Dynamics of the bouncer

Introduction

In an early generation of the wafer–stepper (≈ 1980) there was a need for a quick exchange of masks for the subsequent illumination of dies with functional patterns in the first step and alignment or test patterns in the second.

A so–called bouncer was developed to carry these two masks on a rotor and then rapidly switch them by rotating the rotor between two positions and then catch and position with a high degree of accuracy the rotor and thus the masks in either end position.

A demonstrator of this bouncer was developed. In this assignment you will study this bouncer demo, with particular attention for the dynamic elastic modes. You will be asked to propose design modifications to the sensor and actuator positioning in order to improve the dynamic behaviour of the system. Different simulation tools will be used, starting with a 3D-CAD package (SolidWorks), a finite element simulation tool (COMSOL Multiphysics), a numerical mathematics package (Matlab), and a dynamic systems simulation package (SimMechanics).

Part of the authors' analysis of the system is provided to you, to be used to kickstart your own analysis.

Suggestions and questions to guide your analysis are scattered throughout this assignment description and are indicated by blue lettering.

Sensor design

An optical sensor is used to determine the position of the rotor. A light beam is focused on the edge between dual mirrors that each reflect part of the incident light beam at a slightly different angle. The amount of light in each light beam that is reflected back is measured using two light intensity sensors. A small displacement of the edge between the mirrors changes the amount of light on both sensors (one increasing, the other decreasing) and the displacement can be measured.

