THE PATHS TO MOMENTUM TMDS WITH EXCELLENT PERFORMANCE

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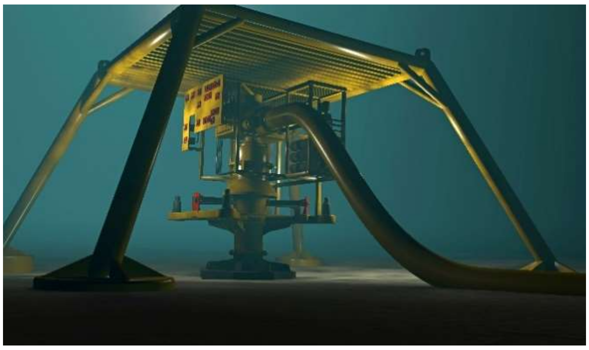
Momentum Technologies delivers top of the class tuned mass dampers. Momentum TMDs are excellent candidates for reducing high frequency (i.e. higher than 20 Hz) resonant vibration, typically for vibration of small bore connections in process facilities, where sound is the main force and where supports or bracing are difficult to install or unviable.

The name «Tuned Mass Damper» (TMD) indicates that the damper needs to be set up correctly (is «tuned») in order to obtain good vibration reduction.

We often get asked by a potential customer if we have a catalogue to show the different TMDs available. It is unfortunately not that simple to have catalogue material as there are many factors involved that you need to get right if the damper shall do a good job, e.g. the selection of mass, spring and damper in the damper, length of damper, orientation and location are essential. Dampers can be provided in diameters from 1" to 36" and even larger upon request.

So how can we tune a Momentum TMD when the project engineers are in France, the plant is in Asia and Momentum is in Norway? This white paper describes this in short.

Technical details are available in a separate datasheet.



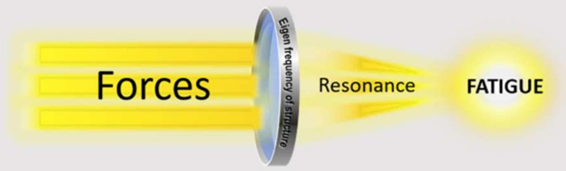
MOMENTUM TMDS CAN BE PROVIDED FOR SUBSEA APPLICATION.

UNDERSTANDING VIBRATION AND VIBRATION DAMPING

To understand vibration and vibration damping we need a set of tools to study how they behave. It is well known for a Linear Time Invariant system (LTI, a system that is linear and not changing with time) that the output is the result of an input that is convolved with the amplification/gain of the system when one is observing a system in the time domain. In the frequency domain this can be described similarly that the output is the input multiplied with the amplification.

This all seems very complicated, but I think this is a great intuitive understanding of how vibration occur: vibration output is the result of the force input multiplied with the amplification of the mechanical system:

$$D(f) = F(f) * G(f)$$



The simple figure to the right describes most of vibration and strategies on how to mitigate it; vibration can be reduced by either reducing the input force $F(f)$ or the amplification $G(f)$ (illustrated by a magnifying glass) of the mechanical system. All parts of the equation are complex valued functions of the frequency. The highest vibration is obtained when the force frequency is high where the system is responding strongly, that is at one of the natural frequencies. The phenomenon that happens if a forcing frequency is close to or at the natural frequency is called resonance and can occur for both sound and vibration.

Momentum TMDs work by reducing the magnification at a range of natural frequencies $(G(f))$. The magnification is used to optimize the damper for a single degree of freedom with a systematic approach. If there is a range of frequencies that are of concern and/or if the vibration occurs in multiple locations and orientations, we need to use more sophisticated and iterative approaches to obtain an optimal solution.

