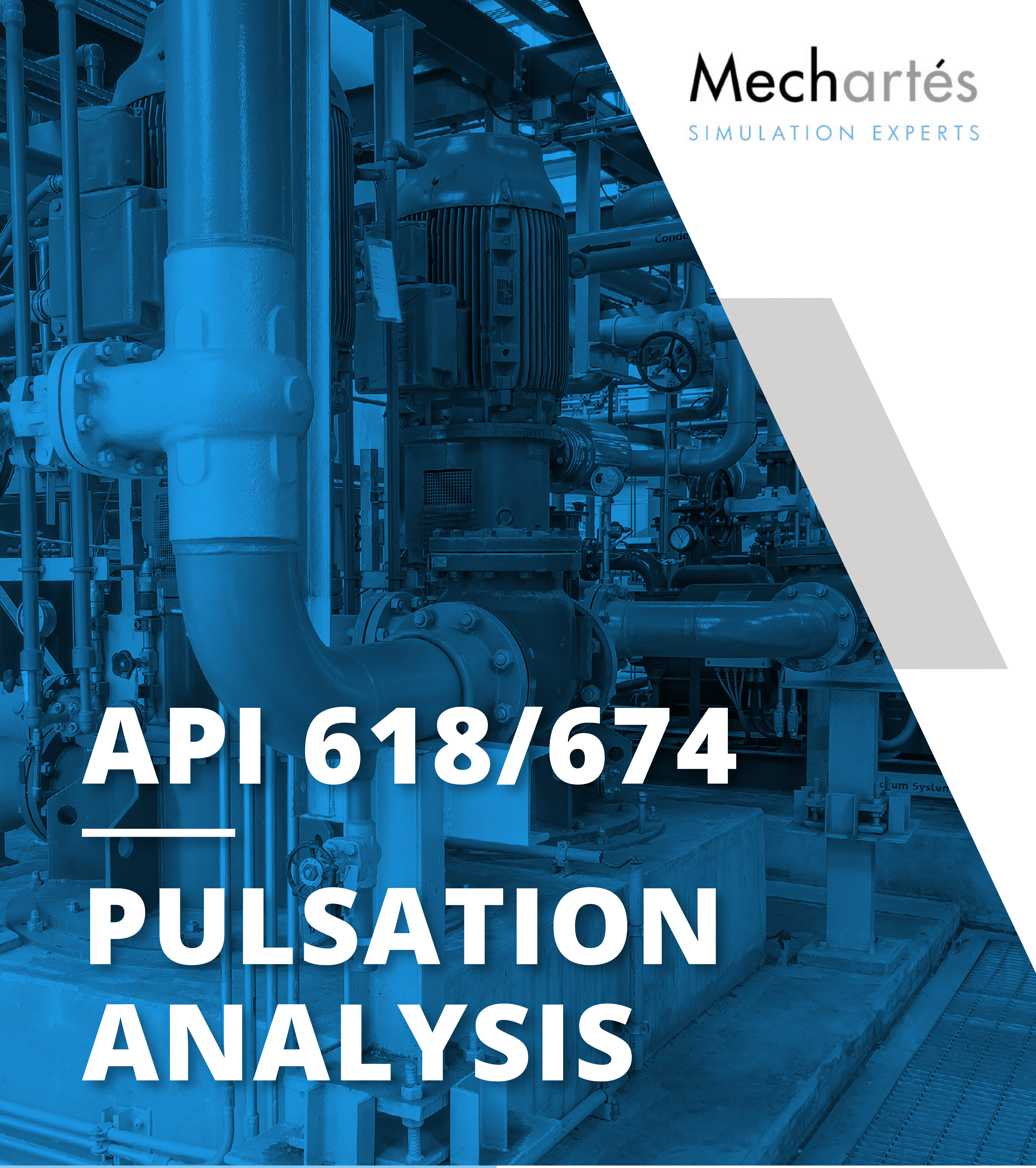
Mechartés
SIMULATION EXPERTS



API 618/674

PULSATION ANALYSIS

Table of Contents

Introduction

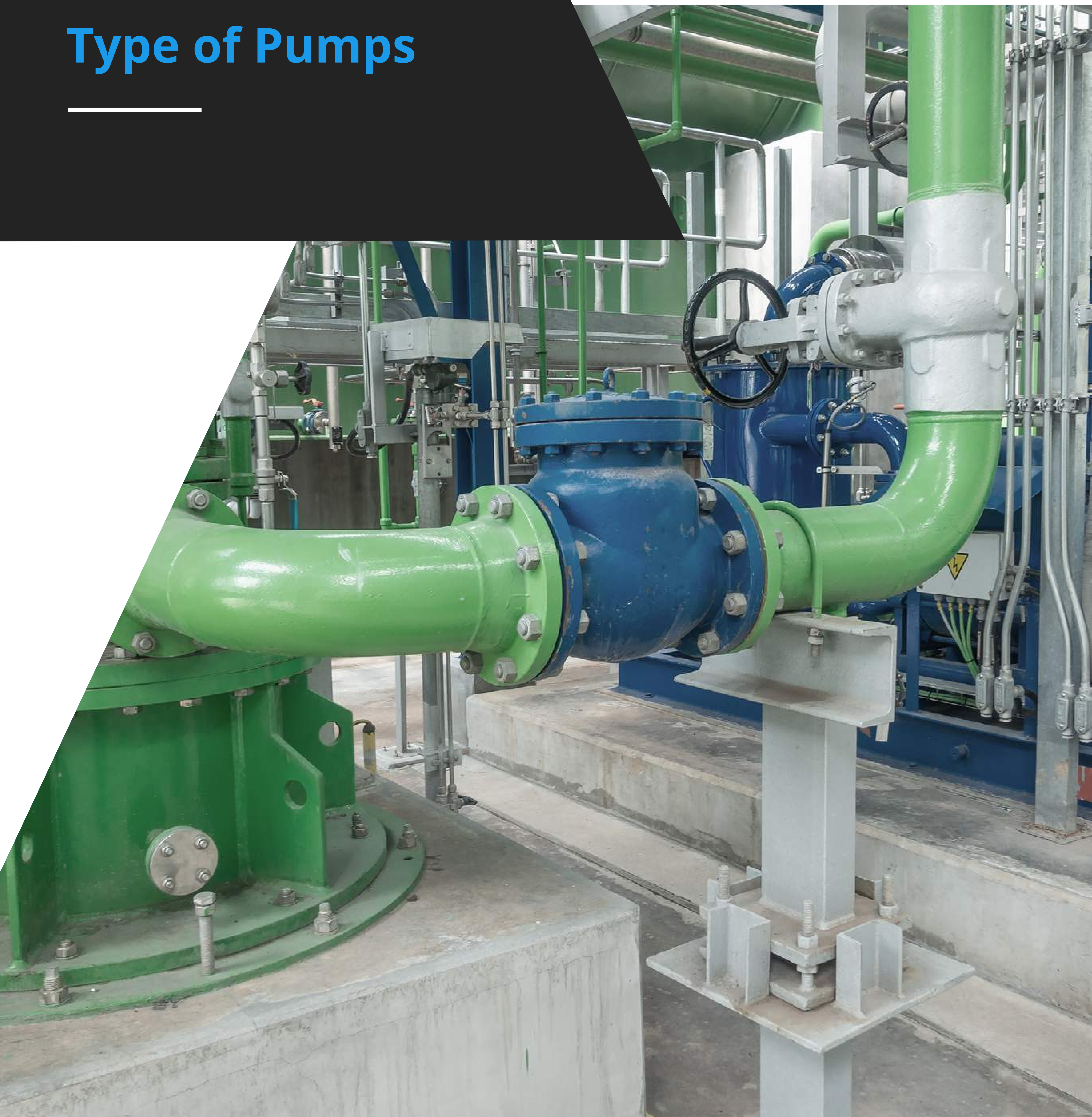
Fluids need to be transported and stored for varied industrial/ domestic applications and for this purpose, some external force has to be applied to them. Unlike our rainwater cycle, where billions and billions of gallons of water is transported from oceans to interiors of our continents, stored and transported in the form of clouds and with a phase change happening, all this without any engineering/ financial support to the Sun. Thus, providing relief to our existence and improving our economy too. But unlike the rainwater cycle, we need to install complex systems for other liquids to transport and store them, especially w.r.t oil & gas and process industries.

Pulsation in the piping system can be defined by a variation of line pressure due to the reciprocating action of pumps/compressors.

Positive displacement pumps or compressors are used in many different applications like oil & gas, thermal power plant, polymer plants, cement industries, etc.

All these pumps and compressors have one common problem called pulsation which is due to their working principle. These pressure pulsation can lead to high unbalanced shake forces at pipe elbows and Tees which can cause high vibration and hence fatigue failure of the piping system at the site. The geometry of the connected piping, piping supporting, and equipment can further amplify these pulsations due to acoustical resonances.

