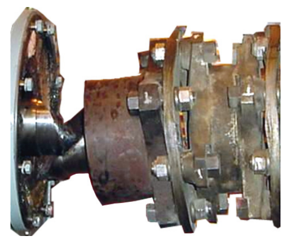
Torsional Vibration Analysis (TVA)

Beta Machinery Analysis (Beta) is the global industry leader in performing TVA studies. Customers trust Beta, as our expertise helps minimize risk and improve system reliability, which saves them money. Our strength is based on our independent assessment, comprehensive technical review, superior software tools, experience, and field service capabilities. TVA is one of our core services.

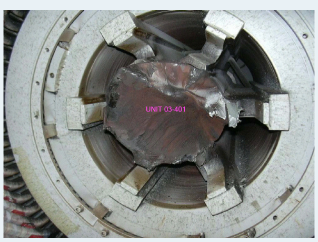
Torsional Failures:



Excessive torsional vibration and resonance leads to very expensive failures such as damaged shafting, couplings, gears, auxiliary equipment, and more. Repair costs to such equipment can easily exceed $1,000,000 in parts, labor, and downtime.

Machinery systems continue to increase in speed and horsepower leading to higher torsional excitation. Preventing failures caused by this requires adequate analysis over the equipment's intended range of operating conditions.

Examples of Damaged Shafts and Couplings



Motor failure

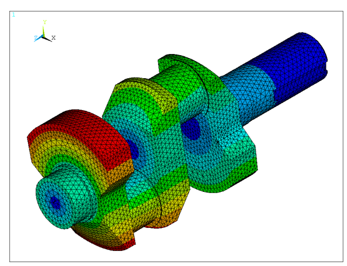
Coupling destroyed

Shaft fracture

Melted rubber coupling

TVAs Are Very Affordable:

For a typical package, the cost of a TVA is usually less than $5,000. Negligible compared to the cost of failure.



Applications:

A TVA is ideal for these applications:

- Reciprocating Gas Compressors (engines, motors, or other drivers)
- Screw Compressors
- Plunger & Centrifugal Pumps
- New Driver or Compressor Combinations.

This study can be applied to other units having a similar configuration or design. BETA can help you assess the torsional risk for your application. Visit our website (www.BetaMachinery.com) for a copy of our Risk Rating Chart.

TVA Provides Valuable Design Recommendations Including:

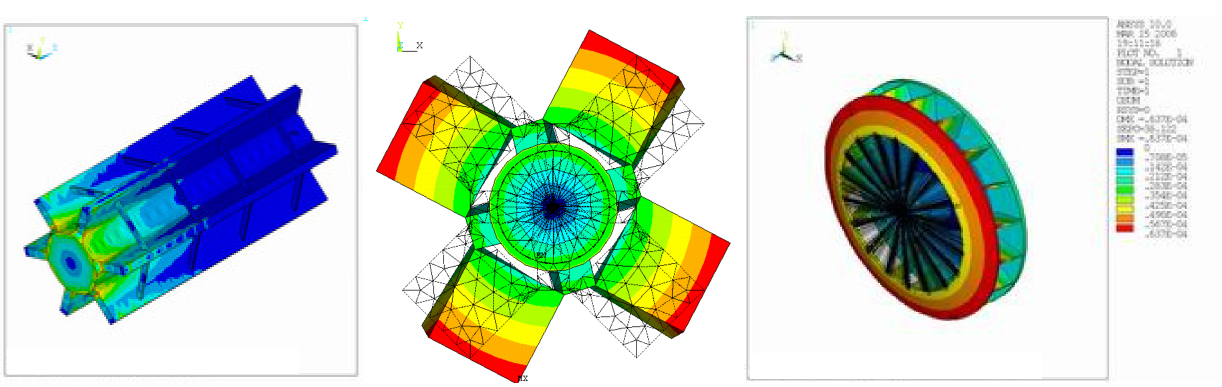
- Flexible Disk vs. Torsionally Soft Coupling
- Optimum Flywheel Size
- Crankshaft Detuners
- Modifications to Material Properties
- Changes to Shaft Geometry – length, diameter, radii
- Changing or Limiting Operating Conditions
- Avoiding harmful speeds

Beta Advantages:

1. Comprehensive evaluation of the ***entire range of operating conditions*** – not just the assumed "worst case." This improves system reliability and avoids the chance of design errors
2. Beta's ***tolerance band analysis*** improves technical accuracy. This technology evaluates the risk and design impact due to the tolerances of key input parameters. Beta's approach reduces the risk of failures and avoids unnecessarily expensive torsional solutions
3. Beta has an ***extensive database*** of engine, motor, compressor and coupling information – resulting in faster and more accurate analysis
4. Our ***system approach*** focuses on the entire package including engine, driver, coupling, etc. This approach is more comprehensive and accurate compared to services focused primarily on the engine (or compressor)
5. Leading expert in reciprocating machinery applications (compressors and engines)

Important TVA Features	**Beta Machinery Analysis**
Torsional analysis is a core in-house service for fast, efficient and high quality analysis	✓
Dedicated team of torsional analysts with the ability to support your projects	✓
Total drive train evaluated to consider all elements in machinery system	✓
Evaluation of entire range of operating conditions is standard.	✓
Input risk tolerance bands analyzed to reduce overall risk of vibration/failure and avoid excessive design costs	✓
Large database for all standard engines, motors, couplings, and compressors	✓
Expert field staff to perform field studies, troubleshooting, and start-up checks	✓
R&D program to enhance torsional software capabilities	✓
Warranty for TVA studies	✓
Experience in reciprocating machinery systems (compressors and engines)	✓
Integrated design approach that coordinates torsional recommendations with other key reciprocating design studies (pulsation, mechanical, thermal, structural or performance analysis) to make informed decisions	✓

About Beta:
What started out as a small company in Calgary, Alberta, in 1967, has developed into one of the world's premier machinery engineering firms, solving challenging vibration, pulsation, and torsional problems. Our extensive storehouse of experience and software technology enables us to effectively help our customers minimize downtime, increase reliability, and save money by keeping their equipment running smoothly. We invite you to visit our web site at www.BetaMachinery.com or contact our torsional team at +1-403-245-5666, or 800-561-2382.



Example of Torsional Modeling Capability for Design Studies (Motor Rotor Core with Spider Bars and Fan)

Common Torsional Vibration Analysis (TVA) Questions and Answers

1. What should be considered in conducting a TVA?

The torsional analysis provider must have an **impartial (independent) view of all components** of the system. The system should be modeled accurately from end to end. Motors should be modeled stepwise through shafting diameters, lengths, and radii rather than a single spring mass model. Compressors and engines should have torsional excitation applied at each throw instead of a phased sum applied at the drive end.

Any **forced response should consider the entire operating range** the equipment will see through its life cycle, or further analysis should be done for major changes in operation. Intentional or upset compressor conditions, no load cases, and also engine misfire and worn damper conditions should also be considered. One or two points on either end of the operating envelope are not sufficient. Points of operation that have lower peak to peak torque can have higher individual harmonic orders that interfere with torsional natural frequencies resulting in excessive response (resonance). Trends and worst cases can be extracted from these multi-run analyses.

Consider the **error tolerance, or uncertainty, band** for all the input data in the model. Also, test for resonances that may exist within the range of predicted torsional natural frequencies.

2. How does a TVA save me money?

Beta's TVA provides valuable savings to packagers and owners in the following ways:

- Eliminates downtime and repair costs due to excessive torsional vibration. Avoid million dollar failures.
- Quantifies risk of different design solutions, enabling wise investments decisions.
- Reduces the capital costs for packages with overly conservative designs. If large flywheels, soft couplings, or other components can be eliminated, this can save significant construction and maintenance capital.

3. What software does Beta use?

Torsional response is modeled using a combination of proprietary software developed by Beta and ANSYS, the leading commercially available Finite Element Analysis (FEA) program. Beta draws upon a vast population of previously analyzed pumps, compressors, couplings, engines, motors, and more. These data are built into a database allowing Beta analysts to build models quickly and efficiently. The proprietary component has been developed through consultation with leading OEMs and through ongoing comparisons between field data and model results.

4. Should we do a field survey to measure torsional vibration?

A field torsional review is recommended for situations such as:

- highly critical machinery
- VFD applications – excitation from the VFD controller has proven to be critical in some cases
- when designers need to make compromises due to constraints in time, economics, or available information
- when failures have occurred, to troubleshoot systems
- new untested designs, or designs with many assumptions
- when determining what speeds to avoid
- to confirm damping requirements
- spider rotors – high variability in stiffness, even between identical motors

5. Why is it important to evaluate the entire range of operating conditions for a reciprocating compressor?

Reciprocating compressor packages often have 20 different conditions and, many times, there are over 50. To help answer this question, an actual example of a 4 throw compressor and engine with over 150 conditions is used.

