Piping Stress Analysis

Piping Engineering

INTRODUCTION

STRESS ANALYSIS IN PIPING SYSTEM

"PIPING SYSTEMS" ARE COMPOSED OF PIPING, VALVES, FITTINGS AND OTHER ACESSORIES WHICH HAVE THE OBJECTIVE OF TRANSPORTING FLUIDS (LIQUID OR GAS) BETWEEN DIFFERENT POINTS OF THE INDUSTRIAL SITE.

CONSIDERING THE RESTRAINTS IMPOSED BY THE SUPPORTS OR/AND EQUIPMENT's NOZZLE EVERY PIPING HAS THE MECHANICAL BEHAVIOUR OF A STRUCTURE, WHICH MEANS THAT IT'S SUBJECT TO STRESS AS TRACTION, SHEAR, TORSIONAL, ETC.

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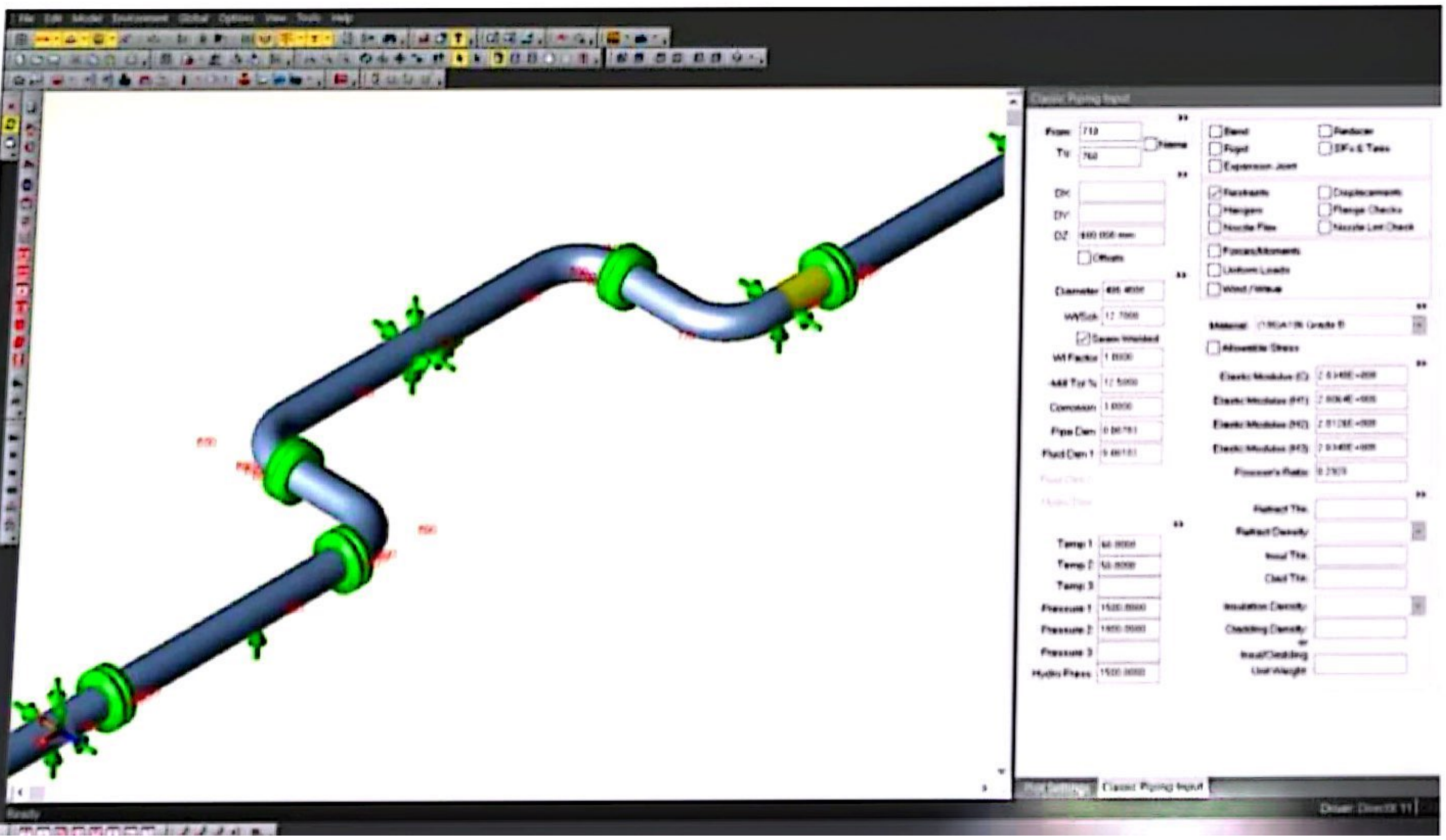
STRESS ANALYSIS IN PIPING SYSTEM



MAIN ACTING LOADS ON PIPING

STRUCTURAL:

- **PIPING WEIGHT;**
- **FLUID WEIGHT;**
- **THERMAL INSULATION WEIGHT;**
- **INTERNAL COATING WEIGHT;**
- **VALVE AND ACESSORIES WEIGHT;**
- **THERMAL CONTRACTION/EXPANSION OF PIPING;**
- **THEMAL CONTRACTION/EXPANSION OF EQUIPMENT;**
- **INTERMEDIATE RESTRICTIONS;**

"NON-STRUCTURAL":

- **INTERNAL PRESSURE;**
- **EXTERNAL PRESSURE;**

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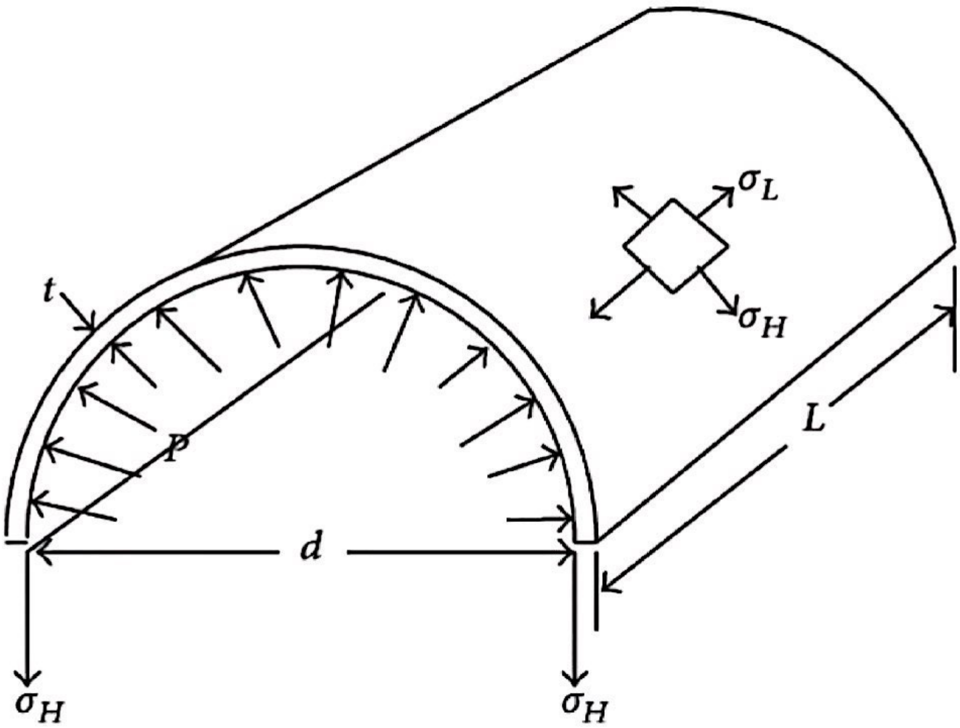
STRESS ON PIPING



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STRESS ON PIPING

HOOP STRESS:

THIS TENSION IS PERPEDINCULAR TO THE TO THE PIPING AXIS AND TEND TO CAUSE THE DISRUPTION OF PIPING ALONG THE GERETRIX. IT'S COMPOSED MAINLY BY THE INTERNAL PRESSURE.

$$\sigma_{h} = \frac{P.D}{2.t}$$

LONGITUDINAL STRESS:

THIS TENSION ACTS PARALLEL TO THE PIPING AXIS, IT TENDS TO CAUSE THE DISRUPTION ON THE CYLINDER AS A GUILLOTINE

$$\sigma_{l} = \frac{P.D}{4.t}$$

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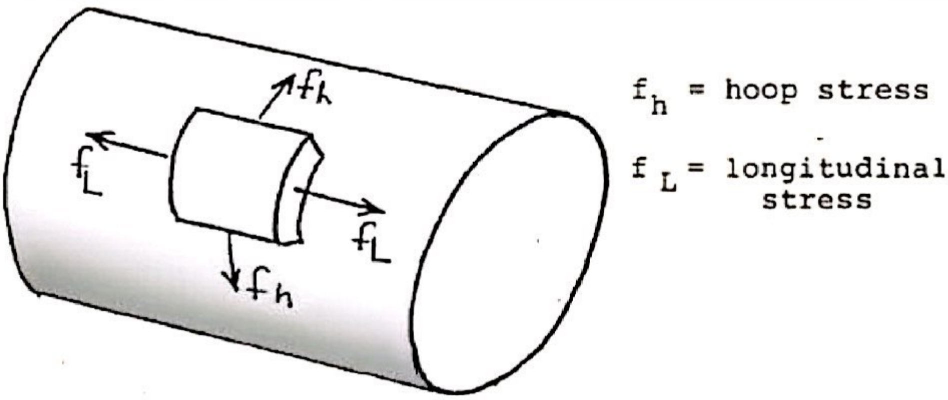
STRESS ON PIPING

$$\sigma_{h} = \frac{P.D}{2.t} \quad \sigma_{l} = \frac{P.D}{4.t}$$



Stresses acting on a cylindrical pressure vessel

$$\sigma_{h} = 2\sigma_{l}$$

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FAILURES DUE INTERNAL PRESSURE

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PRIMARY/SECONDARY LOADCASES

PRIMARY STRESS LOAD

CONTINUOUS OR PERMANENT LOADS WHICH ACTS ON PIPING AND MAINTAIN A CONSTANT VALUE FOR THE WHOLE TIME THAT REQUEST IS ACTING. PRODUCING DEFINING CONTINUOUSLY GROWING.

- MAINLY PRODUCED BY HOOP STRESS;

SECONDARY STRESS LOAD

IN PIPING SYSTEMS, THE MOST IMPORTANT SECONDARY LOADCASES ARE GENERATED FROM THE VARIATION OF TEMPERATURE ON MATERIAL AND TEND TO BECOMER LOWER WITH TIME DUE “STRESS RELAXION”. THESE ARE MAINLY PRODUCED BY:

- LONGITUDINAL STRESS DUE EXPANSION/CONTRACTION;
- SHEAR STRESS;

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ALLOWABLE STRESS ON PIPING

OUR ALLOWABLE STRESSES ARE BASED ON THE STANDARD ASME B31.3 – PROCESS PIPING

PRIMARY ALLOWABLE STRESS

1. THE MAXIMUM STRESS DUE INTERNAL OR EXTERNAL PRESSURE *(Sp máx)* SHALL NOT BE GREATER THAN THE ALLOWABLE STRESS FOR THE MATERIAL IN THE CONSIDERED TEMPERATURE (*Sh*) – TABLE A1M FROM ASME B31.3.

$$1.\ S_p m\acute{a}x \leq S_h$$

2. THE SUM OF THE PRIMARY LONGITUDINAL STRESS FROM PRESSURES, WEIGHT, OVERWEIGHT AND ANOTHER PERMANENT LOADS *(Se)* (WITH EXCEPTION TO SECUNDARY LOADS) SHALL NOT BE GREATER THAN THE ALLOWABLE STRESS FOR THE MATERIAL IN THE CONSIDERED TEMPERATURE (*Sh*) – TABLE A1M FROM ASME B31.3..

$$2.\ \sum S_e \leq S_h$$

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MINIMUM WALL THICKNESS CALCULATION

BASED ON ASME B31.3 – PROCESS PIPING

THIS EXPRESSION CORRELATES THE PRESSURE WITH THE MINIMUM WALL THICKNESS; BASED ON THAT WE ARE ABLE TO CALCULATE THE MAXIMUM PRESSURE THAT A PIPING CAN WORK BASED ON THE REMAINING WALL THICKNESS.

ALSO IT'S POSSIBLE TO CALCULATE THE MAXIMUM STRESS FOR A PIPING WITH "*t*" WALL THICKNESS SUBMITTED TO INTERNAL PRESSURE "*P*".

$$t_m = \frac{1}{1-0,125}\ t = 1,143\left[\frac{PD}{2\ (S_h E + PY)} + C\right]$$

$$S = \frac{P\left[1,143\ D + Y(2,286\ C - 2\ t)\right]}{2\ E(t - 1,143\ C)}$$

P = pressão interna de projeto.
D = diâmetro externo; d = diâmetro interno.
S_h = tensão admissível do material na temperatura de projeto.

E = coeficiente de eficiência de solda, válido para o caso dos tubos com costura; para os tubos sem costura, $E = 1,0$. São os seguintes os valores desse coeficiente de acordo com a norma ASME B 31:

Tubos com costura por solda de topo, totalmente radiografada: $E = 1,0$
Tubos com costura por solda de topo, radiografia parcial: $E = 0,90$
Idem, sem radiografia, solda pelos dois lados: $E = 0,85$
Idem, idem, solda por um só lado: $E = 0,80$

Y = coeficiente de redução de acordo com o material e a temperatura do tubo. Para tubos de aço-carbono e de outros aços ferríticos, em temperaturas até 485°C (900°F), temos $Y = 0,4$, e para tubos de ferro fundido $Y = 0$. Os valores desse coeficiente estão também tabelados na norma ASME B 31.

C = soma das margens para corrosão, erosão, e abertura de roscas e de chanfros.

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ALLOWABLE STRESS ON PIPING

OUR ALLOWABLE STRESSES ARE BASED ON THE STANDARD
ASME B31.3 – PROCESS PIPING

SECONDARY ALLOWABLE STRESS

1. THE STRESS RESULTED FOR THE VARIOUS SECUNDARY STRESS (EXPANSIONS, CONTRACTION, MOVEMENTS, ETC.) SHALL BE LOWER THAN THE S_A (ALLOWABLE DISPLACEMENT STRESS RANGE) AS FOLLOWING EXPRESSION:

$$S_A = f\,(1.25 S_c + 0.25\, S_h)$$

SA = Allowable Stress Range Displacement (MPa);
f = Stress range factor;
Sc = Basic Allowable Stress Range at Minimum Temperature (MPa);
Sh = Basic Allowable Stress Range at Maximum Temperature (MPa);

