

Energy harvesting with actuators

Multifunctional Ceramics
Division R+D

Multilayer actuator

Material: SP 505

Dimension: 7 x 7 x 32 mm,

Capacitance C (small signal): 2,1µF;

d₃₃ about 500pC/N,

n= 300 layers

Summary

The amount of energy harvested with an actuator is demonstrated in the frequency range of 30-80 Hz @10g and small seismic masses.

Theorie:

Charge generated: $Q = d_{33} \cdot n \cdot F$ (1)

Max. Energy generated $W = \frac{1}{2} \cdot \frac{Q^2}{C} = \frac{1}{2} \cdot \frac{(d_{33} \cdot n)^2}{C} \cdot F^2 = \frac{1}{2} \cdot \frac{(d_{33} \cdot n)^2}{C} \cdot (m \cdot a)^2$ (2)

With $C = \epsilon_{33} \cdot \epsilon_r \cdot n \cdot \frac{A}{d}$; A: Area and d thickness of layer (3)

→ $W = \left(n \cdot \frac{d}{A} \right) \cdot \frac{(d_{33})^2}{\epsilon_{33} \cdot \epsilon_r} \cdot (m \cdot a)^2$ (4)

Design: long actuator (n*d) with a small footprint (A) is best adapted.

Material: d₃₃²/ε₃₃ should be large (SP505 well suited)

Force: should be as large as possible without depolarizing the Piezo.

Therefore the choice of 7*7 footprint and 32mm length (28mm active)

Experiment:

The actuator is mounted on a shaker (Pic 1 and 2). The first measurement takes only the actuator into account, the frequency range being 30Hz up to 80Hz. The acceleration of the shaker is controlled to be about 10g. The measured values are the displacement of the shaker and the resulting voltage. The displacement (peak to peak) of the shaker with the calculated acceleration in units of g is shown in table 1.

The signal is sinusoidal and follows the equation:

$$dl(t) = \hat{dl} * \sin(\omega t)$$

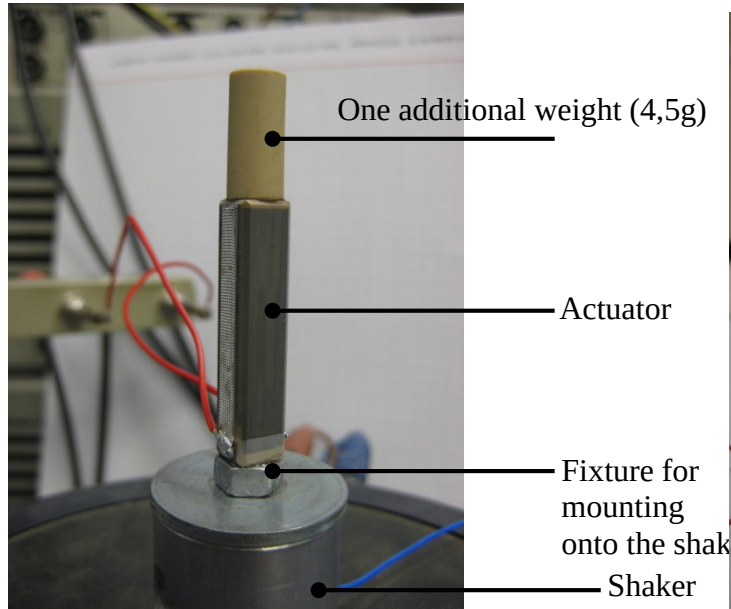
The maximum acceleration is then calculated by:

acceleration $\hat{a} = \omega^2 \cdot \hat{dl}$ (ω being the rotation frequency and $\hat{dl}$ the amplitude of the displacement).

f/Hz	30	40	50	60	70	80
^dl/mm	2,71	1,615	1	0,67	0,575	0,35
acceleration/g	9,82	10,40	10,06	9,71	11,34	9,01

Table 1

In the following step a weight of 4,5g is mounted onto the actuator (Pic 1a). The values of Δd and U_{pp} are measured. This is repeated until three weights are glued onto the actuator (Pic. 1b).