Type of Pumps



Type of Pumps

There are **three basic** types of pumps: positive-displacement, centrifugal and axial-flow pumps.

Reciprocating Pumps are positive displacement machines typically used for **low-flow, high-pressure operations**. ANSI and the Hydraulic Institute categorize reciprocating pumps into four distinct types. Both pistons and diaphragms are used to provide pumping action while valves regulate flow into and out of the pump body. Reciprocating pumps are used **where a precise amount of fluid is required to be delivered**, and also where the delivery pressure required is higher than that can be achieved with other types.

Type of Pumps

The basic and main difference between centrifugal pumps and reciprocating pumps is that **centrifugal pumps use the kinetic energy of the impeller to continuously supply fluid**.

In reciprocating pumps, on the other hand, the piston sucks the fluid and then pushes it out in the form of pockets which does not give a continuous supply and hence generates a pressure pulsation and unbalanced forces inside the piping network. Therefore, pulsation and mechanical vibration analysis is required for new or modified reciprocating pumps to avoid typical problems at the site such as:

- Pressure pulsation-induced cavitation in the suction piping network.
- Excessive piping vibration
- Piping failures due to excessive stresses caused by high unbalanced shake forces.
- Small-bore attachment failures

Pulsation Analysis (Acoustical Analysis)

Pulsation Analysis (Acoustical Analysis)

Pulsation is carried out worldwide for pumps and compressors as per the requirements detailed in the API standards.

Advantage of Reciprocating pumps/compressors

Although each pump category has its own use and applications, we will focus more on reciprocating pumps/compressors.

Reciprocating pumps (including diaphragm pumps, plunger pumps, and other positive displacement pumps) are used in many applications. Interactions with connected pipelines and system parts must be taken into consideration as well as the system optimization with correct sizing of pulsation dampeners.

Pulsation Analysis (Acoustical Analysis)

These reciprocating pumps are suitable for handling most liquids for Oil & Gas (including petroleum production facilities and refineries) and industrial applications. Common applications are:

- Methanol Injection
- Glycol circulation
- Boiler feed
- Slops injection
- Reverse osmosis
- Water injection, production, & jetting
- Hydrocarbon – condensate
- Closed drain pumps

Understanding API Standards – API 618 & API 674

Understanding API Standards – API 618 & API 674

These are specifications by the American Petroleum Institution.

Most of the pulsation studies carried out worldwide follow the requirements detailed in API Standards 618 & 674.

API 674 and API 618 are both specifications issued by the American Petroleum Institute that cover the examination of piping systems for pressure pulsation and mechanical response (modal vibration) attached to reciprocating power pumps. API 674 covers power pumps dealing with liquids, whilst API 618 deals with gas compressors.

In both specifications, pressure pulsation analysis means the examination of the piping system for resonances and harmonics of the frequency at which the pump or compressor discharges slugs of liquid or gas into the piping system.

Mechanical response means the examination of the piping system for its modal or frequency response, sometimes referred to as natural frequency and the higher order modes of vibration.

Understanding API Standards – API 618 & API 674

API 674 is the API standard that covers the minimum requirements for **reciprocating positive displacement pumps** and pump units for use in the petroleum, petrochemical, and gas industry services. Both direct-acting and power-frame types are included. Controlled-volume pumps, hydraulically driven pumps, and rotary pumps are not included.

As per API 674, guidelines, There are two different approaches for a pulsation analysis which can be used for new or modified reciprocating pumps

Design Approach 1 (DA1)

The analytical study includes the design of a pump pulsation suppression device using proprietary and/or empirical analytical techniques to meet the pulsation levels specified in API 674.

It involves good engineering practice and does not require a pulsation analysis.

Design based on a good piping layout and support principles, adequate Net Positive Suction Head available can be used here.

This approach is generally used for non-critical applications.

Design Approach 2 (DA2)

This approach involves pulsation control through the use of pulsation control devices, developed using proven acoustical simulation techniques in conjunction with the mechanical analysis of pipe runs and support systems (support types and spacing) to achieve control over vibration response.

It involves Pulsation Analysis of suction and discharge piping network connected with a reciprocating compressor. Pulsation analysis is performed as per guidelines given in API 674, Annexure-C.

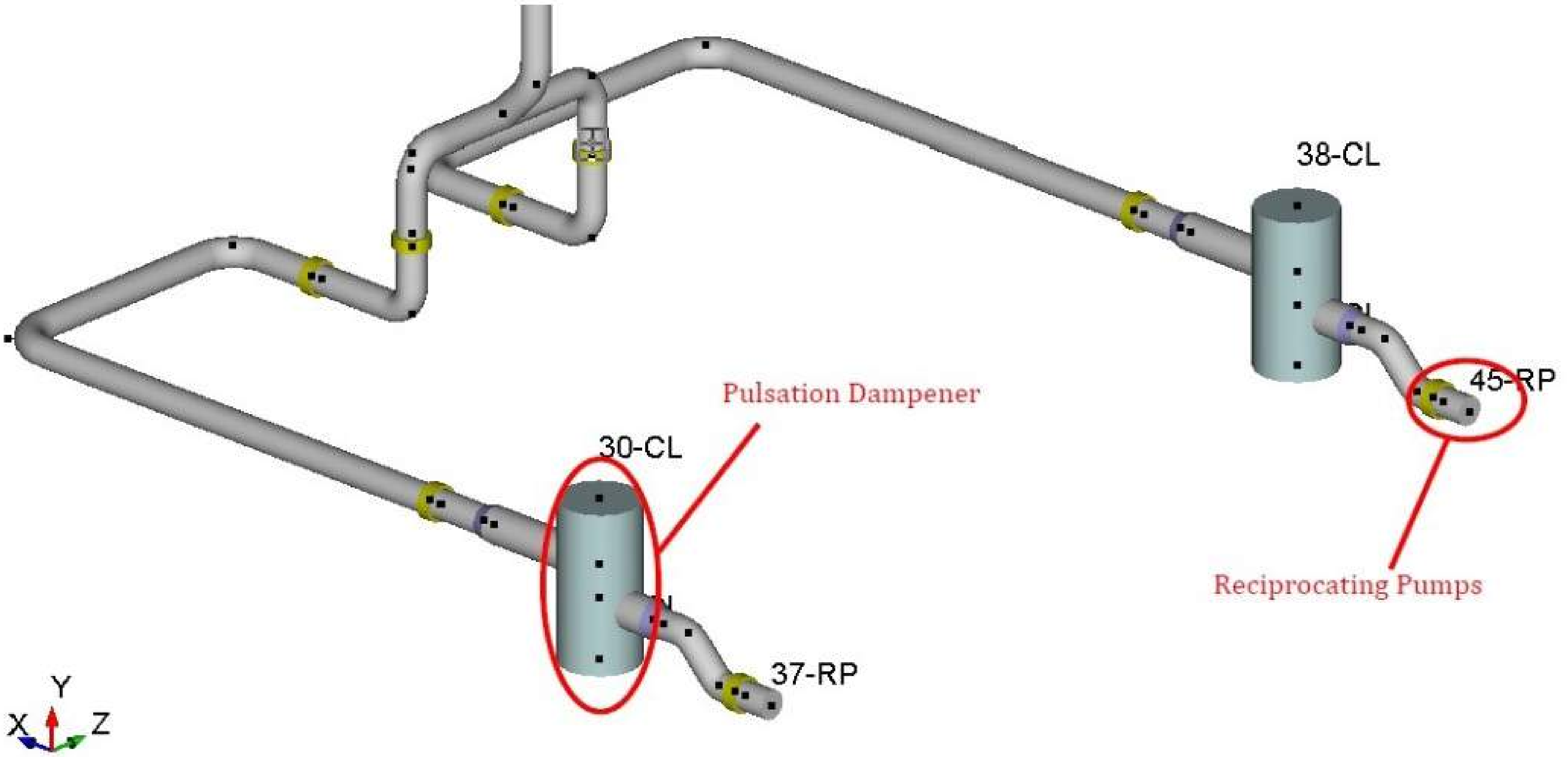
In this study, pressure pulsation is evaluated across the entire pumping system and the predicted pulsations and shaking forces throughout the system are compared with the API 674 guidelines.

Pulsation control solutions such as pulsation dampeners and orifice plates are recommended as design suggestions.

The minimum suction pressure required to prevent cavitation is evaluated based on the pulsation amplitudes.

A mechanical review of the piping system is done to evaluate support types in the piping system. Support types will be suggested to avoid vibrations of the piping system.

