Functional Capability of Valves Subject to Loads Imposed by Piping and by Earthquake Motion

E. Le Guillouzic, S. Cohen
Framatome, Tour Fiat, F-92084 Paris-la-Defense Cedex 16, France

M. Maurin
Electricité de France, SEPTEN, Tour EDF/GDF, F-92080 Paris-la-Defense Cedex 08, France

M. Marsin
C.E.A., CEN Saclay, CENS, F-91191 Gif-sur-Yvette Cedex, France

Abstract
The CEA, EDF and FRAMATOME have jointly constructed a test bench designed to analyze the behaviour of valves subjected to loads simulating those transmitted by piping and earthquake. We present a description of the test bench and an example of its use to monitor valve operation and behaviour under load.

Finite element analysis of the valve gave body deformation results similar to those obtained experimentally. This test bench is currently in use for qualification to ANSI B 1641 requirements of valves subject to this type of load and for investigation of valve behaviour.

1. Introduction
Valve design standards specify the minimum body wall thickness required to resist pressure. Additional dimensioning rules ensure that the valve body and internals will withstand other hydraulic and mechanical loads such as those due to piping or earthquake motion.

Reliability is particularly crucial in nuclear power plants, where valves play a major role in safety. This has led to the implementation of thorough and rigorous qualification testing.

Consequently, CEA, EDF and FRAMATOME have jointly constructed a test bench designed to analyse the behaviour of valves subjected to loads applied to body ends simulating the loads of connected piping and to yoke simulating the inertial effect due to earthquake motion.

This paper describes the test bench designed for the application of such loads, discusses the calculation of maximum body end and seismic loads and gives an example of the use of the bench to test an active 3" valve flexible wedge gate, with details of the testing procedure results and interpretations. The paper also gives a description of the finite element analysis carried out on the valve body; the results are compared with measured values.

2. Test equipment
The ESPOE (EFFORTS STATIQUES OPERABILITE) test bench is designed for performing exercisability tests on PWR plant valves. The bench consists of:
- A rigid stand designed to be assembled in three configurations for small valves (2" to 6"), large valves (6" to 20"), and safety and relief valves. It acts as a bearing surface for the application of tensile, torsional, bending and earthquake loads from the hydraulic cylinders via swivel flange mounting plates 1 and 2 (figure 1).

This makes it possible to apply loads to the valves separately or simultaneously, without
resulting deformation; disturbing the system of applied forces, and without any interaction between the loads applied.

The range of loading values are:
- tensile $+100$ daN up to $30\,000$ daN, Earthquake: $\pm 100$ daN up to $\pm 15\,000$ daN
- torsion $\pm 100$ daN.m up to $\pm 40\,000$ daN.m, bending $\pm 100$ daN up to $40\,000$ daN.m

- A 6-way hydraulic (oil) unit controlling pressurization of the four hydraulic cylinders and 2 auxiliary systems. A control panel is provided to allow line-by-line adjustment of pressure (0 to 200 bar), pressurization time (10 to 300 s) and selection of lines (individual or simultaneous operation).

- A hydraulic (water) unit allowing pressurization (0 to 250 bar) of the whole assembly, or of either the upstream or downstream side. Leak measurement apparatus is fitted.

- A 50-channel measurement unit, which stores on floppy disk the data collected by load, pressure, displacement and deflection angle sensors and strain gauges. These data are then processed by computer to provide a graphic display of variations in the parameters measured and to supply result sheets for each loading applied.

- Analog records show any sudden variation in valve exercising characteristics.

3. Values of applied loads

The valve may be exercised under severe loads:

a) bending and torsional moments are determined taking the standard pipe compatible with the valve rating and assuming that the tresca stress intensity value at all points of the pipe cross-section is 210 MPa. The calculations assume the material's behaviour to be perfectly plastic.
b) tensile load is taken as one-tenth of the product of the pipe cross-section (para. a)) and a stress of 210 MPa.
c) the pressure applied inside the valve body is the design pressure multiplied by the ratio between the Young's moduli for cold and hot conditions, so as to allow for the actual deformation undergone by the valve under hot conditions.
d) the horizontal seismic load is $W_m$, where $m$ is the weight of the yoke and actuator, $g$ is the acceleration due to weight and $k$ is 3.2 for OBE ( Operating Basis Earthquake) and 4 for SSE (Safe Shutdown Earthquake). The valve yoke is assumed to be rigid.
e) the value of cumulated loads is such that when added to pressure, the resulting (Tresca) stress intensity at all points on the pipe cross-section is equal to 210 MPa.

