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Condition monitoring and failure analysis of liquefied natural gas plant flow control valve stem packing system

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Abstract

Maintenance of safety critical equipment is vital for preserving system function of Liquefied Natural Gas (LNG) plant. A common approach to improving the reliability of complex equipment, is through adequate condition monitoring, and preventive replacement of critical components within the system. Therefore, a well thought out maintenance program that optimise the costs and maximise equipment availability should be in place. This paper investigates multiple stem packing failures on Flow control Valve (FV) in (LNG) plant. Root cause analysis (RCA) approach is used to analyse historical failure and maintenance data. Vibration in the valve stem has been identified as the likely cause of the valve packing damage that has resulted in several leaks. An increased flow rates, causes the valve stem to vibrate vertically relative to the valve body, yoke through the packing. The (FV) study presented in this paper are experiencing packing leaks and trash build-up in the packing area. To protect the stem against trash build-up and provide a level of safety against vibration, the packing configuration was re-designed, and wiper rings are added to the top and bottom of the area to prevent against trash buildup. A stem guides with tight tolerances are also added for lateral stem support, v-ring packing-multi-contact paking designed with eight point of contact with the stem compared to three in the current design. The modification provide a robust arrangement for vibration resistance, and reduce the flow excitation of the valve stem that result in premature packing wearing and subsequent leaks. Condition monitoring graphs of the valve vibrations and pulsation is presented to give an insight of the defect patterns to support decision on maintenance.

Keywords: maintenance; reliability; condition monitoring, failure; vibration; leaks; root cause analyses.

1. Introduction

Forces cause stress in the part when a load contacts the part. The smaller the contact area the greater the induced material stresses. Parts ‘age’ as they are used. Loads stress the physical structure and it breaks under high loads. Defective items fail early and the failure rate decreases over time as they fall out of the population, this portion of the curve is known as “infant mortality.” the strongest part take more stress before they too fail.“Constant likelihood of failure” items are failing from random events, cannot predict when a particular part will fail so its vital to use condition monitoring to check for failure mechanism. “wear out” parts are more likely to fail as time goes on, change parts as part of a Preventive Maintenance (PM) on a time,usage basis is useful. When the load is too great the part fails from ‘overload’, when the material weakens and degrades it fails from ‘fatigue’. Figure 1 show the degradation as a curve of material strength from most strong to least strong[1].

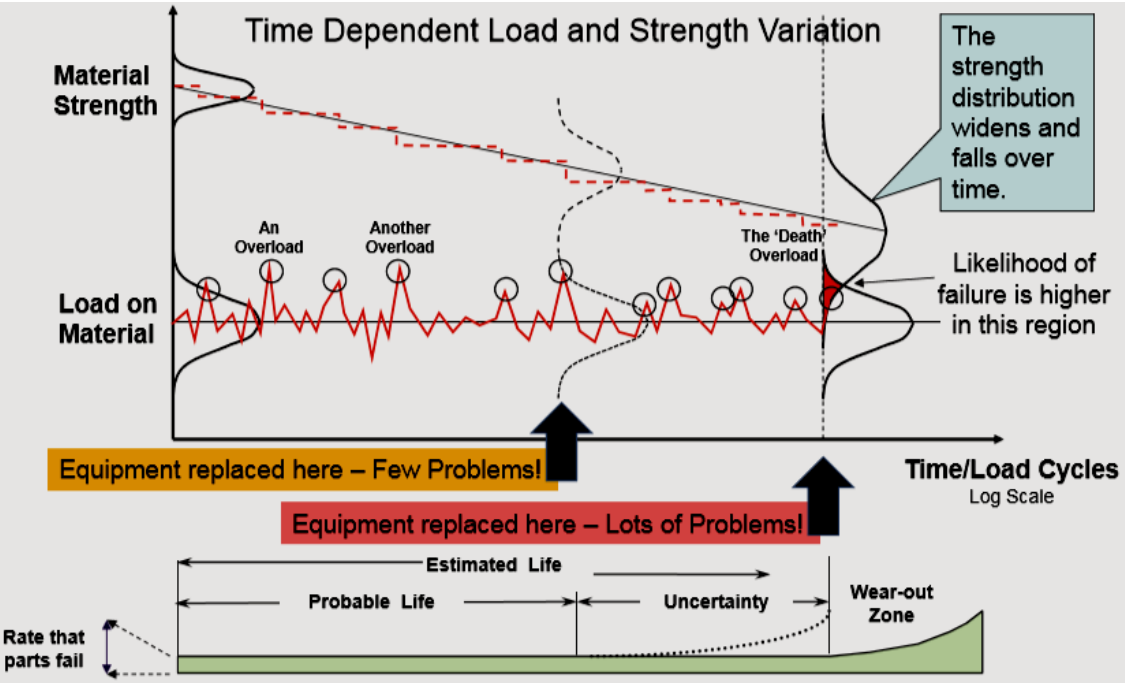


Figure 1 Cause of aging failure

2. Flow control valve system description

Flow control valve is installed in the feed gas piping leading into the (LNG) plant to control gas flow from offshore blocks, through a series of valves and a gas heater prior to tying into the feed gas header. (FV) in (LNG) plant has experienced multiple stem packing leaks and failures[2]. The failures have recently occurred while operating at higher flow rates from offshore blocks Alfa, Bravo and Charlier. Increased vibration was observed which is believed to be a contributing factor to the premature packing failures. Based upon past flow rates from block Alfa, Bravo and Charlier, as well as vibration guidelines provided by the Original Equipment Manufacturer (OEM), the plant has been oprating at reduced flow rates which is limiting production in the (LNG) plant. Table 1 and 2 provide additional details of the valve and design process conditions. Figure 1 show the valve structural framework.

