ResonanceKiller™ – Broadband Mass Damper

Contents

Abstract 1
Resonance Phenomena 1
Introduction of Tuned Mass Damper 2
ResonanceKiller™ 5
Advantages and Usage of ResonanceKiller™ Technology 6
Reference Examples 7
Summary 7
Frequently Asked Questions 8

Abstract

This paper explores the progress in tuned mass damper (TMD) technology, focusing on patented ResonanceKiller™ technology which unlike traditional fixed-stiffness TMDs, responds to dynamic conditions in real-time, ensuring superior vibration control across a broad range of frequencies. This innovation opens new horizons for structural stability in civil engineering, mechanical systems, powerplants, and other application areas.

Resonance Phenomena

When an impact is applied to an object, the object vibrates at a specific frequency. This is called the natural frequency. Since the natural frequency is determined for each object, no matter what kind of impact is applied, the object vibrates at its natural frequency. Industrial applications often have the vibration excitation as sinusoidal vibration coming from rotating shaft. Even the shaft is balanced and alignment is good, there is always some excitation present. In some cases, the excitation can originate from even wind or sea movement.

Then, what is resonance? When an object is subjected to an external vibration of the same frequency as the object's natural frequency, the stationary object begins to vibrate. This is resonance. If a vibration of the same frequency as the natural frequency of an object is repeatedly applied from the outside, the amplitude increases, and the vibration becomes larger and larger. This phenomenon of vibration response being much larger than the applied force is resonance. [1]

At resonance damping of the system itself is the main factor that defines the vibration level. Most of the industrial systems are built from steel. The damping of the steel is low. Mostly the damping comes from the joints (welds, bolt connections) of the construction. Still the damping is so small that amplification at the resonance can be in the range of 20 to 30. In comparison to forced vibrations, the vibration amplitude that would be 1 mm/s, can be 30 mm/s at resonance because of this phenomenon.

[1] Text taken from TDK's webpage: link

What can we do to reduce excessive vibration at resonance? The possible solutions:

- Changing the natural frequency away from operation range
- Reducing excitation forces
- Install tuned mass damper

Changing the natural frequency of the construction in resonance is maybe the best solution since the excitation forces are most likely already at minimum or they should be minimized anyway. Sometimes it is hard to change the natural frequencies, especially if the excitations are broadband. If you add mass and reduce natural frequency, there can be another mode that is excited and vibration levels remain the same or if you add stiffeners another higher mode might be excited. Installing a tuned mass damper is easy solution for existing challenge. It will create opposite force to the excitation force and reduce vibration. Mass dampers are being used in design phase of products. For example, automotive industry is doing this for resonance issues that cannot be solved in other reasonable way. There are millions of installations done every year.

Introduction of Tuned Mass Damper

Structures like ships, wind turbines, power plants, offshore installations, bridges and buildings all have a property called natural frequencies. This means that the structure is prone to vibrate at this frequency and the only limiting factor at this frequency for vibration is the damping properties in the structure. Typically, in steel and concrete structures, the damping is very low.

The natural frequencies as such are not a problem, but when some vibration excitation occurs near or at the natural frequency, there is a resonance vibration. As mentioned, at this frequency, the only limiting factor is the structure's damping properties. The excitation can originate from various sources, for example from rotating machines (e.g. motors, generators, propellers, pumps) or environmental factors (winds, currents etc). At the resonance, vibration levels can get very high causing multiple problems from machine durability issues to operator or passenger comfort. Especially the bearings of the products are vulnerable for this kind of vibrations.

The problematic vibration at resonance can be damped with a tuned mass damper. The principle of tuned mass damper is to make a one-degree of freedom vibration system, whose natural frequency is tuned to the same natural frequency than the resonance in the structure occurs. The main idea of the tuned mass damper is for the mass to vibrate in roughly opposite phase with the excitation and thus creates a counterforce for the structural vibration excitation. This principle of tuned mass damper is over 100 years old, invented by Hermann Frahm around 1901.