- Compressor: 32 conditions (min/avg/max for suction and discharge pressures and cylinder clearance plus upset single acting per cylinder and bypass or unloaded conditions)
- Engine: at least 5 conditions (normal, 2 worn damper, and at least 2 misfire conditions)

Analyzing the conditions represents a significant challenge for the packager and end user. What condition represents the worst case for torsional vibration? What condition(s) should be evaluated?

- Arbitrarily picking 4 or 5 conditions and paying extra for additional conditions is not cost-effective in most cases.
- Asking a packager or OEM to choose conditions is unreasonable, as they are not experts in this area.
- For many packages, it is nearly impossible to identify the worst conditions in advance, because each combination of compressor, coupling, and driver responds at different twisting frequencies. Only when the drive train geometry has been modeled and torsional natural frequencies and vibration mode shapes calculated, can the worst conditions be identified. These are often the conditions that have the highest torque near the torsional natural frequencies. However, other non-resonant conditions that have high overall total torque can also be rough torsionally (for example, an unloaded two throw compressor).
- This creates a reliability risk – for potential failure now, or in the future, as conditions change and affect the torsional vibration.

Because of these factors, Beta has developed advanced software tools to take the guesswork out of evaluating a wide range of operating conditions. Packagers and end users no longer need to worry about gambling on what the worst case conditions are. We will input the data and assess the torsional vibration levels on the entire system (i.e., compressor, coupling, driver, and auxiliary equipment). The software can process all operating conditions in a single run, saving considerable time and cost.

In the example we are using, note that conditions 11, 12, 39 and 60 are the worst cases for different locations in the drive train. This illustrates that all conditions should be evaluated in torsional design.

Beta: Torsional Vibration Analysis (TVA) - Example of Operating Condition Summary

Worst Cases Highlighted Below (note: problems may be based on Safety Factors, Speed Fluctuation, and/or Stress)
All 64 conditions modeled using Beta's proprietary software system

Operating Condition#	Minimum Design Safety Factors			Speed Fluctuations (RPM)				Max. Unintensified Engine Stresses (psi)		
	Comp.	Coupling	Engine	Compressor ODE		Engine ODE		Overall (0-pk)	Harmonics (0-pk)	@ Order
				-ve	+ve	-ve	+ve			
1	2.9	1.2	1.6	-25.4	34.0	-18.8	16.5	6,029	3,104	0.5
2	2.7	1.2	1.5	-32.0	28.0	-19.0	16.4	6,054	3,094	0.5
-- conditions 3-10 omitted for brevity --										
11	2.6	1.1	1.5	-32.9	28.7	-19.6	17.0	6,236	3,200	0.5
12	2.6	1.1	1.5	-33.8	29.6	-20.1	17.8	6,450	3,344	0.5
-- conditions 13-37 omitted for brevity --										
38	2.6	1.1	1.5	-32.8	28.6	-19.6	17.0	6,236	3,203	0.5
39	2.6	1.1	1.5	-33.7	29.5	-20.1	17.8	6,451	3,347	0.5
-- conditions 40-58 omitted for brevity --										
59	2.7	1.2	1.6	-29.7	29.8	-20.5	14.6	6,013	2,954	0.5
60	2.8	1.1	1.5	-29.5	28.2	-19.0	15.6	6,176	2,954	0.5
61	3.0	1.3	1.6	-30.4	26.3	-19.9	16.3	5,925	3,010	0.5
62	2.8	1.2	1.6	-29.5	28.4	-18.3	17.4	5,989	3,010	0.5
63	2.9	1.2	1.5	-32.0	30.4	-19.0	15.6	6,169	3,010	0.5
64	3.2	2.0	2.4	-18.8	19.3	-9.0	9.9	3,948	2,654	2

SUMMARY

Worst Condition #	**11**	**60**	**39**	**12**		**39**		**39**	**39**	
Worst Case	**2.6**	**1.1**	**1.5**	**-33.8**	**29.6**	**-20.1**	**17.8**	**6,451**	**3,347**	**0.5**
	(case: min safety factors)			(case: max speed fluctuations)				(case: max stress)		
Other Notes:										
Worst Speed *	1,000	992	899	1,000		1,000		899	1,000	
Worst Phase Diff **	240	120	120	120		0		120	0	
Worst Location ***	16	17	25	1		29		25	24	

Definitions:

* Speed = speed at which the worst case occurs (RPM)

** Phase diff = phase difference (between compressor cylinder 1 outer dead centre and engine cylinder 1 top dead centre) at which worst case occurs (degrees)

*** Location = location in torsional model at which worst case occurs

ODE = opposite drive end

For more information, call our torsional team at 403-245-5666, or 800-561-2382, or visit our web site at www.BetaMachinery.com.