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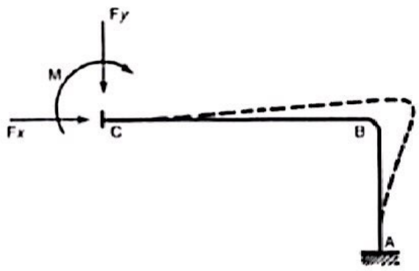
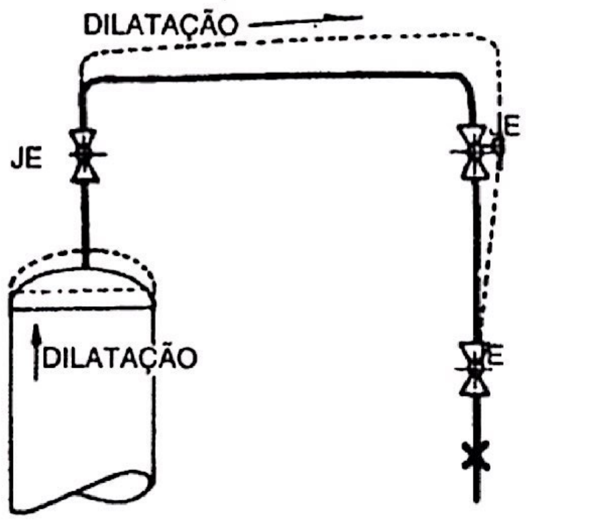
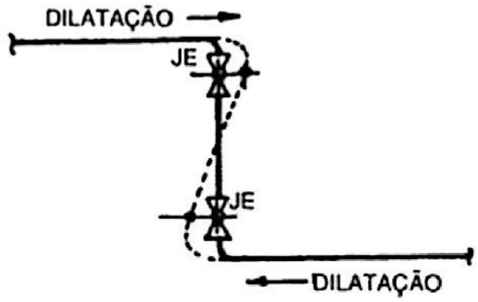
PIPING FLEXIBILITY

THE TEMPERATURE VARIATION ON PIPING WOULD NOT BE A PROBLEM TO "PIPING STRUCTURE" IF THE EXTREMITS WERE FREE TO MOVE. HOWEVER, THE EXISTENCE OF EXTERNAL RESTRICTIONS OF MANY TYPES APPLY STRESSES TO PIPING WHICH NEED TO BE ASSESSED AND CONTROLED.







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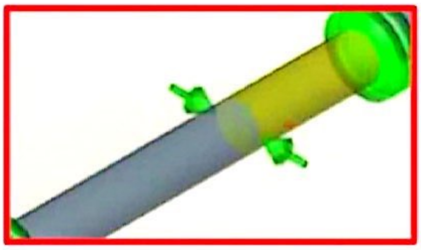
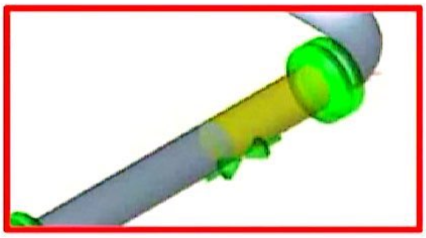
PIPING RESTRAINTS

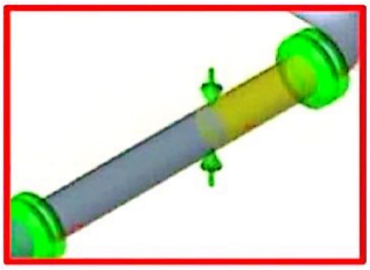
THE MOST IMPORTANT TYPES OF ARE ANCHORS, GUIDES, STOPS AND RESTING WHICH SHALL BE APPLIED TO PIPING IN ORDER TO CONTROL DEFORMATION.



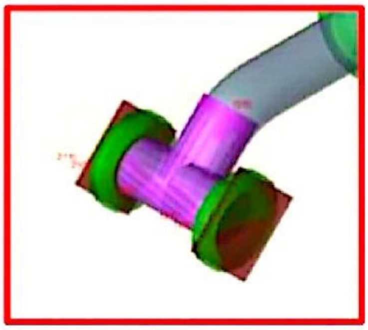
GUIDE



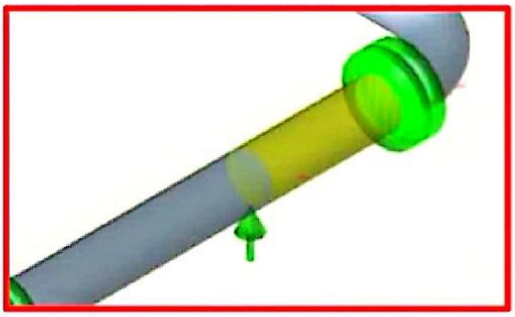
STOP / LIM



HOLD DOWN



ANCHOR



RESTING

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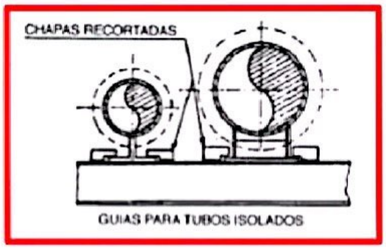
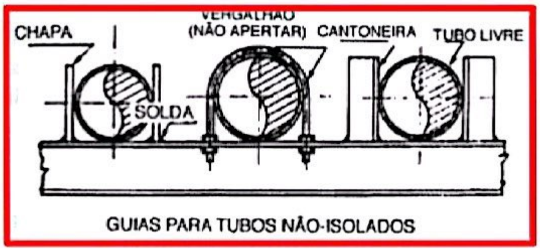
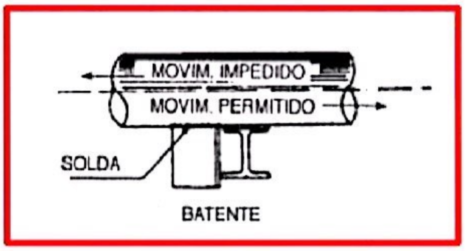
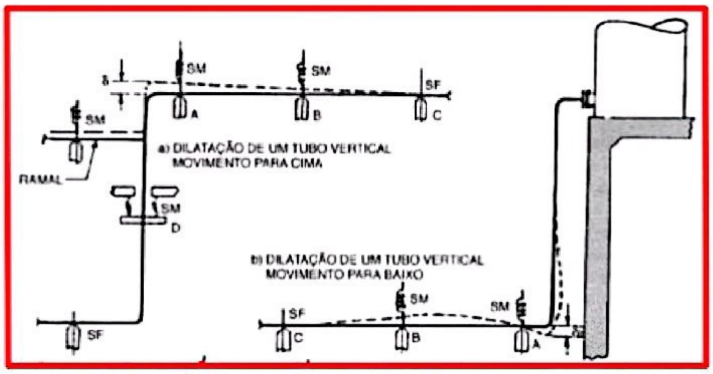
PIPING SUPPORTS

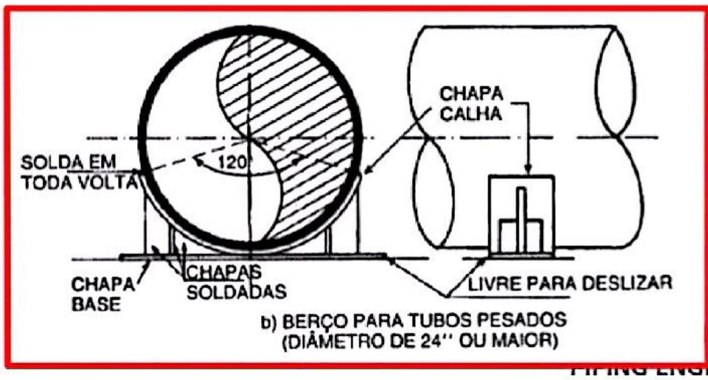
Pipe supports and hangers are devices which transfer the loads from the pipe or the structural attachment to the supporting structure or equipment. They include rod hangers, spring hangers, sway braces, turnbuckles, struts, anchors, saddles, rollers, brackets, and sliding supports. Structural attachments are elements that are welded, bolted, or clamped to the pipe, such as clips, lugs, clamps, clevises, and stops.











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Piping Vibration Analysis & Troubleshooting

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INTRODUCTION

VIBRATION – THEORICAL DEFINITION

- **ANY MOTION THAT REPEATS ITSELF AFTER AN INTERVAL OF TIME IS CALLED VIBRATION OR OSCILLATION.**

- **THE VIBRATION OF A SYSTEM INVOLVES THE TRANSFER OF ITS POTENTIAL ENERGY TO KINETIC ENERGY AND OF KINETIC ENERGY TO POTENTIAL ENERGY, ALTERNATELY.**

- **IF THE SYSTEM IS DAMPED, SOME ENERGY IS DISSIPATED IN EACH CYCLE OF VIBRATION AND MUST BE REPLACED BY AN EXTERNAL SOURCE IF A STATE OF STEADY VIBRATION IS TO BE MAINTAINED.**

Mechanical vibrations / Singiresu S. Rao. 5th ed.

