Riccardo DeSalvo - VIRGO

Talk - LIGO Science Meeting

Tues. Sept. 23rd 1997

LIGO-G970256-00-D

Precipitation hardened steel

ESTIMATION OF RESIDUAL CREEP

With Maraging observe the creep speed

to increase x 30 for 10°C rises

Bake blades under stress at >= 80°C for a week

Observe creep at < 1 μm / day @ 80°C

Observe creep at < 50-100 nm / day @ 65°C

Estimate residual creep at < 1 nm / day @ 20°C

1 Crystal slippage / day

Most residual creep may be due

to pure dislocations

(slippage under threshold)

Non Stochastic Noise (NSN) sources

all sources that inject energy

in the interferometer

in a non controlled non thermal mode

Generate events

outside the exponential noise distribution.

A) Internal sources

B) Couplings to outside world

NSN Sources

A) INTERNAL

Creep noise on wires and springs

Thermal movement noise and upconversions

Cabling problems — mechanical noise
- contact noise
- triboelectricity noise

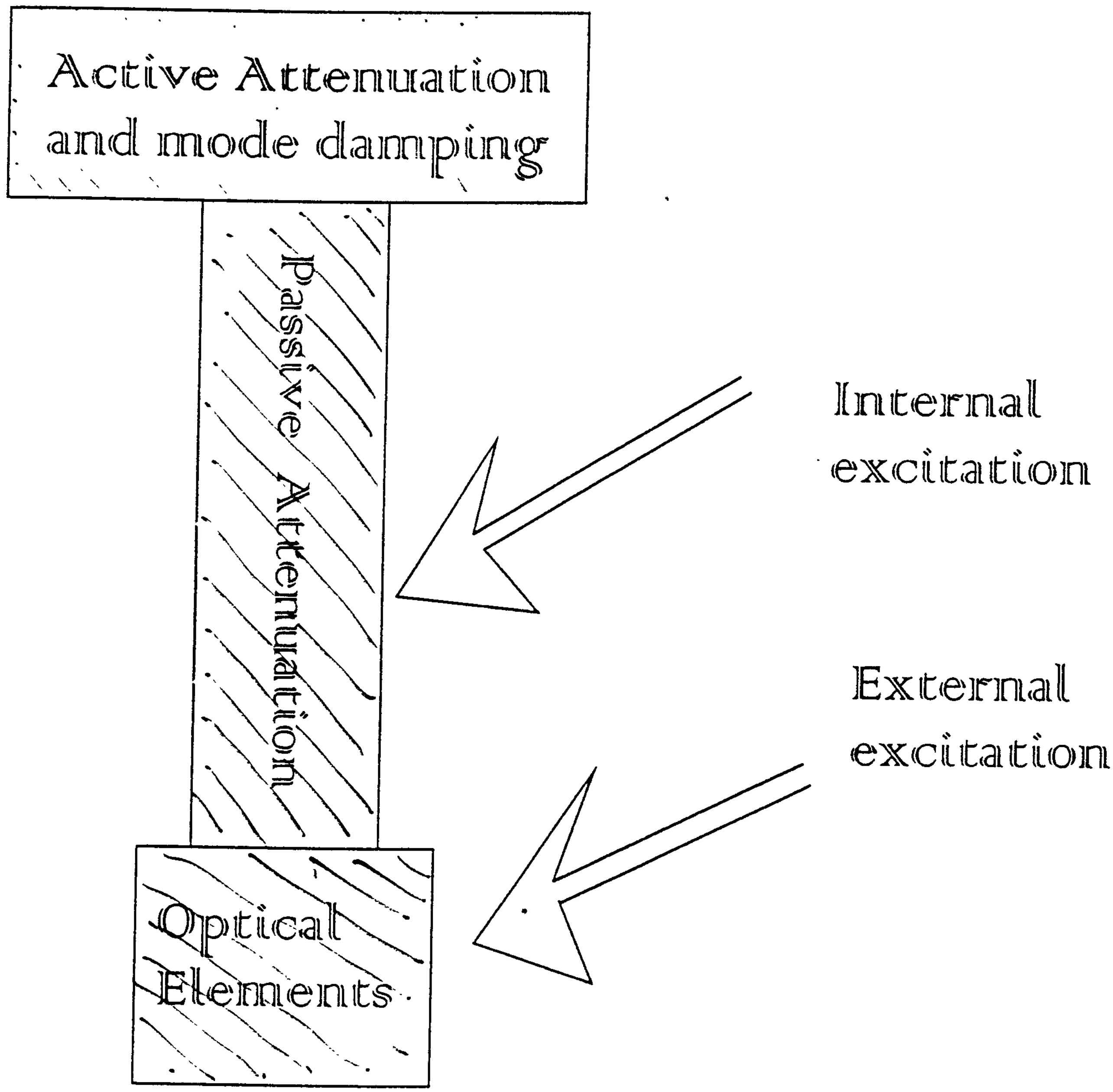
•

B) EXTERNAL COUPLINGS

•

•

•


Active Attenuation
and mode damping
Passive Attenuation
Internal
excitation
External
excitation
Optical
Elements

Creep noise

CAUSE

Dislocations inside single crystals

accumulate stress on

Crystal border **impurities**

EFFECT

Eventually will exceed stress yield point

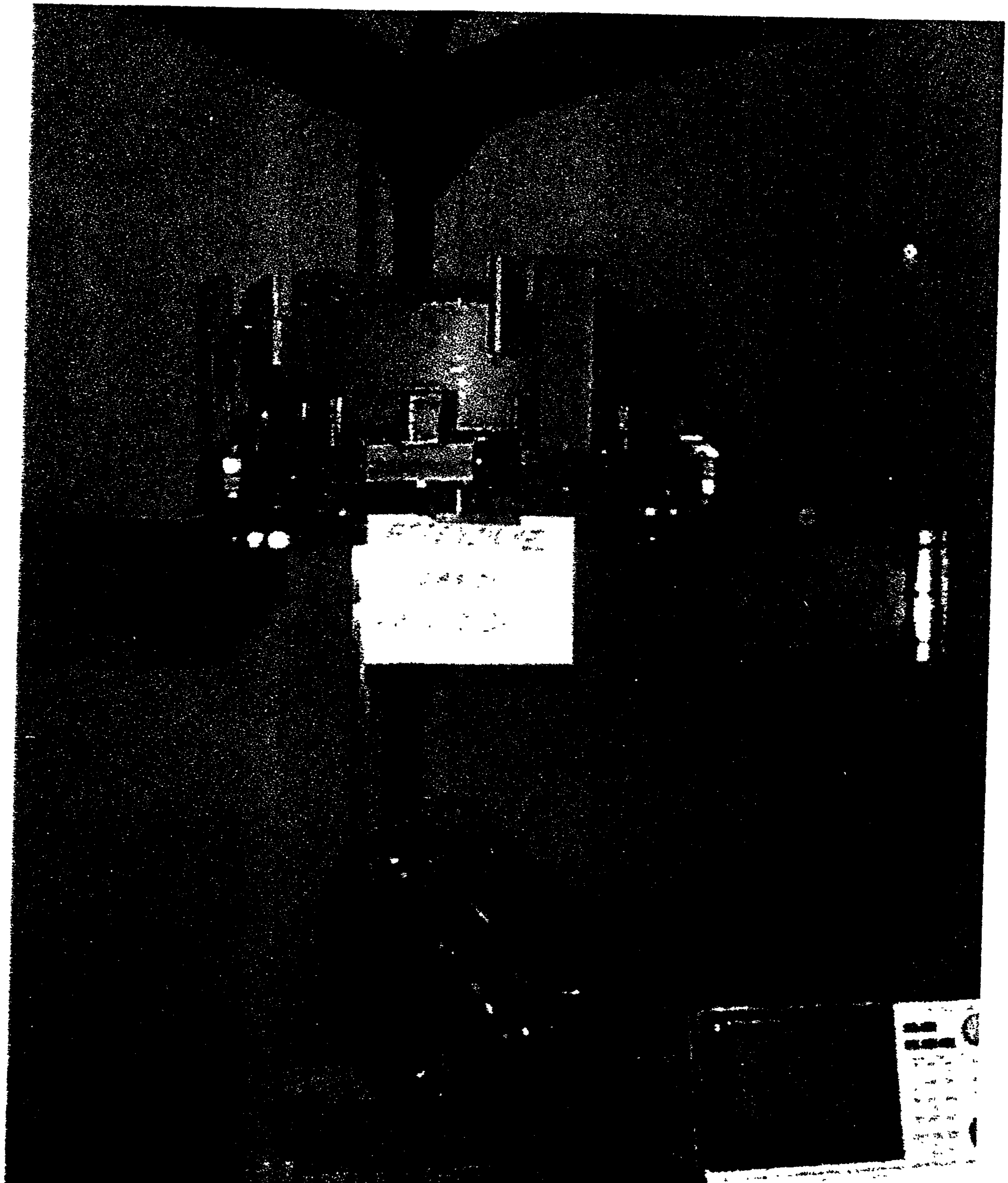
all crystals **will** slip

OBSERVABLE (MACROSCOPICALLY)

Integrated continuous motion.

OBSERVABLE (MICROSCOPICALLY)

JERKING MOTION



Creep noise

Energy releases in the S.A. chain

can generate nano-seisms

Suspended masses are inexhaustible reserve of energy

Consider Crystal slippage $\sim 10^{-9}$ J

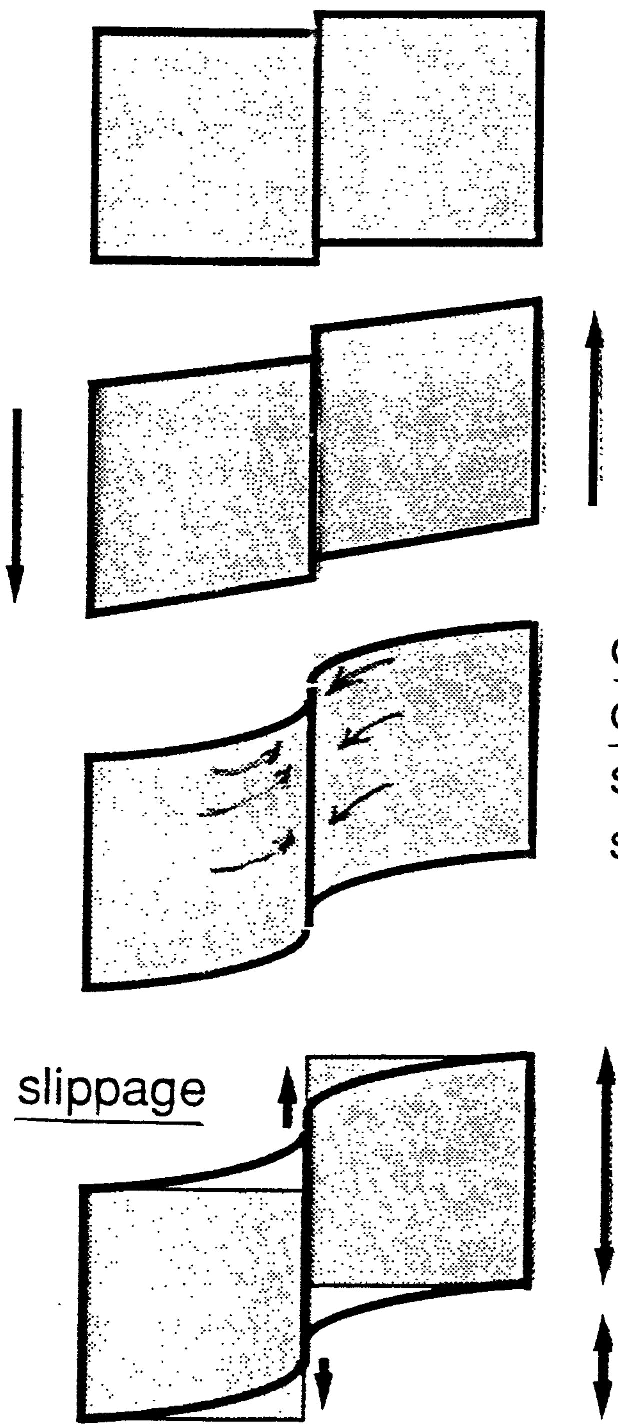
one single Crystal stressed near the metal yield point of the metal contains (and releases at slippage) energy equivalent to the dropping of the suspended optical component by **several pm**

A pico-meter is a **Mega-nano-nano-meter**

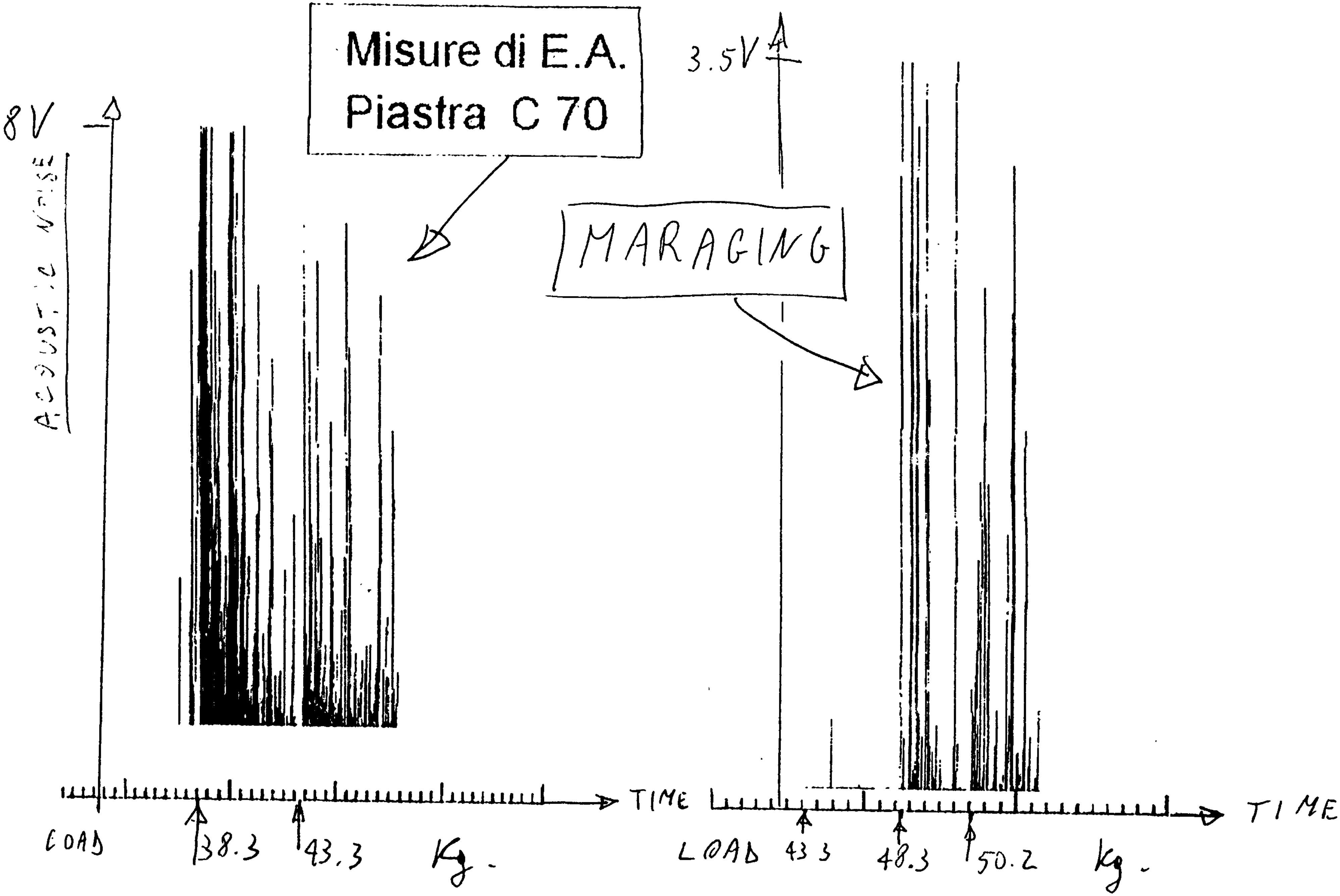
It's **the "big one"**

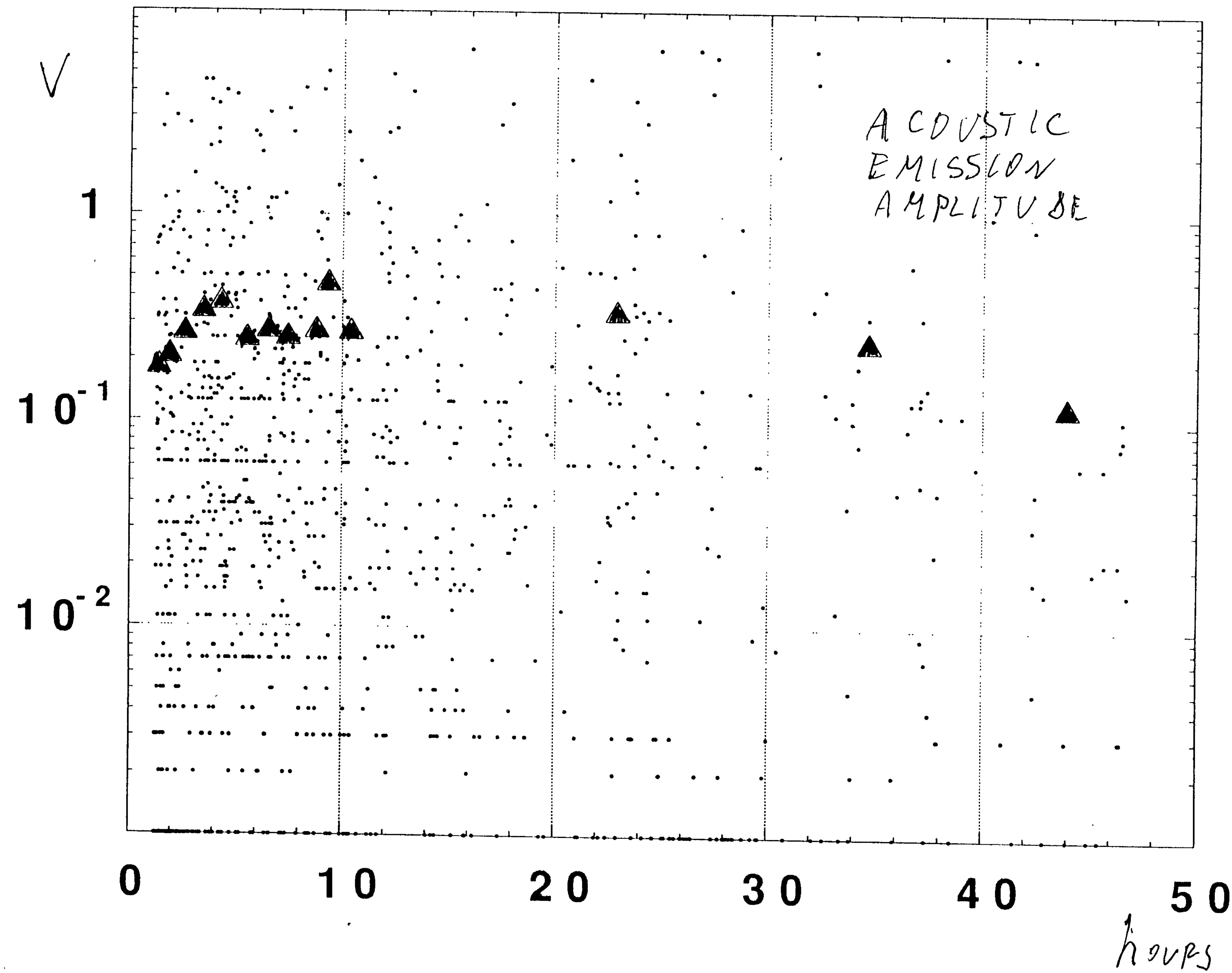
WE WILL GO
INSIDE ONE
OF THESE
5 μm
CRYSTALS

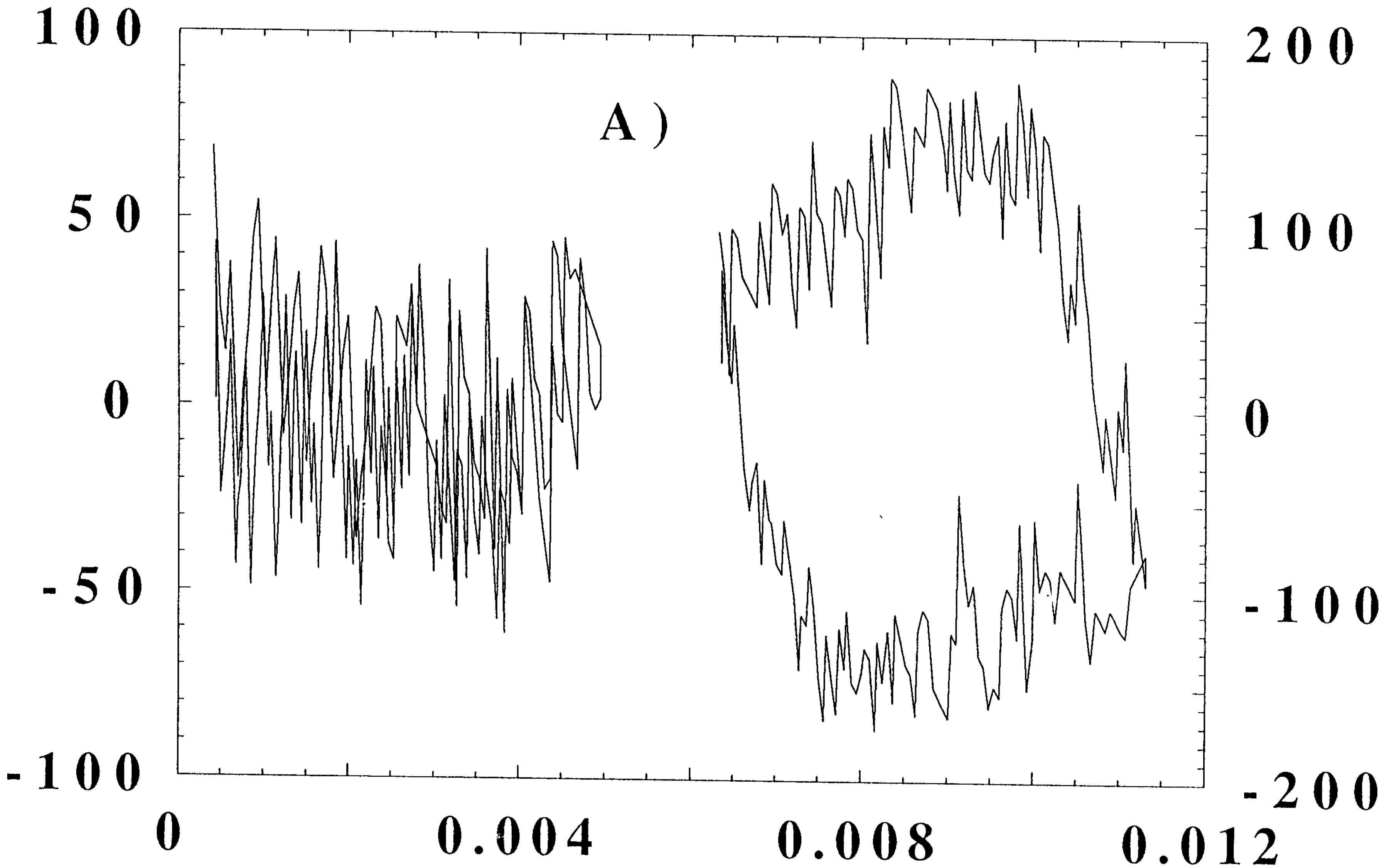
the creep noise mechanism

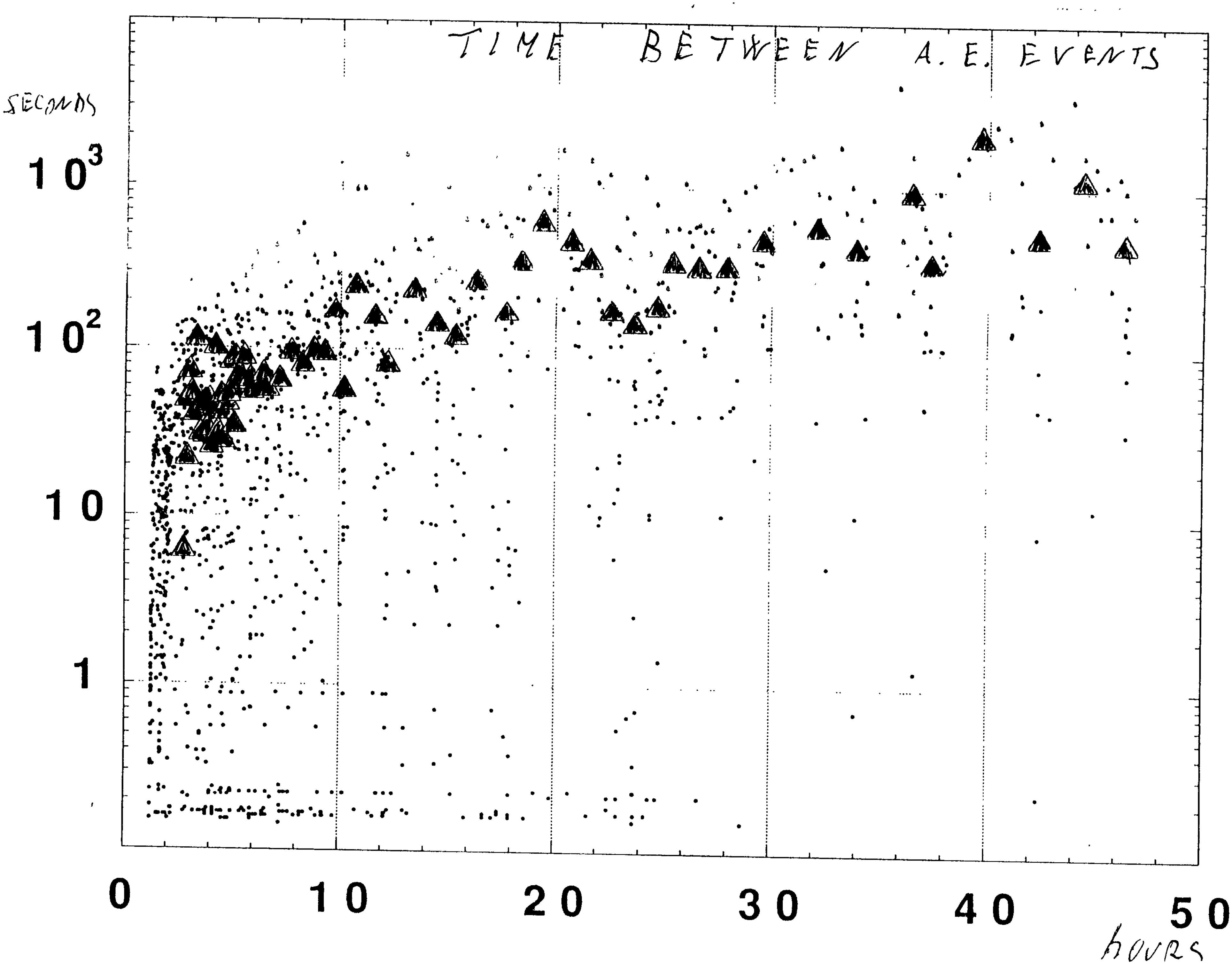


ACOUSTIC NOISE MEASUREMENTS

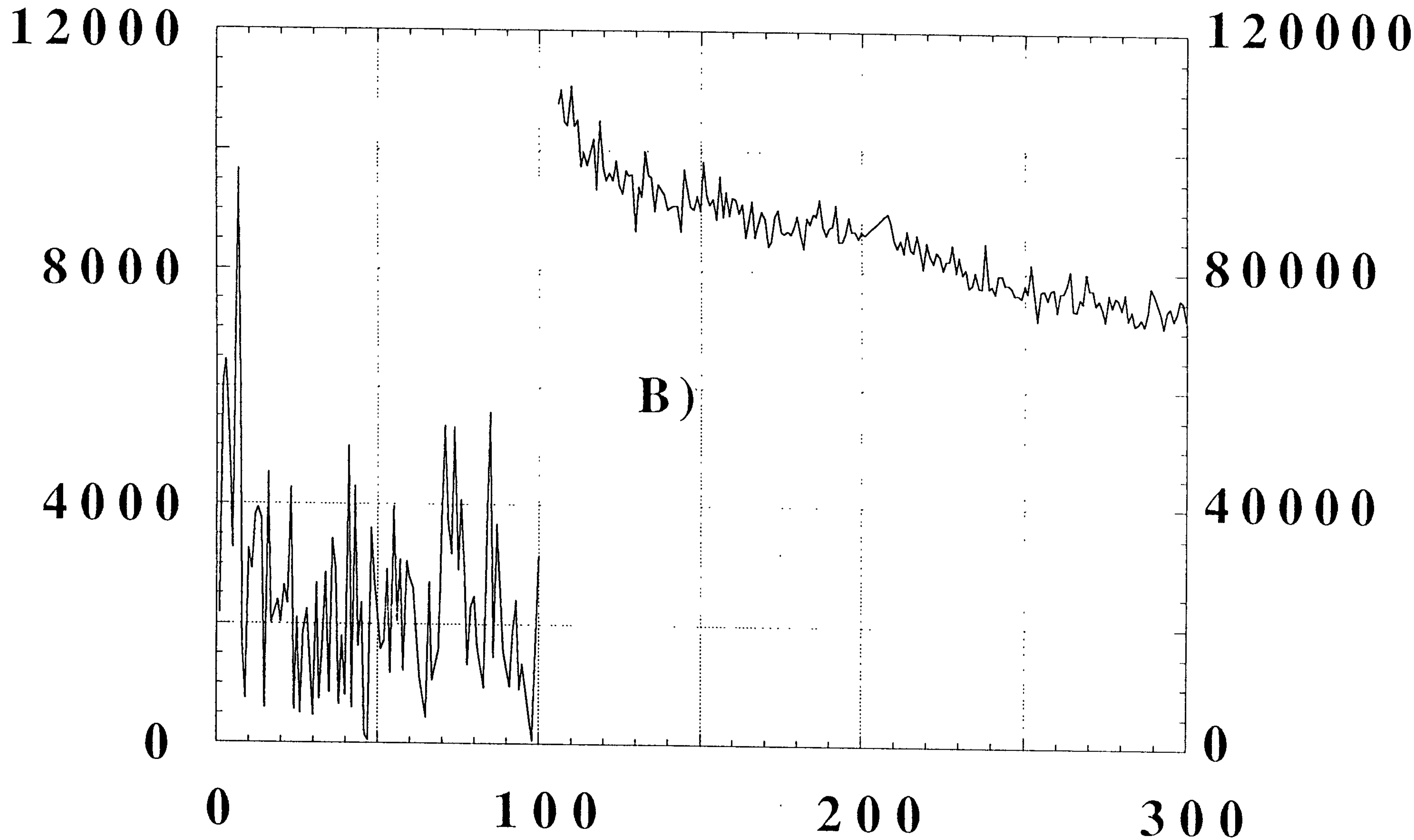



V
ACOUSTIC
EMISSION
AMPLITUDE
1
10^{-1}
10^{-2}
0
10
20
30
40
50
hours


A)
100
50
0
-50
-100
200
100
0
-100
-200
0
0.004
0.008
0.012



TIME BETWEEN A.E. EVENTS
SECONDS
10^3
10^2
10
1
0
10
20
30
40
50
hours



12000
8000
4000
0
120000
80000
40000
0
B)
0
100
200
300

NEED TO <u>ELIMINATE</u>

<u>THE SOURCE</u> OF SLIP

NEED TO <u>STOP</u> THE

<u>DISLOCATIONS !!</u>

Creep noise

The only ways out are:

a) Infinitely small crystals

(gain with d^3 but unfeasible)

b) frozen crystals

b1) freeze by cooling

b2) chemical freezing

Creep noise

Dislocations have activation energies

of few Kcal/mole

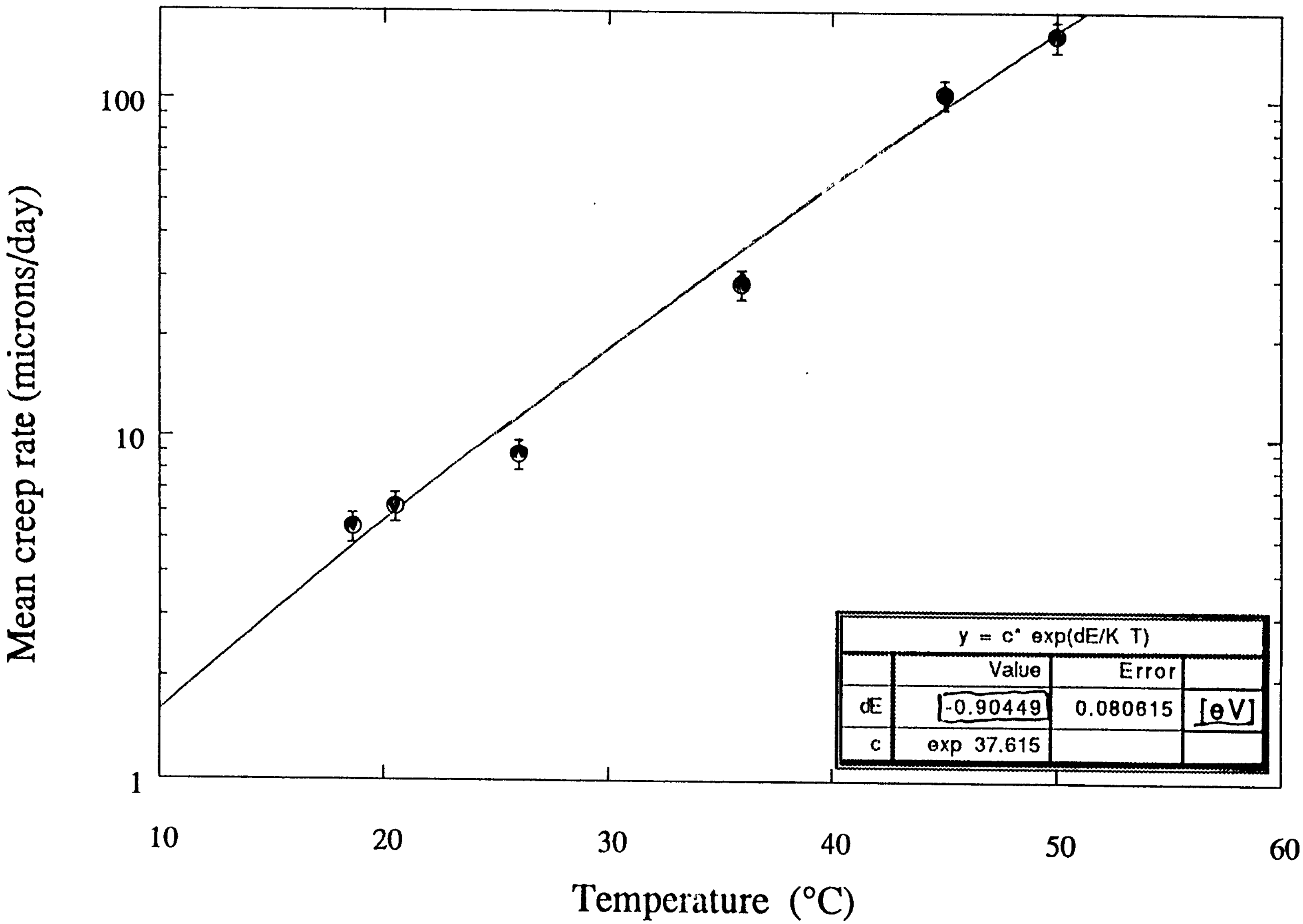
$$\text{Freq.}_{\text{slippage}} = \mathbf{n}\ e^{\frac{\Delta E}{KT}}\ (\mathbf{Bq})$$

Creep Speed **x 10** for $\Delta \mathbf{T} = \mathbf{5 - 20^{o}C}$

Creep speed is controlled by the temperature

AISI 1070 blade creep vs temperature

β CREEP (CONTINUOUS)



Creep noise

Freezing crystals by cooling

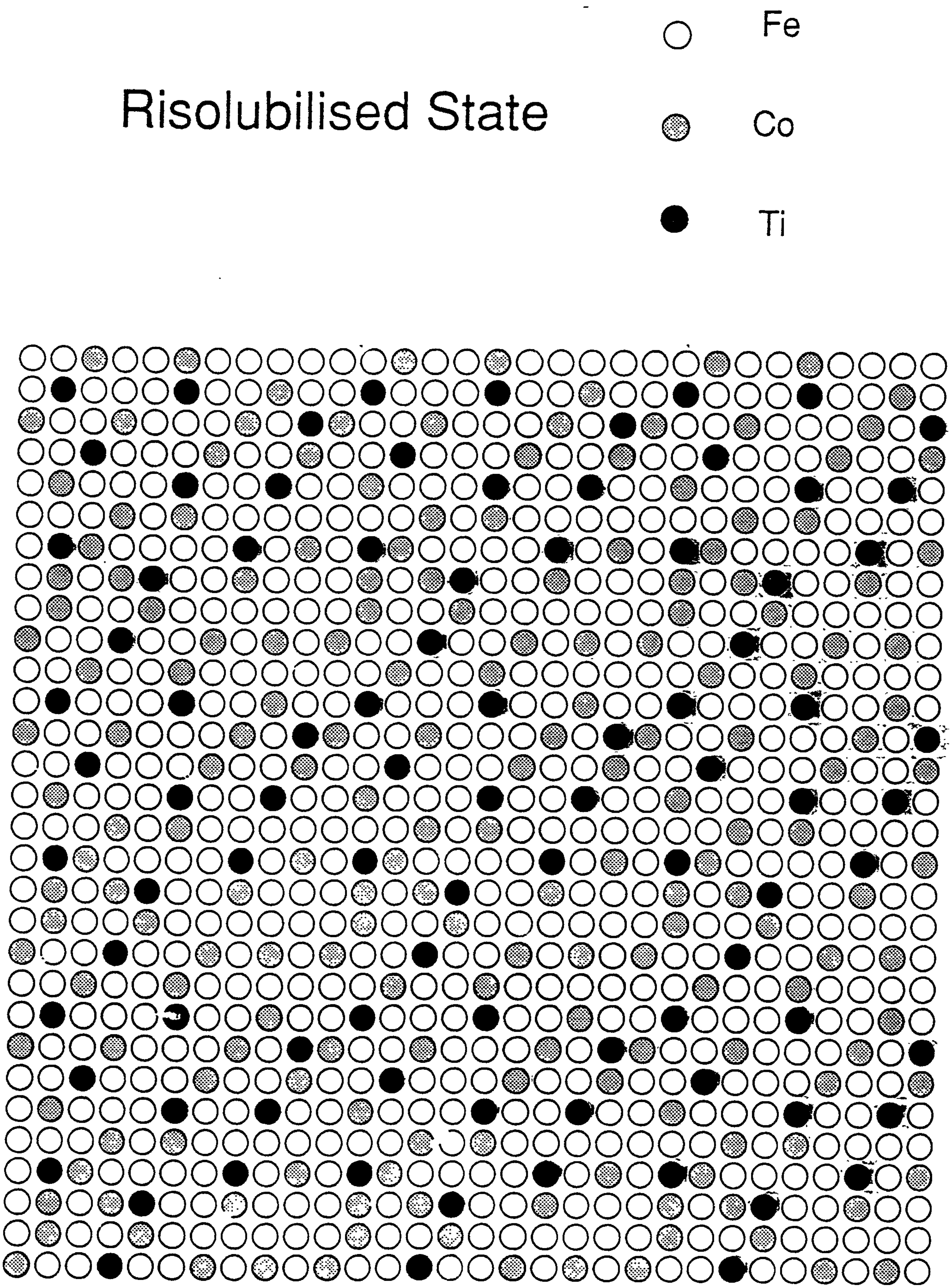
Metal brittleness

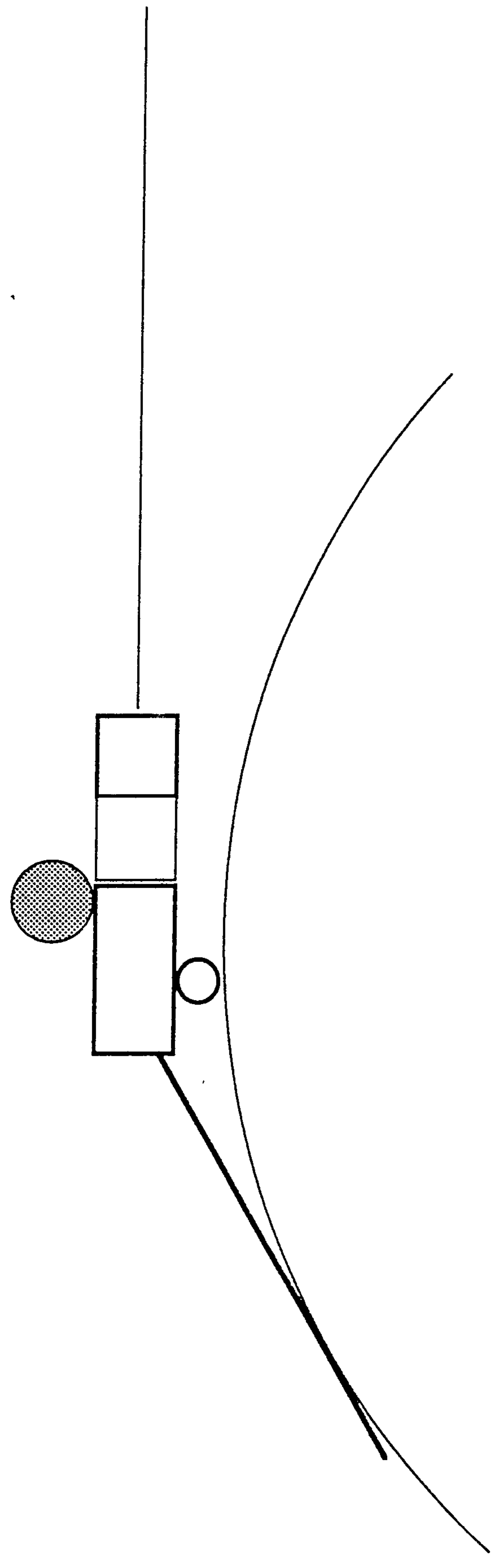
Spontaneous fracture

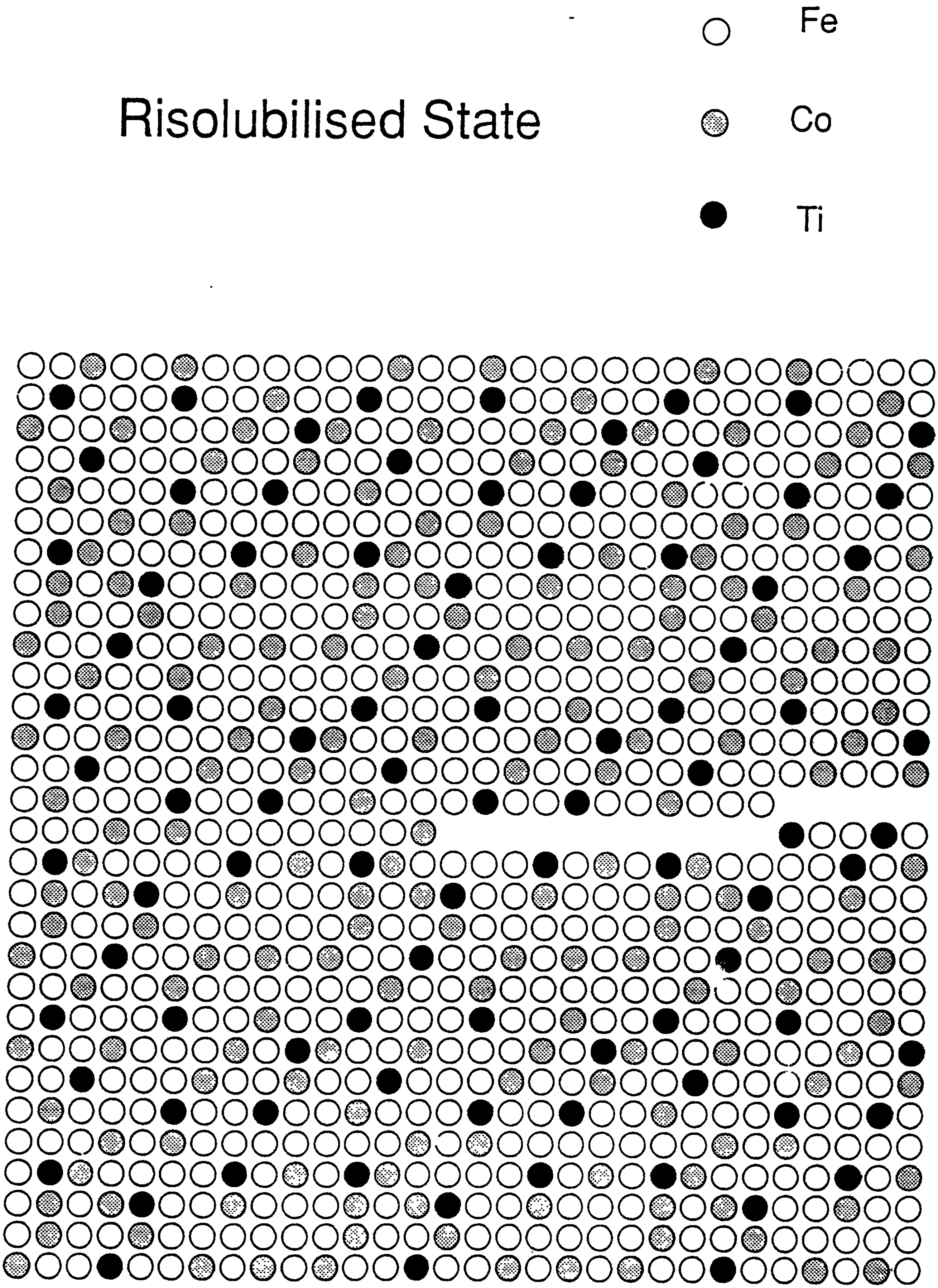
freeze only high ΔE dislocations

low ΔE dislocations can still move and

generate catastrophes


Risolubilised State
Fe
Co
Ti




Risolubilised State
Fe
Co
Ti

Creep noise

Chemical freezing of crystals

Precipitation hardened steel

Maraging

Fe	+	Co	+	Ni	+	Ti
[illegible]%		20%		10%		4%

High purity (no precipitation centers)

- Solution stable in Fusion

- Solid solution stable at > 850°C

-Solid solution thermodynamically unstable <450°C

in 10^{many} years would precipitate

Ti-Co nano-crystals inside Fe crystals

Precipitation hardened steel

Precipitation process is impeded

at room temperature

by lack of Co and Ni diffusion

inside Fe crystals

Solubilised form metastable at 20°C

At 450°C Fe Crystal are still stable but

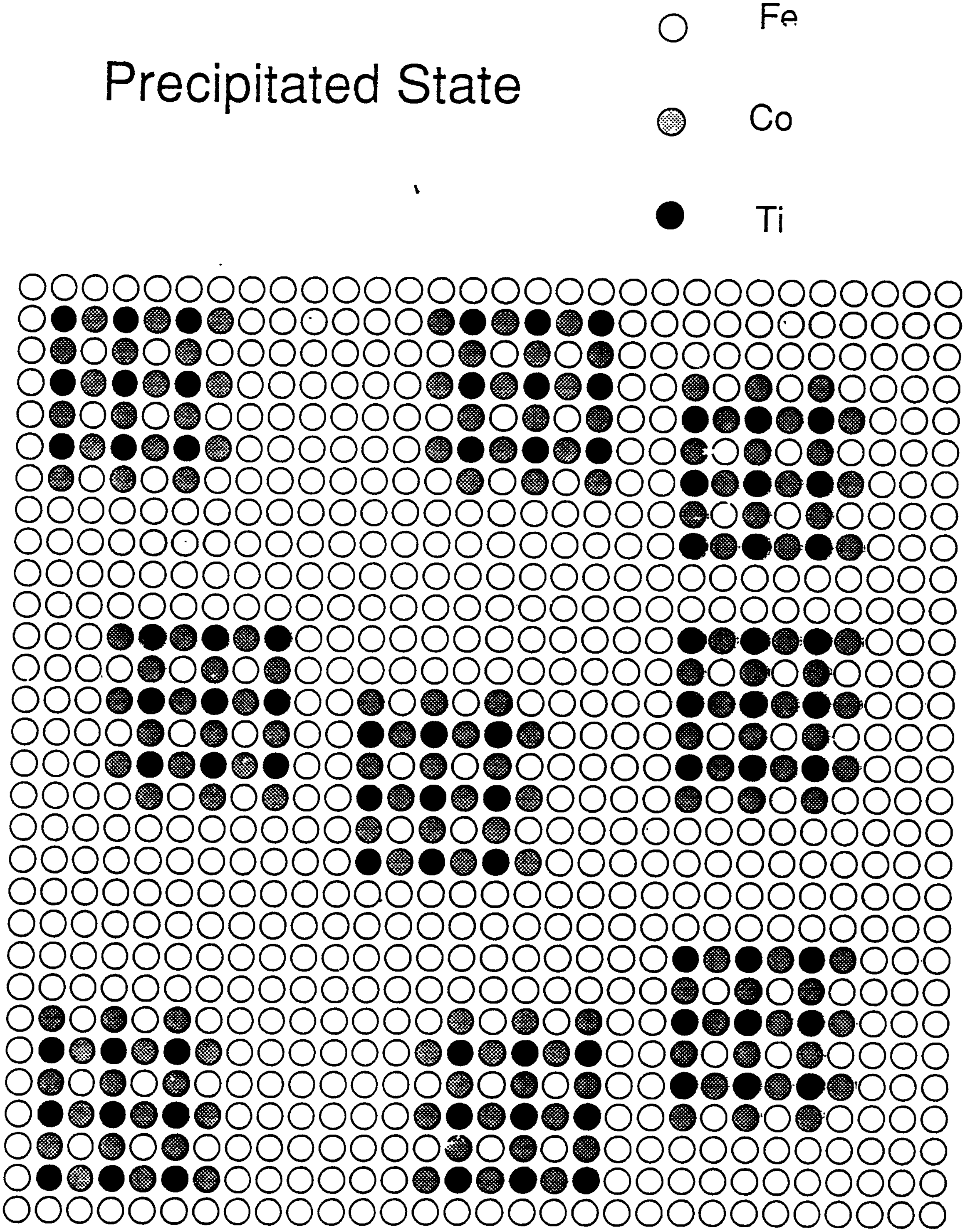
Co, Ti, Ni atoms can diffuse

typical diffusion distance 30 nm

Every 30 nm a nano-crystal forms inside the otherwise un-perturbed Fe Crystal

about 10^6 nano-crystals/Crystal

Precipitated State



Precipitation hardened steel

Nano-crystals inside crystals

form dislocation drift barriers

Dislocations are trapped throughout the Crystal

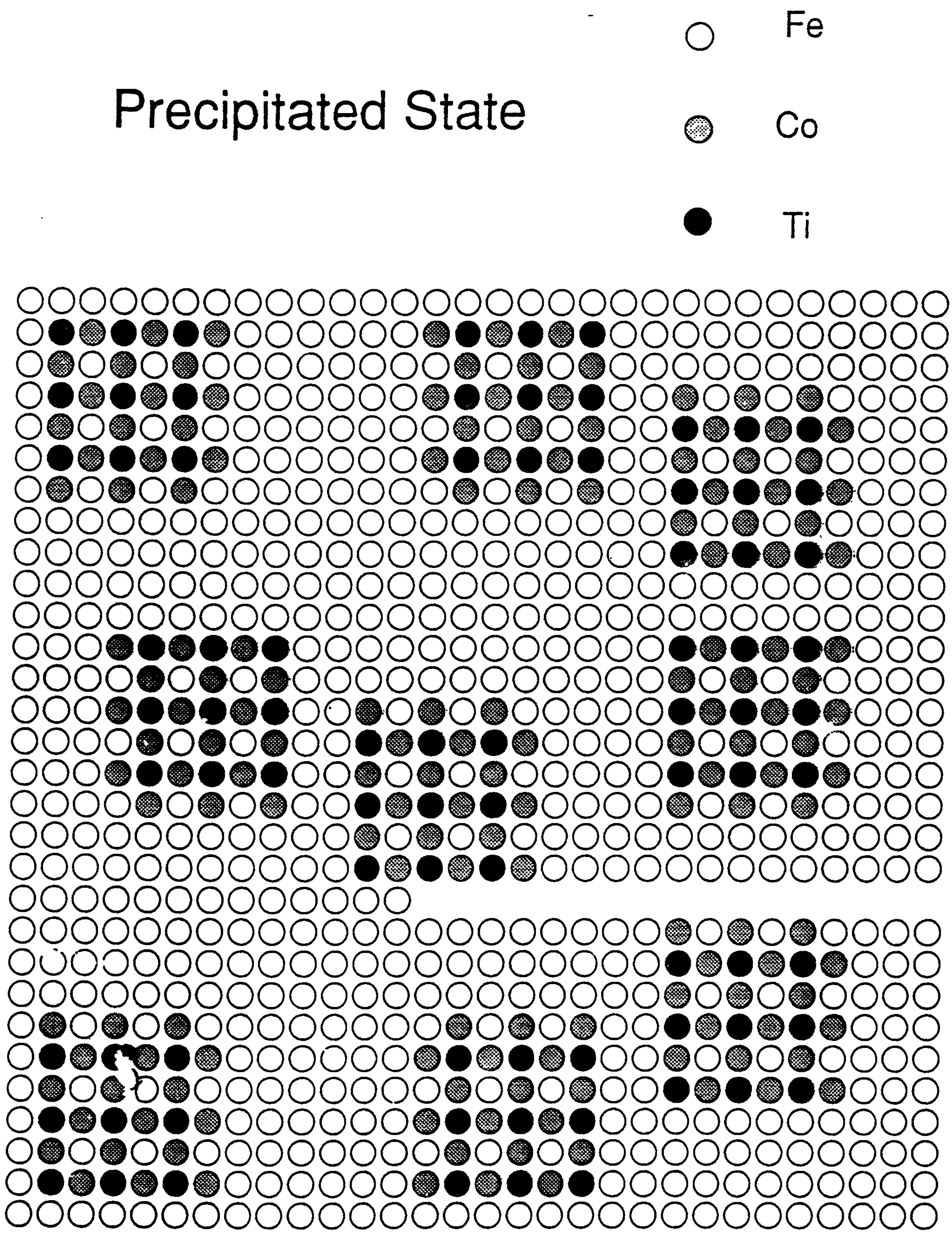
Dislocations impeded to reach the Crystal border

cannot trigger Crystal slippage

creep stops ! ! !

R. DeSalvo Amaldi conference 2/5 July 1997

Precipitated State



Precipitation hardened steel

After precipitation hardening, ∝ creep

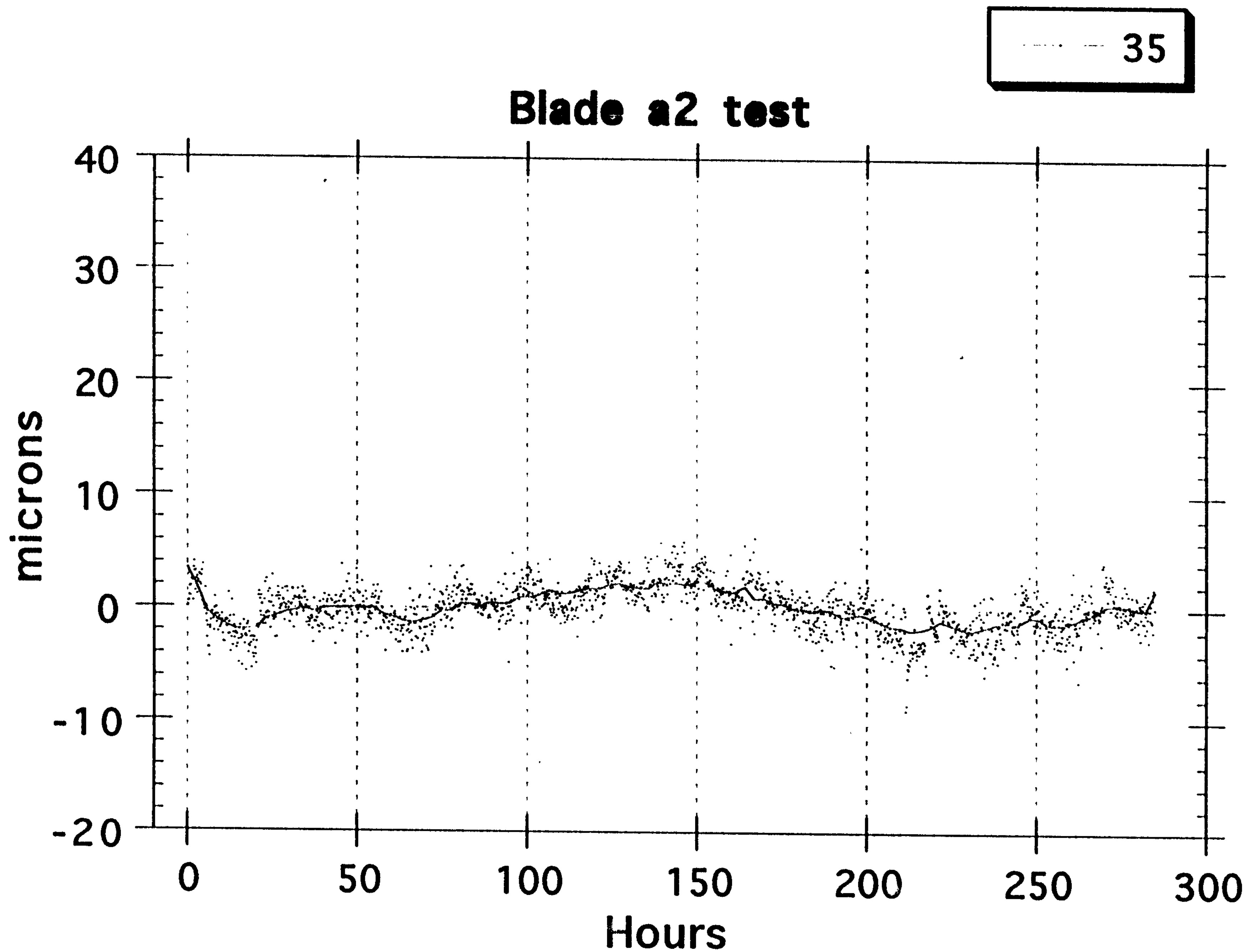
creep shows logarithmic behavior vs. t.

