

Design and implementation of an active vibration isolation solution for a ceiling mounted microscope.

S. Bank, R. Rijkers, J. van Seggelen, B Bakker

Servas bank, Ronald Rijkers, Johan van Seggelen and Bernhard Bakker, all work for MECAL High-tech/Systems.

s.bank@mecal.eu

Abstract

This paper discusses the development and realisation of an active vibration isolation platform for an eye surgery microscope, based on MECAL's patented active vibration isolation (Hummingbird®) technology and model based design approach. Pictures of the realisation and installation at the University Eye Clinic Maastricht are shown and measurement results are compared to the specifications as set at the start.

Keywords: active vibration isolation, tilt to horizontal decoupling, 6 DOF decoupling, model based design, model based performance analysis, first time right, modal analysis, modal measurement, low noise inertial sensors

1. Introduction

To magnify the eye during micro invasive surgery, surgeons look through a powerful microscope that is connected via an adjustable arm to the ceiling of the operating room. A steady microscope image is required to handle the epiretinal membrane which is about 0.05 mm thick. Measurements at the University Eye Clinic Maastricht showed image quality disturbed by low frequency vibrations of the building that are caused by people walking nearby, traffic and wind. Furthermore these building vibrations were magnified by the microscope arm dynamics.

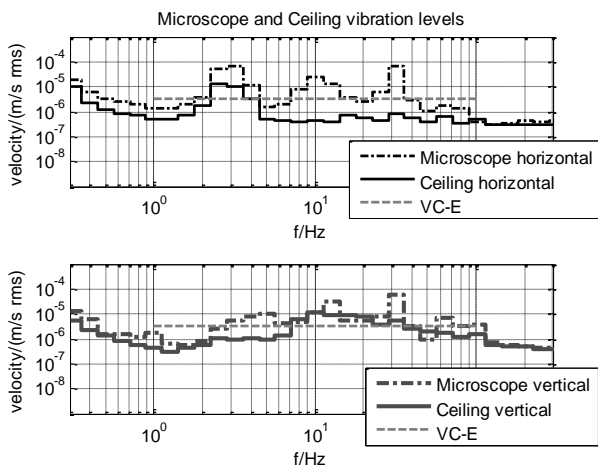


Figure 1. Vibrations leading to reduced image quality

The microscope is a medical instrument which is tested for very stringent medical standards. It was not feasible to add any component or alter the existing microscope; therefore it was decided to install an active vibration isolation platform in between the ceiling and the microscope arm.

A first time right approach with model based design was used to design this solution. Paragraph 2 discusses the critical elements of the design approach such as the modal measurements and model based performance analysis.

Paragraph 3 discusses critical elements of the final design such as the vibration isolation technology for high isolation at low frequencies and low absolute vibration levels. The final paragraph discusses the results and provides a summary.

2. Design approach

Based on the initial measurements the following two main requirement specifications are proposed:

- S1) Dominant microscope vibrations between 2-30 Hz must be decreased by at least a factor 10, in both horizontal and vertical direction.
- S2) Microscope mobility and robustness may not be altered: the user should be able to use the microscope in the same way as they would the original microscope.

2.1. Modal measurements & Analysis

The vibrations at the ceiling where the microscope arm is suspended are transmitted through the microscope arm. The modal behaviour of microscope and arm is crucial for the vibration level at the microscope and for the stability of the control system. Extensive modal measurements of the existing arm were performed resulting in a modal model of the arm.



Figure 2. Modal measurements of the microscope. Dots indicate sensor points.

2.2. Model Based Performance analysis

Information from the modal measurements and from the vibration measurements at location was used together with design parameters of the MECAL Hummingbird® 6DOF isolation system to form a predictive 6DOF dynamic model. This model was used to test whether high isolation factors could be reached at specific frequencies and to optimise the design. It was predicted that a factor 10 reduction could be reached at the microscope, at the dominant 3 Hz vibration peak.

2.3. Previously tested building blocks & concepts

Though the design problem is very unique it was possible to use previously tested building blocks and concepts such as the 2DOF sensor-actuator unit with patented MECAL tilt to horizontal decoupling [1,2,3] which was earlier used in isolation tables based on Hummingbird® technology. The design and the models as well as practical experience were at hand for these important parts, greatly speeding up the design process.



Figure 3. Existing 2DOF Sensor-Actuator Unit with patented tilt to horizontal decoupling.

3. Active vibration isolation system

The active vibration isolation system faces several difficulties. These difficulties are discussed in paragraph 3.1 to 3.3.

