International Research Journal of Engineering and Technology (IRJET) **e-ISSN: 2395 -0056**
Volume: 03 Issue: 09 | Sep-2016 **www.irjet.net** **p-ISSN: 2395-0072**

Optimization of Piping System for Nozzle Loads

Suyash Chougule[*]**, Kiran Patil**

Department of Petroleum Engineering, Maharashtra Institute of Technology, Pune, India-411038

***

Abstract-*Piping systems in petroleum, petrochemical, and storage plants used for the transportation of oil and gas goes through a great thermal stress and strains due to difference between ambient and operating temperature of process & utility fluid flowing through them. These types of changes give rise to different types of expansions, loads and moments. These loads will get transmitted to end points of the piping systems which generally are connected to equipment nozzles. If these nozzles cannot sustain these loads then there can be failure of nozzles giving rise to fracture in the system. The expansion is the result of thermal loads. Exceeded sustained weights can be minimized by addition of support in the piping system whereas expansion loads are compensated by addition of expansion loop. These loops and supports can be designed and added with the help of codes given by American Society of Mechanical Engineering. Generally ASME B31.3 is widely used for such type of designs. To ensure this a static flexibility analysis can be done by using engineering tool called CAESARII. Generally the end nozzles are connected centrifugal pump. In case if the piping nozzle is connected to centrifugal pump the system has to pass conditions given in clause F.1.2.a, b and c of API610. If the system is having more values of stresses as that given in Table 5 of API610 then it is mandatory to reduce them to optimum level. These can be done by addition of support near to pump nozzle or adding expansion loop anywhere in the piping system. This paper applies API610 to existing piping system and checks weather it is passing it or not. The paper also suggests two modifications in given system which validates all requirements in the given code.*

Key Words**: *Thermal stress, Nozzle Loads, Expansion Loops, CAESARII, ASME B31.3, API610, Flexibility Analysis.***

****Author for Correspondence:****suyashchougule@yahoo.com*

1.INTRODUCTION

Piping systems are nerves of oil and gas industry. They carry both raw as well as final products to their destinations. These pipelines are exposed to various environmental and operational conditions, which changes physical properties of these pipelines. Such as, change in temperature and pressure will either increase or decrease the length of pipeline. Change in fluid properties can increase weight of system resulting in increase in sustained weight of system.[1] To deal with thermal expansions piping systems are equipped with anchors and guide supports. These supports are designed with help of design codes given by American Society of Mechanical Engineers (ASME). The design of pipeline should be such that wall bursting, tearing, fracturing should not occur. The equipment which are connected to end points of piping system experiences the loads created by thermal expansion. As the equipment is fixed to the base it cannot change its position to compensate the loads. In results the pipe starts buckling and nozzle will start fracturing. In worst case scenario pipe can rupture and leakage can occur. Such type of leakage can be dangerous in case of Class M fluid, as these fluids are extremely inflammable. Piping systems with end nozzles connected to centrifugal pump have to satisfy the Clause F.1.2.a, b and c given in API610.[1-3,7] The paper gives detailed idea about purpose and designing of expansion loop so that the piping system can pass the Clause given by API610.

2.PIPING DESIGN

2.1 Codes and Standards

Generally code defines requirements for design, material, fabrication, erection, test and inspection of piping system. The formula and calculations given in codes are based on years of experiments. Collection of ASME B31 codes, previously known as ANSI 31, covers pressure piping was created by the American Society of Mechanical Engineers which combines codes for power piping, pipeline transportation systems for liquid hydrocarbons, fuel gas piping, process piping and other liquids, refrigeration piping and heat transfer components, and building services piping.[4]

A standard contains more-detailed design and construction parameters and standard dimensional and tolerance requirements for individual piping components, such as various types of valves, pipe, tee, flanges, and other in-line items to complete a piping system.[4]

2.2 Pipeline Design Philosophy

In order to come to optimized design of piping system one has to take care of following parameters [7]:

1.Social aspects
2.Long term integrity
3.Maintaince required
4.Environmental impact aspect
5.Material of construction

6.Construction method and welding aspect
7.Government regulations
8.Existing infrastructure and facility
9.Operator's standards
10.Pipeline routine

