Nonstationary electrical charge distribution on the fused silica bifilar pendulum and its effect on the mechanical Q-factor

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Motivation

Measuring Q-factor of all fused silica pendulum in the case when plate with gold electrodes was placed under the pendulum bob with separation gap of 1 mm we have found the variance of Q of about 30% in various long lasting runs. This corresponds to additional loss of about 10^{-8} . (Adv. LIGO goal for pendulum $Q^{-1} \approx 5x10^{-9}$).

What is the cause of such variance of the pendulum Q?

May be electrical charges sitting on the fused silica pendulum bob is a cause.

Mechanical loss in fused silica oscillators due to electrical charges or field

Experimental groups in Glasgow Univ., MSU and MIT investigated effect of electrical charges and fields on mechanical loss

Univ. of Glasgow (Class. Quantum Grav., 14 (1997) 1537, **- pendulum mode**

Moscow State Univ. (Phys. Lett. A., 278 (2000) 25, **bifilar pend. torsional mode**

MIT (Rev. Sci. Instrum., 74 (2003) 4840, **internal mode**

They searched losses associated with interaction of charges located on the test mass with environment (Charge of order 10^{11} e/cm^2)

The value and mechanisms of losses are not clear so far (only hypotheses were proposed)

The goal: more detailed search of dissipation in all fused silica pendulum associated with electrical charging

What has to be taken into account when investigating the dissipation associated with electrical charges?

What is a source of losses?

- *Dielectric test mass*
- *Nearby metal*
- *Nearby dielectric*

Aged gold electrodes sputter-deposited on a fused silica plate give minimal loss

What kind of charge may be responsible for the losses?

Volume or surface

Mobile or trapped

Single or dipoles

?

What has to be taken into account when investigating the dissipation associated with electrical charges?

Distance dependence of losses

It is determined by configuration of the charge distribution and other factors. Losses decrease with the distance to the environment. Small distances (less than 100μm) may be dangerous for the Q but they are excluded in the LIGO suspension.

We use a separation gap of about 1 mm to search these losses.

Frequency dependence of losses

No direct measurement are available.

Only indirect evidence for reduction of these losses with increasing of the frequency.

This is why we use pendulum modes to search these losses.

What has to be taken into account when investigating the dissipation associated with electrical charges?

Losses may depend on the history and preparation of the fused silica test mass

- procedure of cleaning of the surface (remainders of substances on the surface)
- presence of adsorbed and absorbed water
- initial distribution of electrical charge on the test mass, in particular due to the contact electrification

The best way to investigate dissipation is to carry out experiments without opening of the vacuum chamber

The line of research

- ***Measurement of Q in the process of gradually increasing of electrical charge located on the fused silica test mass (without opening of the vacuum chamber)***

Initial charge is of order of 10^{-12} C/cm^2 (10^7electron/cm^2)

Deposition of additional charge by means of contact electrification step by step

We have found that after the contact electrification there is a long transient both for the charge and for the change of the amplitude. It required additional investigations.

Experimental setup

Vacuum ***p <*** *10^{-7} Torr (turbopump)*

All fused silica bifilar pendulum:

Mass: 0.5 kg, Fibers: ***d =*** *200 μm,*

Torsion mode ***f*** *$\approx$ 1.14 Hz,*

Quality factor ***Q*** *$\approx 8\times10^{7}$,*

Relaxation time τ^* $\approx 2.2\times10^{7}$ sec,

Initial amplitude ***A*** *$\approx$ 0.03 rad*

Multistrip capacitive probe #1
(*separation gap 1 mm*)

