SET POINT TESTING

An investigation of safety relief valve set point testing techniques

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Introduction

In 1995/6 a BP group-wide work group met to consider various aspects of safety relief valve management and performance. One subject considered was the setting of these valves and, in particular, the use of **on line set point verification** (OLSPV).

Traditional methods of testing such valves in BP Amoco group companies conform to the recognised industry standard API 576, and the usual procedure requires that all PSVs are removed from the plant periodically so that their condition can be evaluated in a workshop. Prior tore-installation valves are then "pop" tested on a test bench. On steam boilers the bench set pressure must also be proven in-situ by "floating" the valve. This method is both time consuming and costly. There are, however, methods of testing safety relief valves on line (with and without pressure), notably the Furmanite 'Trevitest" safety valve testing system and comparable in-situ test systems offered by e.g. Crosby and Consolidated. The benefits of these methods are lower costs and, where valves are not "spared", extended plant run times.

Although these techniques are well established in the power generation industry on steam service confidence in process industries has been low and little controlled testing has been conducted. The Working Group proposed an investigation, carried out in collaboration with the vendors, to test the reliability of OLSPV and better define its limitations. This paper describes the resulting tests. At the same time the opportunity was taken to investigate the accuracy of the widely used bench testing technique.

Most of the in-situ tests were performed using Furmanite's "Trevitest" system but a smaller number of tests (three valves on air and steam) were also carried out using Tyco Flow Control's Crosby system to provide confirmation of results and a comparison of the techniques.

For the two participating vendors (Furmanite and Crosby) the apparatus, hardware and basic operating procedure were similar, differing mainly in the software and presentation of data. Other vendors may offer different in-situ test methods. (The inclusion of these two vendors in the programme does not imply approval and is not a comment on competing techniques which were not evaluated.)

Note that, regardless of the method of set point verification employed, it is necessary to remove relief valves periodically in order to inspect and refurbish the valve internal parts and to inspect and maintain pipework. The necessity is greater on dirty, fouling or corrosive duties than on clean service.

Description of the on-line set point verification technique

A hydraulic power pack supplies energy to a hydraulic ram located in the cross-head of a mechanical rig. The hydraulic ram displaces vertically upwards, overcoming the spring force and causing the valve to lift when the upward force exerted by the working fluid overcomes the downward force exerted by the spring. The force generated during this operation is measured using a strain gauged load cell and recorded on a portable computer where it can be converted into an equivalent pressure. If the test is undertaken with line pressure present, the calculated pressure is added to the line pressure present to give the as-found set pressure.

Line pressure is measured by means of a calibrated pressure transducer connected to the portable computer. Valve lift is measured and recorded using a displacement transducer. The computation of this information, captured graphically on portable computer, leads to the determination of the set pressure, valve lift or displacement, spring adjustment rate, an indication of the effect of the nozzle and guide rings and the re-seat pressure.

The accuracy with which the effective seat area of the valve is known has an effect on the accuracy of set pressure prediction. In this case the valve seat area was estimated based on average seat face width. A more accurate approach is to conduct a "fingerprint" test under known conditions which allow the effective seat area to be calculated and recorded for future use.

Test objective

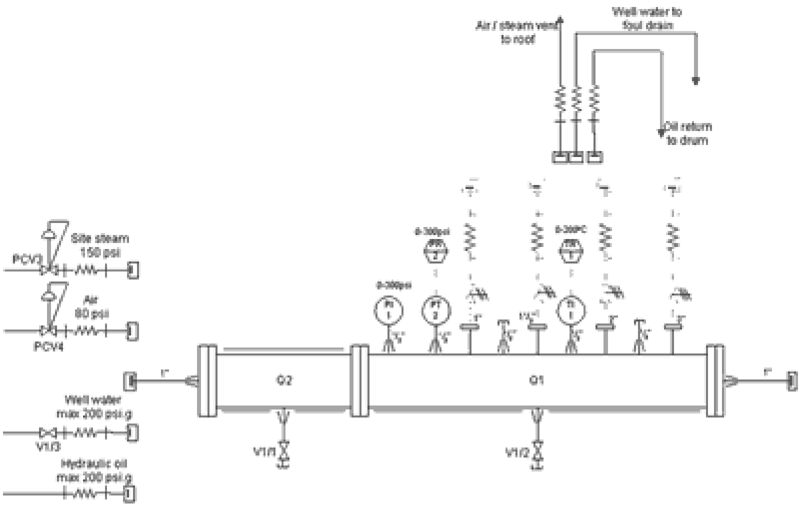
The aim was to assess the effects of operating pressure, seat area, test fluid, and valve design on the accuracy of OLSPV and to compare actual lift pressure, bench set pressure and on-line set pressure.

