« Speed estimator for a piezoelectric vibrating tool »

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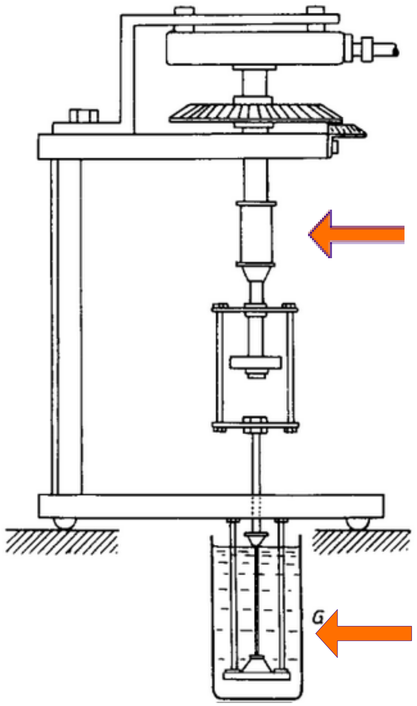
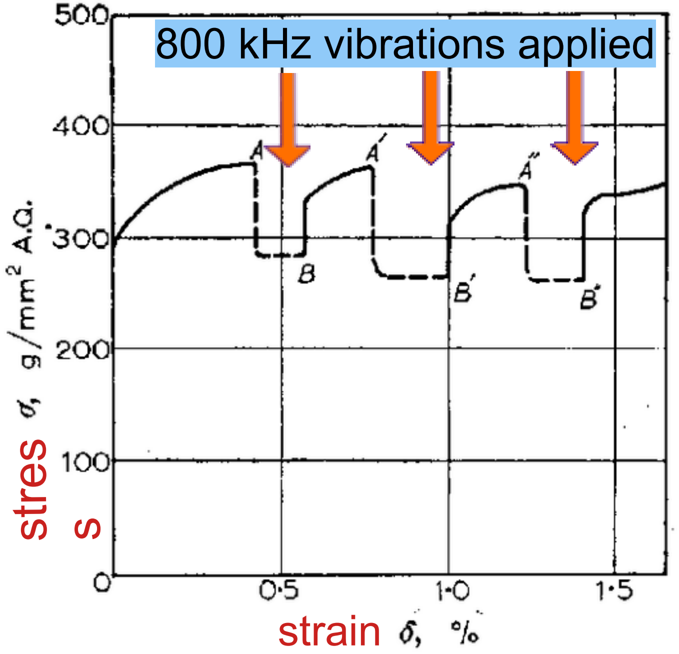
« Context »

