Main Index

NSFMW.97

North Sea FLOW Measurement Workshop

Paper 10: 2.4

SOFTWARE TESTABILITY, TESTING AN VERIFICATION IN FISCAL OIL AND GAS FLOWMETERING

BASED ON VOLUME, DENSITY, TEMPERATURE AND PRESSURE MEASUREMENTS

Authors:
Kanaga Saba Pathy Mylvaganam, Bergen College, Norway

Organiser:
Norwegian Society of Chartered Engineers
Norwegian Society for Oil and Gas Measurement
Co-organiser:
National Engineering Laboratory, UK

SOFTWARE TESTABILITY, TESTING AND VERIFICATION IN FISCAL OIL AND GAS FLOWMETERING BASED ON VOLUME, DENSITY , TEMPERATURE, AND PRESSURE MEASUREMENTS

Kanaga Saba Pathy Mylvaganam
Høgskolen i Bergen (Bergen College)
Postbox 6030
N- 5020 Bergen
(Visiting Address: Nygårdsgate 112, N-5008 Bergen)
NORWAY
Tel: + 47 55 58 76 09
Fax: + 47 55 58 77 90
email: Saba.Mylvaganam@lhg.hib.no

NORTH SEA FLOW MEASUREMENT WORKSHOP 1997

27 - 30 October 1997

Kristiansand

NORWAY

SOFTWARE TESTABILITY, TESTING AND VERIFICATION IN

FISCAL OIL AND GAS FLOWMETERING

BASED ON

VOLUME, DENSITY, TEMPERATURE, AND PRESSURE MEASUREMENTS *

Kanaga Saba Pathy Mylvaganam
Høgskolen i Bergen (Bergen College),Norway

Keywords: Fiscal Flowmetering, testing and verification, oil & gas measurement, flow computer.

ABSTRACT

Many of the companies in the oil and gas industries have different program modules for including volume, density and temperature measurements to evaluate the amount of oil/gas in the context of fiscal measurements. These measurements are very often done not at the same location in the pipe lines, but in different locations of the oil and gas transportation lines. These modules have to be put together and run on a main frame computer to get at the desired result, viz. the mass flow. The Norwegian Petroleum Directorate states in its "Regulations relating to fiscal measurement of oil and gas etc.": "The computer part shall be tested for each metering tube to verify that the different functions are operational. Each independent program routine, shall be verified to be in accordance with, or better than, the accuracy stated in §47 (e) ". This is an outcome of testability paradigm very much in discussion in many standards and regulations not only in the oil and gas industry.

Due to the need for a compact programme to handle such measurements along with the standards ISO 6976, ISO 5167 and stipulations covered in AGA No.8, Norsk Hydro in Bergen along with the Høgskolen i Bergen (Bergen College) developed programs to verify the results obtained from fiscal flowmeters. How this testability paradigm is incorporated in ultrasonic flowmeters is also discussed in this paper.

This paper presents the background (both physical and software) for the program development with some relevant details from the program, which in a modified form is currently used by the Norsk Hydro in fiscal oil and gas flowmetering. The experience of the end user is also presented. This paper is an outcome of a work performed for Norsk Hydro.

The demonstration of the programs discussed here is an integral part of the workshop presentation.

* This paper is based on a collaboration with Norsk Hydro as. Thanks are due **Mr. Trond Folkestad of Norsk Hydro as, Sandsliveien 90, N-5020 Bergen , Tel: +47 55 99 57 90, Fax: +47 55 99 66 05, email: Trond.Folkestad@nho.hydro.com** for valuable information from practical experience in using the programs developed for software testability under discussion.

BACKGROUND

The amount of oil or gas sold/bought is basically dependent on four different measurands: volume flow rate, density, temperature, and pressure. Due to reasons of space unavailability at the same spot for the necessary measuring devices, all these measurands are monitored in slightly different locations of the pipeline transporting oil or gas, necessitating calculation among different conditions of state as well as calculations to standard conditions. Both measurements and calculations must be performed to a very high degree of accuracy, as it involves huge amount of monetary transactions.

All the oil & gas companies use computer programs to verify the calculations in the metering stations. These computer programs are not very user-friendly nor efficient to use. Hence the need for testing and verification of existing programs. The practising engineer needs more user-friendly computer programs to enable efficient verifications.

The procedures are described in various documents including some ISO papers and guidelines published by local oil/gas companies, [1], [2], [3].

The Norwegian Petroleum Directorate stipulates [4], various procedures as to how the calculation of the volume flow of gas and oil should be performed in order to insure that accurate measurements are behind the calculation of sales value, royalty and tax on the measured quantity of produced oil and gas. In fact the measured quantity used for sale or calculation of royalty and tax is called fiscal quantity.

The following paragraphs in the set of regulations [4], are specially relevant to this paper:

§47 The computer routines for fiscal measurement calculations shall fulfil the requirements detailed in the applied standards. The computer routines shall further include the following:
(e) Algorithm and unintentional rounding off errors for computations of fiscal quantities in the computer part shall be less than ±0.001 %.

The computer part shall be tested for each metering tube to verify that the different functions are operational. Each independent program routine, shall be verified to be in accordance with, or better than, the accuracy stated in §47 (e). The integration accuracy shall be checked over at least three values, maximum, and minimum hydrocarbon flow and one value at mid range.
§72 Checking of the computer part (oil/gas): An independent review of the calculation accuracy of the computer part shall be performed at least on an annual basis (c.f. §47 (e), 57)

Earlier, the verifications of the flow computer calculations were carried out with the help of many small modules within the larger program. This procedure took considerable amount of time and the person doing the checking had to have a good insight in the program before doing the calculation.

The Norwegian Petroleum Directorate stipulates that the calculation accuracy of the computer shall be reviewed independently at least on an annual basis, implying, for example usage of an independent PC based program.

This paper touches on the topics of testing, testability and verification of programs in general and describes the main parts of the PC- programs developed for fiscal metering of both oil and gas. Part of the work for these programs are described in [5], [6] and [7].

MEASURANDS

The measurement system for the gas transport normally consists of,

1. an orifice plate to measure the volume flow
2. differential pressure transmitter to measure the differential pressure between the input and output sides of the orifice plate mentioned in 1
3. PT-100 resistance based temperature sensor to measure the temperature of the gas in the pipe.
4. a pressure gauge to measure the pressure in front of the orifice plate
5. a densitometer to measure the density of gas

as shown in **Figure 1**.

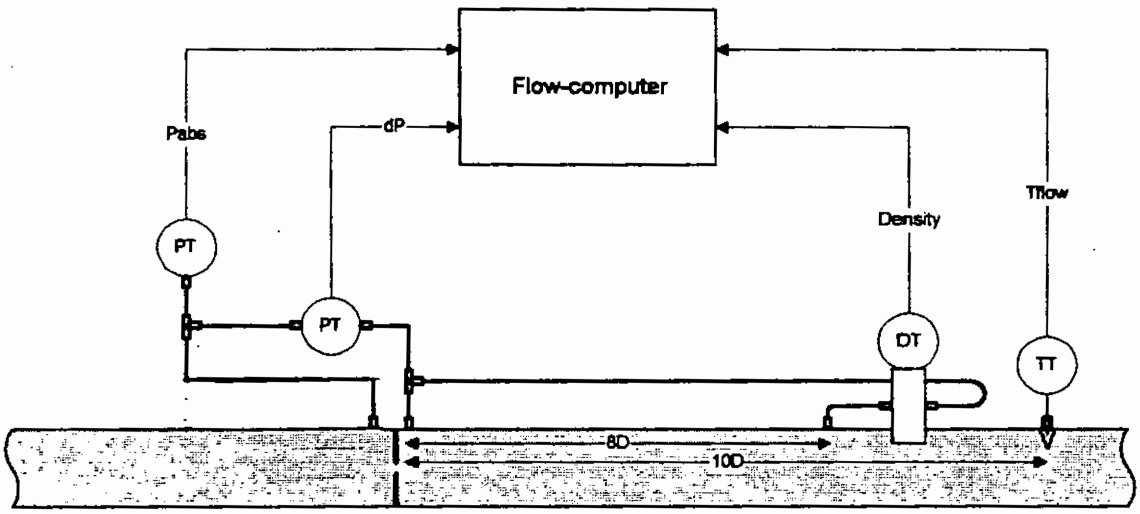


Figure 1 The schematic representation of a gas metering station. DT : Density transmitter; TT: Temperature transmitter; PT: Pressure Transmitter; Pabs: Absolute pressure; dP: Pressure difference. 10D and 8D represent the length in number of diameters of the pipe.