2.3 Stress Analysis of Piping System

It is mandatory for companies to check whether the pipeline designed by them is enough flexible to sustain expansions or not. If the system does not comply the minimum requirements given in code it is failed in code check, in that case we can either change support span or add expansion loop to compensate thermal expansion. Addition of loop can change the overall layout of existing piping system. Hence it is necessary to final placing of expansion loop considering layout of current piping system. There is a big difference between flexibility analysis and pressure design, as flexibility analysis depends on range of stress values whereas pressure design is for a particular value. These stresses are secondary-type stresses which mean they are self-limiting. Here temperature change and expansion creates stresses. The allowable stress at higher temperature is usually not the same as that lower temperature.

2.4 Stress Intensification Factor

The Stress Intensification Factor (SIF) can be defined as:

$$\mathrm{SIF} = \frac{\text{Maximum Stress Intensity}}{\text{Normal Stress}}$$

The significance of SIF is it is used as a safety factor to account for the effect of localised stresses on piping under respective loading. In case of piping system there are some components where fatigue can occur due to high stress concentration, such as bends, welds, branch connections. For such types of components SIF were found by A.R.C.Markl and his team in 1950s[5]. In case of codes, each code is having different method for calculation of SIF and hence each code can give different value for same component. For B31.1 and ASME Section III codes require that the same SIF be applied to all the three-directional moments while the B31.3, B31.4, B31.5, and B31.8 codes require that different SIFs be applied to the in-plane and out-of-plane moments, with no SIF required for torsion[5].

3 DESIGN CODES

3.1 ASME B31.3

ASME B3.3 basically covers piping system found in petroleum production station, petroleum refineries, bulk storage station and pumping stations. Code gives requirement for selection of material of construction, components, design fabrication, assembly, erection, examination, inspection and testing of piping. This code is applicable for refrigerants, raw and final chemical and their products, gas, steam and water, fluidized solids and cryogenic fluids. The main use of this code is in petroleum companies.[6]

3.2 API 610

API610 is designed by American Petroleum Institute to guide in selection of centrifugal pumps for petroleum, petrochemical and natural gas industries. The code gives guidelines for selection of pump basis of type of services, types of pumps, loads and moments on nozzle of pump. In Annex F of API610 the criteria for piping design is given for centrifugal pump. The Annex F of API610 has three clause F1.2.a, b and c. if the piping system connected to centrifugal pump passes these three clause then it can be said that the system produces stresses under the limit given by code. Else otherwise one has to modify piping layout in order to make it happen. The three clause are given below [7]:

1.The individual component forces and moments acting on each pump nozzle flange shall not exceed the range specified in Table 5 of API610 by a factor of more than 2.

2.The resultant applied force (F_{RSA}, F_{RDA}) and the resultant applied moment (M_{RSA}, M_{RDA}) acting on each pump-nozzle flange shall satisfy the appropriate interaction equations as given in equations F.1 and F.2:
a.$[F_{RSA}/(1.5\times F_{RST4})]+[M_{RSA}/(1.5\times M_{RST4})]<2$..........(F.1)

b.$[F_{RDA}/(1.5\times F_{RDT4})]+[M_{RDA}/(1.5\times M_{RDT4})]<2$.........(F.2)

3.The applied component forces and moments acting on each pump nozzle flange shall be translated to the centre of the pump. The magnitude of the resultant applied force, F_{RCA}, the resultant applied moment, M_{RCA}, and the applied moment shall be limited by Equations (F.3) to (F.5),
a.$F_{RCA}<1.5(F_{RST4}+F_{RDT4})$..............................(F.3)

b.$|M_{YCA}|<2.0(M_{YST4}+M_{YDT4})$..........................(F.4)

c.$M_{RCA}<1.5(M_{RST4}+M_{RDT4})$..........................(F.5)

If the system is passing above three clause the system is passed, if the system fails then it is necessary to make changes in system in order to make it pass. The case study contains one example in which with the help of change in piping layout the system has made safe for centrifugal pump. The system was failing to satisfy the clause F.1.2.b and c given by API610 and hence it was necessary to make changes in layout of the same so that the excessive thermal expansions will be compensated by the expansion loop.
By addition of expansion loop we can prevent piping system from failing due to thermal load but it can still fail due to sustained loads of fluid and pipe. In that case we need to add one more support compensate excessive sustained loads.

