Tutorial for Harmonic Analysis using CAEPIPE

The following are the Steps to perform Harmonic Analysis using CAEPIPE.

General

- A harmonic analysis is performed to determine the response of a piping system to sinusoidal loads. Harmonic forces can arise from unbalanced rotating equipment, acoustic vibrations caused by reciprocating equipment, flow impedance, and other sources. These forces can be damaging to a piping system if their frequency is close to the piping system's natural frequency, thereby introducing resonant conditions.

  It is feasible that multiple harmonic loads may be applied simultaneously at different locations of a piping system. More complex forms of vibration, such as those caused by the fluid flow, may be considered as superposition of several simple harmonics, each with its own frequency, magnitude, and phase.

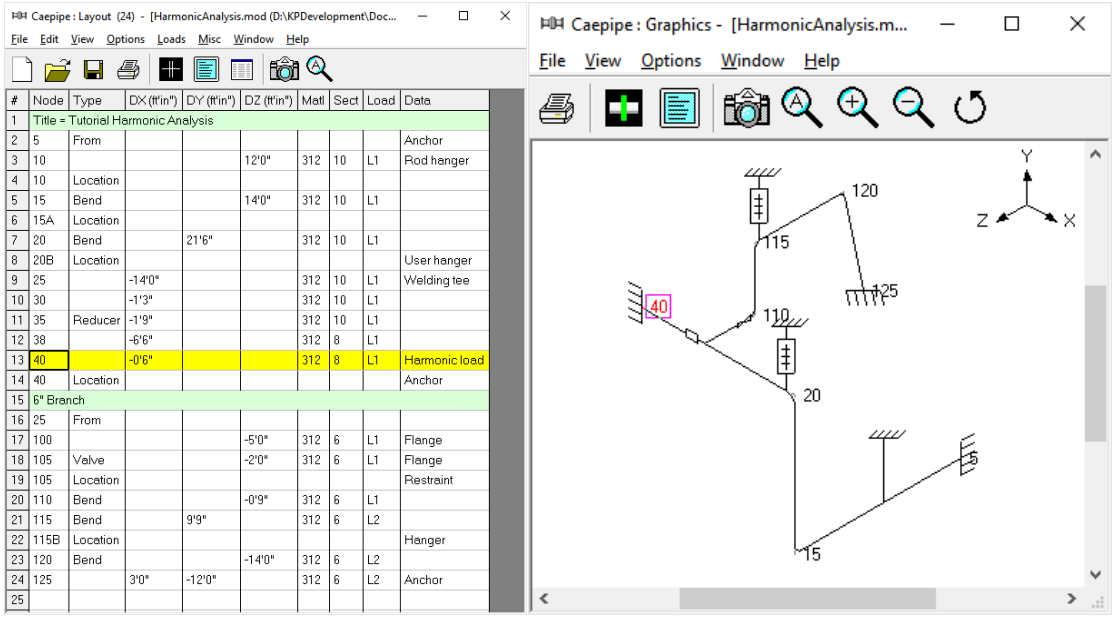
- A harmonic analysis uses the results from the modal analysis to obtain a solution. A single damping factor is used for all modes.

  First, the maximum response for each harmonic load is obtained separately. Then, the total response for multiple simultaneous harmonic loads is determined by combining the individual responses. The combination method may be specified as the Root Mean Square (RMS) or Absolute Sum. Even in the case of a system with a single harmonic load, the said combination is always carried out, so that the resulting solution becomes an "unsigned" case. For an unsigned case, the actual values for displacements, element forces and moments, etc. computed internally by CAEPIPE prior to such combination can be +ve or -ve for the dynamic event.