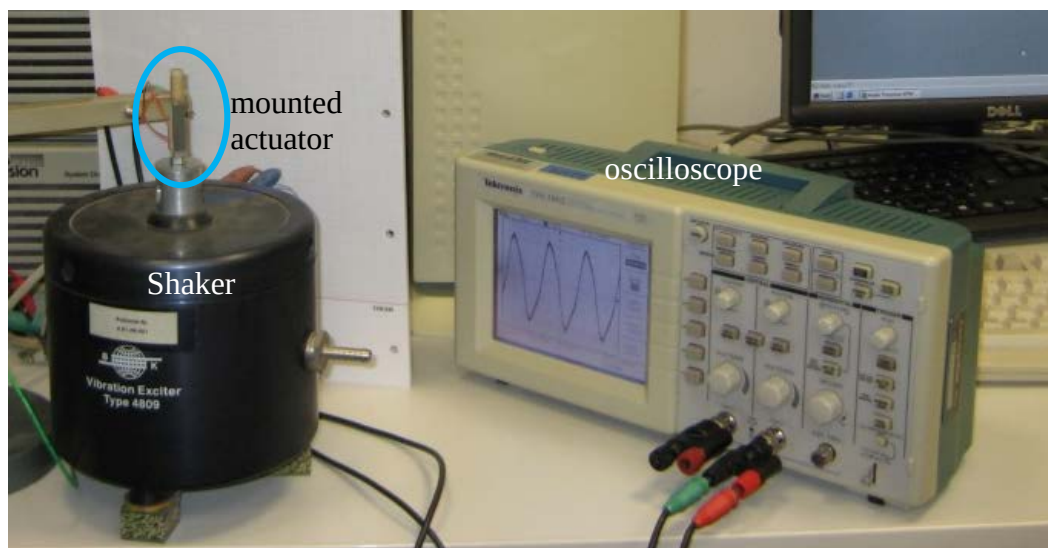


Pic. 1a Actuator with one weight on it



Pic 1b Actuator with three weights

The resulting voltage is displayed and measured on an oscilloscope (Pic 2).



Pic. 2 Shaker test device with mounted actuator, computer and oscilloscope

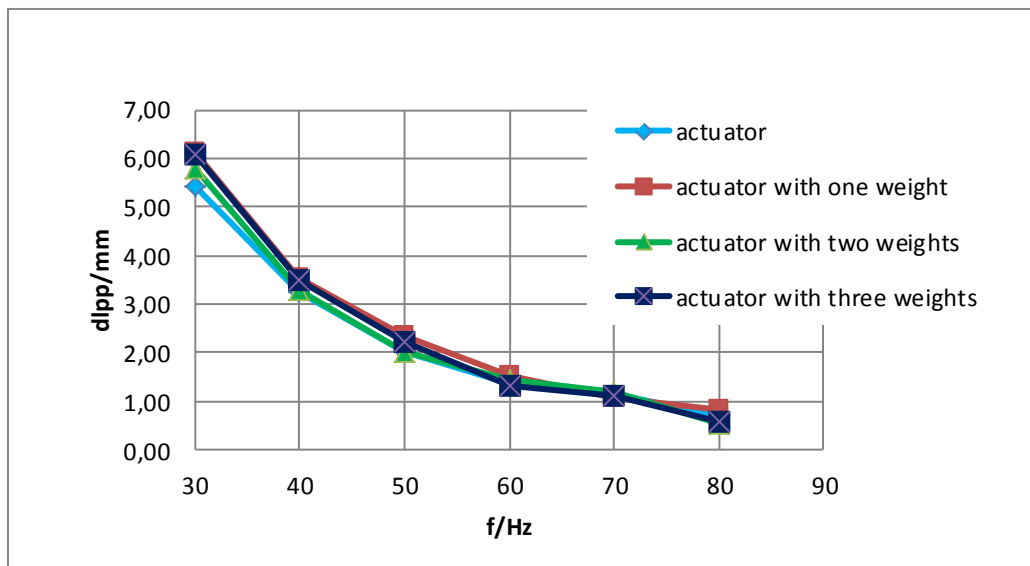
Result:

In the following diagram (Diag 1) the displacement ($d_{pp} = 2 \cdot d_l$) of the actuator has been measured depending on the oscillating frequency of the shaker.