Design Example-1 Fig. Showing Piping network near discharge line near to reciprocating pumps



As per API 674 3rd addition Annexure, C clause C.1.5, the peak to peak pulsation levels in the suction and discharge piping systems beyond the pulsation control devices shall not exceed the levels calculated by equation 1, which specifies the allowable peak to peak pulsation level of each individual pulsation frequency component.

$$P_1 = \frac{3500}{\sqrt{(ID * f)}}$$

Where:

- **P1** = maximum allowable pulsation level in kPa, peak to peak of individual pulsation components corresponding to the fundamental and harmonic frequencies. One should note here that suction and discharge pulsation levels have to be limited to values that will not cause cavitation or relief valve lifting.
- **ID** = inside diameter of line pipe, in mm.
- **f** = pulsation frequency, in Hertz, derived from the following equation, in which rpm is pump speed and n = 1,2,3,...., corresponding to the fundamental frequency and harmonics thereof.

The minimum value of suction complex pressure wave Pmin at the inlet reference point shall not be lower than the highest liquid vapor pressure, with a margin of 10% as shown in the equation below:

$P_{min} > 1.1\, P_v$

Where:

Pv = Highest vapor pressure of the pumped fluid

As per API 674 3rd addition Annexure, C clause C.1.7, Relief valve setting pressure is calculated by using the equation given below.

Pp < Prv – Pd – (0.05 * Pd)

Where,

- **Pd** is the maximum specified value of average discharge gauge pressure in bar.
- **Pp** is the positive peak of the pulsation complex wave, expressed in bar.
- **Prv** is required relief valve setting in gauge pressure, expressed in bar.

Separation Margin Requirements for Piping Systems

The following separation requirements should be met to avoid a coincidence of excitation frequencies with mechanical natural frequencies of the pump, pulsation suppression devices, and the piping system.

a. The minimum mechanical natural frequency of any manifold or pipe system element shall be designed to be greater than 20% above the significant frequency of the unbalanced forces. When the minimum mechanical natural frequency guideline is not met, or when there is significant excitation energy at higher orders, the separation margins as defined in b) shall be maintained.

b. The predicted mechanical natural frequencies shall be designed to be separated from significant excitation frequencies by at least 20%.

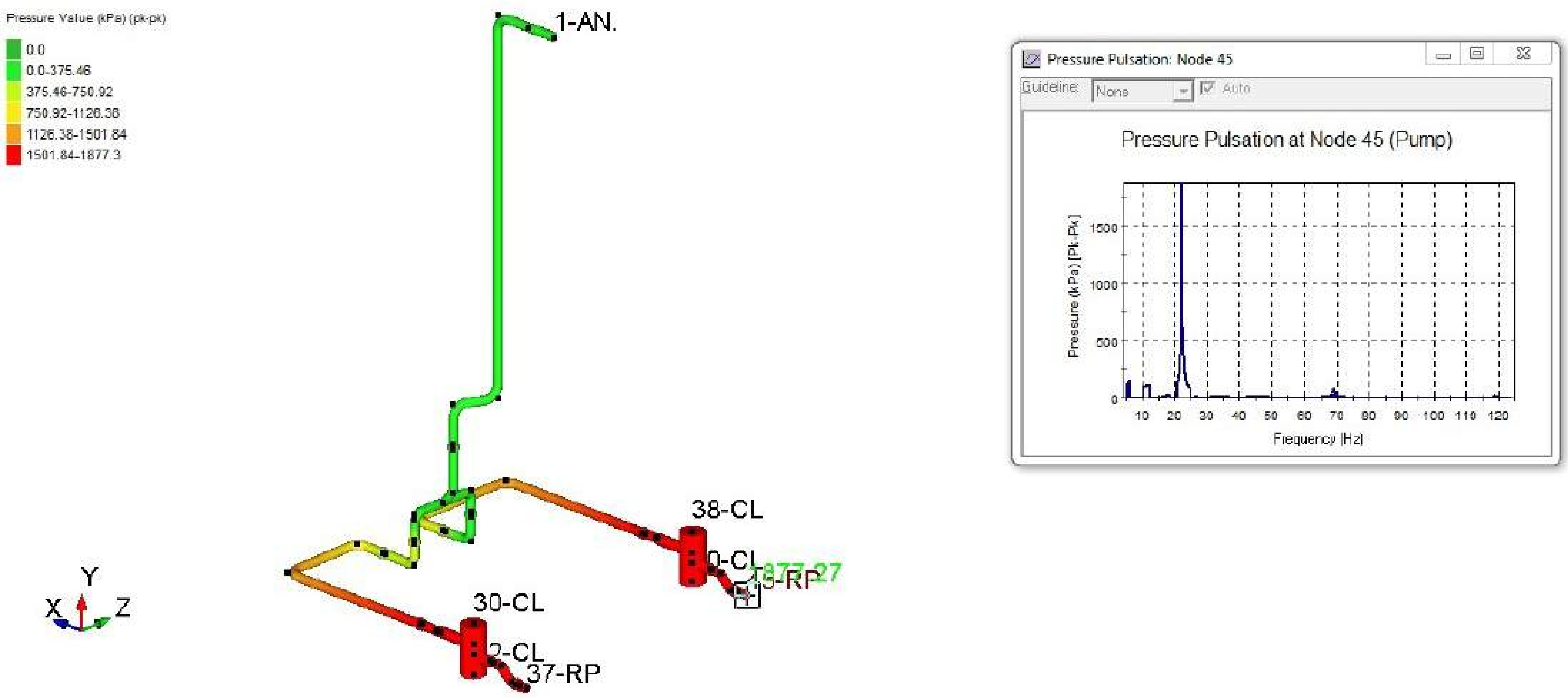


Figure 5: Pk-Pk Pressure vs Frequency - Comparison with API 674 - Suction Line (Without Dampeners - Node #45)

