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Research Article

Dynamic Load Factor (DLF) Bonus Regarding Piping System

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Abstract

In this study a piping system has been investigated in terms of dynamic load factor as a useful tool that indicates the effect of dynamic response in design field by finding out the natural frequencies of the piping system that will be exited by a rotary machine for several subdivided cases. The natural frequencies have been found out for the piping with three cases (guide –guide , guide – fixed and fixed-fixed) taking into account the excitation and pulsation effects from a rotary machine where the value of lowest natural frequency (Wn) with run speed of this rotary machine (Ω) have been used in the equation of the dynamic load factor for undamped forced vibration, subsequently the effect of pulsation due to expected blast in the system has been discussed also , depending on illustrated fig . for triangular pulsation. A little consideration will show that a given data for the system have been considered to be in full compliance with API 5L for pipes , API 618 for reciprocating machine and with a well-known companies standards as a practical convenience , and then some points have been concluded for other several cases by estimating the (DLF).

Keywords: *DLF, Piping System etc.*

Introduction

Structural analysis is mainly concerned with finding out the behavior of a physical structure when subjected to force. In essence all these loads are dynamic. The distinction is made between the dynamic and the static analysis on the basis of whether the applied action has enough acceleration in comparison to the structure's natural frequency.

If a load is applied sufficiently slowly, the inertia forces (Newton's second law of motion) can be ignored and the analysis can be simplified as static analysis.

Structural dynamics is a type of structural analysis which covers the behavior of structures subjected to dynamic (actions having high acceleration) loading. A little consideration will show that the dynamic loads include people, wind, waves, traffic, earthquakes, and blasts or any exited sinusoidal effects. Any structure can be subjected to dynamic loading then the dynamic analysis can be used to find the dynamic load factor (DLF), dynamic response, time history, and modal analysis as indicator for a likelihood failure for any case study e.g. if the dynamic load factor is equal to 1.25 means that the dynamic deflection and stresses are 25% above those calculated by the static analysis (N. Datta *et al*, 2014) .

A dynamic analysis is also related to the inertia forces developed by a structure when it is excited by means of dynamic loads applied suddenly i.e. (pulsation effect) like wind blasts, explosion, earthquake.

Dynamic analysis for simple structures can be carried out manually, but for complex structures finite element analysis can be used to calculate the mode shapes and frequencies.

In this case study we focused on the natural frequencies for piping system related with excitation (as sinusoidal effect) or pulsation effects (for expected blast) of rotary machine , consequently the dynamic load factors have been investigated (DLF) as a powerful tool for design thereby some pointed have been illustrated .

Main procedure

Calculate the natural frequencies of the piping, preferably by the following equation, for straight pipes without free-hanging valves and other related weights; such that the following equation can be used for hand calculation of the piping natural frequencies (API 618 4th edition, 1995).

$$f_n = \frac{a}{2\pi L^2}\sqrt{\frac{EI}{m}} \qquad (1)$$

Where

f_n = natural frequency of the pipe (Hz)

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a = Fixation constant depending on boundary conditions and mode shapes (see table A).
L = Span length between pipe support guides or fixation support (m).
E = Young's modulus for pipe material (N/m^2)
I = moment of inertia (m^4)
m = Effective mass per until length of pipe (kg/m)