Test equipment

The test rig is shown in Figure 1. It was constructed to Class 300 rating and consisted of a 6" manifold with flanged nozzles of 1", 1.5", 2" and 3" diameter. Where increased volume was required a length of 6" diameter pipe was connected to the manifold. Test fluids were as follows:

- Steam from a 200 psi main via a PCV.
- Air from a main via a PCV
- Water from a pressurised flow loop via a PCV
- Oil from an air driven hydro-pump fitted with an accumulator to reduce pressure pulsations.

Figure 1 Schematic of the test rig (click image to enlarge):



Notes:

- All vents to be run in 1"BSP galvanised pipe
- Main vessel to be lagged using 50mm thick matting

Operating parameters:

- Design & disk temperature - 20.6 barg
- Design temperature - 20 to 200^{o}C
- Hydrostatic test temperature - 30.9 barg at ambient
- Maximum working relief valve pressure - 200 psig

Test procedure

On arrival at Sunbury, the relief valves were inspected and set to a requested range of bench set pressures by Strata Technology Ltd, the engineering services contractor on site, in a workshop. Cold set tolerances are ±0.15 bar for bench set pressures of 5 bar or below, and ±3% for bench set pressures greater than 5 bar. The method conforms with BP Amoco standard practice.

The valves were then transported by cart to the test rig and each valve was lifted in-situ whilst at atmospheric internal pressure (0% of bench set pressure) to determine the lift point for this condition.

The first test medium was **air** and tests were repeated for each valve using **steam, water and oil**. The on-line lift pressure was determined using OLSPV at internal pressures of 30%, 60% and 90% of bench set pressure. The OLSPV apparatus was then removed and the actual lift point determined by raising the on-line pressure until the valve popped. Throughout this process the line pressure was monitored using pressure transducers and a chart recorder.

Valves tested

All valves tested in this investigation were loaned by operating plants. Nine valves were obtained from three different BP Amoco sources. All were metal seated and three were bellows sealed. Some were new and some had seen previous service.
Details and of each valve are shown in Table 1.

Table 1 Details of relief valves tested

Valve No.	Manufacturer	Valve type	Seat ID (mm)	OD (mm)	Mean seat area (inches^2)	Bench set pressure (barg)
#1	Farris	26JA10-140	36	38	1.701	2
#2	Farris	26JA10-140	36	38	1.701	3
#3	Bailey Birkett	3K 432	46.4	48	2.727	17
#4	Bailey.Birkett	1F 232	18.7	20.2	0.467	13.7
#5	T.Milano	3111CGB	17.5	19.6	0.416	8.2
#6	Farris	26DA10-120	13.2	15	0.24	9.6
#7	Crosby	JB 25A	14.6	17.1	0.304	10.3
#8	Broady	2531F-DP XB20	21.4	23.5	0.616	20
#9	Broady	2531F-DP XB20	21.4	23.5	0.616	30
Note: All valves tested had a 'hard seat'.						

Test results

The following is an example of the way in which test results were presented.

The specific result is that obtained using the Furmanite Trevitest method on valve No. #9, with an on-line pressure of approximately 30% of the bench set pressure and where the test medium is air.
The result first appears in Figure 2. Its position shows that Furmanite's prediction of the actual lift point deviates by +9.2% from the bench set pressure of valve #9, which is 30 bar; i.e. The valve is predicted to lift 9.2% higher than the bench set pressure and the valve will lift heavy in the event of over-pressure whilst on-line.

The result appears again in Figure 3. This shows the test results accuracy relative to the actual lift point for each valve. The plots show that this particular result deviates by -1.95% from the actual lift pressure for valve #9, which is 33.4 bar; i.e. The OLSPV prediction is conservative, even though, relative to the bench set pressure, the prediction appears un-conservative.