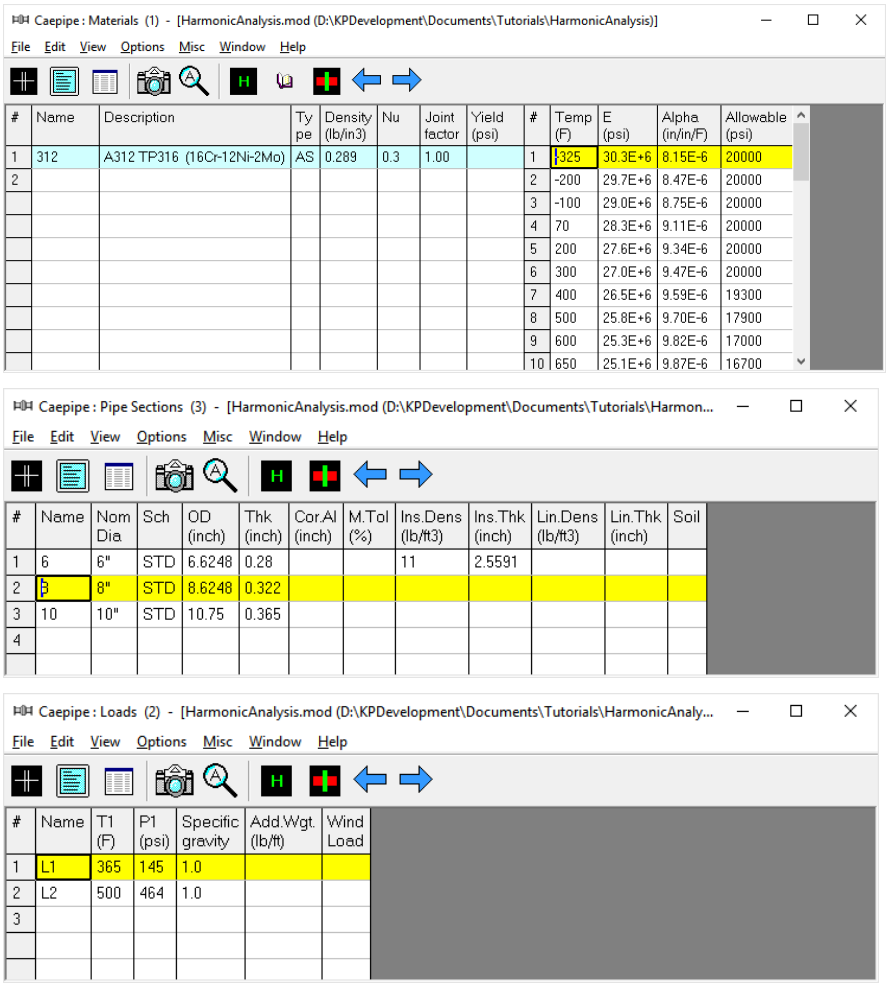
Step 1:

Attached is a CAEPIPE model for Harmonic Analysis. For this model, let us assume the following.

1. Node 5 is connected to a Tank.
2. Node 40 is connected to a Pump Suction Nozzle.



#	Node	Type	DX (ft'in")	DY (ft'in")	DZ (ft'in")	Matl	Sect	Load	Data
1	Title = Tutorial Harmonic Analysis								
2	5	From							Anchor
3	10				12'0"	312	10	L1	Rod hanger
4	10	Location							
5	15	Bend			14'0"	312	10	L1	
6	15A	Location							
7	20	Bend		21'6"		312	10	L1	
8	20B	Location							User hanger
9	25		-14'0"			312	10	L1	Welding tee
10	30		-1'3"			312	10	L1	
11	35	Reducer	-1'9"			312	10	L1	
12	38		-6'6"			312	8	L1	
13	40		-0'6"			312	8	L1	Harmonic load
14	40	Location							Anchor
15	6" Branch								
16	25	From							
17	100				-5'0"	312	6	L1	Flange
18	105	Valve			-2'0"	312	6	L1	Flange
19	105	Location							Restraint
20	110	Bend			-0'9"	312	6	L1	
21	115	Bend		9'9"		312	6	L2	
22	115B	Location							Hanger
23	120	Bend			-14'0"	312	6	L2	
24	125		3'0"	-12'0"		312	6	L2	Anchor
25									



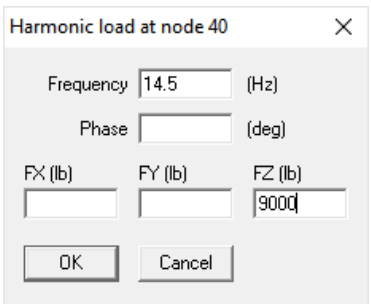
Step 2:

The harmonic load can be imposed as a Force (FX/FY/FZ) at a specified frequency and phase angle. You may be able to get more information on the harmonic loading (mass, rpm, etc.) from the manufacturer of the equipment.