Similarly, the measurement system for the oil transport generally consists of

1. a turbine meter to measure the volume flow
2. PT-100 resistance based temperature sensor to measure the temperature of the oil in the pipe.
3. a pressure gauge to measure the pressure
4. a densitometer to measure the density of oil (only applicable for pipeline transport)
5. the meter prover designed so that five consecutive trials leads to values within a band of 0.020% of the average volume

Figure 2 shows the measurement loop used for oil.

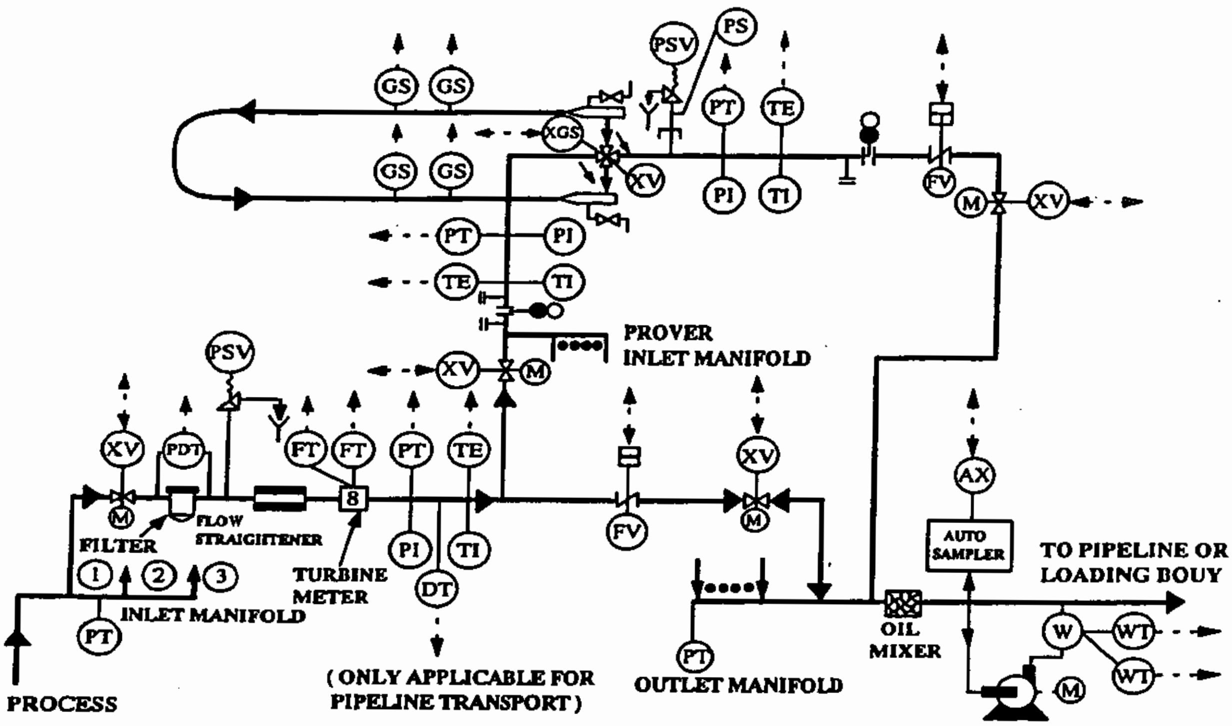


Figure 2 The schematic representation of an oil metering station, reproduced from [4].

The volume flow can also be determined using the contrapropagating transit time ultrasonic flowmeter, which in its multi-path form has been formally accepted as a fiscal meter for gas flowmetering by the Petroleum Directorate.

SOFTWARE TESTABILITY, TESTING AND VERIFICATION

European System and Software Initiative (ESSI) is an active action within the European Union paralleling the stipulations of the Norwegian Petroleum Directorate and has Software Best Practice as the target. Software Best Practice is aiming in all industrial sectors to improve their efficiency, provide better quality and better value for money. In the sense of Software Best practice, we could visualise a series of steps given in **Figure 3**.

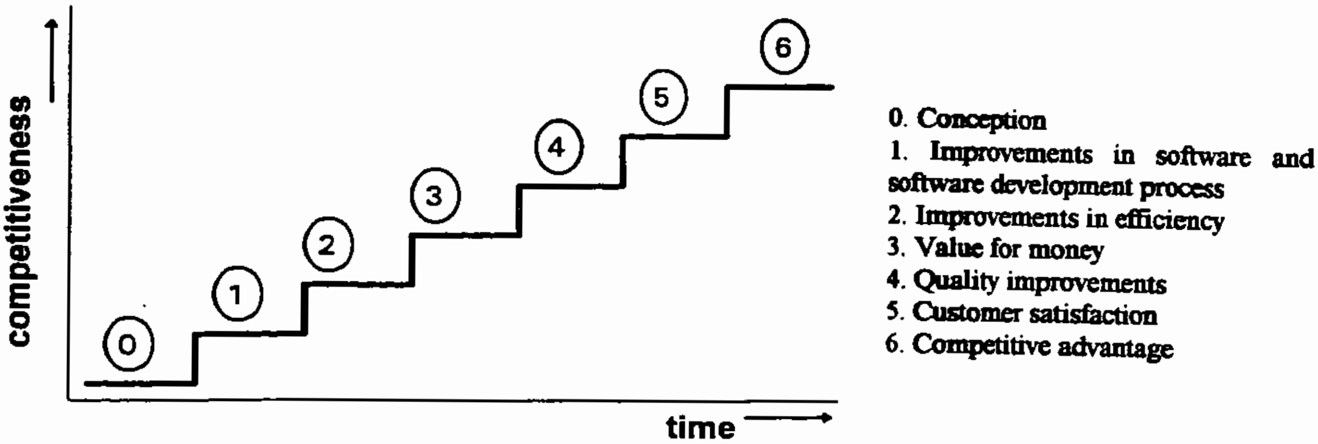


Figure 3 The increasing competitiveness due to Software Best Practice

Testability is used to confirm that each sub-unit performs its required function, that the sub-units are interconnected in the correct manner, that they interact correctly, and that the whole program executes its intended function. In the hardware branch, especially in the production of ICs , electronic devices are selected, where possible, with Built-In Self-Test (BIST) to perform test pattern generation and response analysis. This is the primary test mechanism used during wafer probe testing of ICs and should provide a high degree of fault coverage (>95%). This could be seen as the extension of the traditional test points selected already in the design stage of a circuit to test whether the circuit is functioning as intended without showing signs of faulty operation.

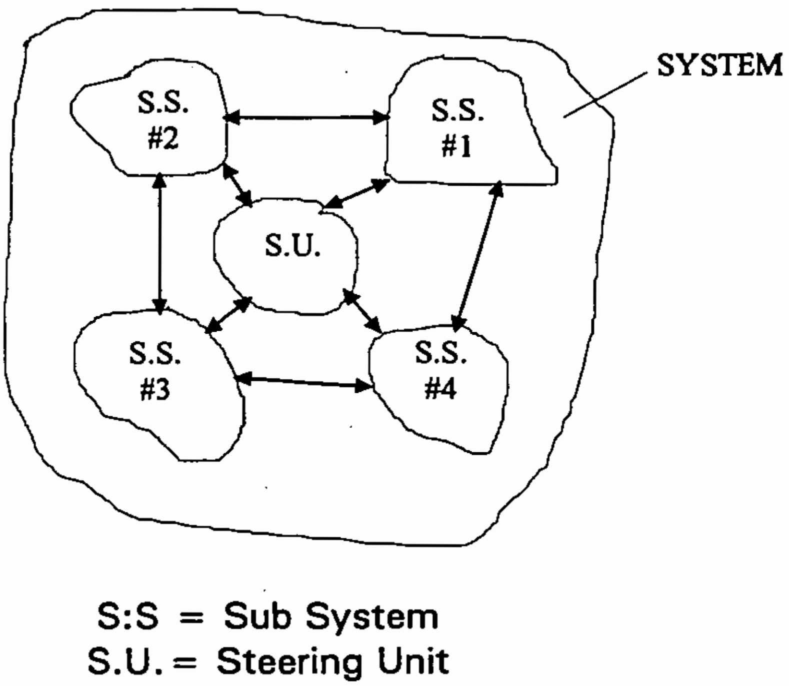


Figure 4 The interaction within a program with the subsets of modules (called sub-units in figure) with the steering unit.

