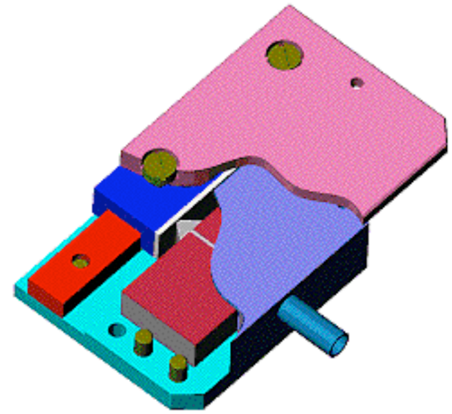
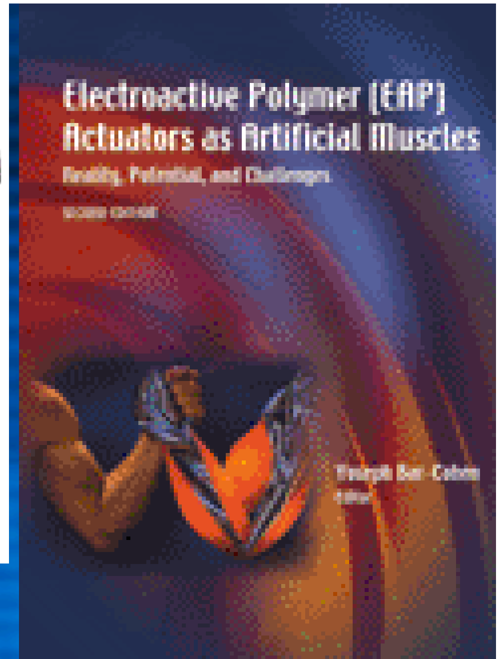
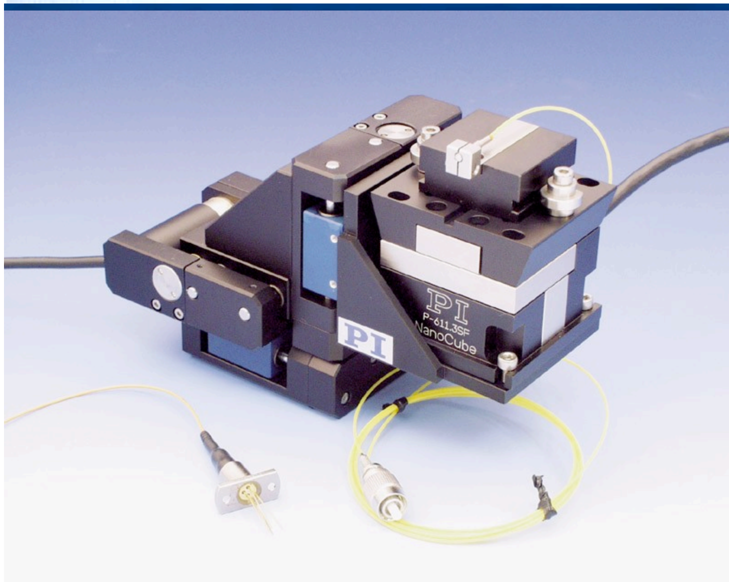
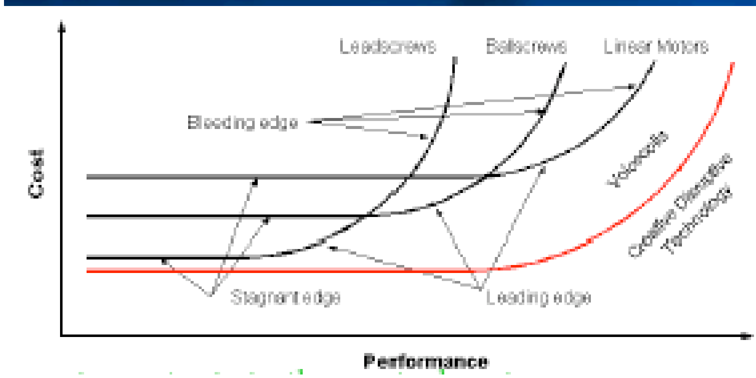
Selecting the right actuators in machine design