Generally this additional support is placed near to pump nozzle to minimize weight on it.

4. CASE STUDY: OPTIMIZATION OF PIPING SYSTEM FOR NOZZLE LOADS

The case study was done at 'Zuari Indian Oiltanking Limited', Sancoale, Goa. The pipeline taken for case study is used to transport refined petroleum product from Tank-112 to centrifugal pump station. From pumping station it is send to tankers which carries it to nearest petrol filling station. The site is located on NH-17B, Sancoale, Goa-403 726. The facility is well maintain and having good infrastructure. The petrol bunk is equipped with all new instruments and hazard equipment.

Table 1: Input Parameters in CAESARII

Parameter	Value	Unit
Pipe diameter	16	Inch
Schedule of pipe	20	-
Thickness of pipe	0.3120	Inch
Mill tolerance	12.5%	-
Corrosion	0.1180	Inch
Pipe density	0.28300	Lb/cu.in.
Fluid density	0.02818	Lb/cu.in.
Operating temperature	60°	Fahrenheit
Maximum temperature	113°	Fahrenheit
Operating pressure	0.0028	Lb/sq.in.
Insulation thickness	-	-
Insulation density	-	-
Material	API 5L Gr.B	-
Modulus of elasticity	2.9500E+007	Lb/sq.in.
Poisson's ratio	0.2920	-
Weight per unit length	52.32	Lb/ft
Minimum test pressure	820	Psi

Tank-112 is used to store motor sprit (MS) having capacity of 16836.97 KL, but the working capacity of 15000KL. Pumping rate for both filling and emptying the tank is 2000m^3/hr. Material of tank is IS 2062 Gr.A/B, whereas tank is constructed with API650 design standard. The diameter of tank is 35m and height is 17.5m. The discharge line nozzle of Tank-112 is connected suction nozzle of pump P 112 which is having 300m^3/hr. The design code used for construction of this piping system is ASME B31.3.The details of pipe input in CAESAR II spread sheet are given in Table above.

4.1 Calculation of Stress Intensification Factor (SIF)

In given model there are total 7 bends whereas 6 tees are present out of which 4 are equal and 2 are unequal tee. For each bend and tee we need to calculate SIF. In CAESARII we can directly calculate these factors. The calculated SIFs are given below,

Table 2: SIFs for Bends

Sr. no.	Pipe diameter (Inch)	Bend radius (Inch)	Schedule/ thickness (Inch)	Bend angle	SIF inplane	SIF outplane
1	8.625	12.9375	0.3120	90°	2.495	2.079
2	11.81	17.715	0.3120	90°	3.844	3.204
3	9.84	14.76	0.3120	90°	2.992	2.493
4	8.625	12.9375	0.3120	45°	2.495	2.079

In case of pipe intersection the following SIFs were calculated

Table 3: SIFs for Intersections

Sr. no	Header pipe		Branch pipe		SIF (Inplane)	SIF (Outplane)
	Diameter (inch)	Schedule (inch)	Diameter (inch)	Schedule (inch)		
1	16.00	0.3120	8.625	0.3120	6.043	7.724
2	8.625	0.3120	8.625	0.3120	4.043	5.058
3	11.81	0.3120	8.625	0.3120	4.959	6.279
4	11.81	0.3120	9.84	0.3120	4.959	6.279
5	9.84	0.3120	9.84	0.3120	4.404	5.539

These SIFs are used as input in classic piping input window under bend and tee tab. In present layout one end is connected to tank nozzle and another is connected to suction nozzle of Pump-112. The main nozzles are given in below table:

Table 4: Nozzle Node Numbers

Node no.	Line no.	Connected to
20	NAP-02035-A1d-400	Tank-112
240	NAP-02018-A1d-200	Tank-112
1340	NAP-02211-A1d-250	Centrifugal Pump-112

In CAESAR II we have different load cases; each load case gives different values of nozzle load. Each case have different amount of expansion with different amount of sag. Hence in given layout following load cases occurs,