Table 1 Valve specifications

Body Configuration and Size	Flanged 12″ × 12″ Globe with a Bolted Bonnet
Plug Size	8″ Balanced Plug
Trim	Drag, Multi-Path, 2-Stage
Valve Characteristics	Modified Linear
Packing	Teflon/Peek
Actuator Type	Pneumatic Piston
Installed Orientation	Flow –to-Close

Table 2 Design process conditions

Condition	**Minimum Flow**	**Normal Flow**	**Maximum Flow**
Gas Volume Flow Rate (Nm^3/hr)	20,000	802,235	802,235
Flow Rate (MMSCFH)	0.75	30.0	30.0
Inlet Pressure (BarG)	103.36	102.71	102.62
Outlet Pressure (BarG)	82.56	83.72	83.19
Differential (Bar)	20.8	18.99	19.43
Inlet Temperature (Deg C)	-9.3	14.2	25.0

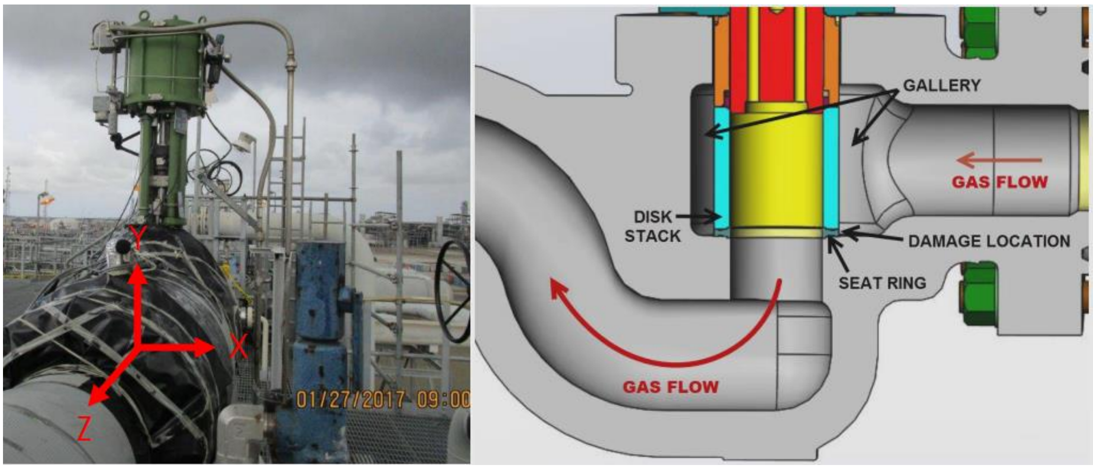


Figure 1 Flow control valve structural framework

Failure history

The stem packing failures described occurred primary on the backside (downstream end) of the stem. Figure 2a,b show stem wear patterns and spring failures. In an attempt to reduce the vibration and relative moviment of the actuator and valve body a brace back was installed as show in figure 3. The brace have reduced the relative moviment but it did not eliminate the stem packing failure. In addition (OEM) had concerns that the brace may distort and misalign the valve stem[3].

Figure 2 (a) Failed stem packing o the left and new stem packing on the right

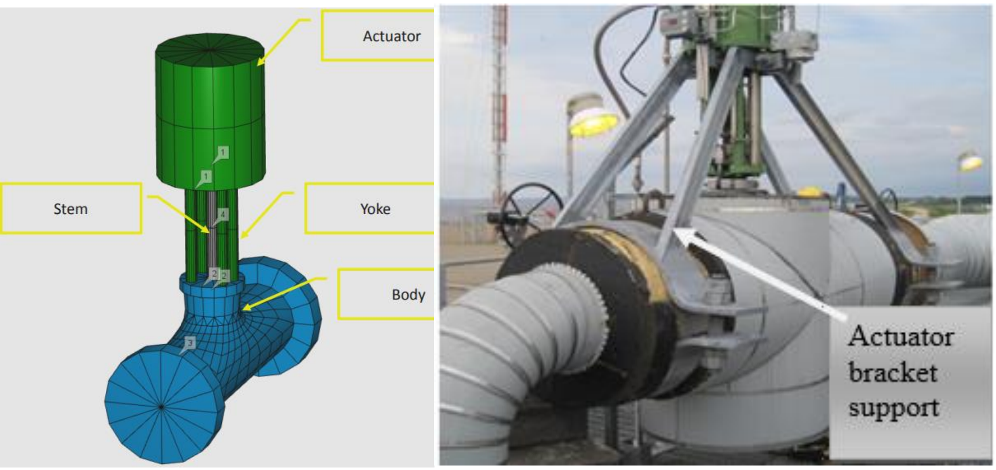


Figure 2 (b) Show an actuator bracket support installed due to the levels of vibration within the system, and the cantilevered mass of the top works.

Vibration data

Vibration data were acquired usisng magnetically mounted tri-axial accelerometers. This piezoelectric devices produces a voltage output proportional to acceleration.This acceleration signals were digitally integrated to obtain vibration in velocity and or displacement units. Figure 3 show vibration test points. Vibration data were acquired at the following locationns:

- Top of valve yoke
- Bottom of valve yoke
- Valve body
- Valve stem.

Several terms were used to describe the direction of vibration:

- Horizontal (X) refers to vibration penpendicular to the flow through the valve (North-South)
- Axial (Z) refers to vibration parallel to flow through the valve (East-West).
- Vertical (Y) refers to vibration in the up-down direction. The directions of vibration are noted in figure 4