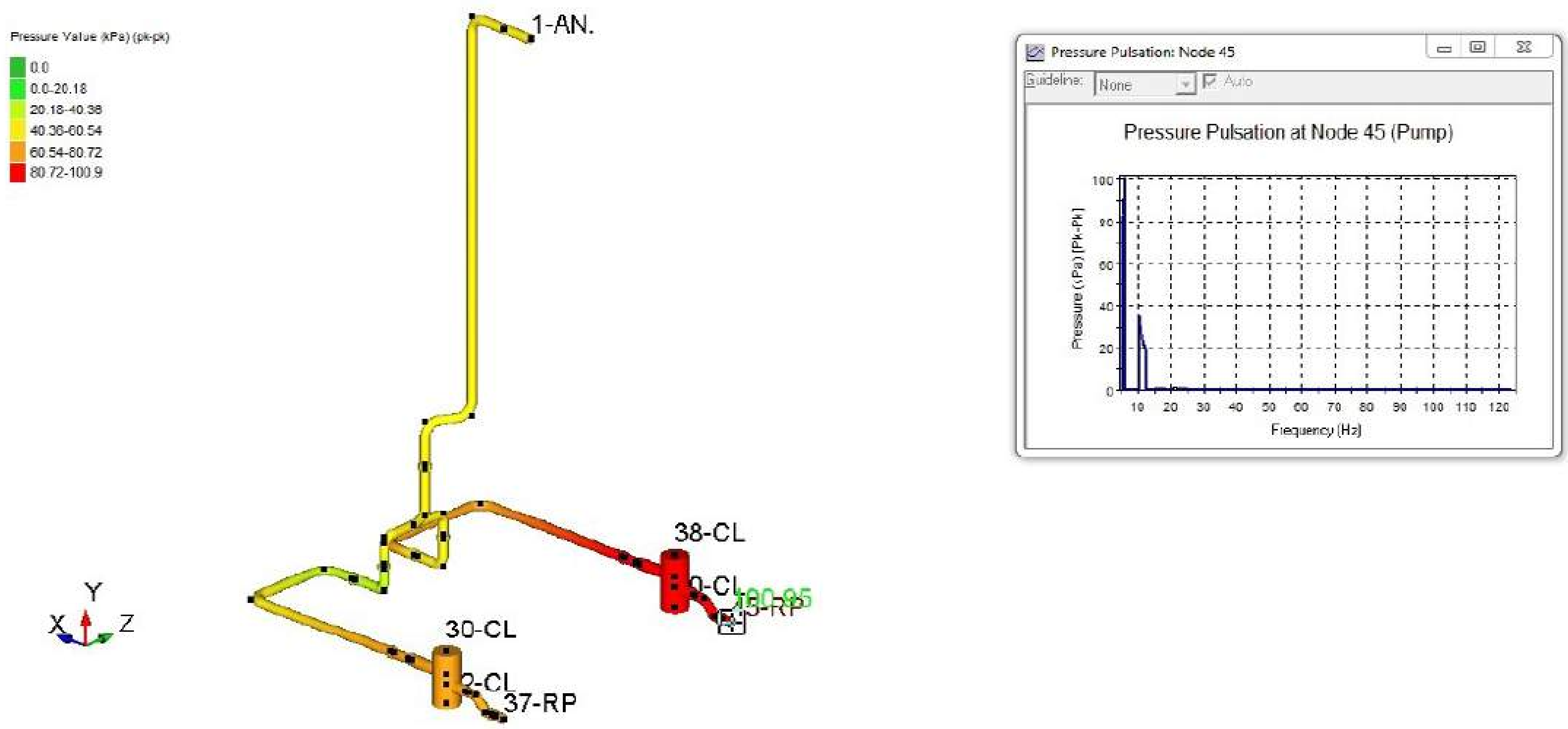
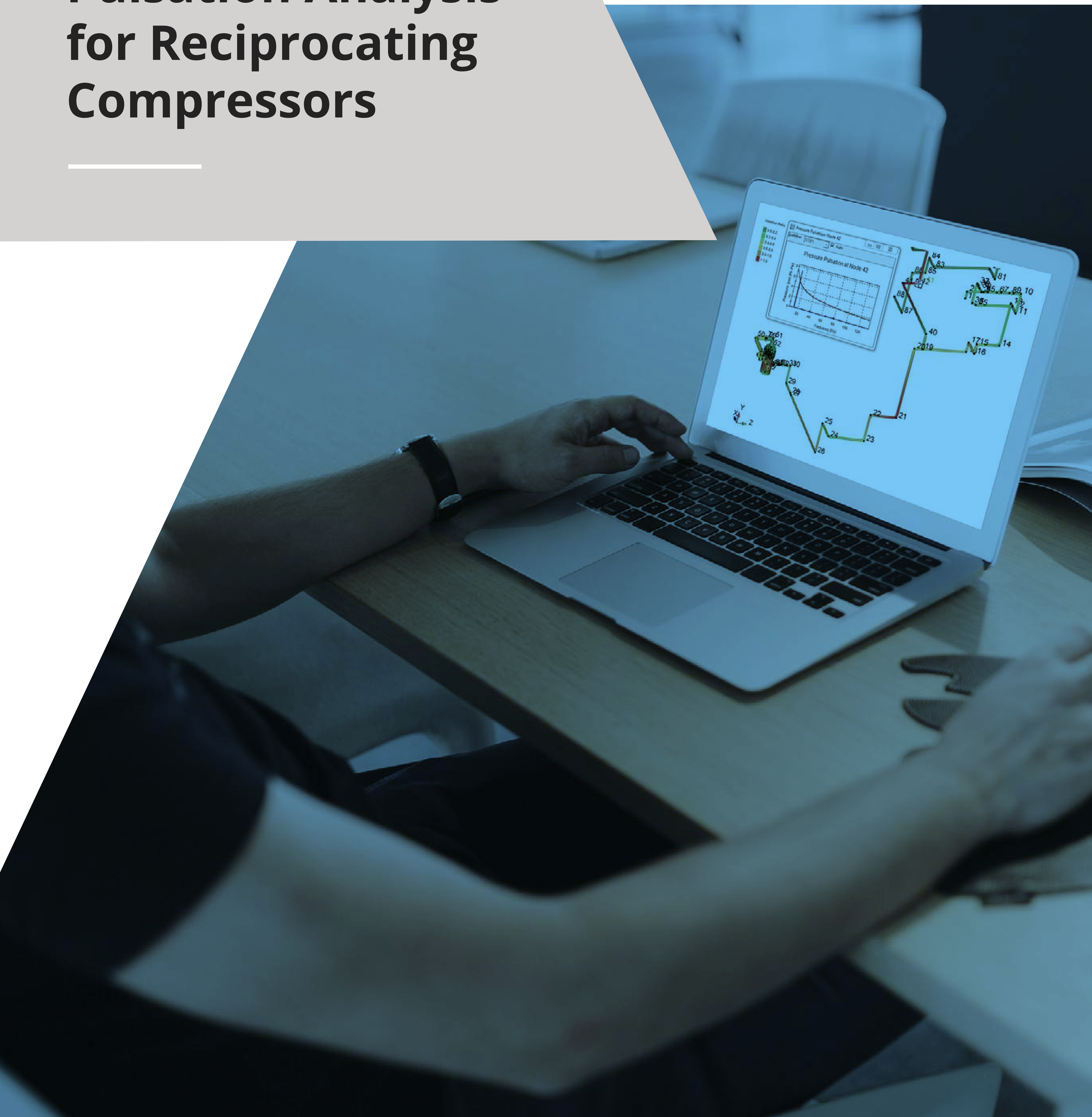


Figure 5: Pk-Pk Pressure vs Frequency - Comparison with API 674 - Suction Line (With Dampeners - Node #45)

Pulsation Analysis for Reciprocating Compressors



Pulsation Analysis for Reciprocating Compressors

Pressure pulsation comes from the discontinued nature of gas flow in the reciprocating compressor. Pulsating actions of the piston to compress gas generates the fundamental pulsation whose frequency corresponds to the compressor speed of rotation.

Cylinder valves and other accessories generate various harmonics of the fundamental pulsation (frequencies are multiples of the fundamental frequency). Machine-generated pulsations propagate in the gas in the form of waves. These pulsations interact (for example due to reflection) with plant facilities and piping in upstream and downstream of compressors.

The level of harmonic components can be increased considerably due to resonance with plant installations (resonance between harmonic frequency and natural frequency of piping or facilities in the plant).

Pulsation studies and reviews shall be performed for all operating conditions as well as all transient operating cases and combinations of pressures, speeds and load steps.

Pulsation Analysis for Reciprocating Compressors

API 618 covers the minimum requirements for **reciprocating compressors** and their drivers used in petroleum, chemical, and gas industry services for handling process air or gas with either lubricated or nonlubricated cylinders.

Reciprocating compressors covered by this standard are of low to moderate speed and in critical services. Also covered are related lubricating systems, controls, intercoolers, aftercoolers, pulsation suppression devices, and other auxiliary equipment.

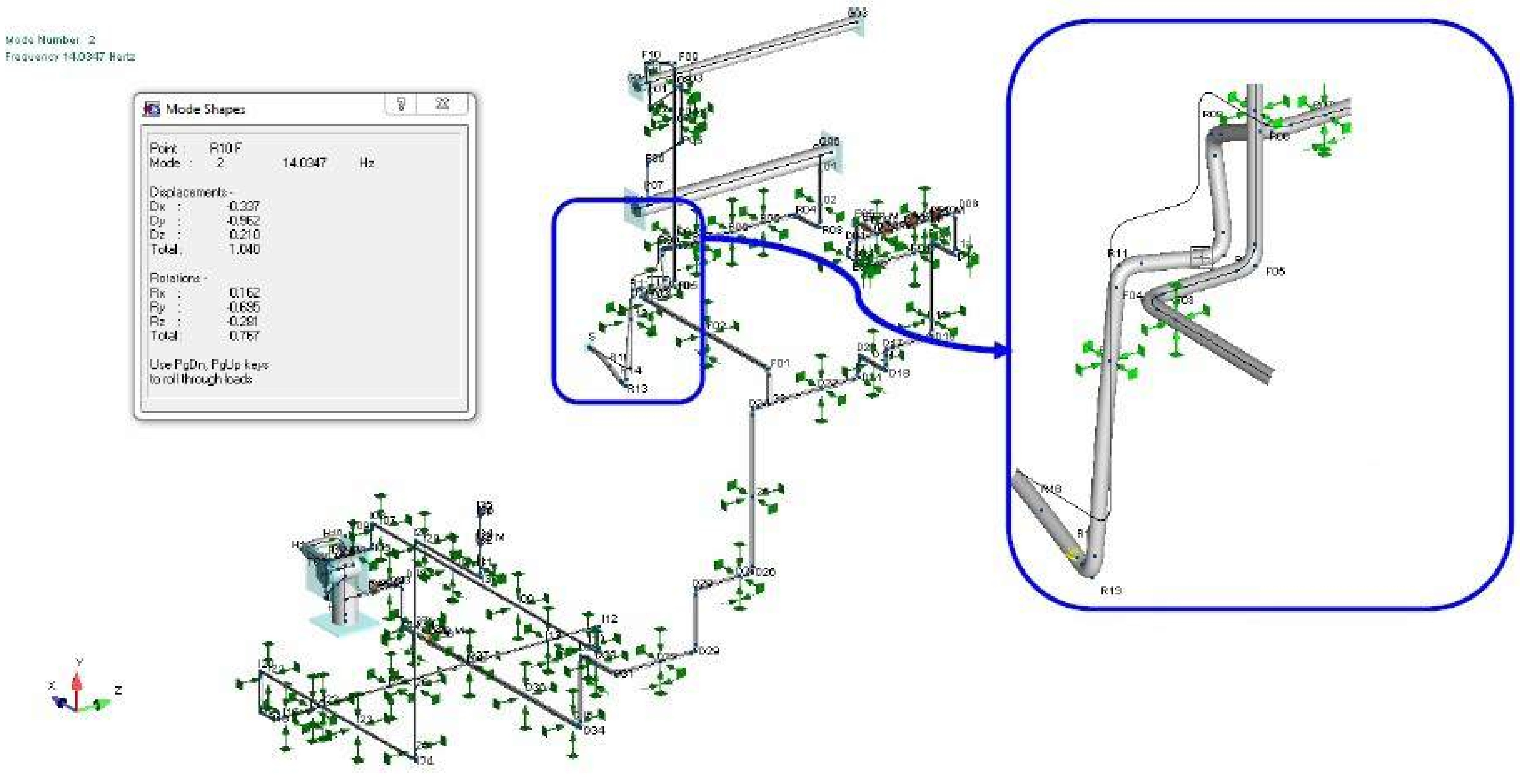


Fig. Showing Mode shapes – Discharge Piping network – Modal frequency at ** Hz

There are three design approaches given in API 618, 5th edition

Design approach 1:

It involves basic bottle sizing using empirical calculation. This does not include the pulsation study.