For this Tutorial, the following assumptions are made.

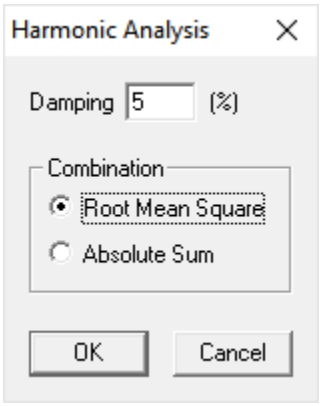
1. Frequency of the rotating equipment = 14.5 Hz.
2. Force in Global Z Direction = FZ = 9000 lb.

The above parameters are entered for analysis by creating a “Data” type called “Harmonic Load” through Layout window > Misc > Data types… at Node 40. See snap shot below for details.



Step 3:

Define “Percentage of Damping” and “Combination” method for Harmonic analysis through CAEPIPE Layout window > Loads > Harmonic…



Step 4:

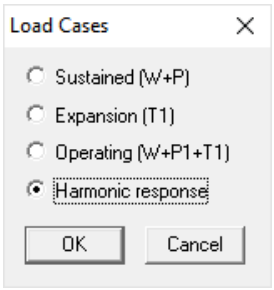
Then, include “Harmonic response” for analysis through Layout window > Loads > Load cases.

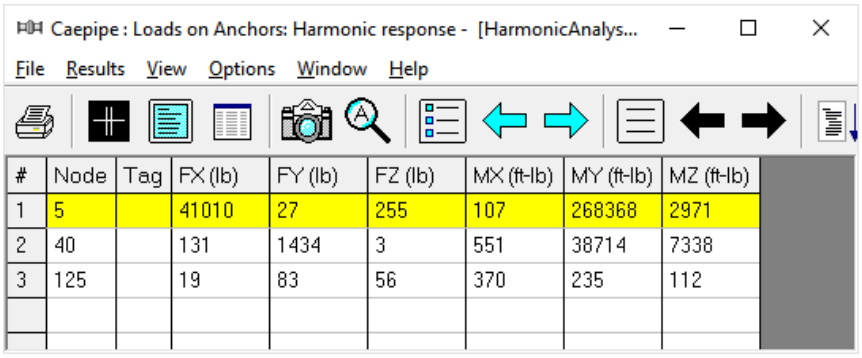
Step 5:

Save the model and perform the analysis through Layout window > File > Analyze. CAEPIPE will apply these loads to compute the response of the piping system by performing a Harmonic analysis along with other load cases defined in the piping system.

Step 6:

Upon successful analysis, CAEPIPE will now show a “Load case” with name “Harmonic response” under “Support Loads”, “Displacements”, “Element forces” and “Support load summary” results.





#	Node	Tag	FX (lb)	FY (lb)	FZ (lb)	MX (ft-lb)	MY (ft-lb)	MZ (ft-lb)
1	5		41010	27	255	107	268368	2971
2	40		131	1434	3	551	38714	7338
3	125		19	83	56	370	235	112

Caepipe : Displacements: Harmonic response - [HarmonicAnalysis.res (D:\KP...

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#	Node	Displacements (global) X (inch)	Y (inch)	Z (inch)	XX (deg)	YY (deg)	ZZ (deg)
1	5	0.000	0.000	0.000	0.0000	0.0002	0.0000
2	10	2.945	0.000	0.000	0.0012	0.4857	0.0841
3	15A	0.346	0.002	0.000	0.0078	2.0330	0.1734
4	15B	0.875	0.007	0.007	0.0362	1.7742	0.0590
5	20A	0.054	0.007	0.073	0.0379	0.7250	0.2483
6	20B	0.001	0.036	0.077	0.0736	0.3527	0.1016
7	25	0.000	0.118	0.223	0.0251	0.2493	0.0373
8	30	0.000	0.107	0.144	0.0235	0.3283	0.0488
9	35	0.000	0.085	0.001	0.0201	0.4231	0.0655
10	38	0.000	0.001	0.503	0.0014	0.0776	0.0140
11	40	0.000	0.000	0.507	0.0000	0.0000	0.0000
12	100	0.035	0.018	0.225	0.1335	0.2244	0.0426

Caepipe : Pipe forces in local coordinates: Harmonic response - [HarmonicA...

