EPFL

Exercise 9 – Part II:

Design and force balancing of a flexure-based parallel stage

Context:

A flexure-based parallel stage is subjected to fluctuating linear accelerations along the x-axis due to motion of its base. To be insensitive to this specific perturbation, we wish to force balance the mechanism.

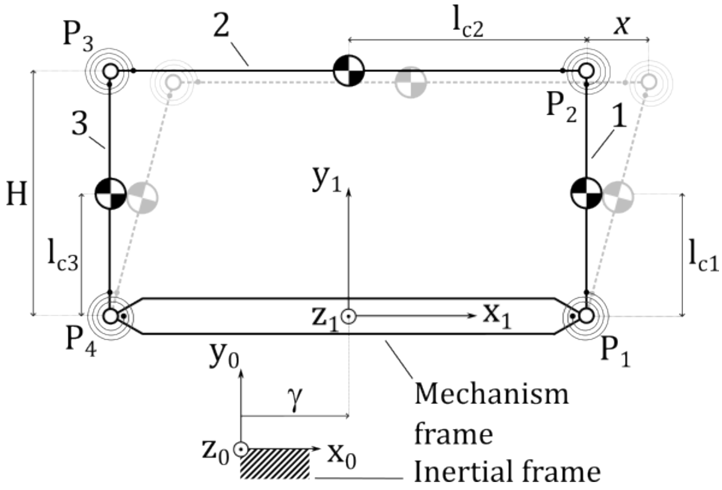

Fig. 1: Flexure-based parallel stage Pseudo-Rigid-Body-Model before its force balancing.

Figure 1 shows the Pseudo-Rigid-Body-Model (PRBM) of the studied flexure-based parallel stage before its force balancing. The mechanism has one degree-of-freedom and is composed of three moving rigid bodies: solids **1**, **2** and **3** articulated in P_1, P_2, P_3 and P_4.

Each solid $i = 1 \dots 3$, has:

- a mass m_i,
- a center of mass (COM) c_i (represented by the symbol ◕) located by a distance l_{ci},
- an inertia tensor $\bar{\bar{J}}_i$ given at c_i.

Each pivot $P_{i=1\dots4}$ has an angular stiffness k_i that represents the intrinsic stiffness of the future flexure-based implementation.

First, the parallel stage mechanism is actuated by a voice coil whose permanent magnet is fixed to the mechanism's base and whose coil is fixed to solid **2**. The voice coil applies a force **F** at c_2 along the x-axis. The parameter x is used to locate the displacement of solid **2** relative to its base.

Last, the linear displacement that corresponds to the motion of the mechanism's base is represented by the parameter γ.

Part II: Design of the flexure-based pivots

The flexure implementation of the PRBM shown in Figure 2 is illustrated in Figure 3. Pivot joints P_1 to P_4 along with their torsion springs of stiffness k_1 to k_4 are replaced by *remote center of compliance* (RCC) flexure pivots (red lines on Figure 3).

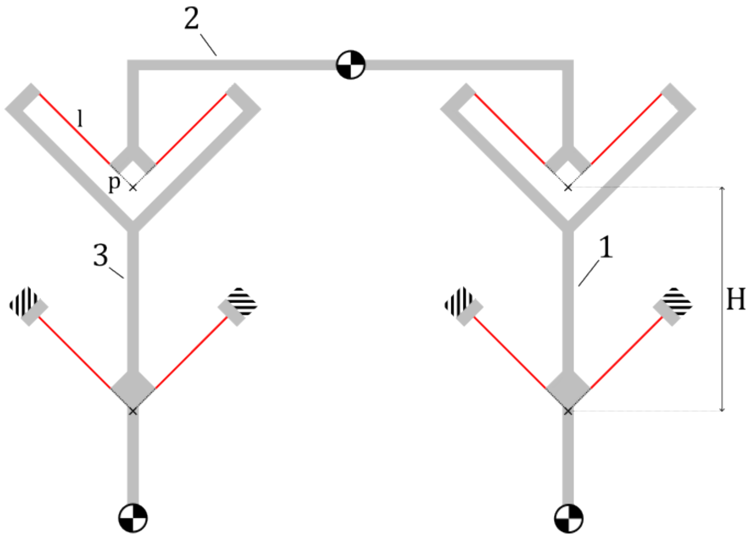

Fig. 2: Flexure-base implementation of the force balanced parallel stage.

The flexure-based parallel stage will be carried on board a rocket. During take-off, the mechanism will be subjected to vibrations along the x-axis. To protect it, solid **2** is rigidly locked (no translations and no rotations) relative to the base of the mechanism so that solids 1 and 3 are kinematically immobilized. Thus, during take-off, the acceleration forces that apply on solids 1 and 3 go through pivots P_1 and P_2, and P_3 and P_4, respectively.

Technical specifications:

Solid **2** of the flexure-based parallel stage has an admissible stroke of ± 410 µm. RCC flexure-based pivot should withstand the take-off vibrations specified from the ASD given by Figure 4.

The flexures are made out of Ti-6Al-4V.

