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High turndown orifice plate measurement using a single DP Cell

1.6

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C O N T E N T S

1.0 SUMMARY

In this short paper we propose to put foreward a method of measuring flow through an orifice plate with high turndown using a single DP cell. Accuracy is at least as good as that obtained using the traditional 3DP cell approach.

By virtue of the equipment used, further advantages are obtained in problem solving.

The paper first briefly reviews the current method of dealing with high turndown flow conditions in an orifice plate.

It then goes on to describe the transmitter which can replace triple DP cells, the Honeywell ST3000.

Using the technology available in the Honeywell transmitter, Spectra-Tek have produced a device which will alow a computer to change ranges on the Honeywell ST3000, the QST.

Using their standard gas flow computer Spectra-Tek have developed special software to enable the computer to use the Honeywell ST3000 DP transmitter as if it were three DP cells with 3 ranges.

2.0 REVIEW OF THE CURRENT METHOD

2.1 Arrangement

A normal 3DP cell set up has 3 cells sitting on one manifold individually isolated.

Each cell signal goes through a pair of wires through barrier sets and the signal is read by the computer.

2.2 Operation

When reading the differential pressure the cells operate starting at the lowest range. As the range increases to say 95^{o} of full scale value, the second cell is used for determining the differential pressure.

When on the second cell again, if the cell arrives at 95% of its full scale the third cell is used for determining the differential pressure.

When DP is falling, if the differential pressure say on cell number 3 reduces to the equivalent of 90% of full scale on cell 2, cell 2 is used in the determination of pressure.

Why use 3 cells?

Accuracy (See table 1)

It can be seen from table 1 that the accuracy of the cell considerably improves if 3 cells are used. I have taken, throughout this discussion, the error to be a percentage of the actual reading at each point.

For ease of comparison I have chosen ranges of 125, 250 and 400mbar and assumed switchover at 100%.

TABLE 1

ACCURACY CALCULATIONS FOR STANDARD CELL

ENTER ERROR PERCENT- .2

INPUT RANGES

RANGE 1(LOWEST)- 400

RANGE 2(MIDDLE)- 400

RANGE 3(UPPER)- 400

DP	%ERROR	RANGE	%FLOW ERROR
400	0.2	400	9E-2
300	0.266	400	0.13
251	0.318	400	0.15
250	0.32	400	0.15
201	0.398	400	0.19
200	0.4	400	0.19
126	0.634	400	0.31
125	0.64	400	0.31
100	0.8	400	0.39
63	1.269	400	0.63
62.5	1.28	400	0.63
50	1.6	400	0.79
20	4	400	1.98
10	8	400	3.92
5	16	400	7.7

INPUT RANGES

RANGE 1(LOWEST)- 125

RANGE 2(MIDDLE)- 250

RANGE 3(UPPER)- 400

DP	%ERROR	RANGE	%FLOW ERROR
400	0.2	400	9E-2
300	0.266	400	0.13
251	0.318	400	0.15
250	0.2	250	9E-2
201	0.248	250	0.12
200	0.25	250	0.12
126	0.396	250	0.19
125	0.2	125	9E-2
100	0.25	125	0.12
63	0.396	125	0.19
62.5	0.4	125	0.19
50	0.5	125	0.24
20	1.25	125	0.62
10	2.5	125	1.24
5	5	125	2.46

3.0 DESCRIPTION OF THE HONEYWELL ST3000

The ST300 is a so called "smart" DP transmitter (it is also available as an ordinary pressure cell).

The transmitter has on board a microprocessor which performs several functions.

It enables the device to be interrogated providing diagnostics and setting up facilities.

The transmitter is basically like any other transmitter with the process variable represented by a 4-20mA current.

Where it differs from other transmitters is in the communications. By using the hand held field communicator, it is possible to talk to the transmitter in the field. When this occurs the process variable signal is interrupted and is restored at the end of communications.

The hand held communicator has a host of facilities, including setting the cell to linear or square root action, setting 4mA and 20mA (LRV and URV), setting damping, calibration, zeroing, error checking and many more.

Communication is via the 4-20mA loop using the same wires. It involves a special protocol and special baud rate, together with a method of "waking up" the transmitter and putting it into communications mode.

The facilities were developed to enable the transmitter to be stocked as a standard item and configured to appropriate functions, range and tag number in the engineering department, before using in the field.

The key area that interests us in re-ranging. It is possible by downloading a command to set the LRV (lower range or 4mA value) and URV (upper range or 20mA value) from the hand held communicator.

So the Honeywell transmitters can be used to replace 3DP cells by taking three standard models, setting the ranges in the workshop and replacing the normal cells.

