New Folder Name state of Mirrors

State of the Mirrors: Input Coupling vs. Losses

R. E. Spero

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LIGO-T900020-00-R

Present state of mirrors

The cavity mirrors have recently been cleaned, and input coupler transmissions and cavity storage times have been measured. This is the first time the input mirrors have been cleaned in over two years, because they were previously inaccessible. The input transmissions and storage times are:

	Left Arm	Right Arm
Input Transmission T_1	720 ppm	600 ppm
Half-Energy Storage Time τ_2	176 μsec	189 μsec
$\tau_e = \tau_2/\ln 2$	254 μsec	273 μsec
$\tau_M \equiv 2L/cT_1$	370 μsec	440 μsec
$\beta \equiv \tau_M/\tau_e$	1.46	1.61
$4(\beta - 1)/\beta^2$	0.86	0.94

The uncertainty in T_1 is 20%. τ_2 is the half-life of the intensity in a cavity ringing down; it is pulled from scope traces, and has an uncertainty of approximately 3%.

The significance of τ_M, β, and the last row are described below. The history of storage time measurements of these cavities is shown on the accompanying graph. For completeness, the ringdown data for the mode cleaner are also shown.

Visibility and Coupling

The visibility of each cavity individually is given by[1]

$$V = \frac{4M\gamma_1(1+\gamma_2)}{(1+\gamma_1+\gamma_2)^2} \tag{1}$$

where

$$\gamma_1 = T_1/(L_1 + L_2)$$

[1]See *Contrast, Throughput, and Storage Time*, R.E.S., September 14, 1987, on file. The quantity K in that report identified as "contrast" is more correctly called "visibility"; $V = K$.

$$\gamma_2 = T_2/(L_1 + L_2)$$

R_1, T_1, L_1 and R_2, T_2, L_2 are reflection, transmission, and losses of mirrors 1 and 2, in terms of energy (amplitude squared). Here M is the fraction of the input light correctly mode matched. ($M = 1$ for perfect alignment and mode wavefront curvature matching.)

Defining

$$\chi \equiv \gamma_1/(1 + \gamma_2) = T_1/(T_2 + L_1 + L_2), \tag{2}$$

$$V = \frac{4M\chi}{(1+\chi)^2}. \tag{3}$$

V reaches its maximum value, M, when $\chi = 1$. This corresponds to the well-known optimization, $T_1 = L_1 + L_2 + T_2$.

Optimum Storage Time

The storage time is determined by the reflectivities:

$$\tau_e = \frac{2L}{c}\left[(1 - R_1) + (1 - R_2)\right]^{-1}. \tag{4}$$

Define the ratio of maximum to actual storage time:

$$\beta \equiv \tau_M/\tau_e. \tag{5}$$

Then from Equation 4 and the relation $\tau_M = 2L/cT_1$,

$$\beta = \frac{2 - (R_1 + R_2)}{T_1}. \tag{6}$$

The energy conservation equation, $R_1 + R_2 + T_1 + T_2 + L_1 + L_2 = 2$, then gives the sum of losses other than T_1:

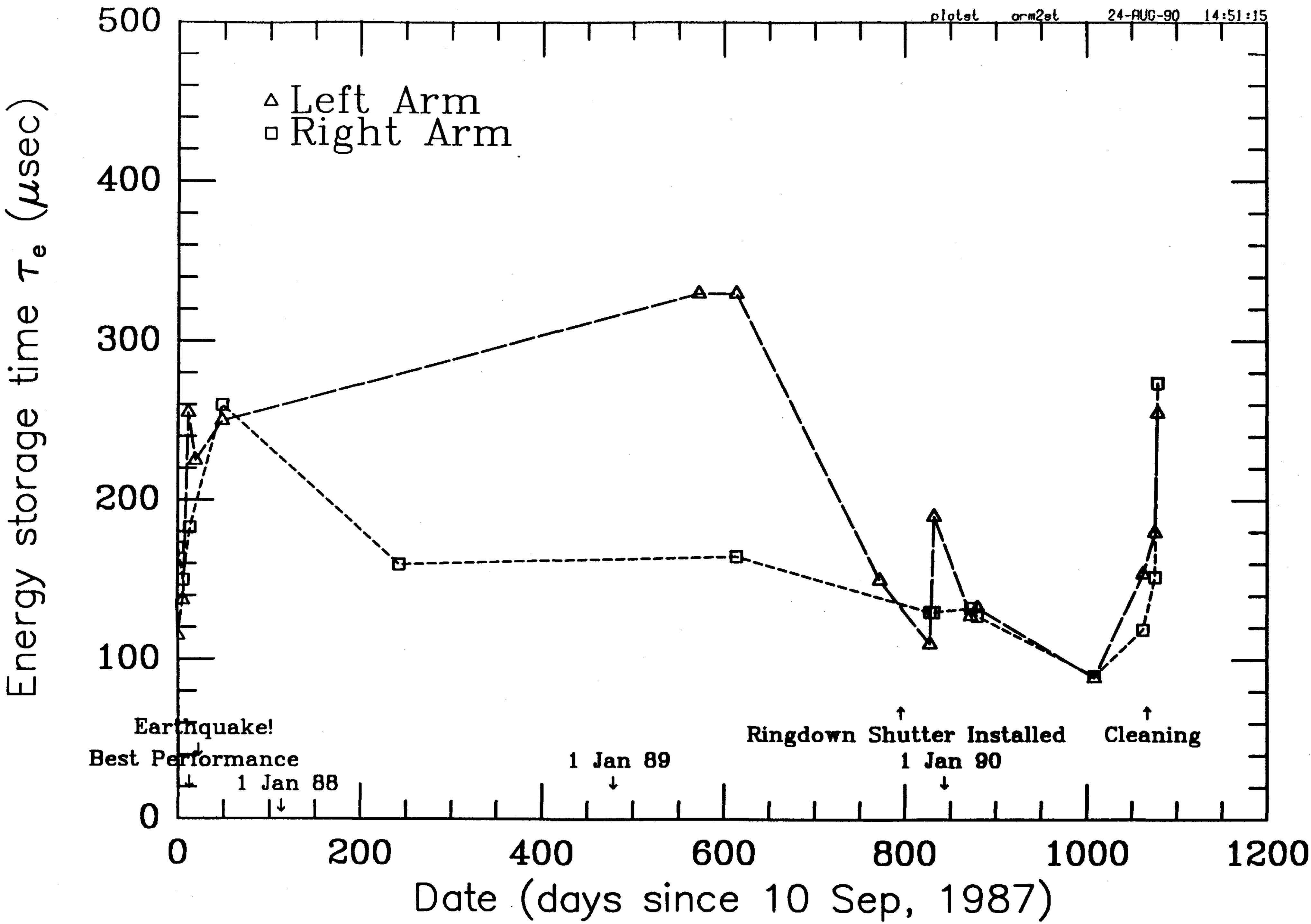
$$L_1 + L_2 + T_2 = T_1(\beta - 1). \tag{7}$$

