SUITABILITY OF CODES WITH RESPECT OF DTRCURAL DAMPING

Gilles OUDIN

MULTITECH VIBRATION CONTROL – 9 Rue du Gué – 92 500- Rueil-Malmaison, France

Email : multitech-fr@wanadoo.fr – phone :+33-1.6.63.35.82.43

www.multitech-fr.com

1. ABSTRACT

This paper presents a practical example of a stack with bolt failure where it was not expected; This single flue stack is lined by 75 mm heavy refractory and high damping was expected. The stack is made in 6 flanged segments. All flanges are over sized and fitted with pre-stressed bolts.

A few years after the stack was erected the bolts began to fail with replacement required approximately every 6 months On some occasions the stack suffered huge noisy vibrations obliging the Client to shutdown the plant in order to prevent a major accident.

An investigation was carried out and the main results are presented below.

2. STACK DESCRIPTION

2.1 Sketch of the stack

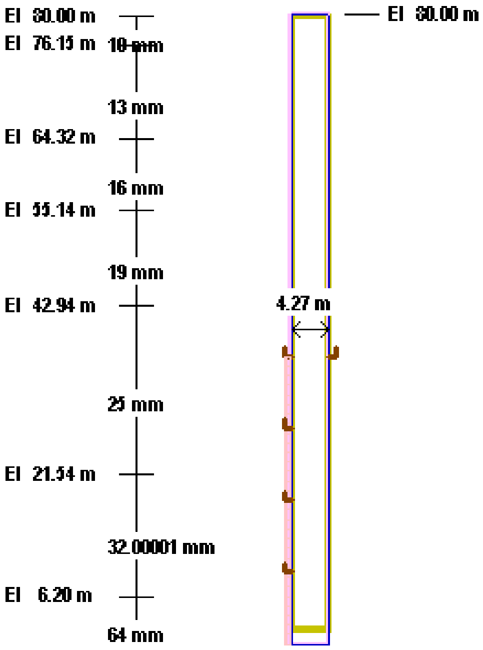

Fig 1 : General shape of the stack

2.2 Flange description

Level (m)	Width (mm)	Thick (mm)	No bolts (-)	Bolt dia (mm)
61.76	108	25	108	19
43.48	108	35	184	19
31.20	124	64	156	32
15.90	135	92	128	44
6.790	135	120	172	35

Table 1 : flange description. (*) Dimensions are equivalent in metric system of US dimensions.

All flanges are fitted with pre tensioned bolts and no gussets.

3. DESCRIPTION OF THE PROBLEM

Since the stack was commissioned the chimney has vibrated with bolts failing and needing to be replaced approximately every 6 months.

Having substantiated that the chimney suffered excessive oscillations it was decided to take measures to secure the stack against bolt failure at the flanged joints.

This stack serves a sulphur unit. Failure of the chimney could be considered as a major accident with risk of hundreds of dead.

It was decided to make a preliminary check of the stack and carry out site measurement.

4. DAMPING VALUES ACCORDING DIFFERENTS CODES

The target of these calculations was to make sure the stack was originally well designed taking into consideration the codes .

4.1 Damping values according different Codes

4.1.1 Damping according STS 1-2000

Support	Rigid support	Elastic support
Type Welded Stack		
Unlined	0.002 (0.013)	0.004 (0.025)
Lined (mini 2" thick 100 pcf)	0.003 (0.019)	0.006 (0.038)

Table 2: Damping values according STS 1-2000 – Number between (...) is the decrement of log damping

4.1.2 Damping according CICIND rev 1-2000

Type of chimney	Damping ratio
Unlined, un-insulated	0.002 (0.013)
Un-lined, externally insulated	0.003 (0.019)
Lined with refractory concrete	0.005 (0.031)
Lined with brickwork	0.015 (0.094)
Chimney with steel liner $\lambda < 26$	0.006 (0.038)
Chimney with steel liner $\lambda > 28$	0.002 (0.013)

Table 3 : Damping value according CICIND – Number between (...) is the decrement of log damping

4.1.3 Damping according DIN 4133 – Nov 91

Type of chimney	Damping ratio
Unlined, un-insulated, fully welded or junction with pre-stressed bolts	0.0024 (0.015)
Unlined, un-insulated, junction with normal bolting	0.0032 (0.020)
Outer insulated or with one liner	0.004 (0.025)
Multi flue stack with insulated liners	0.048 (0.030)
Internally refractory lined	0.0111 (0.070)

Table 4: Damping value according din 4133- Number between (...) is log damping

4.1.4 Damping according Eurocode

Similar to DIN 4133

4.1.5 Damping according BS 4076

The type of joint affects the coefficient K. The K values are based on Logarithmic damping values for the various joint types (B3.8).