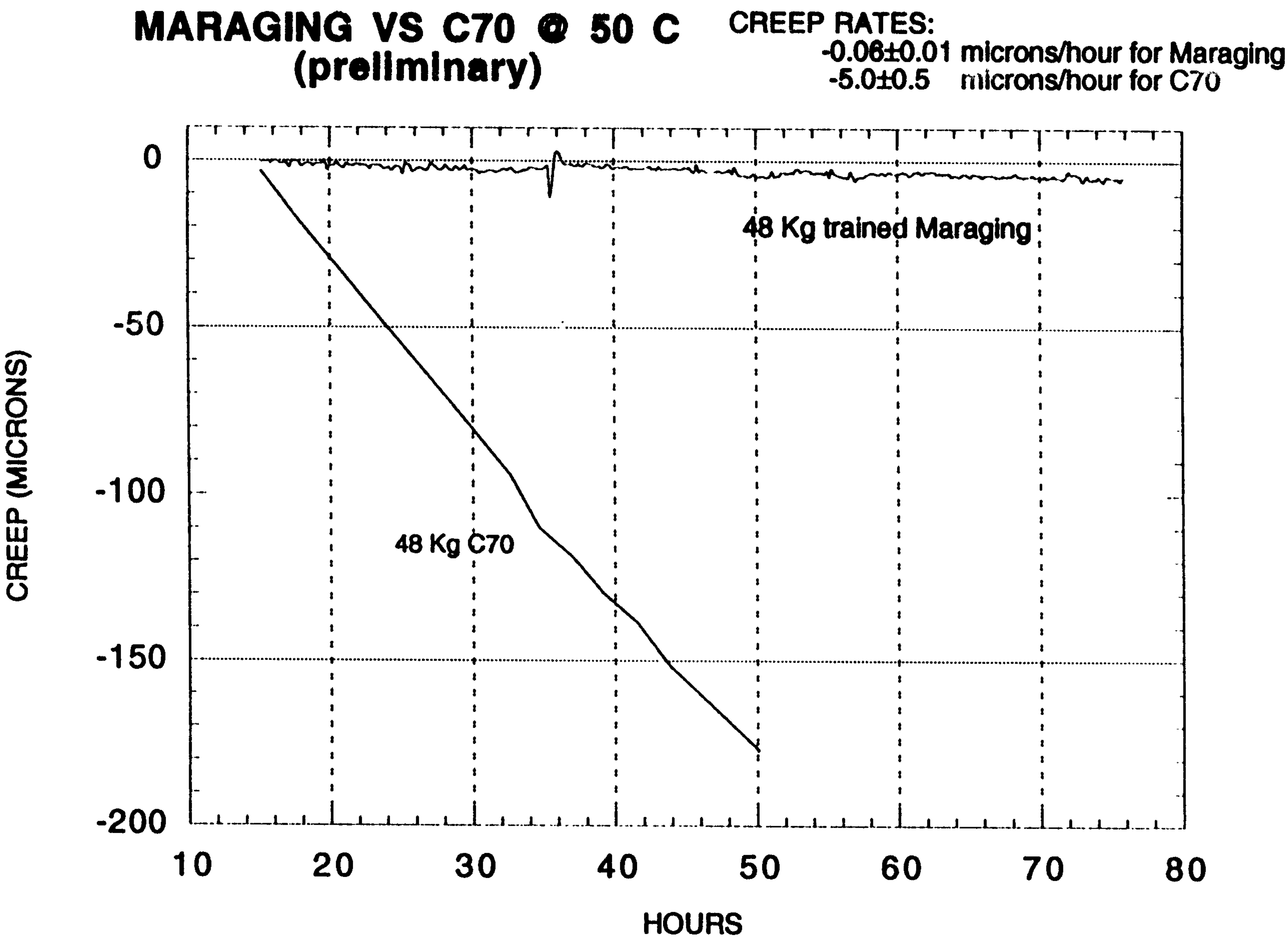
Given our measurement errors creep

can be directly measured at < 50-100 nm/day

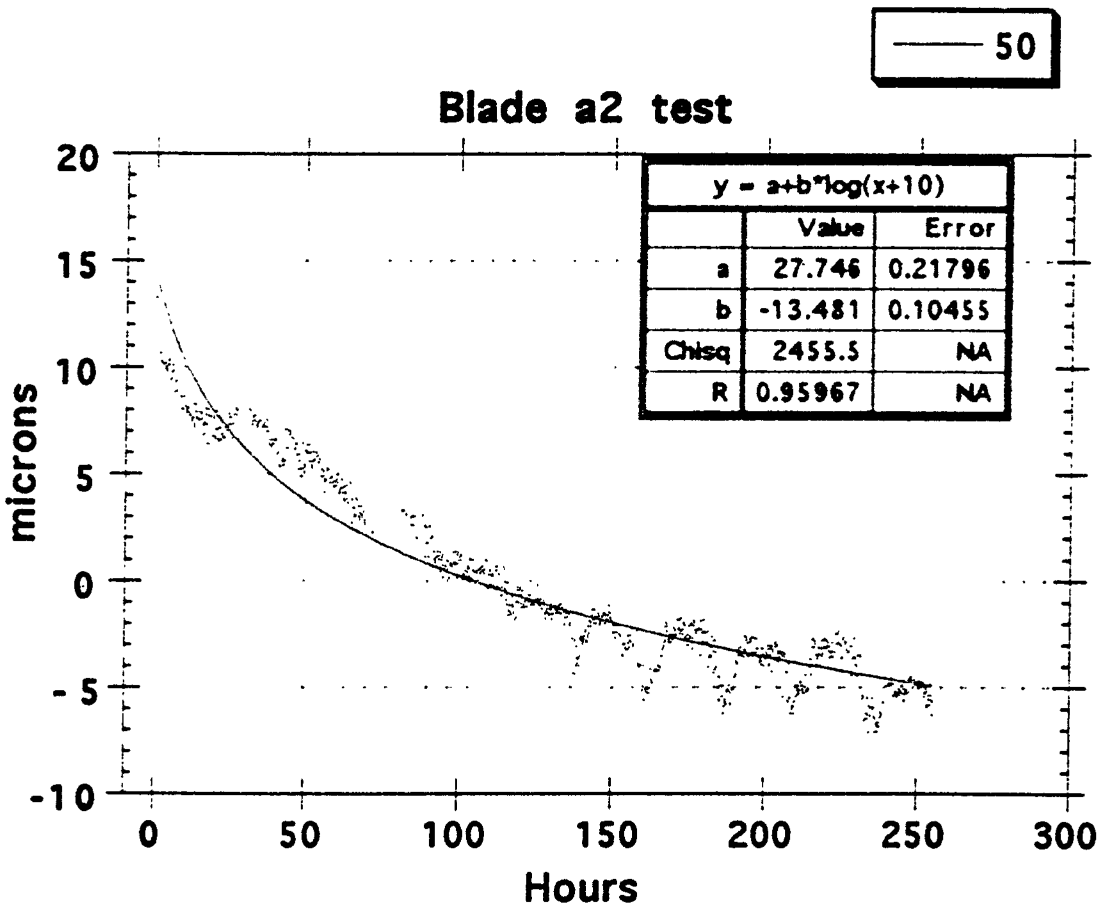
Need an indirect measurement.

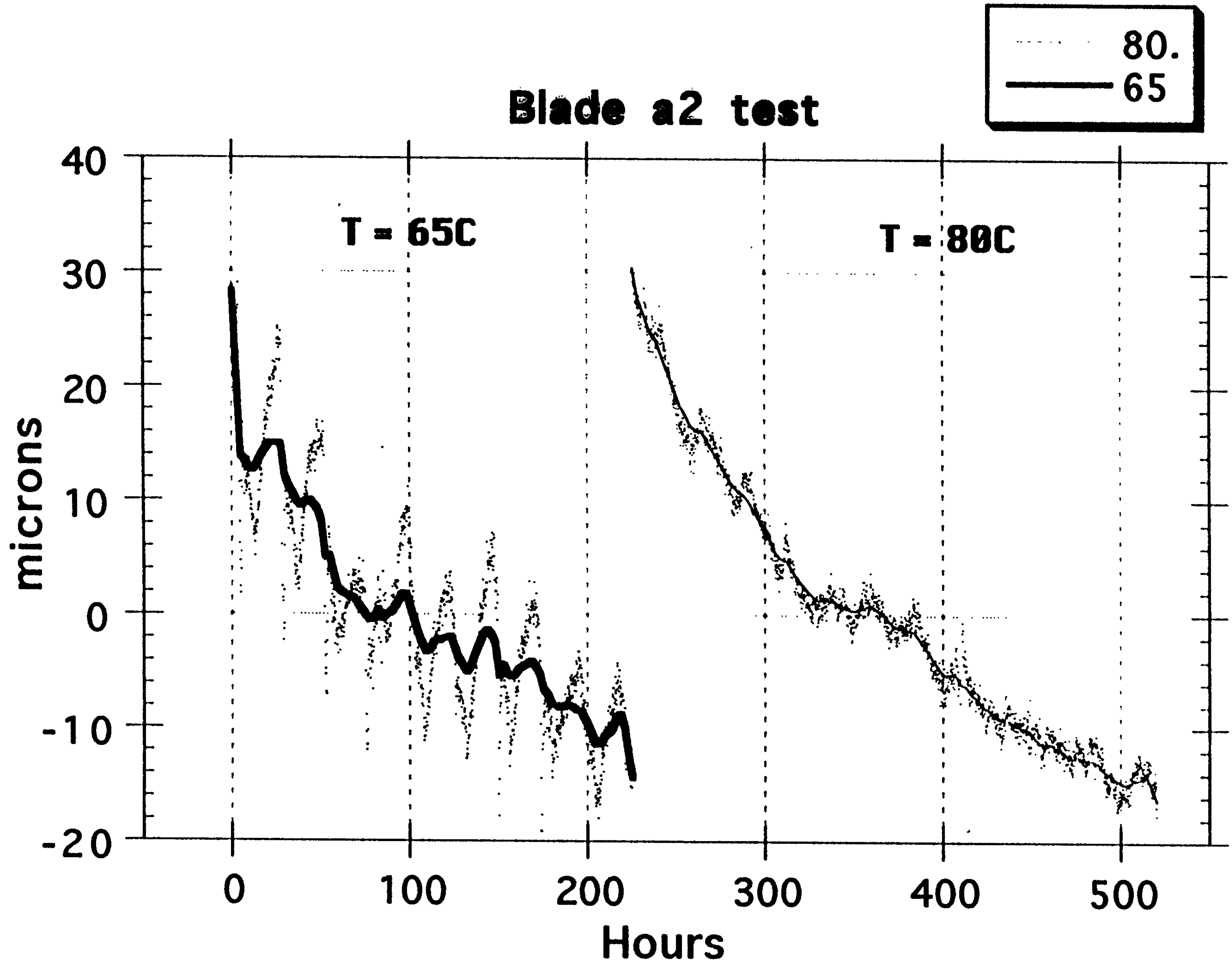
Need to guarantee much lower creep level


35
Blade a2 test
40
30
20
10
0
-10
-20
microns
0
50
100
150
200
250
300
Hours

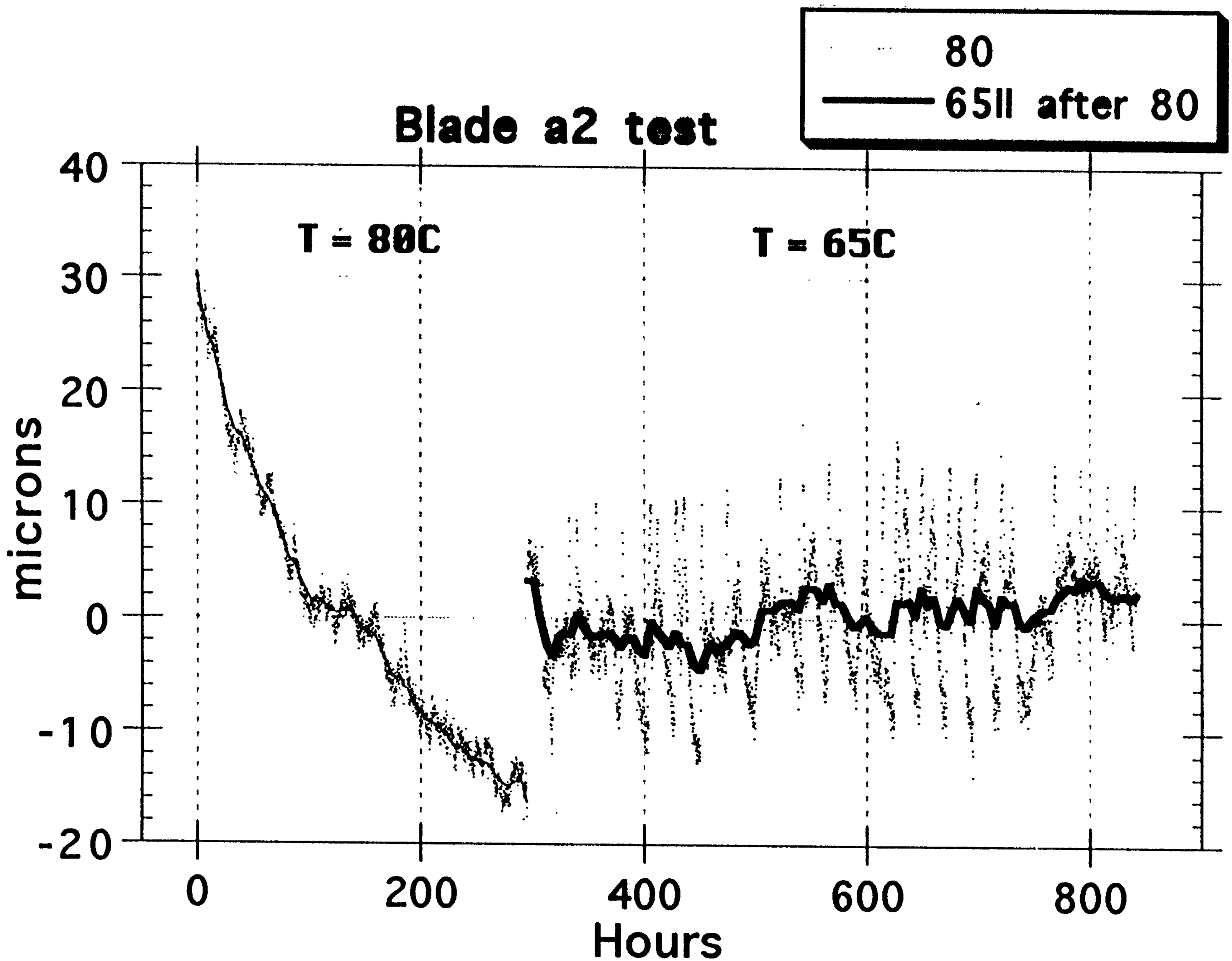


MARAGING VS C70 @ 50 C
(preliminary)
CREEP RATES:
-0.06±0.01 microns/hour for Maraging
-5.0±0.5 microns/hour for C70
0
-50
-100
-150
-200
CREEP (MICRONS)
48 Kg trained Maraging
48 Kg C70
10
20
30
40
50
60
70
80
HOURS


50
Blade a2 test
y = a+b*log(x+10)
Value
Error
a
27.746
0.21796
b
-13.481
0.10455
Chisq
2455.5
NA
R
0.95967
NA
microns
20
15
10
5
0
- 5
-10
0
50
100
150
200
250
300
Hours



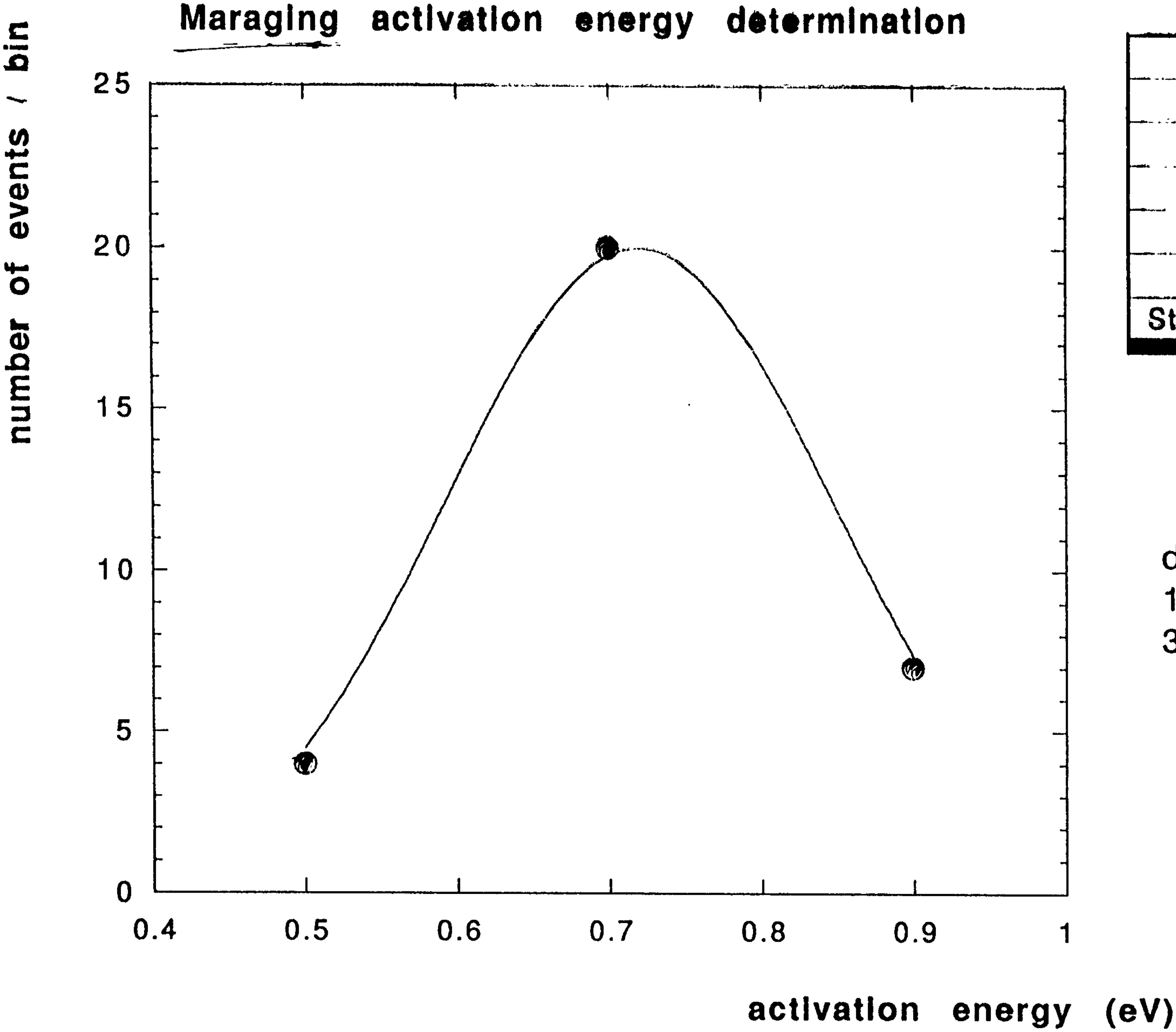
Blade a2 test
80.
65
T = 65C
T = 80C
40
30
20
10
0
-10
-20
microns
0
100
200
300
400
500
Hours



Blade a2 test
80
65ll after 80
T = 80C
T = 65C
40
30
20
10
0
-10
-20
microns
0
200
400
600
800
Hours

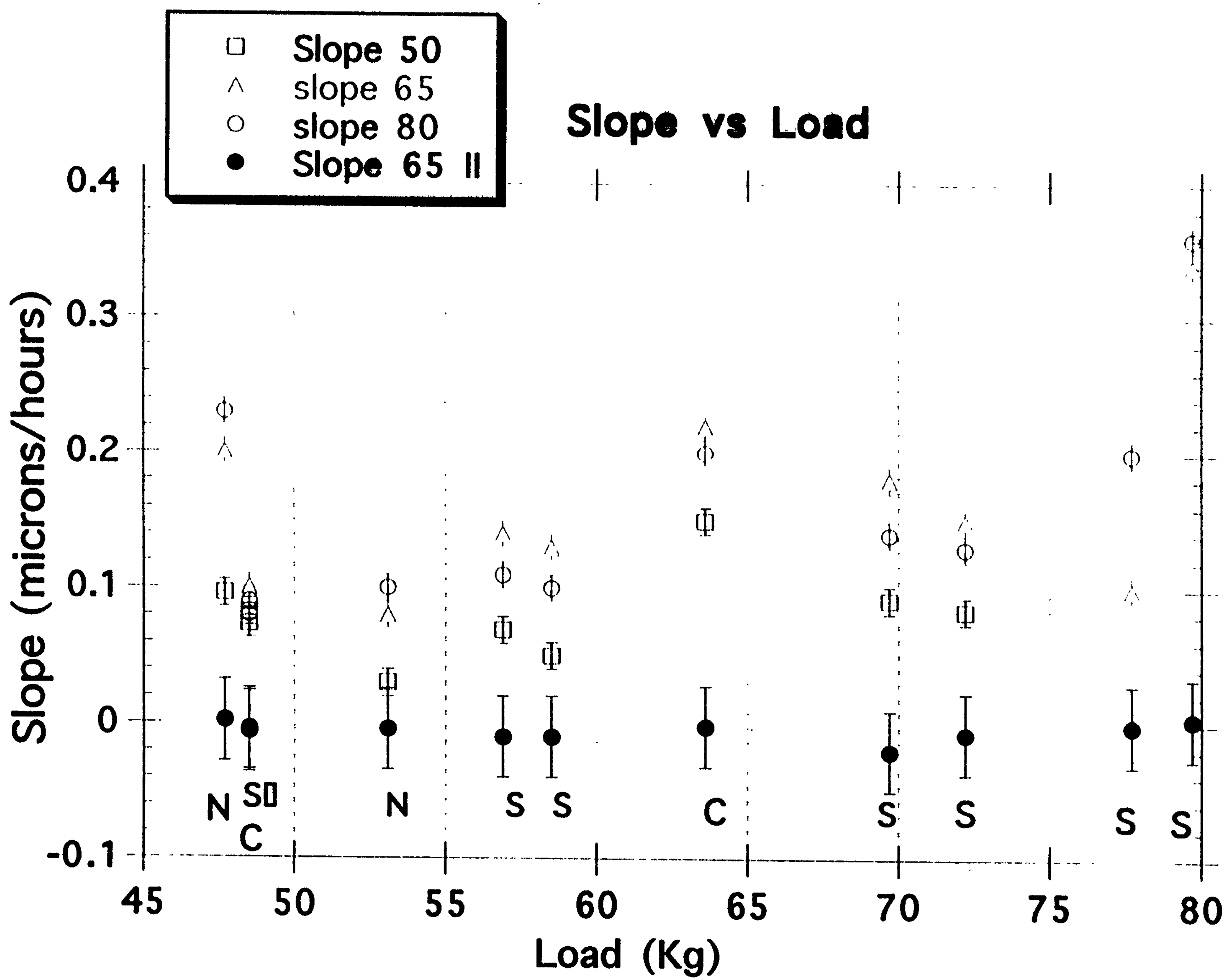
dL CREEP (LOGARITHMIC)

Maraging activation energy determination



	X
Minimum	0.51405948
Maximum	0.95582467
Sum	22.237414
Points	31
Mean	0.71733593 [eV]
Std Deviation	0.10820836

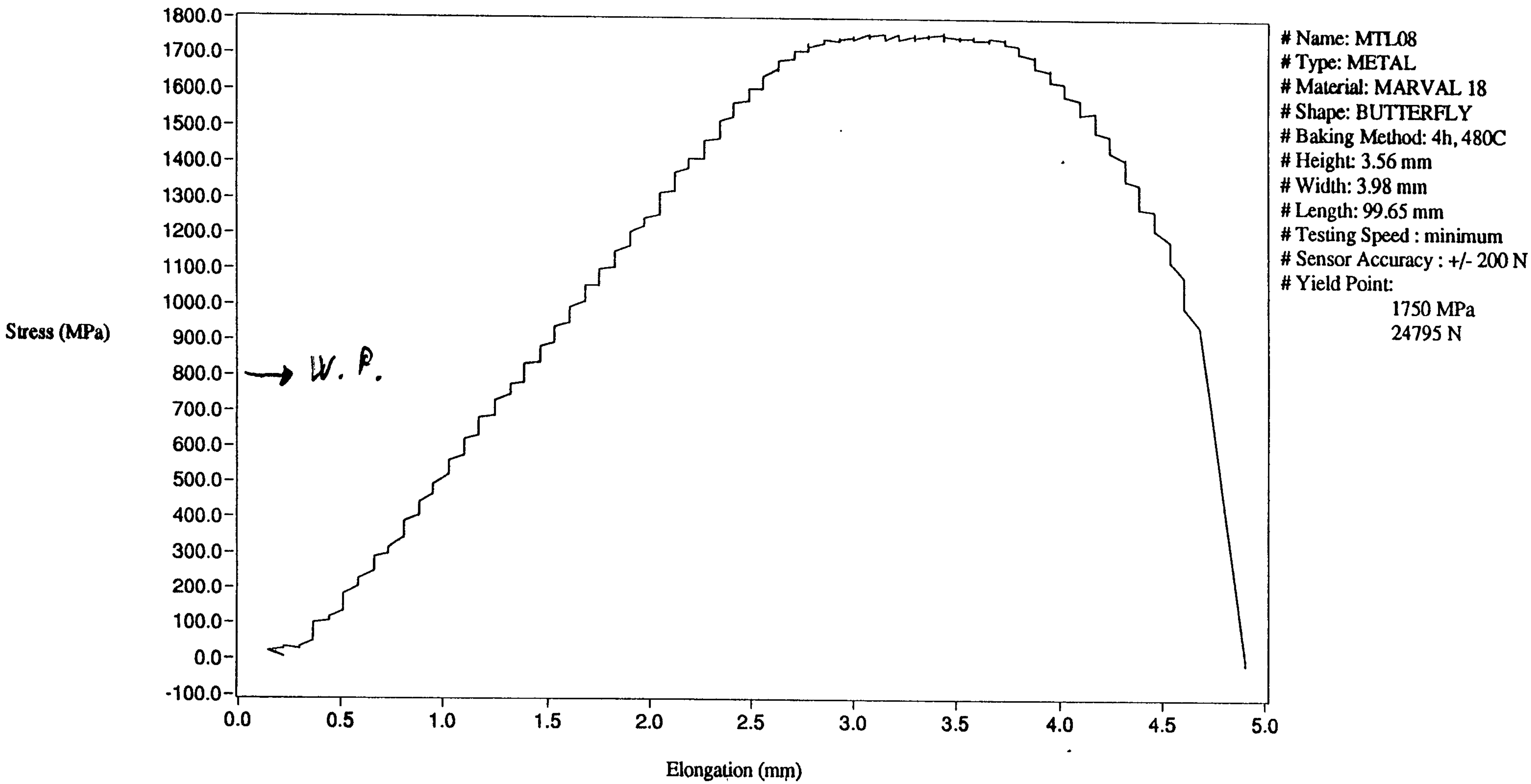
dE determination on
11 blades and
3 temperature steps

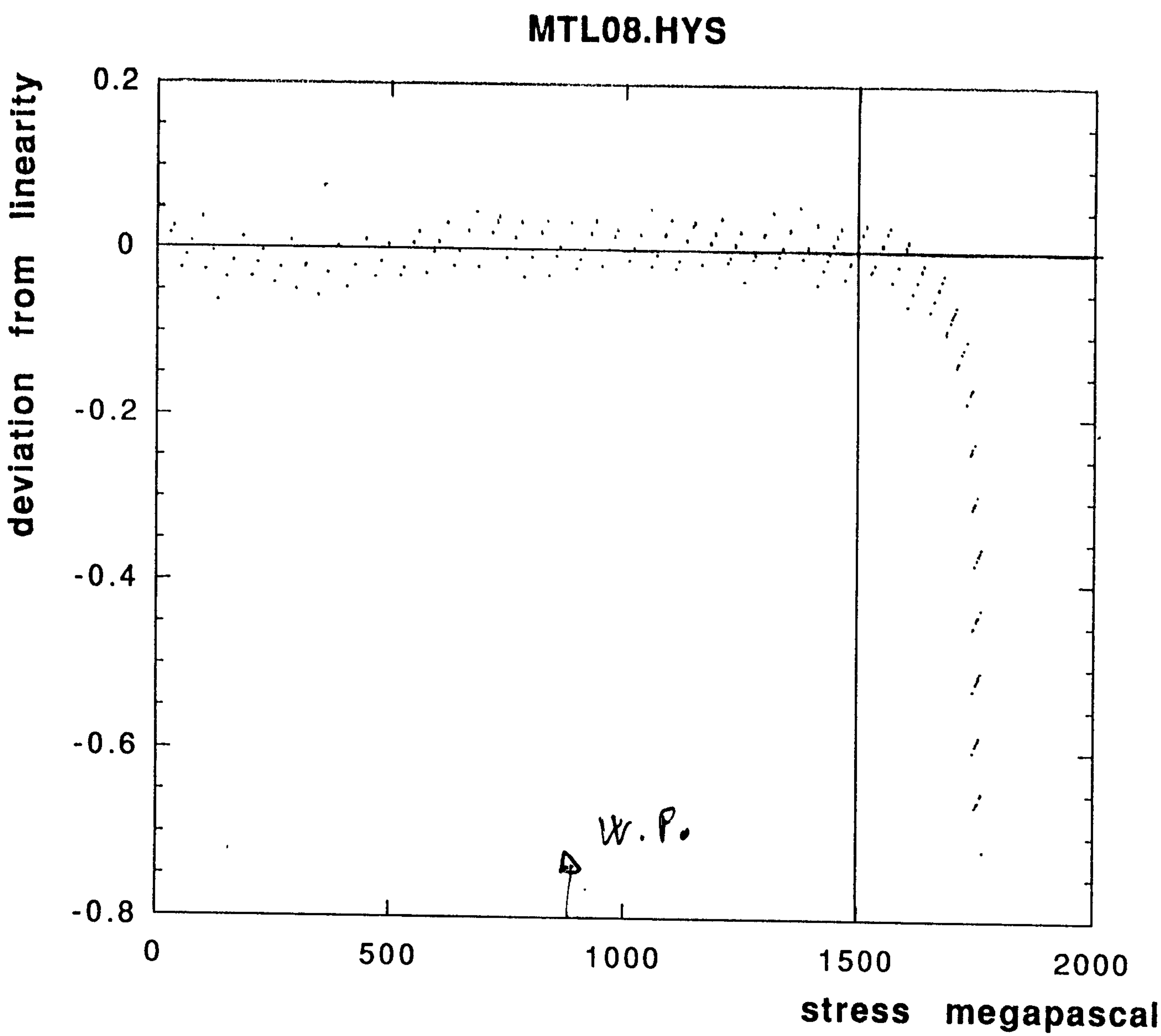


Slope vs Load
Slope 50
slope 65
slope 80
Slope 65 II
Slope (microns/hours)
Load (Kg)
0.4
0.3
0.2
0.1
0
-0.1
45
50
55
60
65
70
75
80
N
S
C
N
S
S
C
S
S
S
S

STAY WELL INSIDE OF
LINEAR REGION IN LOW FILTERS

Strain -Stress Curve




MTL08.HYS
deviation from linearity
0.2
0
-0.2
-0.4
-0.6
-0.8
0
500
1000
1500
2000
stress megapascal
W.P.