3.1. Isolation at intermediate frame

An intermediate frame is suspended from the ceiling at a resonance frequency of about 10 Hz. Inertial sensors detect the remaining movement of the suspended platform and a controller is used to generate a feedback signal to six voice coil actuators.

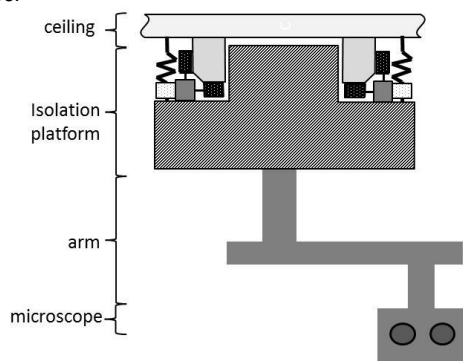


Figure 4. Isolation platform and microscope.

The microscope arm with resonances in the relevant frequency range poses two challenges. First of all the isolated levels at the isolation platform should be much lower than the objected vibration levels at the microscope. Furthermore dynamics and resonances of the microscope and arm pose a severe challenge for the stability of the control loop.

3.2 Tilt to horizontal coupling

A substantial isolation is needed at frequencies as low as a few Hz. In order to achieve this isolation the bandwidth of the controlled system (i.e. open loop gain is greater than 1) should

start at frequencies well below 1 Hz. At these low frequencies a fundamental problem is posed by the inability of a horizontal inertial sensor to distinguish between tilt and horizontal acceleration. Instability of the controller at low frequencies due to this effect can be avoided with the patented MECAL tilt to horizontal decoupling.

3.3. Low vibration levels

Achieving high isolation factors at low vibration levels requires special attention to the sensor in terms of noise level and dynamic range. MECAL has developed inertial velocity sensors which can reach noise levels well below $1E-8$ [m/s].

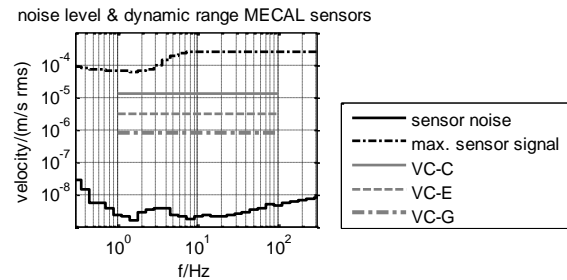


Figure 5. Noise level and dynamic range MECAL inertial sensors.

4. Results & discussion

The results for the horizontal dimension are plotted in figure 6 showing isolation at the dominant frequencies well over a factor 10, in accordance with modelling predictions. Vertical vibrations show similar results. Vibration level at the isolation platform is typically a factor 3-5 lower.

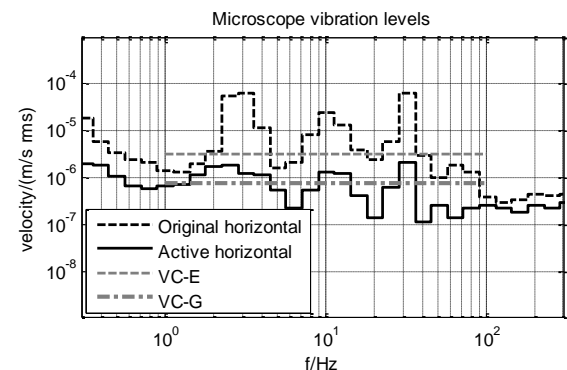


Figure 6. Vibration levels in horizontal direction at the microscope.

With a careful investigation of the problem, a model based design process including predictive performance analysis, the use of previously tested building blocks and careful implementation of the design MECAL was able to generate a first time right solution for the microscope at the University Eye Clinic Maastricht.

This active vibration isolation platform has been produced and installed in the hospital's operation room. Vibration levels at the ceiling and at the microscope have been measured before and after installation. A vast improvement of the microscope's image stability has been achieved and benefits doctors and patients every day.

References

- [1] Bakker B and van Seggelen J 2010 *Microniek* **50(2)** 14-20
- [2] Rijkers R, de Smit J, van Grinsven J and Semeyko O 2013 *Microniek* **53(4)** 40-44
- [3] de Kort J, Denie D, Schabbink JGH, Bank SL, Bakker BM WO2011115488 (A1) — 2011-09-22 ACTIVE VIBRATION ISOLATION SYSTEM, ARRANGEMENT AND METHOD