Piezomechanik GmbH

Current/Charge Control Amplifiers for Piezo Actuators

The innovative approach for dynamic control of piezo motion (position, speed, acceleration)

for

Active vibration control
Adaptronics
Fast response devices

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1. Basics

(Further details: see in broschure "Piezomechanics: An Introduction" chapter 7)

Piezo-electrical and piezo-mechanical (inverse piezoelectric) devices make basically use of the electromechanical coupling between the balance of **electrical charge Q** (stored in the piezo device) and the **related piezo-kinetic parameters** like

Piezo actuator's

(1) Stroke $\ell = Q \cdot \ell_{max} / (C_{eff} U_{max})$

(2) velocity $v = d\ell/dt = I \cdot \ell_{max} / (C_{eff} U_{max})$

(3) acceleration $b = dv/dt = dI/dt \cdot \ell_{max} / (C_{max} U_{max})$

$\Rightarrow$ **(4) stroke/position** $\ell \sim \int I \, dt$

With

Q electrical charge transferred to actuator

I charging current (= dQ/dt)

dI/dt charging currents slew rate

ℓ_{max}: specified maximum stroke at specified maximum voltage U_{max}

U_{max}: specified max. voltage

C_{eff}: piezo actuator's real capacitance

The dramatic advantage of the electrical charge philosophy of driving piezo actuators are

- **Linear response (typical 1%)**
- **nearly no hysteresis (better 1%)**
- **no creep**
- **much higher dynamic open loop actuator stiffness**
- **improved feedback response in closed loop systems**

Why have voltage controllers mostly been used in the past:

The answer is rather simple:
Voltage amplifiers are simpler devices to handle static or low dynamic open loop positioning problems than charge controllers.
But: voltage control results in the well-known imperfections of open loop voltage control of piezo actuators for positioning tasks like

Hysteresis (up to 20% of actual stroke) (fig. 1b)
Nonlinearity (up to 10%) (fig. 1b)
Creep (percent range over time)
Reduced actuator stiffness due to floating charges

(The reason for the nonlinearity etc. is, that PZT ceramic is a ferroelectric material, where the dielectric permittivity ϵ (determining actuator's capacitance C) is not invariable, but depends to some extent on the driving voltage (electrical field strength) and on activation time t.

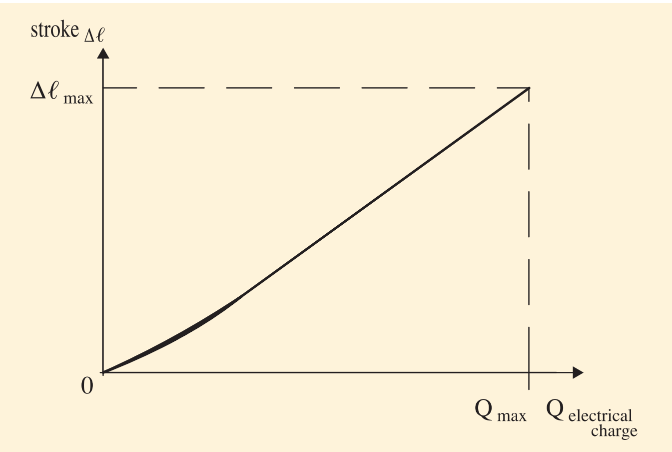

Fig. 1a: Linear stroke response of a piezo-stack under electrical charge control

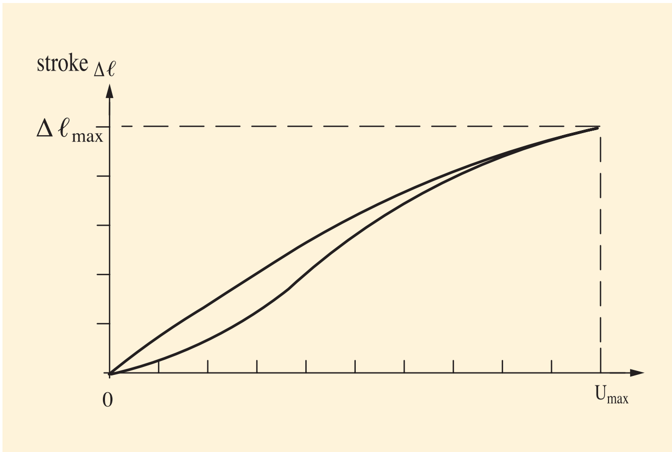

Fig. 1b: Nonlinear piezo stroke response under voltage control

2. Current control:

the new driving philosophy for piezo-actuators in dynamic applications

Piezo actuation technology faces an ongoing trend towards dynamic applications:
Remarkable high electrical energy and powers shall be transferred to a piezo system, defined by voltage and current according

