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Numerical estimation of precision equipment vibration isolation system

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Abstract

This work is devoted to the numerical estimation of the effectiveness of high-precision lithography scanner foundation and its vibration isolation system when it is installed in a reconstructed building. The manufacturer requires that the scanner's foundation has to be isolated from both the background vibrations and from the vibration sources that occurs inside the considered building. Based on manufacturer specifications of the foundation, its dynamic stiffness and power spectral density of the basement surface vibration accelerations in the frequency range 1 – 100 Hz have to be within specified limits. In the course of this work, we performed field measurements of the vibration levels of the construction site, as well as at the bottom of the excavation. The results of the measurements revealed the presence of non-stationary random vibration sources at frequencies from 7 up to 150 Hz. The problem of assigning the appropriate thicknesses of elastic and damping elements of the vibration isolation system is that at the time of designing the system, there was no information available about the levels of dynamic influence from the installed in the building vibrating equipment. To ensure utilization of the company's process technology, there was planned to install inside the building powerful ventilation systems, air conditioning, feeding and batching system of liquid nitrogen and other chemicals, etc. In order to meet the requirement of the foundation dynamic stiffness special reinforcing technology was applied, and to meet the vibration requirements – an increase in the mass of the concrete block due to under-foundation structure with gravel mixture filling was considered. To evaluate the effectiveness of the designed vibration isolation system, an analysis of vibration propagation from vibrating equipment through the supporting structures of the building and the ground layers to the scanner's foundation was performed using finite element package MSC Patran/Nastran. The results of non-stationary dynamic analysis of vibration propagation allowed us to estimate the amplitudes of foundation oscillations and to adjust the parameters of the vibration isolating materials both in the scanner's foundation, and at the sources of vibration.

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Keywords: vibration isolation; precision equipment; numerical estimation; lithography scanner; vibration isolation materials; FEM; MSC Patran.

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Nomenclature

RMS	root-mean square value
PSD	power spectral density
HVAC	heating, ventilating and air conditioning

1. Introduction

This paper proposes solutions for structural design and efficiency estimation of vibration isolated foundation for high precision lithography scanner. The manufacturer requires that the scanner's foundation has to be isolated from both the background vibrations and from the vibration sources that occurs inside the considered building. As the vibration requirements are stated in frequency region from 1 to 100 Hz and the contractor wants to reduce the foundation cost, the out-of-the-box solution has to be proposed and it's efficiency to withstand vibration from different sources has to be proved prior to the construction.

The design process and further maintenance of precision equipment vibration isolation systems occurs to be a complex task due to uncertainty in external background noise vibrations [1], structure-sensitive vibration transmission paths from different types of vibration sources [2], located inside the building. Because of high wave speeds both in longitudinal and transverse directions in concrete or steel which are most frequently used in load-bearing structural elements, the transition of vibration from the source to the receiver (isolated foundation for precision equipment) depends not only on the soil conditions underneath considered building, but also on its structural scheme and elastic-damping characteristics of applied materials. This problem was also investigated in works [3, 4], which presented results of frequency response analysis for a finite element structural model used to predict vibration spectrum inside the already-built laboratory building. Paper [5] investigates the vibration sources arising from external oscillating processes like traffic or foot-induced vibrations and suggests measurement technique used to evaluate and design the vibration isolation system for high-precision instrument.

The problem of vibration isolation system efficiency estimation gets more sophisticated when the task is to evaluate the expectative levels on the foundation of precision equipment located inside a building under construction. Any change in structural scheme or weight distribution from dead or live loads inside a building tends to modify its intrinsic structure that leads to variation of its natural frequencies and transfer functions. As a result, this building exhibit different dynamic response one every stage of construction process being subjected to same external excitation. Namely this inability to measure the building's response due to external excitation on one of the construction stages and forecast the vibration level to the end of construction force us to find different methods to ensure the performance of the precision equipment vibration isolation system.

Due to high complexity of implemented on the equipment technical process, its importance to the science and overall equipment's cost, the manufacturer produces severe requirements that set the maximum allowable vibration levels underneath equipment's foundation. However, the latest investigations [6] revealed the necessity to establish the foundation dynamic stiffness also.

2. Design requirements

The target of the research is a high precision lithography scanner, produced by ASML and placed inside a reconstructed building, located in Moscow. The manufacturer's requirements to the RMS velocity PSD values, measured on the foundation surface in frequency range from 1 to 100 Hz are shown in Fig. 1a. As the foundation can affect the scanner's performance by being too floppy, the manufacturer establishes required stiffness parameters in axial and bending directions - 1×10^8 N/m. Both vibration and stiffness parameters can be achieved by an appropriate design of steel reinforcement [7], material selection for bending elements, soil replacement underneath the foundation bed and application of different vibration-shielding techniques as presented in [8].