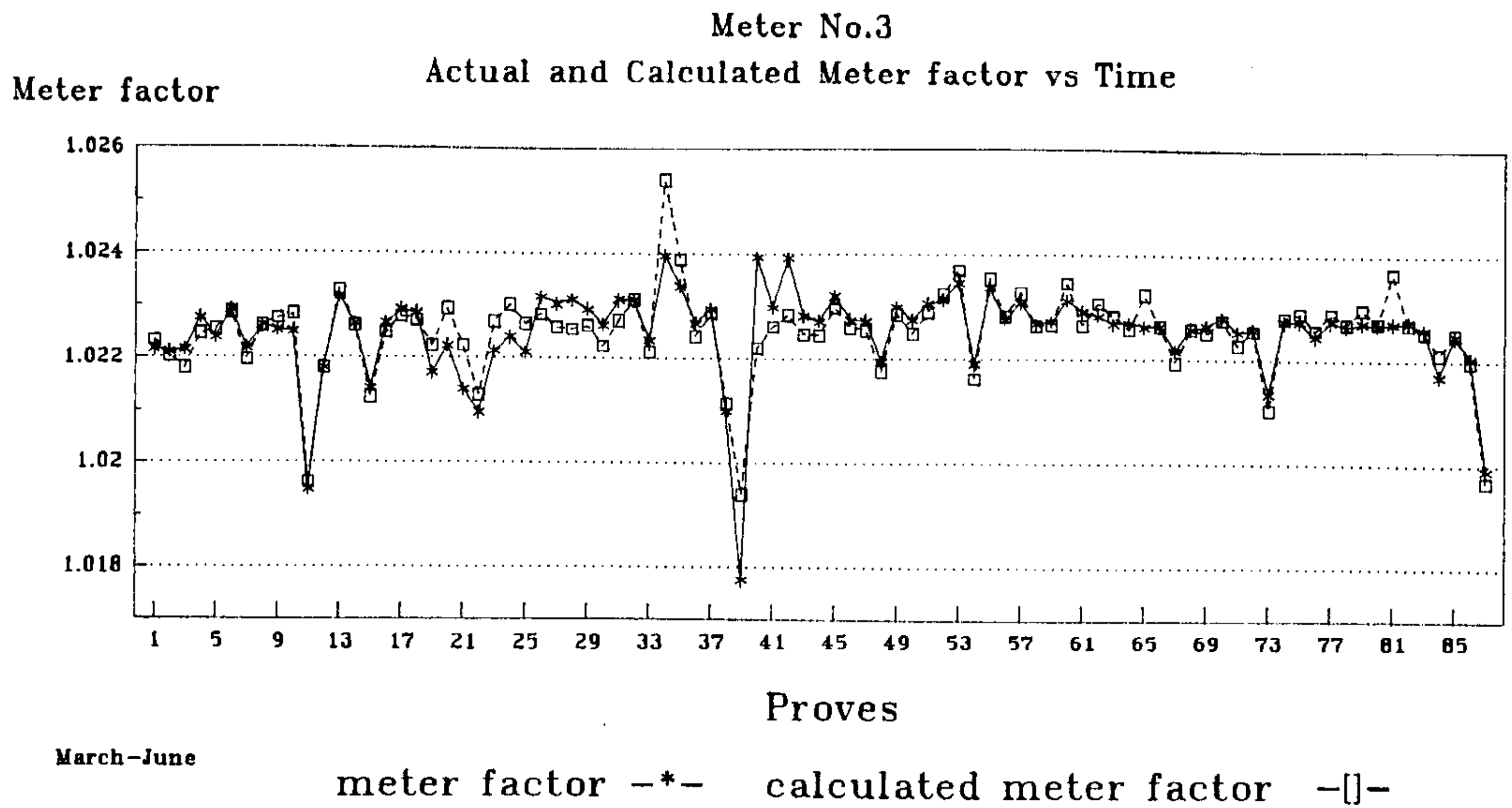