The next step is of course to consider whether one cell can be used to cover all three ranges in situ.

This question was first proposed to us by Shell. It might be possible to use one Honeywell ST3000 to replace the traditional 3 transmitters by using this re-ranging facility.

This involves waiting until the transmitter is near the top of its operating range and sending an instruction to it to change its LRV and URV to more suitable values. Similarly as flow reduced ranges could be manipulated to keep the current to a reasonable value.

What is needed?

1. To make a decision about when to change range.

2. Interact with the ST3000 to change range.

3. Interpret the results of change.

4. Cope with the loss of process variable signal during communication.

5. The ability to communicate.

This is best done with a dedicated computer.

There is a problem, however. The ST3000 transmitter will not accept 'normal' communication from a computer. This is because it has a special protocol and a special baud rate.

4.0 THE SPECTRA-TEK QST

The key to successful communication is to be able to convert a "standard" protocol with normal baud rates into one which can be used by the ST3000.

It was necessary to invent a piece of hardware to perform this trick and translate a normal RS232 type ASCII protocol into a suitable form. The transaction is required to be bi-directional.

So, Spectra-Tek developed a piece of hardware with an on board processor that could perform the task. Bearing in mind that we find it useful to provide maximum flexibility we built the QST.

So it has been developed with a multidrop capability talking to up to 4 ST3000, facilities which can be fully developed on a larger systems.

The QST has been designed to mount on standard top hat and asymmetric DIN rail. All connections are by screw terminals. The QST will operate an ST3000 either through a standard IS barrier or without any barrier and special links are provided to ensure that the hand held communicator will operate with no barrier present.

When used normally, the 4-20mA process variable signal is conditioned through 01.0% precision 50 ohm resistors. This provides a 0.2 to 1 volt signal to the host computer. When communication takes place this signal is corrupted and should not be read.

4.1 Communication

The communication with the QST involves the use of a special protocol.

The QST receives a pre-packaged message from the host computer via a standard communications link using 1200 baud transmission rate. The message is transmitted using standard ASCII characters.

The packaging of the message includes an address for the ST3000 on the QST board. Each QST board has links which can be set to provide an address. The QST will only repsond if the polling address is its own. A checksum system is used to validate the incoming message.

When a QST receives a poll it first checks if the message is for it. If so it then wakes up the Honeywell ST3000 that is addressed. At the same time the received message is changed to a format suitable for the ST3000 and passed on to the ST3000. During this time the process variable signal is disturbed and is no longer valid. Care must be taken to ensure that the reading of the process variable is suspended during communication. A typical communication time is 1.5 secs.

Having talked to the ST3000 the QST then waits for a reply. If a reply is received it is checked for transmission error, packaged to include the address of the ST3000 and that of the QST and returned to sender. If no reply is received an error message is returned to the sender.

5.0 IMPLEMENTATION OF RE-RANGING

We now have the ability to talk to an ST3000 from a computer. We can therefore use the computer to make decisions about when to change the range.

Once it has decided to action the range it sends the approriate information to the ST3000 to change the range and adjusts its own internal register appropriately.

This means that instead of listening to 3 cells the computer re-ranges the ST3000 to act as an appropriate cell.

When, say, on the lowest range the Honeywell cell reaches 95% of the full scale value, the computer, via the QST sends a message to the ST3000 to re-range to range 2.

Having done this it reads the PV as if it were from range 2.

Similarly at 95% of range 2 the Honeywell cell is re-ranged to to range 3. The same thing happens on the way down.

We can now cope with high turndown with only one set of wires, one set of barriers and one header.

6.0 ACCURACY

We have seen how the accuracy of a single cell deteriorates in comparison with a standard 3 cell system. Can the Honeywell ST3000 provide the accuracy required?

The answer is of course, YES. Indeed in comparison with a widely used cell the accuracy figures are better.

To demonstrate this I have produced calculated accuracy figures for a standard 3 PP cell system and compare them with the Honeywell ST3000.

I have taken published figures from a widely used transmitter. For the ST3000, I have used the formulae below.

Including combined effects of linearity, hysterisis and repeatability.