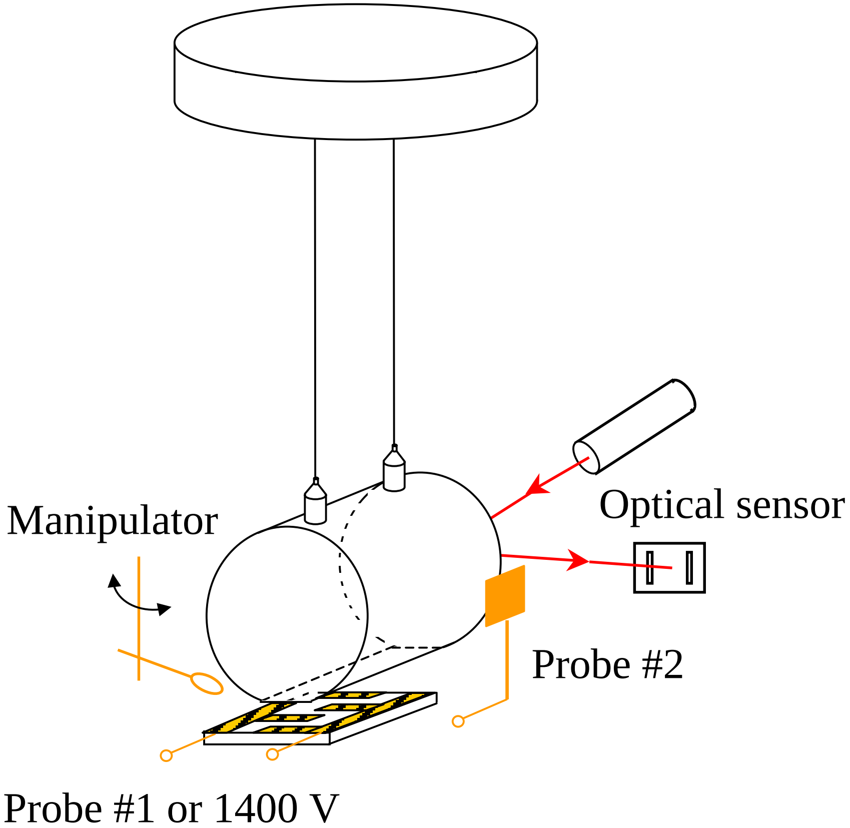
Capacitive probe #2 (*gap 2 cm*)

Both are connected with high impedance amplifiers. Output voltage is proportional to charge and the pendulum amplitude

Optical sensor *to measure amplitude*

Manipulator *to touch the end face by the nickel-chromium wire*

Schematic of all fused silica pendulum with additional arrangements used to investigate effects associated with electrical charging of the cylinder



Relaxation of the charge distribution to the equilibrium state after its disturbance

Deposition of charge from the single contact is of order of

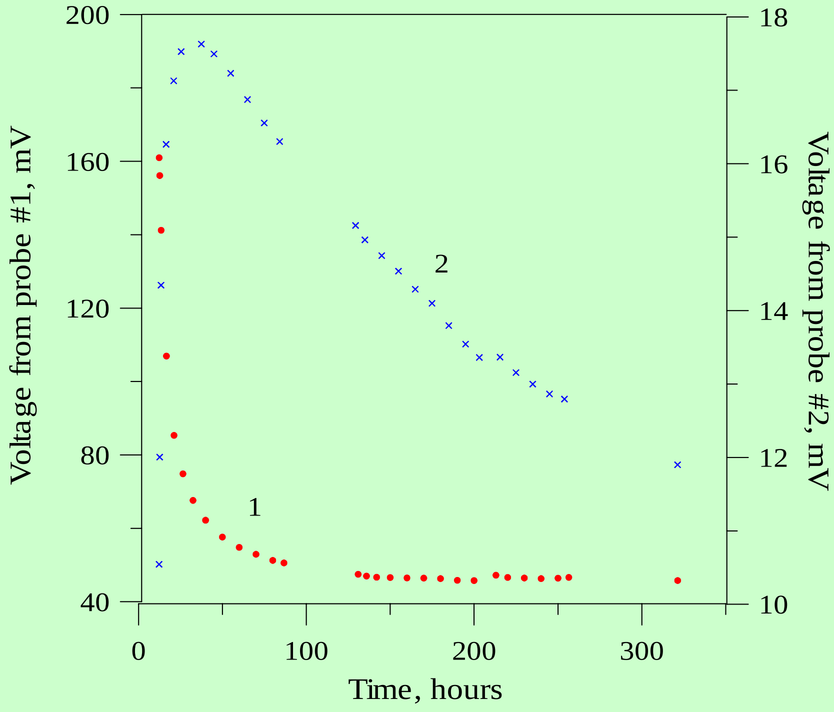
$10^{-13} \div 10^{-11}$ C

Nonexponential relaxation of the charge distribution due to complicated mechanisms of carrier motion in fused silica and due to geometric position of the probe.

