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Synthesis and optimisation of large stroke flexure hinges

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Abstract

Flexure hinges are used in a variety of high-precision applications, where their lack of hysteresis, friction, and backlash offer a significant advantage over conventional hinges. A drawback of flexible hinges is that their range of motion is limited due to increasing stresses and a decreasing support stiffness when the hinge is deflected. Currently available hinges are typically designed for strokes of up to 10° and only a few hinge types achieve a stroke of 40° [1]. This research aims at enlarging the stroke to 90° without a large decrease of the support stiffness. It deals, on the one hand, with the conceptual design of large stroke flexure hinges and, on the other hand, with the development of a method for the design optimisation of such hinges.

First the performance assessment of the hinges is considered. The main characteristic that determines how well a hinge performs is its support stiffness. Therefore Berselli *et al.* [2] propose to evaluate the compliance matrix. The matrix coefficients reflect both the (high) hinge compliance, i.e. the compliance of the hinge about its axis of rotation, as well as the (preferably high) stiffness in all other support directions. A performance measure can be computed by comparing the (preferably low) support compliances with the hinge compliance. However, applying this performance measure is not trivial as e.g. rotational and translational stiffnesses need to be compared.

This scaling of the stiffnesses is implicitly accounted for by using the natural frequency f_2 of the second external vibration mode of the loaded hinge as a performance measure [1]. Obviously, this natural frequency not only depends on the stiffness of the hinge, but also on the mass and inertia of its load. Although that may seem to be disadvantageous as it doesn't give a unique performance measure of the hinge, it has the advantage that the performance of the hinge is assessed in relation to the intended application.

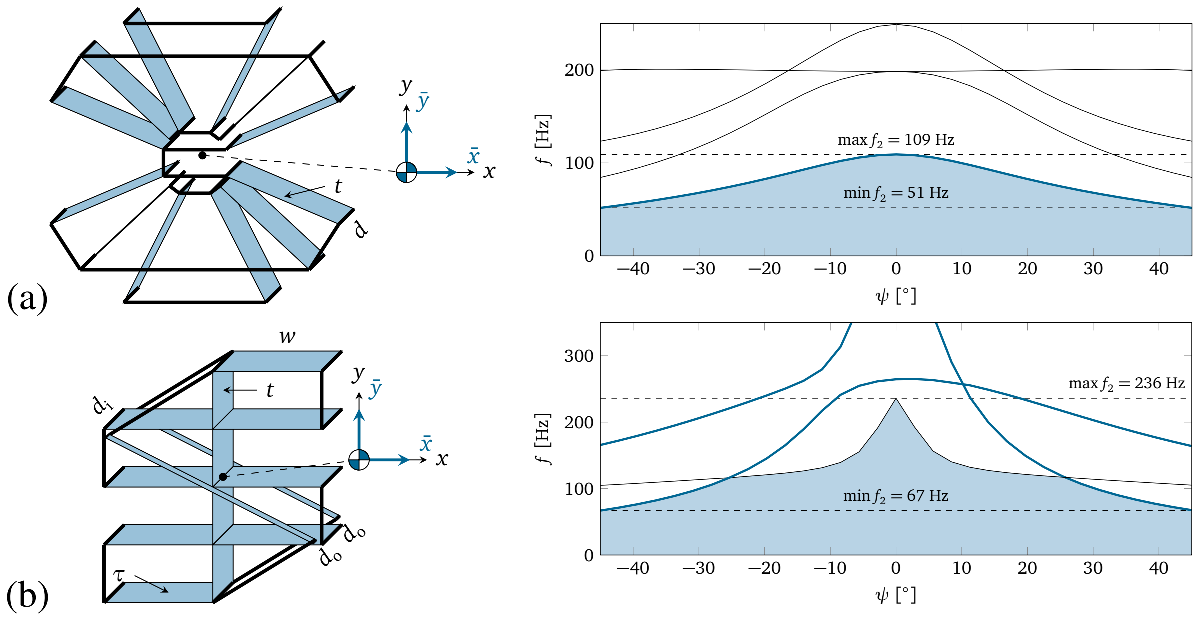

Figure 1: Optimal designs for the (a) Butterfly Hinge (BFH1) and (b) Infinity Flexure Hinge "IFH2" with a plot of the second and higher natural frequencies f as a functions of the deflection angle ψ.

Next, some existing flexure hinges [1, 3] are evaluated using this criterion, where the same load has been applied as in our previous study [1], which is an L-shaped rigid arm. To achieve a larger stroke the following design options are considered:

- In e.g. the butterfly hinge (BFH) [4], the decrease in support stiffness is avoided by combining serial and parallel leaf springs such that the deformation of each leaf spring is only a fraction of the total hinge deformation. For a larger stroke more sets of leaf springs can be combined, see Figure 1(a).
- Known hinge concepts can be stacked. Consider e.g. the infinity hinge (IFH) [1] where the torsional stiffness of the main leaf spring is increased using auxiliary bodies. For a larger stroke this concept can be stacked, provided internal motions are suppressed, see Figure 1(b).

For further detailing of these concepts, parametric geometric models are created. To obtain the optimal parameters of each design, a numerical optimisation routine has been set up and implemented, making use of the tools present in the ANSYS finite element program:

- The flexure leafs are modelled with `shell181` elements that are well-suited for linear and nonlinear applications with large rotations and strains, such as occur in the flexure hinges.
- For all design parameters reasonable ranges are defined. To speed up the optimisation routine, the number of parameters is kept small, e.g. by removing a parameter from the optimisation if it is known beforehand or from the simulations that its value is always close to one of the bounds.
- It is required that the maximum stress remains below a threshold value, in particular at maximum deflection. If the maximum stress is too large, the design is infeasible.
- In some hinge types like the butterfly hinge, an internal mode needs to be constrained. This can be accomplished by adding a constraint equation for the rotation of the intermediate body.
- A objective function is minimised in ANSYS, which is defined to be

$$J = F - f_2, \tag{1}$$

  where f_2 is the lowest natural frequency of the second vibration mode at maximum deflection and F is some sufficiently large constant to ensure a positive objective function J.

The conceptual hinges are synthesised and optimised for a range of $\pm 45°$. Their behaviour is studied and compared to two existing flexure hinges that are also optimised for this large stroke. A performance gain of about 250% with respect to the best performing existing design has been achieved.
This research has shown that it is possible to design flexure hinges for large strokes of up to 90°. And, more importantly, a method for analysing their performance and optimising their geometry has been established. The method allows for a quick assessment and optimisation of future large stroke flexure hinges.

References

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