Defences against creep noise

A)

Maraging steel used in all stressed components

B)

>150°C baking of assembled attenuators

relieves excess stresses and

consumes all possible slippage

C)

If will detect problems with Virgo operation

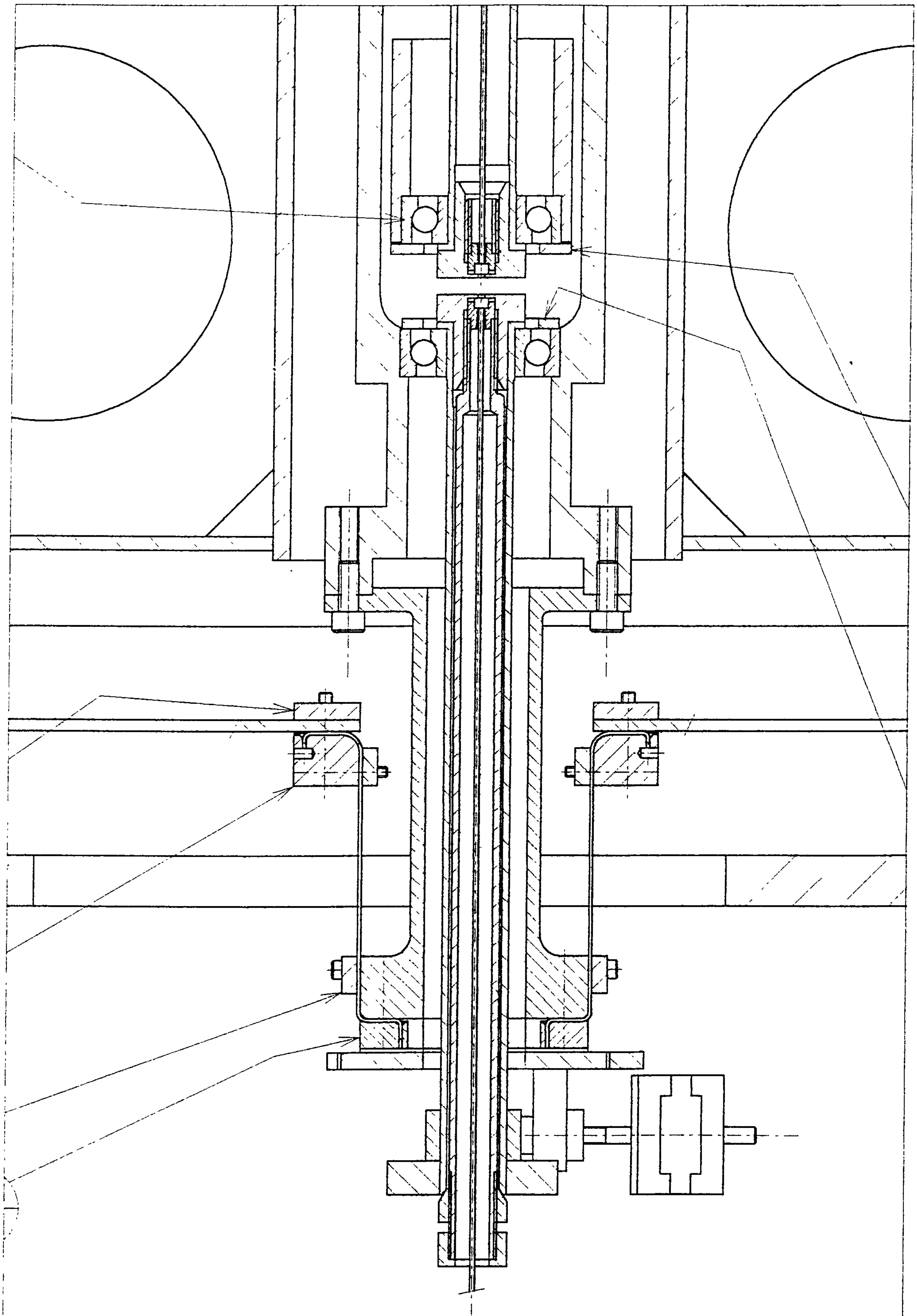
further safety factor by chilling

No low temperature brittleness with Maraging

DEFENCE AGAINST

CREEP LIKE NOISE

FIGHT AGAINST HISTERESIS



Thermal movement noise and upconversions

if quantised fraction is 10^{-6}

if thermostatisation < 10 m°K

and if creep like (10^{-12} m) steps

then thermal movement noise will generate

1 step / hour

but if quantised fraction is 10^{-5}

if thermostatisation < 100 m°K

then thermal movement noise will generate

100 steps / hour

Thermal movement noise and upconversions

Filter motions of 300 μm/°C

with a thermal stability of 10 m°K =>

3 μm motions with a time scale of 3 Hours

=> 1 μm/hour

MAGNITUDE OF THE PROBLEM

of this 1 μm/hour motion

what fraction is smooth?

what fraction is quantised?

10^{-3} ? 10^{-6} ? 10^{-9} ?

↑ > FROM Q

can expect :

- creep like steps
- larger steps (screeching noise)

Precipitation hardened steel

Additional comparisons between

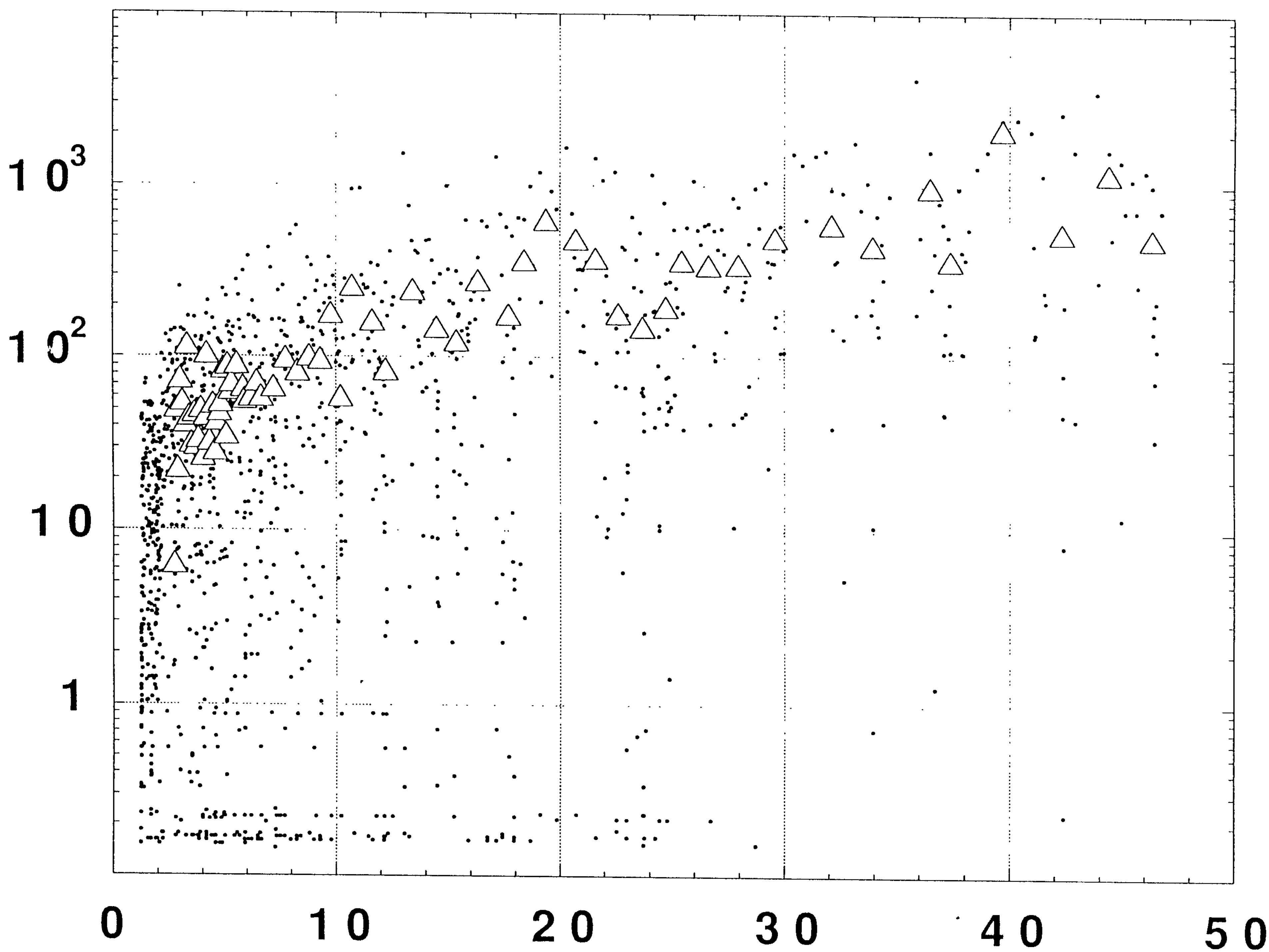
standard spring steel and

precipitation hardened steel

Comparisons of histeresis cycles on wires.

R. DeSalvo Amaldi conference 1/4 July 1997

figure isteresi su fili



10^3
10^2
10
1
0
10
20
30
40
50

observed after this initial cycle.

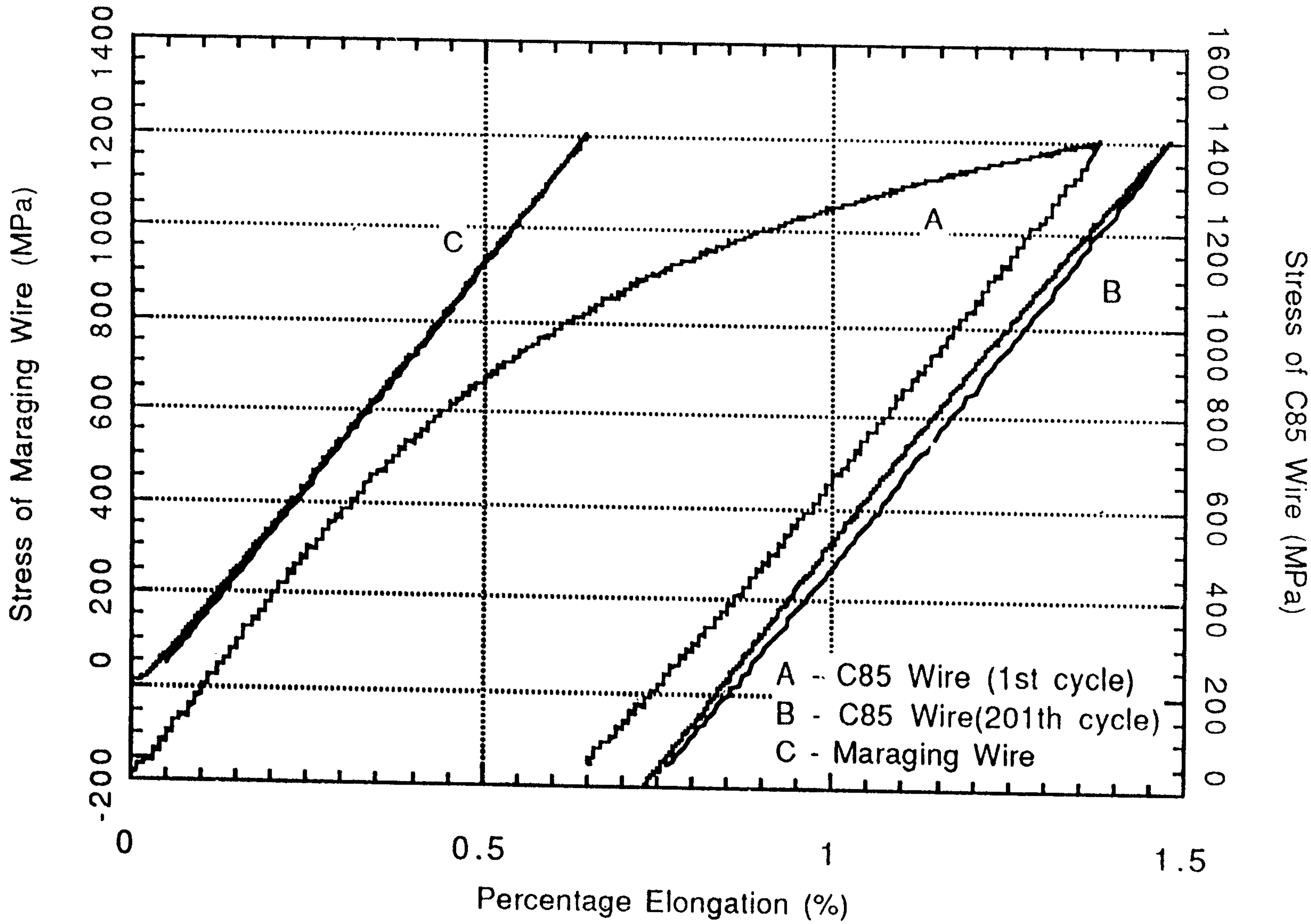
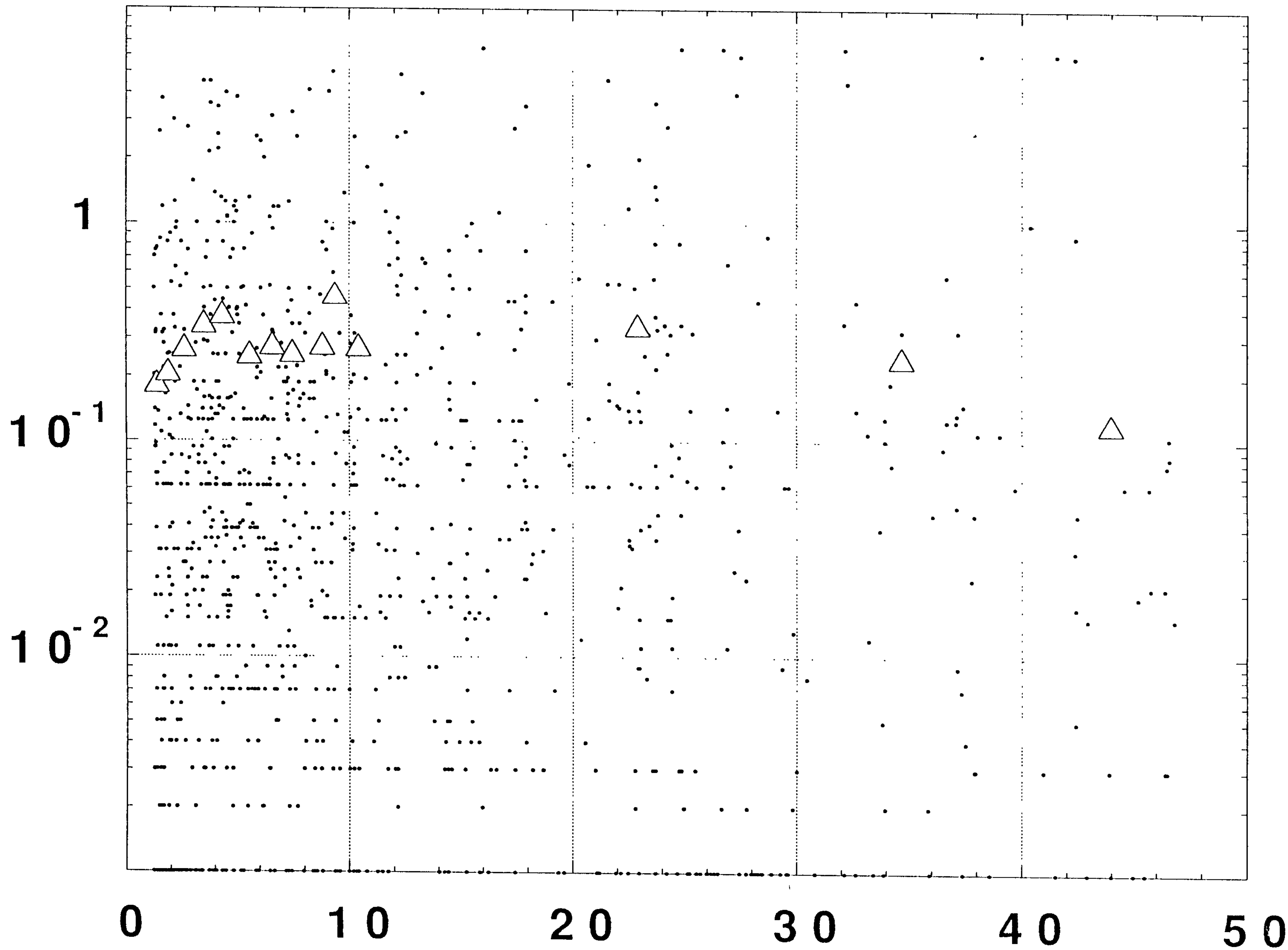


Fig.2 Behavior of Strain and Stress of the Piano and Maraging Wires


1
10^{-1}
10^{-2}
0
10
20
30
40
50

SUSPENSION WIRE
HYSTERESIS MEASUREMENT

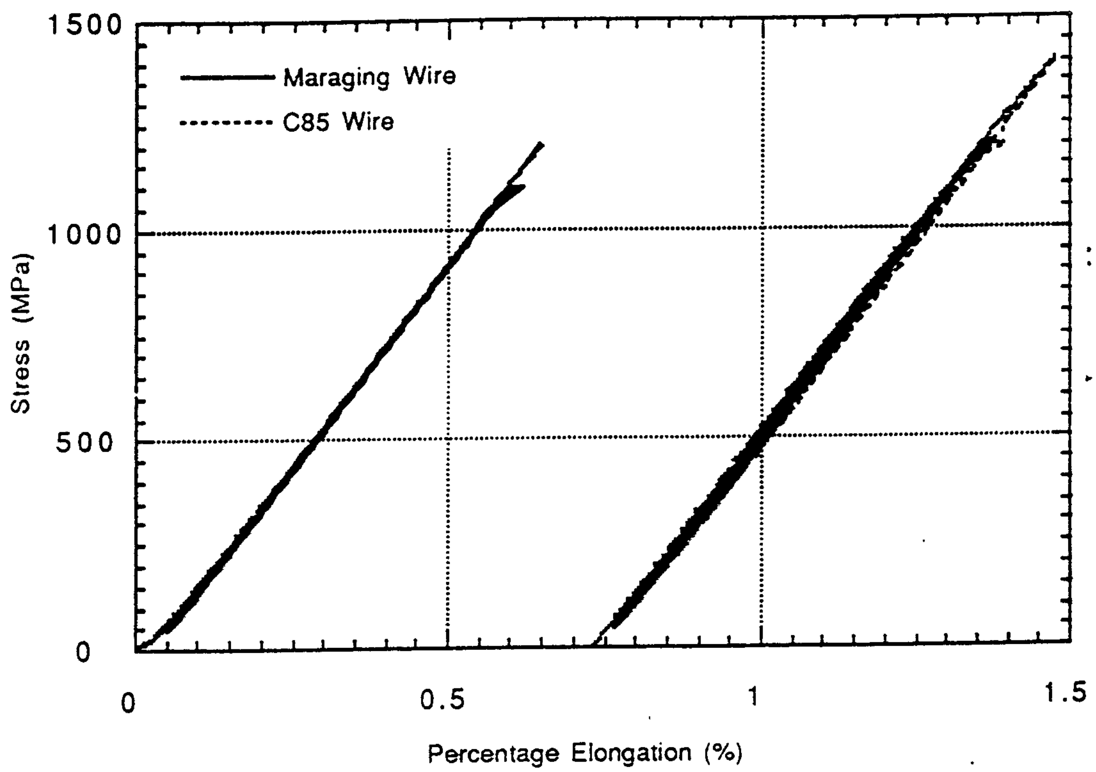
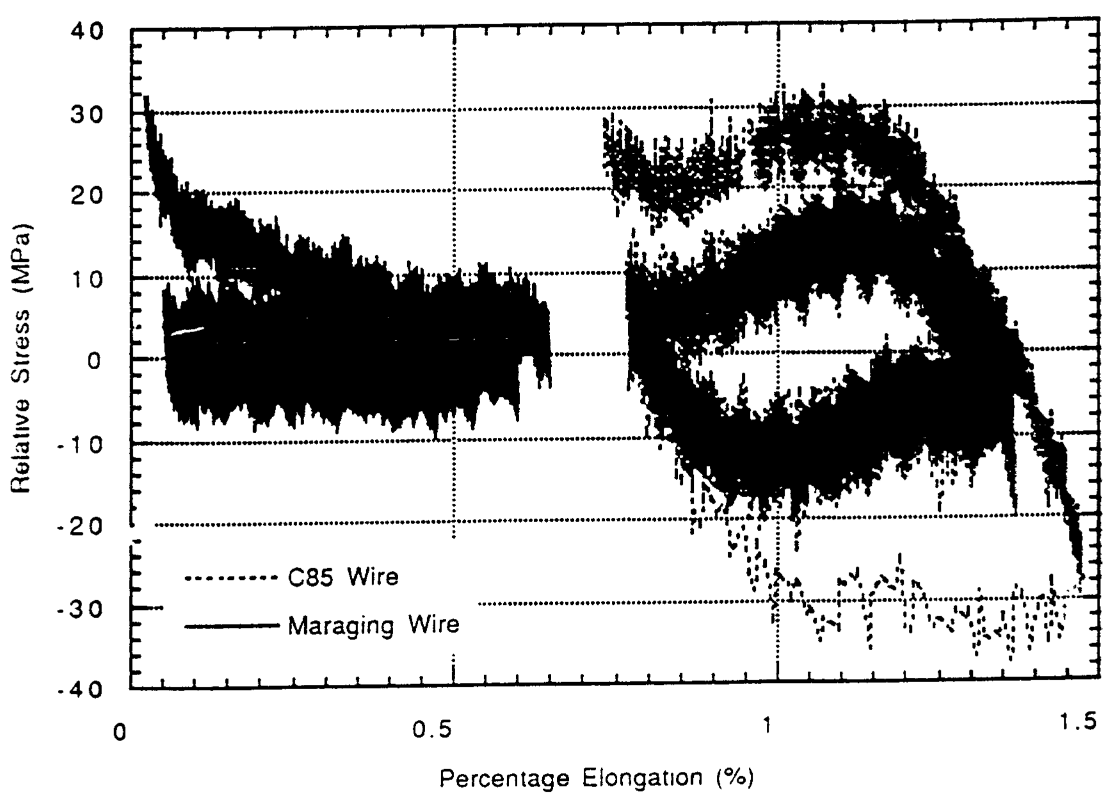
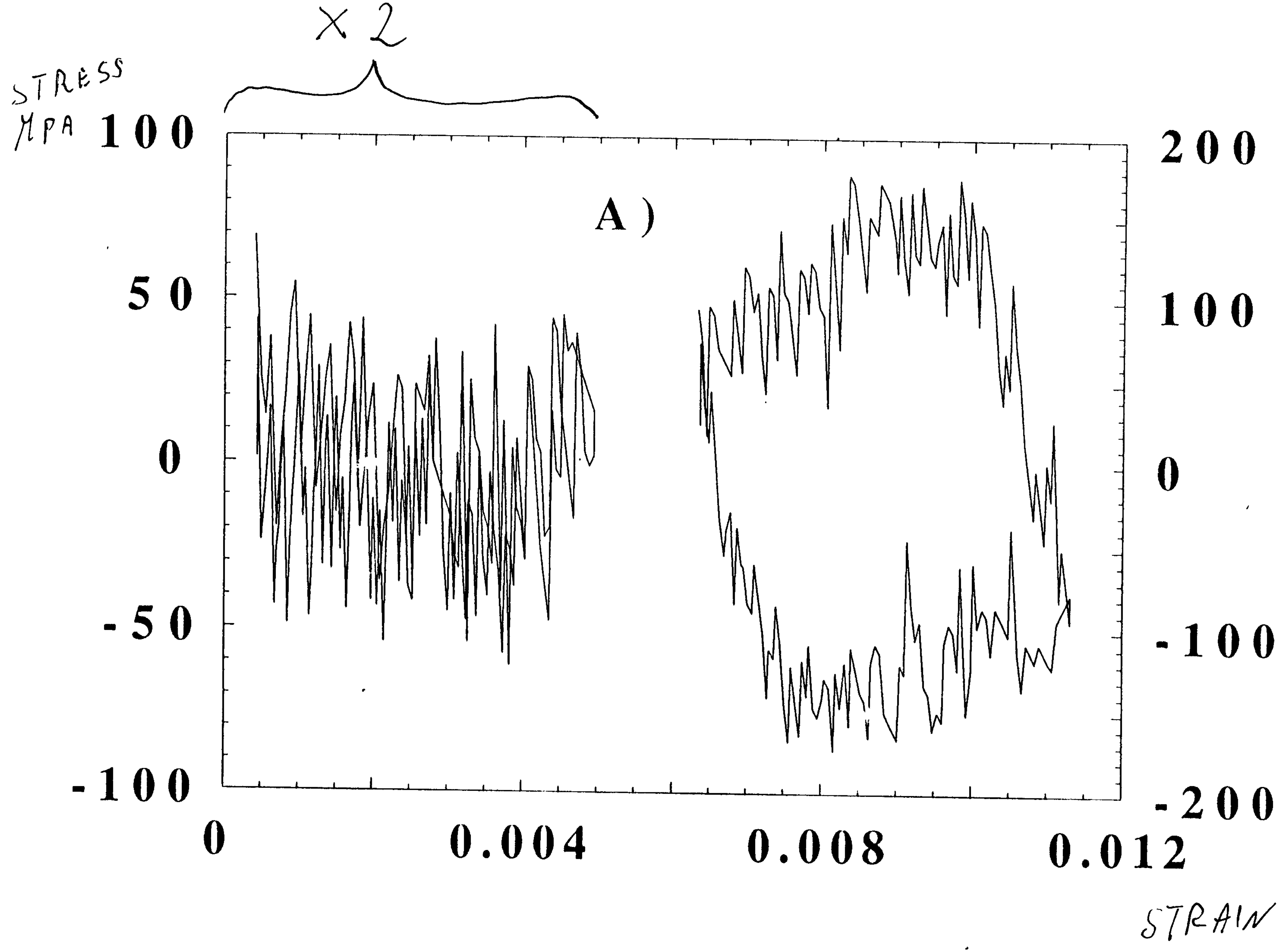
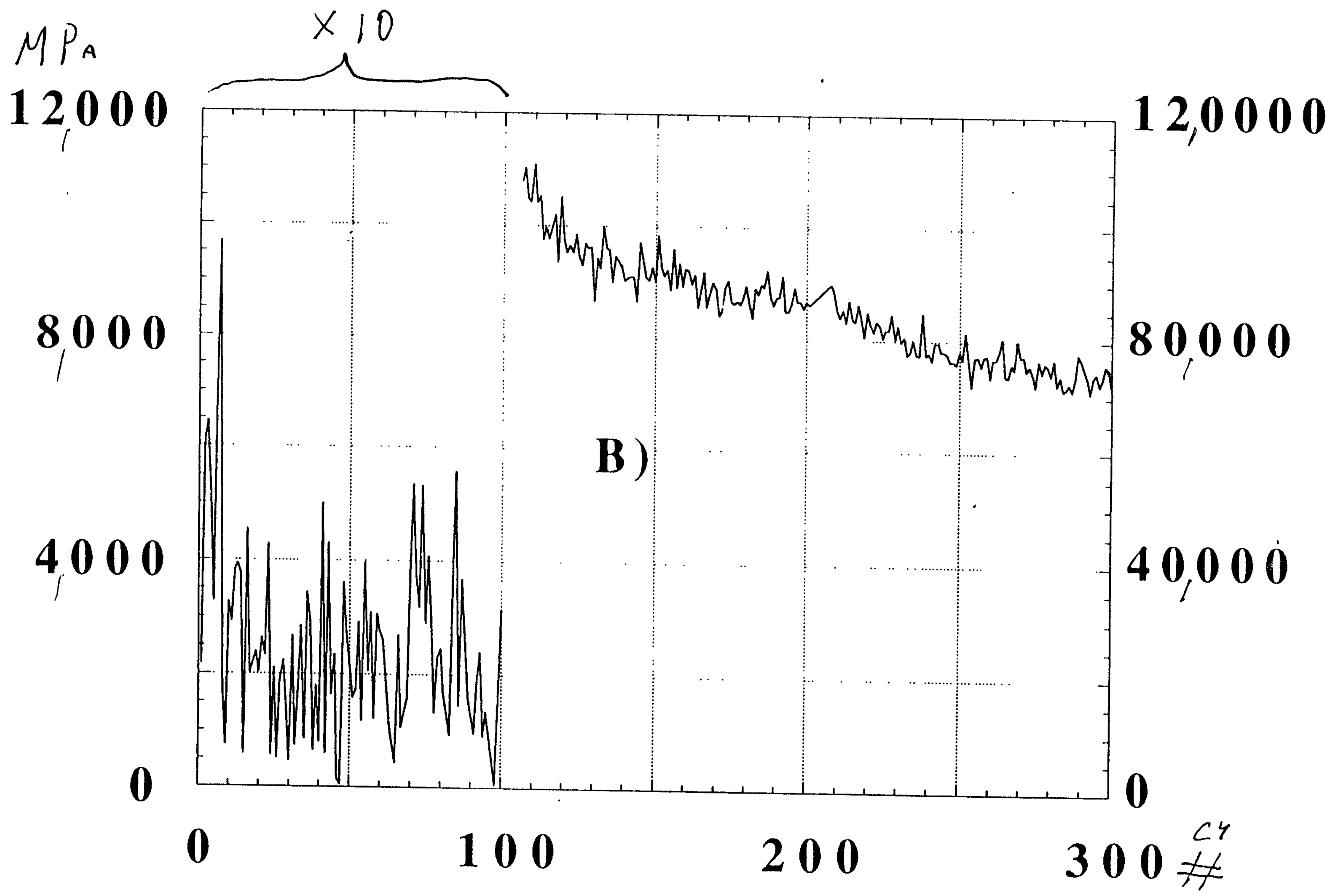