Characteristic time $T_{local} \approx$ 10 hours in the beginning and $\approx$ 100 hours at the end (probe #1)

Characteristic time $T_{entire} \approx$ 50 h in the beginning and $\approx$ 200 hours at the end (probe #2)

Time dependence of the probes voltages after electrical charge deposition produced by means of the contact electrification



Free decay of the pendulum amplitude

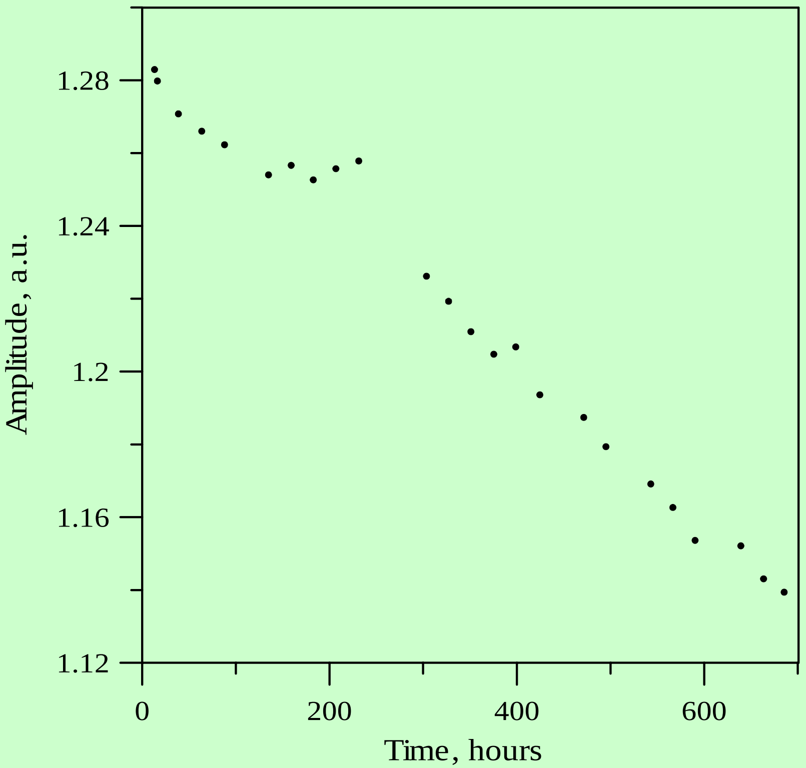
Long lasting mechanical relaxation (variation of the rate of free decay of the amplitude) **with *T of order of 300 hours was observed after the touching.***

It may be associated with modes coupling.

This may be interpreted as variations of Q

$$|\delta Q^{-1}| \approx 10^{-8}$$

Free decay of the pendulum amplitude after electrical charge deposition produced by means of the contact electrification



Relaxation of the charge distribution to the equilibrium state after its disturbance

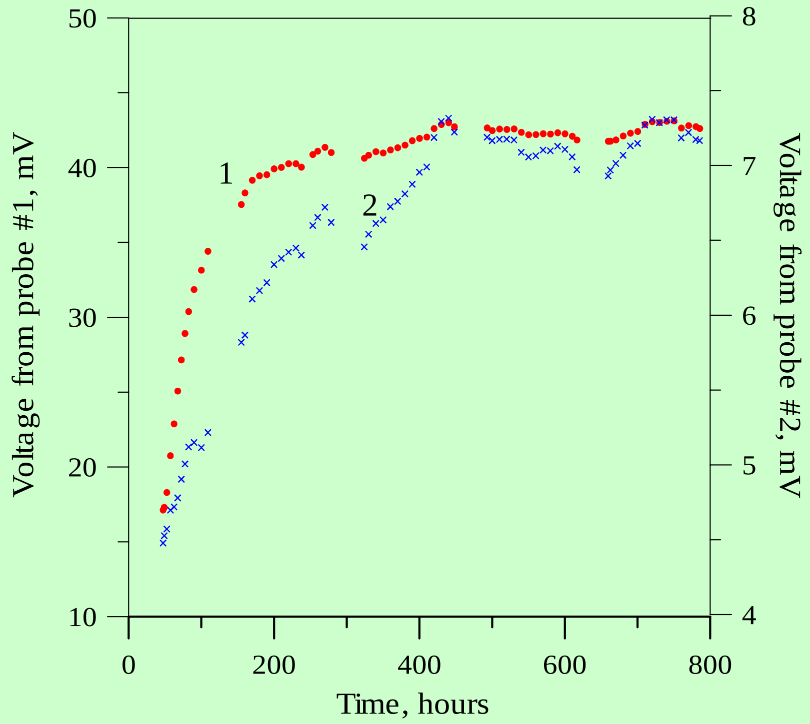
To exclude the large mechanical disturbance from the touching we changed the charge distribution by applying 1400 V to electrodes under the pendulum during 10 h.