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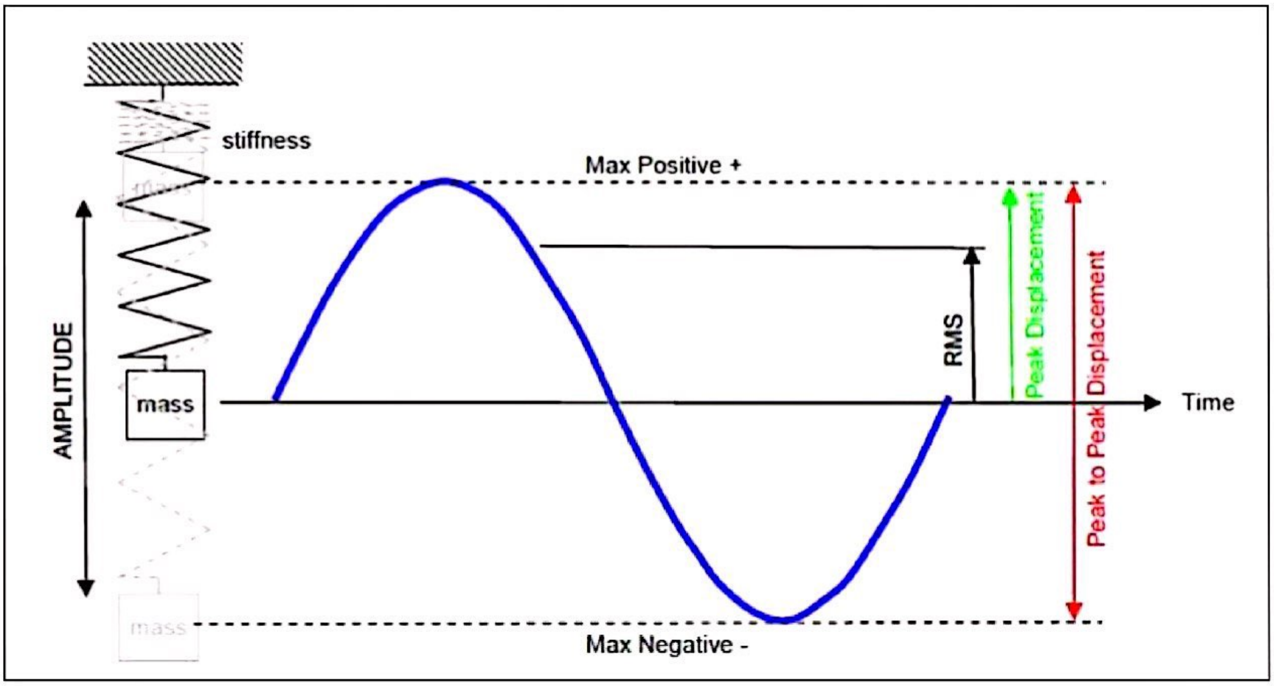
INTRODUCTION

VIBRATION – THEORICAL DEFINITION



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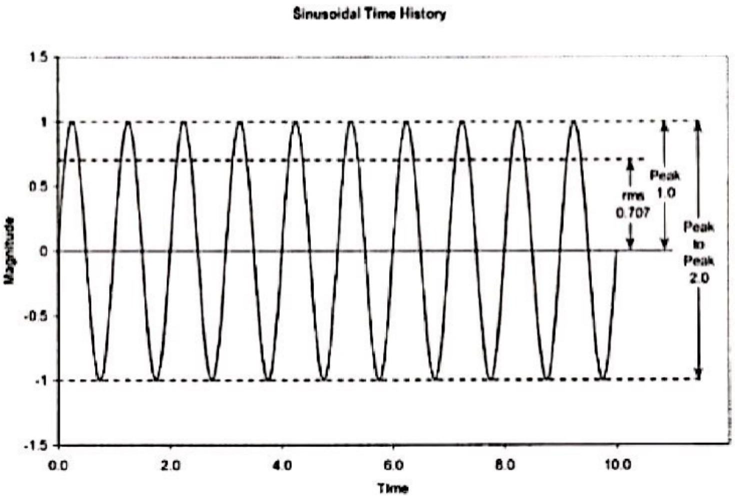
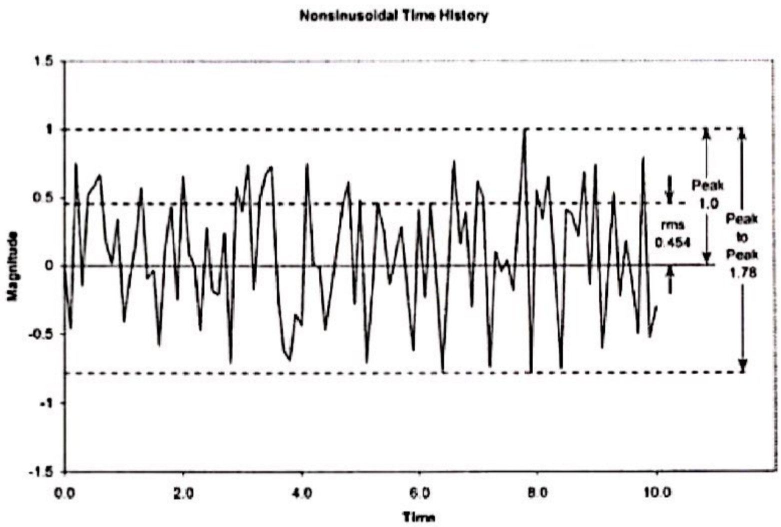
VIBRATION – THEORICAL DEFINITION





$$\text{Natural frequency: } f_n = \frac{1}{2\pi}\sqrt{\frac{\text{spring stiffness}}{\text{mass}}}$$

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VIBRATION – RESSONANCE

TACOMA BRIDGE

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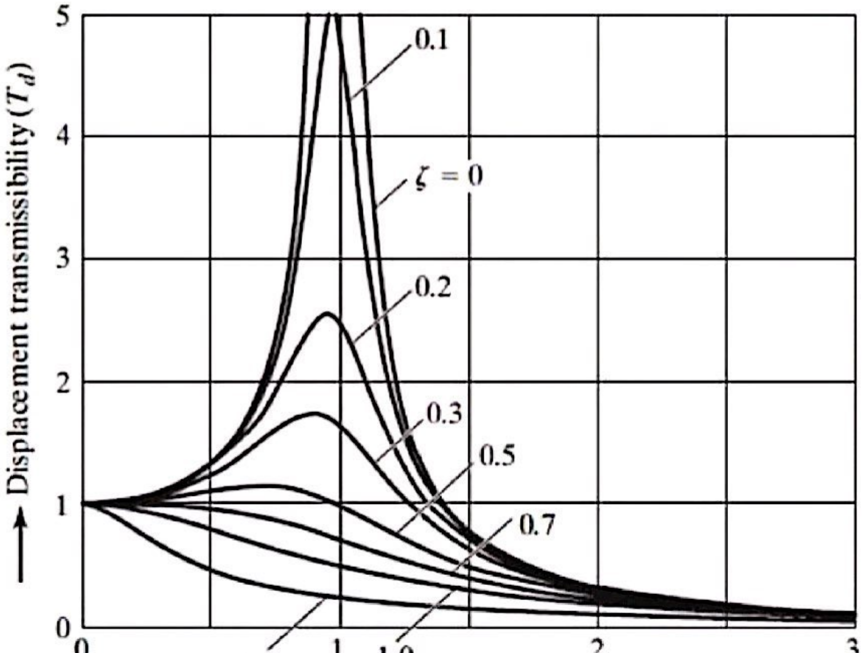
INTRODUCTION

VIBRATION – RESSONANCE



$$r = \frac{\omega}{\omega_n}$$

damping ratio ζ

$$r = \sqrt{1 - 2\zeta^2}$$

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INTRODUCTION

REDUTION OF VIBRATORY MOTION OF THE MASS

1. The displacement transmissibility increases to a maximum value at (Eq. (3.33)):

$$r = \sqrt{1 - 2\zeta^2} \tag{9.97}$$

Equation (9.97) shows that, for small values of damping ratio ζ, the displacement transmissibility (or the amplitude of the mass) will be maximum at $r \approx 1$ or $\omega \approx \omega_n$.