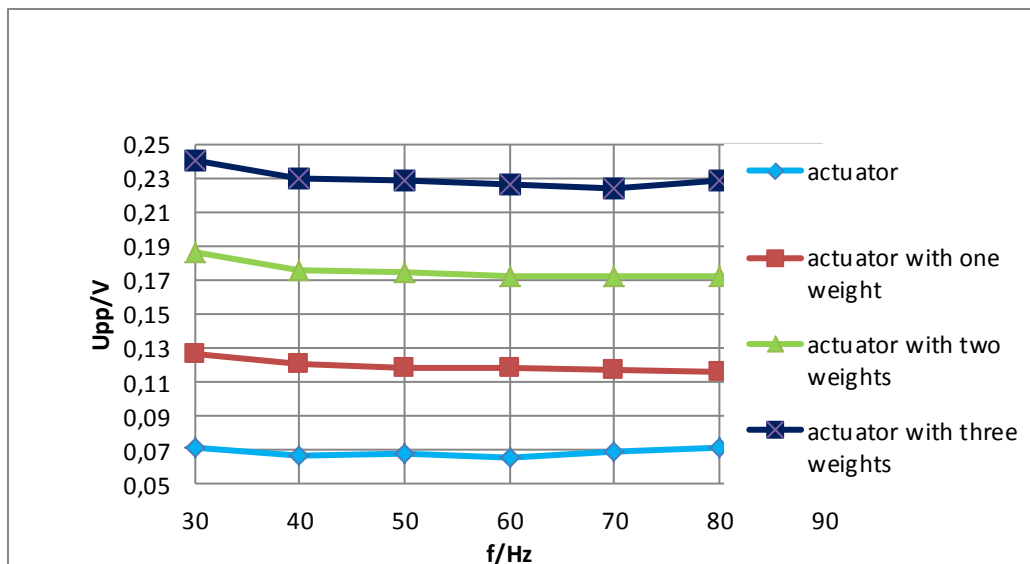
The bright blue line shows the curve of an actuator without any weight on it. Here the used weight is half of the mass of the actuator ($12,05\text{g}/2 = 6,025\text{g}$).

The next measurement (red line) is done with a weight of about 4,5g additionally to half of the actuator-mass. So the effective weight is about 10,53g.

The green line shows the actuator with two added weights (together 15,03g). And finally the dark blue line shows the actuator with three added weights (pic 3).



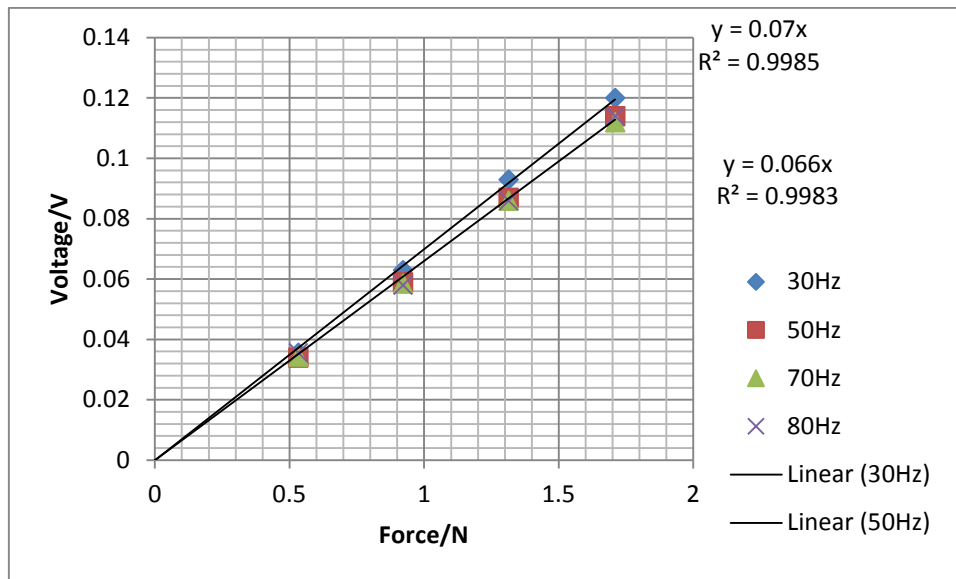
Diag. 1: Displacement (peak to Peak) versus frequency



Diag. 2 resulting Voltages

In diagram 2 the resulting voltages are plotted.

