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Effective vibration isolation with mechanical or electro-pneumatic level control

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Abstract
The following article identifies the problem of vibrations affecting machinery, equipment for production and measuring processes. It explains how these vibrations can be isolated with the help of air springs in combination with mechanical and electro-pneumatic level control systems. Both systems are compared with each other on the basis of vibration measurements.

Vibration isolation, damping, resonance amplification, electro-pneumatic, mechanical, level control, natural frequency, air spring

1. Introduction

The world never stands still. This fact is a huge challenge for anyone dealing with dimensional accuracy and tolerances of technical processes. With increasing precision of manufacturing processes, efficient vibration isolation is becoming increasingly important. Vibrations can be caused by a machine itself or by the production periphery.

Numerous manufacturers supply vibration isolation systems based on different technologies, e.g. rubber material, air springs, steel springs, coils and piezo actuators. Each technology has its individual pros and cons concerning isolation performance, levelling accuracy, settling time, load capacity, electromagnetic compatibility, heat creation and of course financial effectivity. In recent years, air spring systems in combination with a high-quality mechanical level control were the first choice for the best compromise between achievable accuracy and associated costs. The isolation effect can newly be improved dramatically through the use of electronic systems that enable precise and application-specific adaptation of the control parameters. If mechanical and electronic level control systems can be combined with the same type of air spring elements, no structural changes to the machine bed or the supports of the isolators are required. Therefore, the costs of the entire isolation system are not disproportionately increased.

2. Fundamentals

As Figure 1 shows, the isolation effect does not only depend on the ratio between the excitation frequency and natural frequency of the isolator, but is also significantly influenced by the individual damping characteristics of the isolators used in the specific application.

The efficiency of any vibration isolation system significantly depends on the matching ratio η between excitation frequency and natural frequency of the isolator, see [1]. In general, the efficiency of vibration isolation increases as the natural frequency of the isolator drops. The graph in Figure 1 shows that the system only isolates when this ratio exceeds $\sqrt{2}$. If the ratio is less than $\sqrt{2}$, the vibration will be amplified due to resonance effects. The damping factor D determines the amplification resonance and the transmissibility with high frequencies.

Typically, the objective is to achieve a ratio of between three and four [2], whereas a ratio of three is considered to be the minimum effective target value where an isolation efficiency of nearly 80 % can be achieved, and a ratio of four to be an economic limit.

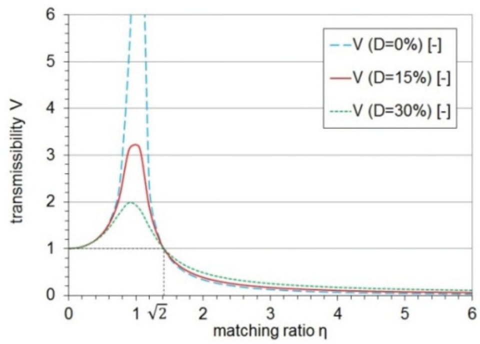


Figure 1: Transfer function of a vibration isolator subject to damping and ratio between excitation frequency and natural frequency of the isolator.

3. Electro-pneumatic level control systems

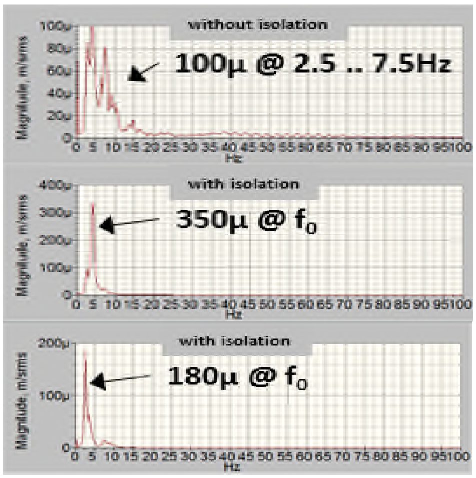
Electro-pneumatic position control systems (EPPC) for air spring vibration isolators (see Figure 2) can be combined with three or six groups of standard air springs to control up to 6 degrees of freedom.

Figure 2: EPPC level control including position sensors and servo valves (three units) and electronic control unit.

In each degree of freedom the machine position and air pressure inside the air springs are monitored to control the dynamic behavior of the system. High-performance electronic and pneumatic components allow almost noise-free operation and significantly improve the performance of passive air springs with mechanical-pneumatic level control (MPN). Thus, the achievable damping of approximately 15 % (MPN) may be increased to up to 30 %, which leads to a significant reduction of the resonance amplification and settling time. This is unprecedented in connection with a semi-active system.