Ultrasonic vibrations superimposed during tensile tests reduce the forging load



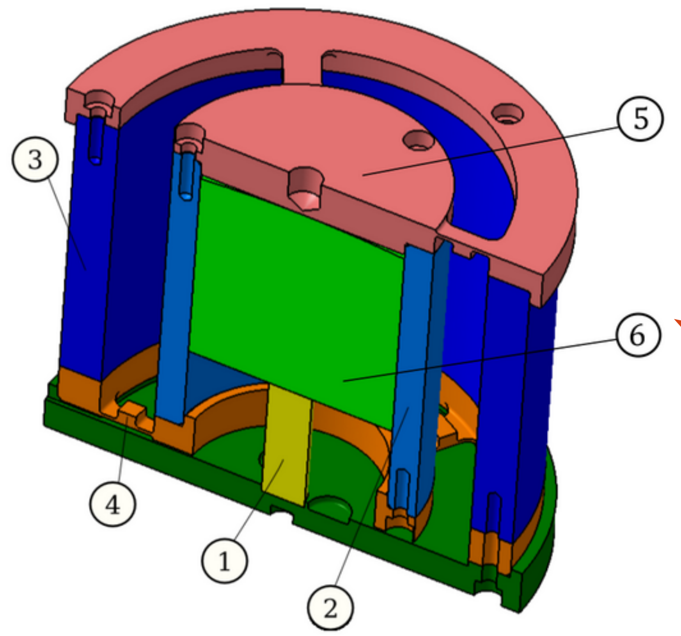


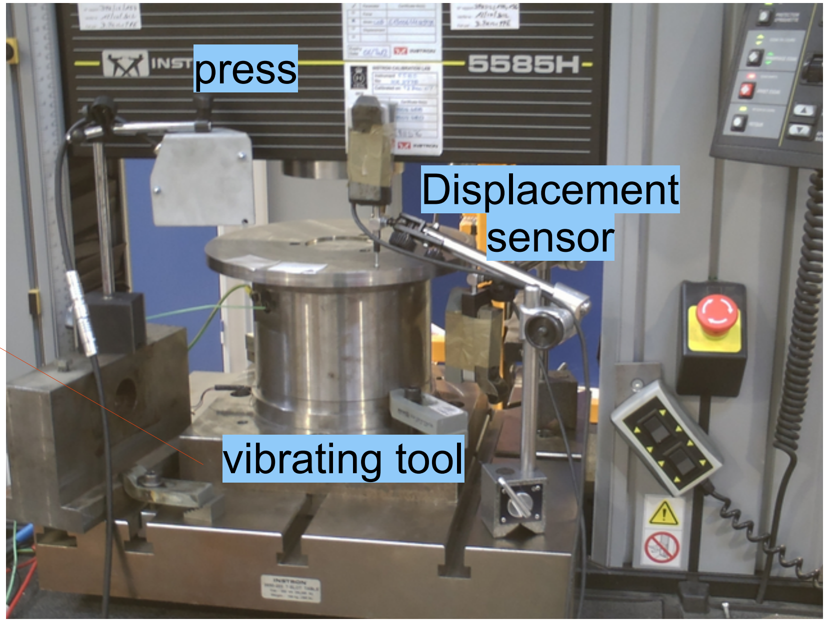
[Blaha 1959]

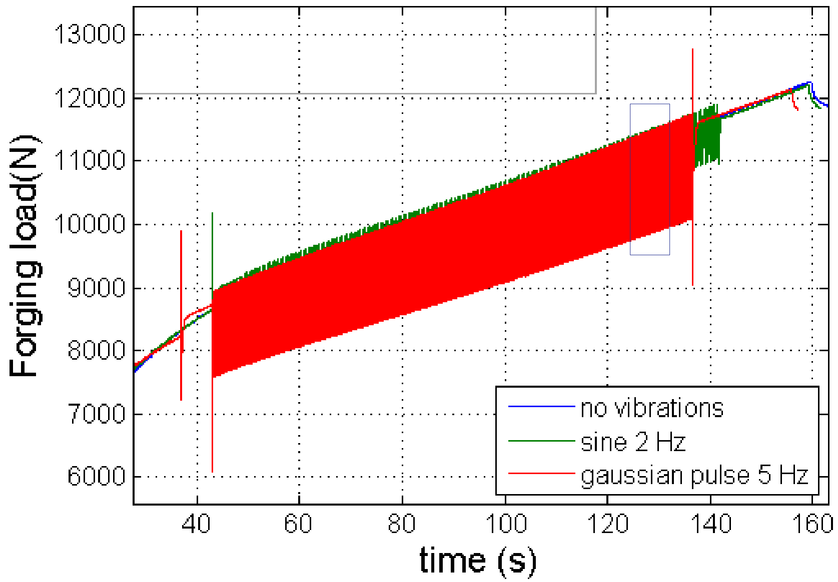
- Small displacements,
- High forces
- Short time response