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#	Node	Axial (lb)	y Shear (lb)	z Shear (lb)	Torque (ft-lb)	Inplane(ft-lb) Moment	Inplane(ft-lb) SIF	Outplane(ft-lb) Moment	Outplane(ft-lb) SIF	SL+SO (psi)
1	5	255	27	41010	2971	107		268367		109567
	10	255	27	41010	2971	222		223758		93456
2	10	281	96	18015	2971	222		223758		93458
	15A	281	96	18015	2971	1006		5938		4309
3	15A	310	173	13985	2971	1006	2.54	5938	2.12	6129
	15B	173	310	13985	23419	834	2.54	14509	2.12	15245
4	15B	282	949	314	23419	14509		834		12656
	20A	282	949	314	23419	3520		5134		11289
5	20A	381	1867	1480	23419	3520	2.54	5134	2.12	12158
	20B	1867	381	1480	3283	6329	2.54	25269	2.12	19068
6	20B	1862	50	120	3283	6329		25269		12296
	25	1862	50	120	3283	-26794	2.11	5685	2.49	19879
7	25	124	848	9574	551	-40860	2.11	5606	2.49	28501
	30	124	848	9574	551	4546		28892		13348

Caepipe : Support load summary for anchor at node 5 - [HarmonicAnalysis.r...

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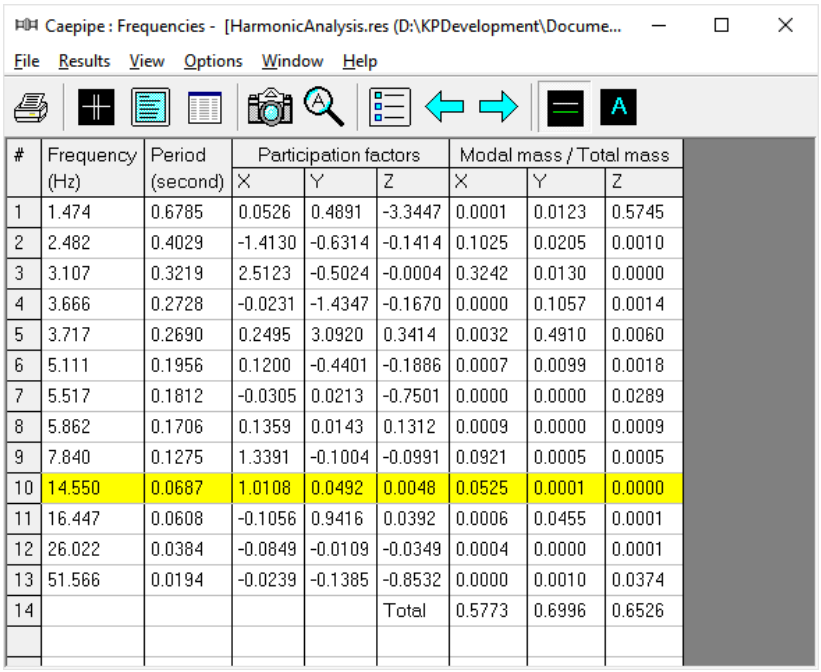
Load combination	FX (lb)	FY (lb)	FZ (lb)	MX (ft-lb)	MY (ft-lb)	MZ (ft-lb)	Displacer X (inch)	Y
Sustained	-23	226	-99	-1755	-871	-192	0.000	0
Operating1	195	792	-108	-3973	4150	-2082	0.000	0
Sustained+Harmonic	40987	254	156	-1647	267497	2779	0.000	0
Sustained-Harmonic	-41034	199	-354	-1862	-269238	-3164	0.000	0
Operating1+Harmonic	41206	820	147	-3866	272518	890	0.000	0
Operating1-Harmonic	-40815	765	-363	-4081	-264217	-5053	0.000	0
Maximum	41206	820	156	-1647	272518	2779	0.000	0
Minimum	-41034	199	-363	-4081	-269238	-5053	0.000	0
Allowables	0	0	0	0	0	0	0.000	0