Table 6: Load Cases in Case Study

Case no.	Load case	Condition	Load case type
1	WW+HP	Hydro test case	HYD
2	W+T1+P2	Operating condition 1	OPE
3	W+T2+P2	Operating condition 2	OPE
4	W+T3+P2	Operating condition 3	OPE
5	W	Sustained case condition 1	SUS
6	W+P2	Sustained case condition 2	SUS
7	L2-L5	Expansion case condition 1	EXP
8	L3-L6	Expansion case condition 2	EXP
9	L2-L3	Expansion case condition 1-2	EXP
10	L4-L5	Expansion case condition 3	EXP
11	L2-L4	Expansion case condition 1-3	EXP
12	L3-L4	Expansion case condition 2-3	EXP

The structure is sufficiently flexible and the deflection of pipe is under allowable limit given by code (ASME B31.3). All the nozzle loads and moments are under the limit so that there are no excess stresses on end points and hence there is no possibility of fracture and cracks on flanges. The following tables shows the values of forces and moments that has been induced in end nozzles of piping system due to sustained weight of piping system and thermal expansion due to temperature change.

Table 5: Forces and Moments on Nozzles

Load case	Forces on nozzle in Lb			Moments on nozzle in Lb		
	FX	FY	FZ	MX	MY	MZ
1(HYD)	-84	31	-770	-847	3611	59
2(OPE)	-287	101	-695	-872	3352	532
3(OPE)	-25	11	-688	-733	3208	-58
4(OPE)	-153	55	-691	-800	3278	229
5(OPE)	-74	28	-689	-759	3235	51
6(SUS)	-74	28	-689	-759	3235	51
7(EXP)	-213	73	-6	-113	118	481
8(EXP)	49	-17	1	26	-27	-110
9(EXP)	-262	90	-7	-139	145	591
10(EXP)	-79	27	-2	-42	43	177
11(EXP)	-135	46	-4	-71	74	304
12(EXP)	127	-44	3	67	-70	-287

By inputting these values of nozzle loads and nozzle moments in Suction nozzle tab the system is put for analysis and then the system checks the conditions given in clause F.1.2.a, b and c of API610. If the resultant loads and moments exceeds the value given in table 4 of API610 then the system is fail. It means the piping system is not enough flexible near to the pump nozzle even though it is flexible inside the routing. The results of condition F.1.2.a, b and c given by software package are summarized below,

Table 6: Results of Analysis in API610 for F.1.2.c

Load case	Condition F.1.2.c						Overall Pump status
	1.5 (FRSt4 + FRDt4)		2.0 (MYSt4 + MYDt4)		1.5 (MRSt4 + MRDt4)		
	Condition Res.>Req.		Condition Res.> Req.		Condition Res.> Req.		
	Res.	Req.	Res.	Req.	Res.	Req.	
1(HYD)	3300	775	3600	4253	7500	4337	FAILED
2(OPE)	3300	759	3600	3931	7500	4074	FAILED
3(OPE)	3300	689	3600	3781	7500	3852	FAILED
4(OPE)	3300	710	3600	3854	7500	3996	FAILED
5(OPE)	3300	694	3600	3809	7500	3885	FAILED
6(SUS)	3300	694	3600	3809	7500	3885	FAILED
7(EXP)	3300	225	3600	123	7500	567	PASSED
8(EXP)	3300	3118	3600	3867	7500	1462	FAILED
9(EXP)	3300	277	3600	3978	7500	697	FAILED
10 (EXP)	3300	84	3600	45	7500	209	PASSED
11 (EXP)	3300	1875	3600	3850	7500	4100	FAILED
12 (EXP)	3300	134	3600	72	7500	338	PASSED

PASSED- Piping system has passed Clause F.1.2.a, b and c of API610.

FAILED- Piping system has failed Clause F.1.2.a, b and c of API610.

The nozzle loads given in above table are due to layout1 which on which presently system is working. With careful observation we can say that the system is failing mainly due to excess loads that are occurring due to thermal expansion of piping system. This expanded system puts excessive load on pump nozzles, giving rise to failure of pump nozzle due to fatigue failure.

4.2 Modification in Current Layout for Optimization of Piping System

This problem can be solved by two options. For compensating the thermal loads we can introduce thermal expansion loop inside pipe routing and for compensating sustaining loads we can either shorten the distance between last support and pump nozzle or we can add one more support near to the pump nozzle.