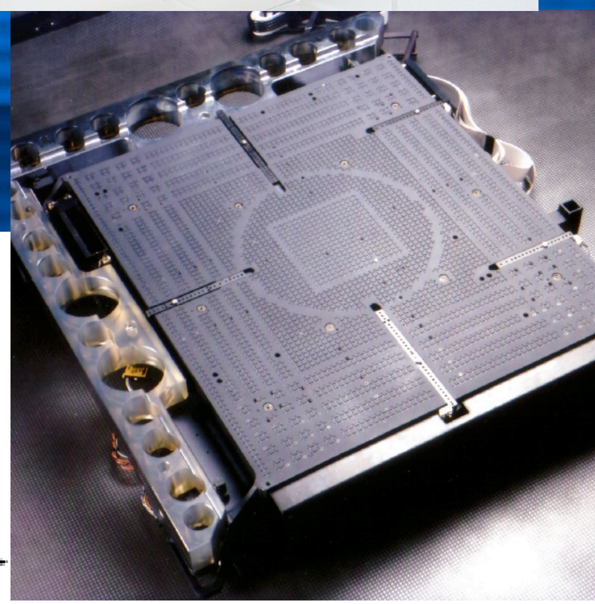
Manu Prakash, 5 April 2004




Electroactive Polymer (EAP)
Actuators as Artificial Muscles



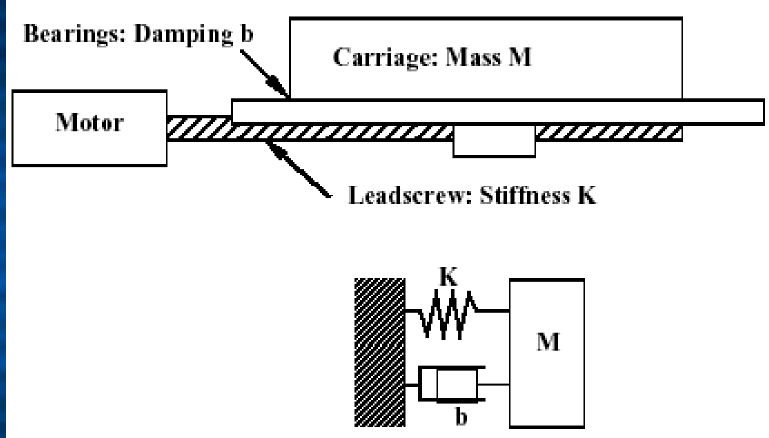

Leadscrews
Ballscrews
Linear Motors
Bleeding edge
Cost
Voicecoils
Creative Disruptive Technology
Stagnant edge
Leading edge
Performance



Designing a Servo system

- Servo mechanism intricately linked with mechanical design
- Build a dynamic model of mechanical system
- Determine transfer function
- Size components accordingly

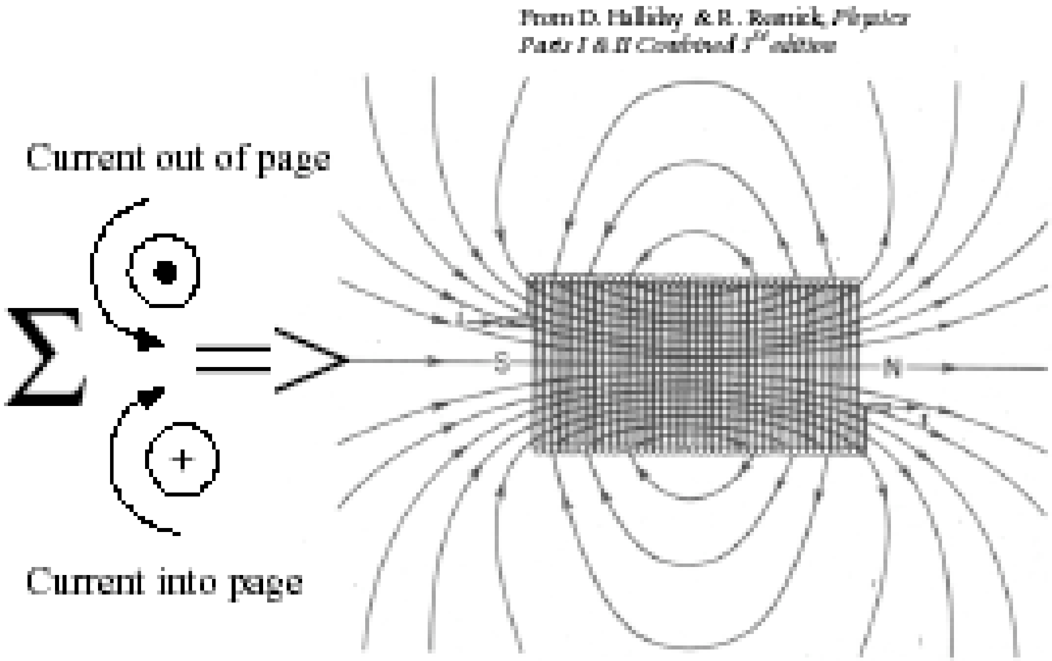
Consider a mass, spring, damper system:

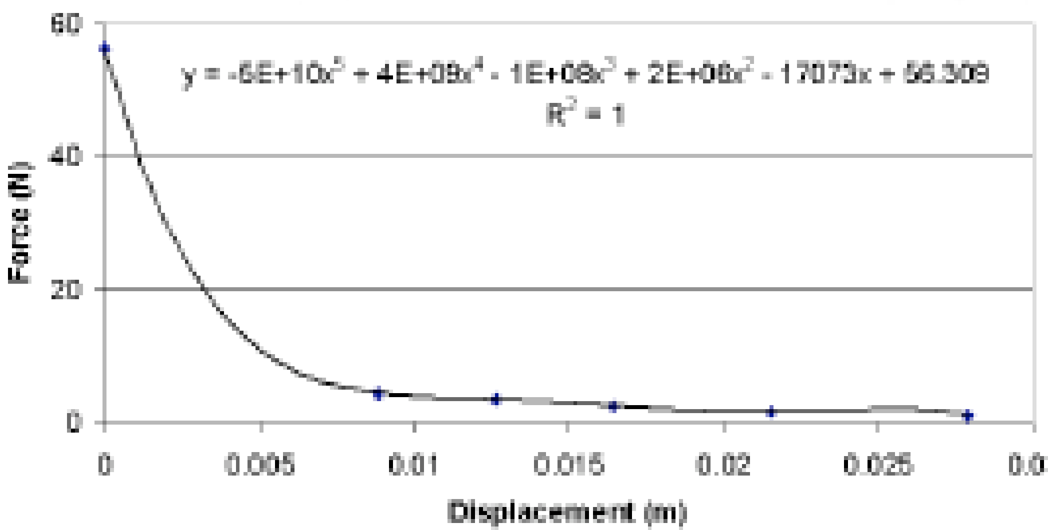


$$\frac{md^2x}{dt^2} + \frac{bdx}{dt} + kx = u(t)$$

PMD : Intro to servo control : 2.75 website

solenoids





Coil wrapped around a magnetic circuit

Easy to build, low cost.

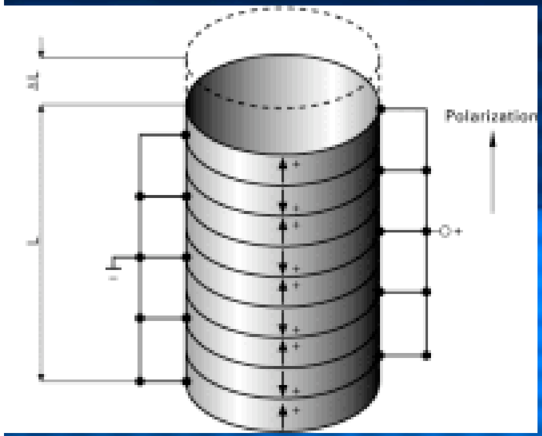
Force decreases drastically with distance x