Comments

The minimum value for valve body wall thickness is specified in ANSI B 1634 and is calculated using a method similar to that used to determine the minimum wall thickness for a cylinder subjected to internal pressure. Additional rules to be taken into account allow for the mechanical effects of piping and are given in ASME Section III, Subarticle NB 3500. These rules cover only Class 1 valves having an inlet piping connection larger than 4 in. nominal
pipe size. These rules require that in the crotch region, primary bending stress must be less than 1.5 Sm times the design stress intensity value. This is based on a value Fb,Sm for the bending moment applied at the valve body ends; Sm may be considered as less than 210 Mpa. For the 1974 edition of the ASME code, Fb is the bending modulus of the standard pipe compatible with the valve rating, whereas in the 1983 edition, Fb is the bending modulus of the pipe having a theoretical minimum wall thickness able to withstand the standard design pressure of the valve. The 1983 edition therefore reduces the bending moment considered to be applied to the valve by the surrounding piping.

These maximum loads used for the test are compared with those obtained from elastic calculation of piping systems respecting NB 3600 criteria, they are found to be compatible if Design and Level A service limits are to be satisfied. II Level C and D service limits are to be met, there is a degree of uncertainty since those concern only primary stresses due to mechanical loadings, and the effects of thermal expansion are disregarded. These effects are, however, present and give rise to mechanical loads in the valve body. Random sampling of piping calculation results shows that loads imposed by piping on valves under faulted conditions remain lower than those covered in Para. a) and e) above.

4. Testing a 3" wedge gate valve

4.1. Test description

4.1.1. The photograph in figure 2 shows the connection between the valve and flanges 1 and 2. Two stainless steel sleeves are welded on the one side to the valve and on the other to two carbon steel reducers (dissimilar metal welds), which are in turn welded to the test bench.

4.1.2. The measurement system incorporates 42 discrete recording tracks:
- 7 "loading" tracks, monitoring applied loads and pressure of water,
- 4 "operating" tracks, recording stem force, displacement, contact and motor voltage,
- 31 "behaviour analysis" tracks, monitoring angular displacement, diametral deformation, bolt loads and local deformation via strain gauges mounted on the valve body and yoke. Part of this instrumentation is shown in the photograph figure 2.

Exercisability is also monitored, recording variation with time of stem displacement, loads and motor voltage and stem limit switch contact lines.

4.1.3. The test program after the valve conformance inspection comprises two main stages:
- analysis of valve behaviour under dimensioning loads of valves. The valve is then completely dismantled to allow examination of all internal components and liquid penetrant testing of the hardened surfaces of valve seat and disk.
- the second phase consists of applying the higher loads described in Para.3, then dismantling and inspecting the valve.

Each stage consists of two types of test:
- exercising test, with 6 open/close cycles (4 under load) - at minimum and maximum motor voltage, with the load applied directly at the specified level and leakage measured under load and after removal of load.
- "behaviour analysis" test: progressive loading in 10 stages and optimal open/close cycles
Types of combined loads are given in table n°1.
The measurement system is energized for each test: a sequence of measurements for the
42 tracks is carried out whenever a test parameter is changed (pressure, load, disk movement,
voltage etc.). Measurements are recorded on data sheets and graphic displays are constituted
on the basis of the test sequence.

4.2. Analysis of test results

4.2.1. Valve operation
- 200 open/close cycles were carried out
- disk leak rate remained unaffected by the application of loads, approximately 2 cm³/h,
under the specified value of 8 cm³/h; the pressure differential is 195 bar
- Packing leakage remained zero.
- the disk travel remained complete, 80 mm; strobe time remained stable at approximately
3 seconds, with and without loads.
- post-test inspection shown that the valve was undamaged by the loads applied.

4.2.2. Mechanical behaviour
Valve yoke: surface deformations due to earthquake and valve open/close cycles are the most
significant, corresponding to a stress of 40 to 60 MPa.