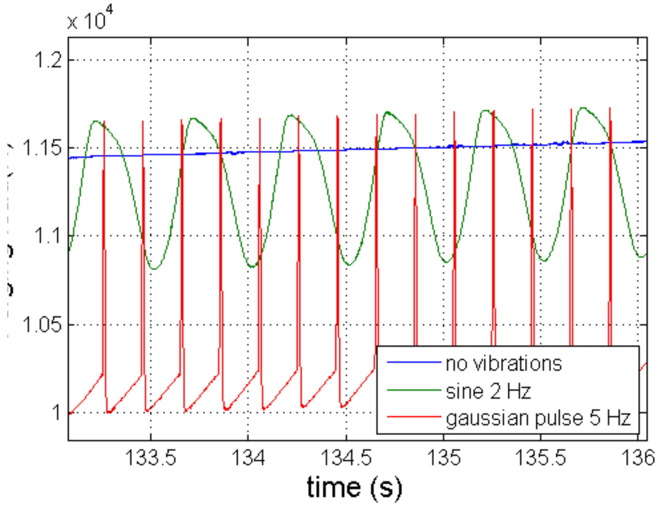
Piezoelectric actuators

Forging : superimposing low frequency vibration during upsetting









Results [Ly 2009, Khan 2011, Nguyen 2014]:

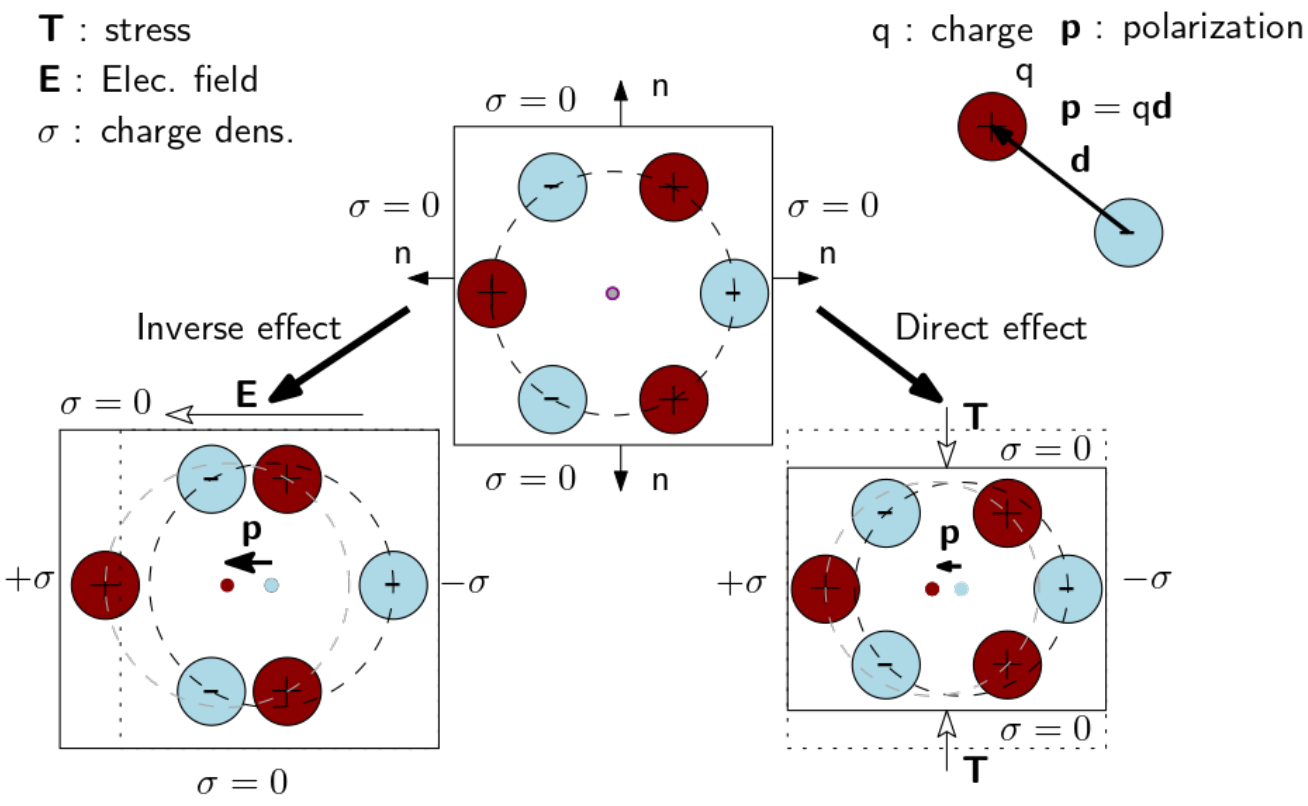
- Similar effect are obtained at low frequencies
- **No lubricants needed !**
- Key parameter : **waveforms**