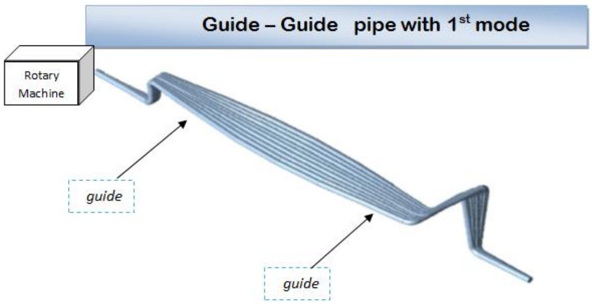


Figure 1 Guide – guide case with 1st mode

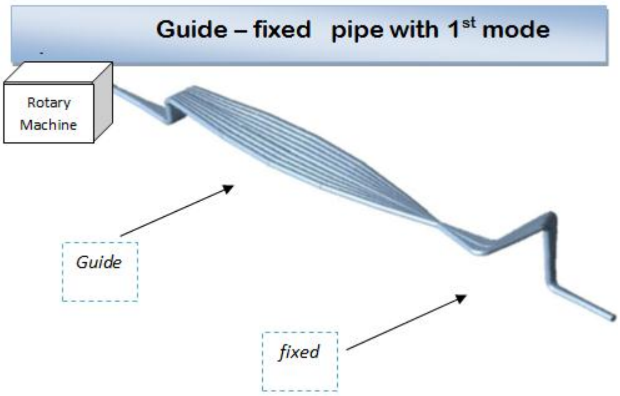


Figure 2 Guide –fixed case with 1st mode

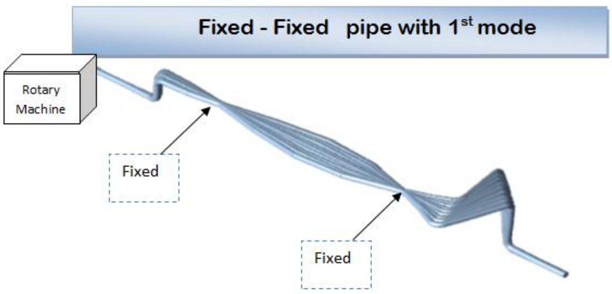


Figure 3 Fixed – fixed case with 1st mode

Case Study

The specifications of the case study have been indicated hereunder, a little consideration will show that all these data have been adopted depending on well-known companies and references:

1.6 inch (STD pipe), (i.e. O.D. =6.625 in), (X42)
2. Water filled weight (31.5 lb/ft) from tables of well-known companies, seeappendix (A).
3. ft = 0.3048 m,Lb = 0.45359 kg) [for unit conversion]
$1\frac{Lb}{ft} = \frac{0.45359\,kg}{0.3048m} = 1.488156\ \frac{kg}{m}$
$\therefore$ $(31.5\ Lb/ft = 46.87\ kg/m)$
4. W=$2\pi f$ =>f$_n$ = $\frac{a}{2\pi L^2}\sqrt{\frac{EI}{m_e}}$
5. I = 1.17136591 * 10^{-5} m^4
6. E = 200 Gpa = 200 * 10^9 N/M^2
7. Seamless pipeSH40(identical to STD)From API 618 and companies standard
8. Suggested max. span length =17 ft (i.e. (5.1816m)).

Case study according to boundary conditions

Referring to above mentioned specifications natural frequencies have been evaluated according to boundary condition and as following:

B.Cs.*(Guide- Guide)*

a = 9.87 (1st mode)
$f_n\,(Hz) = \frac{a}{2\pi l^2}\sqrt{\frac{EI}{m_e}} = \frac{9.87}{2\pi(5.1816)^2}\sqrt{\frac{200*10^9*1.17136591*10^{-5}}{46.87}}$
$f_n = \frac{9.87}{(5.1816)^2}(35.58) = 13.08$ Hz
$W_n = 2\pi f = 82.18\ rad/sec$

B.Cs.*(Guide- Fixed)*

a = 15.4 (1st mode)
$f_n\,(Hz) = \frac{a}{(5.1816)^2}(35.58) = 20.4$ Hz
W_n = 128.22 ra/sec.

B.Cs.*(Fixed - Fixed)*

a = 22.4(1st mode)
f_n(Hz) = 29.68 Hz
W_n =186.5 rad/sec.