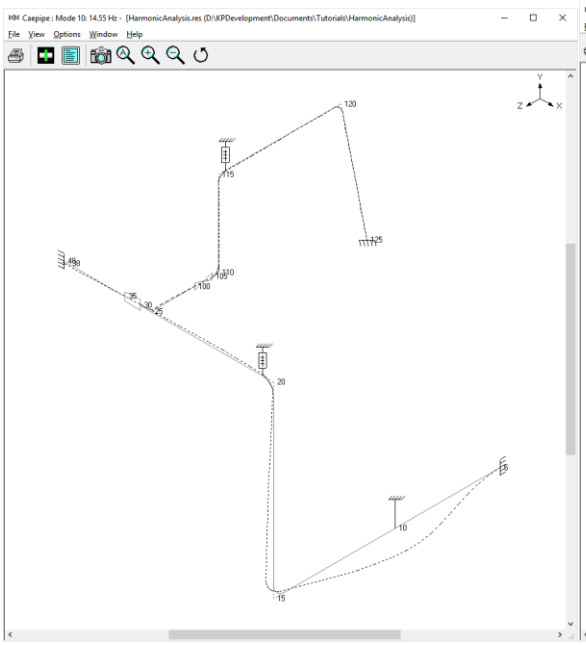
Step 7:

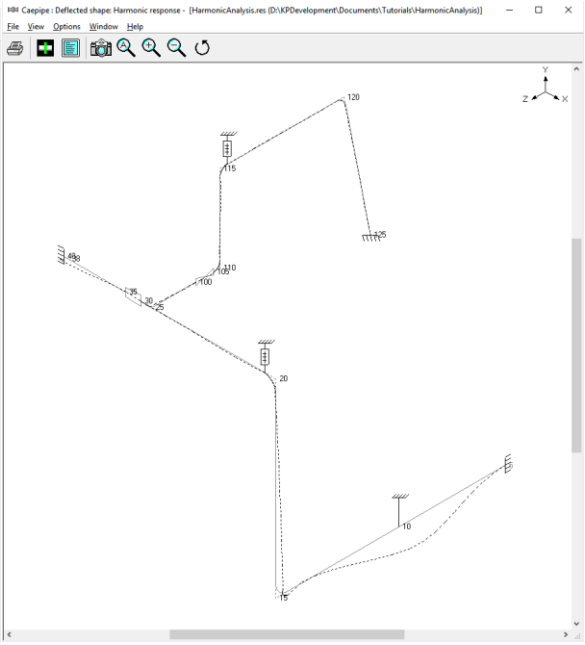
From the review of frequency results of CAEPIPE, it is noted that one of the natural frequencies of this piping system (i.e., frequency for Mode 10 shown in yellow highlight in the snap shot below) is close to the rotating equipment frequency of 14.5 Hz.



#	Frequency (Hz)	Period (second)	Participation factors			Modal mass / Total mass		
			X	Y	Z	X	Y	Z
1	1.474	0.6785	0.0526	0.4891	-3.3447	0.0001	0.0123	0.5745
2	2.482	0.4029	-1.4130	-0.6314	-0.1414	0.1025	0.0205	0.0010
3	3.107	0.3219	2.5123	-0.5024	-0.0004	0.3242	0.0130	0.0000
4	3.666	0.2728	-0.0231	-1.4347	-0.1670	0.0000	0.1057	0.0014
5	3.717	0.2690	0.2495	3.0920	0.3414	0.0032	0.4910	0.0060
6	5.111	0.1956	0.1200	-0.4401	-0.1886	0.0007	0.0099	0.0018
7	5.517	0.1812	-0.0305	0.0213	-0.7501	0.0000	0.0000	0.0289
8	5.862	0.1706	0.1359	0.0143	0.1312	0.0009	0.0000	0.0009
9	7.840	0.1275	1.3391	-0.1004	-0.0991	0.0921	0.0005	0.0005
10	14.550	0.0687	1.0108	0.0492	0.0048	0.0525	0.0001	0.0000
11	16.447	0.0608	-0.1056	0.9416	0.0392	0.0006	0.0455	0.0001
12	26.022	0.0384	-0.0849	-0.0109	-0.0349	0.0004	0.0000	0.0001
13	51.566	0.0194	-0.0239	-0.1385	-0.8532	0.0000	0.0010	0.0374
14					Total	0.5773	0.6996	0.6526

