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STRENGTH AND SAFETY VERIFICATION OF PIPING SYSTEM EXPOSED TO VIBRATIONS

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ABSTRACT
Very often, during normal operating conditions , piping systems are additionally exposed to vibrations which occurs due to different reasons.
Usual calculations of piping systems does not include loads caused by vibrations because such loads are unexpected and its level can not be correctly specified in advance .
In the article is described a case when the vibrations occured after few years of normal system operation . Vibration measurements have been done , but from frequency analysis is not possible to exactly detect exitation.
In that case , calculation of piping system have to be performed considering vibration measurements to get the loads & stresses for evaluations and verification of strength and safety of system .
High Pressure Live Steam system together with High Pressure Bypasses and Steam pipe to Start up Ejector is taken as an example from practice .
Keywords: pipes, vibrations, strength

1. FOREWORD

After a few years of normal system operation ,vibrations have been detected at HP steam pipes & at Steam to Start Up Ejector pipe .Due to this reason , site inpection/survey [1] have been done for ''as built'' pipe routing and pipe support design .Inspection outcome is compared with available design documentation – pipe isometrics,pipe support design drawings and pipestress calculation report .
Vibration measurements & analysis have been performed as well[6].Measured values and analysis summary have been taken as input for stress analysis[1].Mainly,stress analysis is performed to calculate stresses and loads due to vibrations.And , by evaluation of these results ,to check are the vibrations so high to cause damages in the piping system .

2. STRESS ANALYSIS FOR NORMAL OPERATING CONDITIONS

Stress calculation [1] is performed for normal operating conditions of the system considering "as built" pipe routing and pipe support design.For this purpose , calculation model has been prepared as it is presented at Figure 1.Calculation is performed according to ANSI/ASME B31.1 standard [2] and using Rohr2 calculation program. Furthermore , the highest pipe design parameters (e.g. temperature and pressure) are employed in the calculation.

Calculation analysis shows that maximum calculated stresses and loads in the system do not exceed allowable values given by ANSI/ASME B31.1 standard and manufacturer of steam turbine and condenser. Maximum stress utilization between calculated stresses for normal operation and allowable stresses is 72.5 % at the TEE connection between HP steam pipe and Bypass to condenser[1].

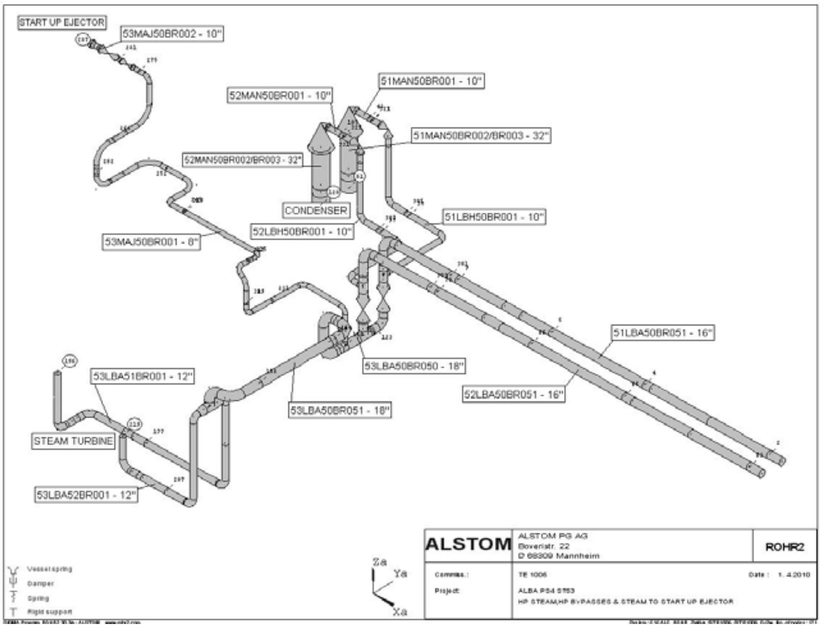

Figure 1. Calculation model of HP Steam pipes , Bypasses to Condenser & Steam to Start Up Ejector

3. CALCULATION OF STRESSES DUE TO VIBRATIONS

3.1. Calculation of stresses due to vibrations according to ANSI/ASME B31.1 standard

Calculation of stresses and loads due to vibrations is performed by ‘’Harmonic exitation’’load case, considering maximum measured values for vibration velocity / displacements at exact frequency and at exact measuring locations . Measured values & measurement locations are presented at Table 1 and Figure 2 [1,6] .