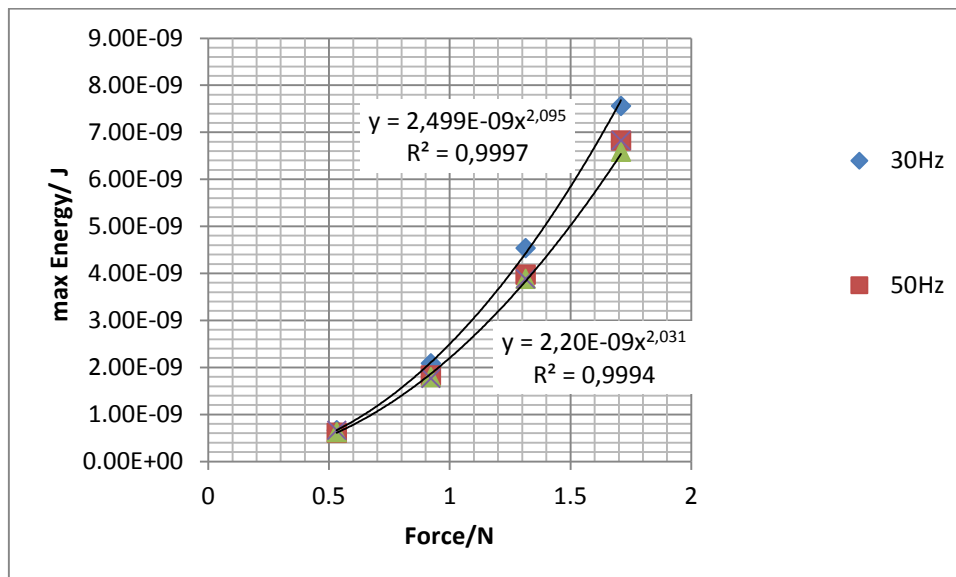
Maximum voltage (Peak to Peak) achieved is about 0,25V.



Diag 3 Voltage versus force

Plotting voltage versus calculated force gives a straight line, the slope being determined by d33, capacitance and the number of layers. The maximum energy E in the experiment can be calculated by:

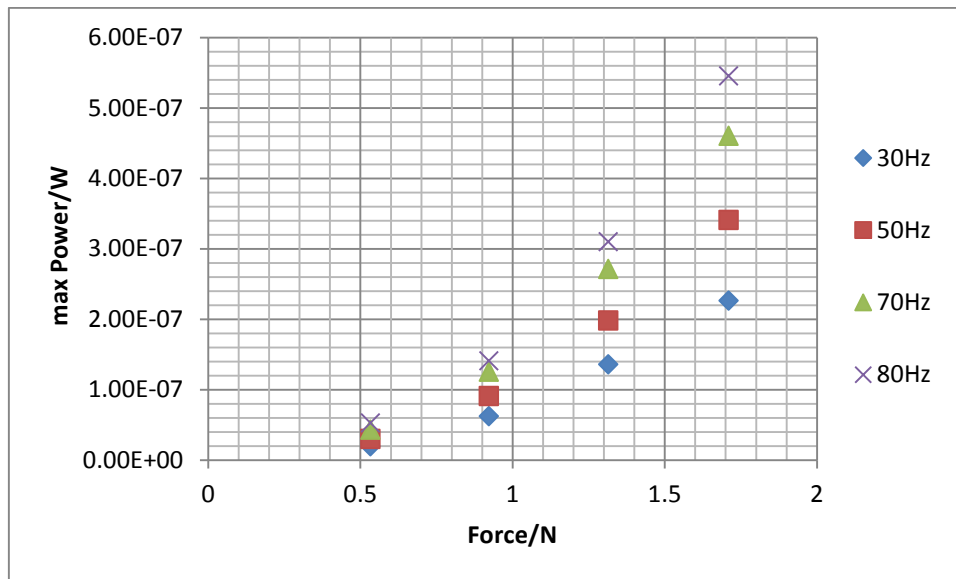
$$E = \frac{1}{2} * C * U_{eff}^2$$



Diag 4 Energy

The calculated energy is shown in Diag. 4, it follows the square of the force, as predicted by theory (2). Extrapolating from this measurement, a force of 100N would result in a maximum energy off about 20μJ and at 500N about 500μJ.

Higher forces could tend to depolarize the Piezo.



Diag. 5 Power versus force

The resulting Power $P=f \cdot E$ is shown in diagram 5;

At 500N and 80Hz the maximum Power could be about 40mW. The actual usable power would be lower, because it has to be taken into account that this is the power on actuator level and electronics necessary to rectify the signal and so on will lower the consumable energy.