Finally the point appears in Figure 4. where the percentage deviations of the on-line set point verification results from the actual lift point for each valve are plotted against the seat size of each valve. Valve #9 has a seat size of 0.616 square inches. The vertical positioning of the result is the same as shown in Figure 3 that is 1.95% less than the actual lift point.

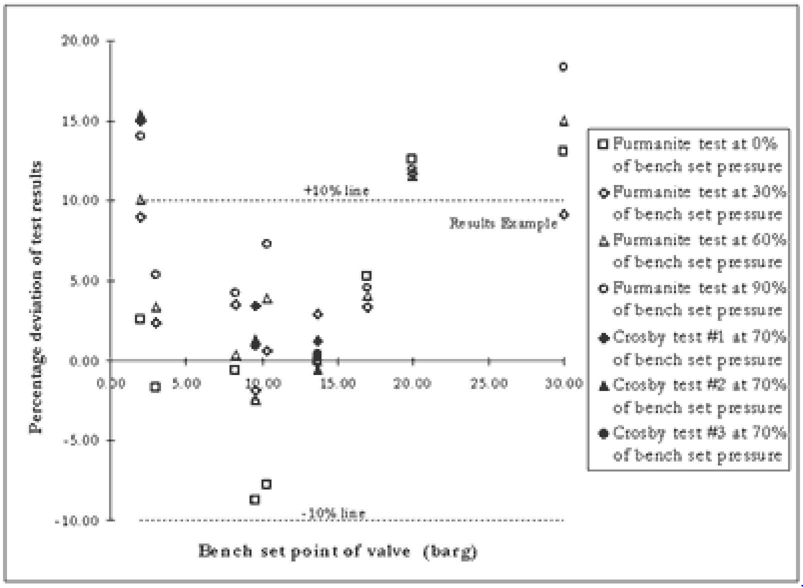


Figure 2 Chart showing the percentage deviation of on-line set point verification results vs. the bench set pressure for each valve, tested on air (click image to enlarge)

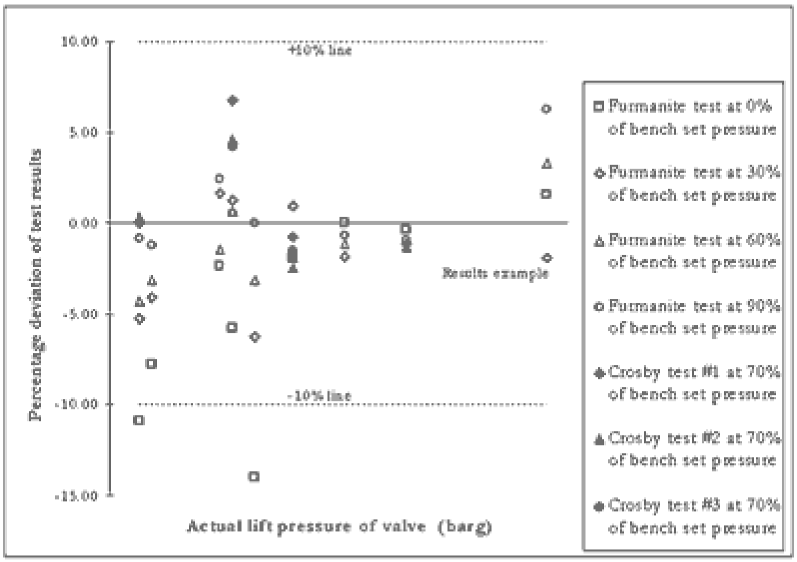


Figure 3 Chart showing the percentage deviation of the on-line set point verification results vs. the actual lift point for each valve, tested on air (click image to enlarge)