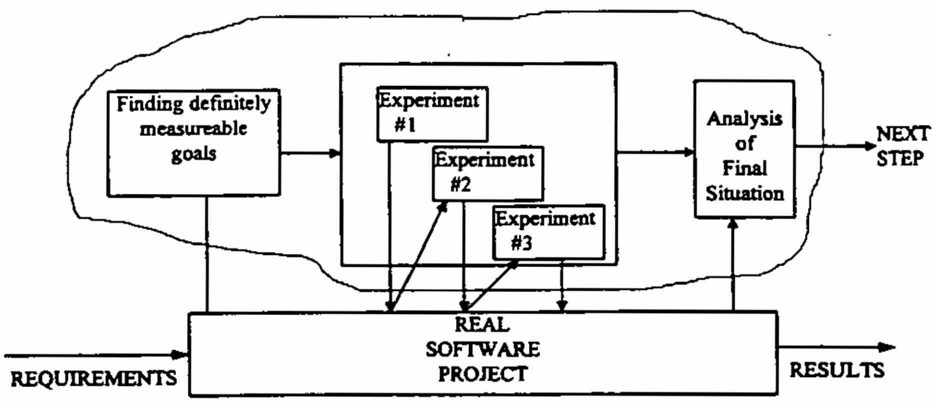


Figure 5 Process Improvement Experiments as part of testing, testability and verification. The tests done in the context of the present paper can be looked upon as a venture to improve the process based on testing and verification.

There are a plethora of discussions and definitions of testability and testing in the context of software development, [8],[9],[10], and [11]. The present forum is not the right place or the present author is not the right person to delve into these nuances in the software engineering. However, it is interesting to look into some of the definitions in use.

Testability

" (1)The degree to which a system or component facilitates the establishment of test criteria and the performance of tests to determine whether those criteria have been met, and (2) the degree to which a requirement is stated in terms that permit establishment of test criteria and performance of tests to determine whether those criteria have been met." [11]

Testing

Dynamic software testing is the process of executing the software repeatedly until a confidence is gained that either (1) the software is correct and has no more defects, which is commonly referred to as probable correctness, or (2) the software has a high enough level of acceptability. Testing can alternatively be subdivided into two main classes: white-box and black-box. White-box testing bases its selection of test cases on the code itself; black-box testing bases its selection on some description of the legal input domain, [11].

Verification

IEEE Software Dictionary [10] defines software verification to be the
"process of evaluating a system or component to determine whether the products of a given development phase satisfy the conditions imposed at the start of that phase."

This tallies very well with the concept of Process Improvement Experiments discussed in the circles of ESSI.

Software verification can be seen as the process that assesses the degree of "acceptability" of the software, where acceptability is judged according to the specification. In the present context, the specifications as given by Norwegian Petroleum Directorate and Norsk Hydro.

Finally, we quote from [11]:,

"Software testability, software testing, and formal verification are three pieces in a puzzle: the puzzle is whether the software that we have, has a high enough true reliability. Every system has a true (or fixed) reliability which is generally unknown; hence we try to estimate that value through reliability modelling. If we are lucky enough to have a piece of software that (1) has undergone enormous amounts of successful testing, (2) has undergone formal verification, and (3) has high testability, then we have three pieces that fit together to suggest that the puzzle is solved—high reliability is achieved.

Software testability, software testing, and formal verification are three pieces of the reliability puzzle, which developers must complete to get a picture of the software's true reliability. Each of the three puzzle pieces offers a unique bit of information about software quality. The goal is to combine all three. Testability analysis is related to but distinct from both software testing and formal verification, which makes it a good complement to the other two pieces. Like software testing, testability analysis requires empirical work to create estimates. Unlike testing, however, testability analysis does not require an oracle a program that performs the same functions as the software being developed. Thus, testing can reveal faults, while testability cannot, but testability can suggest places where faults can hide from testing, which testing cannot do. Testability complements formal verification by providing empirical evidence of behavior, which formal verification cannot do."

That the software system should undergo enormous amounts of successful testing and verification is the motivation behind the stipulations from the Norwegian Petroleum Directorate.

ALGORITHMS USED

Introduction

Due to the variables (measurands as well as constants related to the gas composition, pipe dimensions etc.) involved in the equations for volume and mass flow, some of the necessary routines in a dedicated PC-program will involve

- extracting and storing values of measurands
- extracting and storing variables associated with gas/oil
- extracting and storing constants associated with the pipe line
- extracting and storing the constants associated with the orifice meter[1] or turbine meter
- extracting and storing the constants associated with the density meter

It is not the aim of this paper to go into the details of the physics behind all these calculations. However, it is essential to note that the state variables at the orifice meter or turbine meter will not be the same as those at the density meter, or those at the locations of pressure and temperature transmitters. In the estimation of fiscal quantities, the unit used in transactions is the standard cubic meter, written [m^3 (15 °C, 1.01325 bar)]. This means all the measurements should be reduced to standard temperature and pressure conditions. Hereby, the stipulations of Institute of Petroleum, American Gas Association and Norwegian Petroleum Directorate should be taken into account. For purposes of verification, the mass flow will also be calculated although the sales quantity is the standard volume.

Fiscal Gas Metering

The volume flow on the downstream-end of the orifice plate is given by,

$$q_{vu} = A_2\sqrt{\frac{2(p_1 - p_2)}{\rho(1-m^2)}} \quad \text{with} \quad m = \frac{A_2}{A_1} \leq 1 \qquad (1)$$

where

A_1 = pipe diameter

A_2 = orifice diameter

ρ = density of gas

[1] in future, possibly the multi-path ultrasonic transit- time flowmeter

The corrections for vena contracta positioning and compressibility are taken care of by the factors α and ε in the following form:

$$q_v = \alpha \varepsilon q_{vu} \qquad (2)$$

In equations (1) and (2), the parameters involved all vary according to the changes in state variables. The volume flow changes with temperature, the orifice diameter changes with pressure and temperature and so on. The calculation of these parameters under changing state variables is clearly specified by international organisations. The essence of the program is the handling of these parameters and the necessary recursive routines to arrive at the required quantities such as volume flow, mass flow, energy flowrate etc.

Energy flowrate is also required to be calculated by the and Norwegian Petroleum Directorate. Energy flowrate Q_e is given by

$$Q_e = Q_{vr} CV \qquad (3)$$

where Q_{vr} = Volume flowrate and CV = calorific value as defined in ISO 6976.

For the program meant for the fiscal metering of gas, from Figure 1, we can see that we need information on the measurands, gas composition, calibration data, densitometer calibrations and means of converting the results to standard conditions.

Fiscal Oil Metering

Figure 2 illustrates that there are four major components in the case of oil metering station: oil flow based on the number of pulses form the turbine meter, prover readings, the temperature and pressure. There are a number of equations for all these calculations. The important ones are:

$$V_L = \frac{MR}{Mkf} C_{tsm} C_{psm} \qquad (4)$$

V_L = volume at line conditions, MR = number of pulses in the measurement period , Mkf = meter k-factor for the turbine meter, C_{tsm} and C_{psm} are correction factors, [12].

The mass is calculated, with the subscripts S and L referring to "standard" and "line" conditions, from the volume flow and density V_L, ρ_L and $V_S \rho_S$

$$M = V_L \rho_L = V_S \rho_S \qquad (4)$$

The series of coupling equations of different line parameters, state variables etc. are given in [12]. When an on-line densitometer is used for measuring the density at line conditions of a flowing liquid, the density at standard conditions has to be calculated.