Thus the value of $r \approx 1$ is to be avoided in practice. In most cases, the excitation frequency ω is fixed and hence we can avoid $r \approx 1$ by altering the value of the natural frequency $\omega_n = \sqrt{\frac{k}{m}}$ which can be accomplished by changing the value of either or both of m and k.

2. The amplitude of the mass, X, approaches zero as r increases to a large value. The reason is that at large values of r, the applied force $F(t)$ varies very rapidly and the inertia of the mass prevents it from following the fluctuating force.

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VIBRATION ANALYSIS OF PIPING SYSTEMS

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INTRODUCTION

PIPING VIBRATION IS TIPICALLY DIVIDED IN TWO TYPES:

- **STEADY-STATE VIBRATION**

PIPING STEADY-STATE VIBRATION CAN BE DEFINED AS REPETITIVE VIBRATION THAT OCCURS FOR RELATIVELY LONG TIME PERIOD.

- **DYNAMIC-TRANSIENT VIBRATION**

DIFFERING FROM THE STEADY-STATE VIBRATION IT OCCURS FOR RELATIVELY SHORT TIME PERIODS AND IS USUALLY GENERATED BY MUCH LARGER FORCES.

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STEADY-STATE VIBRATIONS

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STEADY-STATE VIBRATIONS

CAUSES:

- CAVITATION OR FLASHING
- FLOW-TURBULENCE
- ROTATING OR RECIPROCATING EQUIPMENT
- VORTEX SHEDDING

EFFECTS:

- MATERIAL FATIGUE / CRACKS
- PIPING FAILURE
- SMALL BORE CONNECTION FAILURE
- MECHANICAL FAILURE OF ATTACHED EQUIPMENT
- INSTRUMENTATION FAILURE

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EXCITATION MECHANISMS

FLOW INDUCED TURBULENCE

FLOW TURBULENCE WILL GENERALLY HAVE A BROABAND OF FREQUENCIES RANGING FROM 0 TO 30 HZ AND THE TURBULENCE MAGNITUDE WILL GENERALLY INCREASE AS THE FLOWRATE IS INCREASED. SIGNIFICANT STRUCTURAL FREQUENCIES OF MOST PIPING SYSTEMS ALSO RANGE FROM 0 TO 30 HZ.

TURBULENCE WILL THEREFORE CAUSE ALL PIPING TO VIBRATE TO SOME DEGREE; HOWEVER, PIPING VIBRATION PROBLEMS USUALLY DO NOT RESULT IN MAJOR PROBLEM UNLESS A STRUCTURAL FREQUENCY IS EXCITED.

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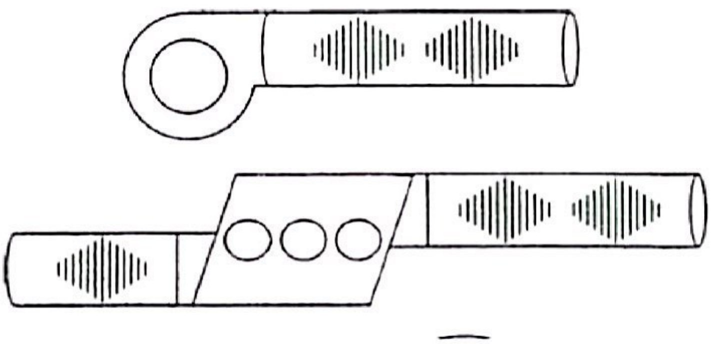
EXCITATION MECHANISMS

PUMP-INDUCED PULSATION

PUMP-INDUCED PRESSURE PULSATIONS OCCUR AT DISTINCT FREQUENCIES, WHICH ARE MULTIPLES OF THE PUMP SPEED. PULSATIONS ORIGINATE AT THE PUMP AND TRAVEL THROUGHOUT THE ENTIRE DISCHARGE PIPING. IN SOME INSTANCES, ESPECIALLY WITH RECIPROCATING PUMPS, PULSATIONS MAY ALSO BE INDUCED IN SUCTION PIPING.

THE EFFECTS OF PRESSURE PULSATIONS CAN BE MORE SEVERE WHEN THEY COINCIDE WITH AN ACOUSTICAL AND/OR STRUCTURAL FREQUENCY OF THE PIPING.



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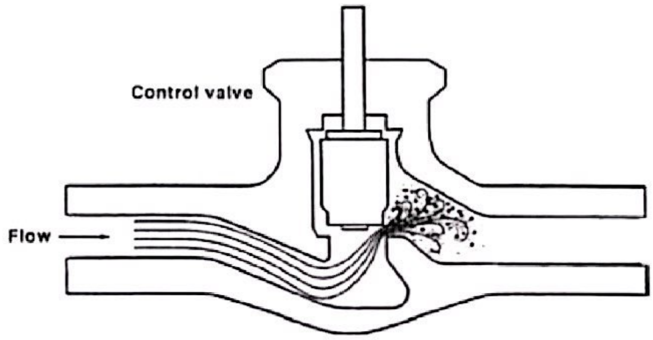
EXCITATION MECHANISMS

CAVITATION

CAVITATION COMMONLY RESULT FROM OVERTHROTTLING OF CONTROL VALVE AS SLIDE IMAGE. IT RESULTS IN BROADBAND-PRESSURE PULSATIONS, WHICH CAN CAUSE SEVERE VIBRATION AT THE CAVITATING COMPONENT AND THE PIPING DOWNSTREAM OF THE COMPONENT.

CAVITATION WILL ALSO WEAR AND ERODE PIPING AND COMPONENTS; IT TYPICALLY IS CATEGORIZED BY A LOUD CRACKLING NOISE. OTHER EXAMPLES OF WHEN CAVITATION CAN OCCUR ARE USING BLOCK VALVES FOR FLOW CONTROL, TOO-RAPID PRESSURE REDUCTIONS AT FLOW ORIFICES OR PRESSURE-REDUCING VALVES, AND SUDDEN FLOW TERMINATION FROM A PUMP TRIP.



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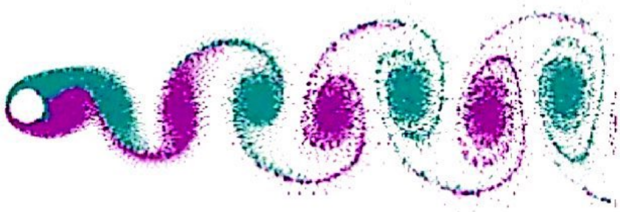
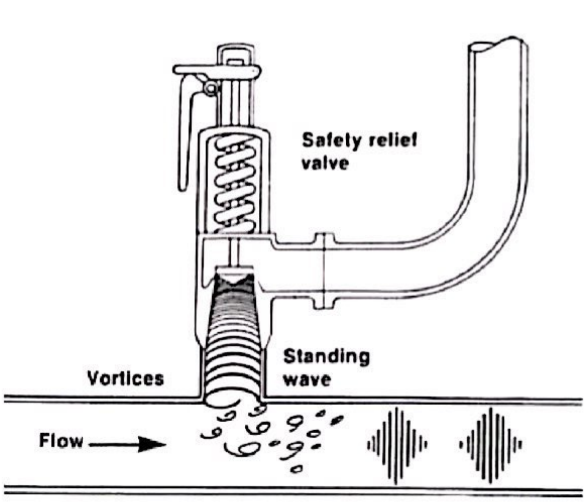
EXCITATION MECHANISMS

<u>VORTEX SHEEDING</u>

PRESSURE PULSATIONS RESULTING FROM VORTEX SHEDDING OCCUR AT DISTINCT FREQUENCY BANDS. PULSATION FREQUENCY IS PROPORTIONAL TO FLOW VELOCITY; THEREFORE, THE FREQUENCY WILL VARY WITH THE SYSTEM FLOW. VORTEX SHEDDING BECOMES SIGNIFICANT WHEN THE PULSATION FREQUENCY COINCIDES WITH THE PIPING ACOUSTICAL AND/OR STRUCTURAL FREQUENCY.