Maximum Run speed of compressor (excitation frequencies)

The following excitation frequencies have been selected to be in full compliance with practical implementation:

900 RPM = 15Hz= 94.24 rad/sec.
1200 RPM = 20 Hz = 125.66 rad/sec.
1800 RPM = 30 Hz = 188.49 rad/sec.
3000 RPM = 50 Hz = 314.159 rad/sec

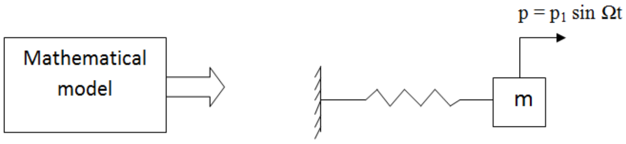
The Pulsation frequency (f) is derived from:

$F = \frac{rpm\ N}{60}$

rpm = machine speed.
N = the integer 1,2,3,...... corresponds to the foundational frequency and harmonics of rpm. (API 618 4th edition, 1995)

Assumptions

Suppose the mathematical model as undamped forced vib. (William T. Thomson, 2014), and assume a sinusoidal dynamic load (p) is applied to the system



$p = p_1 \sin \Omega t$

$m\ddot{x} + kx = p_1 \sin\Omega t$

$\ddot{x} + \frac{k}{m}x = \frac{p_1}{m}\sin\Omega t$ (2)

$x = x_p + x_c$

$x_p = c \sin \Omega t \dot{x}_p = c\Omega \cos \Omega t$

$\ddot{x}_p = - \Omega^2 \sin \Omega t$sub. ineq. (1)

$c\,\Omega^2 \sin \Omega t + \frac{k}{m}\, c \sin \Omega t = \frac{p_1}{m} \sin \Omega t$

$$\frac{k}{m} = w_n^2$$

$$(w_n^2 - \Omega^2)C = \frac{p_1}{m} \;=>\; C = \frac{p_1}{m(w_n^2 - \Omega^2)}$$

$$\therefore x_p = \frac{p_1}{m(w_n^2 - \Omega^2)}\sin\Omega t$$

$X_c = A \sin w_n t + B \cos w_n t$

$X = A \sin w_n t + B \cos w_n t + \frac{p_1}{m(w_n^2-\Omega^2)}\sin\Omega t$ (3)

B.Cs.at $t = 0$,$x = x_o = 0$

$\therefore B = 0$ sub. In eq. 2

Att $= 0, \dot{x} = x_o = 0$

$\dot{x}_o = 0 = Aw_n \cos w_n t - Bw_n \sin w_n t + \frac{p_1}{m(w_n^2-\Omega^2)}\cos\Omega t$

$A = \frac{-p_1}{w_n m(w_n^2-\Omega^2)}$ sub. in eq.(2)

$$X(t) = \frac{-p_1\Omega}{w_n m(w_n^2-\Omega^2)}\sin w_n t + \frac{p_1}{m(w_n^2-\Omega^2)}\sin\Omega t$$

$$X(t) = \frac{p_1\left(\sin\Omega t - \left(\frac{\Omega}{w_n}\right)\sin w_n t\right)}{m(w_n^2-\Omega^2)}$$

$$X(t) = \frac{p_1 \sin\Omega t - \left(\frac{\Omega}{w_n}\right)\sin w_n t}{m w_n^2\left(1-\left(\frac{\Omega}{w_n}\right)^2\right)}$$

$$X(t) = \frac{p_1/_k\left(\sin\Omega t - \frac{\Omega}{w_n}\right)\sin w_n t}{1-\left(\frac{\Omega}{w_n}\right)^2}$$

$$p_1/_k = x_s t$$

$$\text{DLF} = \frac{x(t)}{x_s t} = \frac{\sin\Omega t - \left(\frac{\Omega}{w_n}\right)\sin w_n t}{1-\left(\frac{\Omega}{w_n}\right)^2} \quad (4)$$

The following four case studied have been studied with more details whereby several concluded points pointed out:

***Case (a):*(** $\Omega = \mathbf{94.24}\ \boldsymbol{rad/sec}\ \boldsymbol{w} = \mathbf{128.22}\ \boldsymbol{rad/sec}$)