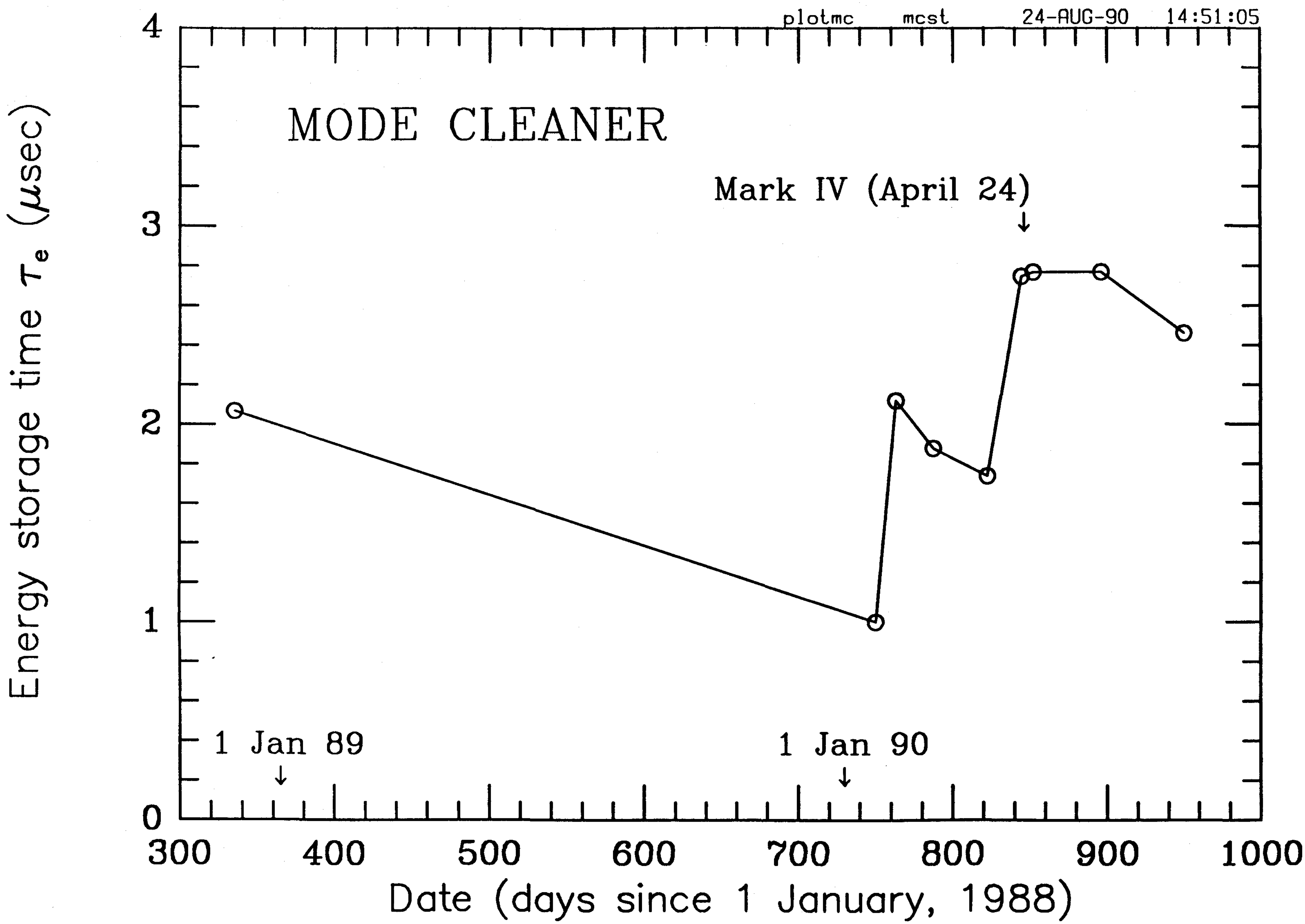
Then from Equations 2 and 3,

$$V = \frac{4M(\beta - 1)}{\beta^2}. \tag{8}$$

The cavity is overcoupled or undercoupled if $\beta < 2$ or $\beta > 2$, respectively. Maximum (100%) visibility is achieved when $\tau_e = \tau_M/2$. Inverting Equation 8, $\beta = \frac{2}{V}\left[M \pm \sqrt{M^2 - MV}\right]$; for $M = .9$ and $V > .8$, β must be in the range $1.5 < \beta < 3.0$.

The mirrors in their current state are overcoupled, allowing maximum visibility of 86% and 94% in the left and right arms, respectively. Given the uncertainty in T_1, this is consistent with $M \lesssim 0.9$ and the observed visibilities $70\% < V < 80\%$.


plotst arm2st 24-AUG-90 14:51:15
Left Arm
Right Arm
Energy storage time τ_e (μsec)
500
400
300
200
100
0
Earthquake!
Best Performance
1 Jan 88
1 Jan 89
Ringdown Shutter Installed
1 Jan 90
Cleaning
0
200
400
600
800
1000
1200
Date (days since 10 Sep, 1987)


plotmc mcst 24-AUG-90 14:51:05
MODE CLEANER
Mark IV (April 24)
1 Jan 89
1 Jan 90
Energy storage time τ_e (μsec)
Date (days since 1 January, 1988)
0
1
2
3
4
300
400
500
600
700
800
900
1000