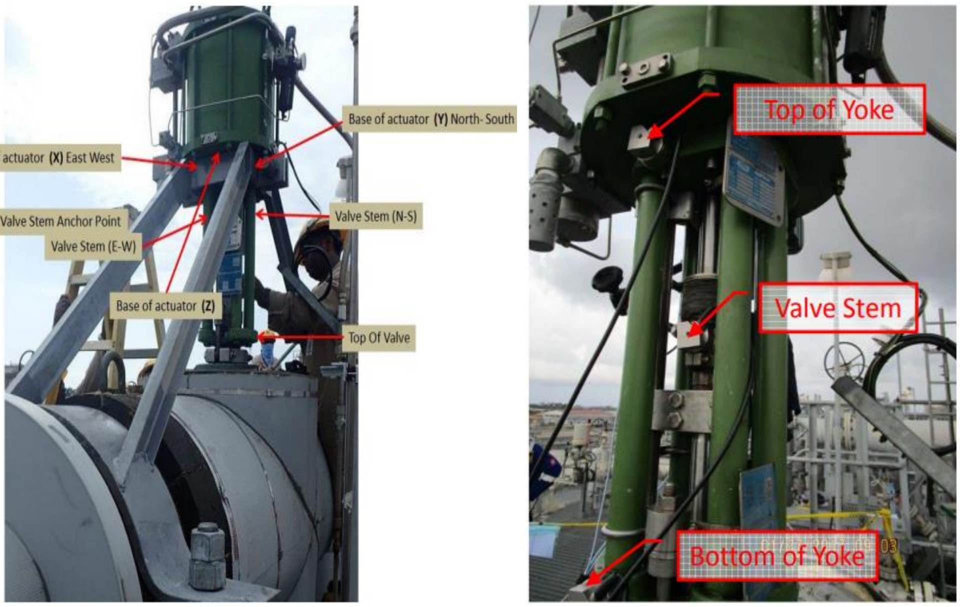


Figure 3 Vibration test points

Pressure

Pressure pulsation was acquired usisng dynamic pressure transducers. These piezoelectric transducers only measure the dynamic component of pressur, not the average mean) pressure. The static pressure (mean pressure) was acquired usisng static pressure transducers. These pressure transducers are capable of measuring the static (mean) component as well as the dynamic component (pulsation) up to ~ 500 Hz. Pressure data were acquired in the following location:

- Piping approximately 22,884 mm (75 feet) upstream of (FV)
- Piping approximately 7,620 mm (25 feet) downstream of (FV)

Low level pulsations due to the vortices can be amplified when the stroughal frequency is coincident with the acoustical natural frequency of a stub. These stubs are referred to as quarter wave stubs and the acoustical natural frequency of the quarter wave stubs can be computed usisng the following equation (1)

$$F = \frac{c}{(4L)}$$

$$\begin{aligned} where\ F &= acoustic\ natural\ frequency, Hz \\ c &= speed\ of\ sound\ of\ the\ gas, \frac{ft}{sec} \\ L &= length\ of\ stub\ between\ the\ header\ and\ pressure\ transducer, ft \end{aligned}$$

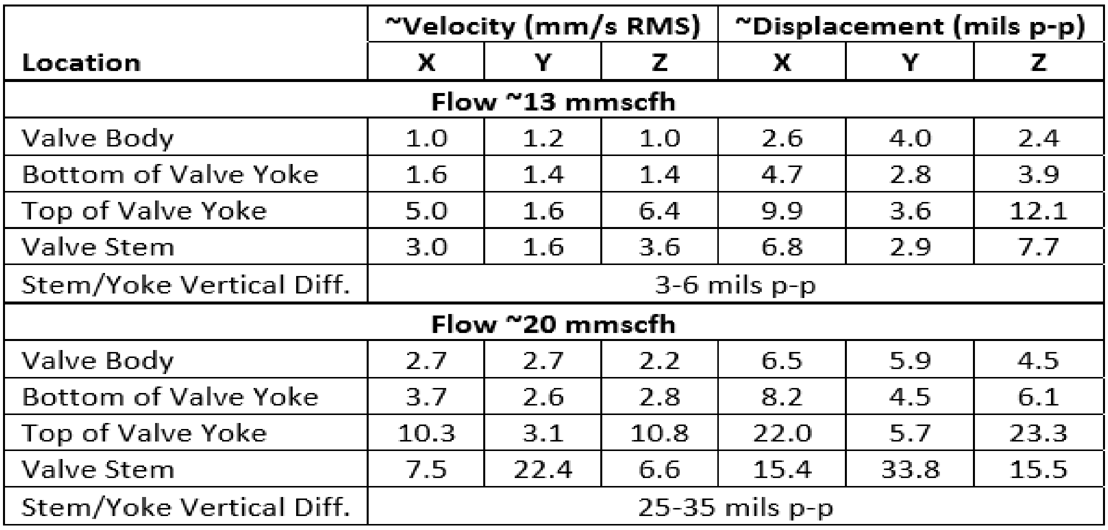
The speed of sound value was computed to be approximately 1,200 ft/sec for the gas. Using this speed of sound value and stub lenghts of 4.5 feet and 6 feet for the upstream and downstream drain tap, the acoustical natural frequency was computed to be approximately 67 Hz and 50Hz for the upstream and downstream pressure tap drains, respectively.

Flow variation testing

The flow through (FV) was increased from 13 Million Standard Cubic Feet per Hour (mmscfh) to 20 (mmscfh) while the inlet/outlet temperatures and pressure were held relatively constant. The following observations were made:

- The overal vibration amplitudes measured on (FV) increased as the flow through the valve increased as shown in the trend plots in figure below.
- A summary of the vibration amplitudes measured at 13 and 20 mmscfh are shown in table 3.

Table 3 Flow control valve overall vibration levels



Location	**~Velocity (mm/s RMS)**			**~Displacement (mils p-p)**		
	X	**Y**	**Z**	**X**	**Y**	**Z**
Flow ~13 mmscfh						
Valve Body	1.0	1.2	1.0	2.6	4.0	2.4
Bottom of Valve Yoke	1.6	1.4	1.4	4.7	2.8	3.9
Top of Valve Yoke	5.0	1.6	6.4	9.9	3.6	12.1
Valve Stem	3.0	1.6	3.6	6.8	2.9	7.7
Stem/Yoke Vertical Diff.	3-6 mils p-p					
Flow ~20 mmscfh						
Valve Body	2.7	2.7	2.2	6.5	5.9	4.5
Bottom of Valve Yoke	3.7	2.6	2.8	8.2	4.5	6.1
Top of Valve Yoke	10.3	3.1	10.8	22.0	5.7	23.3
Valve Stem	7.5	22.4	6.6	15.4	33.8	15.5
Stem/Yoke Vertical Diff.	25-35 mils p-p					

As displayed in the trend plots (figures 4 and 5) and complex wave plots (Figure 6 and 7), the vibration was sporadic in nature (not steady-state) which is a typical characteristic of flow induced turbulalce. The amplitude modulation tended to increase as the flow increased. The vibration response on (FV) was broad-based banded below 50 Hz with several peaks of 5 – 8 mils peak-peak as shown in figure 8. As the flow rate through the valve was increased, an excessive amount of valve stem vertical oscillation occurred relative to the valve body, yoke. The amount of differential vibration is not linearly proportional to the increase in flow. As shown in the table 3. 3 to 6 mils peak-peak of differential motion of the valve stem occurred at the flow rate of 13 (mmscfh).