Fig.3 Hysteresis Cycles of the Piano and Maraging Wires





x 2
STRESS
MPA
A)
100
50
0
-50
-100
200
100
0
-100
-200
0
0.004
0.008
0.012
STRAIN



MPA
X 10
12,000
8,000
4,000
0
12,0000
80,000
40,000
0
B)
0
100
200
300
CY
#

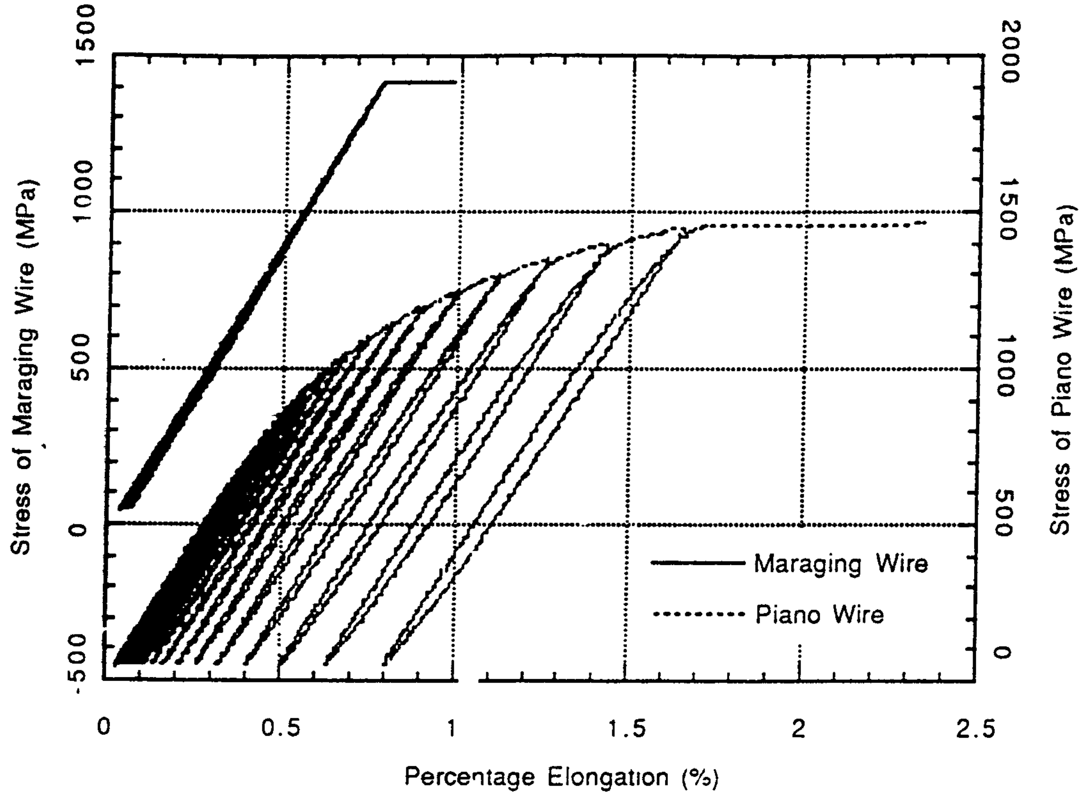


Fig.7 Hysteresis Cycles of the Broken Wires

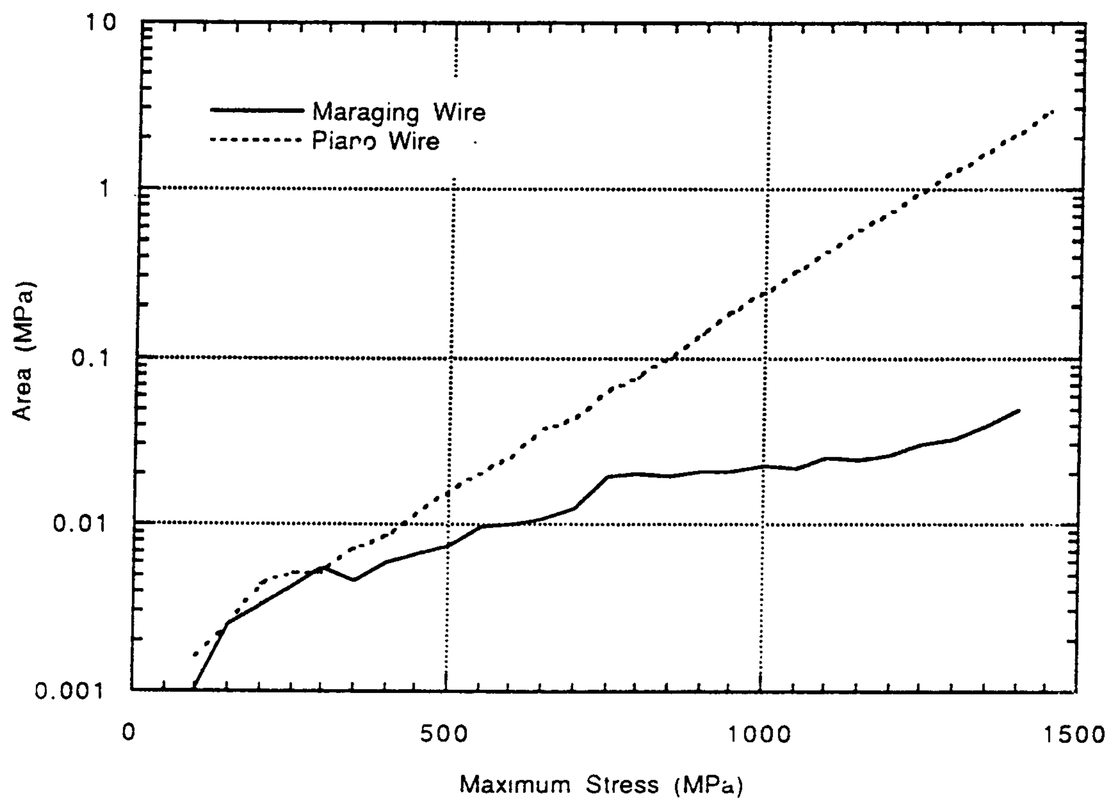
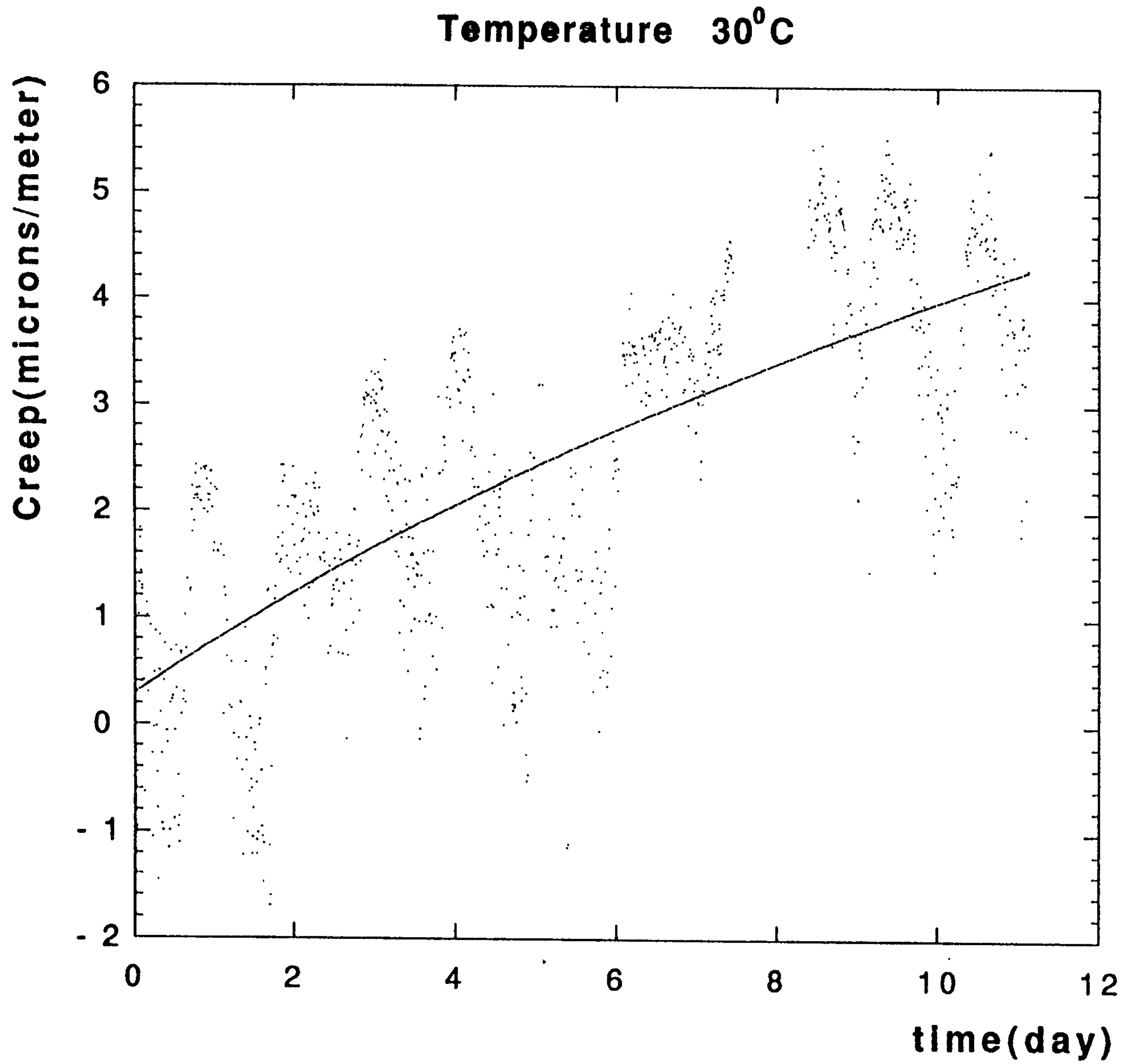
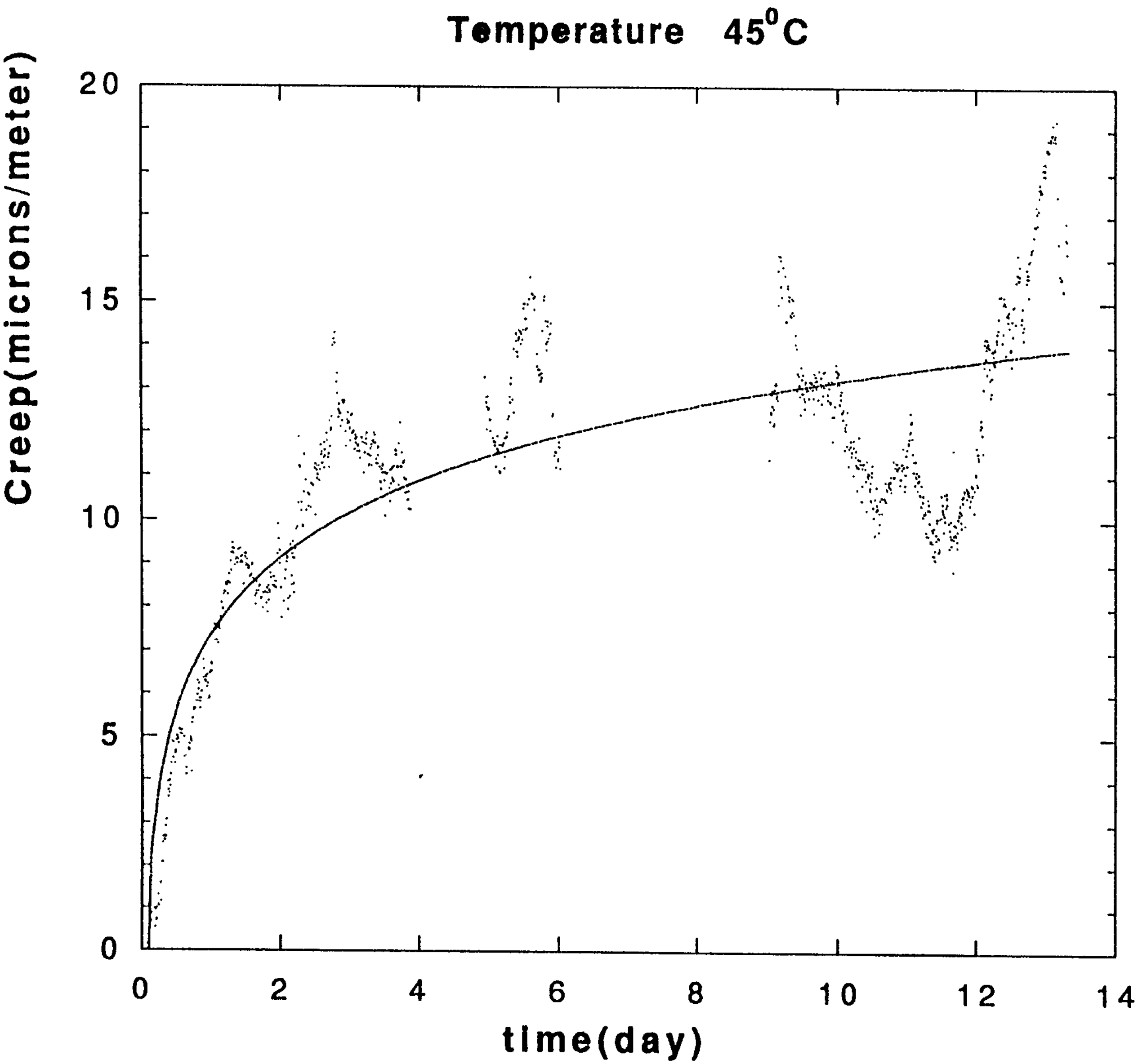


Fig.8 Hysteresis Area of the Broken Wires

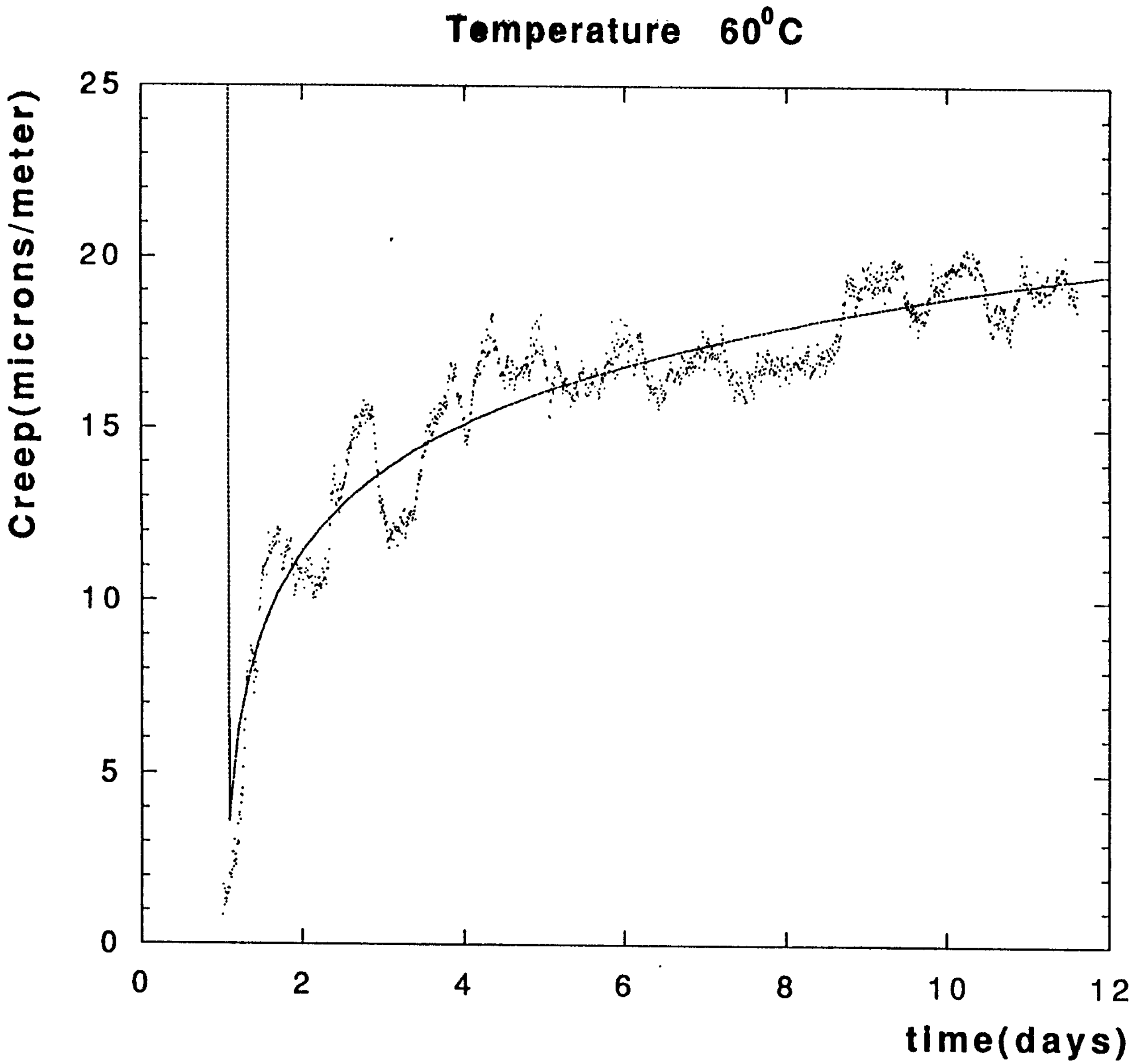


WIRE

y = a+b*log(m0+c)		
	Value	Error
a	-13.543	5.4837
b	13.214	3.3455
c	11.128	3.9894
Chisq	1564.9	NA
R	0.74596	NA

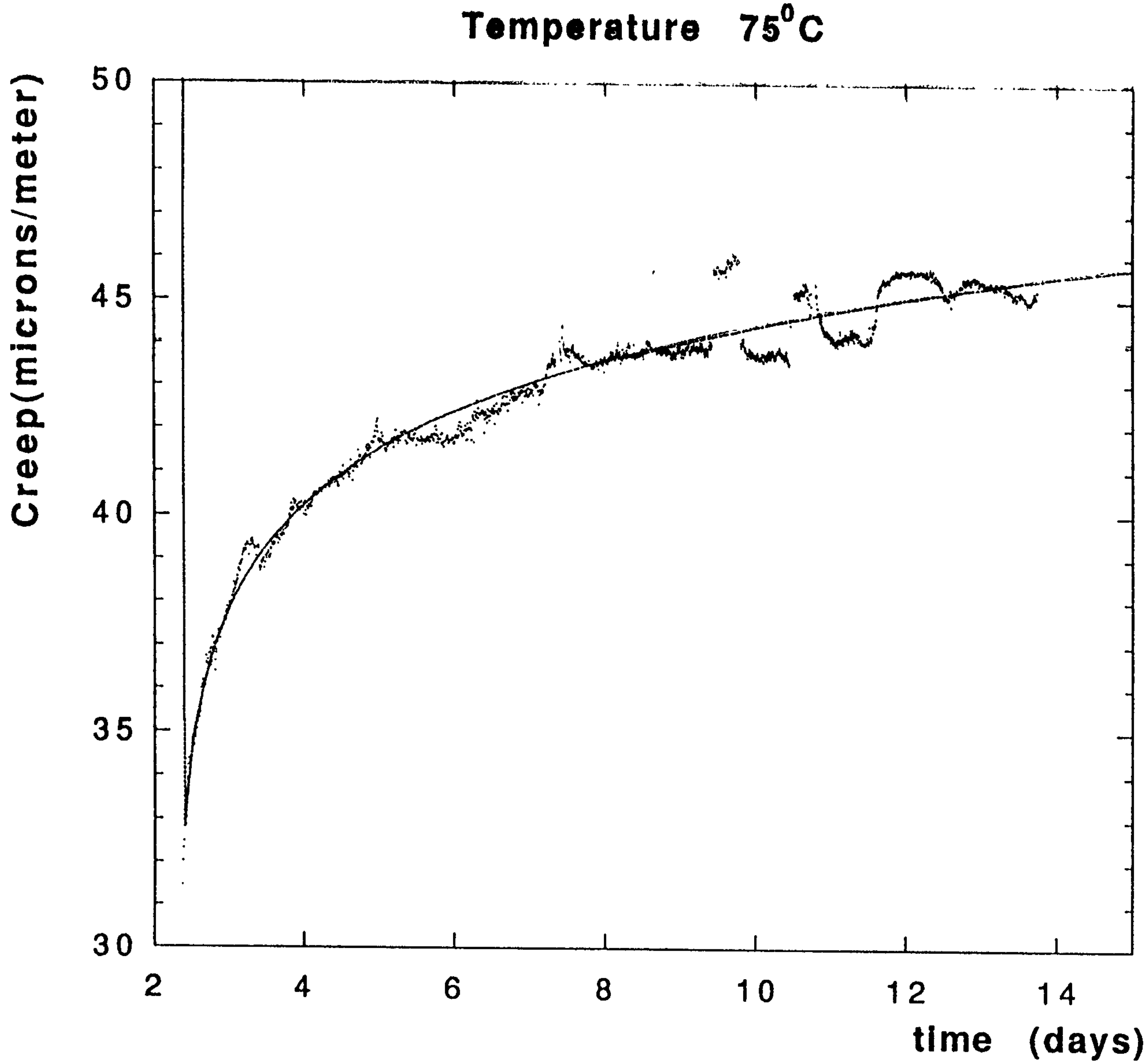


y = a+b*log(m0+c)		
	Value	Error
a	7.3535	0.094554
b	5.8276	0.11665
c	0.0037034	0.0028299
Chisq	5337.4	NA
R	0.82741	NA



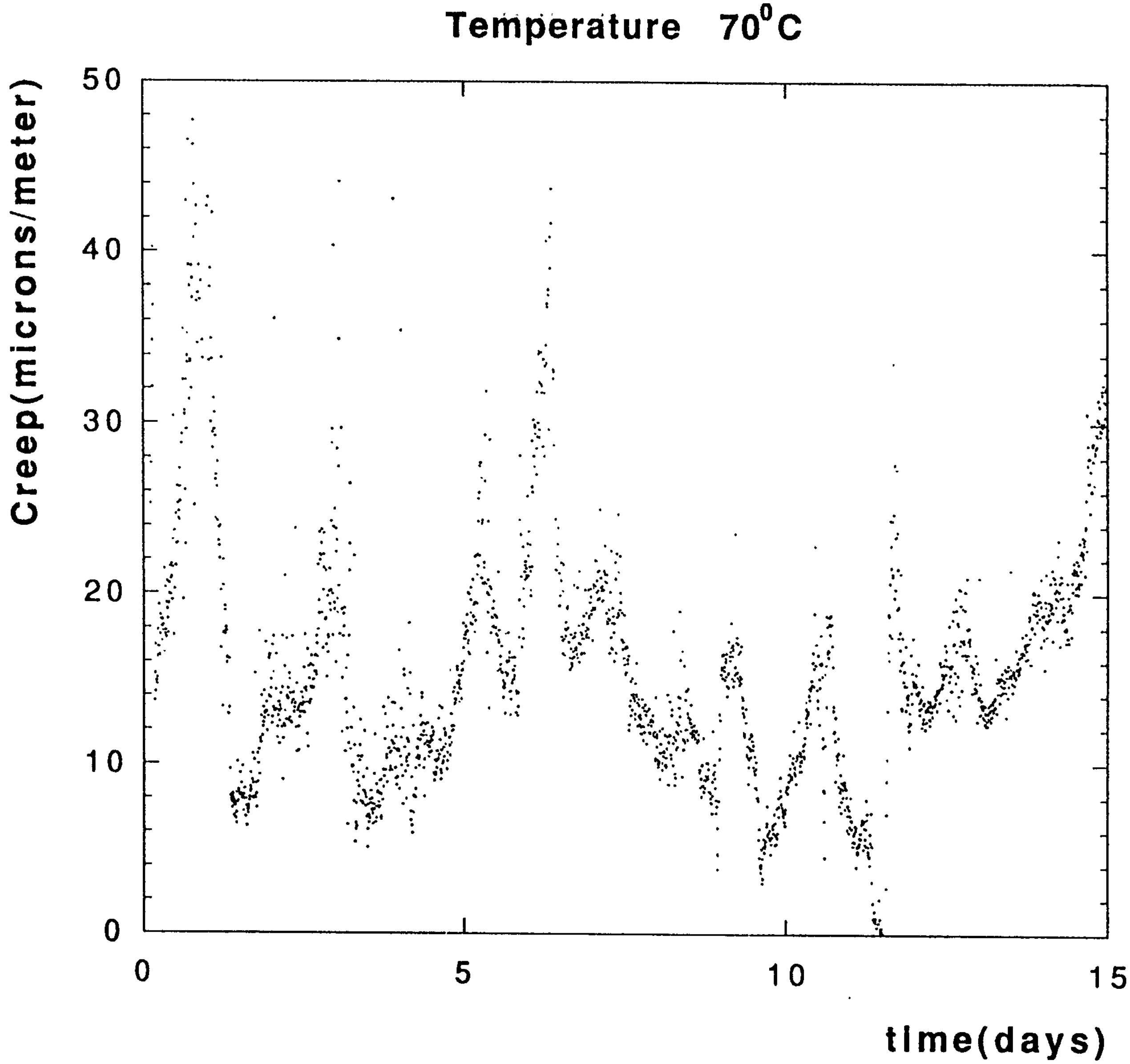
y = a+b*log(m0+c)		
	Value	Error
a	11.346	0.060988
b	7.8179	0.081742
c	-0.98853	0.0041677
Chisq	1754.9	NA
R	0.95085	NA

SUSPENSION WIRE TESTS

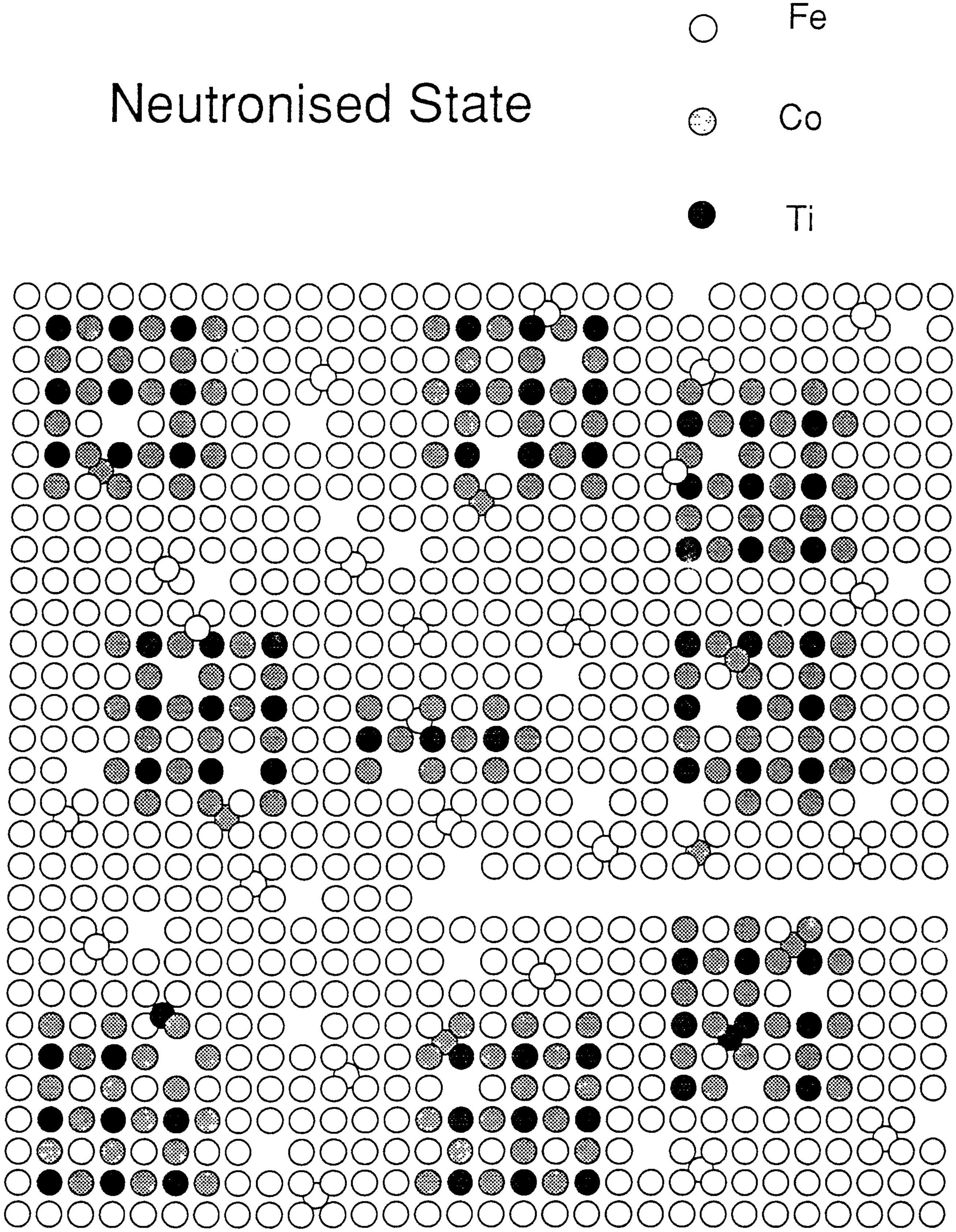


y = a+b*log(m0+c)		
	Value	Error
a	38.691	0.042863
b	6.4114	0.050935
c	-2.2695	0.008277
Chisq	409.32	NA
R	0.98063	NA