4. Comparison between mechanical and electro-pneumatic level control systems

Figure 3 shows the results of a vibration measurement with and without vibration isolation in combination with mechanical-(MPN) or electro-pneumatic (EPPC) level control. The air spring isolators used in this system have a vertical natural frequency f_0 of 2.5 Hz, which leads to a certain resonance amplification in this frequency range, see Figure 1. It equals factor 3.5 as far as the conventional mechanical position control (MPN) is concerned. Due to the very high electronically adjustable damping of the EPPC, this system reduces the amplification factor to less than 2.



3a. Without vibration isolation.

3b. With mechanical-pneumatic level control (MPN).

3c. With electro-pneumatic level control (EPPC).

Figure 3: Vibration measurement with and without vibration isolation in combination with mechanical-(MPN) or electro-(EPPC pneumatic level control.

Despite the high damping, the transmissibility of the vibration energy from the ground to the machine is greatly reduced at higher frequencies. At 7.5 Hz, the original oscillation amplitude decreases from 90 microns to about 15 microns. This equals an efficiency of around 85 %.

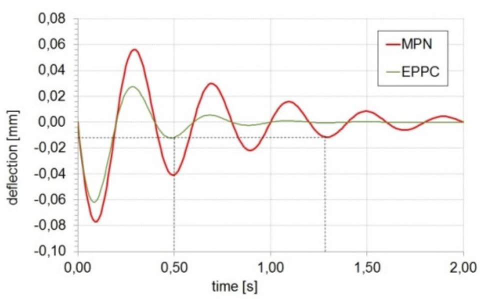


Figure 4: Comparison of the settling time between electro- (EPPC™) and mechanical- (MPN) pneumatic level control.

Figure 4 shows the settling time which is required to achieve a stable position within a prescribed tolerance range, for both a mechanical (MPN) as well as an electronic level control (EPPC). At a vertical excitation amplitude of about -80 microns, the response curve of the corresponding isolation system reaches a stable position e.g. within +/- 10 microns in about 1.25 s (MPN) and 0.5 s (EPPC), corresponding to a reduction of 60 %, respectively.

Due to the significant improvement of performance described above, new categories of applications characterized by very high dynamic loads due to rapid movement of work pieces or machine components like scanning units, tool changing units etc. with very high requirements for settling time and constant leveling, can be handled much more cost efficient. As an example, Figure 5 shows the measured values obtained by a vibration analysis of an isolated coordinate measurement machine (CMM). In the described application, the footprint of the CMM is approx. 2.0 m x 5.5 m. The maximum height of the machine itself is more than 5.0 m. The weight of the CMM incl. work piece is more than 40 tons. The anti-vibration isolation was realized by a 100 tons concrete foundation in combination with an EPPC system. In order to meet the requirements according to the limit values given by the CMM manufacturer and the vibration scenario coming from the environment from the CMM, the foundation block was put on standard air spring elements which are characterized by a reduced natural frequency of 1.7 Hz.

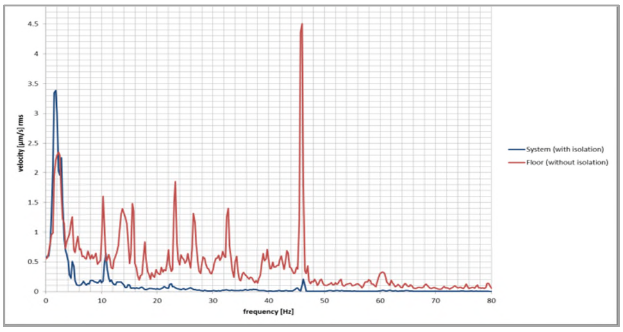


Figure 5: Vibration analysis of an isolated coordinate measurement machine with and without vibration isolation system.

Again, the resonance amplification can be observed around 2 Hz. Due to the unique achievable high damping of the EPPC the resonance amplification is less than factor 2. With increasing frequencies the isolation efficiency is drastically improving.

Conclusion

Electro-pneumatic level control systems provide highly effective vibration isolation solutions even for low frequency vibration problems. The novel combination of high-performance electronic and pneumatic components, optimized pneumatic design and sophisticated air spring technology facilitate the daily work and provide optimal performance for applications with very high dynamic loads, which are e.g. due to rapid change of position of the work piece or machine components (scan units, tool change units, etc.) as well as very high demands on settling time and level stability. This new isolation solution enables the handling of applications and requirements which could not be handled in the past in a cost efficient way.

References

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