Since $\frac{\Omega}{w} = \frac{94.24}{128.22} = 0.73$

DLF $(Guide - Fixed) = \frac{\sin\Omega t - 0.73(\sin w_n t)}{1-(0.73)^2}$

DLF $= 2.14\sin(\Omega t) - 1.56 \sin w_n t$ (Forced Part) (Free Part)

DLF max.=3.7

Case (b): ($\Omega = \mathbf{94.24}\ \boldsymbol{rad/sec}\ \boldsymbol{w} = \mathbf{186.5}\ \boldsymbol{rad/sec}$)

DLF *(Fixed – Fixed)* $= \frac{\sin\Omega t - 0.5(\sin w_n t)}{1-(0.5)^2}$

$\frac{\Omega}{w} = \frac{94.24}{186.5} = 0.5$

DLF = $1.33 \sin(\Omega t)$-$0.666 \sin w_n t$

Forced Part) (Free Part) (DLF max.=2)

Case (c): ($\boldsymbol{\Omega} = \mathbf{125.66}\ \boldsymbol{rad/sec}\quad \boldsymbol{w} = \mathbf{128.22}\ \boldsymbol{rad/sec}$)

In case of compressor speed equal to 1200 RPM (125.66 rad/sec) we will select the*guide-fixed*case where W_n= 128.22 rad/sec(i.e. near to resonance case).

$\frac{\Omega}{w} = \frac{125.66}{128.22} = 0.98$ Critical

DLF $(Guide - Fixed) = \frac{\sin\Omega t - (0.98)\sin w_n t}{1-0.98^2}$

DLF = $25.25 \sin \Omega t - 24.74 \sin w_n t$ (Forced Part)(Free Part)

DLFmax. $\cong 50$

Case (d): ($\boldsymbol{\Omega} = \mathbf{125.66}\ \boldsymbol{rad/sec}\quad \boldsymbol{w} = \mathbf{186.22}\boldsymbol{rad/sec}$)

Ω= 125.66 rad\sec.

W= 186.22 rad\sec.

DLF $= \frac{\sin\Omega t - \left(\frac{\Omega}{w}\right)\sin w_n t}{1-\left(\frac{\Omega}{w}\right)^2}$

DLF (*Fixed – Fixed*)= $1.81 \sin \Omega t$- $1.21 \sin w_n t$ (Forced Part)(Free Part)

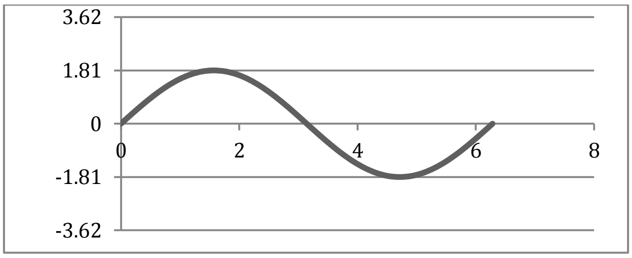


Figure 3 Forced Part $1.81 \sin \Omega t$

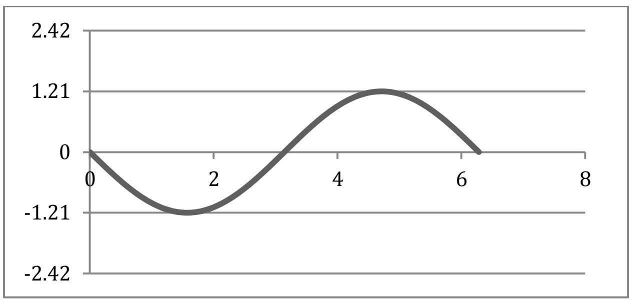


Figure 4 Free Part $-1.21 \sin w_n t$

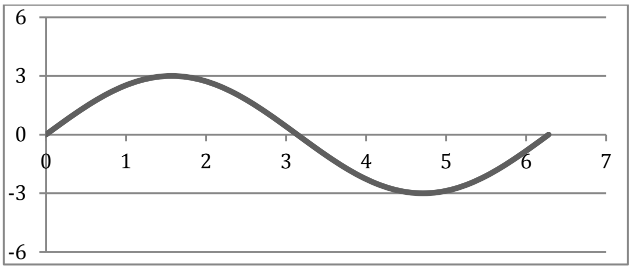


Figure 5 DLFmax.