Alliage	E [GPa]	R_m [MPa]	$R_{0.2}$ [MPa]	$\sigma_D(10^7)$ [MPa]
Titane 6Al-4V	114	900	830	500

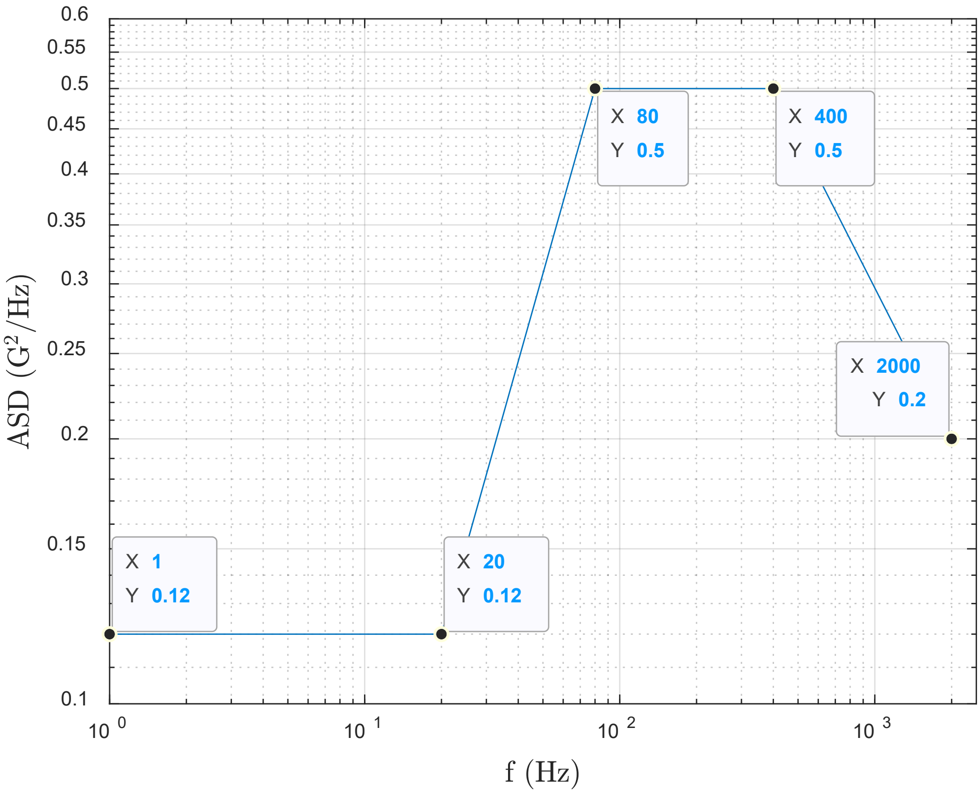

Fig. 3: ASD that the flexure-based parallel stage must withstand.

1. Considering $p = 2$ mm, find the parameters:
   - l: length of the blade
   - h: thickness of the blade
   - b: depth of the blade

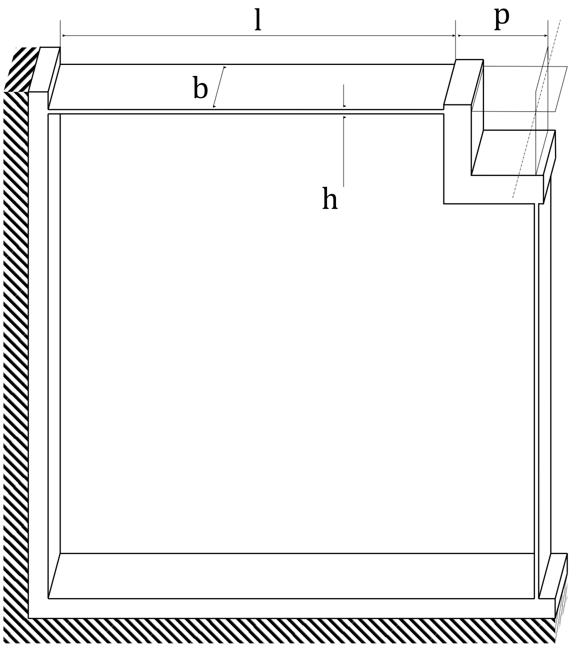

Fig. 4: Illustration of an RCC flexure pivot with its main parameters.

So that the flexures:

- withstand the stroke of solid $\mathbf{2}$ for a number of cycles $n > 10^7$ with a safety factor S=2.5.
- do not buckle for the worst-case scenario specified by the ASD with a safety factor S=2.5.
- do not plastify for the worst-case scenario specified by the ASD with a safety factor S=2.5.

Reminder: to identify the worst-case scenario specified by the ASD, use the Mile's equation for all frequencies using a quality factor of $Q = 100$.

2. The flexures from the linear stage will be manufactured from a 10 mm thick titanium plate. We therefore consider $\mathrm{b} = 10$ [mm], which should be higher than the minimal theoretical value computed from the previous question. Compute the linear equivalent stiffness k_{eq} of the parallel stage.
3. Compute the frequency f_{init} and f_{final} of the parallel stage before and after it is force balanced.