SUSPENSION WIRE TESTS



Neutronised State



Defences against Thermal movement noise

SCREECHING NOISE

Differential thermal expansion coefficients

kept to a minimum

All points subject to movement

made with flex joints

Best reasonable thermostabilisation

ULTRA LOW HISTERESIS MATERIALS

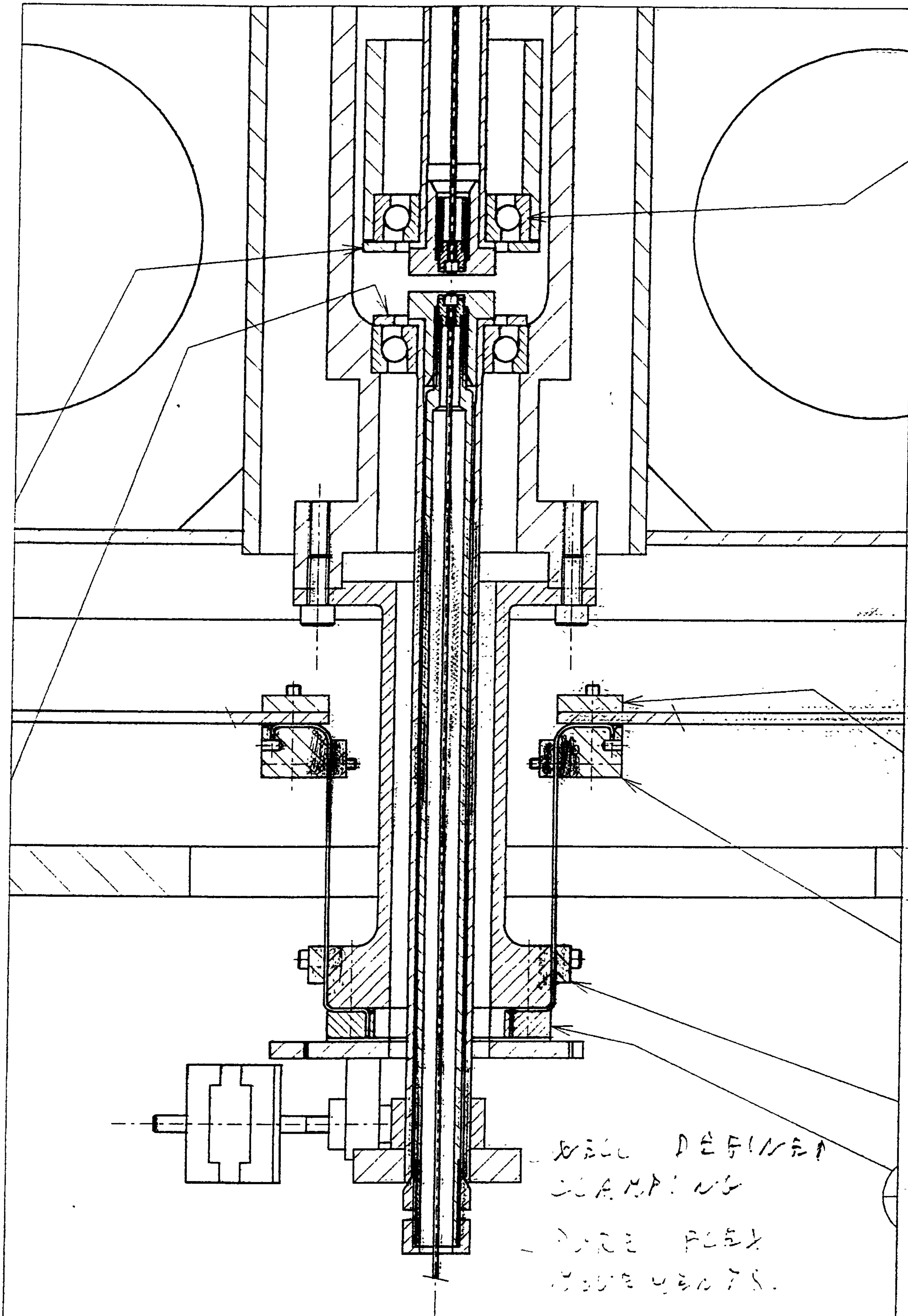
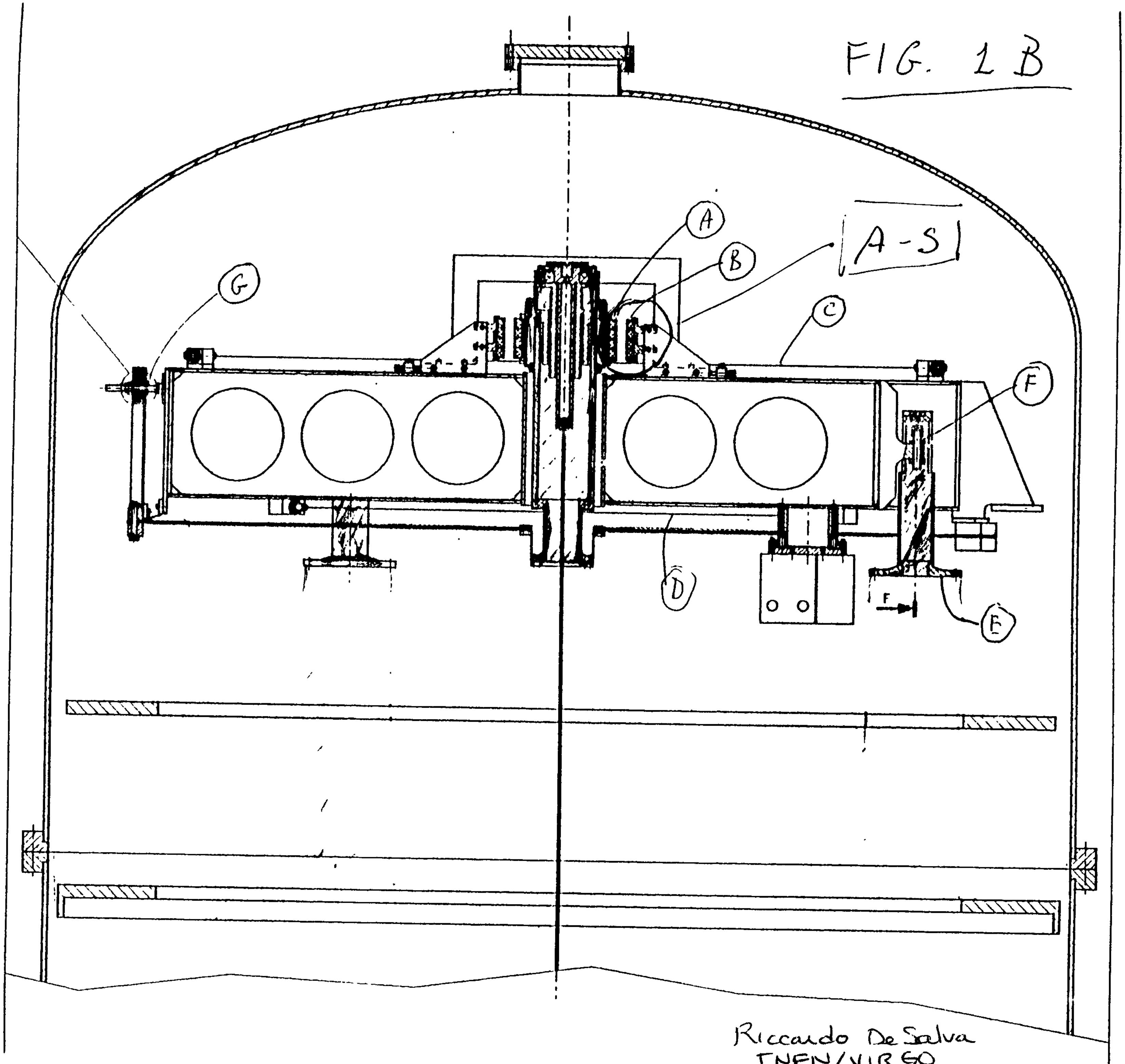
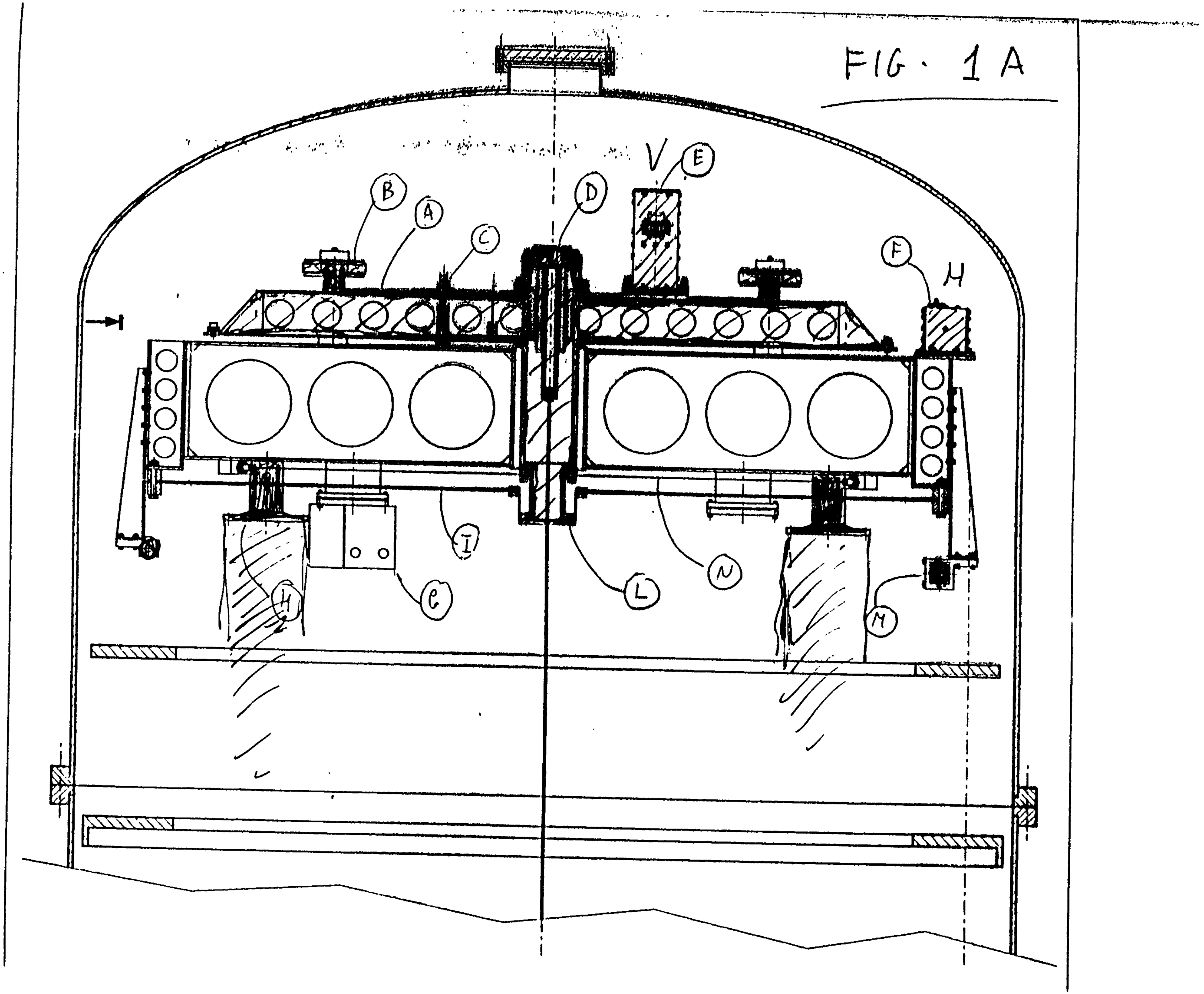

- WELL DEFINED CLAMPING
- LARGE FLEX MOVEMENTS.

FIG. 1B



Riccardo De Salva
INFN/VIRGO
9/23/97

FIG. 1A



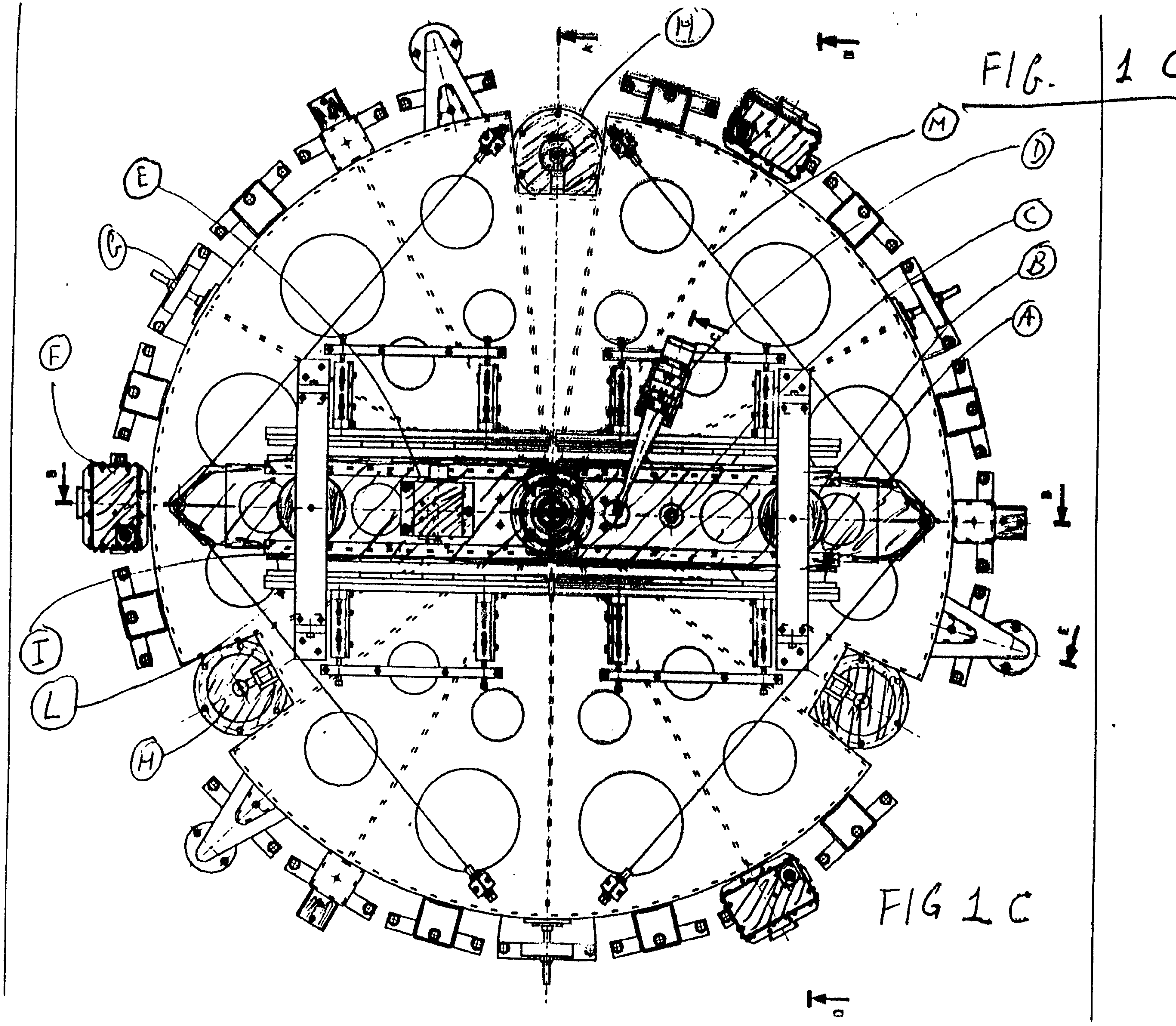


FIG 1 C

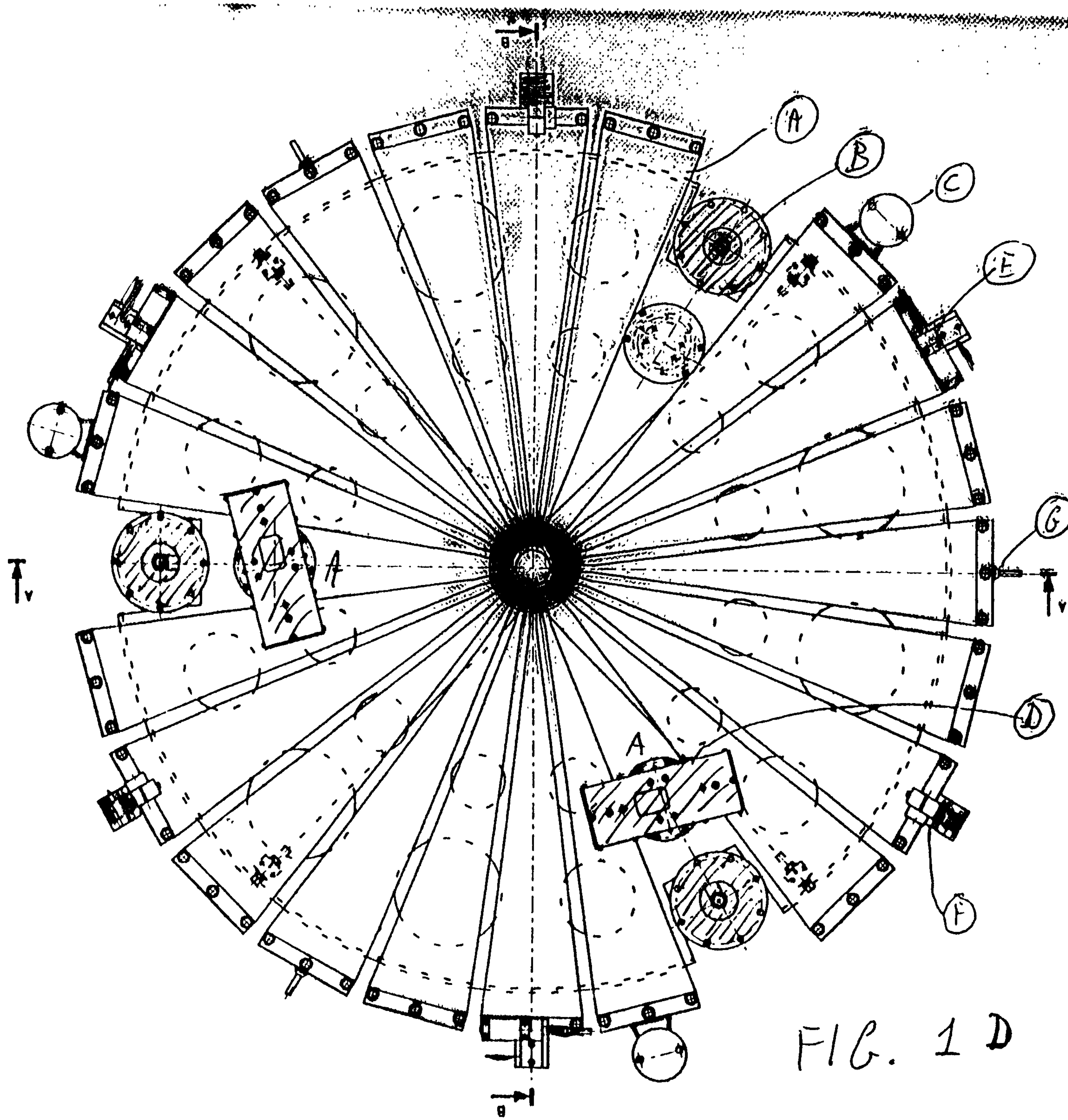
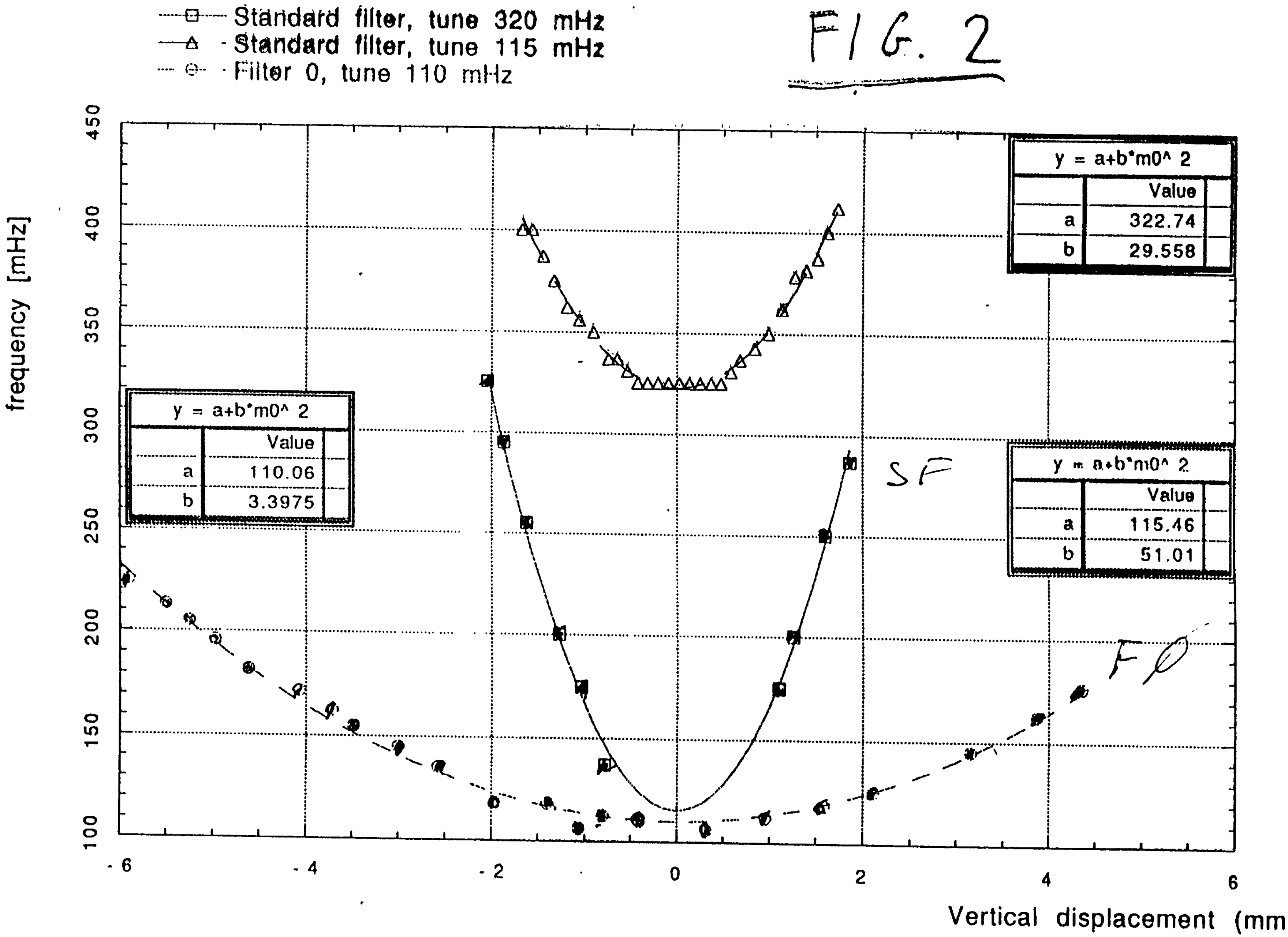
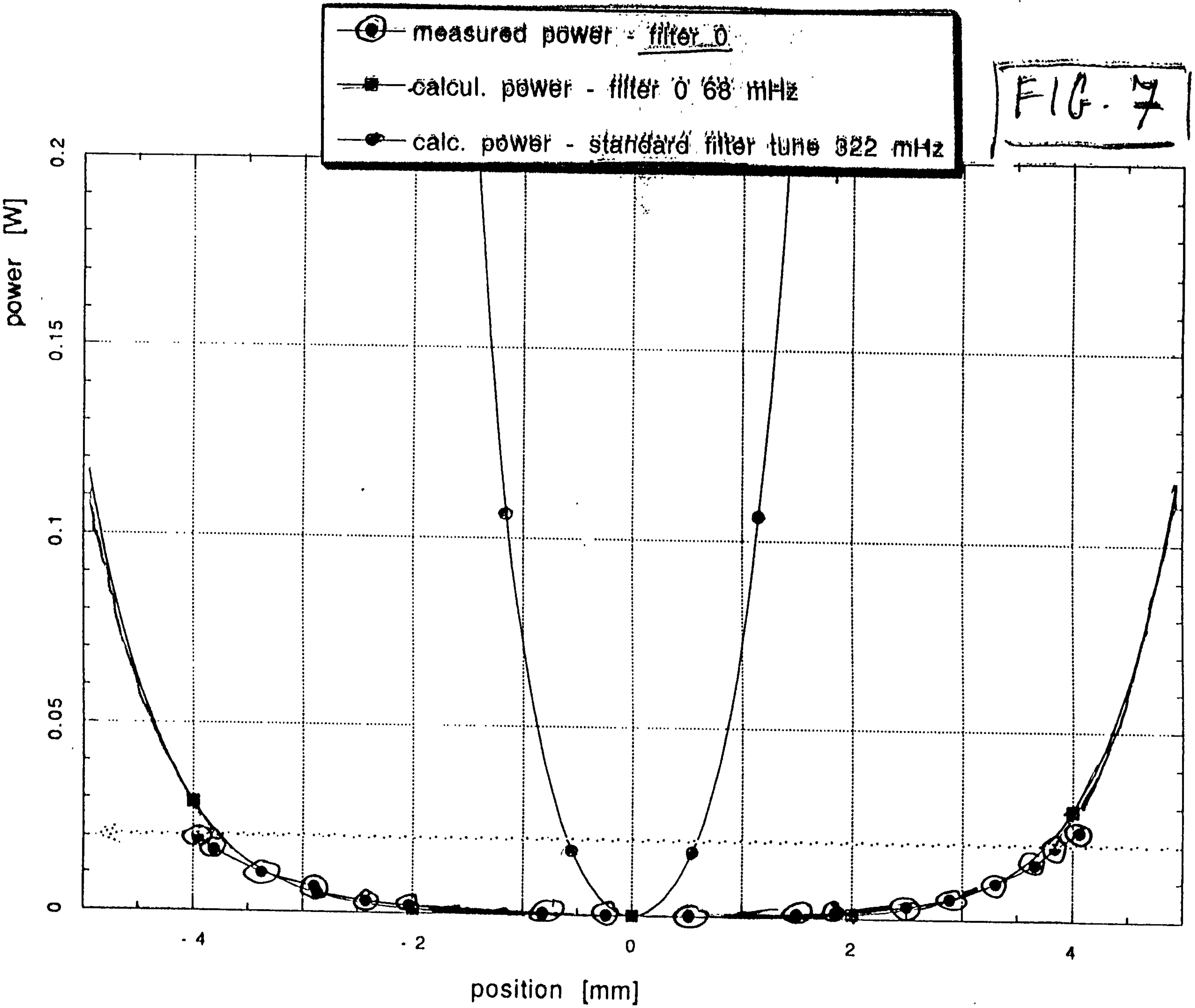


FIG. 1D

FIG. 2



Standard filter, tune 320 mHz
Standard filter, tune 115 mHz
Filter 0, tune 110 mHz
frequency [mHz]
450
400
350
300
250
200
150
100
-6
-4
-2
0
2
4
6
Vertical displacement (mm)
y = a+b*m0^ 2
Value
a 322.74
b 29.558
y = a+b*m0^ 2
Value
a 110.06
b 3.3975
y = a+b*m0^ 2
Value
a 115.46
b 51.01
SF
F0



measured power - filter 0
calcul. power - filter 0 68 mHz
calc. power - standard filter tune 322 mHz
power [W]
0.2
0.15
0.1
0.05
0
-4
-2
0
2
4
position [mm]

FIG. 7

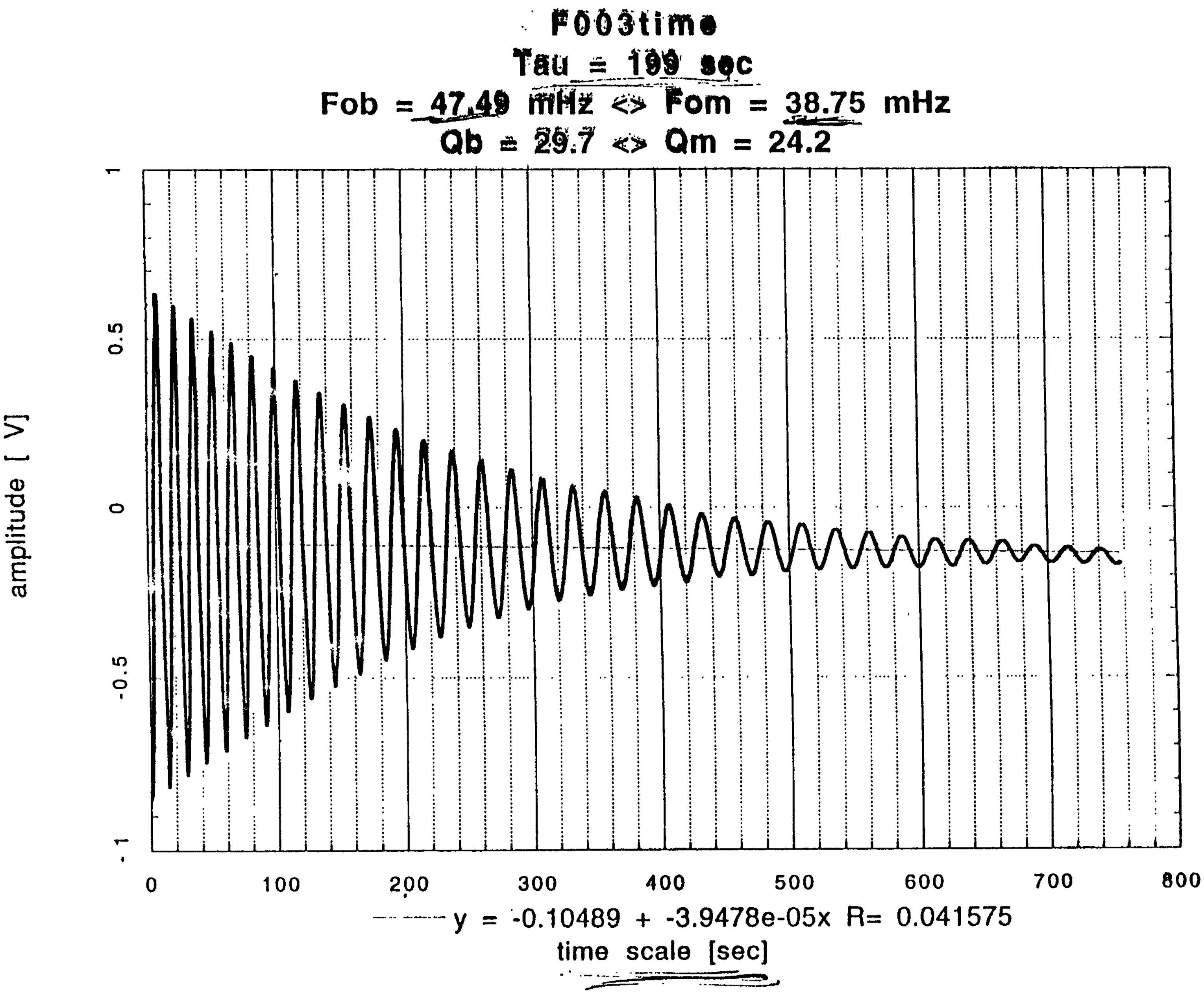
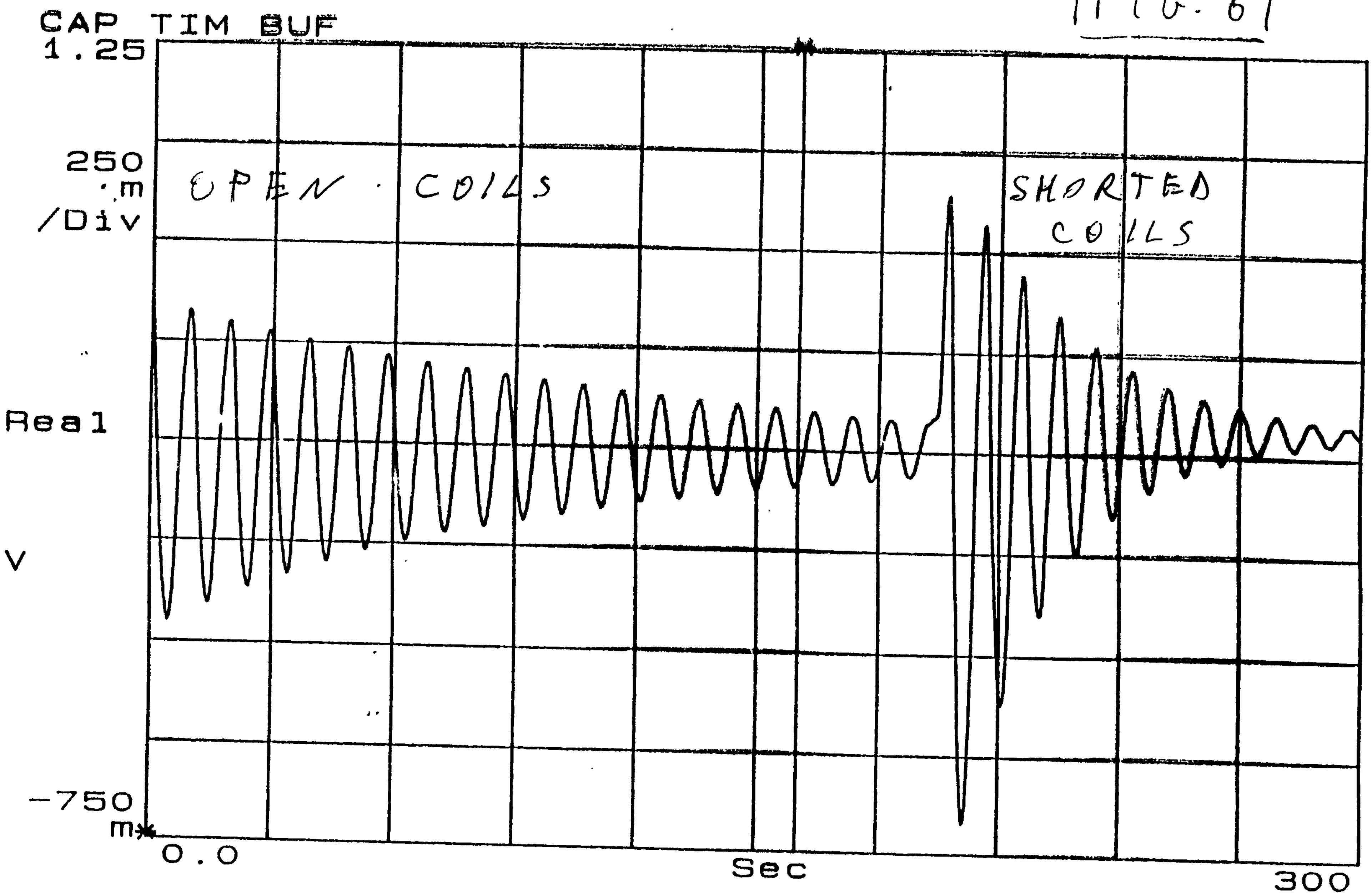
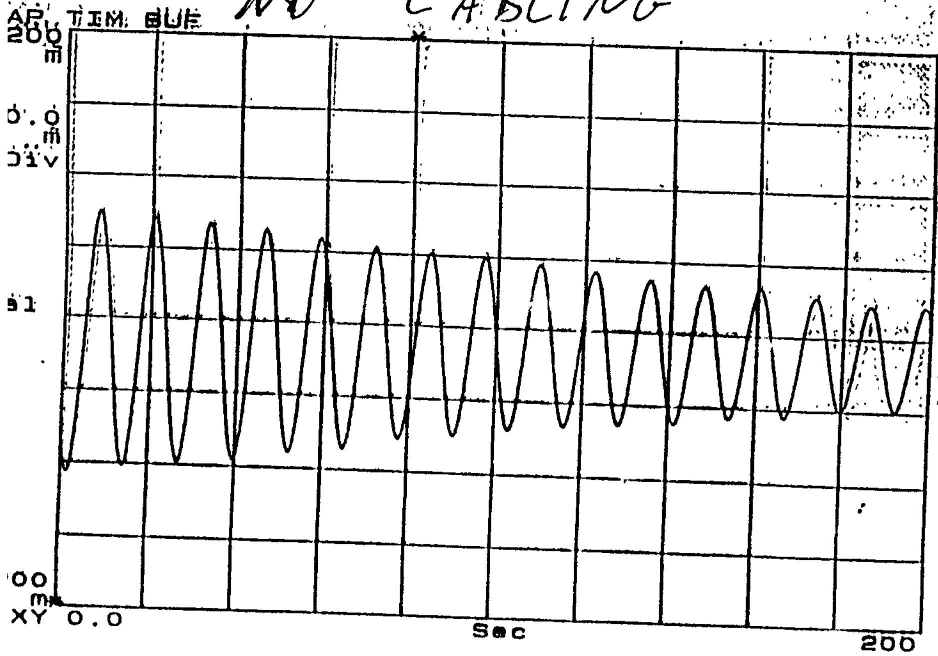