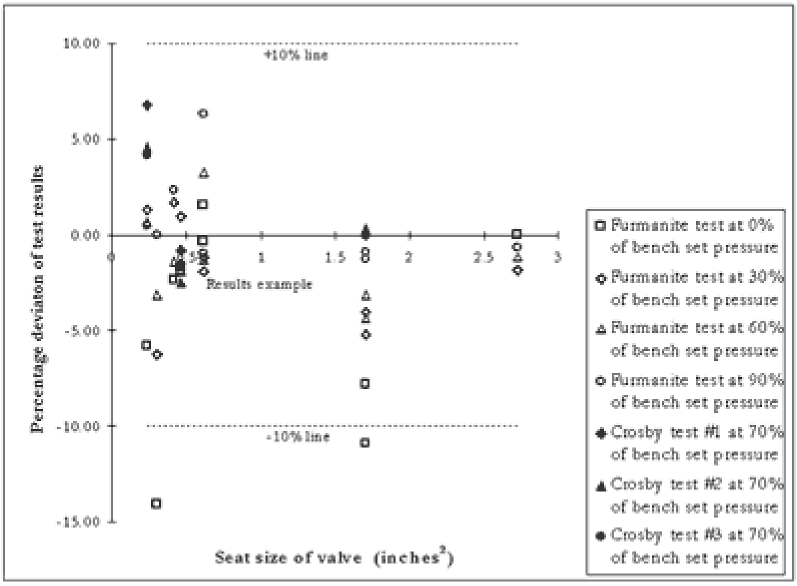


Figure 4 Chart showing the percentage deviation of the on-line set point verification results from the actual lift point vs. the seat size of each valve, where the test medium is air (click image to enlarge)

Discussion of test results

Comparison of the on-line test results with bench set pressure

On examination of Figure 2, it is clear that the set point verification estimates using either of the on-line test methods are generally higher than the estimates obtained by conventional bench testing (bench set pressure). Overall, of the 129 on-line relief valve set point verification tests performed on all test media, 88% were greater than the corresponding bench set pressure. Of these 52% were more than 5% greater, and 32% were more than 10% greater than the bench set pressure for each valve.

This could imply one of two things; that the on-line relief valve set point verification methods err considerably on the side of caution, based on the bench set pressures being reasonably accurate, or conversely that the bench set pressures are un-conservative and relatively inaccurate. (Note: this may not be of practical significance except where operating pressures are close to the set point or where equipment with only marginal tolerance of overpressure is employed)

Comparison between bench set pressure and actual lift point

The results comparing the bench set pressure to the actual lift point are shown in Figure 5. This shows that, of the 9 valves tested, 8 had actual lift points greater than the bench set point for the valve when 'popped' on air, indicating that the bench set valve would lift 'heavy' on-line. Of the 9 bench set pressures 5 deviated by more than +5% from the actual lift point, and 3 deviated by more than +10%.

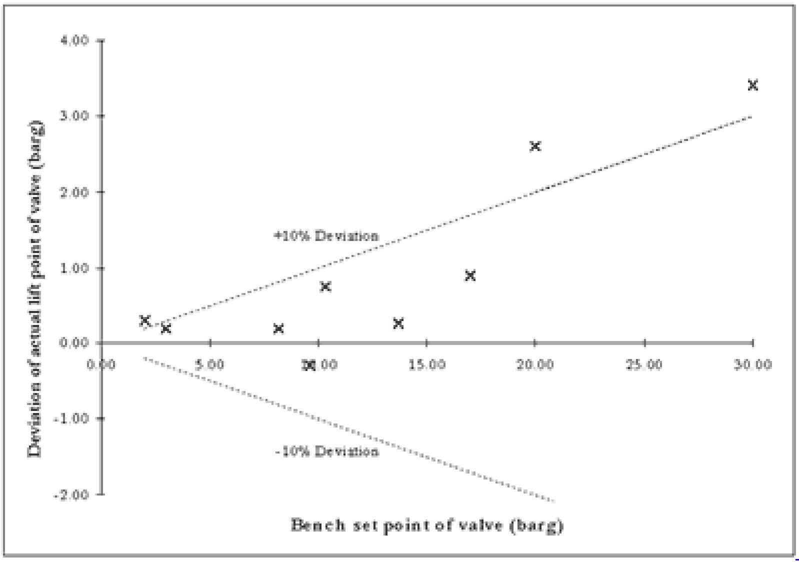


Figure 5 Chart showing the deviation of the actual lift point vs. the bench set point for each valve (click image to enlarge)

Comparison of on-line set point verification results and the actual lift point of each valve

The scatter of data shown in Figure 4 shows that the error decreases with increasing valve set pressure. This was as expected. Of all OLSPV readings taken when the test medium was air, 96% of results fell within ±10% of the actual lift pressure and 84% fell within ±5% of the actual lift pressure. All results falling outside the ±10% limit were obtained at atmospheric pressure (0% of set pressure) and the majority of results gave marginally conservative estimates of the set pressure.