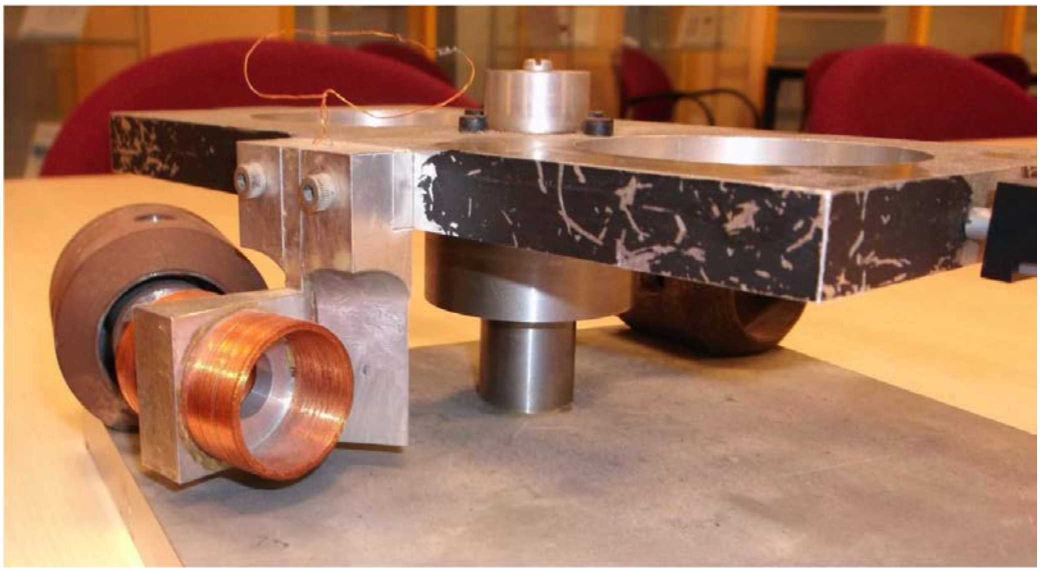

Figure 1: Bouncer demonstrator

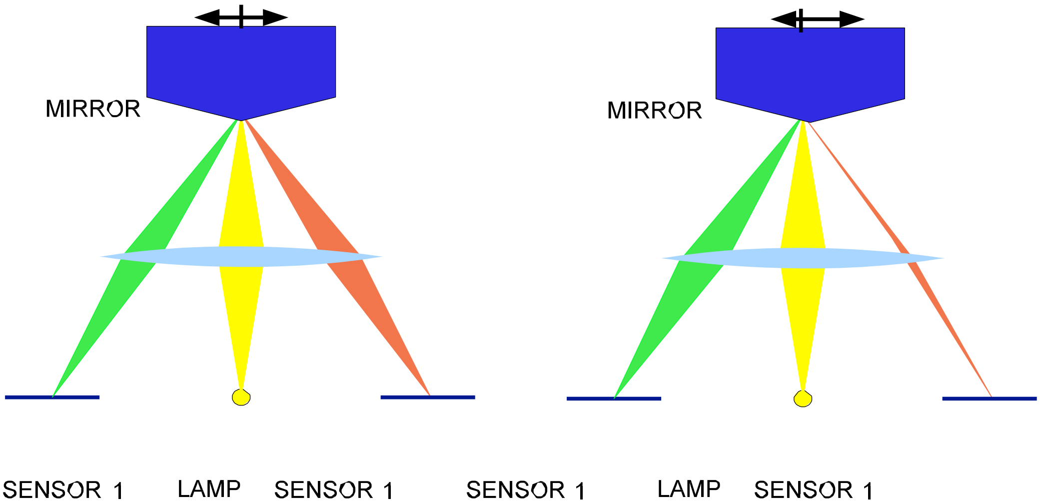

Figure 2: Working principle of the rotor displacement sensor. Left: center position with equal amounts of reflected light, right: position shifted to the right.

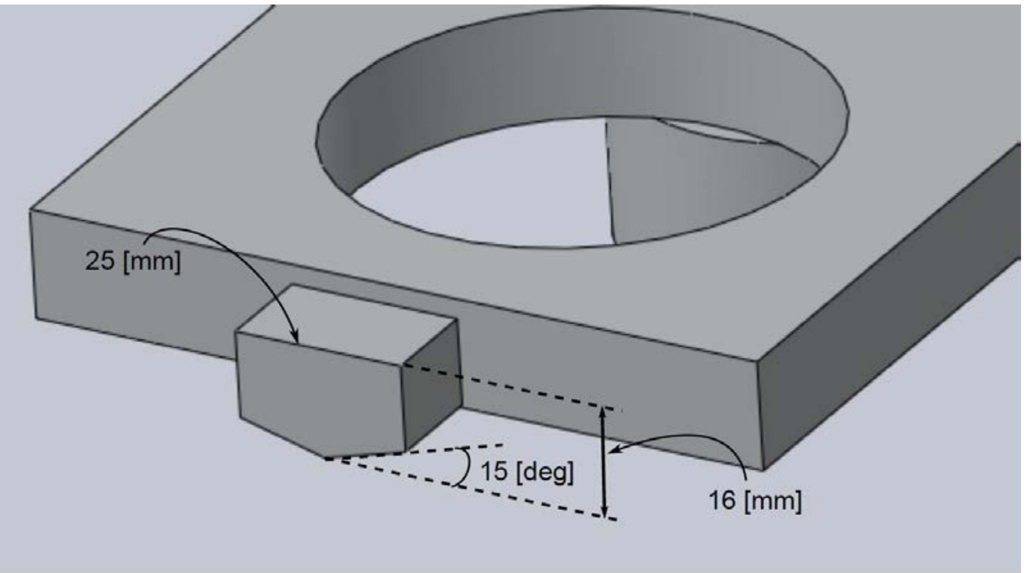

Figure 3: Detail of the sensor block of the bouncer demonstrator

Q1: Study the working principle of the sensor and determine the parasitic sensitivities of the sensor. Which displacements / rotations of the sensor block result in a variation of the measured values?

SolidWorks CAD files

A set of SolidWorks CAD drawings (figure 4) has been developed. These files are collected in the file **CAD bouncer.zip** on BlackBoard. This file contains among others **bouncer.SLDASM** which is the main assembly file.