± 0.1% of calibrated span or upper range value, whichever is the greater, terminal based, except below 125 millibar accuracy equals.

$$0.05 + \left(0.05 \times \frac{125 \text{ millibar}}{\text{span in millibar}}\right)$$

Combined Zero and Span Temperature Effect

Per 28°C ± 0.25% of calibrated span between reference span and Upper Range Unit, except below 125 millibar accuracy equals.

$$0.2 + \left(0.05 \times \frac{125 \text{ millibar}}{\text{span in millibar}}\right)$$

Combined Zero and Span Static Pressure Effect

Per 69 bar ± 0.2% of calibrated span, between reference span and Upper Range Limit, except, below 250 millibar accuracy equals.

$$0.2 \left(\frac{250 \text{ millibar}}{\text{span in miilibar}}\right)$$

6.1 Results

I have chosen ranges of 0-125mbar, 0-250mbar and 0-400mbar with switching points 125mbar and 250mbar as explained above.

For a Standard Cell (Table 2)

The worst error of course occurs at switchover and you can see that at switchover values the worst errors are 0.32% and 0.4% with an error at 20mbar of 1.25%.

For Honeywell Cell including re-range error (Table 3)
(Assuming calibration at mid range).

0.21% and 0.2% with an error at 20mbar of 0.94%.

However, it is possible using the facilities for offset in Quantum and providing values at test to eliminate the re-range error. The figures then become ...

Honeywell Cell without re-range error (Table 4)

0.16% and 0.2% with error at 20mbar of 0.63%

It can be seen that the ST3000 performs substantially better than three standard cells.

TABLE 2

ACCURACY CALCULATIONS FOR STANDARD CELL

ENTER ERROR PERCENT- .2

INPUT RANGES

RANGE 1(LOWEST)- 125

RANGE 2(MIDDLE)- 250

RANGE 3(UPPER)- 400

DP	%ERROR	RANGE	%FLOW ERROR
400	0.2	400	9E-2
300	0.266	400	0.13
251	0.318	400	0.15
250	0.2	250	9E-2
201	0.248	250	0.12
200	0.25	250	0.12
126	0.396	250	0.19
125	0.2	125	9E-2
100	0.25	125	0.12
63	0.396	125	0.19
62.5	0.4	125	0.19
50	0.5	125	0.24
20	1.25	125	0.62
10	2.5	125	1.24
5	5	125	2.46

TABLE 3

ACCURACY CALCULATIONS FOR HONEYWELL CELL WITH RERANGE ERROR

ENTER ERROR PERCENT- .1

INPUT RANGES

RANGE 1(LOWEST)- 125

RANGE 2(MIDDLE)- 250

RANGE 3(UPPER)- 400

CALIBRATED RANGE?(1-3)2

DP	%ERROR	RANGE	%FLOW ERROR
400	0.13	400	6E-2
300	0.173	400	8E-2
251	0.207	400	0.1
250	0.1	250	4E-2
201	0.124	250	6E-2
200	0.125	250	6E-2
126	0.198	250	9E-2
125	0.15	125	7E-2
100	0.187	125	9E-2
63	0.297	125	0.14
62.5	0.3	125	0.14
50	0.375	125	0.18
20	0.937	125	0.46
10	1.875	125	0.93
5	3.75	125	1.85

TABLE 4

ACCURACY CALCULATIONS FOR HONEYWELL CELL WITHOUT RERANGE ERROR

ENTER ERROR PERCENT- .1

INPUT RANGES

RANGE 1(LOWEST)- 125

RANGE 2(MIDDLE)- 250

RANGE 3(UPPER)- 400

CALIBRATED RANGE?(1-3)2

DP	%ERROR	RANGE	%FLOW ERROR
400	0.1	400	4E-2
300	0.133	400	6E-2
251	0.159	400	7E-2
250	0.1	250	4E-2
201	0.124	250	6E-2
200	0.125	250	6E-2
126	0.198	250	9E-2
125	0.1	125	4E-2
100	0.125	125	6E-2
63	0.198	125	9E-2
62.5	0.2	125	9E-2
50	0.25	125	0.12
20	0.625	125	0.31
10	1.25	125	0.62
5	2.5	125	1.24

7.0 A SPECIFIC APPLICATION (Computer Operation with the St3000 using the QST)

The Spectra-Tek Quantum Gas flow computers have been programmed to operate with one Honeywell ST3000 using 1 QST. This combination will act as a 3DP cell system.

NOTE that, while ,for the other systems, it will possible to use the QST to talk to more cells, in Quantum only 1 cell is used with 1 QST for each Quantum.

Facilities Include:

- Setting upto 3 ranges.
- Automatic re-ranging.
- Setting of change up and change down points.
- 4mA and 20mA off sets.
- Initialisation routine.
- Error reporting.

The detailed operation is explained below indicating the displays, facilities and alarms available.

DETAILED DESCRIPTION

1. **Setting Ranges**

The ranges required are set on the displays for DP cell 1; DP cell 2 and DP cell 3. Each of these has a 4mA setting for DP (normally 0, but could be some other value) and a 20mA setting. These should be set, in order, to the scaling required.