Closed loop : speed estimator (sensor too expensive)

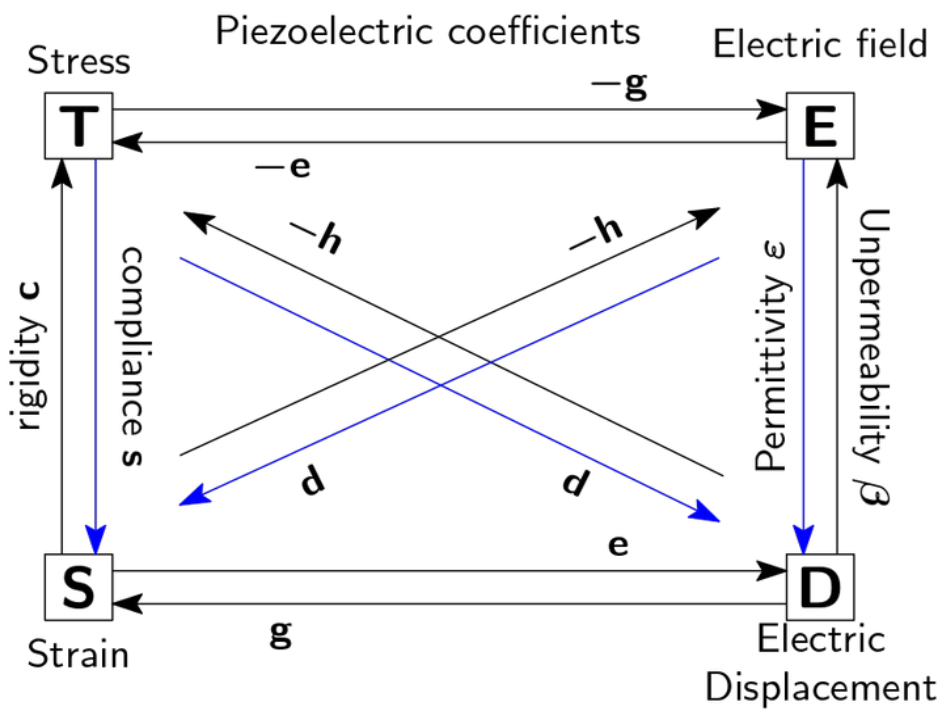
« Model »