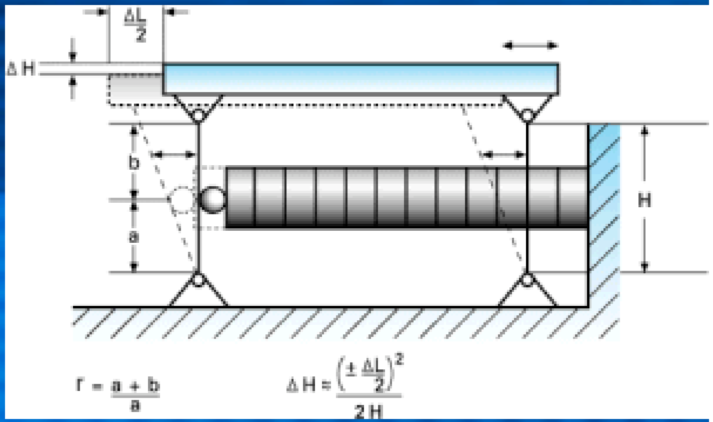
Miniature solenoid valves - lee valves

2.007 notes Prof. Slocum

Solenoid_force.xls

Piezo - motors and linear actuators



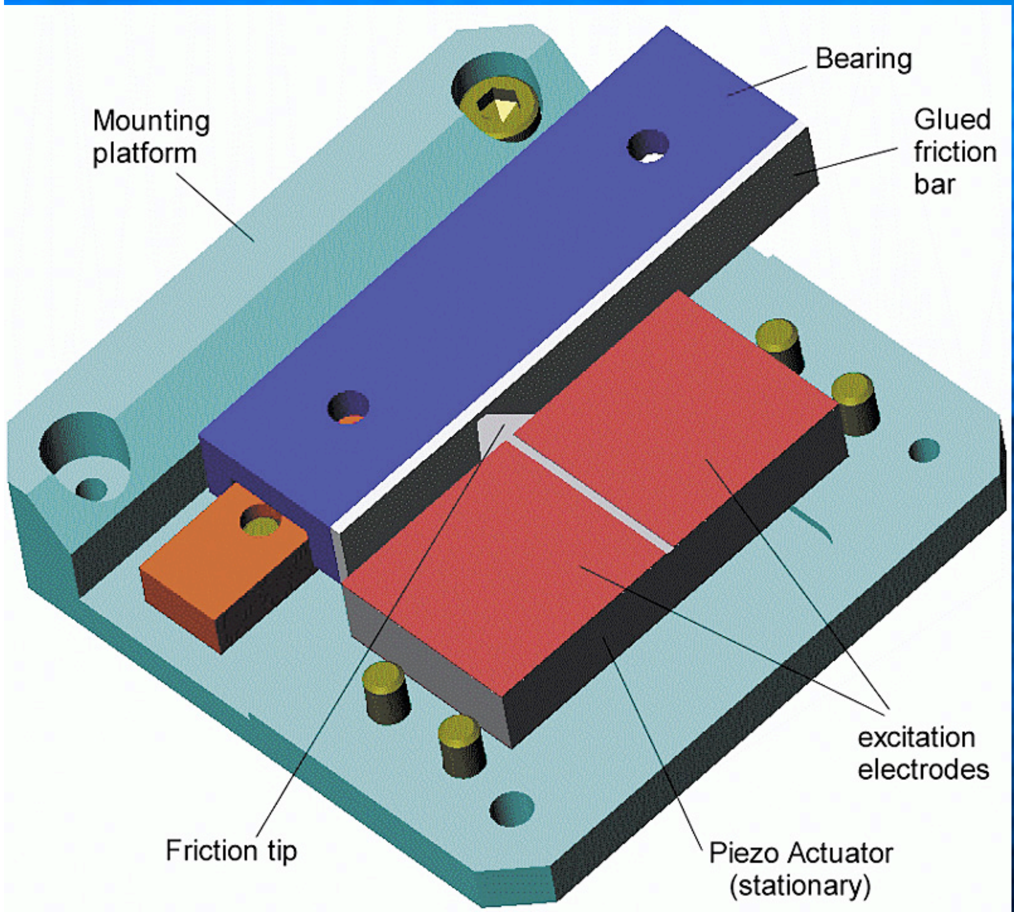


Material : polycrystalline ferroelectric ceramic materials such as BaTiO3 and Lead Zirconate Titanate (Piezo)
Applied potential produces a deformation and vice versa in the crystal
Stacking is used to get large (still order of microns) range of motion
nm order resolution, with very high stiffness.
Very good for nano and micro manipulaiton stages see eg.