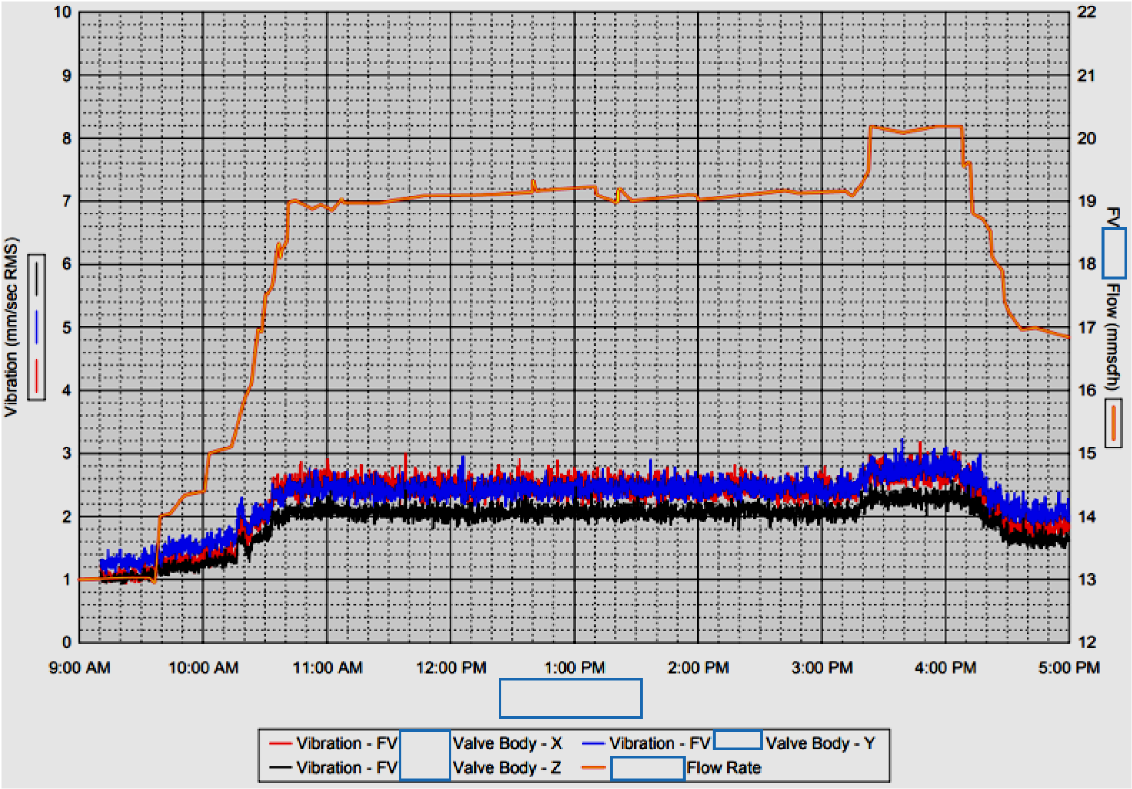


Figure 4 valve body vibration

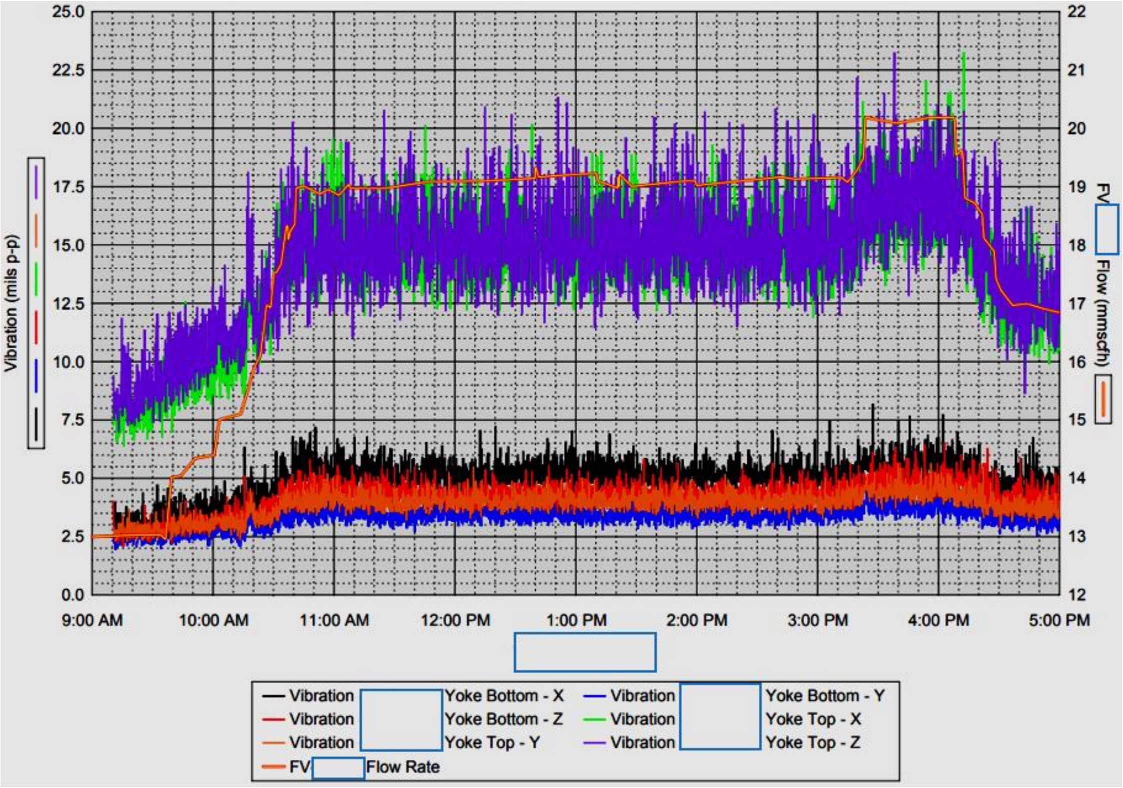


Figure 5 Valve yoke vibration

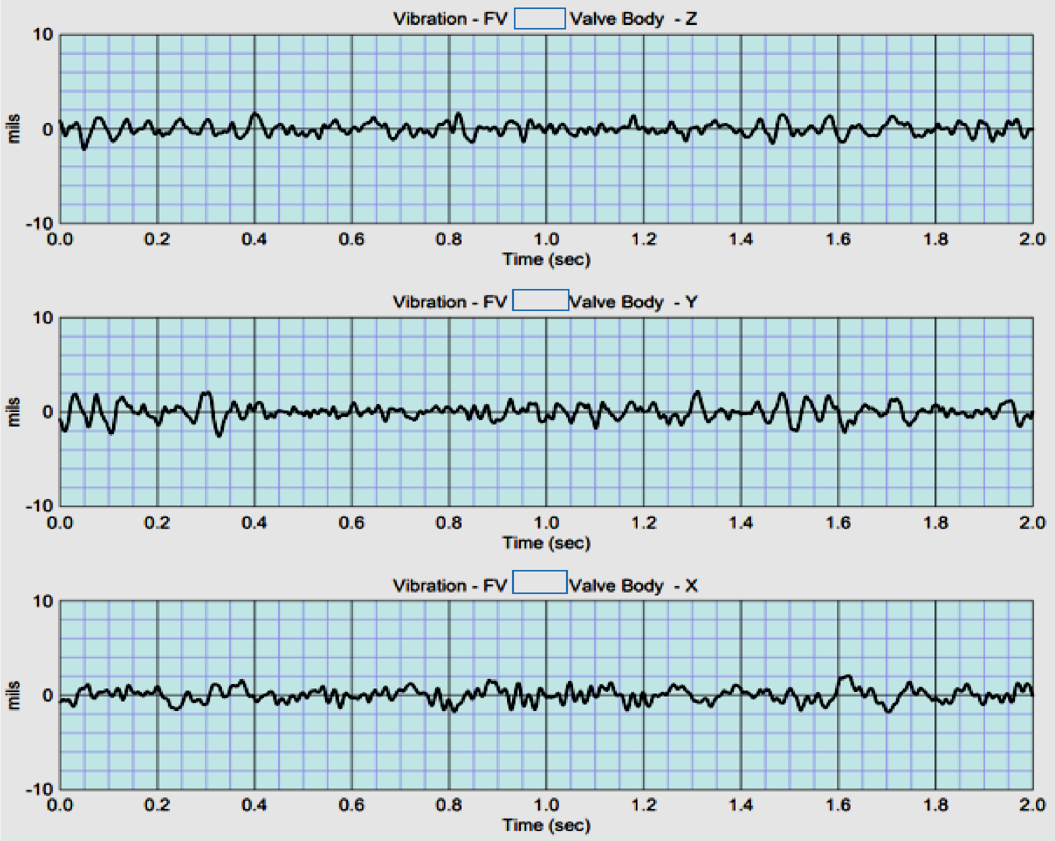


Figure 6 Valve body vibration measured at flow of 20 mmscfh

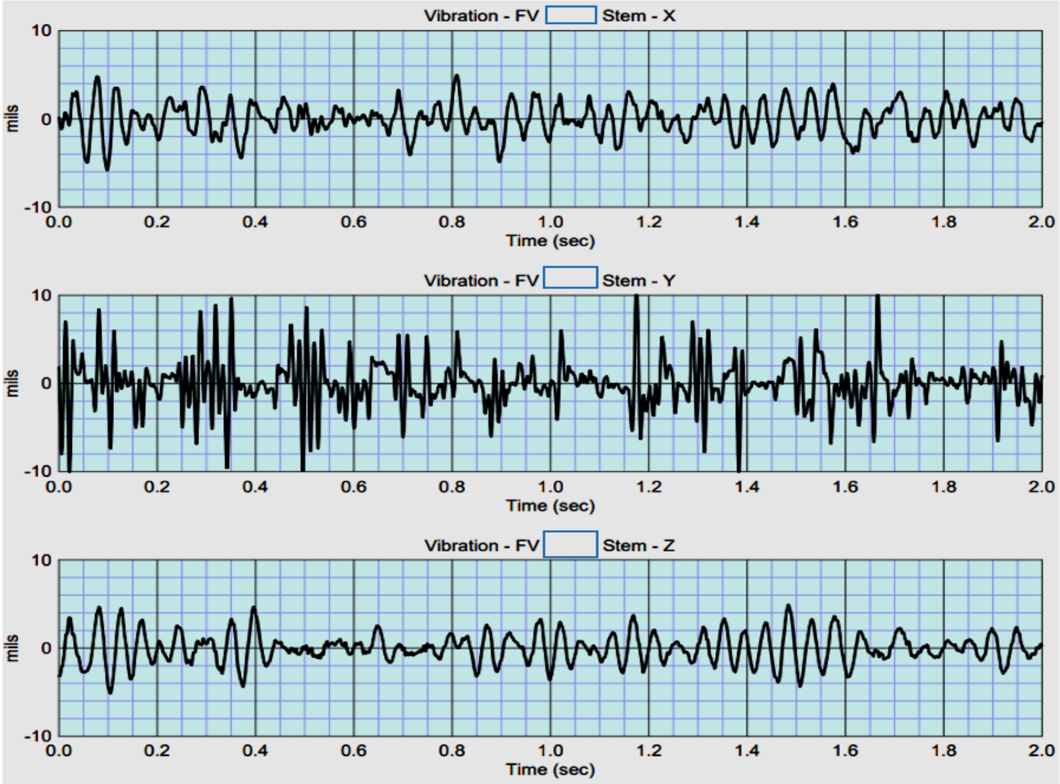


Figure 7 Valve stem vibration above coupling measured at flow of 20 mmscfh

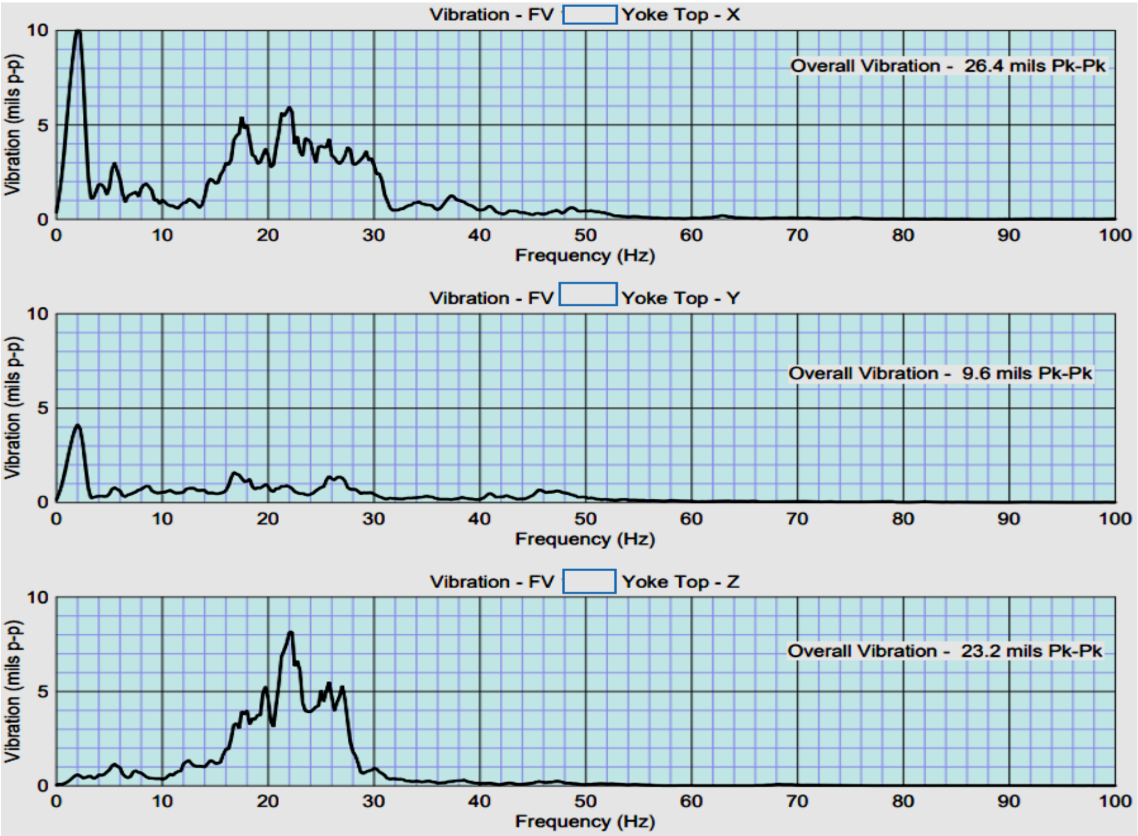


Figure 8 Valve vibration top yoke measured at flow of 20 mmscfh

Tracking the radial relative displacement at the base of the valve stem just above the packing shows the motion was not consistent with flow; although, the moviment was <0.5 mil over the 13 to 20 (mmscfh) flow range as shown in figure 5. The valve stem motion just below the operator moved approximately 1 mil to the east and 1 mil to the north as the flow was increased from 13 to 20 (mmscfh) as shown in figure 9. It is possible that some of the moviment measured at the both locations may be due to a change in position as the valve was opened. Trends plots of the upstream and downstream pulsation amplitudes were sporadic, similar to the vibration characteristics. In general, both the upstream and downstream overall pulsation amplitudes varied and trended up with flow. However while maintaining a flow rate of approximately 19 (mmscfh), the downstream pulsation amplitude did increase while the upstream pulsation amplitude did not. As shown in figure 10. Frequency spectral plots of the upstream and downstream pulsation obtained at the gas flow rates of 13 (mmscfh) and 20 (mmscfh) are shown in figure 11 and 12. The noise level measured downstream of valve (FV) was approximately 83.5 dBC at the flow rate of 19-20 (mmscfh).