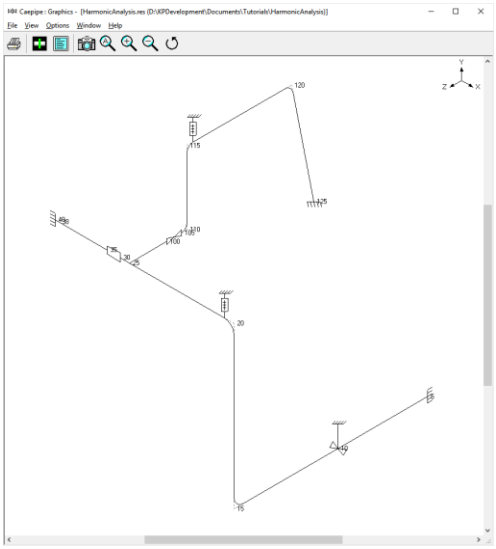
Due to closeness of Mode 10 frequency to the equipment frequency, it is observed that Mode 10 is excited on the piping system by the harmonic load, thereby creating a resonance. This can be seen graphically by plotting the mode shape corresponding to Mode 10 with frequency of “14.55 Hz” (figure shown on the left below) and the deflected shape for “harmonic response” case (figure shown on the right below). See snap shots for details.





Step 8:

In order to prevent piping failure due to resonance, it is important to suppress relevant modes by changing the stiffness of the piping system either by adding or by moving the existing piping supports. For example, for the layout shown above, a lateral restraint in X direction is added at Node 10 as the displacement in X direction is about 3" for Harmonic Response case prior to adding this X restraint. By adding this new support, the stiffness of the piping system is altered. This, in turn, removed the 10th frequency with "14.55 Hz", thereby ensuring that the natural frequency of the piping system is not close to the operating equipment frequency. See snap shots below.



Caepipe : Frequencies - [HarmonicAnalysis.res (D:\KPDevelopment\Docume...

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#	Frequency (Hz)	Period (second)	Participation factors			Modal mass / Total mass		
			X	Y	Z	X	Y	Z
1	1.475	0.6780	0.0052	0.4824	-3.3465	0.0000	0.0120	0.5752
2	2.907	0.3440	0.9680	-0.9277	-0.0808	0.0481	0.0442	0.0003
3	3.518	0.2843	-1.5249	-0.9346	-0.1330	0.1194	0.0449	0.0009
4	3.716	0.2691	0.2049	3.2224	0.3561	0.0022	0.5333	0.0065
5	4.697	0.2129	-1.8948	0.4937	0.0744	0.1844	0.0125	0.0003
6	5.163	0.1937	0.4459	0.3311	0.1873	0.0102	0.0056	0.0018
7	5.519	0.1812	0.0328	0.0194	-0.7484	0.0001	0.0000	0.0288
8	5.865	0.1705	0.2105	0.0099	0.1279	0.0023	0.0000	0.0008
9	7.854	0.1273	-1.3039	0.0965	0.0985	0.0873	0.0005	0.0005
10	16.444	0.0608	-0.0561	0.9427	0.0394	0.0002	0.0456	0.0001
11	26.017	0.0384	-0.1193	-0.0107	-0.0349	0.0007	0.0000	0.0001
12	51.566	0.0194	-0.0250	-0.1382	-0.8527	0.0000	0.0010	0.0373
13					Total	0.4549	0.6996	0.6526