MEASUREMENT BASED APPROACH TO AN EXCELLENT MOMENTUM TMD

The minimum requirement for the measurement-based approach is a drive point FRF measurement conducted with a force instrumented impact hammer and an accelerometer, measured in the point and direction of the vibration, but measured while the system is not vibrating. The hammer measures the input force, and the accelerometer measures the output acceleration and synchronous measurements averaged results in an FRF (accelerance/inertance) that can be used for setting up the damper. The measurements can be further extended by doing a full set of FRFs for a larger system with vibration, and curve and modal fitting can be used to obtain an experimental modal analysis (EMA).

In a laboratory environment it is possible to use vibration exciters / shakers as an alternative forcing for the FRF measurement.

If absolute vibration levels are of interest, it is necessary to conduct vibration measurement with for example accelerometers and strain gauges during operation.

FIGURE 1 - FORCE INSTRUMENT IMPACT HAMMERS

FIGURE 2 – ACCELEROMETER

FIGURE 3 - SHAKER

The real benefit of using the measurement approach is that no assumptions are made to the boundary conditions of the system. The negative side of this approach is that it is necessary to measure at a large number of locations and orientations. This can be time consuming and difficult to do in an industrial environment where downtime equals money. This can largely be mitigated through replacing accelerometers using VibraVision (video-based measurements).

FINITE ELEMENT BASED APPROACH TO AN EXCELLENT MOMENTUM TMD

The minimum requirement for the finite element-based approach is either 1) a single mode shape of interest normalized to mass (default for ANSYS) or 2) the frequency response for unity force in the point of interest.

The mode shapes are readily available from most finite element software (even free ones) but needs to be normalized to mass and exported to a text file for further processing.

In order to communicate back to the customer, the locations and orientations of the TMDs it is also necessary to get a list of the finite element node numbers. So, a complete set of necessities from for example ANSYS, would be the full mode shape matrix, a list of the frequencies for the different modes and the node numbers.

A third option to sending Momentum exports from the modal or frequency response analysis, is to send a CAD model or ISO drawing, boundary conditions and forcing model to Momentum. We then need to set up an in-house finite element model to extract the necessary parameters for tuning the Momentum TMD.

All three variants will yield the same results, but the true benefit of the finite element-based approach is that everything can be done outside the process facility and engineering companies can share information to Momentum for tuning excellent TMDs, without revealing proprietary information. The downside to the pure finite element approach is that the model can contain errors from the real system, both from wrong forcing, wrong mass/stiffness/damping distribution and wrong boundary conditions.

HYBRID OF TECHNIQUES TO AN EXCELLENT MOMENTUM TMD

Hybrid use of measurement and finite element analysis is in many cases the only option available. As an example, the customer might have measured vibration response with an accelerometer and found a vibration spectrum in one or more points and directions. The customer might have a CAD model or ISO drawings, descriptions of the geometries, information about process conditions, etc. In combination it will be possible to set up a finite element model and calibrate the boundary conditions and mass/stiffness/damping distribution in the model from the measurements taken.

The downside to this approach is that only the points measured at are used as the inputs for model calibration. Non-accessible points might have large vibration that is not put into the model and are thus not being considered.

TIME DOMAIN APPROACHES

A Momentum TMD can work for both stationary, transient and random vibration. For non-stationary analysis it is necessary to conduct analysis in the time domain through the use of transient finite element analysis or by convolving the time dependent force with the impulse response of the system. The mechanical system can in most cases be considered linear, though, and tuning of the dampers can follow the same frequency-based approaches as previously described in order to set up an excellent system for non-stationary forces and vibration. The final vibration or stress response can then be evaluated.

EXAMPLE CASE OF VIBRATION REDUCTION USING THE FINITE ELEMENT BASED APPROACH

A small-bore connection (SBC) with two flanges is known to have large vibration during transportation of natural gas.