Joint Type	'K' Value	Log. Damping Value
All Welded	3.5	0.03
Welded With Flanged & bolted Joints	3.0	0.05
Bolted Riveted Or All Riveted	2.5	0.07

Where the lining of the chimney is likely to increase the damping, the value of K may be reduced by 0.5. (**The K value for a refractory lined flanged and bolted chimney could be reduced to 2.5 with the logarithmic damping value being equivalent to 0.07**)

4.2 CHOICE OF DAMPING VALUE

For a single flue refractory lined stack on a rigid support , the damping values are quiet different.

Code	Damping	Equivalent decrement of log damping
STS 1-2000	0.003	0.019
CICIND 2000	0.005	0.031
DIN 4133	0.0111	0.070

Table 5: Damping value for a refractory lined stack and different codes.

There is a ratio of 3.68 between the two most extreme values.

Calculation has been carried out with the smallest value; damping = 0.003 (or decrement of log damping = 0.019) taken from STS 1-2000.

5. BOLT CHECK WITH RESPECT TO FATIGUE

As long as the flanges are pre-stressed fatigue would not occur in the bolts.

It has been stated that the bolts failed perpendicular to the prevailing wind direction. So it was suspected that the bolts failed due to fatigue. The stack was calculated again with the assumption that the pre-stressing was not active and that the bolts were just classical. In the table below the stress amplitude has been computed.

Level (m)	**Stress due to fatigue in the bolts**
61.76	177 Mpa
43.48	362 Mpa
31.20	322 Mpa
15.90	249 Mpa
6.790	395 Mpa

Table 6: Fatigue stress in the bolts due to cross wind in the case of non pre-stressed bolts.

Failure of the bolts occured only at 31.20 m and 43.48 m levels, where the flange thickness was 64 and 35 mm.. Bolt spacing 86 mm (2.70* ∅ bolt) at 31.20 m and 73 mm at 43.48 m. (3.84* ∅ bolt)

The bolts in the crosswind direction were changed continuously and presstressed according to rules. The only explanation of this constant failure is that for some reason, for instance gap between flanges, the prestressing was released. As a result the bolts behave as classical bolts but were not properly designed to withstand fatigue.

According to DIN 4133 the fatigue class shall be 36 ($\Delta\sigma$ = 36 Mpa) for bolts subject to central tensile stresses. Above 5e6 cycles, the remaining amplitude of allowable stress is, according DIN 4133, about 0.73*$\Delta\sigma$ = 26 Mpa.

The bolts were overloaded explaining why they had to be replaced continuously since commissioning.

6. SITE MEASUREMENT

6.1 Frequency measurement

Time signals are recorded under natural excitation (wind) during 10 minutes.
The spectrum is then calculated and averaged on these time signals using Fast Fourier Transform (FFT).

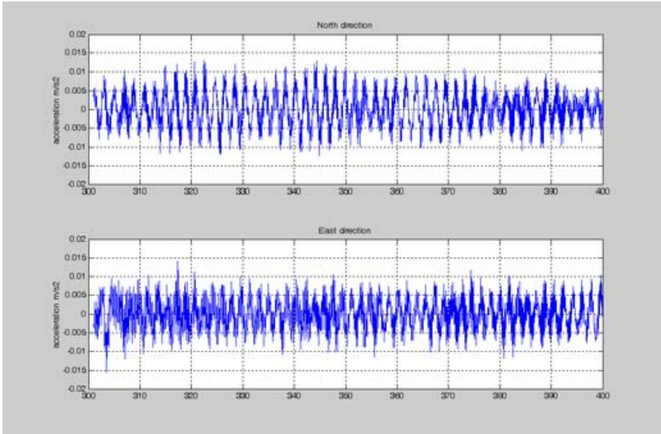

Fig 2: Time signal

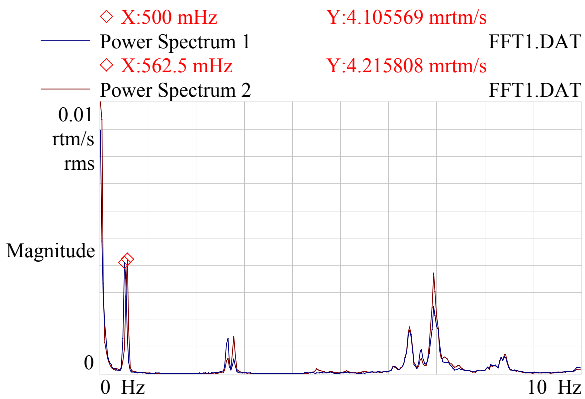

Fig 3 :FFT Spectrum :