$$(5)\ P(t) = U(t) \cdot I(t)$$

P(t) electrical operating power for the piezo device

So obviously compared to the former static /slow motion operations for simple piezo positioning we have now a new situation, where we can decide, which of the two parameters shall be best the primarily controlled: **voltage or current**

⇒ **for a lot of dynamic applications, it makes much more sense to control current!**

a, the linear current response allows harmonic piezo modulation without any sidebands (as caused by nonlinear and hysteretic response under voltage control)

b, direct control of the kinetic parameter velocity v easy control of acceleration b

c, fast and precise feedback closed loop operation of adaptronic/active vibration control setups due to linear response: charge/position and current/velocity

d, for high power applications (e.g. Diesel Fuel Injection DFI) current control avoids erratic current jitter usually impacting reliability and lifetime of the piezo stacks as it seen with other electronic driving methods.

Examples for current controlled piezo-actuation:

- *Shaker applications*
- *Active vibration control*
- *Adaptive structures*
- *Ultrafast mechanical switching (impact generators, high speed fuel valve control, Diesel Fuel Injection)*

3. Terminology

3.1. Charging amplifier

The controlled parameter is electrical charge. The electrical charge is linearely equivalent actuator's stroke (see 1.).
The variation of the input signal defines a distinct quantum of electrical charge transferred to a piezo actuator.

3.2. Voltage amplifier:

The controlled parameter is the output voltage. Voltage is equivalent piezoactuator's position (but shows hysteresis etc.)

The input signal is converted into a distinct high voltage level applied to a piezo actuator.
Works within a distinct bandwidth starting at DC.

3.3. Current amplifier

The controlled parameter is the electrical current. It is transformed into actuator's velocity.
Position/stroke are determined by the time integral (4).
Related to the current flow is a distinct variation in the resulting piezo voltage indicating the change of position.
Current amplifiers are AC devices working within a bandwidth above a distinct low threshold frequency f_{trans}.

3.4. Hybrid amplifier

This is a combination of voltage amplifier and current amplifier.
Both amplifier stages have their individual inputs, the resulting signals are superimposed into one output towards the piezo-actuator.
The voltage amplifier stage is used for the DC/low frequency range up to a distinct frequency threshold (transition frequency f_{trans}, see fig. 2a, b,).
The AC-current amplifier operates above the mentioned threshold f_{trans}.

Hybrid amplifiers are used e.g. for high frequency oscillations (controlled by the current amplifier) around a distinct mid-position defined by the voltage stage (e.g. for tuning the optimum operating mid-point of the oscillation).