Design approach 2:

It involves pulsation control design in conjunction with a mechanical review of the piping system.

Pulsations analysis is done using computer simulation software to evaluate pressure pulsation, forces, and pressure drop. The DA2 scope does not include mechanical modeling to calculate MNFs and harmonic stresses for the piping system.

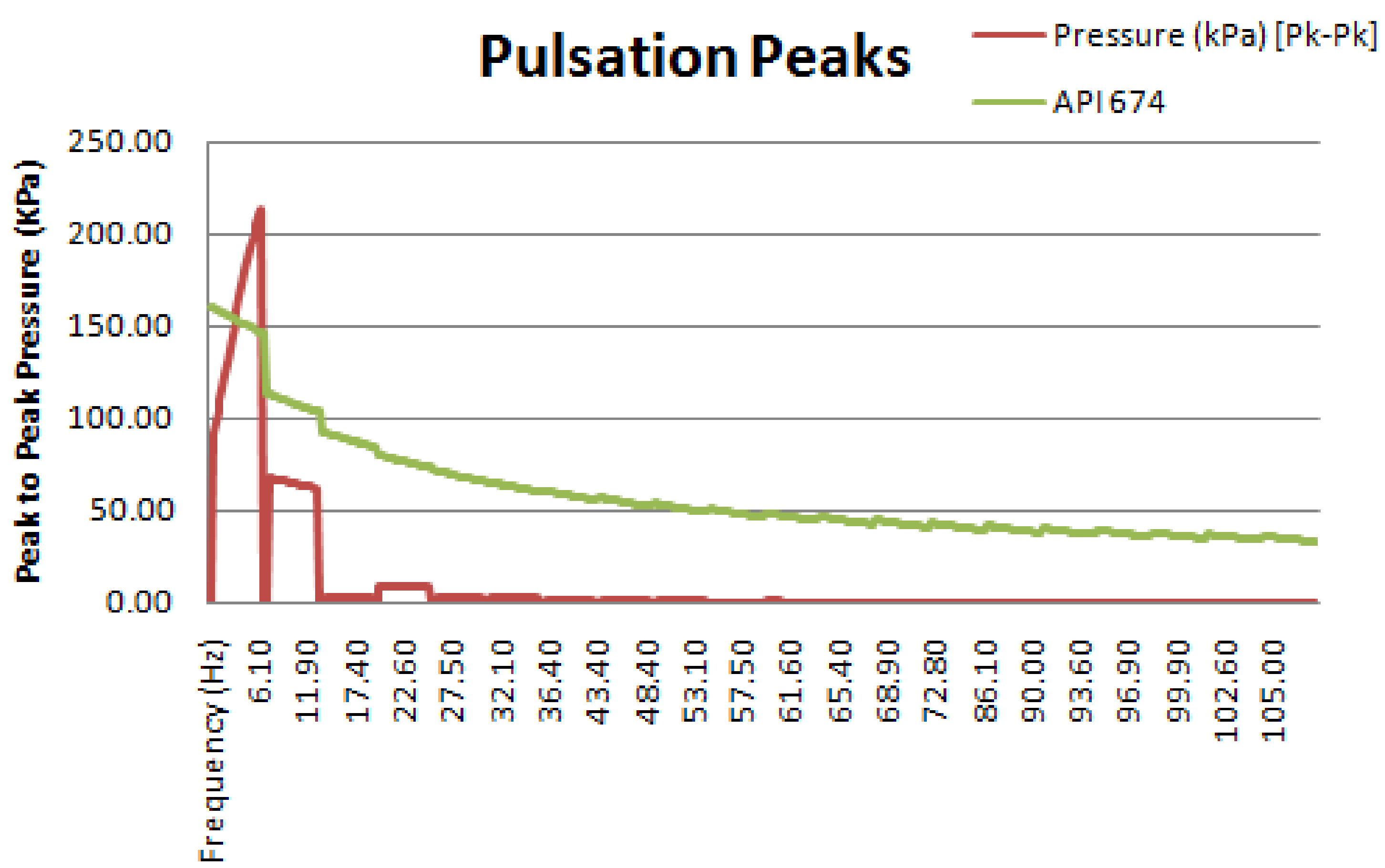


Fig. showing Pk-Pk pressure vs frequency – comparison with API 674 – Discharge line with dampeners.

Design approach 3:

The scope includes Pulsation analysis as per DA2, plus the following:

Step 3a: Accurate Modeling of MNFs. Analyze compressor and piping system to avoid mechanical resonances at frequencies where significant shaking forces exist. The design shall meet two key parameters:

1. The separation margin between MNF and the shaking force or the excitation frequency should be maintained. Minimum MNF of any element in the system > 2.4. The maximum run speed and predicted MNF shall be separated from significant excitation frequencies by ±20%.
2. Acoustic Shaking Forces shall not exceed the limits based upon the calculated effective static stiffness and the design vibration guideline.

If design guidelines for DA2 and step 3a are met, API 618 DA3 is complete. If any of the guidelines are not met, Steps 3b(1) and/or 3b(2) will be required to meet DA3 requirements.

Step 3b(1): Compressor Mechanical Model Analysis - If the separation margin or shaking force criteria in Step 3a above cannot be met, a forced response analysis of the compressor mechanical model must be conducted. The analysis is to include the pulsation shaking forces and cylinder gas forces. The design must meet the allowable cyclic stress criteria.

Step 3b(2): If the separation margin or shaking force criteria in Step 3a above cannot be met, a forced response analysis of the piping system to pulsation shaking forces must be done. The design must meet the allowable cyclic stress criteria and vibration limits. The piping system should include all piping included in the pulsation (acoustic) analysis.

As per API 618 5th edition, the peak to peak pulsation levels in a discharge piping system at and beyond the pulsation control devices shall not exceed the levels calculated by equation 1, which specifies the allowable peak to peak pulsation level of each individual pulsation frequency component.

In SI units:

$$P_1 = \sqrt{a/350}\left(\frac{400}{(P_L X D_I X f)^{0.5}}\right)$$

Where:

- **P1** = maximum allowable peak-to-peak level of individual pulsations components corresponding to the fundamental and harmonic frequencies, expressed as a percentage of mean absolute line pressure.
- **a** = speed source of gas.
- **PL** = mean absolute line pressure.
- **DI** = Inside diameter of line pipe.
- **f** = pulsation frequency, in Hertz

Maximum Allowable Compressor Cylinder Flange peak-to-peak pulsation level at the compressor cylinder flange can be expressed as a percentage of average absolute line pressure and shall be limited to the lesser of 7% or the value computed from the equation given below:

$P_{cf} = 3R\%$

Where,

- $\mathbf{P_{cf}}$ is the maximum allowable unfiltered peak-to-peak pulsation level, expressed as a percentage of average absolute line pressure at the compressor cylinder flange;
- **R** is the stage pressure ratio.

Maximum Allowable Pressure Drop

Unless otherwise specified, the pressure drop for each operating case, based on a steady flow through a pulsation suppression device at the manufacturer's rated capacity shall not exceed 0.25% of the average absolute line pressure at the device, or the value determined by equation given, whichever is higher:

$\Delta P = 1.67 \{(R-1)/R\}\%$

Where

- **P** is the maximum pressure drop based on steady flow through a pulsation suppression device expressed as a percentage of mean absolute line pressure at the inlet of the device;
- **R** is the stage pressure ratio.

