

OWNER

# Overpressure Protection System Hydraulic Analysis

Calculation



Document No.:  PRO-CAL-009

Rev. A, Issued for Review

Date: September 29, 2026

Project:



TORUS

,  County,

# ISSUE SUMMARY AND APPROVAL

This page records each issue of PRO-CAL-009. The preparer, reviewer and approver sign for each revision.

| Rev. | Date       | Issue purpose     | Description |
|------|------------|-------------------|-------------|
| A    | 2026-09-29 | Issued for Review | First issue |
|      |            |                   |             |
|      |            |                   |             |

## Contributors

| Rev. | Discipline | Prepared by | Reviewed by | Approved by |
|------|------------|-------------|-------------|-------------|
| A    | Process    |             |             |             |
|      |            |             |             |             |

# CONTENTS

|    |                                                            |   |
|----|------------------------------------------------------------|---|
| 1. | OBJECTIVE.....                                             | 1 |
| 2. | METHODOLOGY .....                                          | 1 |
| 3. | DESIGN INPUTS.....                                         | 1 |
| 4. | ASSUMPTIONS.....                                           | 2 |
| 5. | REFERENCES .....                                           | 2 |
| 6. | CALCULATION.....                                           | 3 |
|    | 6.1. ACCUMULATION LIMIT .....                              | 3 |
|    | 6.2. FLOW AND PACKING RATE .....                           | 3 |
|    | 6.3. TRIP SETTING AND STROKE TIME .....                    | 4 |
|    | 6.4. DESIGN CASE TRANSIENT .....                           | 5 |
|    | 6.5. SENSITIVITY TO TRUNK LENGTH AND SOURCE PRESSURE ..... | 6 |
| 7. | RESULTS AND CONCLUSIONS .....                              | 6 |

# FIGURES AND TABLES

|                                                                                                     |   |
|-----------------------------------------------------------------------------------------------------|---|
| Figure 6-1. Trunk Pressure After Control Valve Failure .....                                        | 5 |
| Table 3-1: Design Inputs.....                                                                       | 1 |
| Table 6-1: Peak Trunk Pressure by Trip Setting and SDV-102 Stroke (psig, margin to 1,290 psig)..... | 4 |
| Table 6-2: OPSS Transient, Trip 1,225 psig, 4 s Stroke, Two FCVs Open.....                          | 5 |

Table 6-3: Sensitivity to the Packed Trunk Length (source 1,440 psig, 4 s stroke).....6

Table 6-4: Sensitivity to the Upstream Source Pressure (1 mile of trunk, trip 1,225 psig, 4 s stroke).....6

## 1. OBJECTIVE

This calculation shows how the overpressure protection system (OPSS) keeps the receiving pipeline operator's trunkline within the 49 CFR 192.201 accumulation limit if both station flow control valves fail wide open. It determines the flow into the outlet piping and a stated length of trunk, the rate of pressure rise, the process safety time, the peak pressure for combinations of trip setting and SDV-102 stroke time, and the recommended trip setting and stroke.

## 2. METHODOLOGY

The OPSS closes SDV-102 when two of the three transmitters PT-133A/B/C reach the trip setting. Between the control valve failure and full closure of SDV-102, gas enters the outlet piping and the trunk faster than it can leave, and the pressure rises.

At each instant TORUS solved the flow through the station from the upstream source, through the station pressure losses upstream of the control valves, through FCV-131 and FCV-132 wide open, and through the losses downstream to the trunk. The control valve flow follows the ISA-75.01.01 compressible flow equation with the valves' wide-open  $C_v$ , piping geometry factor and pressure drop ratio. The expansion factor uses the isentropic exponent  $\kappa = \rho c^2/p$ . The station losses are scaled from the station hydraulic model in PRO-CAL-002 as  $\Delta P = R W^2/\rho$ , with the density evaluated at the actual mean pressure of each part of the station. The upstream gas is taken at 45 °F, the densest credible state (winter, heater bypassed), because the densest gas gives the highest flow.