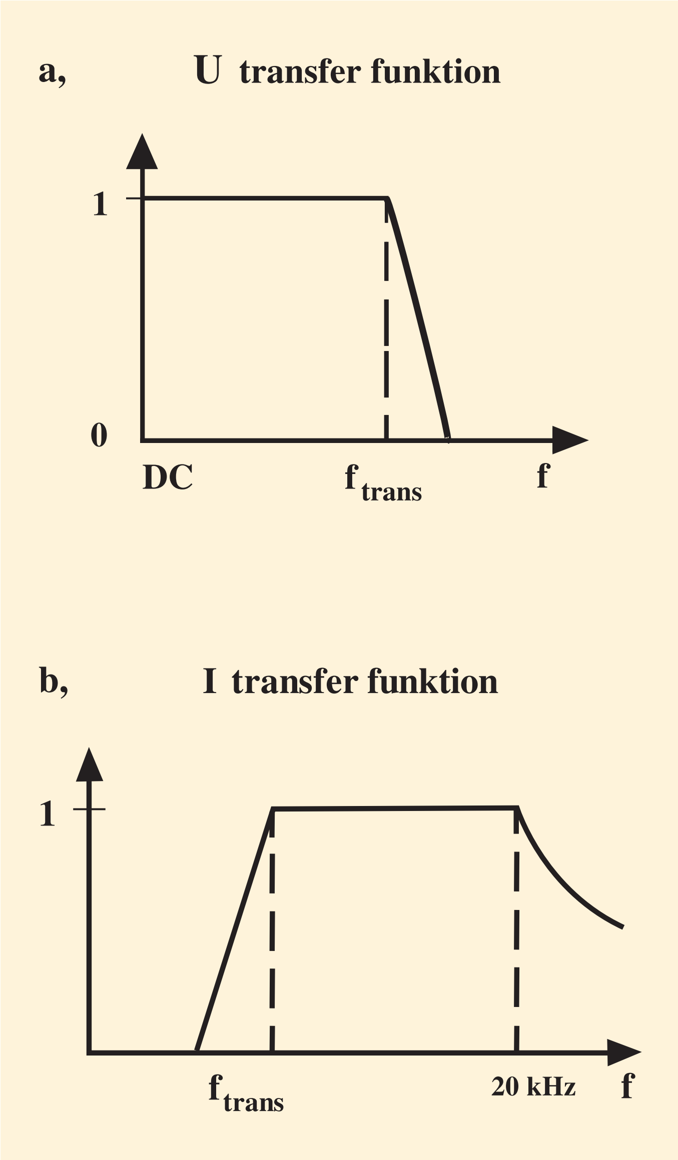

Fig. 2 a, b:
Schematic of the transition frequency definition for the voltage (a) and current (b) amplifier operation

4. The Hybrid Amplifier LE150HYB/020

Voltage amplifier for slow positioning and Current amplifier for high dynamics in one

The amplifier LE150HYB/020 is a multi-purpose piezo-controller according 3.4.
It is preferentially used for high dynamics applications according the current control philosophy with the option for a smooth and steady control of the average/mid-position of the piezo-actuator (e.g. defining an optimum operating point of the setup).

Notice:

Current and Hybrid amplifiers require a modified electrical wiring compared to standard voltage controlled piezo actuators:

The piezo stack operation shows floating ground insulated from casing's ground.

The standard connection for current/hybrid control is carried out by a 2-pole / ground shield LEMO OS 302 connecting system
(Adaption to normal voltage controlling amplifiers can be made by using a connector-adapter.)

Technical data

Voltage range:	−20 V thru +150 V
Peak current:	800 mA (high peak current for shortest reaction times)
Average current:	200 mA (defines charging repetition frequency = sine frequency limit)

Voltage control:

Input:	typical −0.2V ⇒ +3 V (max. −2 V/+7 V)
Voltage control bandwidth:	DC … f_{trans} (see below)
Gain:	50
Input connector:	BNC
Input resistance:	10 kOhms

Current control:

Input:	typical +/−5 V (max. +/−7 V)
Current control bandwidth:	f_{trans} … 20 kHz
Gain:	0.2 Amperes/V input
Input connector:	BNC
Input resistance:	10 kOhms

Voltage ripple, noise:	20 mVpp

Piezo-outputs:

2 banana-plugs (type BÜSCHEL) for stack's +/–, grounding of actuator casing separately

and

1 LEMO 0S 302

Both kinds of connection operate parallel

Note:

Only piezostacks mounted for floating potential fit to this hybrid amplifier.

When using the banana plugs, piezo actuators with casing must show separate grounding for the casing. No common ground for stack and casing.

Order Piezomechanik's piezoactuators with 0S 302 connector for fitting to this amplifier.