Characteristic time $T_{local} \approx$ 20 hours in the beginning and $\approx$ 200 hours at the end (probe #1)

Characteristic time $T_{entire} \approx$ 100 hours in the beginning and $\approx$ 400 hours at the end (probe #2)

***** First 30 hours were omitted to reduce the influence of residual polarization in feedthrough insulators and plate with electrodes.

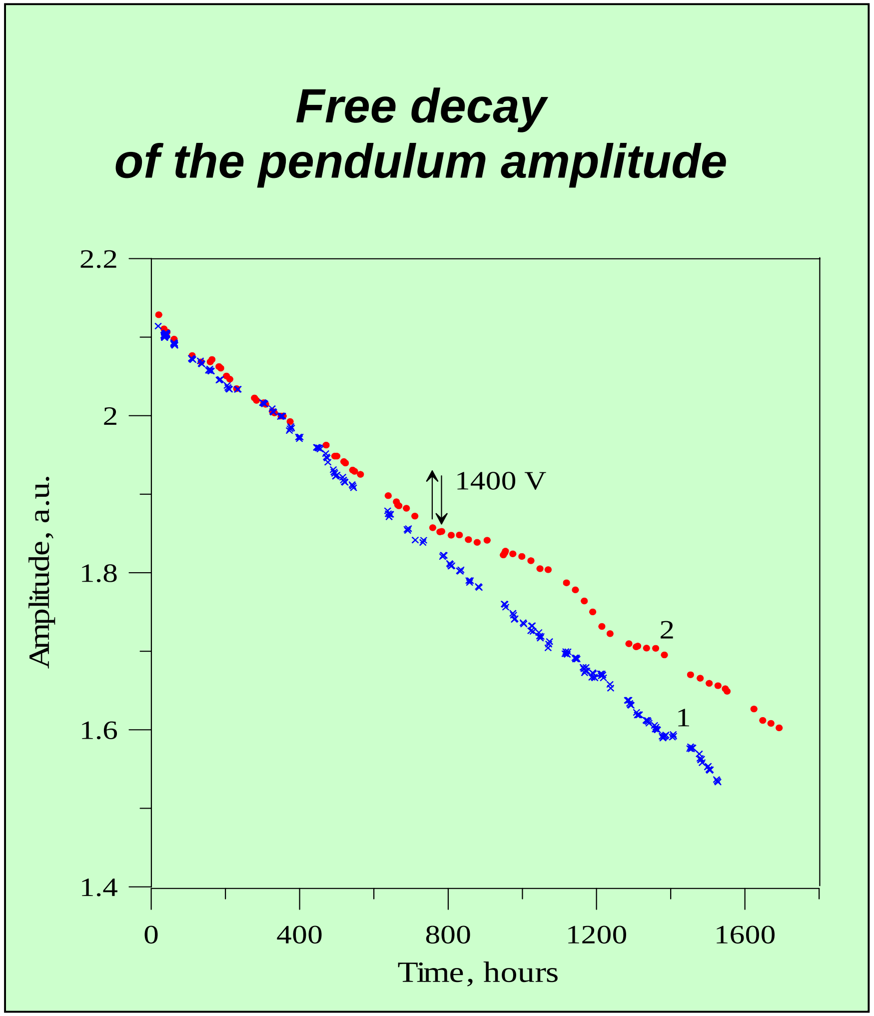
Time dependence of the probes voltages after application of the high voltage*



Free decay of the pendulum amplitude

After application of high voltage and the following transient the losses had a tendency to decrease approaching to the minimal value for this pendulum ($Q = 8x10^7$).

May be it is a result of “shaking” of charges on the fused silica test mass which was swinging continuously in the electric field.



Conclusion

- ***There are many mobile electrical charges on fused silica.***
- ***Relaxation of the charge distribution lasts several hundreds hours and accompanies by variation of the rate of the pendulum amplitude free decay.***
- ***Application of high voltage to electrodes located near the swinging pendulum may be useful for reduction of loss associated with charges.***
- ***The effect of charging on the pendulum Q was relatively small if we did not put a big charge on it. We plan to increase the charge in our experiments step by step. Measurements take a long time.***
- ***We have to have detailed deep knowledge about the behavior of electrical charges, particularly, if the electrostatic actuators will be used for control of the mirrors.***
- ***The work is in progress.***