In mathematical modeling we are perpetually balancing between completeness of the model and numerical efficiency. And because these CAD files have been made after the realization of the system, even these CAD files give at best an approximation of the real system. Most of these approximations are deliberate; others may be the result of less conscious decisions.

The deep–groove roller bearings on which the stage is supported have been replaced by a solid elastic ring of material, with an elastic modulus that is much smaller than that of the bulk material. Furthermore, in the finite element model the interface between this ring and the outside world is assumed to have zero friction.

Q2: Are these assumptions correct? Is there another way to model both the elastic behavior of the bearing and the kinematic properties of the bearing? Check the stiffness of the bearings.

The base of the system and the central shaft around which the stage is rotating are not included in the model.

Q3: Are these simplifications correct? Should the central shaft and the base of the system be included in order to better model the system?

Feel free to modify these CAD–files in order to study more complex design modifications. However, the files as they are at present are certainly acceptable for an initial analysis of the system. And beware; some of the design features in the bouncer have been selected because of fixed design specifications.

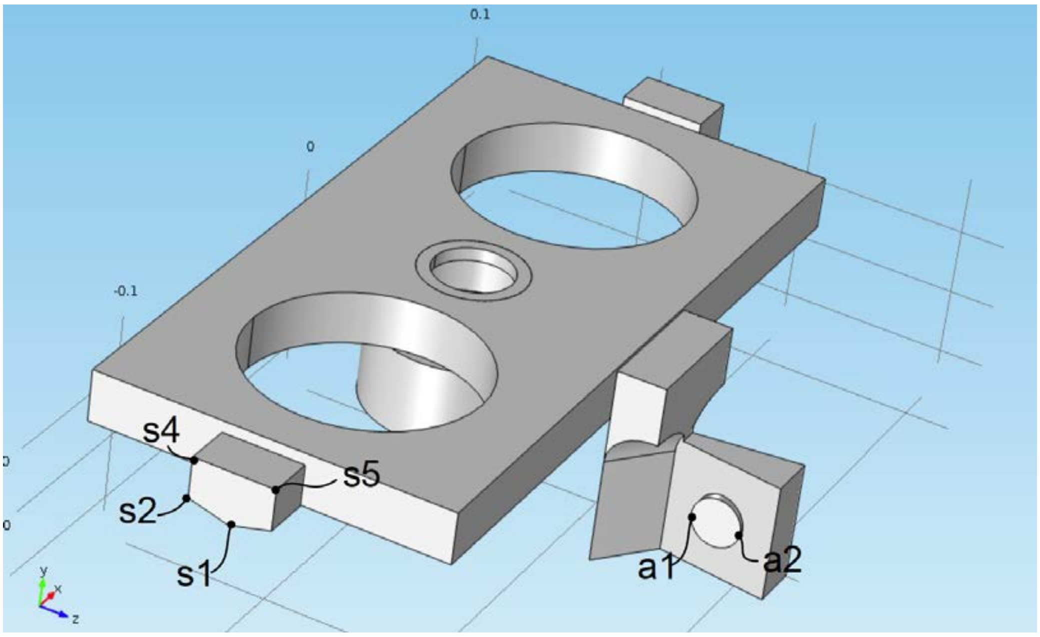

Figure 4: CAD design of the bouncer demonstrator

COMSOL Multiphysics files

The CAD–files can be imported in the finite element package COMSOL Multiphysics. After that, this package can be used to determine the dynamic eigenmodes of the system and the modal masses and stiffnesses from the actuator position to the sensor position. The COMSOL file **ModalMasses.mph** can be found on BlackBoard. This file can be read in COMSOL Multiphysics version 4.2 and later.