Maximum Allowable Acoustic Shaking Force

The maximum allowable non-resonant shaking force based on the design vibration guideline can be determined from the equation given below:

$$SF_k = k_{eff} X V$$

Where

- SF_k is the non-resonant shaking peak-to-peak force guideline relative to static structural stiffness in N.
- K_{eff} is the effective static stiffness along the piping or pulsation suppression device axis where the shaking force acts in N/m2.
- **V** is the design vibration peak-to-peak guideline in m2.

Piping Design Vibration Guidelines

- The predicted mechanical natural frequencies shall be designed to be separated from significant excitation frequencies by at least 20%.
- Amplitude due to pipe vibrations based on the maximum calculated acoustic shaking forces shall be limited to the maximum allowable vibration amplitude of 0.5 mm peak-to-peak for frequencies below 10 Hz.
- Dynamic stresses in the piping system due to shaking forces shall be limited to maximum allowable stress as per applicable standards.

Design Example 2

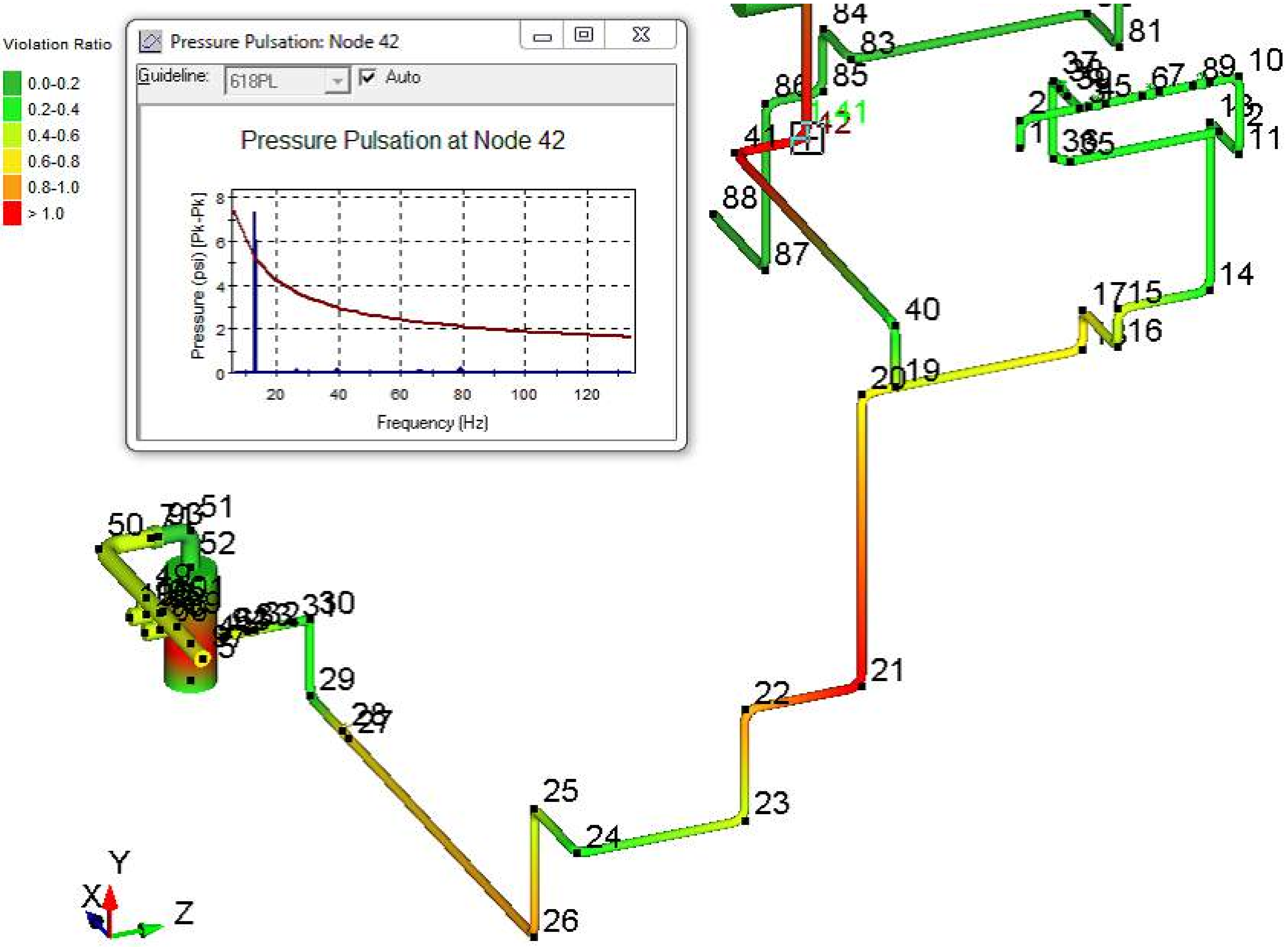
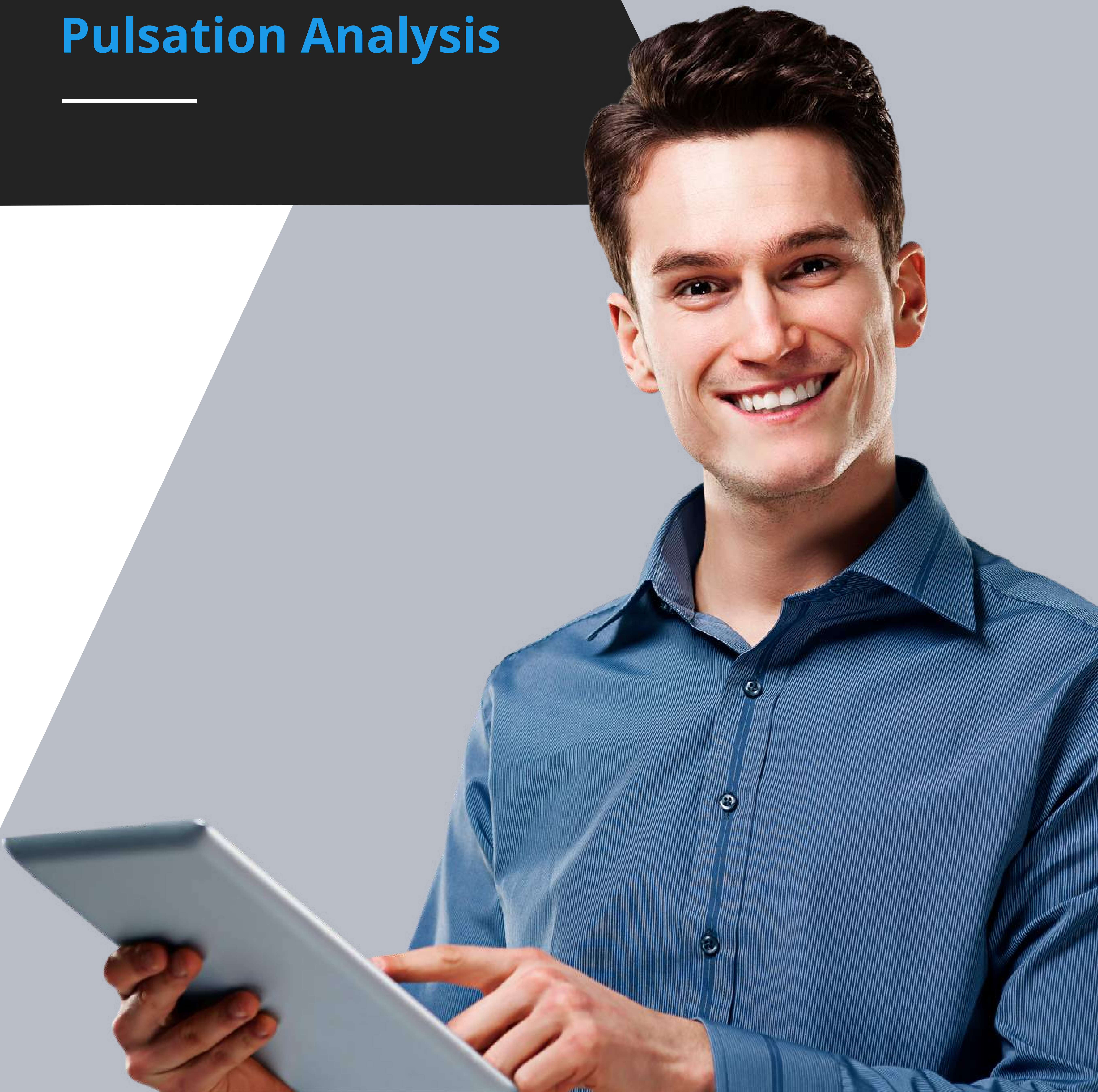


Fig: Showing Pk-Pk pressure vs Frequency at 100% load

Results of a Pulsation Analysis



Results of a Pulsation Analysis

Our report, as per API standards provides:

- Comparison of the expected pressure amplitudes with the maximum permitted values in accordance with API 674.
- A Report describing the Pulsation/Vibration simulation procedure, and explanations on why the model adequately describes the actual situation, boundary conditions, assumptions and results obtained.
- The result will show the cyclic pressure variation inside the pipeline at various locations in the pipeline layout. The plots will show a comparison of maximum pressures at varying frequencies with allowable pulsation levels prescribed in API 674 – Annexure C.
- The report will provide the source of pulsation if the simulation shows a higher pressure level, more than what is allowed as per API 674, Annexure-C.
- The report will also show results of potential cavitation locations across the pipeline for the given operating conditions.
- Stand tubes and pulsations dampeners will be used as a first option to minimize the level of pulsation and resistive devices like orifices will be used as a final alternative if the above-mentioned solutions are not feasible.
- The report will examine the pipe supports and provide suggestions to include extra supports, hangers, and anchors to reduce resonance and displacement in pipes.