Program Structure

Gas

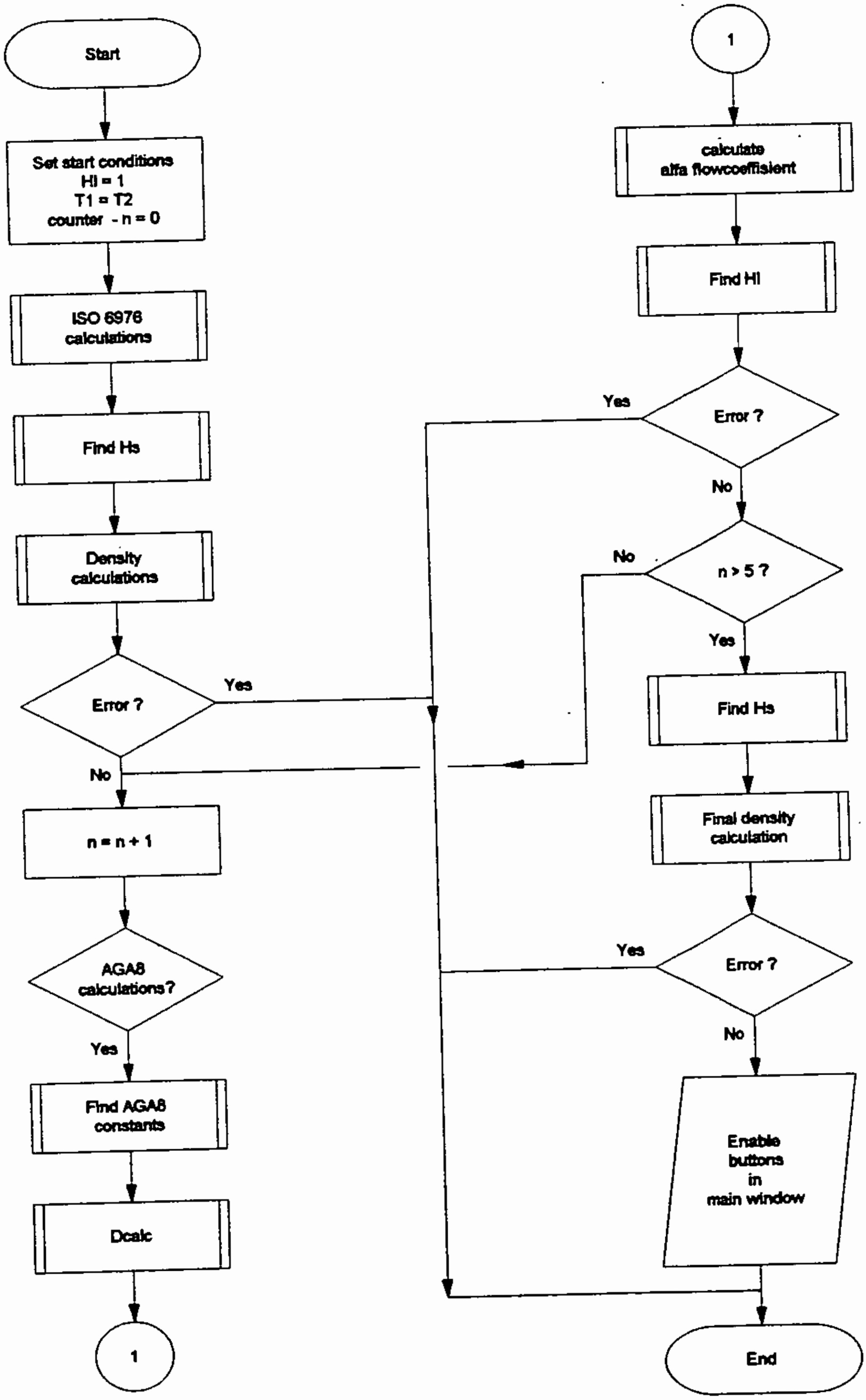


Figure 6 Main program flowchart, [5]. More details during demonstration of program.

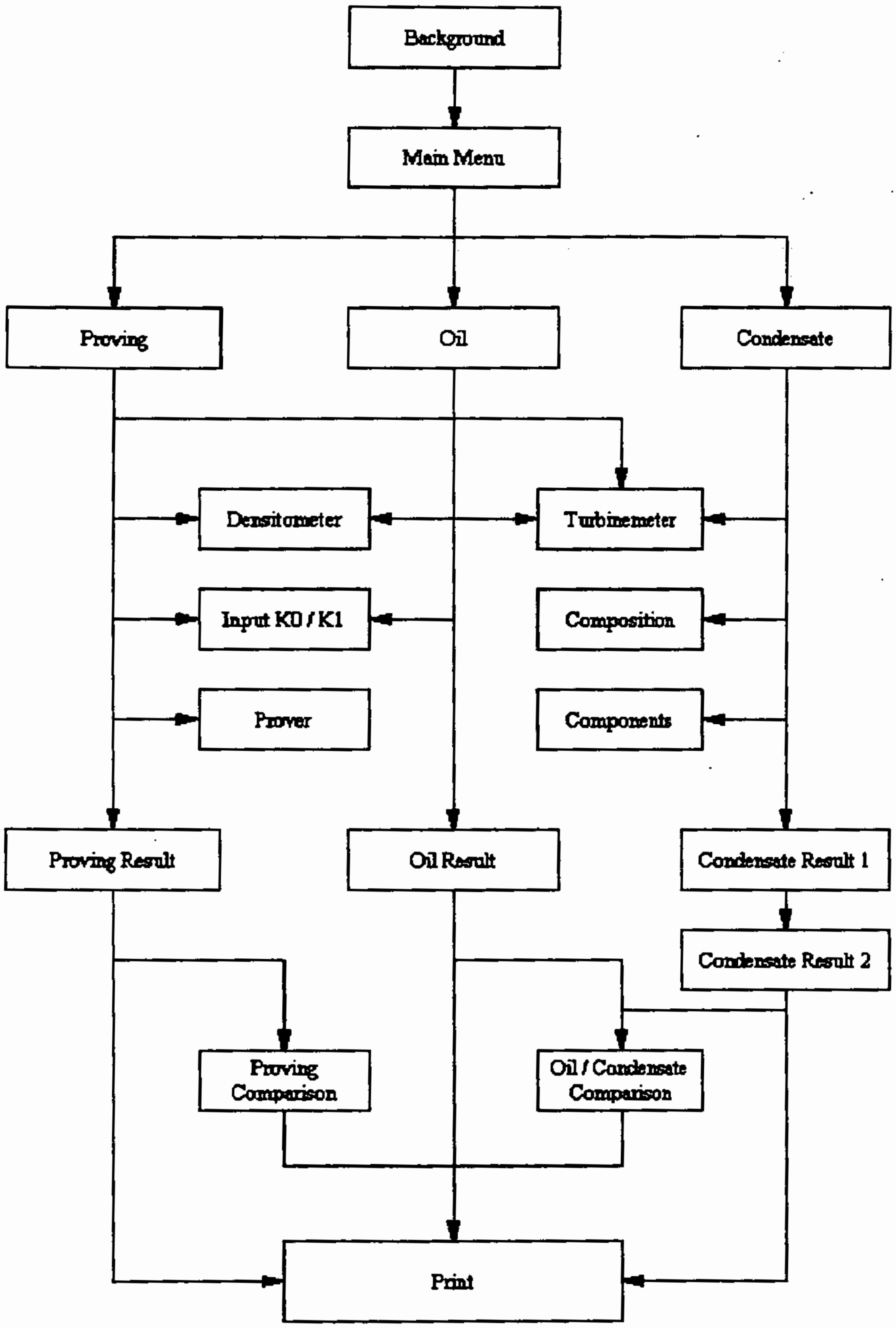


Figure 7 Structure of the program for fiscal oil metering calculations, [6]. More details during demonstration of program.

USER EXPERIENCE

The program discussed in this paper is used by Norsk Hydro to perform the stipulated verifications of the values delivered by the flow computer. Both programs are currently being used by Norsk Hydro for verification on all Norsk Hydro platforms and in new projects. User interface is assessed to be very user friendly compared to earlier verification tools.

As far as the testing is concerned, with the existing flowmeters, the situation is the same as it was, before the verification programs were incorporated into the fiscal metering routines. The verification of the flow computer results is done much faster due to the GUI aspects of the VISUAL Basics programs developed for oil and gas. In fact, the programs are used in fiscal, fuel[2] and flare[3] applications.

Figure 8 and Figure 9 show one of the many GUIs for verifying the flowcomputer estimates of oil and gas flow. Figure 8 is for oil measurement and has the options of selecting the type of calcualtion, viz. IP 2000, computer's full accuracy or the house internal standard at Norsk Hydro.

Figure 9 is the starting window for gas calculations and has the options shown on the different buttons shown there.

See Figure 10 to see the advantage of terminal vs. GUI based verification.

Norsk Hydro is very satisfied with the results and the co-operation with the students and staff of Bergen College.

[2] fuel used to run the gas turbines used in the electricity generation on platforms, which again has to be accounted for by the platform operator to the authorities

[3] gas flared is in effect gas lost and in addition gives rise to an increase in CO_2, which are factors needed by the authorities for fiscal and regulatory purposes.