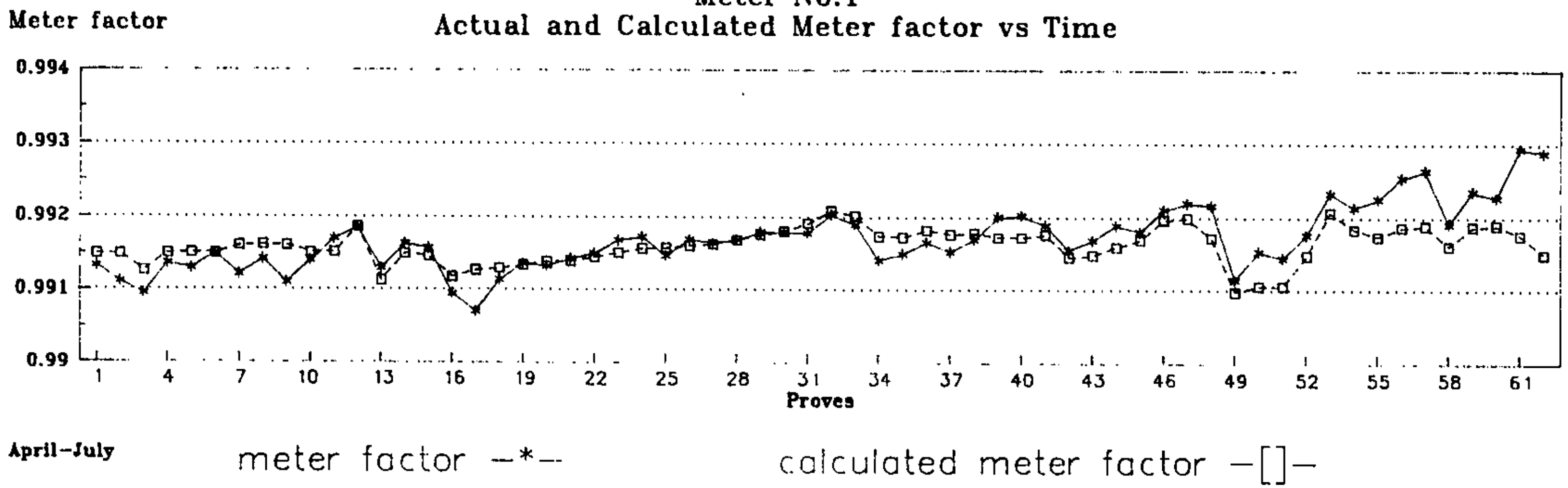


