Squeeze-film levitation characteristics of plates excited by piezoelectric actuators

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Abstract: A small mass is levitated by a vibrating plate with an arrangement of four piezoelectric actuators that generate a squeeze-film in the gap between the plate and the mass. Different arrangements of actuators and plate design are explored using simulation in order to produce better performance.

Introduction: A squeeze-film separating force can be produced in the air gap between two parallel planes subjected to oscillatory relative motion at an appropriate high frequency. Piezoelectric actuators bonded to a plate and excited with an alternating current will produce a squeeze film that levitates small objects placed on the plate. A prototype based on an aluminium plate (160 mm*100 mm*1.9 mm) and four small piezoelectric actuators has been designed with the aim of verifying the feasibility of zero-friction conveying of small items in order to minimise their damage. The levitating behaviour is observed using a scanning Laser Doppler Vibrometer (Polytec PSV 500) across a frequency range of 0-20 kHz in order to find the most effective vibration frequencies and their corresponding modal shapes. The various mode shapes and forced harmonic performance for two different arrangements of four piezoelectric actuators on three different rectangular aluminium plates is then investigated through simulation in ANSYS 15 for a frequency range of 0-40 kHz in order to identify a more effective plate design for levitation [1, 2, 3].

Results:

Table1: Simulation and experimental harmonic frequencies for a vibrating plate with four piezoelectric actuators in a diamond arrangement (Design 1).

Modal Sequence	Simulation harmonic frequencies (Hz)	Experimental harmonic frequencies (Hz)	Difference (%)
1	418	394	6
2	1462	1425	3
3	2292	2116	7
4	4126	3672	11
5	5791	5241	10
6	6123	6038	1
7	7274	6613	9
8	8204	7966	3
9	9797	9669	1
10	11994	11178	7
11	14843	14353	3

From Table 1 it seen that there is good agreement between simulation and experimental results for harmonic behaviour. Therefore, further the designs were explored: six designs of plate and actuator were defined by combining two arrangements of four piezoelectric actuators (longitudinal and diamond) with three different plates, as described in Table 2. For Design 1, within the 0-20kHz frequency measurement range of the Laser Doppler Vibrometer, the greatest levitation effect occurs around 8 kHz when the deflection is 668 microns and a small polymer disk (30 mm diameter, 3 mm thick) of mass 5.3 g was observed to levitate.

Table 2: Maximum deformations of harmonic frequency response for different designs (ANSYS).

Design Type	Max. Deformation (μm)	Frequency (Hz)
Design 1: Rectangular plate (1.9 mm thick) and diamond arrangement of actuators (4 piezoelectrics on 60 mm pitch circle diameter). Physically tested.	668 71 31	8000 29143 38286
Design 2: Rectangular plate (1.9 mm thick) has a 4 slots cut and diamond arrangement of actuators.	88 49 69 39	4571 8571 22286 37143
Design 3: Rectangular plate has a thickness reduction (1 mm thick) and diamond arrangement of actuators.	3117 133 393 98	1143 3429 13714 24571
Design 4: Rectangular plate (1.9 mm thick) longitudinal arrangement of actuators.	239 200 100 188	571 8000 29000 38286
Design 5: Rectangular plate (1.9 mm thick) has a 4 slots cuts and longitudinal arrangement of actuators.	98	26857
Design 6: Rectangular plate has a thickness reduction (1 mm thick) and longitudinal arrangement of actuators.	8940 129 299 64	1143 8571 13714 24571

Note that the maximum values of deformations at low frequencies in Table 2 will be lower in practice because damping was not included in the simulations.

Conclusion:

Choosing the best arrangement of actuator pattern and plate from Table 2 is based on obtaining a high deformation at the highest possible frequency suggesting Design 1 (668 microns at 8 kHz) or Design 3 (393 microns at 13.7 kHz) and Design 6 (299 microns at 13.7 kHz), for which physical experiments will be reported. For Design 1 a small polymer disk (30 mm diameter, 3 mm thick) of mass 5.3 g was levitated by the vibrating plate at 8 KHz.

References:

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