Vendors :
http://www.physikinstrumente.de
http://www.piezojena.com

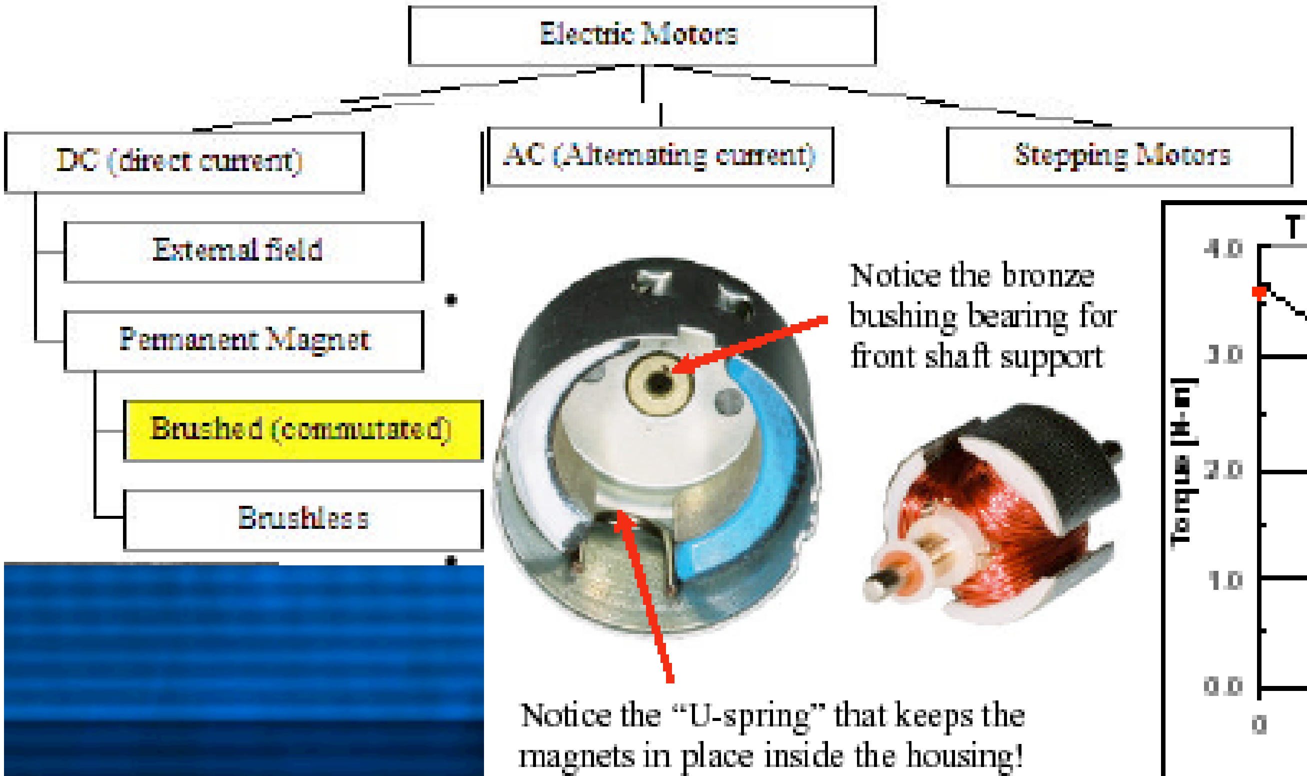
Ultrasonic piezo motors

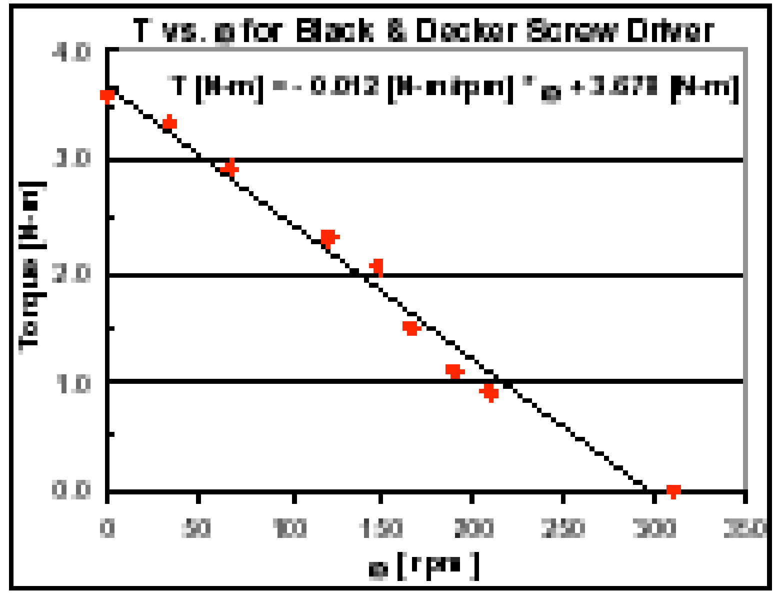
Show video : PI



Smallest large range translation stages
0.1 micron resolution with range dependening on size of friction bed
Velocity upto 800mm/sec achievable