Fig.5 STATION A RESULTS

Meter No.1
Actual and Calculated Meter factor vs Time



Meter No.2
Actual and Calculated Meter factor vs Time

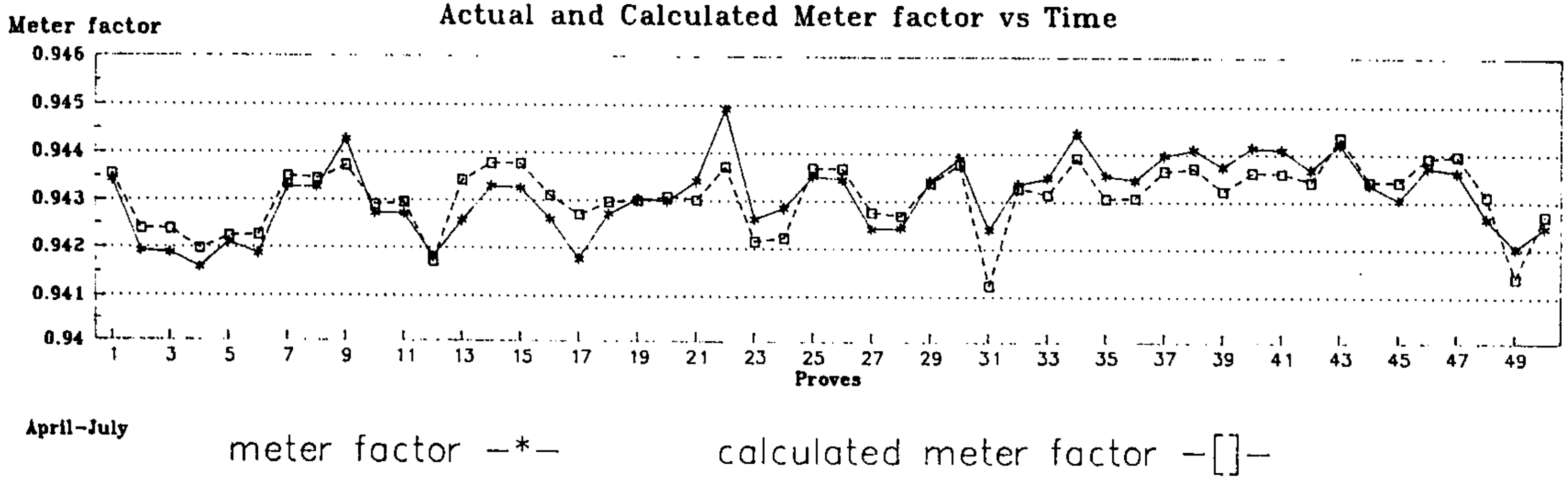


Fig.6 STATION B RESULTS

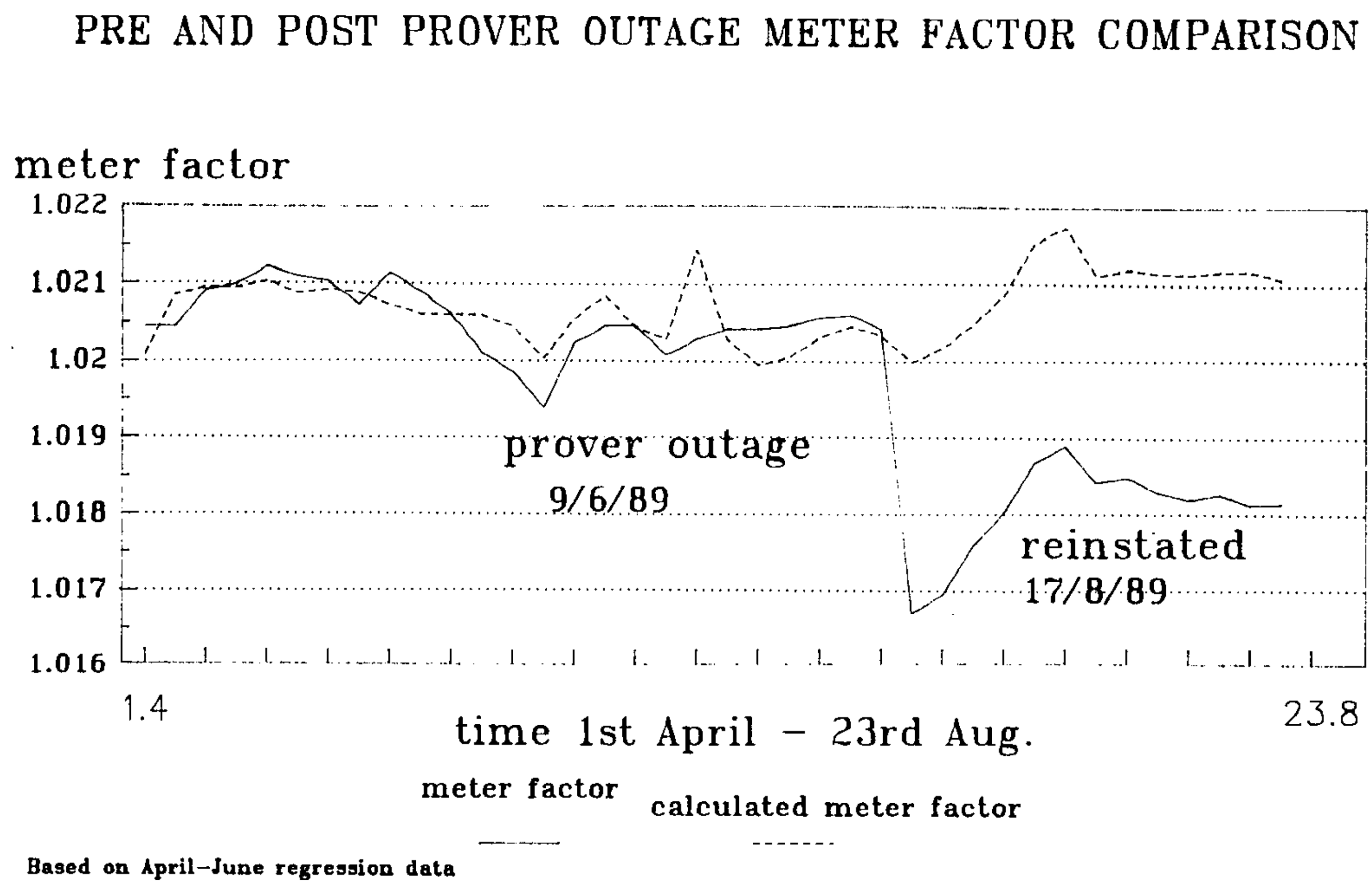
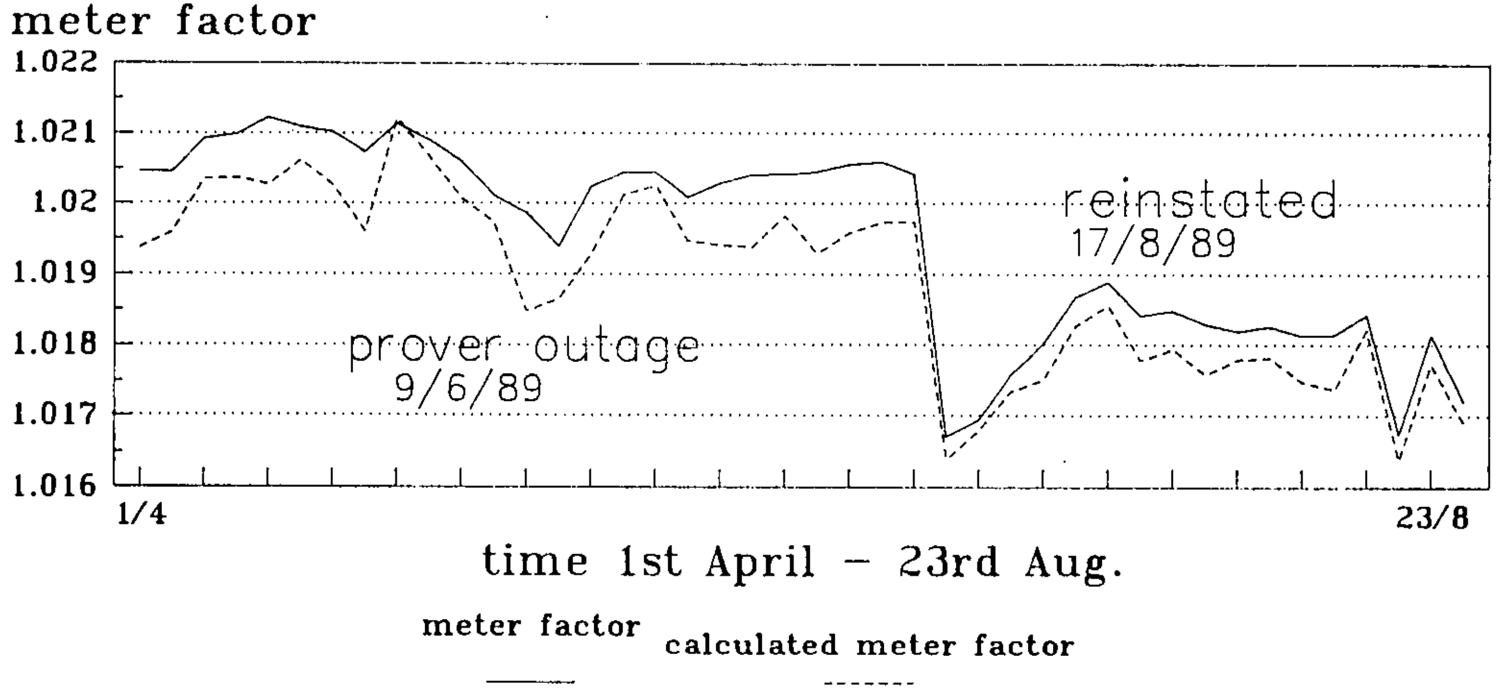