In the COMSOL file a list of modal mass moments is generated:

$$M_i = \int \rho \, \|u_i\|^2 dV$$

where M_i stands for the modal mass moment of the i-th eigenmode. This list is generated under **Derived values**, **Global evaluation**, and is exported to **ModalMasses.txt**. Furthermore selected displacements in a selected number of points are also exported to four text files: **dispXactuator.txt**, containing the x displacement in two points near the actuator, and **dispXsensor.txt**, **dispYsensor.txt**, and **dispZsensor.txt** containing the x, y and z displacements respectively in 5 points around the sensor position. See Fig. 4 for the numbering of the nodes.

Q4: The position of the actuator (out of plane and certainly not ideal) is fixed. The position of the sensor block is much less constrained, and can be moved to a more optimal position. Investigate the influence of the position of the sensor by trying out different locations and discuss the results. Hint: By modifying the COMSOL file more points in the bouncer can be taken into account (Point Evaluation). Perhaps by combining the signals from more sensors a more accurate position measurement could be designed?

Matlab modal analysis files

The modal mass moments that have been calculated in the COMSOL simulation can be exported to Matlab using different methods. It is possible to directly run the COMSOL simulation from Matlab and have the results available immediately in the Matlab environment. We have selected to export the COMSOL results first to a text file, **ModalMasses.txt**, and import that in a Matlab simulation.

Q5: Is this the most efficient way to import these results in Matlab? Would the direct route be more efficient and/or quicker? What are the benefits/disadvantages?

Then, in Matlab the results from the COMSOL simulation are further processed and studied using the Matlab script **bouncer.m**.

Q6: Study the heavily commented matlab script bouncer.m and modify where required. Then study the contribution of the different elastic modes to the total behaviour of the system and select the modes that should be taken into account in the design of the controller.

Q7: The influence of different displacements and rotations were discussed before. At this moment, the Matlab script only plots the transmission from the actuator to the vertical displacement. Adjust the script to find other disturbances that can be of influence and consider the most important modes. Compare the answers with your results found before.

Q8: Reduce the system to a limited number of mass–spring systems, with just the carefully selected modes taken into account to accurately represent the system. The modal masses and stiffnesses of these modes can be imported like the CD-head from assignment 2. Implement the results in a Simulink model to design a controller for the bouncer (example in figure 5). Show the comparison between the plots made with Matlab and Simulink.

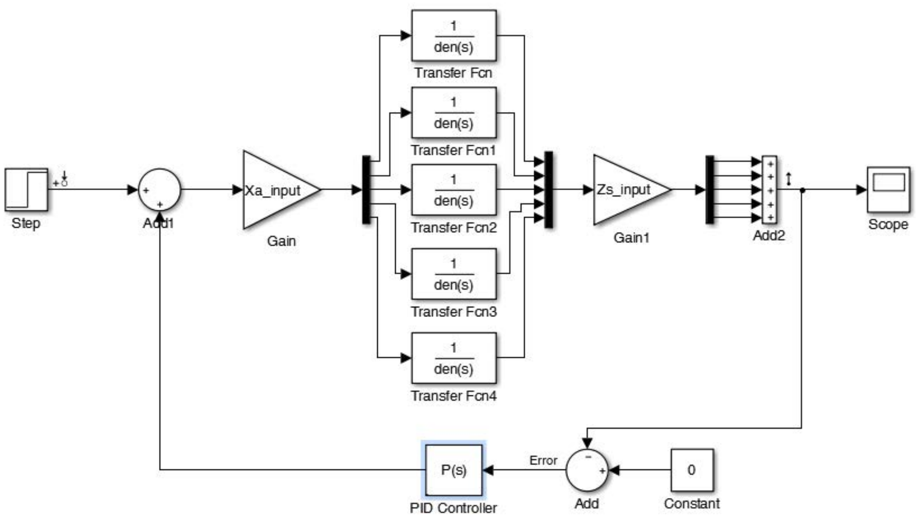

Figure 5: Simulink model for the bouncer demonstrator

Q9: Develop a PID-controller for the bouncer resulting in a BW that is suitable given the first relevant eigen-frequencies and -modes of the bouncer.