TMD application examples - civil Engineering: skyscrapers and tall structures (enhanced stability against wind-induced sway), bridges (improved resistance to oscillations from pedestrian or vehicular loads), seismic protection (reduced damage during earthquakes) - mechanical Systems: automotive (better ride comfort and handling by dampening chassis vibrations), aerospace (minimization of resonances in aircraft structures) and machinery (extended lifespan through vibration suppression in rotating equipment)

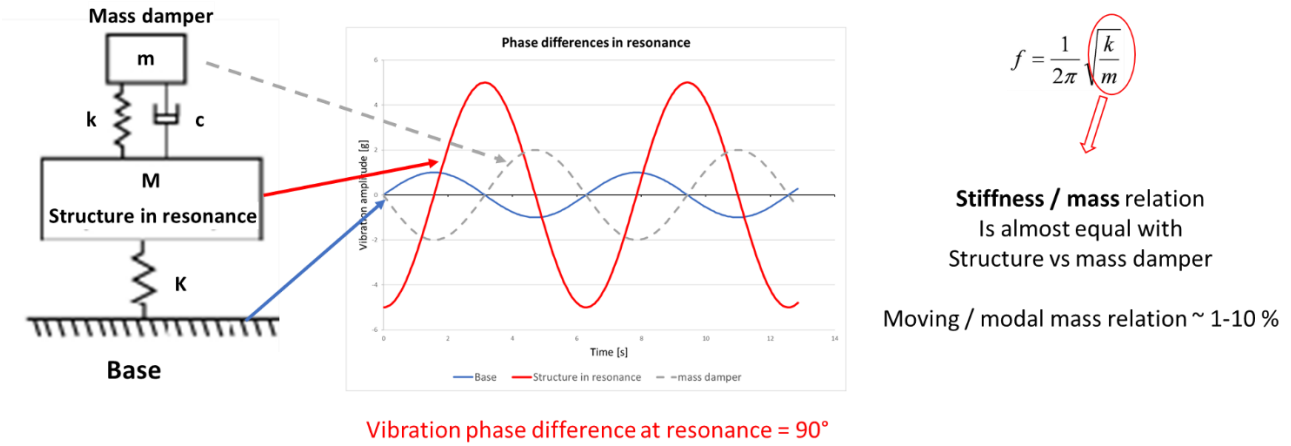


*Figure 1. Tuned mass damper principle: excitation force (blue), original structure (red) and tuned mass damper (gray dashed line). **TMD consists**: **mass** (typically a steel block), **spring** (provides the restoring force, determining the system's natural frequency) and **damper** (dissipates energy)*

With a common tuned mass damper, it is generally observed that the damper works very well at the target frequency, but it brings so-called sidebands near the original resonant frequency. That is, the former vibration peak becomes two peaks below and above the original peak. An image from Wikipedia is used below to illustrate the principle.

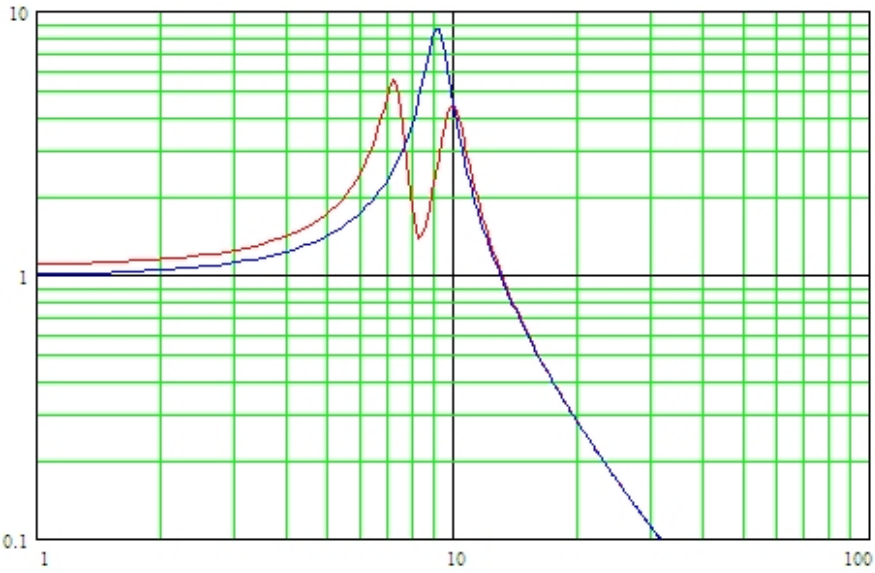


Figure 2. Wikipedia: Tuned mass damper effect to vibration spectra. Original structure (blue) and with tuned mass damper (red)