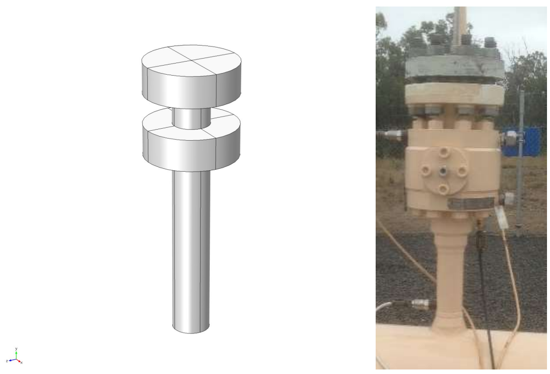


FIGURE 4 - EXAMPLE CASE; TWO FLANGES ON A SMALL-BORE CONNECTION. MANY SUCH REAL-WORLD EXAMPLES EXISTS

The forcing is due to turbulent flow and cannot be changed without largely reducing the production. It is known that turbulent flow results in broadband random forces and will thus set multiple vibration modes in motion. The side branch is modelled in a CAD software and simulated with modal analysis in a finite element software. The results show that the first and third natural modes are lateral vibration and the second is torsion.

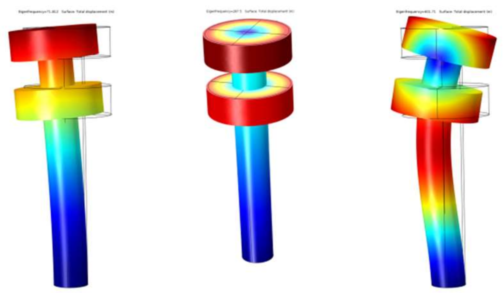


FIGURE 5 - EXAMPLE CASE; FIRST NATURAL FREQUENCIES AND SHAPES

The mode shape matrix scaled for mass, natural frequencies and node numbers are sent to Momentum for evaluating the use of a Momentum TMD. Previous studies have shown damping for the SBC to be very high, about 5%.

The list of natural frequencies received shows 20 frequencies, some being equal due to symmetry and some being torsional or shell vibration.

Node 9 is the location found to have the highest response, and the drive point displacement response (also called compliance) is shown below.

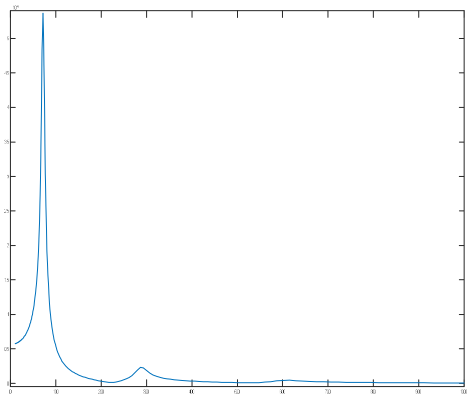


FIGURE 6 – MATLAB RESPONSE FROM MODAL ANALYSIS, DRIVE POINT DISPLACEMENT RESPONSE FOR NODE 9

The next step is to find an optimal solution. In this case the customer is interested in minimizing the maximum vibration velocity response for the first natural frequency. A virtual TMD is connected to the node with the highest vibration and tuned to an acceptable response.

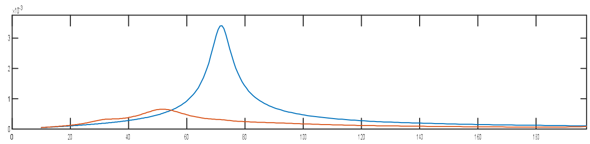


FIGURE 7 - THEORETICAL VIBRATION RESPONSE WITH (RED) AND WITHOUT (BLUE) A MOMENTUM TMD

The results show that the maximum vibration velocity is reduced from 3.4 to 0.65 mm/s/N, a peak reduction of approximately 81% or below 1/5 of the original peak level.

The damper parameters can be sent back to the customer for evaluation in their own finite element software, with their own force scenarios to find the stress levels and fatigue life of their construction with and without Momentum TMDs.

The customer agrees with Momentum that the selected size of damper, location and tuning seems fine, and Momentum starts producing the dampers. The dampers come delivered with necessary documentation, including instructions for installation of the dampers.