F003time
Tau = 199 sec
Fob = 47.49 mHz <> Fom = 38.75 mHz
Qb = 29.7 <> Qm = 24.2
amplitude [V]
1
0.5
0
-0.5
-1
0
100
200
300
400
500
600
700
800
y = -0.10489 + -3.9478e-05x R= 0.041575
time scale [sec]

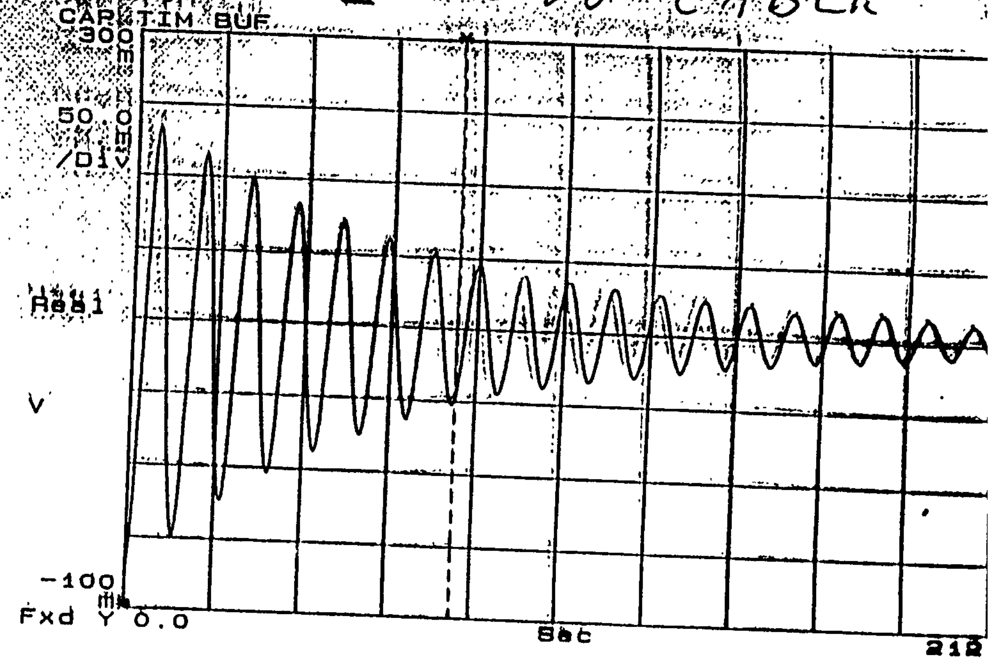
FIG. 6


CAP TIM BUF
1.25
250
m
/Div
Real
V
-750
m
0.0
Sec
300
OPEN COILS
SHORTED COILS

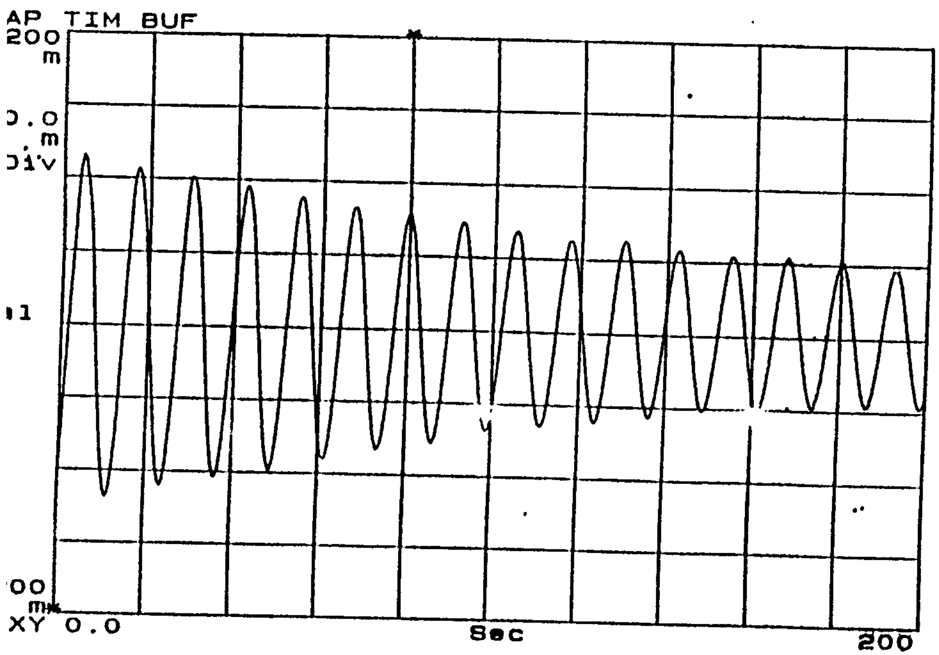
A] NO CABLING



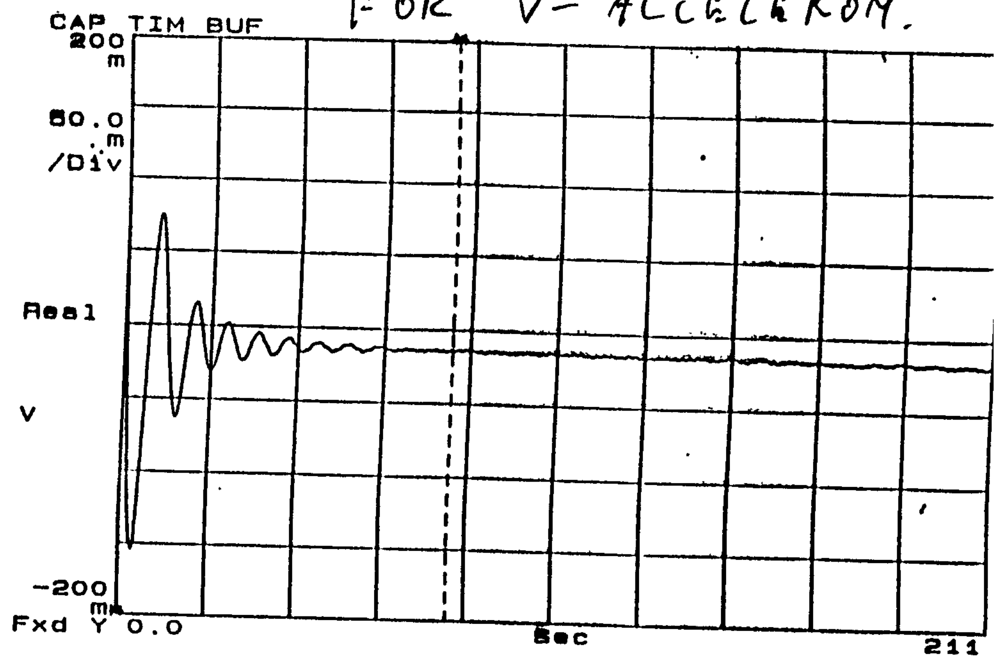
C] 1 LEMO CABLE

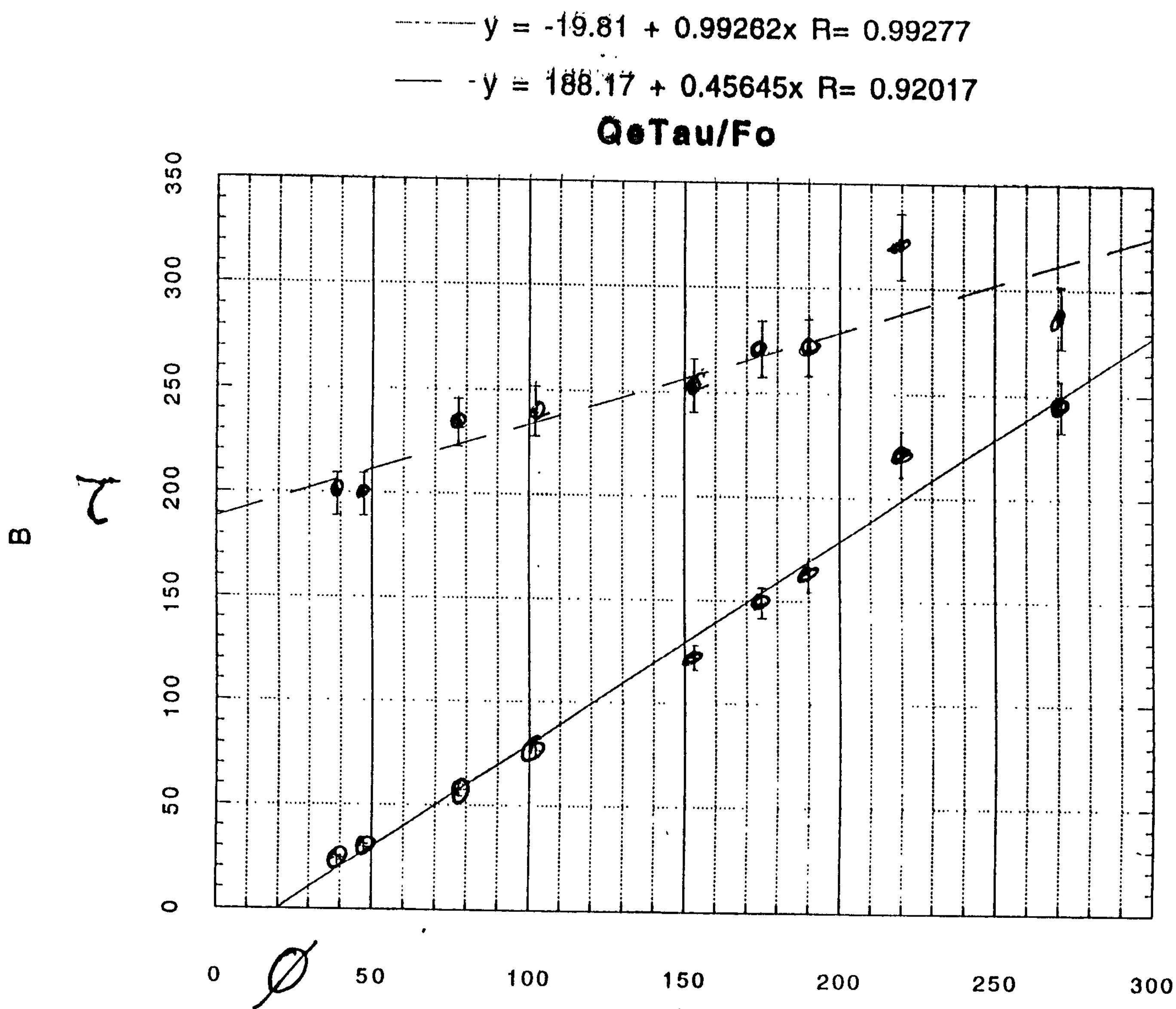


B] AWG 22 TWISTED PAIR



D] 3 SHIELDED TWISTED PAIRS FOR V- ACCELROM.





y = -19.81 + 0.99262x R= 0.99277
y = 188.17 + 0.45645x R= 0.92017
QeTau/Fo
B
τ
0
50
100
150
200
250
300
350
0
Ø
50
100
150
200
250
300
A

tutti dati

F#0 vecchii e nuovi

70 cm 30 **F#7** cm MARAGING BLADES

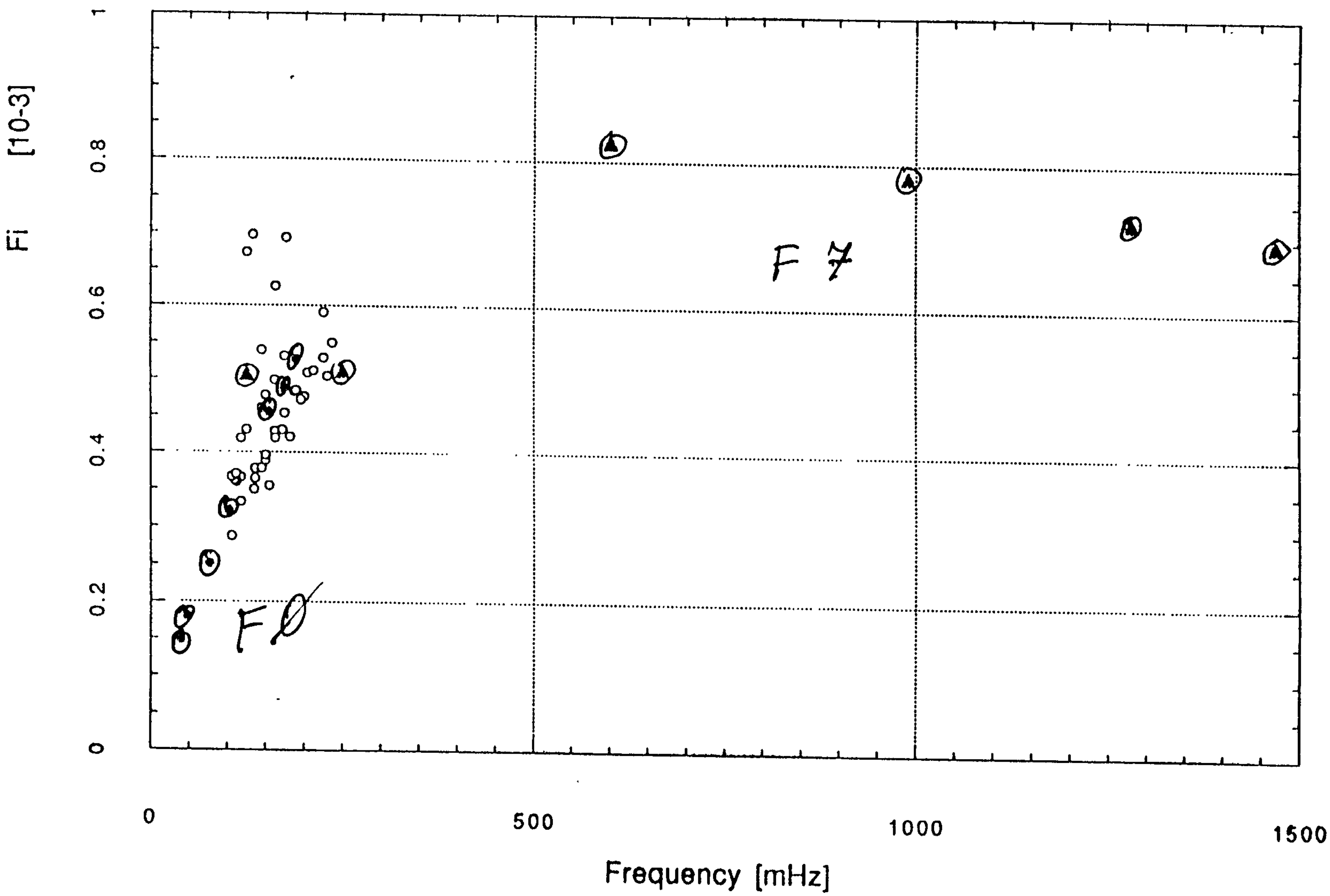


FIG. 3

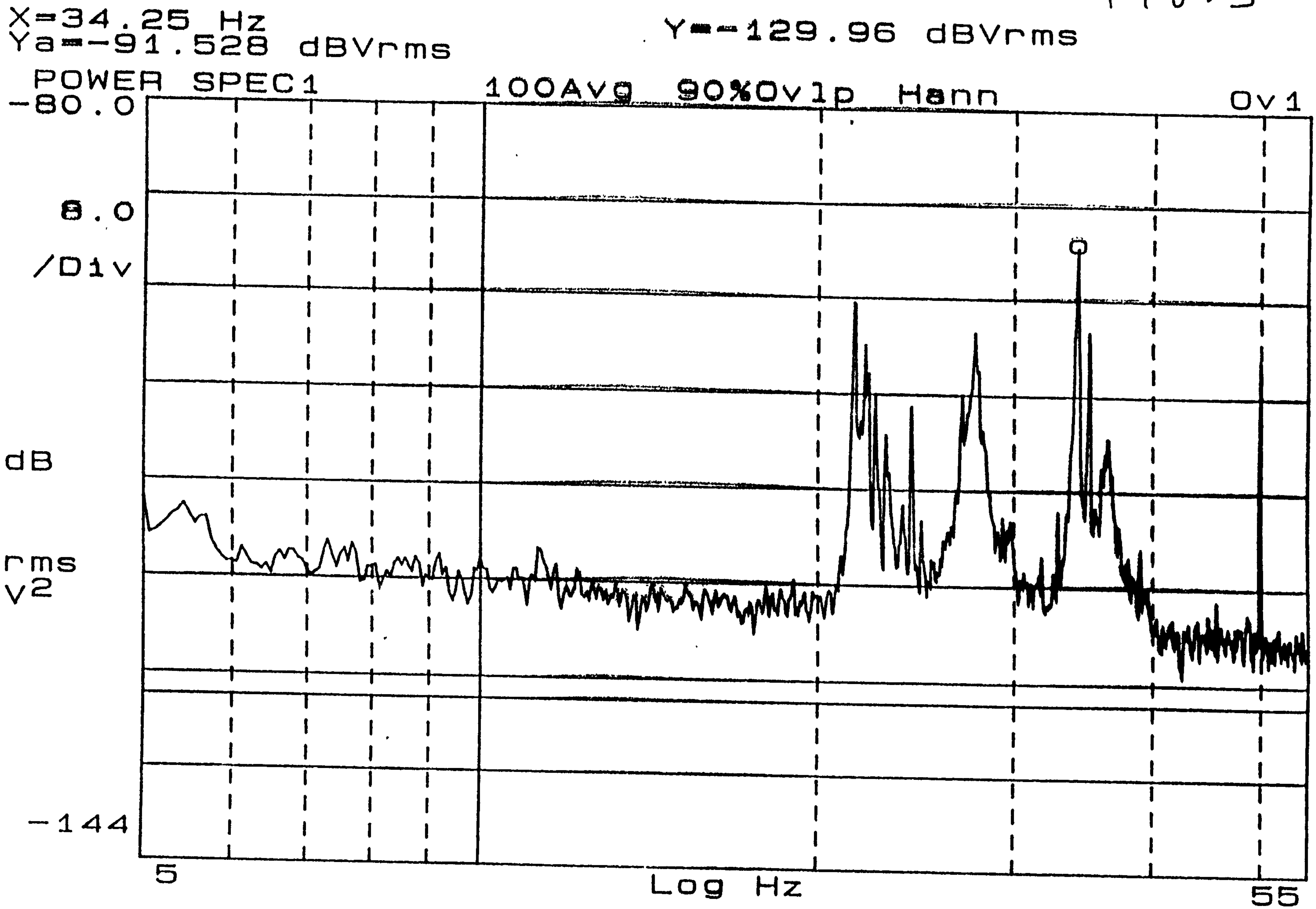
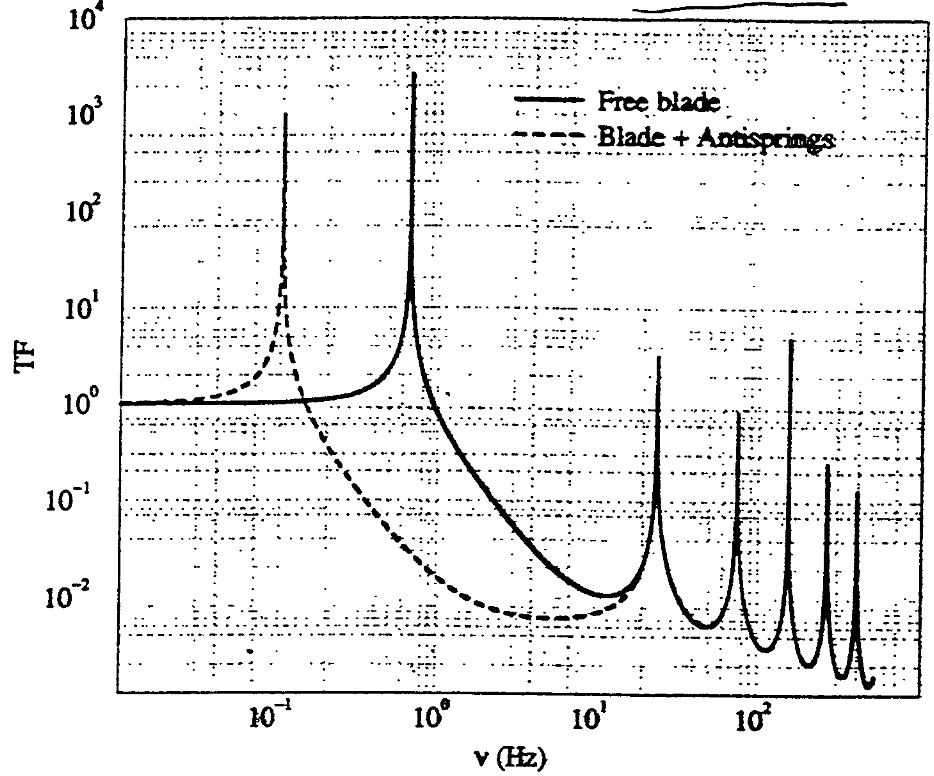
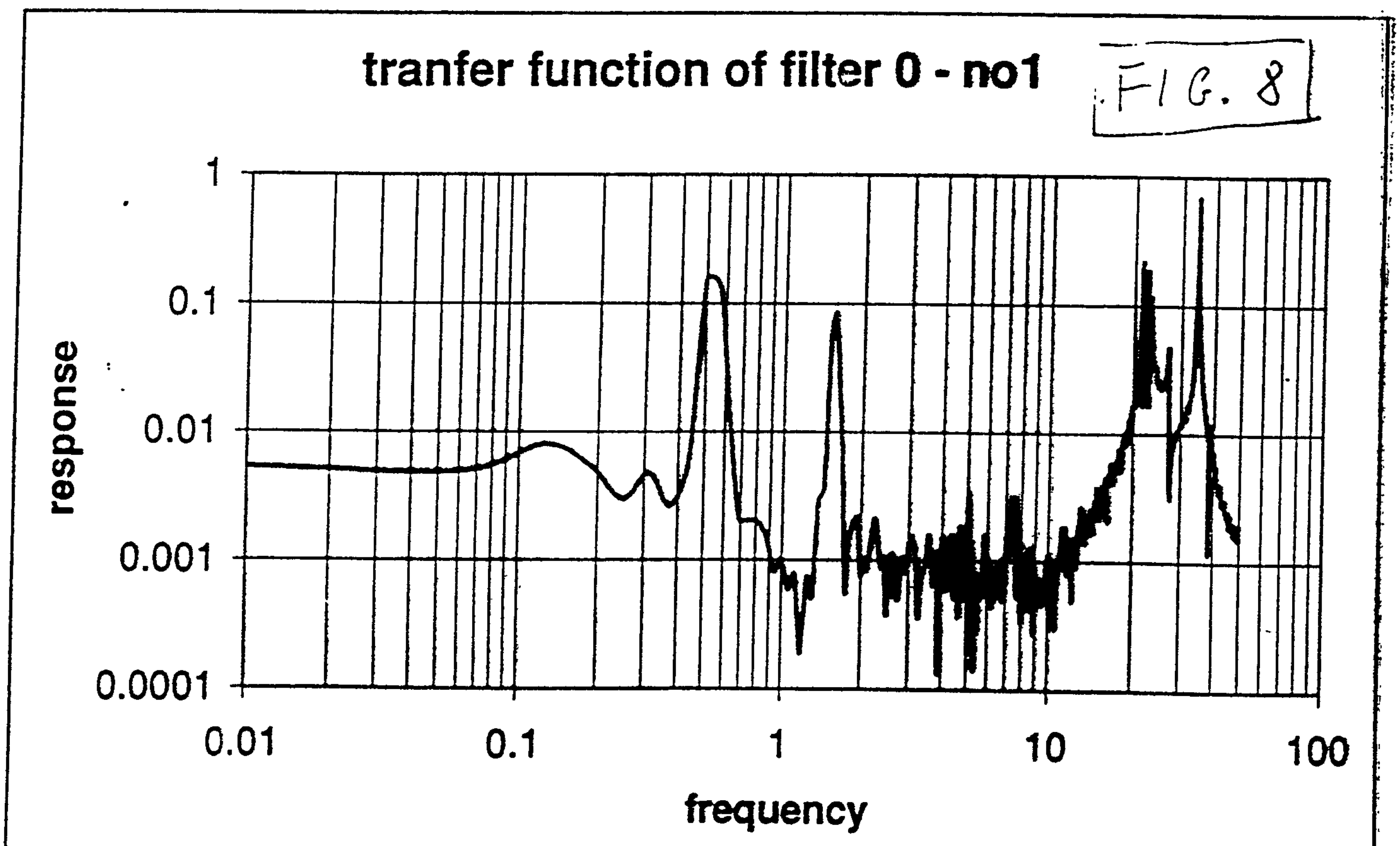

X=34.25 Hz
Ya=-91.528 dBVrms
Y=-129.96 dBVrms
POWER SPEC1
100Avg 90%Ovlp Hann
Ov1
-80.0
8.0
/Div
dB
rms
V2
-144
5
Log Hz
55