VORTEX SHEDDING AT A RELIEF VALVE

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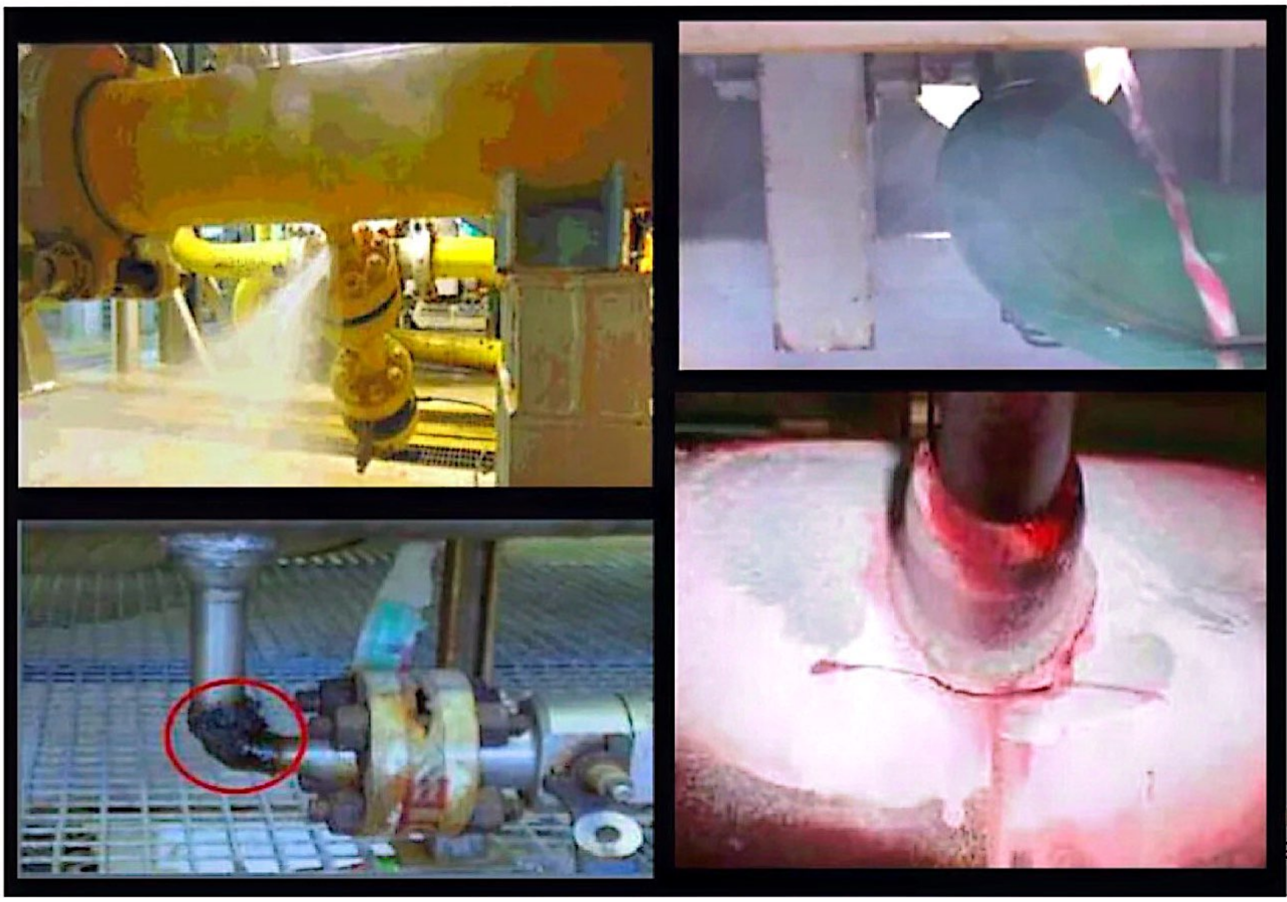
STEADY-STATE VIBRATIONS



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DYNAMIC-TRANSIENT VIBRATIONS

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DYNAMIC-TRANSIENT VIBRATIONS

CAUSES:

- RAPID PUMP START / TRIP
- QUICK CLOSING / OPENING OF CONTROL VALVES
- QUICK CLOSING OF CHECK VALVES DUE TRIP
- RAPID SAFETY/RELIEF VALVE OPENING

EFFECTS:

- LARGE PIPING DEFLECTIONS / DAMAGE
- DAMAGE TO SUPPORTS / INSULATION
- MECHANICAL FAILURE OF SMALL BORE
- MECHANICAL FAILURE OF ATTACHED EQUIPMENT

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DYNAMIC-TRANSIENT VIBRATION

WATER-HAMMER / STEAM-HAMMER

DYNAMIC-TRANSIENT VIBRATION, SUCH AS WATER- AND STEAMHAMMER, ARE SHORT-DURATION EVENTS TYPICALLY OCCURRING IN LESS THAN 1 SEC. BUT WITH DRAMATIC EFFECTS. LARGE, UNBALANCED FORCES CAN BE EXERTED ONTO THE PIPING; DAMAGE TYPICALLY OCCURS TO PIPING SUPPORTS AND RESTRAINTS, AND IN SEVERE CASES, THE PIPING ITSELF MAY ALSO BE DAMAGED.

SAYANO SHUSHENSKAYA
RUSSIAN ACCIDENT
DUE WATER HAMMER

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VIBRATION
RISK ASSESSM

PROACTIVE ASSESSEMENT

METHODOLOGY FOR NEW DESIGN:

1. QUALITATIVE ASSESSMENT AND PRIORITISATION
2. QUANTITATIVE ASSESSMENT
   - MAIN LINE
   - SMALL BORE CONNECTIONS
   - THERMOWELLS

LOF (LIKELIHOOD OF FAILURE)

THE LIKELIHOOD OF FAILURE IS A FORM OF SCOREING TO BE USED FOR SCREENING PUPORSES. THE LIKELIHOOD OF FAILURE IS NOT AN ABSOLUTE PROBABILITY OF FAILURE NOR AN ABSOLUTE MEASURE OF FAILURE.