The flow in excess of zero outflow packs the downstream volume: the outlet piping and a stated length of trunk, taken as blocked in. The pressure rises at  $dP/dt = W/C$ , where the capacitance  $C = V/c^2$  is the isentropic value at 60 °F. The isentropic capacitance gives a faster rise than the isothermal one, so it is conservative. The flow continues at its instantaneous value through the detection time and the full SDV-102 stroke, then stops. This ignores the throttling of the ball as it closes and is also conservative.

The accumulation limit is the lower of the trunk MAOP plus 10 % and the pressure that produces a hoop stress of 75 % of the specified minimum yield strength (SMYS), per 49 CFR 192.201(a)(2)(i).

## 3. DESIGN INPUTS

The inputs in Table 3-1 govern the calculation.

Table 3-1: Design Inputs

| Input     | Value                                              | Source    |
|-----------|----------------------------------------------------|-----------|
| Trunkline | NPS 24, 0.344 in wall, API 5L X60, MAOP 1,200 psig | HOLD H-04 |

| Input                                                 | Value                                                                                     | Source                                                           |
|-------------------------------------------------------|-------------------------------------------------------------------------------------------|------------------------------------------------------------------|
| Upstream source pressure in the overpressure scenario | 1,440 psig at IJ-101, held constant                                                       | Upstream lateral MAOP taken equal to the station MAOP, HOLD H-16 |
| Upstream gas temperature                              | 45 °F                                                                                     | Operating case C6, GEN-DB-001                                    |
| Initial trunk pressure                                | 1,150 psig                                                                                | Outlet pressure override (PIC-134) normal limit                  |
| Outlet pressure override setting                      | 1,150 psig normal, 1,180 psig maximum                                                     | GEN-DB-001                                                       |
| FCV-131 and FCV-132                                   | Wide-open $C_v$ 550 each, $F_p = 0.981$ , $x_{TP} = 0.740$                                | PRO-CAL-006                                                      |
| Packed volume on the station side                     | 190 ft <sup>3</sup> (control valve outlet header, line 1033, lines 1040 to 1042)          | PRO-CAL-008                                                      |
| Trunk segment packed                                  | 1 mile blocked in at both ends (2.96 ft <sup>2</sup> per ft); 0 to 5 miles as sensitivity | HOLD H-04                                                        |
| Detection time                                        | 1.0 s (transmitter response plus safety PLC scan and output)                              | Instrument and control design                                    |
| Transmitter uncertainty                               | ±0.25 % of a 0 to 1,500 psig span, about 4 psi                                            | Typical, HOLD H-15                                               |

## 4. ASSUMPTIONS

1. The upstream source holds 1,440 psig at IJ-101 regardless of flow. The upstream lateral friction and the compressor capacity would reduce the flow, so this is conservative. *Verification required (HOLD H-16).*
2. A 1 mile segment of trunk is blocked in at both ends and takes no gas away. *Verification required (HOLD H-04): the trunk valve spacing, its normal flow, and whether it can be blocked in at the tap.*
3. The packed segment rises in pressure uniformly. The pressure wave crosses 1 mile in about 4 s, so local peaks near the tap may be slightly higher.
4. Flow is unrestricted until SDV-102 is fully closed.
5. The outlet pressure override may overshoot its setting by about 20 psi during a trunk transient. *Verification required during commissioning.*

## 5. REFERENCES

1. 49 CFR 192.195, Protection against accidental overpressuring.
2. 49 CFR 192.199, Requirements for design of pressure relief and limiting devices.

3. 49 CFR 192.201, Required capacity of pressure relieving and limiting stations.
4. IEC 61511 / ISA 84.00.01, Functional Safety: Safety Instrumented Systems for the Process Industry Sector.
5. ANSI/ISA-75.01.01 (IEC 60534-2-1), Flow Equations for Sizing Control Valves.
6. GEN-DB-001, Basis of Design.
7. PRO-CAL-002, Line Sizing and Station Hydraulics; PRO-CAL-006, Control Valve Sizing; PRO-CAL-008, Blowdown and Vent System.