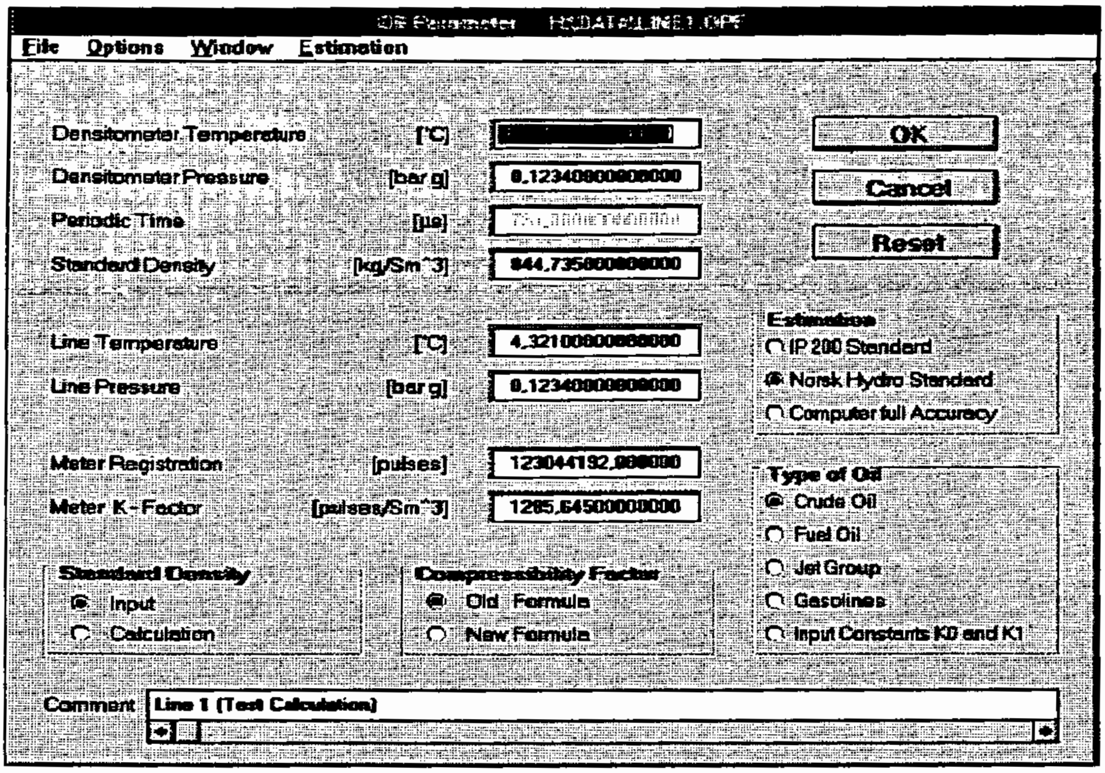


Figure 8 GUI interface from the verification program developed for oil, [6]. More details during demonstration of program.

In the case of oil, IP 2000, computer's full accuracy or the house internal standard at Norsk Hydro can be used in the calculations. In addition, the program can handle different types of oil as shown in the menu under "Type of oil".

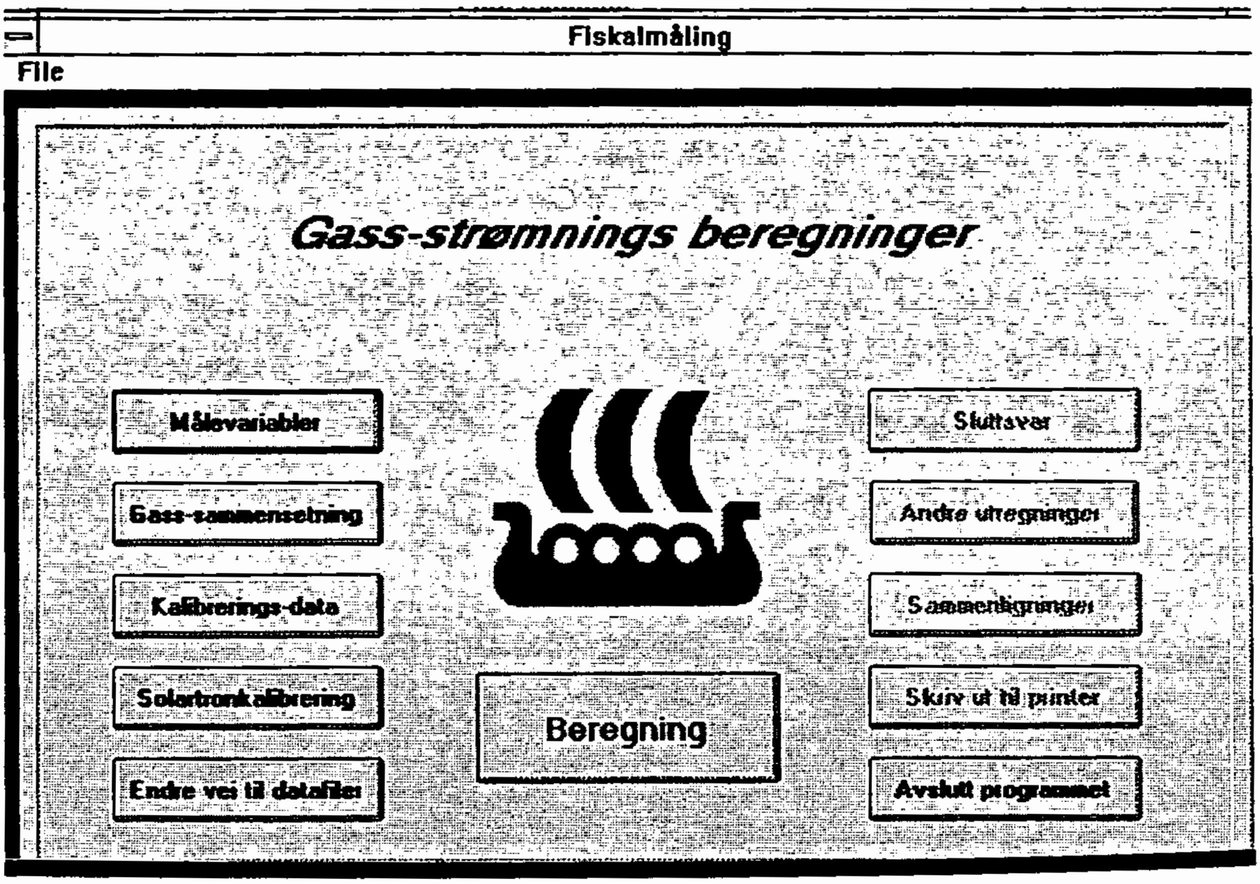


Figure 9 GUI interface from the verification program developed for gas, [5]. Opening window for the program with different options given in Norwegian. The equivalent English formulations are: Målevariabler = Measurands; Gass sammensetning = Gas composition; Kalibrerings-data = Calibration data; Solartronkalibrering = Calibration of the Solartron density meter. Beregning = Calculation; Avslutt programmet = Exit. More details during demonstration of program.

A typical print out given by the programs is given in APPENDIX.

Figure 10 shows the contrast between terminal based operator interaction and GUI based operator interaction. Once the values for parameters are assigned, these parameters can be retrieved selecting the right window and modified if necessary without much work interactively.

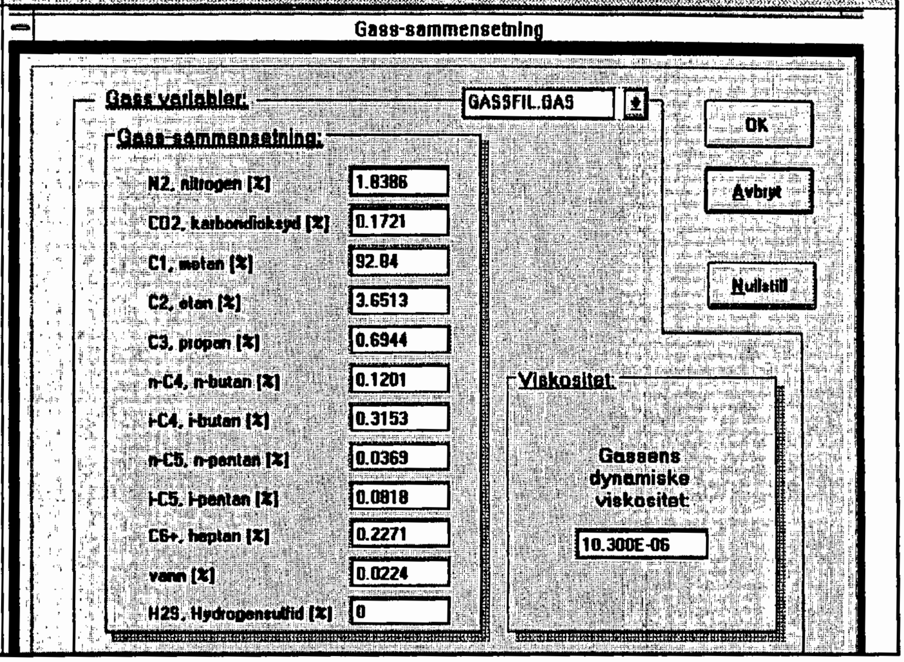
Terminal inputs (DOS era)	GUI
c: \ give line_temp (° C) ? 14.238 c: \ give line_dens (kg/ Sm^3)? 844.730 c: \ give line _ pres (bar g) ? 0.1234 etc. etc. (Once you make the mistake, you are back in "square number 1"! Do the same things again, give the answers for questions generated by the program!!)	