As a base for calculation of stresses due to vibrations ,natural frequency (eigenvalue) calculation is performed to get natural frequencies and mode shapes of system including ‘’as built’’ pipe support concept .Furthermore , by analysing natural frequencies and mode shapes and by comparing it with measurements, exitation and cause of vibrations can be detected.

Calculation model is the same as for analysis explained in Chapter 2.

Table 1- Measured values for vibration velocity & displacements

Measured and Calculated Peak and Overall Vibrations

Plant in normal Operation: Tie Rods and Hangers as found

Meas. points	1Z	1Y	2Z	2Y	3Y	3X	4Z	4Y	4X	5Z	5Y	6Z	TV
Main vibr. peak at ...[Hz] c	4.75	4.75	4.75	6.25	4.50	4.50	4.75	4.75	23.3	4.75	5.50	5.50	4.75
Max velocity in [mm/s] d	2.38	3.32	2.56	1.40	2.73	3.45	6.36	2.65	1.94	4.84	5.03	5.49	3.60
Corresp. peak value in [μm_{pp}] e	226	323	243	101	292	345	603	261	37	459	411	450	341
Calc. narrow band overall value for peak in [mm/s_{RMS}] f	3.50	5.50	3.45	2.80	4.62	4.65	8.66	4.54	3.10	6.42	8.31	7.50	4.74
Approximate corresp. narrow band value for peak in [μm_{pp}] g	332	521	327	202	462	465	820	430	60	608	680	614	450

Explanations:

c: Frequency of the dominant peak within the considered frequency span.
d: Measured max. value, taken from the frequency spectra.
e: Integrated *velocity* p-p value to the corresponding *displacement* p-p value.
f: Calculated *velocity* overall value within the narrow band (see below).
g: Approximate corresponding *displacement* value based on '**f**' , using the peak's centre frequency for the math. Integration.
This value might be the best guess for calculating the stress of the steam lines.

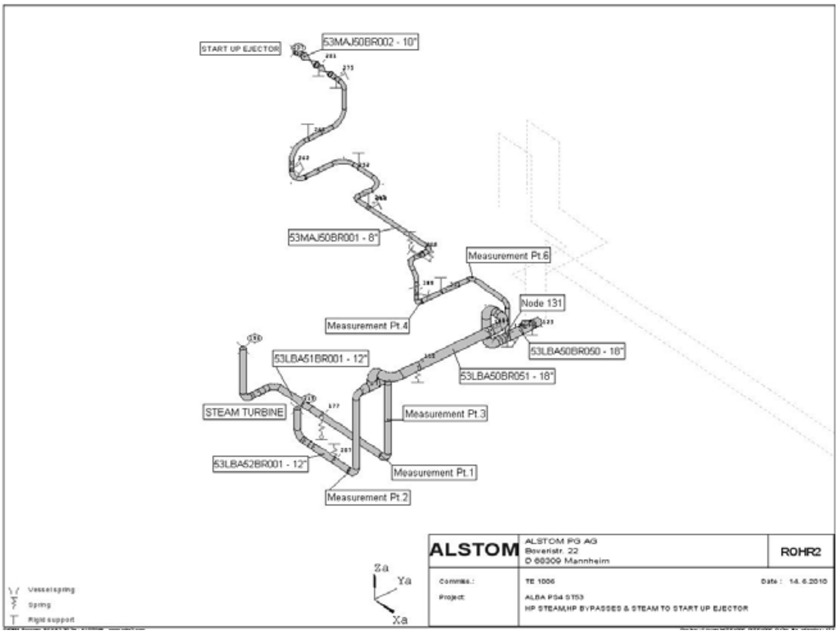

Figure 2. Location of measurement points

Natural frequencies (eigenvalues) have been calculated till 100Hz and there are 132 calculated values[1]. The most interesting are natural frequencies which presents mode shapes for the part of system close to measurement points where the vibrations occur. These natural frequencies are between 4 Hz and 7 Hz. Considering measured values[6] given in Table 1, maximum vibration velocity/displacements are measured in the same frequency range between 4 and 7 Hz. This means,calculation model is correct and calculated values confirm measurements.