Figure 6 shows the deviation from the actual lift pressure of OLSPV results obtained whilst testing on air. It is evident that testing at a pressure closer to the valve set pressure seems to render more accurate results. Other results showed the same trend regardless of the test medium. Generally, the accuracy of OLSPV seems also to be unaffected by the test media with 96% of all on-line results, falling within ±10% of the actual lift pressure and 86% falling within ±5%.

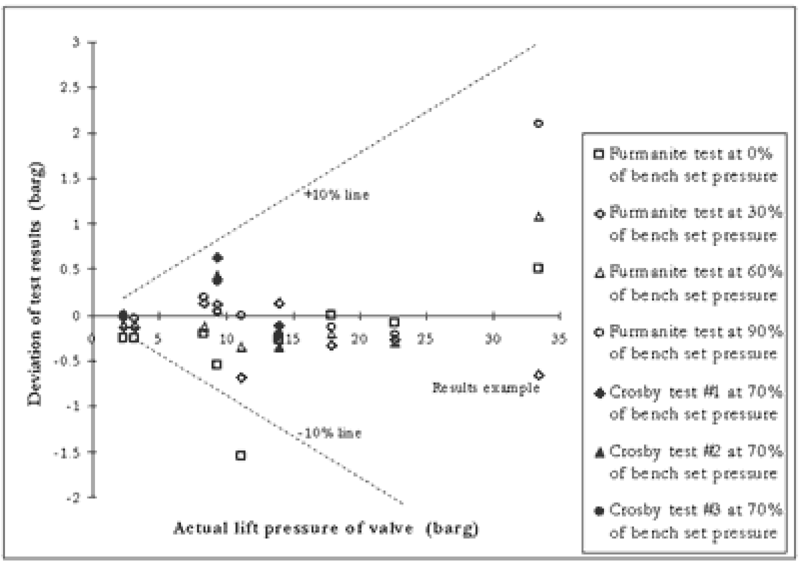


Figure 6 Chart showing the actual deviation of the on-line set point verification results vs. the actual lift point for each valve, where the test medium is air (click image to enlarge).

The results showed a decrease in conservatism with increasing fluid viscosity. The data scatter for the tests on steam being more or less evenly distributed about the pop pressure, whereas the results from the tests using water and oil were generally higher than (but still mostly within 5% of) the pop pressure.

The accuracy of the OLSPV results would be further increased if the effective seat area was derived from a test where pressure and resultant force were known.

Relationship between the accuracy of on-line set point verification and valve orifice size

Figure 7 is typical of the results and indicates an increasing degree of accuracy with increasing valve orifice size. This is consistent with expectation, although it should be noted that only 9 valves were tested in a limited range of orifice sizes from 0.24 to 2.727 square inches.

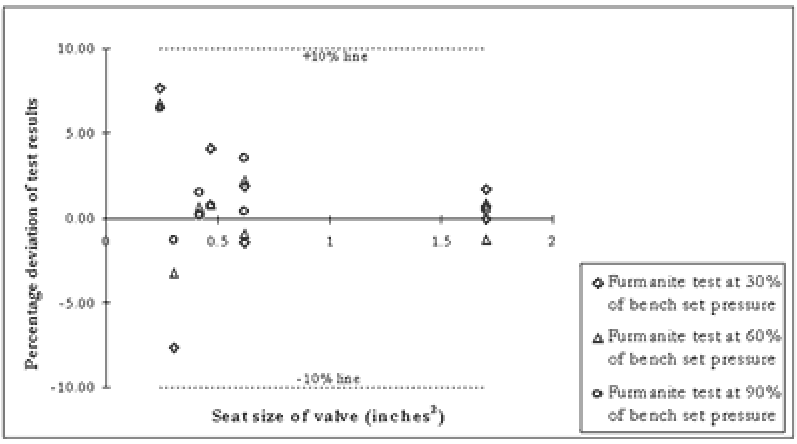


Figure 7 Chart showing the percentage deviation of the on-line set point verification results from the actual lift point vs. the seat size of each valve, tested on water (click image to enlarge).

Effect of pressure balancing bellows on the accuracy of on-line set point verification methods.