The piezoelectric effect : local effect

Local interactions



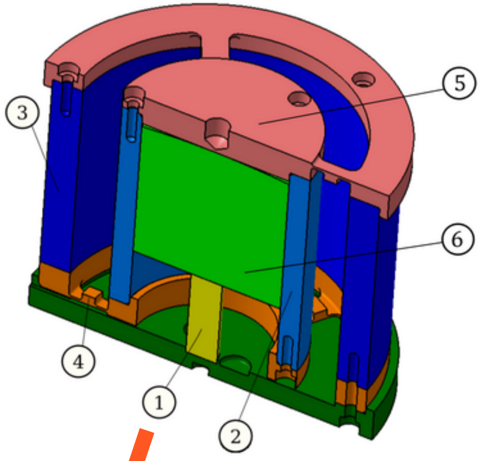
Constitutive laws



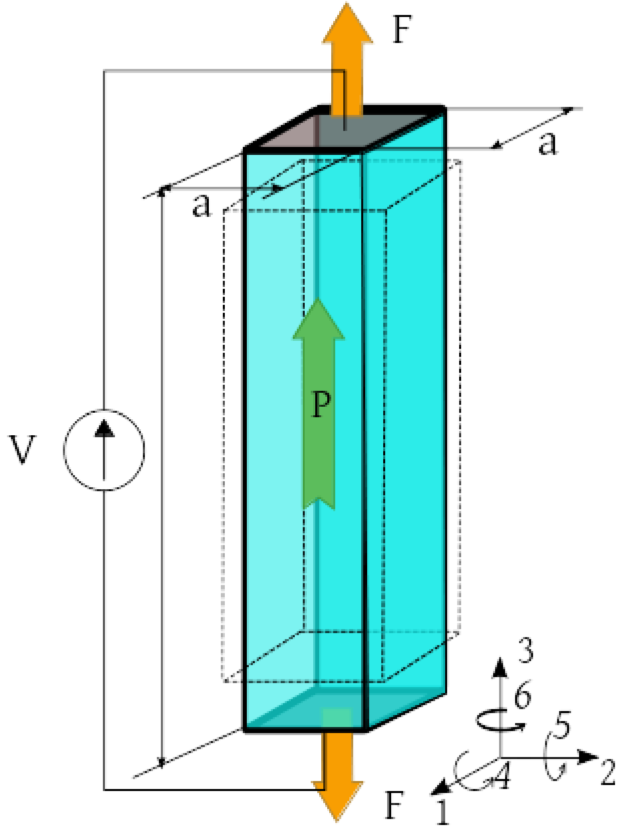
$\mathbf{S} = \mathbf{s} \cdot \mathbf{T} + \mathbf{d} \cdot \mathbf{E}$

$\mathbf{D} = \mathbf{d} \cdot \mathbf{T} + \varepsilon \cdot \mathbf{E}$

Macroscopic model of an actuator



Piezoelectric stack



Simplified model

Slender piezoelectric rod :

- Quasi static motion
- Mechanical load applied on the horizontal surfaces of the rod
- Voltage is imposed on the electrodes
- Unidimensional problem

$$\begin{cases} u_3 = \dfrac{s_{33}^E l_0}{a^2} F - d_{33} V \\ Q = -d_{33} F + \dfrac{\varepsilon_{33}^T a^2}{l_0} V \end{cases}$$

u_3 : displacement ; Q : charge ;
F : force applied to the piezostack ;
V : Voltage applied to the piezostack

« Biographies and references »

Storages :

$$\begin{cases} u_3 = \int \mathring{u}_3 \, dt \\ Q = \int i \, dt \end{cases}$$

$\mathring{u}_3$: speed

i : current

$$\begin{cases} u_3 = \dfrac{s_{33}^E l_0}{a^2} F - d_{33} V \\ Q = -d_{33} F + \dfrac{\varepsilon_{33}^T a^2}{l_0} V \end{cases} \Rightarrow \begin{cases} \int \mathring{u}_3 \, dt = \dfrac{s_{33}^E l_0}{a^2} F - d_{33} V \\ \int i \, dt = -d_{33} F + \dfrac{\varepsilon_{33}^T a^2}{l_0} V \end{cases}$$