Bending in valve body: the maximum bending moment applied (1400 daN.m) gives rise to an
angle of bending of 1.4 mrad, equivalent to a vertical displacement at each body end of
2/10 mm.

Topworks displacement: the seismic load applied (800 daN) gives rise to bending of 3 mrad
in the topworks.

Body deformation: the deviation of the outside diameter from the central point of the valve
body is 50 microns during pressurization, with an additional 30 microns on application of the
positive bending moment. Valve closure may cause a reduction in diameter of up to 50 microns.

Body stress: maximum values occur in C2 and C3 of figure 3. Valve closure gives rise to
tensile stresses: SX = 90 MPa with the notations of figure 3. The maximum elastic bending
moment (870 daN.m gives rise to a significant SX stress (150 MPa)), which is compressive for
a positive moment and tensile for a negative moment.

Bolt loads: the tension of body-to-bonnet bolts is affected very little by bending moment
(0.3 % variation for 100 daN.m) and even less by torsional moment (0.1 % for 100 daN.m).
Internal pressure (195 bar) increases tension by approximately 2.5 to 3 % - valve closure
causes a temporary variation in tension of up to ±1 %. Seismic force (800 daN.) can result
in up to 4 % variation in tension. The very small variation in body-to-bonnet bolt tension
confirms that external loads have very little influence on bonnet deformation and that stem
movement is unaffected.
5. Valve model for calculation

The aim was to develop a simple model of the valve which would allow calculation and analysis of maximum stresses and seat deformation under external loadings.

5.1. Finite element model

Mesh: the mesh was generated using the 2-dimensional axisymmetric option of FRAMATOME's TITUS computer code. The mesh is a 2-dimensional representation of a half-section of the upper valve body along the axis of symmetry. The complete structure is obtained by rotating this half-section around the axis. The model is shown in Figure 4 and is made up of triangles and quadrilaterals. A similar model, including the valve disk was generated for the second calculation described below.

Application of loadings: the same moment (325 daN.m) is applied to both valve body ends. The aim is to calculate forces at individual points on the boundary nodes body ends, using Fourier (cosine) series analysis for the periphery with only the first coefficient. Calculation uses the 2-dimensional harmonic option of the TITUS code. Results can be provided for any cross-section of the structure, though we only deal with those for the reference vertical cross-section (corresponding to the location of strain rosettes on the valve body).

5.2. Calculations

Two calculations are carried out, with the material assured to be elastic.

Calculation n°1: we take the first mesh (without valve disk) and apply a bending moment of 325 daN.m to both valve nozzles. Calculation results for the displacement of seat boundary nodes are used to determine the angular deformation of the valve seat (0.025°). The deformation measured during testing on the ESOP test bench was 0.017°.

Calculation n°2: we take the mesh incorporating the valve disk and apply the same bending moment as above to the nozzles. Table n°1 shows the calculated values for stresses at points on the crotch region fitted with instrumentation, together with the values measured during testing.

5.3. Comparison of calculated and measured results

Analysis of calculation results shows that a simplified model can provide results which give an accurate representation of the mechanical behaviour of the valve body when subjected to loads at body ends. This is particularly true for the most highly-stresses regions of the body (e.g. crotch region—see Table I), overall displacement, and body end and seat rotation.

6. Conclusion

The development of a test bench designed to apply major loads to valve ends and the provision of suitable valve instrumentation shows that piping and seismic loads have no effect on the exercisability or leaktightness of 3" wedge gate valves dimensioned according to standards design rules, the mean primary stress remains low in spite of the high loading values.

Finite element analysis using a relatively simple axisymmetric model also gives results which are largely comparable with those obtained experimentally, despite the complex nature
of valve body geometry.

The development of simple calculation models will allow the introduction of new shapes for valve bodies, while ensuring that the performance characteristics of the new products will be maintained.

Analysis and tests are currently in progress on safety, relief and globe valves of various sizes. The results so far confirm those of the analysis presented in this paper.

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**Figure 1**: Banc ESPE, Support Mecanique.

**Figure 2**: Vanne à colin 3" soudée sur ses brides.

**Figure 4**: Maillage avec opercule.
Tableau 11 - Comparaisons contraintes corps essais/calcul

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Tableau 1
Chargements appliqués dans les essais