## 6. CALCULATION

### 6.1. ACCUMULATION LIMIT

At MAOP the assumed trunk operates at a hoop stress of 69.8 % of SMYS. The pressure that produces 75 % of SMYS is:

49 CFR 192.201(a)(2)(i)

$$P_{75} = \frac{0.75 \times 2 S t}{D} = \frac{0.75 \times 2(60,000)(0.344)}{24} = 1,290 \text{ psig}$$

This is lower than the MAOP plus 10 %, 1,320 psig, so it governs.

The accumulation limit for the trunk is 1,290 psig.

### 6.2. FLOW AND PACKING RATE

With both control valves wide open, the source at 1,440 psig and the trunk at 1,225 psig, the station losses leave 1,304 psig at the control valve inlet and 1,249 psig at their outlet. At the inlet state, 45 °F,  $\kappa = 1.493$ , so  $F_k = 1.067$ . The flow that satisfies the valve equation and the station losses together is:

ISA-75.01.01, compressible flow

$$W = 63.3 F_p (2C_v) Y \sqrt{x P_1 \rho_1} = 1,210,000 \text{ lb/h (595 MMSCFD)}$$

This is 5.0 times the station's 120 MMSCFD design flow. At 1,225 psig and 60 °F the speed of sound is 1,261 ft/s, so the capacitance of the packed volume and the rate of rise are:

Isentropic packing

$$V = 190 + 2.964 \times 5,280 = 15,800 \text{ ft}^3, \quad C = \frac{V g_c 144}{c^2} = 46.1 \text{ lb/psi}$$

$$\frac{dP}{dt} = \frac{W}{C} = \frac{336.7}{46.1} = 7.30 \text{ psi/s}$$

The process safety time is the time from the trip to the accumulation limit:

$$t_{PS} = \frac{P_{limit} - P_{trip}}{dP/dt} = \frac{1,290 - 1,225}{7.30} = 8.9 \text{ s}$$

With the 1,250 psig trip setting of the Basis of Design the rate at the trip is 6.92 psi/s and the process safety time is only 5.78 s. The OPSS response with a 5 s stroke is 6.0 s, which exceeds it: with 1,250 psig the maximum allowable stroke is 4.78 s.

### 6.3. TRIP SETTING AND STROKE TIME

Table 6-1 gives the peak pressure for three trip settings and three SDV-102 stroke times, with the margin below the 1,290 psig limit in brackets, and the margin of each trip setting above the maximum outlet pressure override setting of 1,180 psig.

**Table 6-1: Peak Trunk Pressure by Trip Setting and SDV-102 Stroke (psig, margin to 1,290 psig)**

| Trip setting, psig | Margin above 1,180 psig override, psi | 5 s stroke  | 4 s stroke  | 3 s stroke  |
|--------------------|---------------------------------------|-------------|-------------|-------------|
| 1,250              | 70                                    | 1,290 (+0)  | 1,283 (+7)  | 1,277 (+13) |
| 1,225              | 45                                    | 1,267 (+23) | 1,260 (+30) | 1,254 (+36) |
| 1,210              | 30                                    | 1,253 (+37) | 1,246 (+44) | 1,239 (+51) |

The trip setting must sit far enough above the override to avoid spurious trips: the transmitter uncertainty of about 4 psi plus an override overshoot of about 20 psi during a trunk transient, 24 psi in total. Three options were considered:

1. Keep 1,250 psig. With a 5 s stroke the peak reaches the limit. A 4 s stroke leaves 7 psi and a 3 s stroke 13 psi. A 3 s closure of an NPS 12 ball valve raises surge in the station piping, and margins this small leave nothing for the uncertainty in the trunk data. Rejected.
2. Lower the trip to 1,210 psig. The peak is well below the limit at every stroke, but the trip sits only 30 psi above the maximum override setting, 6 psi more than the 24 psi needed, so spurious trips would be likely. Rejected.
3. Lower the trip to 1,225 psig. With a 5 s stroke the peak is 1,267 psig, 23 psi below the limit. The trip is 45 psi above the maximum override setting and 75 psi above the normal one, which covers the 24 psi allowance with margin. Selected.