The expansion loop can be added anywhere in piping system as to compensate expansion, generally it is done by checking adequate space and then it is added to the empty space. In order to overcome the thermal stresses problem an additional loop was required which was added in above piping system.

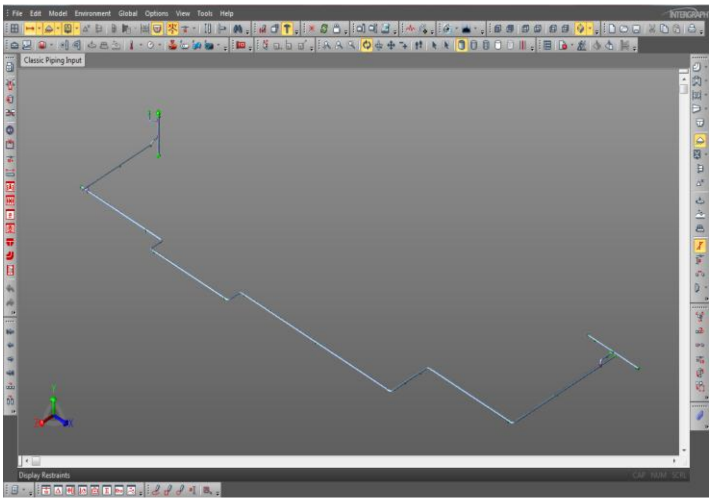

Figure 1: Modified Layout 1

The loop is created on line no NAP-02012-A1d-300 between nodes 506-512. Then this layout is again put for flexibility analysis where pipe was flexible for thermal loads but excess sustained loads were remained same. The loads obtained with above layout are given at the end of paper.

From table it is clear that now the system is passed for expansion loads but the sustained loads remains same and hence in order to reduce excess weight on pump suction nozzle we add support near to pump nozzle. The extra support is added near pump nozzle i.e. node 1340 we get following layout,

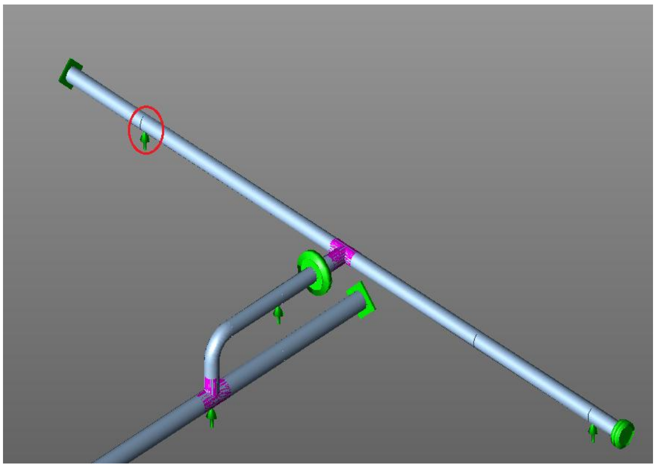

Figure 2: Position of Additional Support

The modified second layout passes all three clause given in API610 i.e. F1.2.a, b, c. it satisfies both conditions of thermal expansion as well as sustained load. The detailed analysis results for this layout are given at the end of this paper.

5. CONCLUSION

From above case study we can conclude that,

1. The present layout is enough flexible for thermal expansion, it can sustain loads induced by temperature change, as well as the sagging due to system weight is also under the limit given by ASME B31.3 which is design code for this system.
2. The pump system fails after application of API610 analysis, in which the piping system does not, satisfies the clause F.1.2.a, b and c given by code.
3. The modified Case 1 is able to compensate loads due to thermal expansion, but is not able to reduce loads due to sustained weight.
4. The modified Case II is able to take both loads and also satisfies the condition given by both API610 and ASME B31.3 codes.

With the help of CAESAR II the piping systems can be optimized for excessive nozzle loads. Modified layouts can be checked with the help of this software for same environmental and operating conditions and optimized layout can be selected.