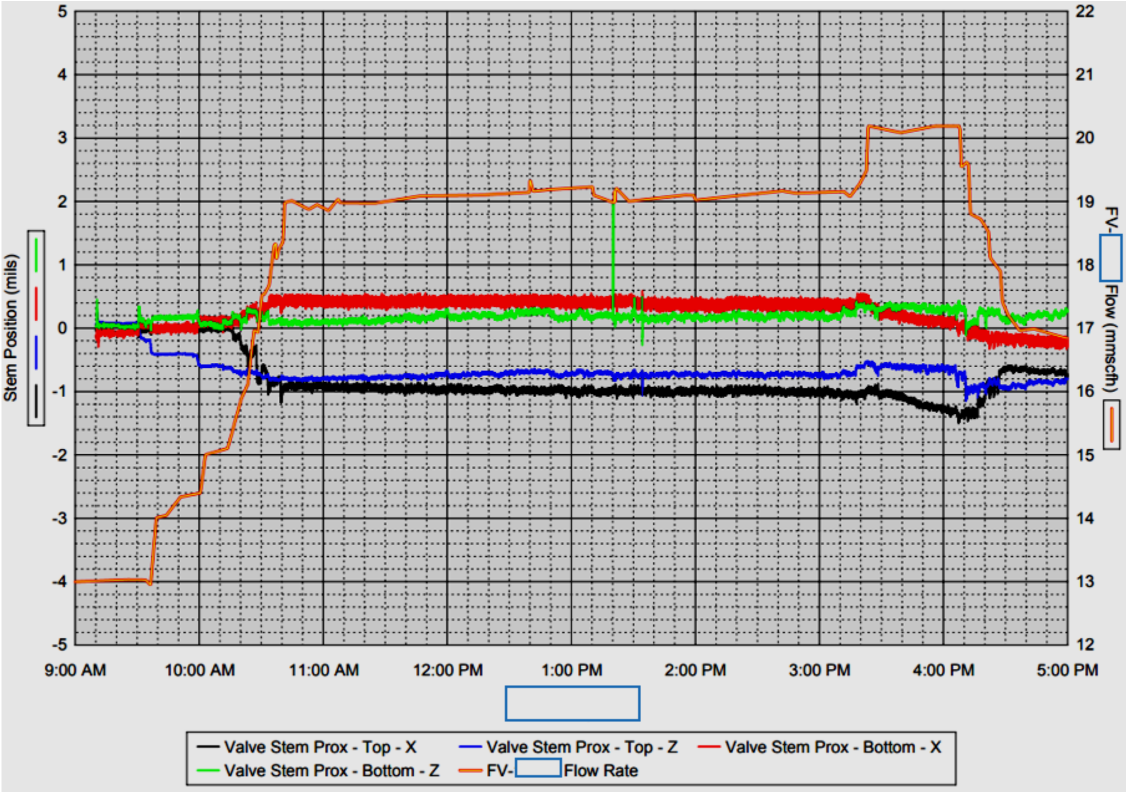


Figure 9 Valve Stem position

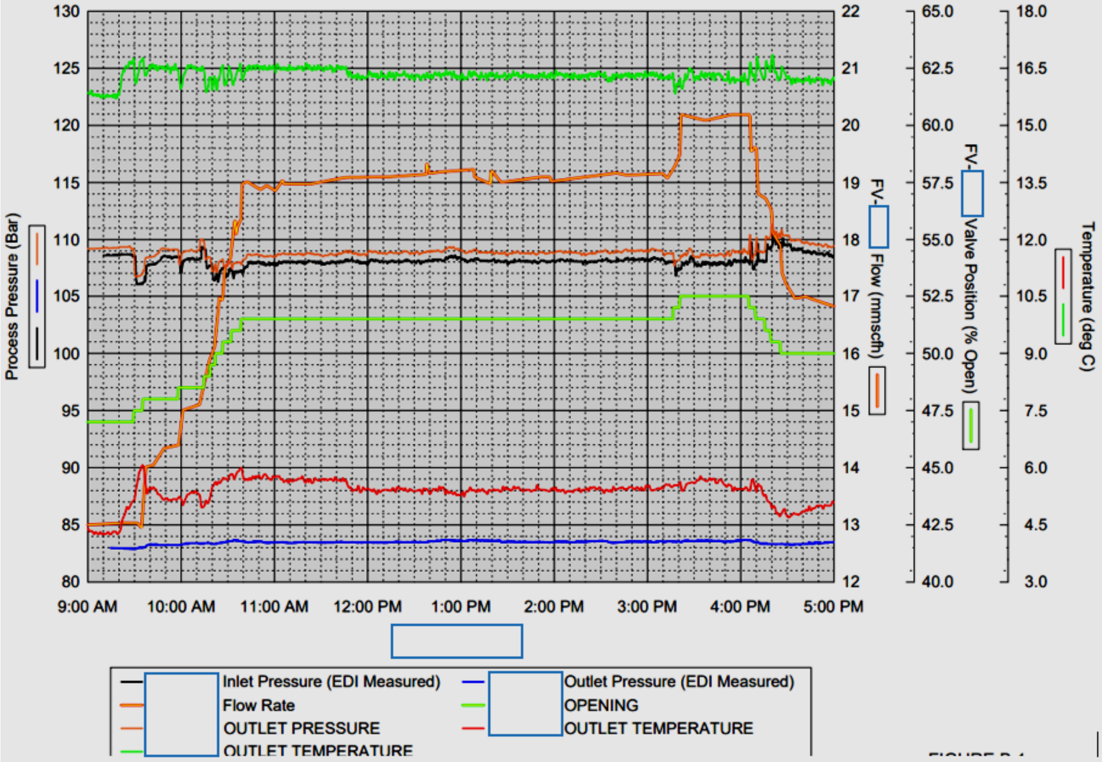


Figure 10 Valve process conditions

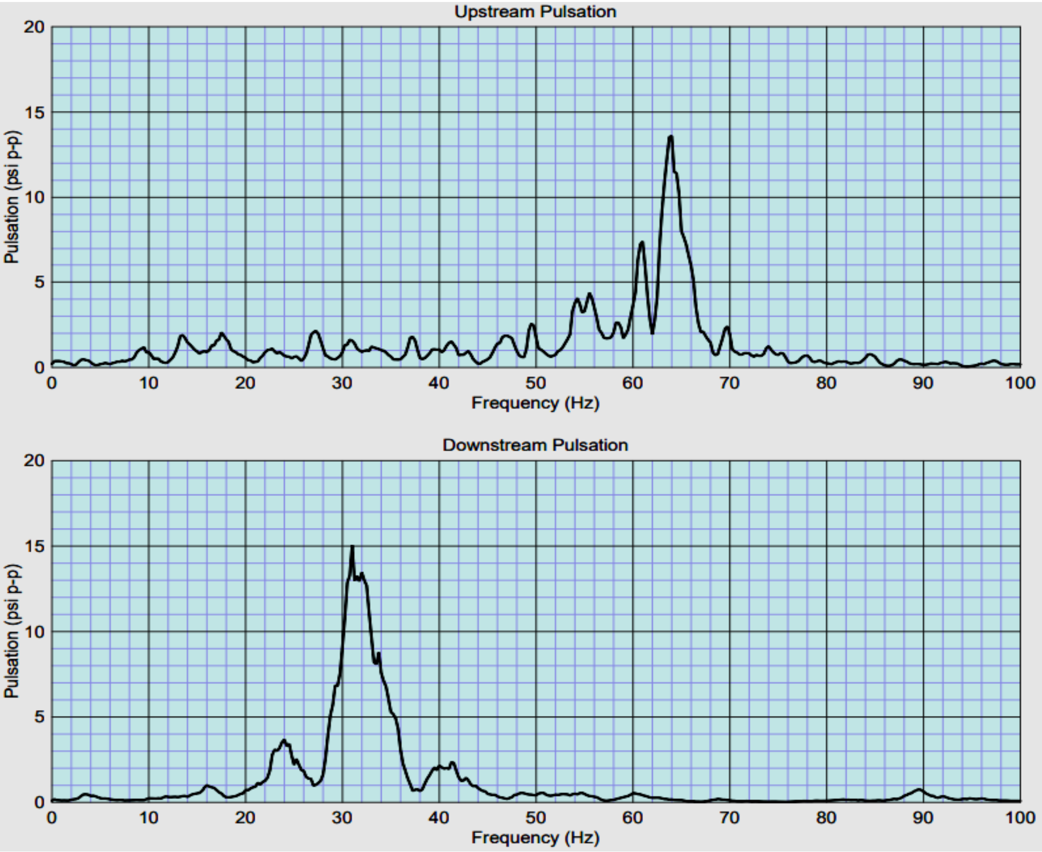


Figure 11 Valve pulsation flow at 13 mmscfh

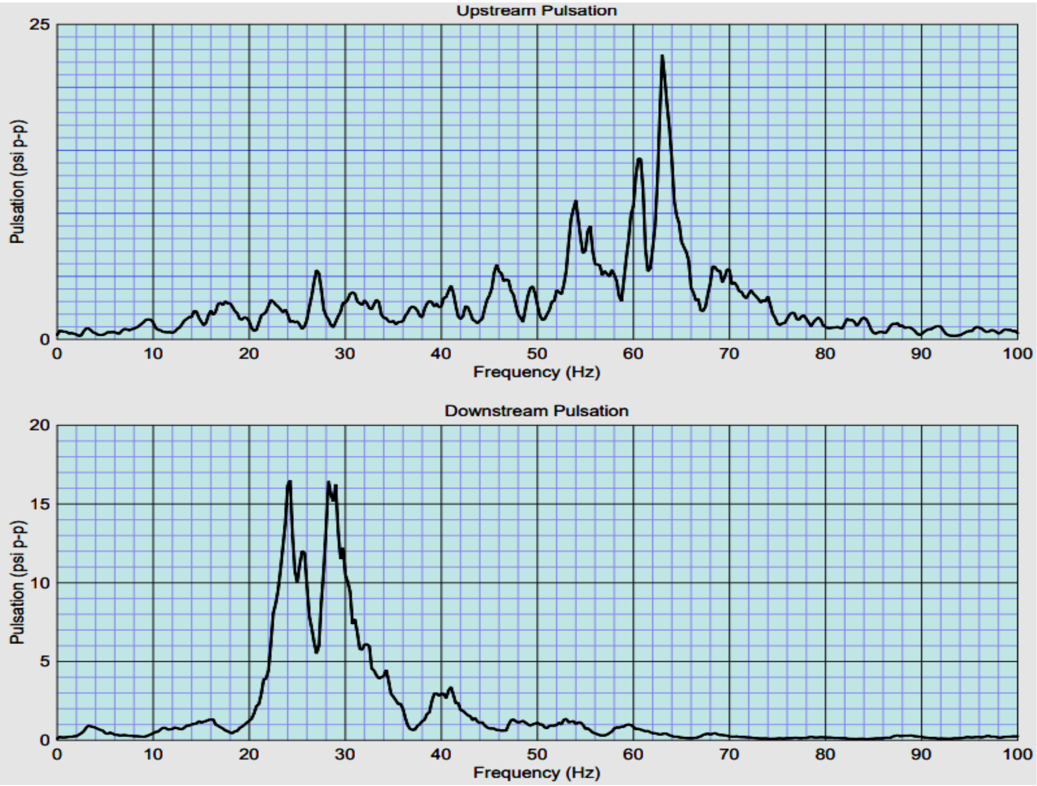


Figure 12 Valve pulsation flow at 20 mmscfh

Root cause analysis

Root causes analysis of the stem packing failure is conducted and are believed to be:

- Vibration studies indicate piping design as the ‘likely’ root cause, creating high flow turbulence and vibration at the valve inlet.
- Valve design is creating pressure pulsations in the outlet piping causing vibration.
- Vibrations in the system is due to flow through the multiple bends comprising the bottom of the valve body. This causes velocity transients (flow fluctuations) around sharp corners inside the valve and at the expander.

Proposed V-ring packing re-design

- The current (FV) valves are experiencing packing leaks and trash buildup in the packing area. To protect the stem against trash buildup and provide a level of safety against vibration the packing configuration will be re-designed per the layout below[4].
- The re-designed packing configuration includes the following:
- Wiper Rings – Wiper rings have been added to the top and bottom of the area to increase prevention against trash buildup.