The design combines the 1,225 psig trip with an SDV-102 full stroke of 4 s or less, which holds the peak to 1,260 psig, 30 psi below the limit. The shorter stroke was chosen over the 5 s allowed at 1,225 psig (1,267 psig peak) because it adds margin for the uncertainty in the trunk data at small cost: an electro-hydraulic spring-return actuator on an NPS 12 ball valve closes in 4 s, and the actuator vendor shall confirm closure without valve slam (HOLD H-15).

**The OPSS trips at 1,225 psig and SDV-102 closes fully in 4 s or less. The process safety time is 8.9 s against a 5.0 s OPSS response, and the peak trunk pressure is 1,260 psig.**

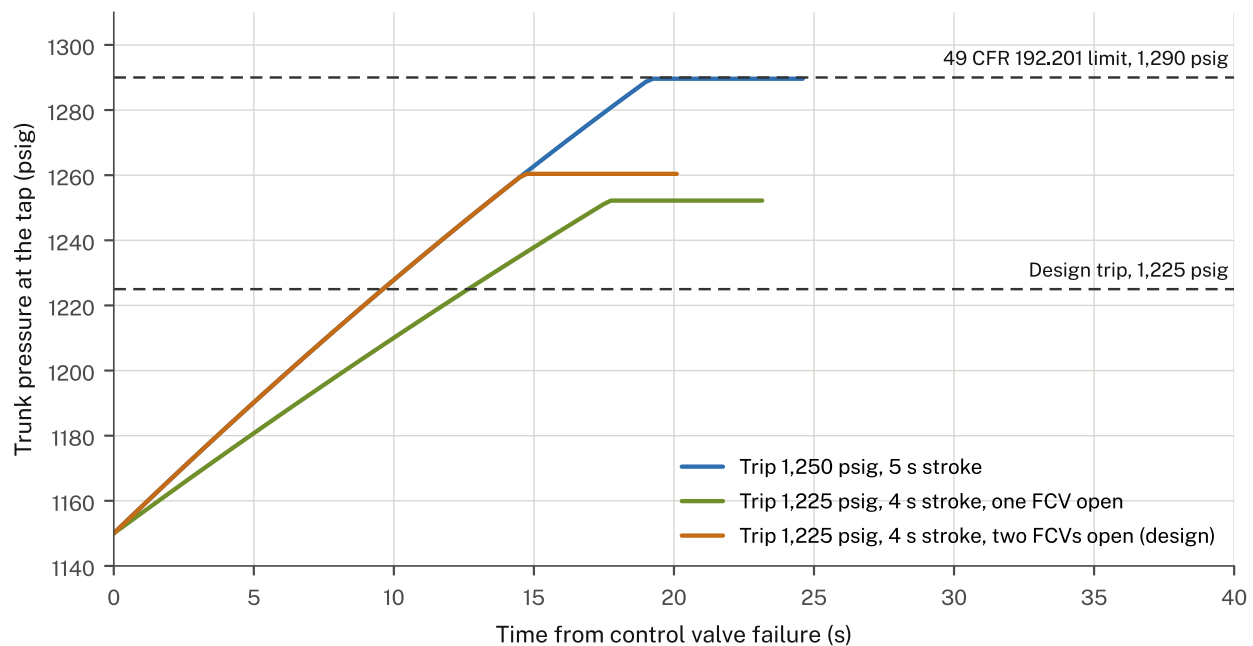
## 6.4. DESIGN CASE TRANSIENT

Table 6-2 traces the design case, and Figure 6-1 compares it with the 1,250 psig trip and with one control valve failed open.

**Table 6-2: OPSS Transient, Trip 1,225 psig, 4 s Stroke, Two FCVs Open**

| Time, s | Trunk pressure, psig | Flow, lb/h |
|---------|----------------------|------------|
| 0       | 1,150.0              | 1,380,000  |
| 5       | 1,190.2              | 1,300,000  |
| 9       | 1,220.5              | 1,220,000  |
| 10      | 1,227.8              | 1,200,000  |
| 11      | 1,235.0              | 1,190,000  |
| 12      | 1,242.1              | 1,170,000  |
| 13      | 1,249.1              | 1,150,000  |
| 14      | 1,256.0              | 1,130,000  |
| 15      | 1,260.4              | 0          |

**Figure 6-1. Trunk Pressure After Control Valve Failure**



If the flow is reduced linearly as the ball closes, which is closer to how a ball valve behaves, the peak is 1,247 psig. With one control valve failed open the peak is 1,252 psig. With the 1,250 psig trip and a 10 s stroke, the original basis, the peak would be 1,319 psig.