Results of a Pulsation Analysis

- The results provide information about the mechanical tensions, forces, moments and deflections to be expected. You will also obtain a detailed Pass/Fail report of your pipeline network.

Inputs Required:

To carry out an acoustic study, we need the following data/inputs:

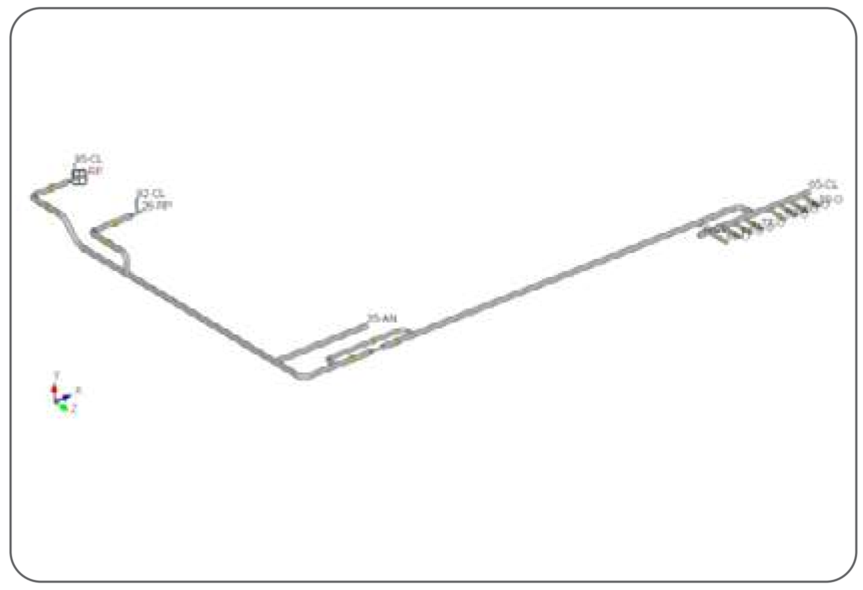
- Fluid data: Density, viscosity, sound velocity, and vapor pressure
- Operating scenarios: No. of pumps running and on standby
- Stroke frequency
- Valve configuration (which are open/closed?)
- Type of fluid used and its properties
- Information about the pressures on the intake and discharge side
- Final isometries and R&I flow diagram
- Position and design of the pipeline support (mechanical analysis)

Do refer to the **Pulsation Analysis Case Study on Reciprocating Pumps** on the next page.

Pulsation Analysis of High Pressure Pipelines

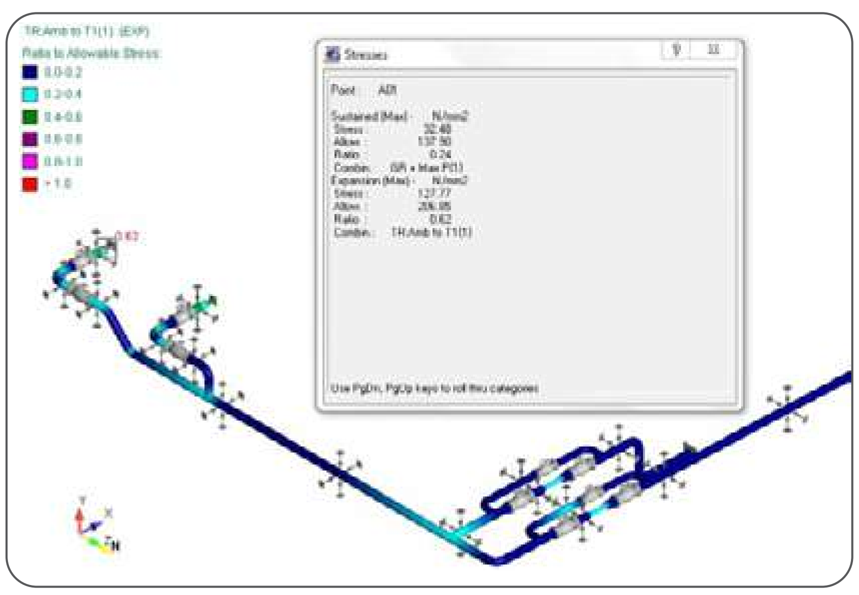
Objective:

Pipe systems with reciprocating pumps are critical factor in the reliability of systems. Excessive vibrations may lead to fatigue and cause damage to vital parts of installations. Pressure pulsations and mechanical vibrations may cause excessive noise and may even lead to damage. The analysis is done for load case in which pumps are running at its full rated speed for suction and discharge lines. Shake Forces generated due to pressure waves are used as an input for this analysis. This design approach in conjunction with pulsation simulation is required to couple technical analysis of piping system to ensure that the piping will have adequate supports and clamps to maintain mechanical natural frequency.



Discharge network with reciprocating triplex pumps

Modeling & Analysis:

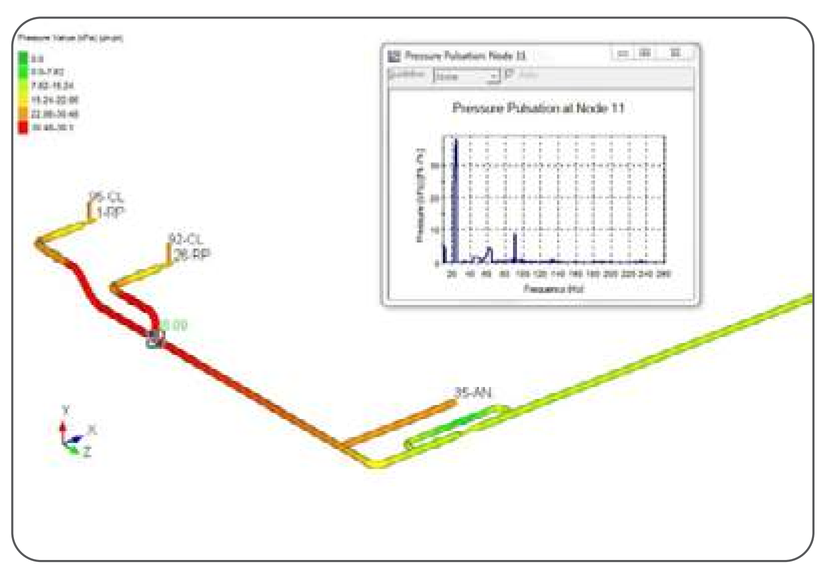


Discharge Network with Stresses

The first design approach involved pulsation and vibration control through the use of good piping layout and support principles, adequate suction pressure and use of pulsation control devices such as dampers, accumulators, hydraulic isolators, inhibitors, acoustic filters and selected piping configurations. To control detrimental pulsation and vibrations, the API standard 674, 3rd edition and API 618 for compressors are used. The acoustical characteristics of the entire pump system, including pumps and all interconnecting piping is simulated. The simulation method should evaluate the effectiveness of selected pulsation control devices. Pulsation analysis is performed using Bentley PULS software and Mechanical vibration analysis using Bentley AUTOPIPE.

Outputs:

- ☞Pressure Pulsation at different nodes.
- ☞Design modification like additional supports to reduce stress.
- ☞Forces & Moments acting on each support in all 3 directions.
- ☞Stress isometric for piping network.
- ☞Structural steel support for Piping system to sustain various loads.
- ☞Marked AutoCAD drawings with support locations & additional supports & other design modifications.