Figures 8 and 9 indicate that the effect of the bellows on the accuracy of the on-line set point verification methods is minimal.

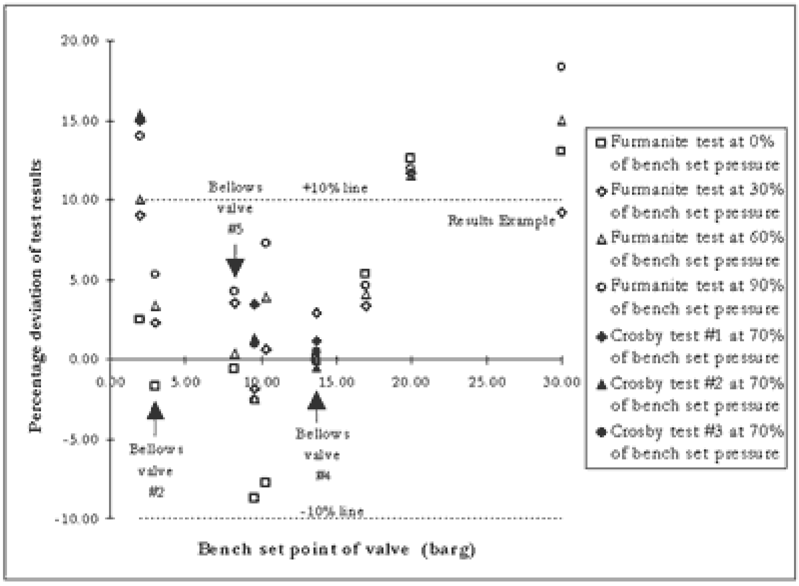


Figure 8 Chart showing the percentage deviation of the on-line set point verification results vs. the bench set point for each valve, where the test medium is air (click image to enlarge).

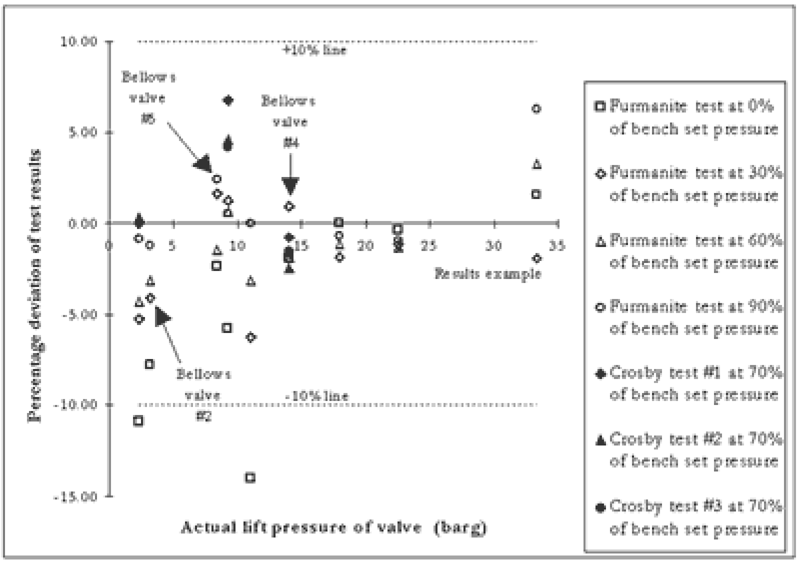


Figure 9 Chart showing the percentage deviation of the on-line set point verification results vs. the actual lift point for each valve, where the test medium is air (click image to enlarge).

The effect of temperature on the accuracy of on-line set point verification methods

Figure 10 shows the results of tests on steam and indicates that the accuracy of the OLSPV technique is unaffected by temperature. The figure shows an even data distribution about the actual lift point of each valve, 89% of results being within ±5% of this value.

Note that it is normal practice to bench set valves operating at elevated temperature to a higher pressure (referred to as the cold set pressure) than the required set point and that this was not done in this case. However, valve manufacturers advise that, for temperatures up to 300° C, the increase would be no more than 1%. If so, this effect will be insignificant compared to the inaccuracies inherent in all the techniques under consideration.