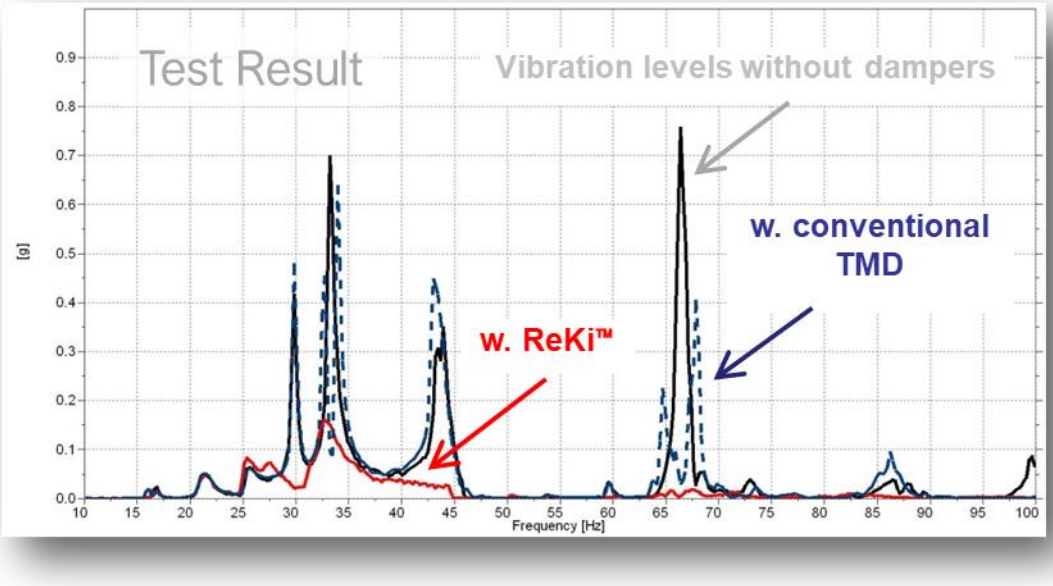


Figure 3. ResonanceKiller™ damper effect compared to tuned mass damper - vibration spectra. Original structure (black), tuned mass damper (dashed blue) and ResonanceKiller™ (red)

These sidebands become interesting or problematic when the vibration excitation is with variable frequency such as motors, generators, propeller, wind etc varying thing. In some cases even if the vibration excitation is at steady frequency, there can be broadband excitations because of multiples of base frequency. These sidebands can then themselves become vibration issues even if the original resonance is not a problem anymore. There is a tradeoff between the vibration reduction capability of the mass damper at the resonance and the height of the sideband peaks.

The ResonanceKiller™ does not have the sidebands since the technology is based on very high non-linearity. This was the major benefit that was noticed when it was invented in technical research center of Finland 2011. Later it was proven in field applications starting from 2013 (which is still in 24/7 usage).

ResonanceKiller™

"I have 30 years of experience in noise and vibration damping at Wärtsilä [2]. This mass damper is the most amazing invention of the past decade. It's incredible"

Kari Saine Wärtsilä's research engineer [3]

The ResonanceKiller™ is based on all metal construction enabling broadband dampening of vibrations that are resonance related. The principle enables construction of various shapes of damper to be integrated into existing structures with minimal changes. Steel structure is inert to environmental effects and material-wise it is cost efficient and recyclable.

Damper benefit is in proven design and integration into structures, and case specific optimization of the damping characteristics. The scalability of the technology is huge – directly proportional to the target structures where it is applied to, from hundreds of grams to hundreds of tons. Commercially smallest ResonanceKiller™ damper has been 80 grams and largest 1 600 kg of moving mass.

