

# THE MYTHICAL ACTIVE VIBRATION ISOLATION

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## SUMMARY

Precision Systems have always been threatened by disturbances originating from vibrations. Active Vibration Isolation Systems have promised significant improvements of precision. Many different concepts have been introduced. Broad application however has not yet occurred. Actual benefits appear not sufficient to accept the added cost. Many aspects contribute to this situation. Three of these aspects will be presented at Euspen's Annual Meeting in June 2010. These aspects are, The following elements will be discussed;

1. Specification of floor induced vibrations
2. Noise Generation in active systems
3. Vibrations induced by driving forces

A short introduction to these elements will be given and special attention will be given to the next three categories of complicating effects;

4. Non-linearity in suspension system and vendor's presentation of performance graphs
5. Sensor sensitivity to cross-talk
6. Sensor sensitivity to gravitation

## NON LINEARITY IN ACTIVE ISOLATION SYSTEMS.

The floor specifications based upon the standards proposed by Bolt, Beranek and Newman, BBN, have been used for many years now. They specified different curves with different levels of vibration suited for different environments. The curves are indicated as BBN-A to BBN-E.

In the design of a precision system the integral influence of vibrations can be predicted using the Dynamic Error Budgeting procedure, Lit 2. In this approach the floor vibrations are described using the Power Spectral Density functions, PSD. Prediction of the resulting vibration on the suspended mass can be done with the use of the

Transfer Function from floor-vibration to payload vibration. Figure 1 shows an example of such a transfer curve that indicates a huge performance over a broad range.

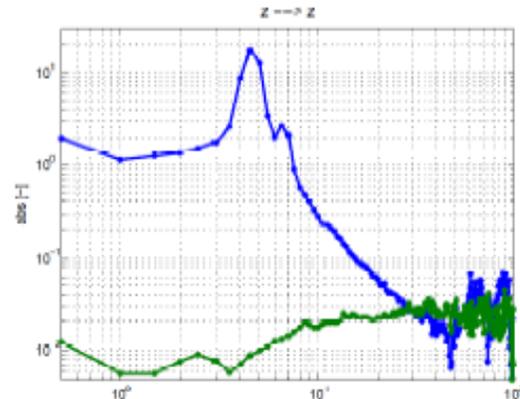


FIGURE 1. Example of transfer function for passive (blue) and active isolation system. (source Lit.1)

The basic approach in Dynamic Error Budgeting is founded on theories for linear systems and stochastic signals. When extremely good isolation is desired levels of vibration will be small and it is important to assess the required linearity. For lower frequencies, say upto 1 Hz, the level of acceleration of the floor is around  $10e-5 \text{ m/s}^2$ . When the active system is reducing the acceleration with a factor 100 the resulting acceleration will be less than  $10e-7 \text{ m/s}^2$ .

When we assume a suspended mass of 1000 kg this means that the forces acting on the payload are smaller than 0.1 mN! The suspension is creating forces of 10,000 N to support the mass. No friction forces, pre-sliding stiffness or hysteresis effects can be accepted. Extremely small values of disturbances must be eliminated. In practical realizations this is extremely difficult to achieve.

## CROSS TALK FROM ACTUATOR TO SENSOR

To achieve good performance at lower frequencies some form of Geophone is used to measure the payload velocities. In the Geophone a small magnet is suspended in springs. Around the magnet coils are placed and the relative velocity from magnet to coil will induce a back-EMF. The measured voltage on the coils will be used as the velocity feedback signal. Due to the stiffness of the flexures used for the suspension the sensor will measure accurately for frequencies above the resonance frequency, typically about 4 Hz. Below that frequency the relative velocity between magnet and coil due to the input velocity decreases dramatically. At 0.4 Hz the relative velocity is only 1/100 times the input velocity and as a result the measured voltage will be very small.

In the active vibration isolation actuators are used to counteract payload vibrations. In many cases these actuators are of electro-magnetic nature. Lorentz type actuators have favorable characteristics. When generating forces these actuators will influence the magnetic fields in their surroundings. As the coil is, in general, sensitive to fluctuations in magnetic fields the driving currents in the actuators may cause voltages to appear on the coil. Although these voltages are small in the normal operating region they may become significant at low frequencies.

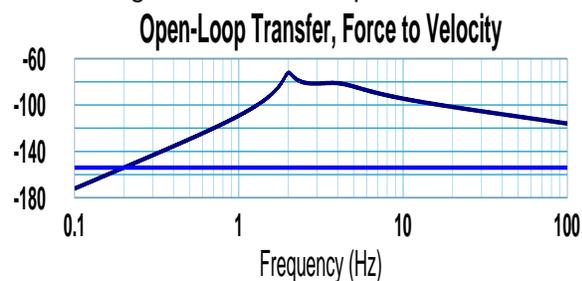


FIGURE 1. The Open Loop Transfer from Force to Geophone output and an estimated cross-talk from motor current to Geophone Voltage.

During the design of the feedback controller stability issues may arise at the 0 dB cross-over frequencies. From the transfer function of driving force to measured velocity shown in figure 2 it is clear that there will be two such frequencies. The high frequency one will be around 40 Hz, while the low frequency cross-over will be around 0.2 Hz. At this low frequency cross-over the Geophone sensitivity will be very small, thus the influence from actuator currents at these frequencies may significantly influence the phase of the transfer

function. Such unexpected phase differences have led to stability problems at low frequencies which made the system fail to start up.

## SENSOR SENSITIVITY TO GRAVITY

In the Geophone the velocity of the magnet relative to the coils is measured. When the sensor rotates the gravity force acting on the magnet will also cause a displacement of the magnet. Small rotations of a vertically mounted sensor can generally be neglected. For horizontal sensors this effect is however quite significant. The voltage measured at the coil will be proportional to the angular velocity of the sensor. As a result the different control directions will become strongly coupled and may introduce non-minimal phase behavior.

To handle this issue different alternatives are available. Most solutions depend on the proper combinations of all sensor information and thus reconstructing the appropriate information. Such an approach is acceptable and interesting for a research environment. For more practical cases the development at MI-Partners has resulted in a pragmatic solution that is easily implemented and does allow for straightforward control solutions.

## CONCLUSION

Active Vibration Isolation systems hold promises to improve the positioning performance of Precision Systems. The extent of the improvement promised is generally over-estimated. The mysteries and myths surrounding this matter have seriously hampered the broader industrial acceptance.

## REFERENCES

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