Figure 10 Terminal inputs from the purely DOS- era to GUI input in tersting and verification.

Comments on accuracy

All the modern PCs use 80 bits in the FPU. The accuracy strived for in the verification calculations are ± 0.001 % (10 ppm). Table 1 shows the accuracy of flowcomputer calculations and the accuracy in the verification routines. The results used for fiscal calculations should be independent of the type of flow computer used.

Table 1 Verification accuracy vs. Flow Computer accuracy

	Significant Digits	**CPU Operation**
Current Flow Computer	7 digits (example1.103759)	8 bits
Verification	15 digits (example1.10375859321368)	32 bits

It is essential at this stage to look at the plethora of data from earlier studies, mostly based on empirical findings, which have been collected from 8-bits FORTRAN calculations. We are using these empirical results such as the one shown in Figure 11 to achieve the 10 ppm accuracy in the verification programs. We can easily see a numerical anomaly in the process. The stipulations as such leads to a series of routines which will help us to achieve good repeatability and high reliability. The measurement problem remains the same.

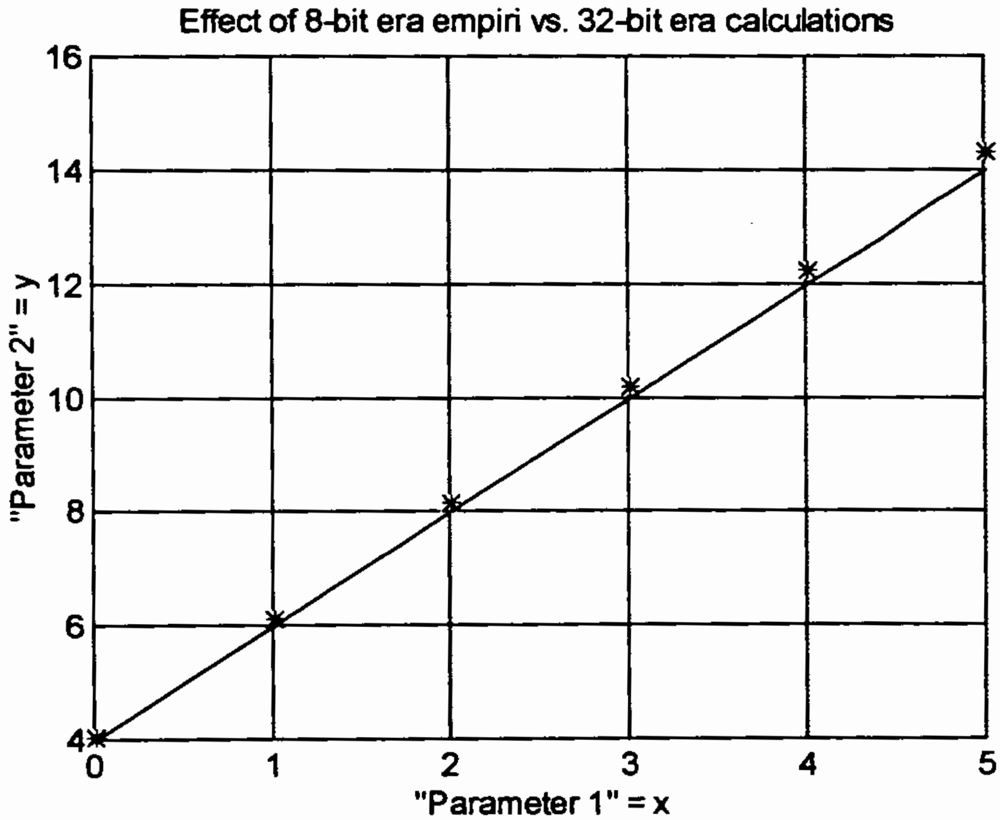


Figure 11 Effect (*exaggerated*) of 8-bit era empiri vs. 32-bit era calculations. The only difference is the variations in the coefficients in the equation $y = a\,x + b$. The continuos line show the line for a set of values for a and b. The values marked '*' are for another set of values given with differing mantissa.

FUTURE TREND

Software in flow computer today is dedicated for measurement purposes. It would be advantageous if the testing facility is in-built in the program used in the flow computer. The testing facilities have to be included already in the design stage in such a way that the program is easily testable. Earlier, they used debugging instead of interface. New flow computers have 15 digits operation with 32 bits CPU / double. Hence, the demand on testing and strategy used for testing will need to be changed.

The strategy used in the production of IC s shown in Figure 12 can be used also in software design. For known series of inputs, the sub-units (modules) in the program should deliver a series of outputs, which are to be obtained with high expectancy. A deviation from the expected values, would indicate faulty operation. One could visualise such test points as "handles" (similar to test points in hardware circuits). Joint Test Action Group (JTAG) bus is defined by IEEE [13] for on-module testing. JTAG is a serial bus containing four signal lines: Test Clock (TCK), Test Mode Select (TMS), Test Data Input (TDI), and Test Data Output (TDO) as illustrated in Figure 12. The system description shown in Figure 4 can be used to adapt this strategy of testing from the hardware industry, at the input and out "ports" of the sub-units shown. The challenge for the measurement and software engineers would be to find the pairs of relevant sets (TDI, TDO) for these sub-units.

In looking at the short term developments, discussions with people in various software engineering branches in industrial applications indicate that the user might continue using the flow computers, but performing tests and verifications using programming tools such as MATHCAD, MATLAB or MATHEMATICA, tools which enables tracing the TDI and TDO according to the system schematic shown in Figure 4 easily.

Long term developments will be based on the philosophy of Built-In Self-Test (BIST) used in the IC design discussed above, incorporated into the system already in the design stage, thus facilitating the solving of the puzzle mentioned earlier: software testability, software testing, and formal verification, which will lead to more reliable engineering in general.

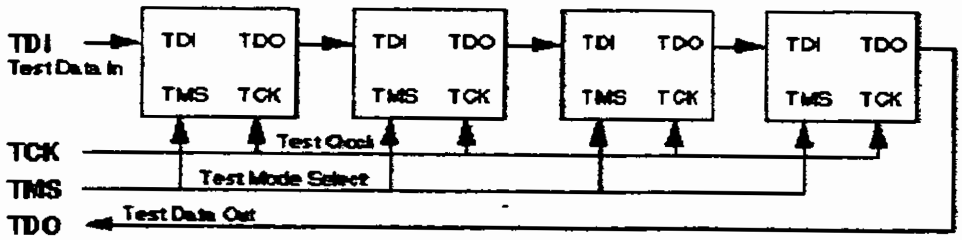


Figure 12 Bus serial connection of components with Built-In Self-Test (BIST) to perform test pattern generation and response analysis. From [13]. TDI and TDO in our system described in Figure 2 might be at any input and output port to and from the sub-units shown there.

NOTE ON ULTRASONIC GAS FLOWMETERS

There is a definite statement in the directives of the Norwegian Petroleum Directorate allowing the use of ultrasonic gas flowmeters for fiscal purposes. It is a well known fact that ultrasonic gas flowmeters are used in flare gas metering. It is planned to install the first ultrasonic gas flowmeter for fiscal measurements already in 1998.

Some of the modern ultrasonic gas flowmeters incorporate the testing and verification facilities in the flow computer itself. As an example of BIST in the ultrasonic gas flowmeter applications is the equation coupling the speed of sound in the medium *c* to the up-stream and down-stream transit times t_{12} and t_{21}. For a given well, the components of gases will be known and hence also the sound velocity. In the case of a multi-path ultrasonic gas flowmeter, the sound speeds calculated using the transit times for each path should be the same, allowing for variations due to some slight temperature changes in the flowing medium. From experience, one could define an acceptable upper and lower limit for the calculated speed of sound. When the estimated speed of sound is outside this band, the BIST will indicate faulty operation. Thus for the case under discussion, we can say that [TDI, TDO] = [[t_{12} t_{21}] , c]. In case , no BIST is available, this set could be used as one of the means in controlling the flow computer calculations.

One could envisage a series of such measures which will help to have BISTs in the software used in the metering process.