For example:

Cell 1 could be set to 4mA Ombar, 20mA 125 mbar.
Cell 2 could be set to 4mA Ombar, 20mA 250 mbar.
Cell 3 could be set to 4mA Ombar, 20mA 400 mbar.

All readings are intepreted by cell 1 which indicates the actual DP being read at the time and the % of the full scale.

2. **Setting change up and change down**

These are set in the displays called DP used. They are normally in the region 90% for change down and 95% for change up. This makes maximum use of the cell and the same time provides some reasonable hysterises preventing "hunting".

The % of change up is applied to the current scale. On change down the % is applied to the cell that it is changing to.

e.g. Suppose we look at 2 cells 0-125mbar and 0-250mbar, change up at 95% will occur when cell 1 is at 95% of 0-125 = 118.75mbar. When on cell 2, 0-200mbar, change down will occur at 90% of cell 1, 112.5mbar.

3. **Using the correction**

Calibrating the Honeywell ST3000 can only be carried out at one range. When the cell is re-ranged some slight adjustments may be required to obtain maximum accuracy by eliminating the re-ranging error. The procedure to be adopted could be as follows:

First calibrate the ST3000 on range (the middle range would be best). Then, re-range the ST3000 to its other two ranges in turn. Using the testing facilities note the current (mA) required for zero and full range values of DP for each of the other two ranges. These 4mA and 20mA correction values can be entered into Quantum, which will then make the appropriate adjustments. Such values will be very close to 4mA and 20mA, e.g. 4.010mA and 19.023mA.

4. **Calibration Error**

This display is set so that an alarm will be caused if the reading before the change disagrees with the reading after the change by more that the % set. It is recommended for the ST3000 that it be set at a large number, e.g. 100%. However, it can be usefully used to indicate that there is a high rate of change at the change over points. In this case the scaling and/or changeover points can be changed to improve matters.

5. **Initialisation**

A display is available to initialise the ST3000 with the machine running. This allows the user to set up a new ST3000 in the system. It ensures that the transmitter is set to the correct range and it is linear. NOTE that if this is used or the mode switch is used to start an ST3000 that damping is set to zero. This may be changed by the hand held communicator after initialisation.

6. **Checking**

Every 10 minutes so the Quantum checks the ST3000 to ensure that it is set to a linear mode and its range is correct. This is to ensure that in the unlikely event of someone changing the cells characteristics, incorrect readings do not continue for any length of time.

7. **Readings**

During communication there is no process variable information from the 4-20mA loop. Quantum uses the last known reading during this period.

8. **Alarms**

A number of alarms are available to assist with diagnosis if problems occur.

ST3000 Telem Failure

This alarm is raised whenever there is a failure in communication between the Quantum and the ST3000. It will be cleared down on a subsequent successful communciation.

ST3000 Critical Status

If the ST3000 has a 'critical status', as defined by the ST3000 manual, then this alarm will be raised. It will be cleared down when the status reverts to normal.

ST3000 Non-Critical Status

If the ST3000 has a 'non-critical status', as defined by the ST3000 manual, then this alarm will be raised. It will be cleared down when the status reverts to normal.

ST3000 Xducer Anamaly

This alarm is raised for two specific instances from data obtained via the regular (every 10 minutes) data base poll. If the LRV and span at the transducer do not agree with the Quantum, or the conformity is not linear, then the alarm is raised.

ST3000 Can't Re-range

If we are at the highest ranges, but exceeding the change up pecentage then this alarm is raised. It is cleared when the current drops below the change up value.

ST3000 Invalid Database

If the transducer indicates that it has an invalid database then this alarm is raised.

9. <u>Use of the hand held communicator</u>

If a critical or non-critical alarm should arise, or any other circumstances, it is still possible to use the hand held communicator to provide a more detailed diagnosis. The flow measurement must, of course be stopped first.

This also makes available all the powerful other features in the smart DP cell; such as zeroing, checking of tags, changing damping, loop adjustment, loop validation and many more.

8.0 CONCLUSION

A traditional 3 DP cell system with 3 sets of wires, three manifold points and 3 barriers are used to provide accurate high turndown metering.

This can be replaced by a single Honeywell smart transmitter to measure the differential pressure.

To do this requires special software (provided in Spectra-Teks Quantum computers) and a special hardware interface also produced by Spectra-Tek (the QST).

Accuracy is improved and only one set of barriers and wires are required, together with a single manifold.

At the same time all the useful additional features provided by a 'smart' DP cell are available to the operator.

9.0 THE FUTURE .....

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.