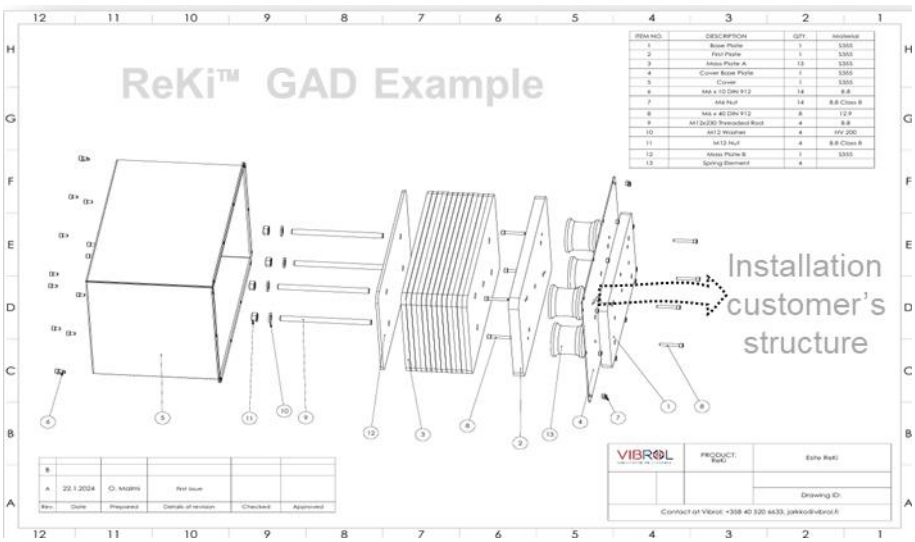


Figure 4. ResonanceKiller™ damper GAD construction example.



Figure 5. ResonanceKiller™ damper examples.

[2] Wärtsilä is stock listed in Nasdaq (www.wartsila.com)

[3] Newspaper article: "No more extra support structures" TEKNIIKKA&TALOUS 5.6.2019 (link)

Advantages and Usage of ResonanceKiller™ Technology

ResonanceKiller™ works without input energy or control, it is passive damper. Since it is all metal solution it is low-cost solution and because of patented technology it reduces disturbing vibrations in broad frequency band and it works in 3 directions. ResonenceKiller™ is used in pumps, machines, engines, pipes and structures. It is used in applications from 0.1 kg to several hundreds of tons. This far the frequency bandwidth where it has been used is 2 to 600 Hz. References available including nuclear plants and applications: marine - powerplants - process industry - offshore – military – paper machines.

Advantages of broadband mass damper: installation simple and fast – only standard tools required, there are no changes to existing structure, local personnel can do the installation, installation can be done during operation of the target, results are available immediately after installation and there are no risks – ReKi™ success rate has been 100% – since 2013 the first commercial installation.

Design input for broadband mass damper: confirmation of resonance phenomenon (FEA or measurements), weight estimation of the target mode (or target), vibration frequency and amplitude – f f t spectra and inform possible installation location. The needed mass for ResonanceKiller™ is typically 5 % of the modal mass that is participating to the vibration mode. For example 100 ton genset's is having a resonance challenge and 2 ton is vibrating at 22 mm/s - 60 Hz frequency, then we will apply a 100kg ResonanceKiller™ damper to a vibrating location and the vibration amplitude will decrease to 8 mm/s which is acceptable to customer.

Normally the delivery of ResonanceKiller™ is four weeks from design to delivery and If needed there is possibility to emergency service when the delivery can be done in co-operation with the customer (asap).

ResonanceKiller™ is used in troubleshooting (installation in situ), design phase tool (solution for resonance problem during design phase): Mathematical models of ReKi™ are available for customers, optimization of applications (natural frequencies are not limitations of design anymore), ResonanceKiller™ enables for example lighter structures (save money with the damper).

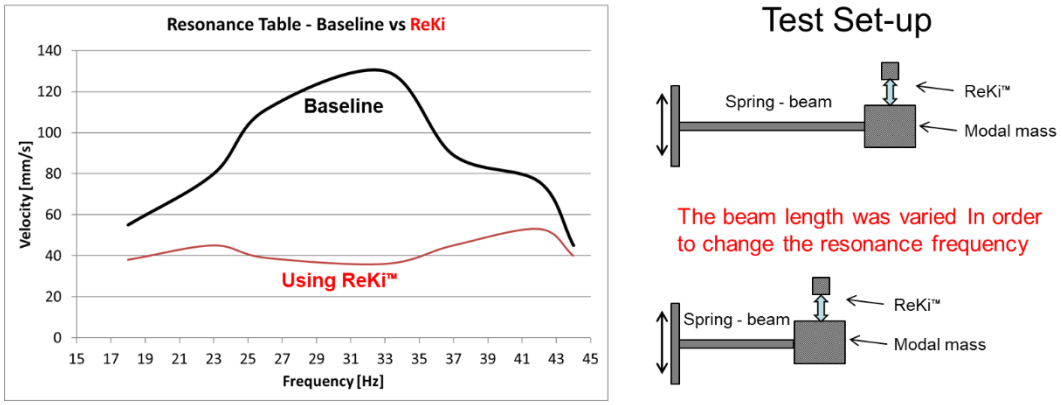


Figure 6. ResonanceKiller™ damper test example. Left: vibration of the resonance in frequency domain with and without ResonanceKiller™ damper and right: test set-up explained (damper remained same during tests).