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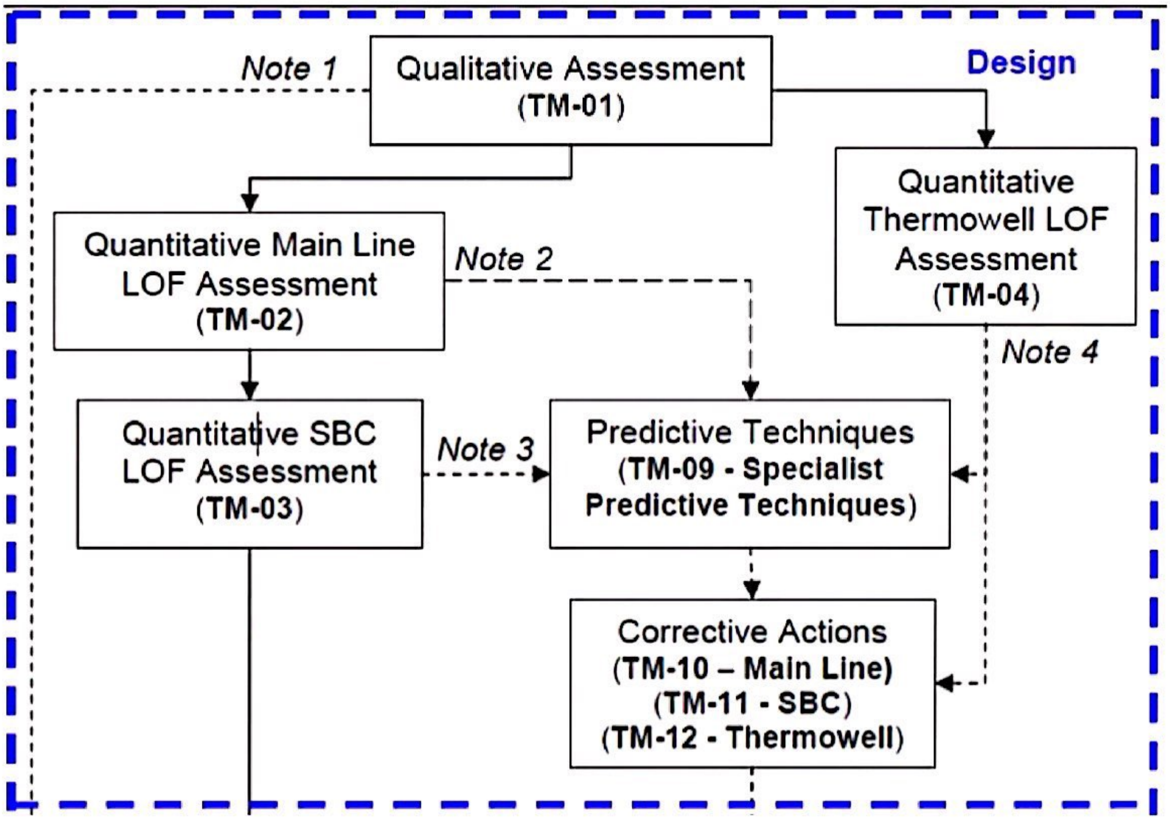
PROACTIVE ASSESSEMENT



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PROACTIVE ASSESSEMENT

AFTER THE LOF ASSESSMENT, SCORE VALUES WILL BE PROVIDED TO EACH CHECKED SYSTEM.

D.2.7 Summary and Interpretation of Main Line LOF Scores

Stream (Sub system) Pipe dimensions	4 (supply to cooler) 14" (sch STD)	5 (supply to suction scrubber) 14" (sch STD)	6 (compressor suction) 14" (sch STD)	7 (compressor discharge) 8" (sch 120)	Recycle line (compressor discharge) 8" (sch 120)	Recycle line (compressor suction) 6" (sch STD)	Relief line (upstream of PSV) 4" (sch 120)	Relief line (downstream of PSV) 6" (sch STD)
Flow induced turbulence	0.01	0.01	0.01	0.02	0.02	0.28	0.34	0.88
Flow induced pulsation	0.2	0.2	0.2	1.0 recycle line	n/a	n/a	0.29	1.0 2 bypass
High frequency acoustic excitation	n/a	n/a	n/a	n/a	0.29	0.29	n/a	0.29
Mechanical excitation	n/a	n/a	0.4	0.4	0.4	n/a	0.4	n/a
Surge / momentum changes	n/a	n/a	0.22	n/a	n/a	n/a	[illegible]	[illegible]

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PROACTIVE ASSESSEMENT

BASED ON SCORE VALUES, ACTIONS WILL BE TAKEN BASED ON THE GUIDELINE ASSESSEMNT TO AVOID FUTURE PROBLEMS DUE VIBRATION.

Main Line LOF ≥ 1.0

A summary of the actions required for a main line LOF score ≥ 1.0 are given below.

Score	Action	Technical Module
LOF ≥ 1.0	The main line shall be redesigned, resupported or a detailed analysis of the main line shall be conducted, and vibration monitoring of the main line shall be undertaken (***Note 1***)	TM-09 TM-07/TM-08
	Corrective actions shall be examined and applied as necessary	TM-10
	Small bore connections on the main line shall be assessed.	TM-03
	A visual survey shall be undertaken to check for poor construction and/or geometry and/or support for the main line and/or potential vibration transmission to neighbouring pipework.	TM-05 TM-06

Score	Action	Technical Module
1.0 > LOF ≥ 0.5	The main line should be redesigned, resupported or a detailed analysis of the main line should be conducted, or vibration monitoring of the main line should be undertaken (***Note 1***)	TM-09 TM-07/TM-08
	Corrective actions should be examined and applied as necessary	TM-10
	Small bore connections on the main line shall be assessed.	TM-03
	A visual survey shall be undertaken to check for poor construction and/or geometry and/or support for the main line and/or potential vibration transmission to neighbouring pipework.	TM-05 TM-06

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REACTIVE ASSESSMENT

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VISUAL INSPECTION - LINE WALK DOWN

THE PIPING ENGINEER WALKS DOWN THE LINE ATTEMPTING TO CAPTURE SPECIFIC ASPECTS ASSOCIATED WITH THE GEOMETRY AND MAINTENANCE OF THE PIPE, AND ASSOCIATED ELEMENTS, WHICH ARE INDICATIVE OF POTTENTUALLY FATIGUE SENSITIVE LOCATIONS AND WHERE SUFFICIENT LEVELS OF EXCITATION MIGHT BE PRESENT.

- HIGH VIBRATION?
- HIGH NOISE?
- FREETTING DAMAGE?
- POOR PIPING GEOMETRY?
- PIPE SUPPORT BAD CONDITION?
- MECHANICAL DAMAGE?

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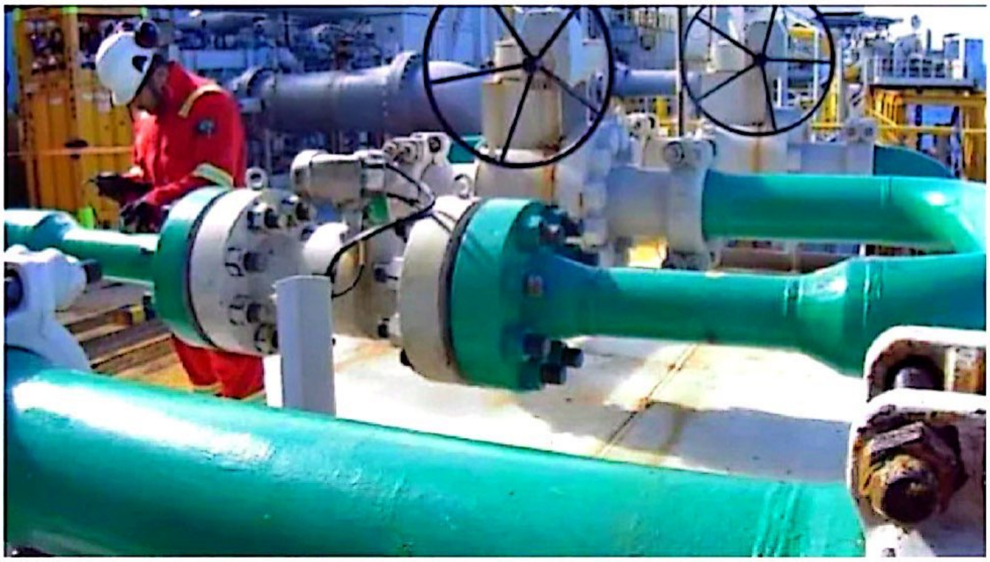
VIBRATION MEASUREMENT

THE USE OF VIBRATION VELOCITY MEASUREMENTS PROVIDES A SIMPLE METHOR FOR SCREENING A PIPING SYSTEM FOR POTENTIAL PROBLEMS.