FIG. 9



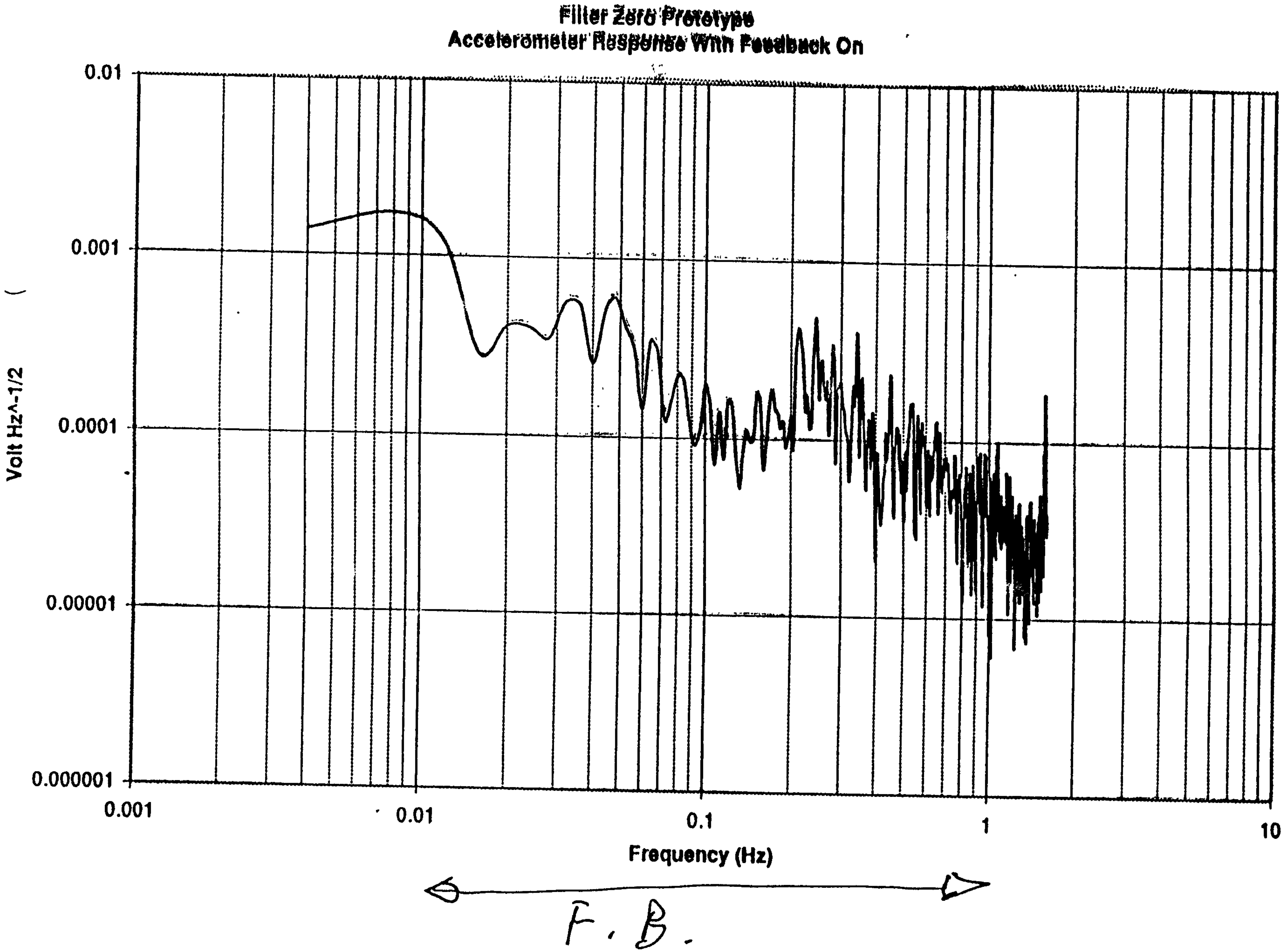
Free blade
Blade + Antisprings
TF
v (Hz)

FIG. 8



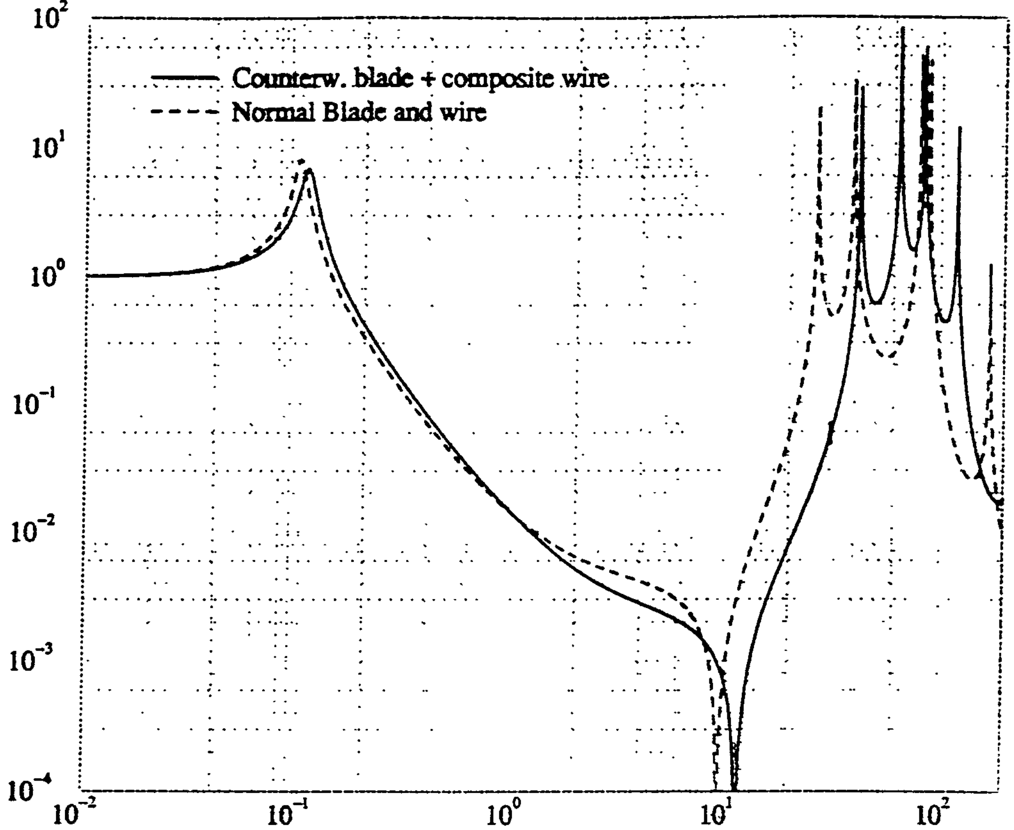
tranfer function of filter 0 - no1
response
frequency

FIG 13


Filter Zero Prototype
Accelerometer Response With Feedback On
0.01
0.001
0.0001
0.00001
0.000001
Volt Hz^-1/2
0.001
0.01
0.1
1
10
Frequency (Hz)
F. B.

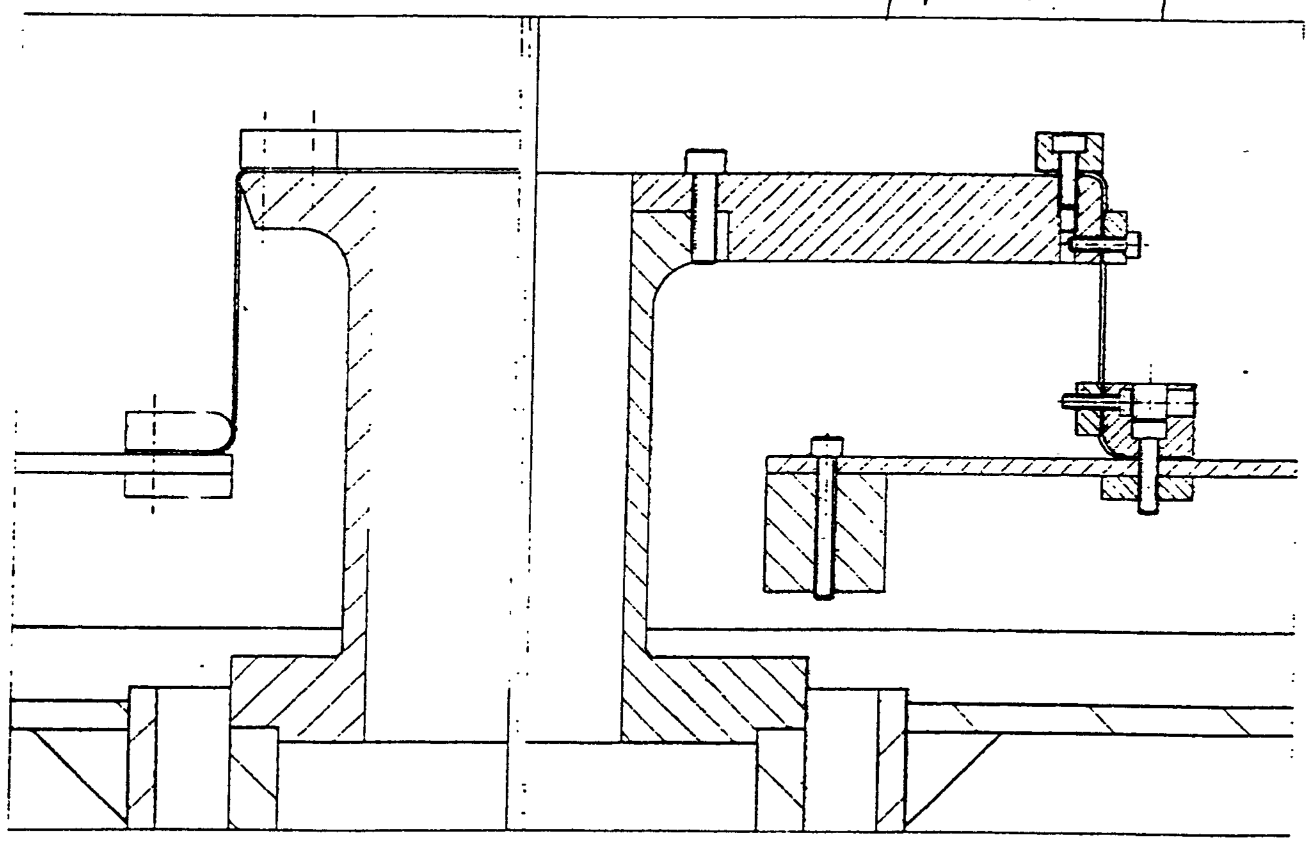
Pg. 23

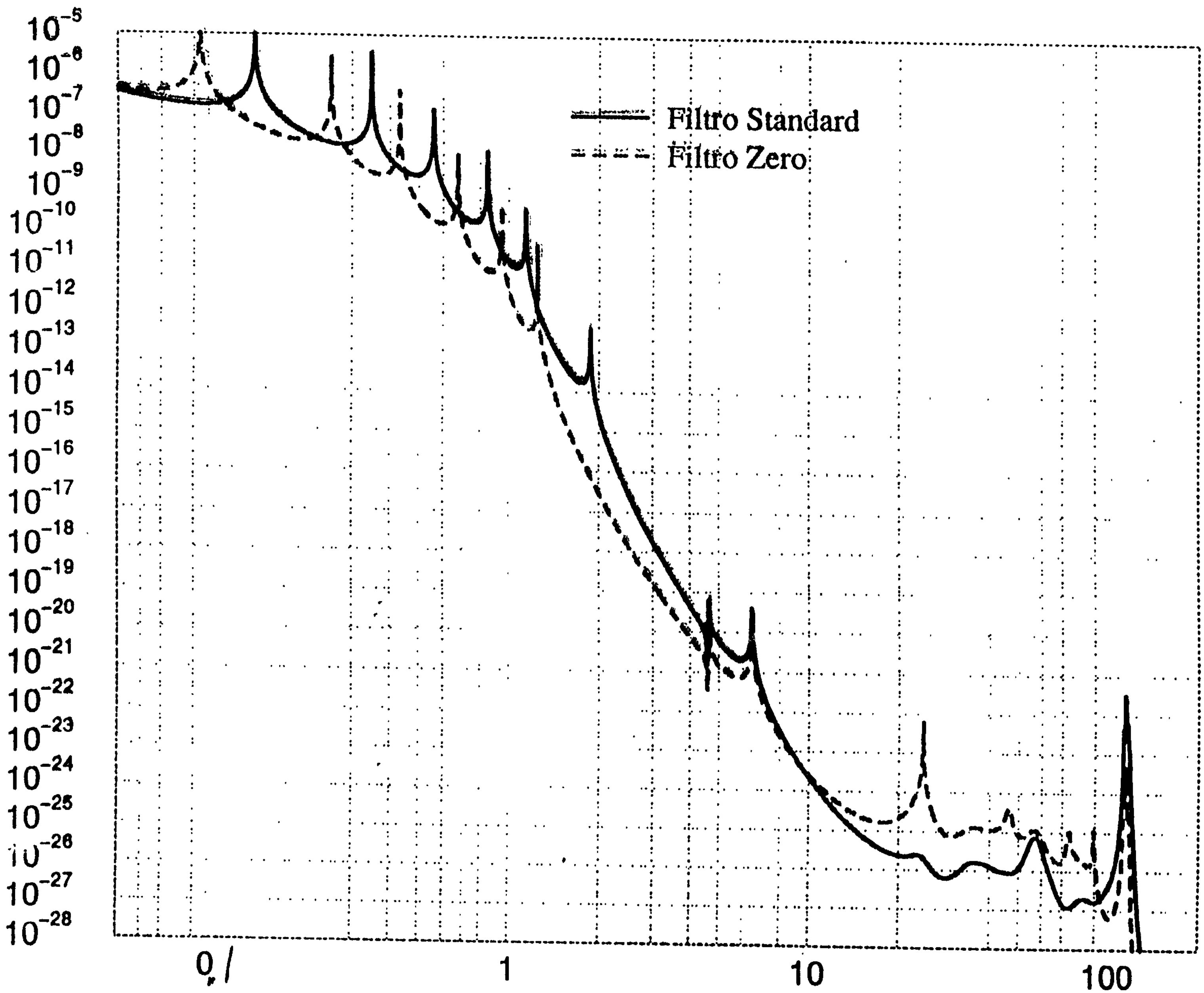
FIG. 16



TF from Vessel to Cross
Counterw. blade + composite wire
Normal Blade and wire
10^{2}
10^{1}
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}

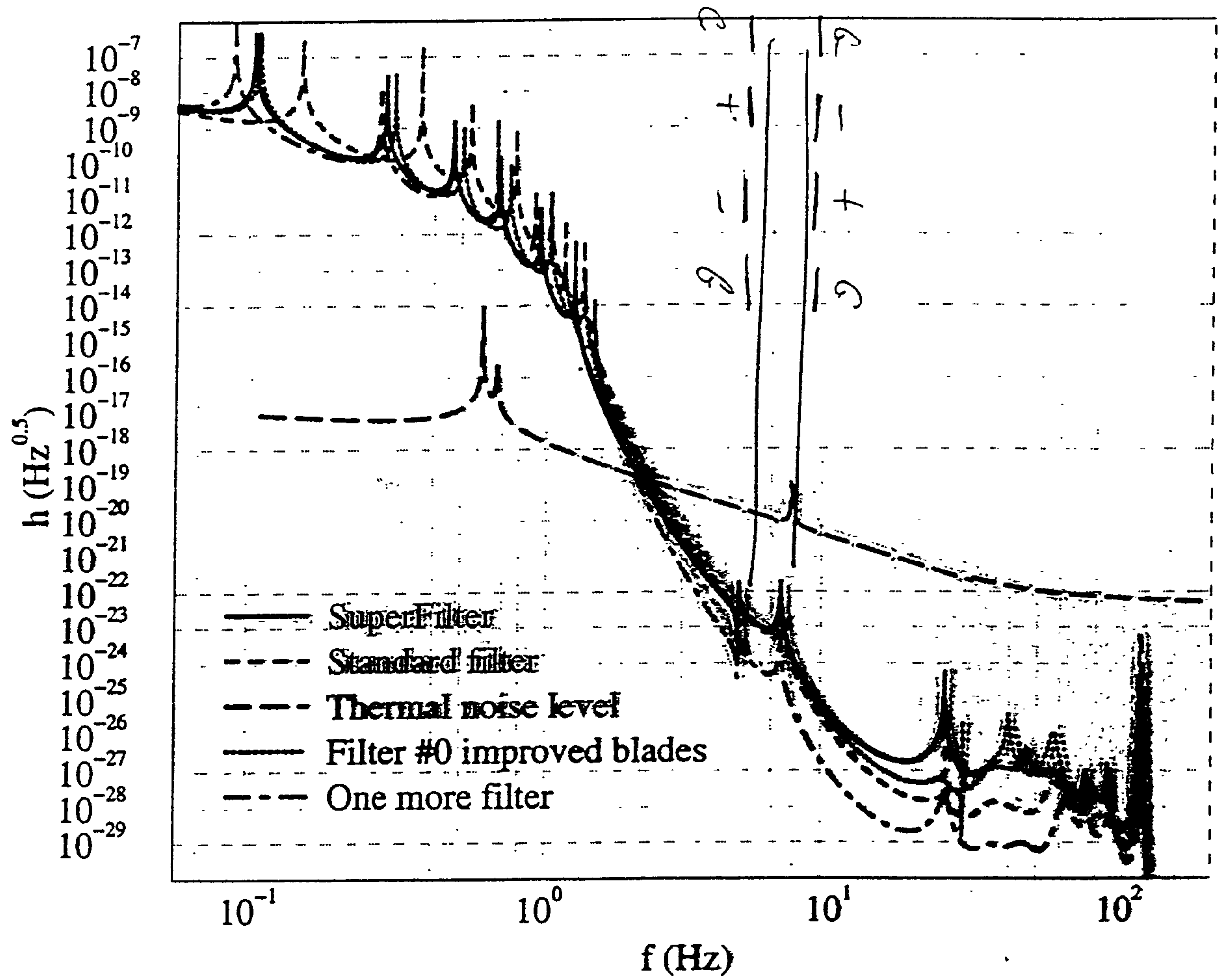
FIG 14



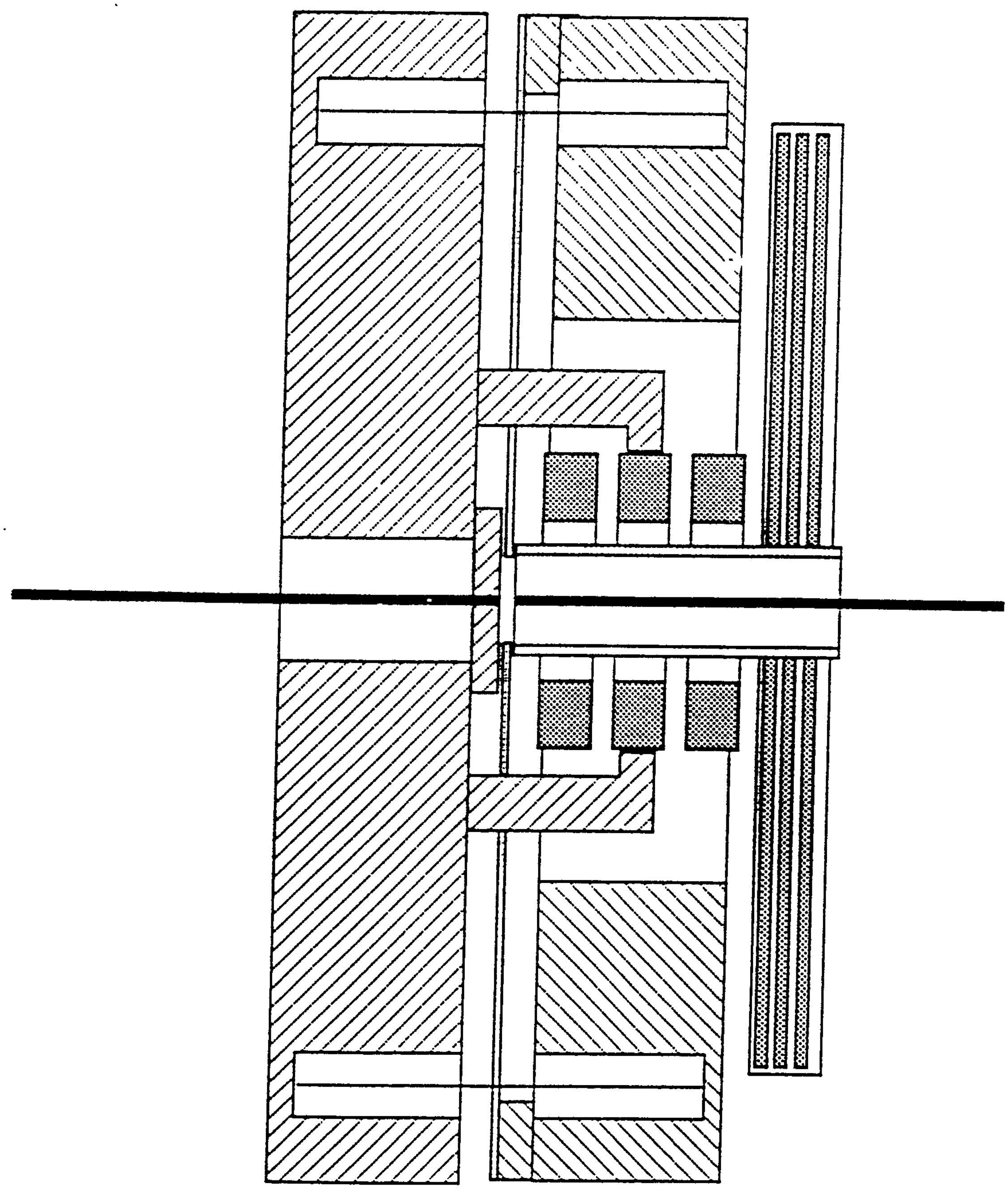


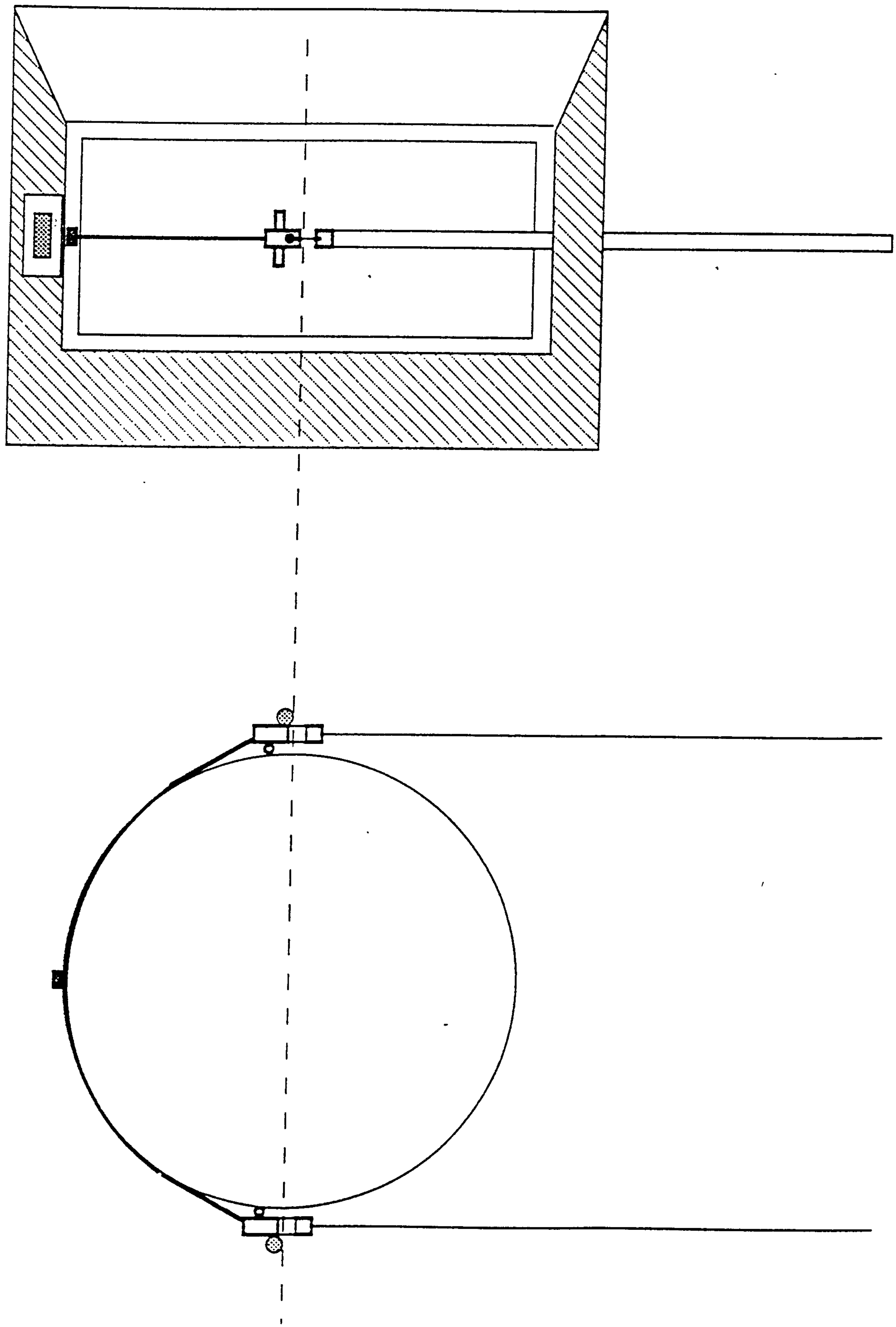
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^{-11}
10^{-12}
10^{-13}
10^{-14}
10^{-15}
10^{-16}
10^{-17}
10^{-18}
10^{-19}
10^{-20}
10^{-21}
10^{-22}
10^{-23}
10^{-24}
10^{-25}
10^{-26}
10^{-27}
10^{-28}
Filtro Standard
Filtro Zero
0,1
1
10
100

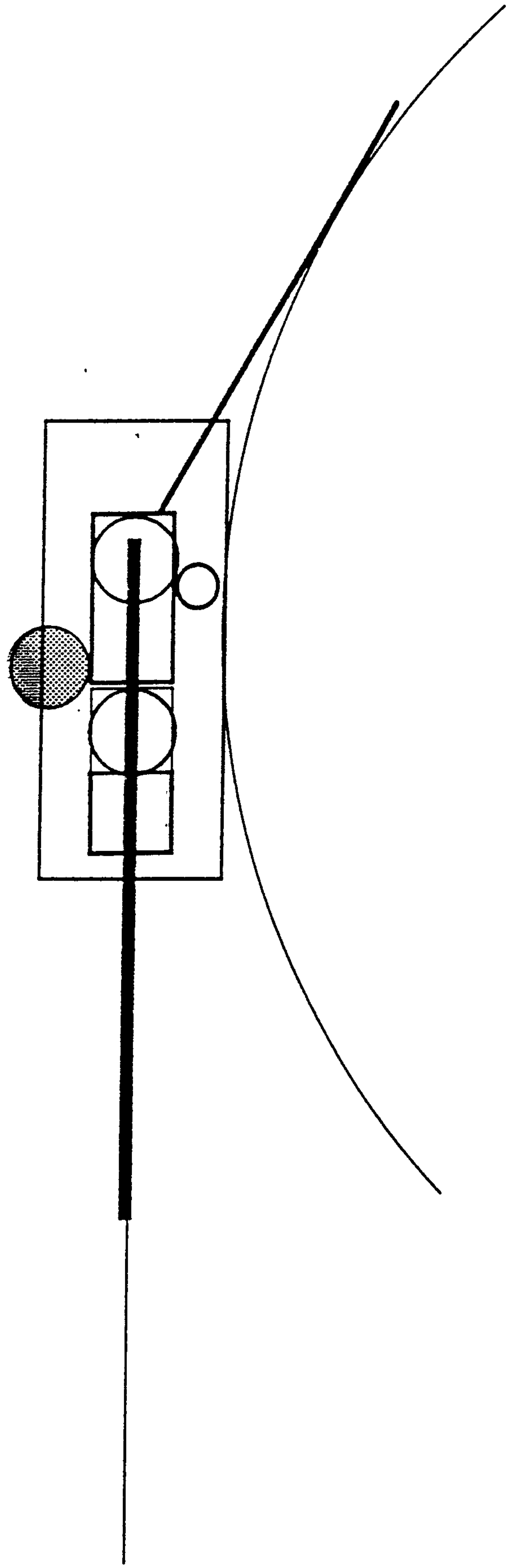
Rumore in h

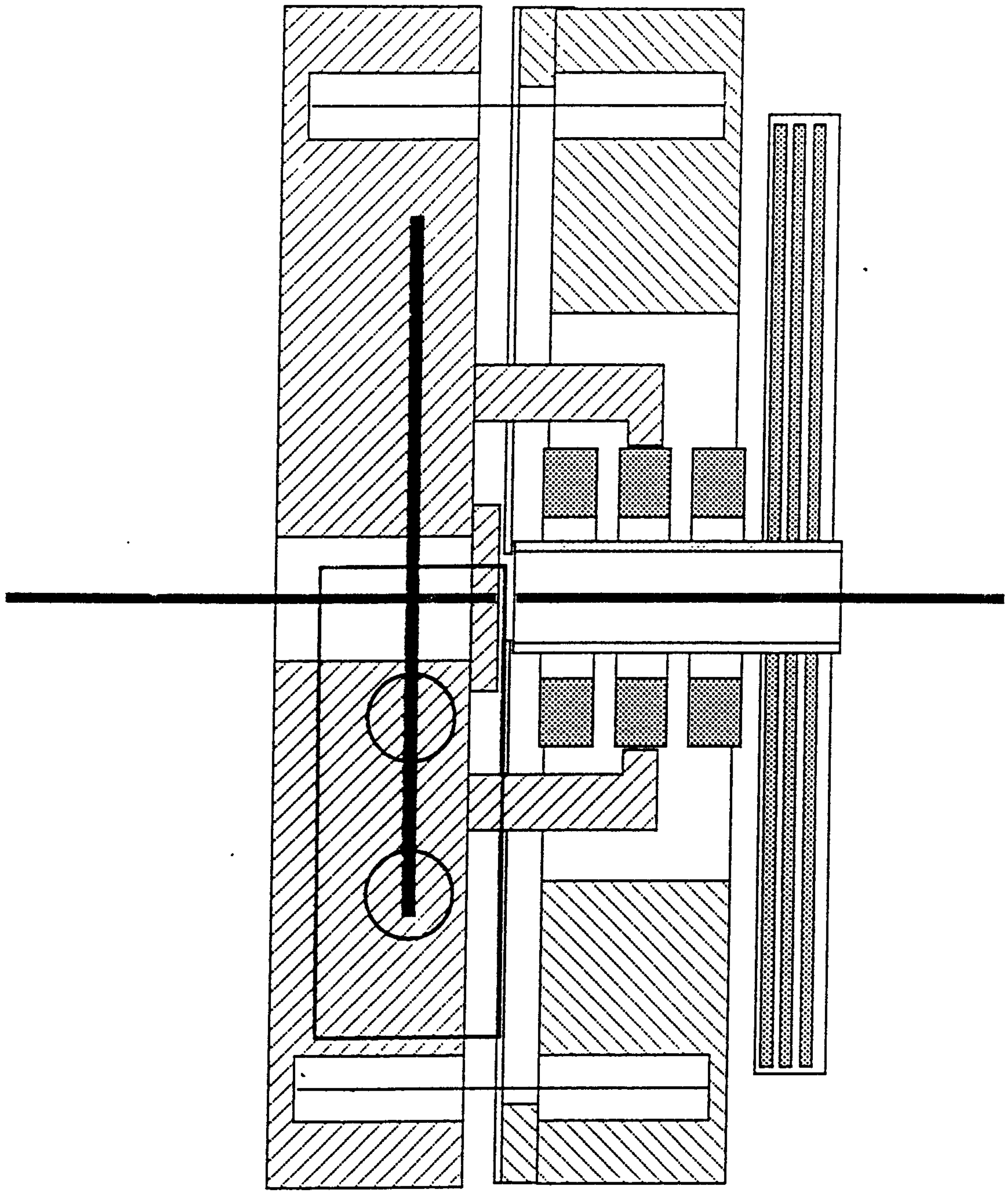


Tutte le soluzioni sono il livello di rumore termico atteso, ma è possibile che i livelli delle risonanze siano errati.









Neutronised State