Reference Examples

Most of the customer projects are not public information. Over 1 000 ResonanceKiller™ damper installations have been globally. Here are few customer examples Using ReKi™ Dampers

Company	Application	Info
Sulzer	Pump / motor	Troubleshooting and FAT
Areva / TVO	Nuclear plant OL1 / OL2 / OL3	Troubleshooting
Wärtsilä	Powerplant / Ship motor	Desing phase, FAT and troubleshooting
ABB	Multiple applications	Desing phase, FAT and troubleshooting
Meyer	Ship	Design phase
Valmet	Paper machines	Desing phase, FAT and troubleshooting

ResonanceKiller™ technology is being used as troubleshooting or design phase tool to control vibration levels of structures. Many other applications from marine to powerplants and process industry is also being installed. First damper was installed 2013 in Dominican Republic and it is still working.

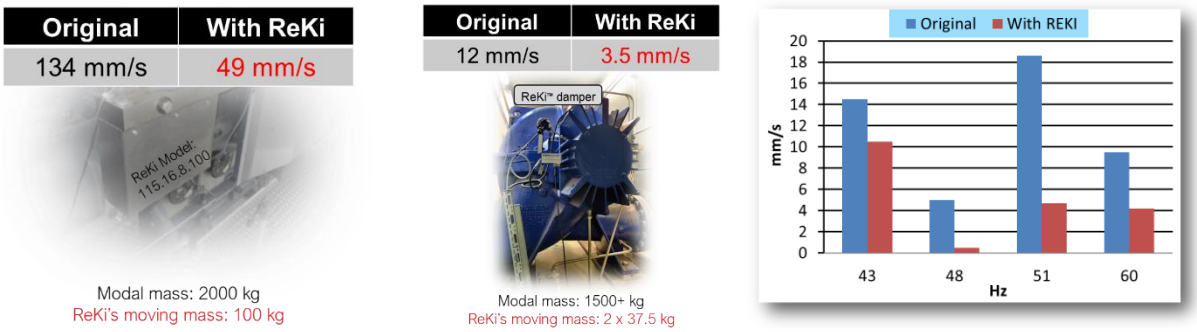


Figure 7. ResonanceKiller™ damper installation examples. Left: engine component (design, manufacturing and installation done in 5 days), middle: district heat pump application and right: electric motor in powerplant. All these examples had vibration over trip level originally and ResonanceKiller™ was designed, manufactured and installed -> vibration levels decreased to acceptable level according to ISO 10816.

Summary

Avoiding resonance phenomena is in some cases challenging since the excitations can be broadband and structures involved are complex. ResonenceKiller™ damper reduces vibration levels at resonance by 50 to 90 %, it is proven technology with over 1 000 installations globally, performance tests conducted in laboratory and field since 2011, long term tests conducted – first commercial ResonenceKiller™ delivered 2013, works in harsh environments – all-metal structure, used in nuclear plants - applications from arctic to marine environments, ready to install for new constructions and retrofits and patented in Europe - America – Ásia.

Frequently Asked Questions

Q. *You are only solving the symptom of the vibration issue with the damper? Not the root cause?*

A. ResonanceKiller™ is reducing vibrations of the resonance phenomena. We are not changing the natural frequency. This is true. In some cases the change of natural frequency is challenging or impossible to apply with reasonable budget or time. In these cases ResonanceKiller™ is a solution that solves resonance vibration issue.

Q. *What if we replace a component (e.g. motor) later in the system?*

A. ResonanceKiller™ is a broadband solution and it will work with new component (e.g. motor) also as long as it is approximately same size as they are with same power range. The damper can also be tuned if needed for the new situation with change of few mass plates.

Q. *Maintenance of the damper?*

A. General maintenance for ReKi™ dampers is not necessary. However, routine inspections (accordance to the plant / ship normal inspection period) can be done during the lifetime. For all works on ReKi™ no special tools and no specific qualification of personnel are required. The spring element can be replaced every 4 to 6 years in order to maintain the damper performance.