Thus, the future flow computers may make programs such as the ones described in this paper redundant! However, the testability, testing and verification paradigm will be dominating the software sector in the sense described in Figure 3, in our discussions above.

ACKNOWLEDGEMENT

The author acknowledges his organisation for the help, facilities and permission in working on and publishing this paper. Preliminary works for the programs discussed have been done by a number of students of Bergen college. Discussions with Mr. Trond Folkestad of Norsk Hydro have given good insight into the practical applications of the verification software discussed in this paper. Dr. C. Thiruarooran of Berkeley Technology Laboratories of the British Nuclear plc, Berkeley in the UK has given the author valuable information on testability, testing and verification in software engineering both in theory and practice.

REFERENCES

1. International Organization for Standardisation, 1983, "ISO 6976 - Natural gas - Calculation of calorific value, density and relative density."

2. International Organisation for Standardisation, 1980, "ISO 5167 - Measurement of fluid flow by means of orifice plates, nozzles and venturi tubes inserted in circular cross-section conduits running full"

3. Norsk Hydro, 1991, "Håndbok for målesystemer for fiskal kvantumsmåling av olje, kondensat og gass."

4. Oljedirektoratet (Norwegian Petroleum Directorate), 1997, "Forskrift for fiskal kvantumsmåling av olje og gass i petroleums-virksomheten" ("Regulations relating to fiscal measurement of oil and gas etc.").

5. Solheim, J.-A., Sætre, L. J.: "Fiskalt kvantumsmålingsprogram for gass."), 1993, Engineering Degree Thesis, Bergen Ingeniør Høgskole (Bergen College of Engineering).

6. Michael, D. , Heinze, T., 1995: "Fiscal Oil Calculations: Visual Basic Program for Verification of Flow Computer Calculations", Høgskolen i Bergen, Project Report Submitted on Completion of in-plant training, Collaboration between Norsk Hydro, Høgskolen i Bergen (Bergen College), Western Norway UETP and Hochschule für Technik und Wirtschaft.

7. Mylvaganam, S., Sætre, L.J., Solheim, J. A., 1993: "Compact Visual Basic Program for PC-based Verification of Fiscal Gas Flowmetering Calculations, incorporating Volume, Density, Temperature and Pressure Measurements", SEARCC Conference 95, Colombo, Sri Lanka.

8. Wing, J. M., "Formal Testability Analysis", 1990, Encyclopaedia of Software Engineering, Marchiniak, J.J., (Editor), Wiley.

9. Voas, J., Morrel, L., Miller, K., March 1991: "Predicting Where Faults can Hide from Testing", IEEE Software, 8(2), 41-47.

10. IEEE, 1990, "IEEE Standard Glossary of Software Engineering Terminology"

11. Voas, J., Miller, K., May 1995: "Software Testability: The New Verification", IEEE Software, 12(3), 17 - 28.

12. Norsk Hydro, 1993: "Håndbok for fiskal kvantumsmåling av olje, kondensat og gass"

13. IEEE Standard: Test Access Port and Boundary-Scan Architecture, IEEE 1149.1-1990, 21 May 1990.

APPENDIX A: Typical Print-out generated with the program in discussion for the platform managers. **GAS**

Solartron Densitetsmåler: Solartron Densitometer
Gass Sammensetning : Gas composition
Rør og blendeplate data: Pipe and orifice meter data
Målte verdier: Measured values
Beregninger: Calculations

The data of different densitometers can be retrieved from files to the GUI. Downstream and upstream measurements are taken into account in measurements as well as calculations.

Hydro
U&P Drift **FISKAL GASSBEREGNING** Ver. 4;0
Bergen

ISO-5167(1980), ISO-6976 OG SOLARTRON DENSITETSBEREGNING. FLANGETAP.

Linje Nr : 1	Brenngass, C04	Dato : 23.03.95
Tag Nr : FE-45-0201	Feil blendediameter fra 11.09.94 til 17.01.95	Tid : 16:53:54

Konstanter

SOLARTRON DENSITETSMÅLER	
K0	-82,860110 kg/m³
K1	-2,228380E-02 kg/m³/µs
K2	4,534184E-04 kg/m³/µs²
K3	1344,0 kg/m³
K4	197,8 kg/m³
K18	-7,620E-06 /°C
K19	1,550E-03 kg/m³/°C
Kal.temp.	25,000 °C
Kal.Gassk.	0,00282
Molvekt Luft	28,9641 g/mol

PTZ-korreksjon fra dens.-densitet til linjedensitet

GASS-SAMMENSETNING	
Nitrogen	0,750 mol%
CO2	1,110 mol%
Metan	82,340 mol%
Etan	8,480 mol%
Propan	4,800 mol%
n-Butan	1,060 mol%
i-Butan	0,450 mol%
n-Pentan	0,280 mol%
i-Pentan	0,260 mol%
C6+(=C7)	0,420 mol%
Vann	0,000 mol%
H2S	0,000 mol%
SUM	99,950 mol%

RØR OG BLENDEPLATE DATA	
Blendeplatediameter	56,123 mm
Blende Kal.temperatur	12,345 °C
Indre Rørdiameter	102,900 mm
Rør Kal.temperatur	20,00 °C

TEMPERATUR UTVIDELSESKOEFFISIENTER	
Blendeplate	1,07650E-05 /°C
Rør	1,60920E-05 /°C

Variabler

GASSENS EGENSKAPER	
Dynamisk Viskositet	1,190E-05 Pa-s
Brennverdi Inferior ISO-6976	40,613545 MJ/m³
Isentropisk Eksponent Std.	1,37176976
Isentropisk Eksponent Linje	1,36446144
Spesifikk Varmekapasitet Std.	1,37615648
Spesifikk Varmekap. Linje	1,48085792

MÅLTE VERDIER	
Trykk Oppstrøms Blendeplate	38,25000 bar g
Trykk Oppstrøms Blendeplate	39,26325 bar a
Differansetrykk Blendeplate	164,000 mbar
Temperatur v/10D Nedstrøms	53,40000 °C
Temperatur v/Densitetsmåler	53,40000 °C
Periodetid Densitetsmåler	650,00000 µs

Beregninger

Korrigert Blendeplatediam.	56,148 mm
Korrigert Indre Rørdiameter	102,9557 mm
Diameterforholdet, beta	0,54536023
Utstrømningskoeffisient, C	0,60428855
Hastighetskoeffisient, E	1,04739762
Strømningskoeffisient, alfa	0,63293027
Ekspansjonsfaktor, epsilon	0,99865012
Reynoldstall, ReD	2,87315222+06
Z Standard ISO-6976	0,99665473
Z Standard BWR	0,99681522
Z Densitetsmåler BWR	0,91888316
Z Linje BWR	0,91877452

Temp. Oppstrøms Blendep.	53,64935 °C
Trykk v/10D Nedstrøms	39,15121 bar a
Trykk v/Densitetsmåler	39,09925 bar a
Densitet Std. ISO-6976	0,86028622 kg/Sm³
Densitet Densitetsmåler	94,80393324 kg/m³
Densitet Linje	95,14019412 kg/m³
Kritisk Temperatur	-57,019522 °C
Kritisk Trykk	46,051126 bar a
Molvekt ISO-6976	20,272860 g/mol
Massestrøm	9952,872184 kg/t
Volumstrøm Linje	104,6126958 m³/t
Volumstrøm Standard	11569,256718 Sm³/t
Energistrøm Inferior	469,8731607 MJ/t
Hastighet	3,4905275 m/s

TOTALER	Beregnet	Målt	Avvik	Strømningstid
Masse	9952,872184 kg	9952,000000 kg	-0,0087631%	3600,000 s
Volum Linje	104,6126958 m³	104,0000000 m³	-0,5856801%	
Volum Standard	11569,256718 Sm³	0,000000 Sm³	-100,0000000%	
Energi Inferior	469,8731607 MJ	0,0000000 MJ	-100,0000000%	

Oljedirektoratets minstekrav til regneneyaktighet er 0,001%

APPENDIX B: Typical Print-out generated with the program in discussion for the platform managers.

OIL

The data of different densitometers can be retrieved from files to the GUI.