Results
First mode in the **North direction is at :** **0.50 Hz**,
First mode in the **East direction is at :** **0.56 Hz.**

6.2 Damping measurement

This measurement consists of a dynamic excitation of the stack at the 40m level by several people (5 to 8) synchronized by a reference generator.
The stack is alternatively excited in the North – South and in the East-West direction.

When a measurable stack acceleration is

obtained, the excitation is stopped, and the decrease is recorded.

Channel 1 accelerometer is oriented in the North-South direction,

Channel 2 accelerometer is oriented in the East-West direction.

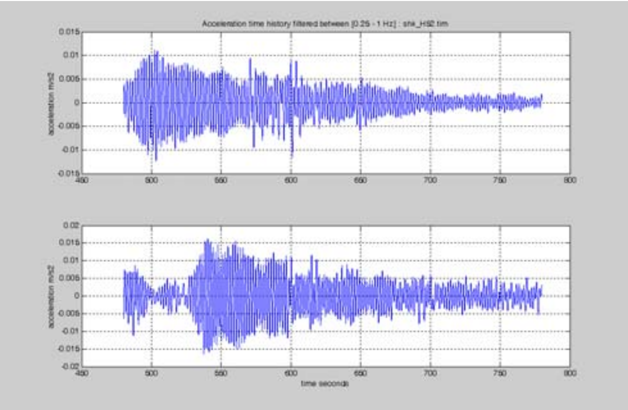

Fig 4 : decreased curve after excitation in two directions

The successive excitation in both directions is clearly visible on the two channels, successively.

Frequency calculated on signals above gives 0.51 Hz in N-S and 0.55 Hz in the E-W direction.

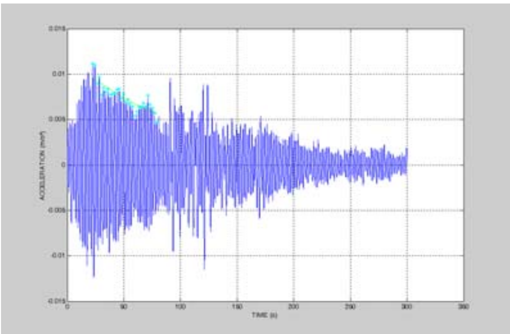

Fig 5 : decreased curve after excitation - enlargement

Damping is estimated to 0.002, in both directions. The lowest value given in the Code is :STS 1-2000 : 0.003

Conclusion: Even the worst, most stringent international recognised Code, is not safe with respect to fatigue; and the "**factor of unsafety** " is **1.50** !!!! This "**factor of unsafety"** reached **2.5** with CICIND and **5.55** with DIN 4133

6.3 Relative movement of the foundation

Position of accelerometers is as follows (cf sketch at the end of this paragraph) :

channel 1 : Accelerometer Horizontal in North direction altitude 40m,
channel 2 : Accelerometer Horizontal in East direction altitude 40m,
channel 3 : Accelerometer Vertical North altitude 0m,
channel 4 : Accelerometer Vertical East altitude 0m,
channel 5 : Accelerometer Vertical South altitude 0m,
channel 6 : Accelerometer Vertical West altitude 0m.

Time signals are recorded under natural excitation (wind) during 10 minutes

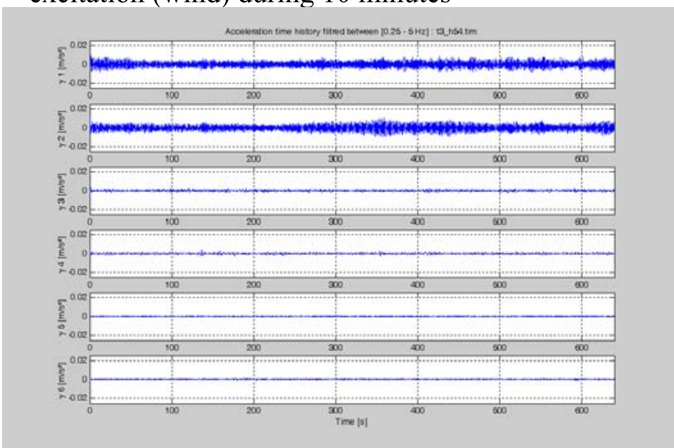

Fig 6 : time signal to check rigidity of foundation

The spectrum is then calculated and averaged on these time signals using Fast Fourier Transform (FFT).