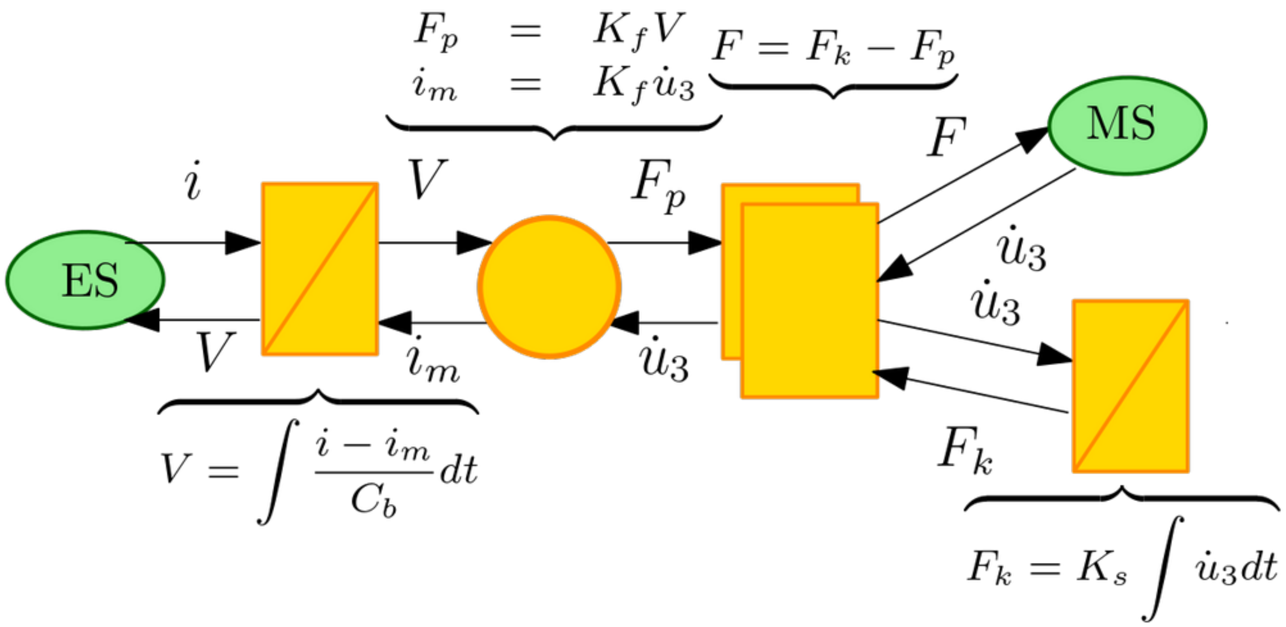
Definitions

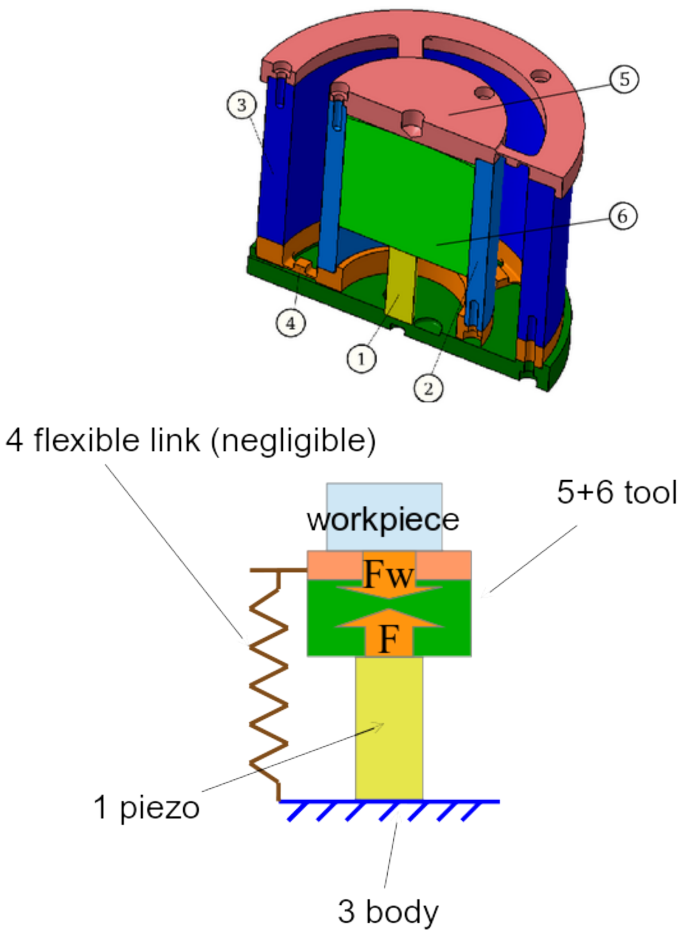
$$\begin{cases} K_s = \dfrac{a^2}{s_{33}^E l_0} & \text{the rigidity of the rod (N/m)} \\ K_f = -d_{33} K_s & \text{conversion (N/V or C/m)} \\ C_0 = \dfrac{\varepsilon_{33}^T a^2}{l_0} & \text{« free » capacitance (F)} \\ C_b = C_0 - d_{33}^2 K_s & \text{« blocked » capacitance (F)} \end{cases}$$