CAESARII Results

The results of API610 analysis done for first modified case are given below:

Table 7: Results of Analysis in API610 for modified Case 1

Load Case	Condition F.1.2.c						Overall Pump status
	1.5 (FRSt4 + FRDt4)		2.0 (MYSt4 + MYDt4)		1.5 (MRSt4 + MRDt4)		
	Condition Res.>Req.		Condition Res.> Req.		Condition Res.> Req.		
	Res.	Req.	Res.	Req.	Res.	Req.	
1(HYD)	3300	775	3600	4253	7500	4337	FAILED
2(OPE)	3300	759	3600	3931	7500	4074	FAILED
3(OPE)	3300	689	3600	3781	7500	3852	FAILED
4(OPE)	3300	710	3600	3854	7500	3996	FAILED
5(OPE)	3300	694	3600	3809	7500	3885	FAILED
6(SUS)	3300	694	3600	3809	7500	3885	FAILED
7(EXP)	3300	225	3600	123	7500	567	PASSED
8(EXP)	3300	52	3600	28	7500	130	PASSED
9(EXP)	3300	277	3600	151	7500	697	PASSED
10 (EXP)	3300	84	3600	45	7500	209	PASSED
11 (EXP)	3300	143	3600	77	7500	358	PASSED
12 (EXP)	3300	134	3600	72	7500	338	PASSED

The results of API610 analysis done for second modified case are given below:

Table 8: Results of Analysis in API610 for modified Case 2

Load Case	Condition F.1.2.c						Overall Pump status
	1.5 (FRSt4 + FRDt4)		2.0 (MYSt4 + MYDt4)		1.5 (MRSt4 + MRDt4)		
	Condition Res.>Req.		Condition Res.> Req.		Condition Res.> Req.		
	Res.	Req.	Res.	Req.	Res.	Req.	
1(HYD)	3300	376	3600	1060	7500	1288	PASSED
2(OPE)	3300	482	3600	1064	7500	1459	PASSED
3(OPE)	3300	317	3600	924	7500	1114	PASSED
4(OPE)	3300	381	3600	993	7500	1245	PASSED
5(OPE)	3300	336	3600	950	7500	1153	PASSED
6(SUS)	3300	226	3600	950	7500	1153	PASSED
7(EXP)	3300	231	3600	114	7500	575	PASSED
8(EXP)	3300	52	3600	28	7500	130	PASSED
9(EXP)	3300	284	3600	140	7500	706	PASSED
10 (EXP)	3300	86	3600	42	7500	212	PASSED
11 (EXP)	3300	146	3600	72	7500	363	PASSED
12 (EXP)	3300	138	3600	68	7500	344	PASSED

ACKNOWLEDGEMENT

I am very thankful to Zuari Indian Oiltanking Limited, Sancoale, Goa for allowing me to carry out this case study. I am also thankful to MIT-Pune for the support.

REFERENCES

1. Chiranjeevi Geddam, C Somasundaram, Sanjay Joshi, STM, ISSN-1785 " Flexibility Analysis of Refinery Piping System" Volume 5 Issue 2, 2015.
2. Srikant Sadafule, Kiran D. Patil, ISSN: 2231-1785 "Study on Effect of Insulation Design on Thermal-Hydraulic Analysis: An Important Aspect in Subsea

Pipeline Designing", STM JoEPT Volume 4 Issue 1, Page no. 33-45, 2014.
3.Mukund Ketkar, Kiran D. Patil, ISSN: 2231-1785, "Review of Subsea Pipeline for Minimizing Thermal and Pressure expansion", STM JoEPT, Volume 4 Issue 1, Page no. 10-22, 2014.
4.Petre Smith, " The Fundamentals of Piping Design", Gulf Publishing Company, 2007.
5.Mohinder L. Nayyar, "Piping Handbook", 7th Edition, McGraw-Hill.
6.ASME B31.3, Process Piping, ASME, New York-2006.
7.API610, Centrifugal Pumps for Petroleum, Petrochemical and Natural Gas Industries, 11th Edition, September 2010.
8.William D. Marscher, "Avoiding Failures in Centrifugal Pumps",2007
9.E.Shashi Menon, "Piping Calculations Manual", 8th Edition, McGraw-Hill, 2009.
10.Eugenia Marinou and Valdir de Souza, SPE-179944, "Review of Typical Challenges in Establishing the Integrity Status of Pipeline", UK, May-2016.
11.User Manual of CAESAR II.