SKF VIBRATION ANALYZER



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VIBRATION MEASUREMENT

STEPS TO BE FOLLOWED FOR VELOCITY MEASUREMENT:

- **VIBRATION MEASUREMENTS SHALL BE MADE IN DIFFERENT POINTS.**
- **THE POSITION OF THE TRANSDUCER SHOULD BE AT THE LOCATION EXHIBITING THE HIGHEST LEVEL OF VIBRATION; TIPICALLY MID SPAN OR UNSUPPORTED LOCATIONS.**
- **THE MAXIMUM VIBRATION LEVEL CAPTURED IN THE SAME POINT FOR THE THREE AXES SHOULD BE USED.**
- **FOR SMALL BORE CONNECTIONS MEASUREMENT SHALL BE PERFORMED AT THE END FLANGE OF THE ARRANGEMENT.**

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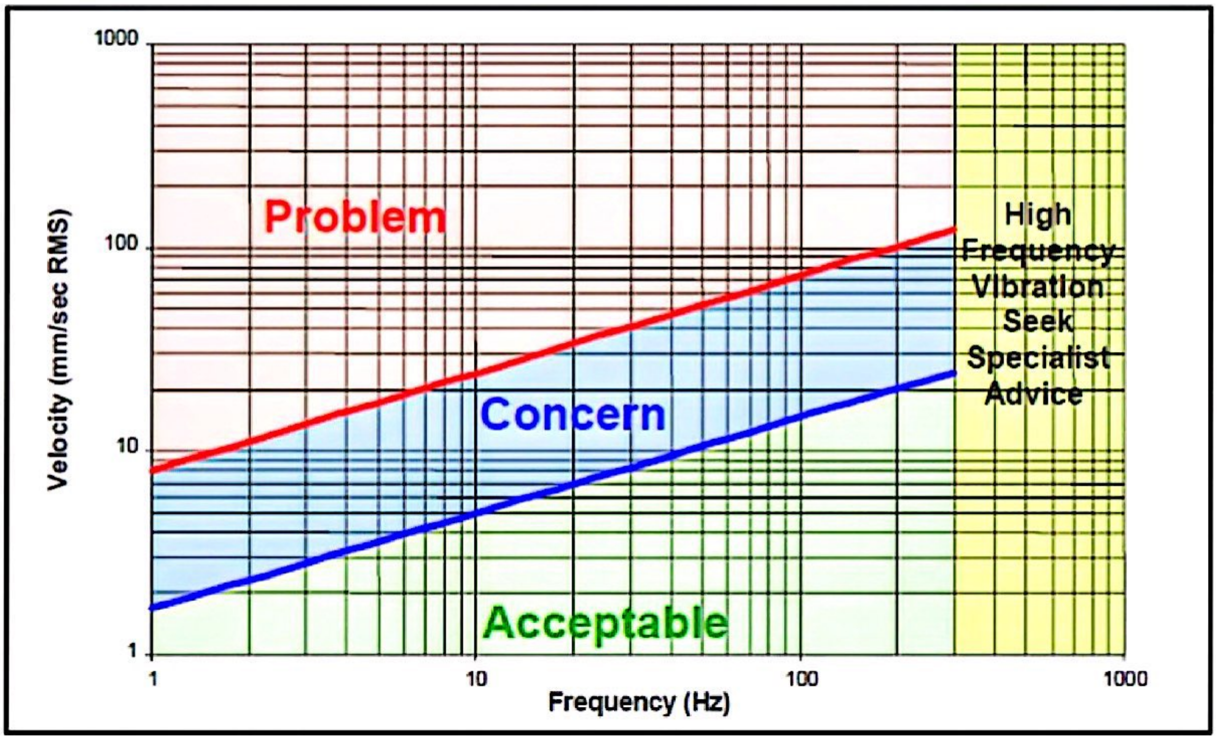
ASSESSMENT CRITERIA

THE COLLECTED POINTS MUST CHECKED USING THE ASSESSMENT CRITERIA BELOW, WHICH CLASSIFIES THE VIBRATION AS "PROBLEM", "CONCERN" OR ACCEPTABLE.



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ASSESSMENT CRITERIA

THE COLLECTED VALUES ARE INSERTED IN A COMPILED WORKSHEET THAT PERFORMS THE ASSESSMENT AND FEEDS THE GRAPHIC.

	WATER INJECTION I6 - 0-100 Hz RANGE					
Measured Peak frequency(Hz) (X):	10.000	1.500	15.000	1.500	1.500	19.000
Measured Peak velocity (mm/s) (Y):	1.000	6.500	1.000	6.000	15.000	1.000
Direction:	P1	P1	P1	P2	P2	P2
Related Point:	H	V	A	H	V	A
Range	0-100	0-100	0-100	0-100	0-100	0-100
CONCERN VIBRATION >= (mm/s)	4.96	2.03	6.00	2.03	2.03	6.71
PROBLEM VIBRATION >= (mm/s)	23.84	9.60	28.96	9.60	9.60	32.44
OK / CONCERN / PROBLEM	OK	CONCERN	OK	CONCERN	PROBLEM	OK

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ASSESSMENT CRITERIA

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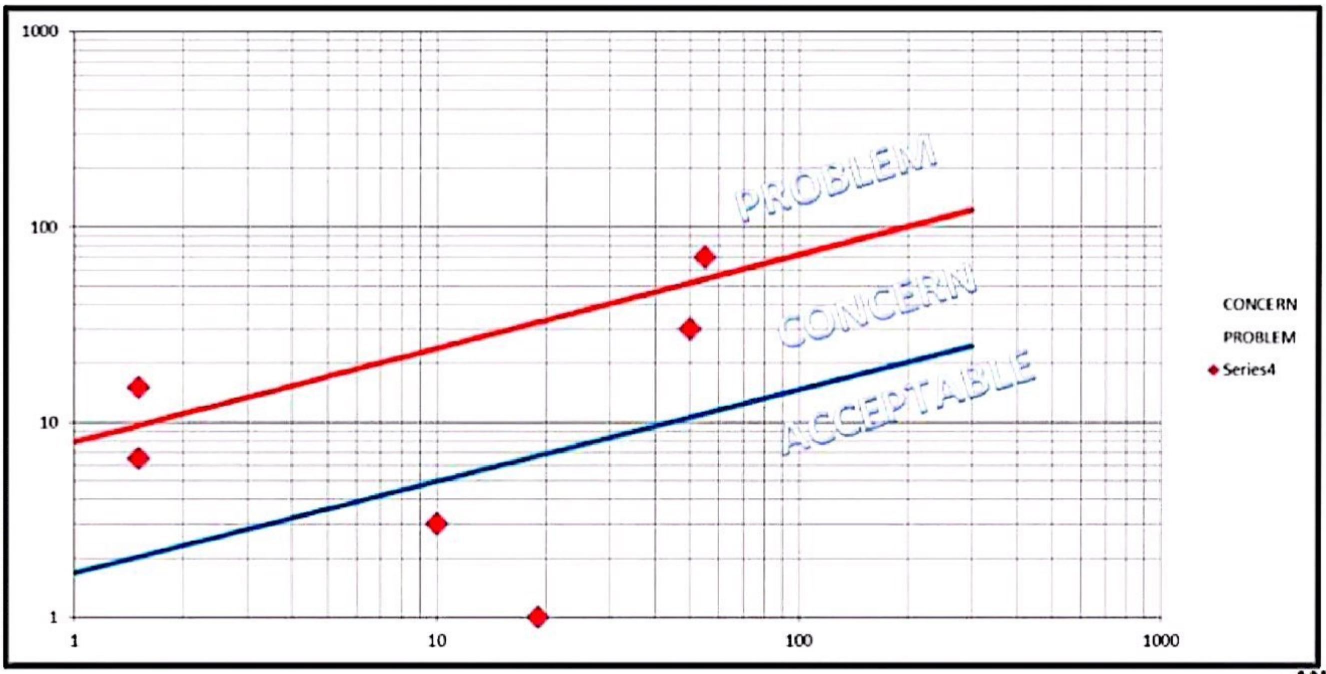

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