Maximum calculated stresses and loads in the system , due to ''Harmonic exitation'' load case do not exceed allowable values given by ANSI/ASME B31.1 [2] standard and manufacturer of steam turbine and condenser. Maximum stress utilization between calculated stresses due to vibrations and allowable stresses is 35.8 % at the TEE connection between HP steam pipe and Steam to Start Up Ejector (calculation Node 131 – location presented at Figure2) [1]..

3.2. Calculation of stresses due to vibrations according to Tresca theory

''Harmonic exitation''load case , explained in Chapter 3.1 , which is used for stress calculation due to vibrations is defined as occasional load case considering requirements from ANSI/ASME B31.1 standard[2].Refering to standard, occasional load acts less than 1% of any 24 hours operating period.
Vibrations are also occasional load , but last permanently for a longer time. So ,additionall stress analysis using Tresca theory [4] is performed for additionall check and evaluation of the stresses due to vibration loads.

Equivalent stresses using Tresca theory [4]have been calculated for ''Operating'' load case (Dead load , Pressure and Expansion loads) and ''Harmonic Exitation''(Vibration displacements) .
Maximum equivalent stresses for ''Harmonic Exitation'' occur at calculation Node 131(location is presented at Figure 2) [1]. This is the TEE connection between HP steam pipe and Steam to Start Up Ejector .
Equivalent stresses at this Node for both calculated load cases are evaluated by using Goodman diagram [3] presented in Figure 3. Furthermore , stress ratio is calculated considering values extracted from the diagram .

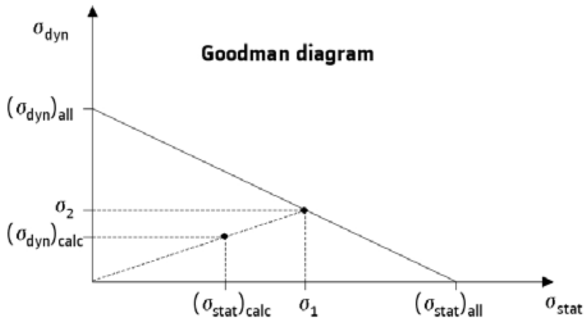

Figure 3. Goodman diagram

Following datas have been used for evaluation :
1.) Calculated equivalent stresses [1] using Tresca theory
$(\sigma_{stat})_{calc}$ = 158 MPa .....maximum equivalent calculated stresses at Node 131 for Operating load case
$(\sigma_{dyn})_{calc}$ = 1.6 MPa ... ..maximum equivalent calculated stresses at Node 131 for Harmonic Exitation
2.) Material properties for A335 P91 at design temperature t = 535 C[5]
R_m = 380 MPa ....Tension Strength
Re = 255 MPa ....Yield Strength
3.) Allowable stresses [4]
$(\sigma_{stat})_{all} = R_m / 1.4 = 272$ MPa
$(\sigma_{dyn})_{all} = 0.4 \times (\sigma_{stat})_{all} = 109$ MPa
where is : Safety Factor = 1.4 ; Factor for dynamic stresses = 0.4 [4]

Values extracted from Goodman diagram [3] for calculating Stress ratio are :
$\sigma_1 = (\sigma_{dyn})_{all} / \{[(\sigma_{dyn})_{all} /(\sigma_{stat})_{all}] + [(\sigma_{dyn})_{calc} /(\sigma_{stat})_{calc}]\} = 265$ MPa
$\sigma_2 = [(\sigma_{dyn})_{all} /(\sigma_{stat})_{all}] \times [(\sigma_{stat})_{all} - \sigma_1] = 2.8$ MPa
Stress ratio is :

$$SR = \sqrt{\frac{(\sigma_1)^2 + (\sigma_2)^2}{[(\sigma_{stat})_{calc}]^2 + [(\sigma_{dyn})_{calc}]^2}} = 1.7$$

4. CONCLUSION

Strenght and safety verification of concerned piping system is performed due to vibrations which occur on several locations .Vibration measurement results have been used as input for analysis Generally ,calculated stresses and loads according ANSI/ASME B31.1 standard and Tresca theory,including stresses due to vibrations , are in allowable limits.
With regard to this fact,no action is necessary for reducing vibrations.

5. REFERENCES

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