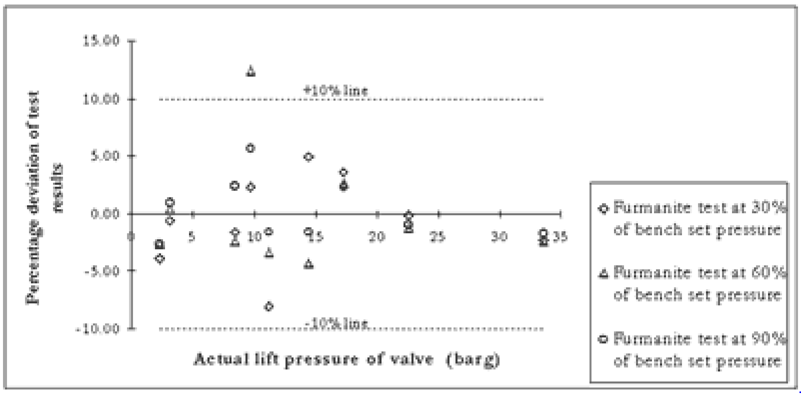


Figure 10 Chart showing the percentage deviation of the on-line set point verification results vs. the actual lift point for each valve, where the test medium is steam.

Conclusions

- Both the OLSPV equipments tested gave a good representation of the actual lift point; 96% of all results were within 10% of the actual lift point and 84% were within 5%. Competing in-situ test systems appear to differ mainly in the way in which data is presented or manipulated and the ease with which the lift point can be determined.
- On average the bench set pressure, which is the recognised standard practice for set point verification, deviated by -7.23% from the actual lift point for each valve tested. Assuming that a +10% discrepancy between desired and actual lift pressure is un-acceptable, 1/3 of the valves tested should have been identified as defaulters but would not have been using current procedures. On this evidence valves set by the bench technique may lift "heavy" when subjected to a plant upset and site inspectors should take this into account.

- Fluid viscosity does not seem to affect the accuracy of on-line set point verification although the results do exhibit a tendency to be less conservative with increasing viscosity. The majority of results fell within ±5% of the actual lift point.
- The accuracy of OLSPV creases with increasing valve orifice size.
- Accuracy does not seem to be affected by testing at reduced pressure.
- Pressure balancing bellows do not appear to affect the accuracy of in-situ set point verification methods.
- Elevated temperature does not appear to affect the accuracy of the on line set point verification methods.
- Differences between the techniques are mainly in the way data is processed and presented and the ease with which the lift point can be identified.
- Consideration should be given to the wider use of in-situ set point verification methods where operating conditions are appropriate. There will always be need to remove valves for inspection from time to time at a frequency which will depend on process conditions and operating history.
- Further work should be undertaken on an operating plant to confirm that the results presented in this report can be reproduced using a different bench test kit and a different inspector.

Question:

Why does the bench setting technique result in valves set higher than the required lift pressure?

This was a clear result of the test work and requires some explanation. The internal report of this work included a recommendation that an operating site should conduct similar tests to confirm the results. At time of writing this has not happened but another company has undertaken testing on site which appears to confirm this finding.
Discussions with the site inspector at BP Amoco Sunbury (an individual with extensive operating site experience) revealed that, in bench setting the valves, the inspector looks for an indication of leakage across the seat and uses this as the indication of set point (valves were tested on air and leakage appeared as bubbles in a beaker of water). Because connecting pipework from the source of pressure is relatively small bore (a feature which is apparently typical of many site installations) attempts to increase the pressure beyond this point simply result in increased leakage.
It will be appreciated that, in a "real" system, the pressure will continue to rise beyond the point at which valve leakage may begin until (depending on the valve design and the fluid) valve lift occurs. This fact is recognised by API 576 which provides a recommendation for a "test bench design" which shows a relief valve directly connected to a 0.13 m3 test drum via a 6" ball valve.
Further site testing (e.g. OLSPV testing of valves which have shown consistently good performance when tested on the bench) should be undertaken.

References

Ref. 1: BP Relief Valve Work Group Report and Proposals
Report No.: ESR.96.ER.059
Issue Date: 8th July 1996

Ref.2: Guidelines For The Use Of The Trevitest Method For Testing Of Safety Relief Valves
Report No.: BPE.91.ER.083
Issue Date: June 1991

Ref.3 API 576 Inspection of Pressure relieving Devices

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