Hydro
U&P Drift
Bergen

FISCAL OIL CALCULATION

ESTIMATION : NORSK HYDRO IP200	COMPRESS. FACTOR : OLD FORMULA	TYPE OF OIL : CRUDE OIL

Line Nr : 1	Line 1	Date :	26.06.95
Tag Nr :	Test Print-Out!	Time :	13:46:36

Constants

DENSITOMETER		
K0	-1.2290 E+03	kg/m³
K1	-4.5515 E-01	kg/m³/µs
K2	3.9942 E-03	kg/m³/µs²
K18	-3.2079 E-05	/°C
K19	-1.4253 E-02	/°C
K20a	-1.3469 E-05	/bar g
K20b	-1.2207 E-07	/bar g²
K21a	-1.8708 E-02	/bar g
K21b	-1.6955 E-04	/bar g²
Cal.Temp.	20.0	°C
Cal.Press.	0.0	bar g

TURBINE METER		
Y-Coefficient	0.00003861	/bar
EH-Coefficient	0.00000846	/°C
ER-Coefficient	0.00000846	/°C

Variables

DENSITOMETER		
Densitometer Temperature	4.3210	°C
Densitometer Pressure	0.1230	bar g
Periodic Time	781.00	µs

TURBINE METER		
Line Temperature	4.3210	°C
Line Pressure	0.1234	bar g
Meter Registration	123044192.0000	pulses
Meter K-Factor	1285.6450	p./Sm³

TYPE OF OIL : CRUDE OIL	
K0	613.9723
K1	0.0

Calculation

Standard Density	844.7350000 kg/Sm³
Compress. Factor Fd	0.0000683
Help Factor Alpha 15	0.0008604
Correction Factor Ctld	1.0091800
Correction Factor Cpld	1.0000084

Line Density	852.4968197 kg/m³
Compress. Factor Fl	0.0000683
Correction Factor Ctlm	1.0091800
Correction Factor Cplm	1.0000084
Correction Factor Ctsm	0.9997290
Correction Factor Cpsm	1.0000048

	Calculation	Measurement	Deviation
Stand. Density	844.7350000 kg/Sm³	844.7350000 kg/Sm³	0.0000000 %
Gross Volume	95680.7143930 m³	95680.7488918 m³	0.0000361 %
Stand. Volume	96559.8734817 Sm³	96559.9106650 Sm³	0.0000385 %
Mass	81567.5047256 Tonnes	81567.5522923 Tonnes	0.0000583 %

Norwegian Petroleum Directorate specifies a minimum accuracy of 0.001%

Calculated by :	Sign :	Date :	26.06.95
Checked & Authorized by :	Sign :	Date :	26.06.95

APPENDIX C: Typical Print-out generated with the program in discussion for the platform managers.

CONDENSATE

Hydro
U&P Drift
Bergen

FISCAL CONDENSATE CALCULATION

CONDENSATE DENSITY CALCULATION IS BASED UPON THE USE OF THE COSTALD EQUATION

Line Nr : 1	Oseberg A	Date : 26.06.95
Tag Nr : 30-UY-651	Test Print-Out!	Time : 13:17:02

Constants

COMPOSITION OF CONDENSATE		
Methane	16.5527800	mol%
Ethane	5.6764200	mol%
Propane	3.3262660	mol%
i - Butane	2.9790970	mol%
n - Butane	1.5895970	mol%
i - Pentane	2.1453070	mol%
n - Pentane	1.2627170	mol%
Frac - 01	2.9843780	mol%
Frac - 02	4.7615500	mol%
Frac - 03	9.2429810	mol%
Frac - 04	10.3320800	mol%
Frac - 05	11.3299100	mol%
Frac - 06	11.8058200	mol%
Frac - 07	7.5094790	mol%
Frac - 08	6.6016230	mol%
Sum	98.1000050	mol%

TURBINE METER		
Y-Coefficient	0.00007861	/bar
EH-Coefficient	0.00000679	/°C
ER-Coefficient	0.00005678	/°C

Variables

TURBINE METER		
Line Temperature	-12.13145	°C
Line Pressure	39.8769	bar g
Meter Registration	40020002.0000	pulses
Meter K-Factor	424.5000	p./Sm³

Calculation

STANDARD CONDITIONS		
Reduce Temperature	0.5713514	
Coefficient Vr0	0.3783342	
Coefficient Vrs	0.2285533	
Volume at Vapour Pressure	0.1235540	
Reduce Density	722.7615893	kg/m³
Coefficient F	-4.4575210	
Coefficient Pr0	-1.7498690	
Coefficient Pr1	-1.9901723	
Reduce Pressure	0.0049081	
Vapour Pressure	0.1687905	bar a
Coefficient B1	16.6698041	
Coefficient D1	1.0015665	
Standard Density	722.8700215	kg/m³

OPERATING CONDITIONS		
Reduce Temperature	0.5175544	
Coefficient Vr0	0.3658068	
Coefficient Vrs	0.2362538	
Volume at Vapour Pressure	0.1191867	
Reduce Density	749.2456923	kg/m³
Coefficient F	-6.8679340	
Coefficient Pr0	-2.1824873	
Coefficient Pr1	-2.6356821	
Reduce Pressure	0.0011937	
Vapour Pressure	0.0410533	bar a
Coefficient B1	19.8785266	
Coefficient D1	1.0629146	
Operating Density	753.6522589	kg/m³

RESULTS INDEPENDENT OF STAND./LINE CONDITIONS		
Acentric Factor (Meth. A)	0.2809899	
Molecular Weight	89.3001013	
Critical Pressure (Meth. A)	34.3902528	bar a
Spherical Volume	0.3489861	
Critical Temp. (Meth. A)	504.3306500	K
Coefficient B	142.0754465	

CORRECTION FACTORS	
Correction Factor Ctsm	0.9980917
Correction Factor Cpsm	1.0031347

	Calculation	Measurement	Deviation
Stand. Density	722.8700215 kg/Sm³	722.8700000 kg/Sm³	-0.0000030 %
Gross Volume	94390.6796873 m³	94390.0000000 m³	-0.0007201 %
Stand. Volume	98410.1523715 Sm³	98410.0000000 Sm³	-0.0001548 %
Mass	71137748.9624447 Tonnes	71137.7970000 Tonnes	0.0000675 %

Norwegian Petroleum Directorate specifies a minimum accuracy of 0.001%

Calculated by : -	Sign :	Date : 26.06.95
Checked & Authorized by :	Sign :	Date : 26.06.95

APPENDIX D: Typical Print-out generated with the program in discussion for the platform managers.

PROVER

The data of different densitometers can be retrieved from files to the GUI.

Hydro
U&P Drift
Bergen

FISCAL PROVING CALCULATION

ESTIMATION : NORSK HYDRO IP200	COMPRESS. FACTOR : OLD FORMULA	TYPE OF OIL : CRUDE OIL
Line Nr : 1 Tag Nr :	Line 1 Test Print-Out!	Date : 26.06.95 Time : 13:15:15

Constants

DENSITOMETER

Input of a given Standard Density!

TURBINE METER

Y-Coefficient	0.00003861 /bar
EH-Coefficient	0.00000846 /°C
ER-Coefficient	0.00000846 /°C

PROVER

Diameter of the Prover Pipe	736.60 mm
Wall Thickness of the Prover Pipe	12.70 mm
Modulus of Elasticity of Prover Steel	2060000.0 /bar
Coefficient of Cubical Expansion	0.0000335 /°C
Base Volume of the Prover	5.0096300 Sm³

Variables

DENSITOMETER

Densitometer Temperature	14.2380 °C
Densitometer Pressure	4.9510 bar g
Standard Density	846.0000 kg/Sm³

TURBINE METER

Line Temperature	14.2380 °C
Line Pressure	4.9510 bar g
Meter Registration	9999.0930 pulses

TYPE OF OIL : CRUDE OIL

K0	613.9723
K1	0.0

PROVER

Prover Temperature	15.9170 °C
Prover Pressure	5.1240 bar g

Calculation

Standard Density

Standard Density was given!

Line Density	846.8467952 kg/m³
Compressibility Factor Fl	0.0000722
Correction Factor Ctlm	1.0006430
Correction Factor Cplm	1.0003577
Correction Factor Ctsm	0.9999807
Correction Factor Cpsm	1.0001912

Meter K-Factor	1998.7619620 p./Sm³
Compressibility Factor Fp	0.0000730
Correction Factor Ctlp	0.9992280
Correction Factor Cplp	1.0003740
Correction Factor Ctsp	1.0000307
Correction Factor Cpsp	1.0001443

	Calculation	Measurement	Deviation
Meter K-Factor	1998.7619620 pulses/Sm³	1998.7620000 pulses/Sm³	0.0000019 %

Norwegian Petroleum Directorate specifies a minimum accuracy of 0.001%

Calculated by :	Sign :	Date : 26.06.95
Checked & Authorized by :	Sign :	Date : 26.06.95