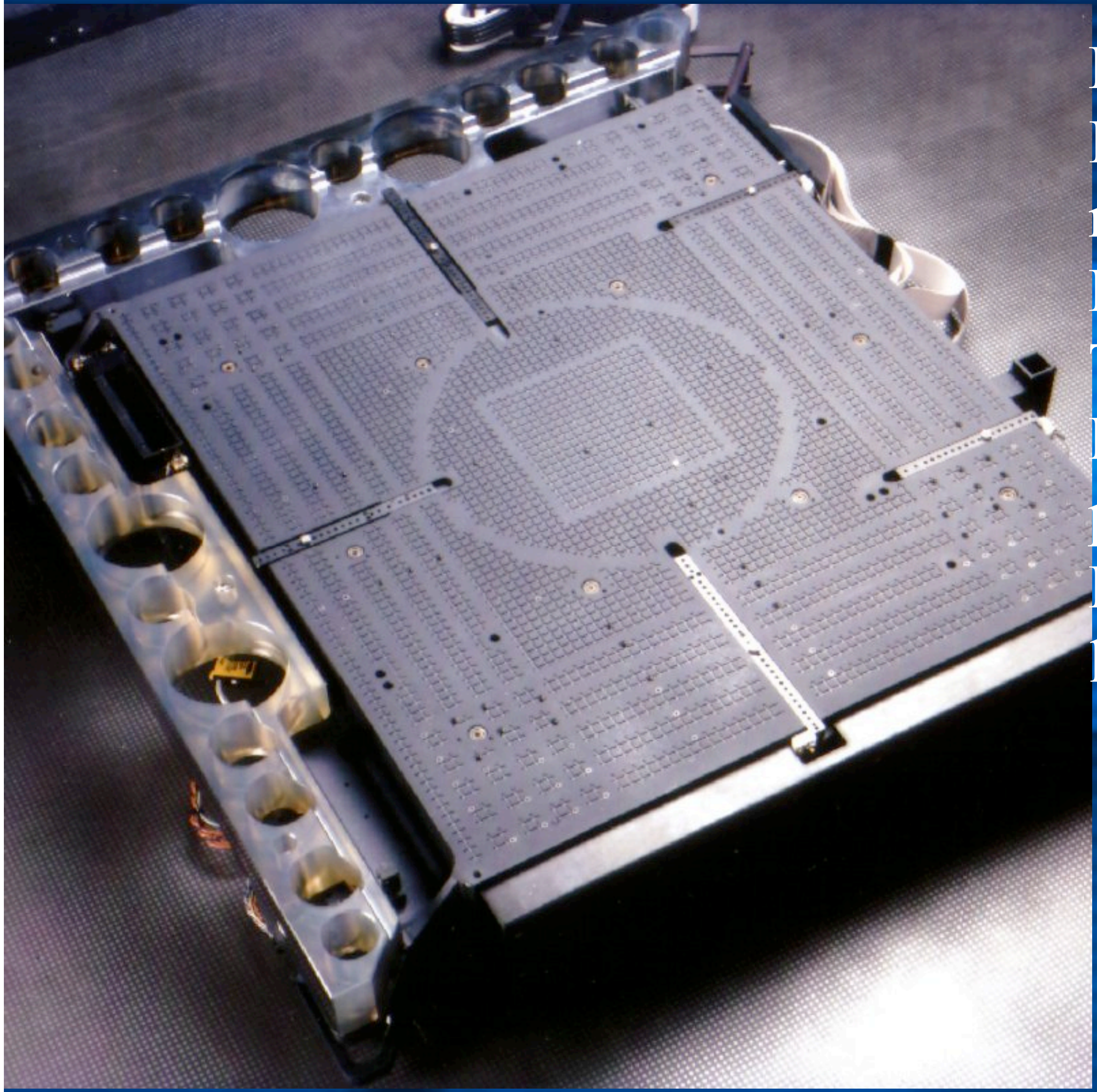
DC servo





* Types of motors
* Linear Torque speed relationship

Stepper motor



- Both rotary and linear stepper
- Interesting linear 2D sawyer motor picture
- Resolution depends on least Turn possible
- Provides decent open loop performance
- Popular in stepper stages in lithography

http://www.azorescorp.com/sawyermotorstage.htm

High resolution DC motors

- DC motors driving a micrometer with a very fine lead screw
- Sub-micron resolution achievable
- Friction needs to be accounted for in the desgin (repetability)