Transition frequencies f_{trans}
(from voltage to current control ranges)

65 Hz for 1 µFarad
13 Hz for 5 µFarad
1.3 Hz for 50 µFarad

Monitoring:

Piezo voltage:	reduction factor 1:50
Piezo current:	1 V/200 mA

Indicators:

Overvoltage:	yellow LED
Undervoltage:	yellow LED
Power limit:	red LED
Temperature limit:	red LED

Fig. 3a:
Front view of hybrid amplifier LE150HYB/020

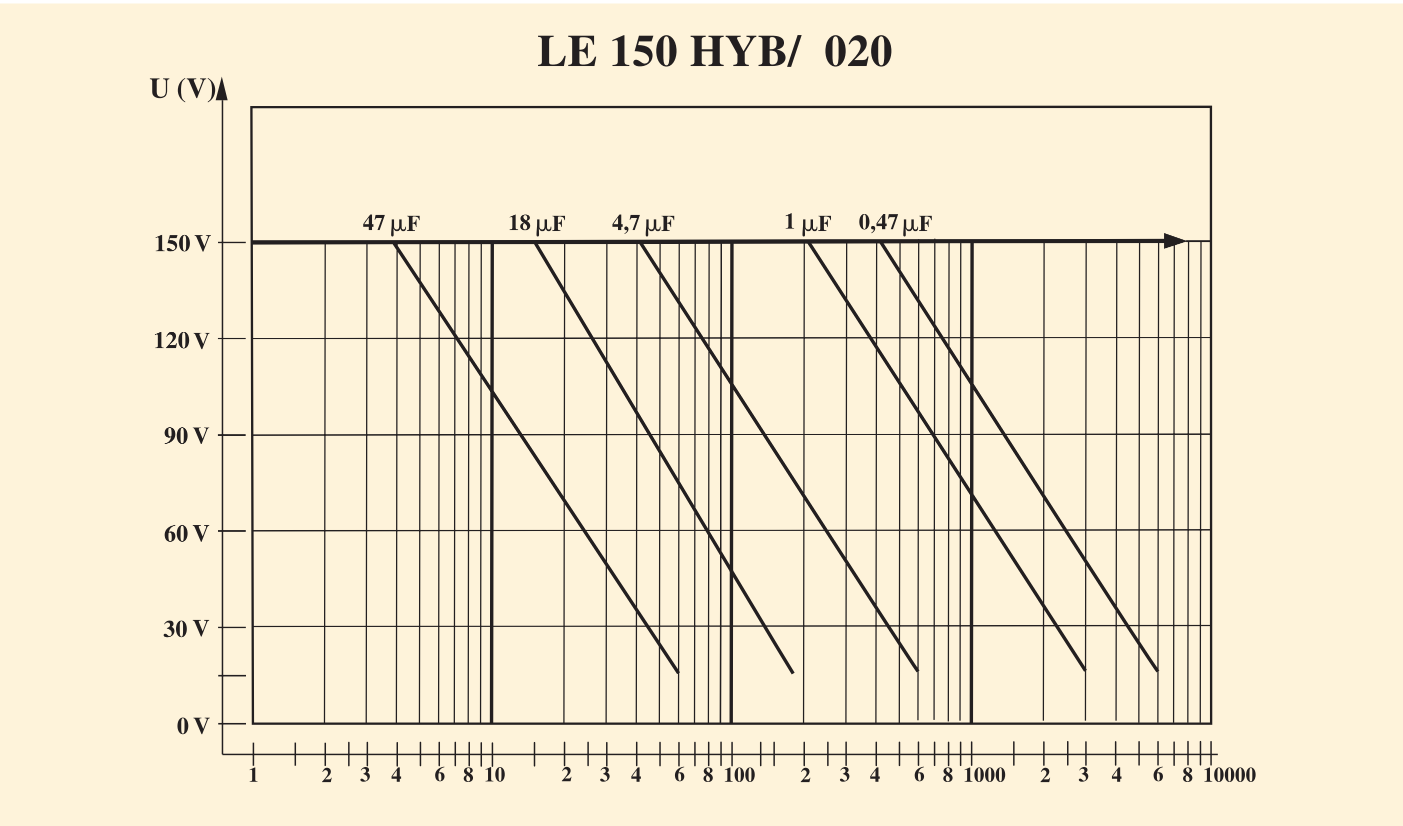

Fig. 3b:
Bandwidths of LE150HYB/020 amplifier for various capacitive loads

Current controlled piezo operating units, available on request

Current amplifiers and hybrid amplifiers for various power ratings

+ 150 V average powers up to 500 Watts
+ 200 V average powers up to 500 Watts
+ 500 V average powers up to 500 Watts
+1000 V average powers up to 500 Watts

Current controlled power pulsers for

Ultra fast actuation
Fast valve switching
Piezo injectors

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