- Stem Guides – Re-designed stem guides with tight tolerances have been added for lateral stem support. This provides a more robust arrangement for vibration resistance.
- V-Ring Packing – Multi-contact packing design with 8 points of contact with the stem compared to 3 in the current design.

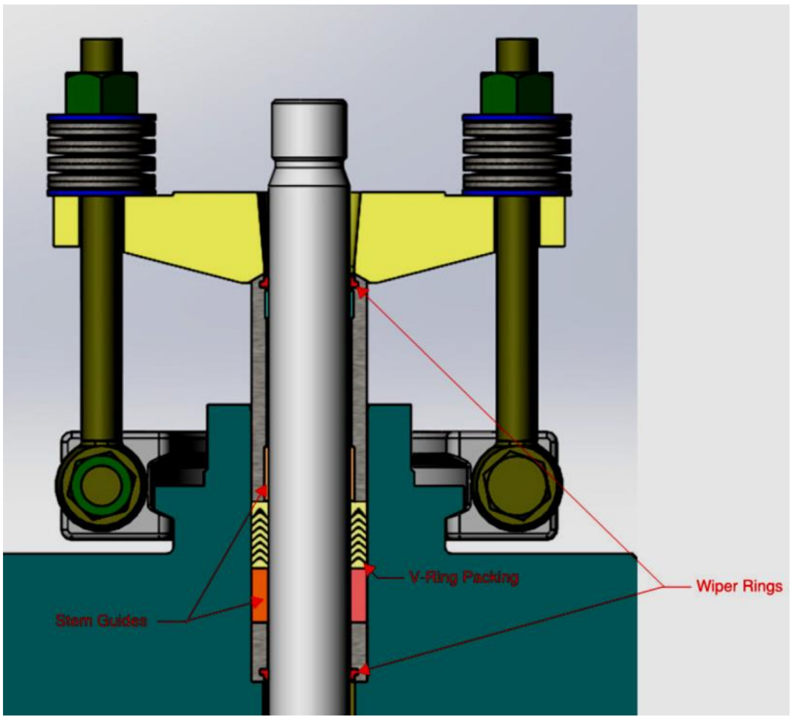


Figure 13 Flow control valve v-ring packing re-design

Conclusions

At increased flow rates, the valve stem sporadically vibrates vertically relative to the valve body, yoke through the packing. This behavior gets progressively worse as the rates increase. Aproximately 3-6 mils peak-peak(1 mil = 0.001 inches) of oscillation occurred at 13 mmscfh and increased to 25-35 mils peak-peak as the flow rate reached approximately 20 mmscfh. It is believed that this amount of vertical oscillation is prematurely wearing out the packing at the higher flow rates. In addition the failure have always occurred in the same quadrant (backside of the stem in direction of flow). This indicates the stem is side loaded while vibrating vertically throug the packing. The valve stem currently installed in (FV) wa machined on site due to long lead times for replacement OEM. It is possible that the surface finish of this machined stem is rougher than that of OEM stem. This rough finish could also contribute to accelerated packing failure.

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