EMR of the piezostack actuator

We rewrite :
$$\begin{cases} F = K_s \int \mathring{u}_3 \, dt - F_p \\ V = \dfrac{\int i - i_m \, dt}{C_b} \end{cases}$$
storages

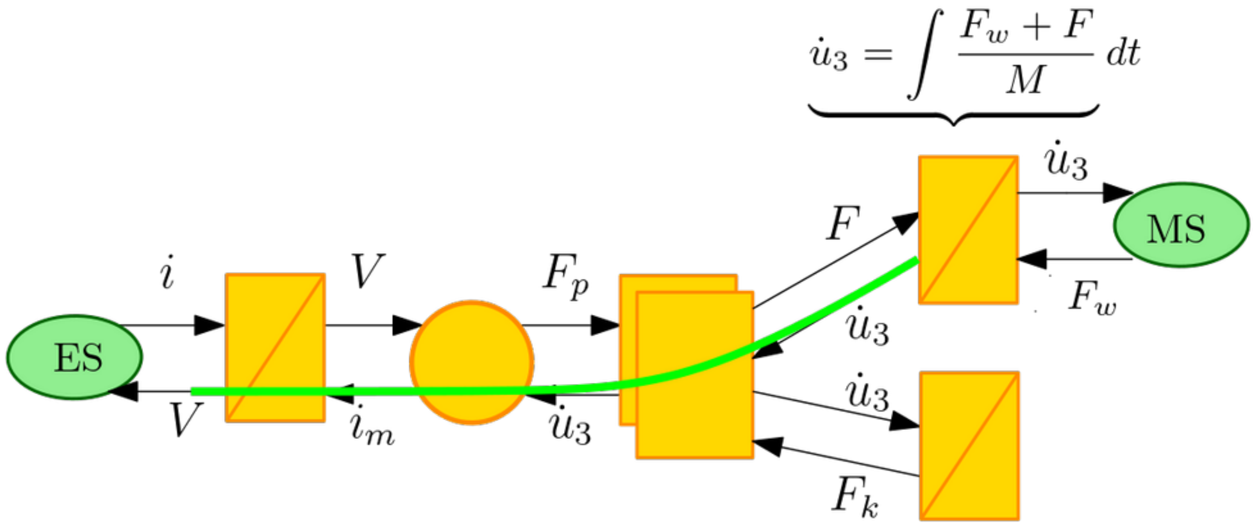
with
$$\begin{cases} F_p = K_f V \\ i_m = K_f \mathring{u}_3 \end{cases}$$
Electromechanical conversion