eg. motor data sheet

MABUCHI MOTOR

RC-260RA /SA

OUTPUT: APPROX 0.4W~20W　　カーボンブラシ

http://www.mabuchi-motor.co.jp

代表的用途　家電機器：マッサージャー／バイブレーター
玩具・模型：ラジコン

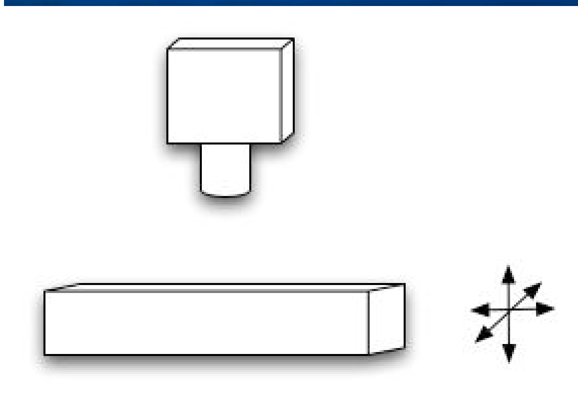
MODEL	VOLTAGE		NO LOAD		AT MAXIMUM EFFICIENCY					STALL		
	OPERATING RANGE	NOMINAL	SPEED	CURRENT	SPEED	CURRENT	TORQUE		OUTPUT	TORQUE		CURRENT
			r/min	A	r/min	A	mN·m	g·cm	W	mN·m	g·cm	A
RC-260RA-18130	4.5 ~ 6.0	4.5V CONSTANT	9800	0.14	7750	0.53	1.48	15.1	1.20	7.06	72	2.00
RC-260RA-2670	3.0 ~ 4.5	4.5V CONSTANT	18500	0.30	15290	1.43	2.14	21.8	3.41	12.3	125	6.80
RC-260SA-2670	3.0 ~ 4.5	4.5V CONSTANT	13700	0.24	11520	1.27	2.66	27.1	3.20	16.7	170	6.70
RC-260SA-2295	3 ~ 6	4.5V CONSTANT	10200	0.20	8300	0.87	2.43	24.7	2.11	13.0	133	3.80

RE Series DC Motors

Motor Data (provisional)			261422	261508	261509	261513	261510	261512
1	Assigned power rating	W	0.5	0.5	0.5	0.5	0.5	0.5
2	Nominal voltage	Volt	2.4	4.2	6.0	7.2	9.0	12.0
3	No load speed	rpm	14500	14700	13900	14900	15000	16200
4	Stall torque	mNm	0.889	0.896	0.824	0.832	0.920	0.889
5	Speed / torque gradient	rpm / mNm	[illegible]	17000	17500	18600	16800	18900
6	No load current	mA	20	11	7	7	5	5
7	Starting current	mA	581	340	207	187	166	130
8	Terminal resistance	Ohm	4.13	12.3	29.0	38.5	54.3	92.2
9	Max. permissible speed	rpm	22000	22000	22000	22000	22000	22000
10	Max. continuous current	mA	411	237	155	134	113	88.8
11	Max. continuous torque	mNm	0.628	0.625	0.616	0.598	0.628	0.593
12	Max. power output at nominal voltage	mW	231	339	293	319	355	370
13	Max. efficiency	%	68	68	67	67	68	67
14	Torque constant	mNm / A	1.53	2.83	3.98	4.45	5.55	6.83
15	Speed constant	rpm / V	6240	3630	2400	2150	1720	1400
16	Mechanical time constant	ms	6	6	6	6	6	6
17	Rotor inertia	gcm^2	0.037	0.036	0.035	0.033	0.036	0.033
18	Terminal inductance	mH	0.04	0.13	0.29	0.36	0.58	0.85
19	Thermal resistance housing-ambient	K / W	48	48	48	48	48	48
20	Thermal resistance rotor-housing	K / W	22	22	22	22	22	22
21	Thermal time constant winding	s	3	3	3	3	3	2

http://www.mpm.maxonmotor.com

Case study : micromilling



Concept : fixed spindle
XYZ micro motion stage

Range = 20mm XY, 10mm Z
Resolution = 0.1 micron
XY translation max. speed = 5mm/sec
M stage ~ 0.5 kg
Spindle rpm > 10,000 rpm
Tool size = 10 mils and below
Micro milling Cutting force Fc = 100mN
(independent of feed rate)
Acceleration time ta = 1sec

$P_{r\text{-cutting}} = (F_{cut})^2 / M$; based on cutting force
$P_{r\text{-cutting}}$ = 0.5 * 10-2 W/sec

$P_{r\text{-load}} = (M_{load} * a + F_f) * a$; based on inertial load
F_f being friction forces; assumed 0.1N
$P_{r\text{-load}}$ ~ 0.5 * 10-4 W/sec (smaller than cutting power rate)

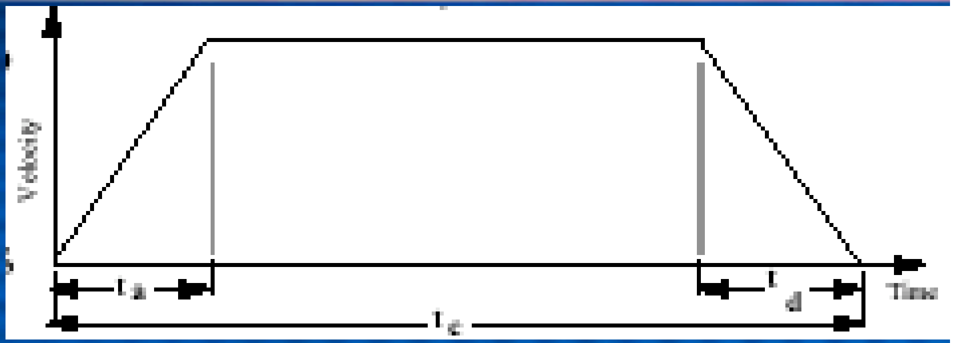
Case study contd.