Below is the FFT spectrum of the 6 measured signals, between 0 and 5 Hz (FFT parameters : Hanning 4096 points).

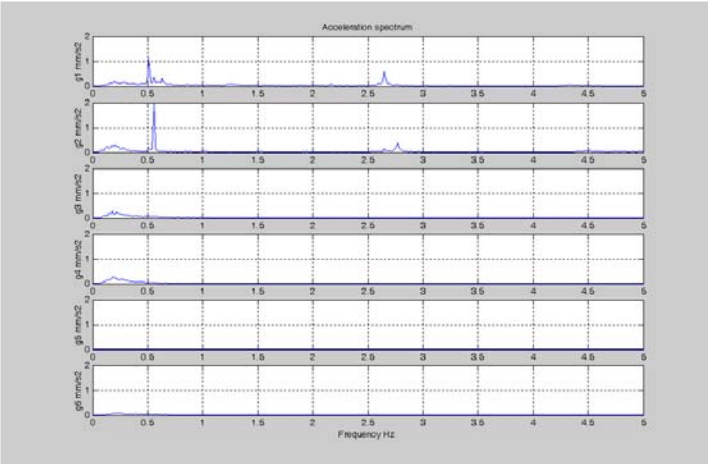

Fig 7 : FFT spectrum of the 6 measured signals on the stack and foundation

The peaking frequencies at 0.5 Hz (North channel) and 0.55 Hz (East channel) do not exist on the accelerometers connected to the foundation, demonstrating that no motion of the foundation exists at this frequency.

The energy around 0.2 hz is due to electronic noise of the transducers.

6.4 Additional observation – effect of opening

The stack is fitted with two opposite circular openings at the bottom.

The stack was originally calculated as a column but without taking into account the openings. As per design the frequency is 0.586 Hz.

This value has to be compared with 0.525 Hz site measured.

We can state that the difference is small and neglect it but with respect to fatigue loading this difference can generate big differences.

If you consider DIN 4133? The number of fatigue cycles over a period of 50 years is expressed by the following formula :

N50= 1e9*f*{Vcri/Vo)^2*exp-(Vcri/Vo)^2

Vo= reference wind speed = 7 m/s in windy area
Vcr= critical wind speed in m/s
f= frequency.

The critical wind speed is a function of frequency. The calculated critical wind speed is 12.96 m/s as per design and 11.61 m/s as per frequency measurement.(Outer shroud diameter). 4.42 m

As a result the number of vibration cycles is 13 e6 over a period of 10 years and reach 18e6 taking into account the frequency measurement. It means that taking into account the weakening of the stack due to the openings increased the number of fatigue cycles and the level of fatigue stress by a ratio of about 1.40, even with only 11% differences on the frequency.

7. RECOMMENDATIONS

7.1 Pre stressed or not pre stressed bolts

The flange design is very important. Even with good manufacturing a quality problem could occur. Having thinner flanges with gussets may be a solution . To be safe a solution could be to design the bolts without taking into account the pre-stressing except to block the nut or to add a damper .

Fig 8 : gap in a flange assembly

7.2 Effect of openings

To take into account the openings in the frequency calculation as a small difference could greatly affect the fatigue calculation especially the critical wind speed and number of vibration cycles.

7.3 Choice of damping value as a function of joint type

To carefully choose the damping value before making any stack calculation. A lot of codes consider only the type of stack : lined or not, insulated or not, with or without liner. Taking into account some past experience we also have to take into consideration how the stack is built. The same stack made in one piece or made of 5 segments assembled with normal bolts or 5 segments with pre stressed bolts would behave differently as the structural damping would be greatly affected by the type of joint.

7.4 Safety factor

If we look at the along wind direction, the wind loading is increased by a partial safety factor. For steel stack very often the cross wind direction is the worst loading case. From the above it could be seen that the damping coefficient is not a fixed value but “an estimation” with great variation. A safety factor should be applied to the damping coefficient.

7.5 Foundation.

The foundation behaviour can affect the frequency leading to a) a significant change in the frequency affecting the critical wind speed and the number of fatigue cycles b) the damping coefficient itself as a rigid foundation generates less damping than an elastic one.