## 6.5. SENSITIVITY TO TRUNK LENGTH AND SOURCE PRESSURE

The result depends on how much trunk is packed. Table 6-3 shows the peak for trunk segments from zero to 5 miles. With the design trip and stroke the peak stays below the limit for 0.52 mile of packed trunk or more.

**Table 6-3: Sensitivity to the Packed Trunk Length (source 1,440 psig, 4 s stroke)**

| Trunk, mi | Packed volume, ft <sup>3</sup> | dP/dt at 1,225 psig, psi/s | Peak, trip 1,225, psig | Peak, trip 1,250, psig | Maximum stroke at 1,225, s | Peak, one FCV, trip 1,225, psig |
|-----------|--------------------------------|----------------------------|------------------------|------------------------|----------------------------|---------------------------------|
| 0.00      | 190                            | 616.81                     | 1,440                  | 1,440                  | 0.0                        | 1,440                           |
| 0.25      | 4,100                          | 28.24                      | 1,345                  | 1,362                  | 1.3                        | 1,321                           |
| 0.50      | 8,020                          | 14.43                      | 1,292                  | 1,313                  | 3.5                        | 1,277                           |
| 1.00      | 15,800                         | 7.30                       | 1,260                  | 1,283                  | 7.9                        | 1,252                           |
| 2.00      | 31,500                         | 3.67                       | 1,243                  | 1,267                  | 16.7                       | 1,239                           |
| 5.00      | 78,400                         | 1.47                       | 1,232                  | 1,257                  | 43.1                       | 1,231                           |

Table 6-4 shows the effect of the upstream source pressure. With the upstream supply at its normal maximum of 1,150 psig the trunk cannot exceed 1,150 psig even with both valves open. The OPSS is challenged only if the upstream source can exceed the trip setting.

**Table 6-4: Sensitivity to the Upstream Source Pressure (1 mile of trunk, trip 1,225 psig, 4 s stroke)**

| Source, psig | Flow at trip, lb/h | dP/dt, psi/s | Time to trip, s | Peak, psig |
|--------------|--------------------|--------------|-----------------|------------|
| 1,225        | Not challenged     | -            | -               | 1,225      |
| 1,300        | 693,000            | 4.17         | 15              | 1,245      |
| 1,350        | 906,000            | 5.45         | 12              | 1,251      |
| 1,440        | 1,210,000          | 7.30         | 10              | 1,260      |

## 7. RESULTS AND CONCLUSIONS

TORUS draws the following conclusions:

1. The 49 CFR 192.201 accumulation limit for the assumed trunk is 1,290 psig, set by 75 % of SMYS rather than MAOP plus 10 %.
2. With both control valves failed open, a 1,440 psig source at 45 °F and 1 mile of blocked-in trunk, the flow is 1,210,000 lb/h and the pressure rises at 7.30 psi/s.
3. With the 1,250 psig trip the process safety time is 5.8 s, shorter than the 6.0 s response of the OPSS with a 5 s stroke. The 1,250 psig setting is not adequate.

4. The design OPSS trip is 1,225 psig, and SDV-102 shall close fully in 4 s or less. The process safety time is then 8.9 s, the response 5.0 s, and the peak 1,260 psig, 30 psi below the limit. The trip remains 45 psi above the maximum outlet pressure override setting.
5. The trip change affects the OPSS safety instrumented function setpoint, its LOPA and SIL verification, the cause and effect matrix and the alarm and trip list in Volume 7, and references in Volumes 8 and 9.
6. If the Owner confirms that the upstream compression and lateral cannot exceed the trip setting at IJ-101, a control valve failure cannot challenge the OPSS.
7. The OPSS relies on closure, not on relief to atmosphere. Check valve CKV-171 does not protect against overpressure.

The following items remain open: the trunk data, valve spacing and flow (HOLD H-04), and the upstream lateral MAOP (HOLD H-16).