Fig.7 PROVER OUTAGE RESULTS

PRE AND POST PROVER OUTAGE METER FACTORS

DENSITY SHIFT ADJUSTED



Based on April-June regression data

Fig.8 PROVER OUTAGE RESULTS

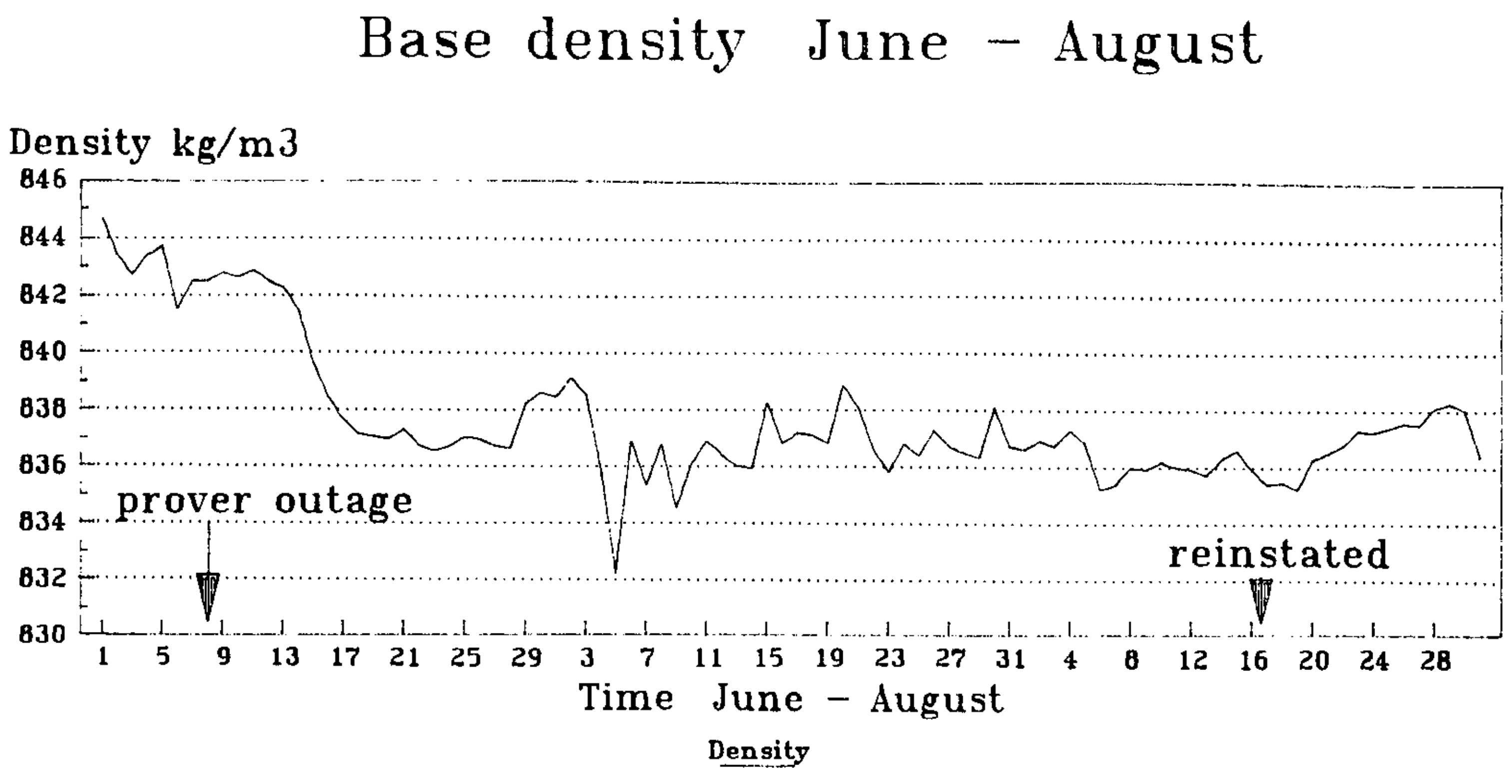


Fig.9 PROVER OUTAGE RESULTS

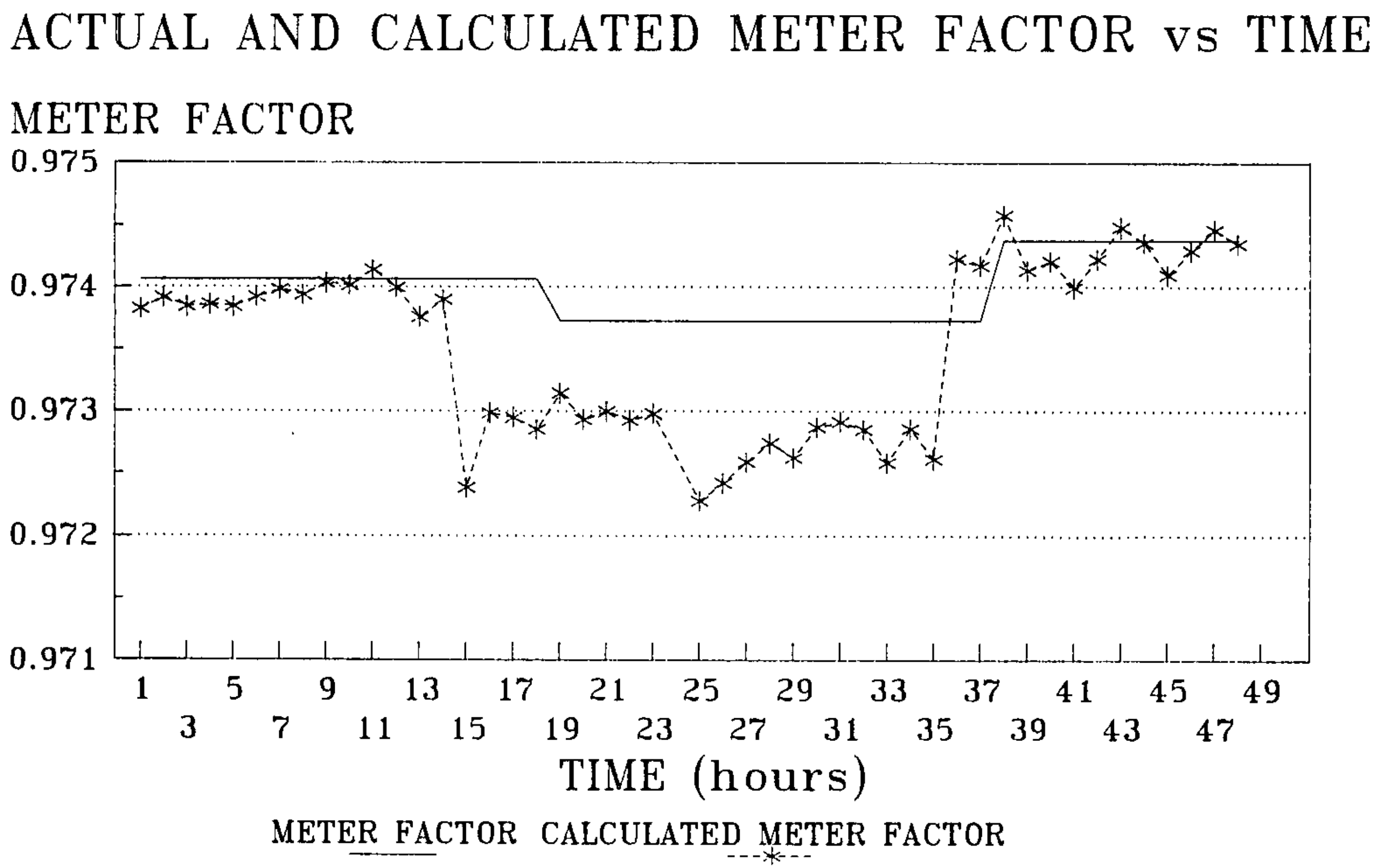


Fig.10 ONLINE MEASUREMENT MONITORING