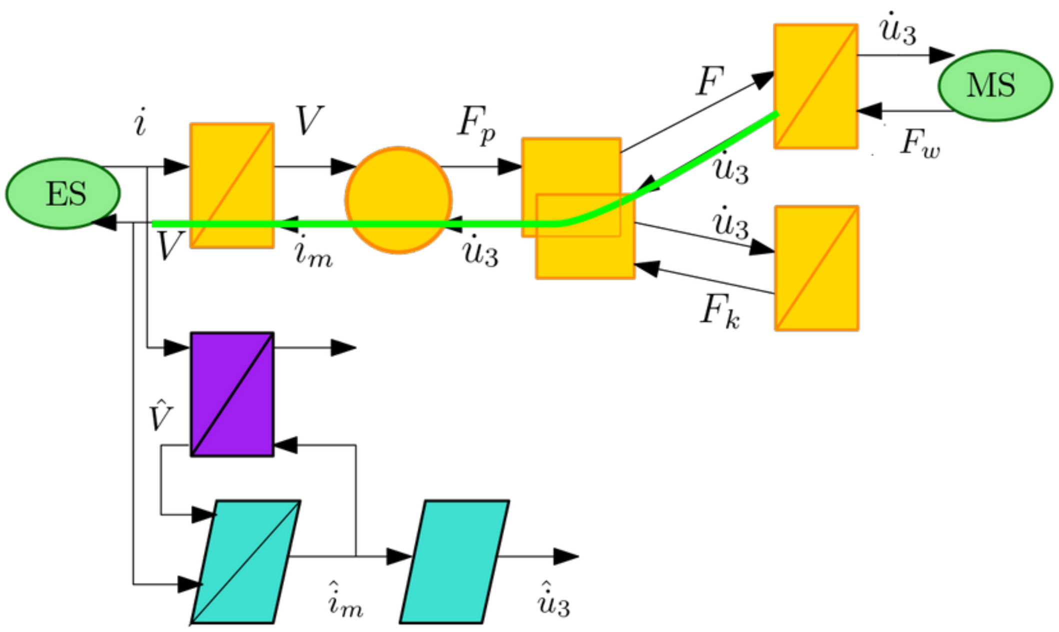
Simplified model of the vibrating tool

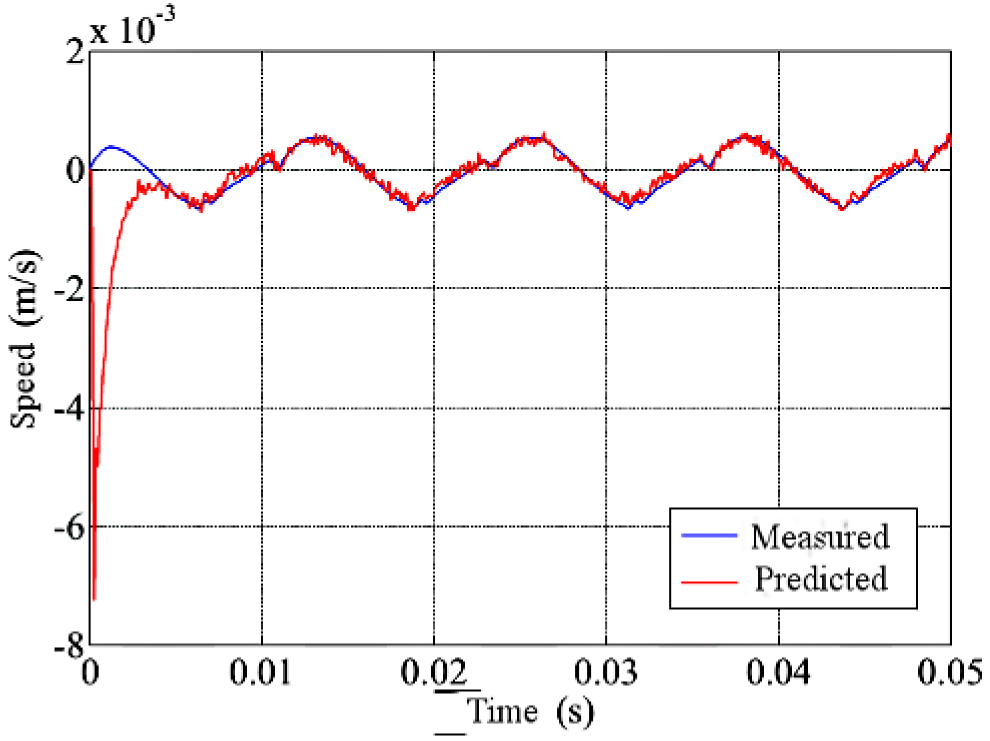
The model is augmented to account for the tooling inertia



The path from the speed toward a measurable electric variable is found using the EMR of the system

The motional current is then estimated by matching the voltage of model of the blocked capacitance (purple block) to the actual voltage using a closed loop





[Giraud-Audine 2011]

1) A physical model of the vibrating tool was derived from local equations
2) Identifying the energy storage to buil the EMR
3) Identify the path from the estimated variable toward a measured or controlled variable
4) Build the estimator by driving the model error to zero using a controller

Thank you for your attention

- References -

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Thanks for your attention !

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