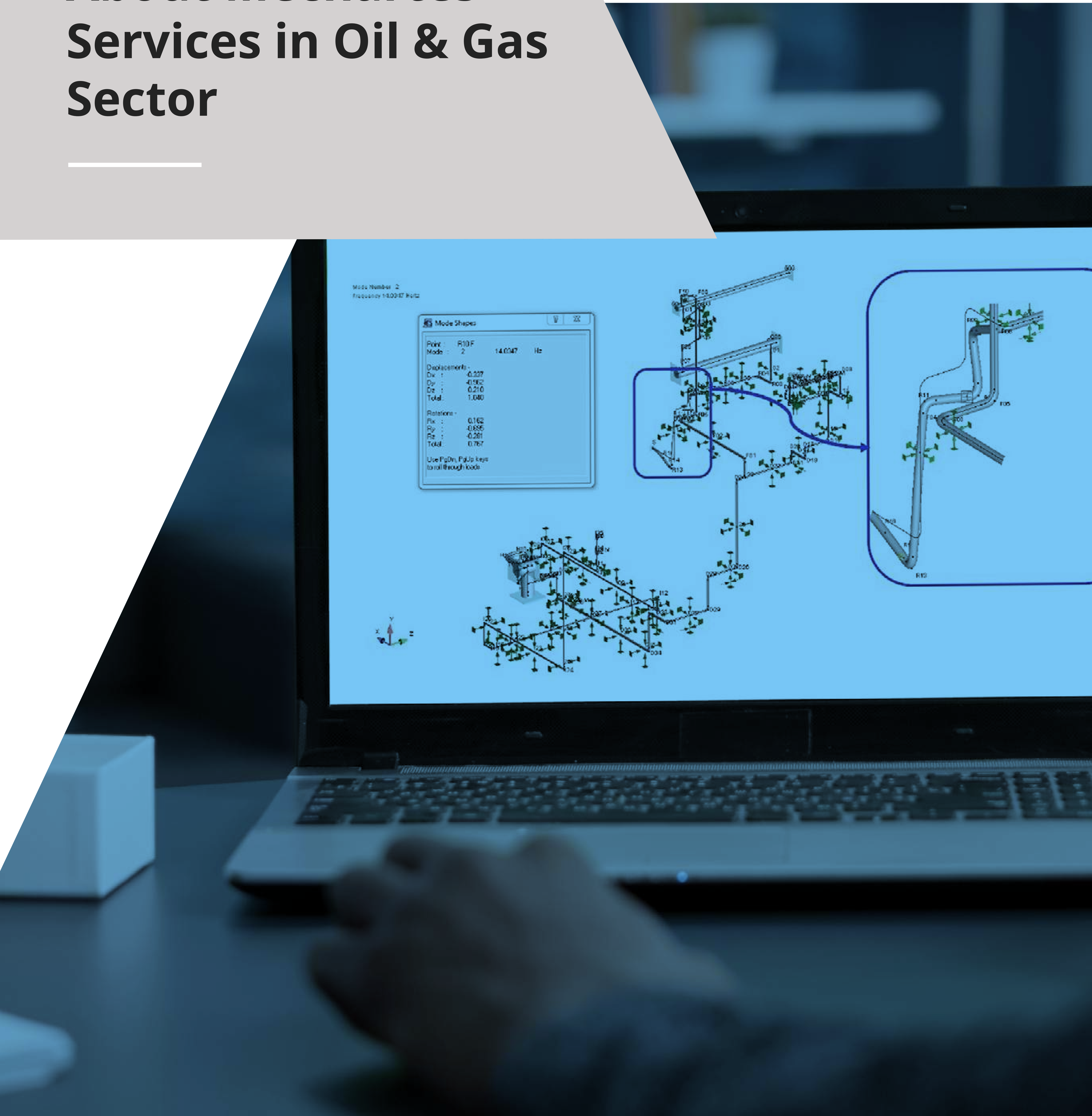


Contour Plots of Temperature in horizontal plane

Selected List of Similar Projects:

- ☞ Multiple sites in Assam, ONGC/EIL - Pulsation & Mechanical Vibration Analysis.
- ☞ Reliance Industries - Pulsation & Mechanical Vibration Analysis for pumps & compressors.
- ☞ Kuwait Oil Corporation - Pulsation & Mechanical Vibration Analysis.

About Mechartes Services in Oil & Gas Sector



About Mechartes Services in Oil & Gas sector

- Single & Multiphase Separator CFD and FEA Analysis
- API 650 AND 620 Storage Tank Mechanical and Structural Design.
- API 674 AND API 618 Based Pulsation and Mechanical Vibration Study.
- Root Cause Analysis
- FIV, FIT, AND FIAV STUDY
- Piping Stress & Support design
- Surge and Slug Analysis
- Mixer and Agitator Design Analysis
- Maldistribution Study
- FEA for Pressure Vessel and Internals

Contact US

Global Sales Office

Mechartes International FZC
PO Box 125396, Dubai, UAE.

+971 4 381 2060

+971 56 1156701 +971 56 1156702

srihari@mechartes.com sales@mechartes.com

Global Engineering Office

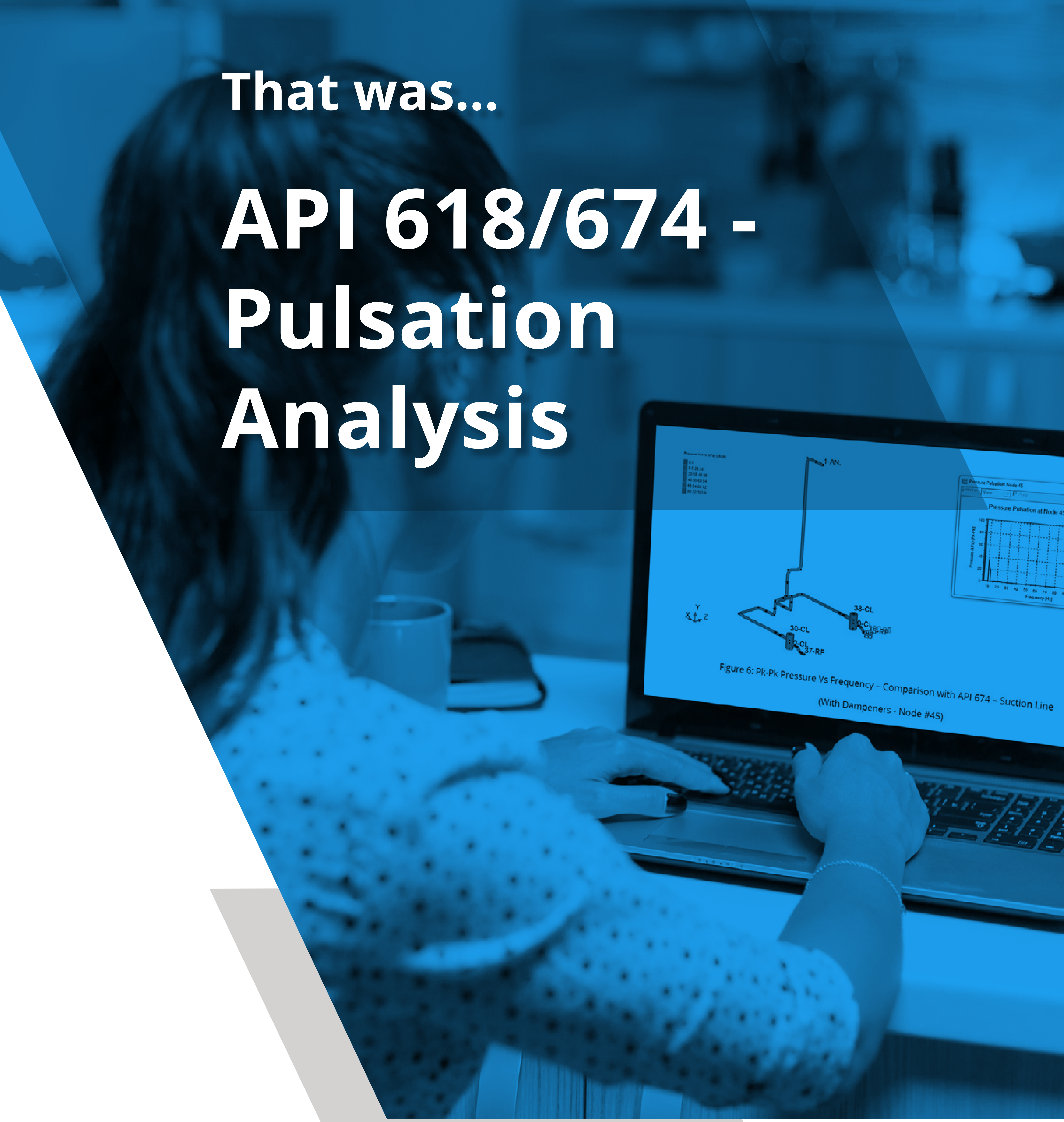
Mechartes Researchers Pvt. Ltd.
D-57, Sector 6, NOIDA, Uttar Pradesh, India - 201301

+91 120 454 0208 +91 120 413 1889

+91 880 017 7554 contact@mechartes.com

That was...

API 618/674 - Pulsation Analysis



Mechartés

SIMULATION EXPERTS