Q. *What about other vibration issues (forced vibrations, bearing damages, alignment issues, etc)* ?

A. ResonanceKiller™ damper reduces the vibration of resonance phenomena. This does not improve or worsen the alignment/ balancing etc. Reducing vibration levels improves the lifetime of the bearings. The forced vibrations can be reduced by some 10% or so in some cases. This technology is not designed normally for forced vibration reduction.

Q. *Do we hide other vibration issues? Do these start to grow?*

A. No. We do not hide any other vibration issues. We only reduce the resonance related vibration levels. This is good for the structures, bearings and welds etc.

Q. *Is continuous monitoring identifying the issues (with the dampers in place) or is there a risk not to identify issues in time?*

A. The continuous monitoring capability to detect vibration issues (bearings, unbalance etc) is not hindered by installation of ResonanceKiller™. From the continuous monitoring can be seen the increase of vibration levels which would indicate the need to change the spring element of ResonanceKiller™ or if there are other issues (balancing, alignment etc).

Q. *Vibrol – dampers not being seen as a proven product. Lack of references for similar applications in oil and gas industry seems to indicate this is still a product under development/prototype. This means additional risks with reliability of the product and performance?*

A. ResonanceKiller™ dampers have been installed since 2013 in commercial projects. Over 1 000 installations have been made successfully including nuclear plants. This technology has been proven in many applications from: pumps – electrical motors – diesel motors - oil / gas powerplants - marine projects – compressors - paper machines – structures and nuclear plants (many applications). For example Valmet (paper machine manufacturer listed in Nasdaq) has taken exclusive right to use this technology in their applications. In addition, this technology is used in multiple nuclear plants which are very sensitive to new technologies. The first installed damper 2013 in Dominican Republic is still in use (gas / oil powerplant). ResonanceKiller™ technology is improved version from tuned mass dampers (tmd) which has been used over 100 years by many industries. The automotive industry is also using tmds and those are installed millions units per year.

Q. *Use of this type of mass dampers on centrifugal pumps and motors is also first time application for the equipment owner/operator and their supporting network. This makes it even more challenging to support as we now have an unproven product in a new application /solution?*

A. The only wearing part of the ResonanceKiller™ is the spring element. This can be replaced by any mechanic in any site. Spring is installed by using standard bolts. Vibrol provides simple instructions for the change the spring element. The wearing of the element takes normally from four to six years or more depending on the application. There are also applications where the spring element will not be changed (lasts over 20 to 30 years). The ResonanceKiller™ does not stop working suddenly. The vibration levels could increase a bit after e.g. five years of usage. Then the spring elements will be changed by site mechanic or Vibrol personnel if needed. The ResonanceKiller™ damper does not stop working suddenly like could happen with active solutions if the logic would fail.

Q. *Lugs to the pump and bolts attached for damper will be subjected to fatigue. It needs to be clarified how this potential integrity exposure has been addressed?*

A. The standard bolts are calculated and tested against the vibration levels occurring in ResonanceKiller™ moving mass. These similar calculations were mandatory in nuclear plant installations and standard bolts had enough safety margin to permanent usage.

Q. *Vibrol is requested to confirm that there will be no adverse impact to bearings, foundation and/or seal life as a result of the installation of the Vibrol dampers?*

A. This can be done by using finite element analysis (FEA). This is not normally included to ResonanceKiller™ projects since most of the customers want to reduce the vibration levels and see this as a positive impact to bearings etc. The ISO 10816 agree that vibration levels of the bearings (and welds etc) are the most important thing that affects to bearing lifetime. ResonanceKiller™ reduces vibration level and increase the lifetime of bearings / structures / welds. Separate study using FEA can be done to show that there are no adverse impact to bearings / foundation or seals. This would be addition to normal ResonanceKiller™ project.

Abbreviations

Frequency, RPM, Orders, Modes, Nodes and node

- Frequency - is how many things happen in a period of TIME = (cycles/second called Hertz and abbreviated (Hz)). The natural frequencies do not change with RPM.
- RPM - is revolutions of the crank per minute
- Orders - are defined as events per crank revolution. Frequency is variable and goes up and down with RPM.
- Mode – describes a natural mode of the system
- Mode mass - describes a mass of the natural mode of the system
- Node – is the location where the vibration level is at minimum in natural mode