Table A-1 value for the fixation constant, (a) depending on boundary conditions and mode shape

Boundary Condition	1st Mode	2nd Mode	3rd Mode
Guide – Guide	A = 9.87	A = 39.5	A = 88.9
Guide – fixed	A = 15.4	A = 50.0	A = 104
Fixed – fixed	A = 22.4	A = 61.7	A = 121

Table (B) Results of investigations for four cases

Several cases	Excitation Ω (rad/sec)	Natural frequencies Wn(rad/sec)	DLF max.
Case a	94.24	128.22 (Guide-Fixed)	3.7
Case b	94.24	186.5 (Fixed-Fixed)	2
Case c	125.66	128.22 (Guide-Fixed)	49.99
Case d	125.66	186.22 (Fixed-Fixed)	3

Dynamic Load Factor for Blast (DLF blast)

If no dynamic analysis or modal analysis to find the DLF for use in static analysis is carried out, then a conservative DLF in the range 1.5-2 should be used in order to be accounted for the dynamic effect of a blast.

Dynamic load factors which are closely linked to the natural frequencies of the pipe span can be found in the British steel construction institutes document no. 209"interim guidance note , section 3 , design guidance for explosion resistance , 1992 '' (API 618 4th edition, 1995).

For a triangular pulse which starts at zero and reaches a maximum value at 30% of the total blast duration time. (t_d) the maximum response as a function of rise time to natural period (T) is shown in figure (6) below.

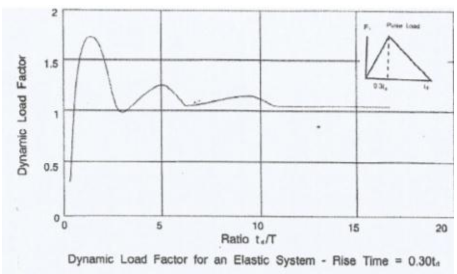


Figure 6 For blast application

Example

In a given project, the DAL, report (design accidental load specification) report, states that figure in the interim guidance note referred to above should be used, this figure is shown below as figure (6). Further, the DAL, specification tells that the blast duration time, t_d = 0.15s should be used in the project.

From model analysis the pipe stress engineer has found that the first mode of vibration for a given pipe span has a natural frequency, f_n = 20 Hz corresponding to the periodic time.

T= 1/ f_n =1/20 = 0.05s, the dynamic load factor are then found by calculating the t_d /T ratio = 0.15/0.05 = 3. From figure (6) it can be seen that the corresponding DLF is approximately= 1.5, which is far less than a conservative value of 1.5-2chosen as default for all piping system when modal analysis is not used.

Conclusions

1. Since advisable DLF should not exceed (2), therefore, only case (b) shall be acceptable.
2. DLF in case (c) = 49.99 where the w_n=128.22 and Ω = 125.66 (i.e. the system near to the resonance state), whereas the system at blast is equal to (around =1.5) and this means that the resonance state is dangerous more than blast state.
3. 3. Since $f_n = \frac{a}{2\pi L^2}\sqrt{\frac{EI}{m}}$, therefore it is clear that $f_n$is reciprocal to L^2, So to increase the natural frequency (f_n) you have to decrease the length as much as possible within reasonable distance and boundary conditions.

Reference

N. Dattaand A. W. Troesch (2014), Dynamic response of kirchhoff' s plates to transient hydrodynamic impact loads.

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