Now

$P_{load} = P_{r\text{-}load} * t_a = 0.5 * 10^{-2}$ W

$P_{motor} > 2\ P_{load}$

$P_{motor} \sim 10^{-2}$ W



For a lead screw carriage system, □ = 6 x 10 ^ 4 x V_{load} / L

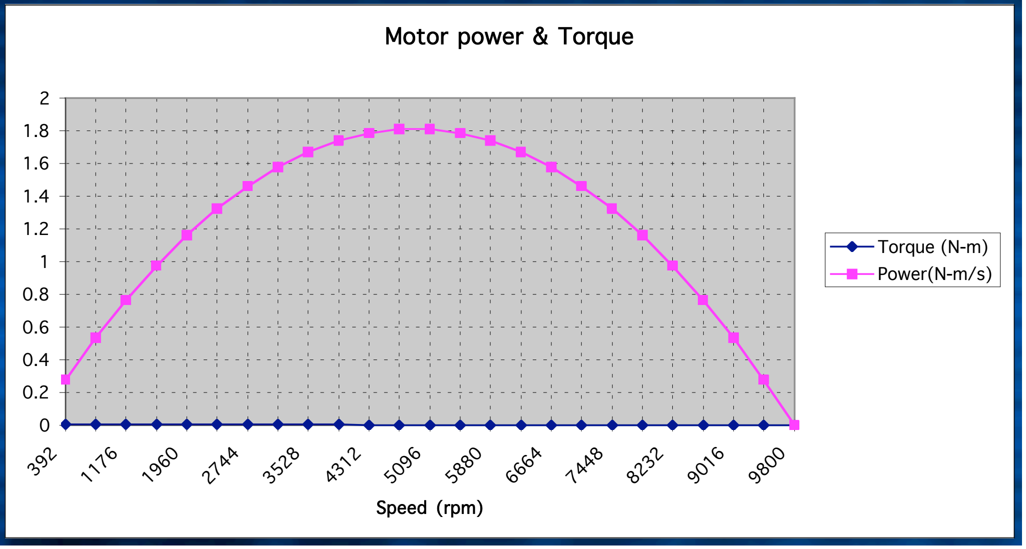
where L (mm/rev) is lead screw lead.Let L =1 mm/rev

□ = 300 revolutions / minute

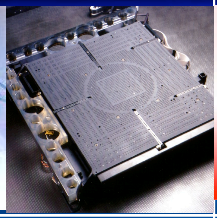
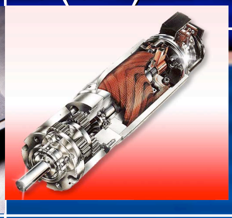
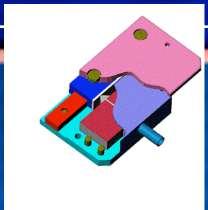
From plot, torque roughly

6.77 mN

Motor power-speed torque plot can be made.



Actuator matrix

Size	Piezo O(cm- mm)	Solenoids O(cm)	Stepper O(cm)	DC/servo O(cm)	Ultrasonic piezoO(cm)	Hybrid	Airmotor O(cm)
							
range	O(um) Usually motion amplified	O(mm-cm)	Dependent O(cm - m)	Dependent O(um- m)	O(mm)	O(mm)	Dependent O(cm-m)
resolu tion	nm resolution	Binary usually	micron	nm with lead screws	nm resolution	nm	microns
force	High O(50N)	O(50 N)	medium	medium	Medium-low	high	high
stiffne ss	Very high	High, sharply falls with x	medium	medium	low	high	-
Power density	low	Medium-high	Medium-high	Medium-high	low	low	Very high
risk	Amplification hard ; high voltages; small range	Force falls with distance	heat produced ; thermal isolation of machine	Thermal isolation	Low stiffness;	-	High pressures
cost	High	medium	Medium-high	-	high	high	medium