Design of a new Gouy telescope for the 40m IFO Mode Cleaner Wave Front Sensors

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Abstract

A new Gouy telescope for the Mode Cleaner Wave Front Sensors has been designed. The new layout has been implemented on the Asymmetric Port table. The output matrix has been adjusted on the EPICS panel after diagonalization.

1 Introduction

The Wave Front Sensors (WFS) of the 40m Mode Cleaner (MC) were not well diagonalized, so the necessity to design a new Gouy telescope came out. Once, the new design has been simulated according the required criteria, the new layout has been implemented on the AP table. Two scripts have been used to diagonalize the output matrix of the WFS. As last step, the output matrix has been adjusted on the EPICS panel.

2 The Gouy telescope

The results of the simulation of the new Gouy telescope for the Mode Cleaner (MC) Wave Front Sensors (WFS) are reported here.

First of all, the scheme of the new Gouy telescope mounted on the AP table is shown in Figure (1): the reflected light from the MC goes through a lens L_1 of focal length f_1 at a distance d_1 from the MC; at distance d_{2a} from L_1 the light is split to reach the first WFS, then goes through a second lens L_2 of focal length f_2 at a distance d_{2b} from the splitter; finally, another splitter let the light goes to the second WFS at a distance d_3.

The distances are listed in the Table 1 : d_0 and d_1 are fixed, $d_2 = d_{2a} + d_{2b}$ is the crucial length to determine (actually d_{2a} is fixed as related to the position

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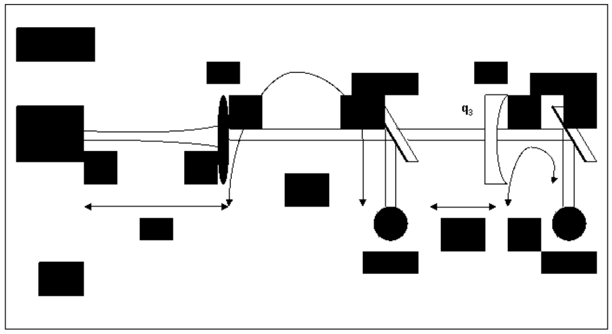

Figure 1: *Asymmetric table (AP)*

of the first WFS, while d_{2b} depends on the position of L_2) and d_3 is calculated using all the other lengths.

The focal lengths of the lenses (nominal and related to the 1064 nm wavelength) and their names in the CVI catalog are listed in Table 2.

Table 1: *Lenses distances*

Distances	[mm]
d_0	0
d_1	1000
d_{2a}	406.4
d_{2b}	2500

Table 2: *Lenses specifications*

Focal length [mm] (nominal)	Focal length [mm] (1064 nm)
1500	1718.3
-25	-29.1

3 Simulation tools of the Gouy phase telescope

The simulation tools to calculate the Gouy telescope parameters can be found in the directory on Sirius machine $/cit/40m/varvella/MC_{WFS}/$; the directory "MC''_{WFS} contains two subdirectories, "matlab" and "mathematica" as two different codes have been used to simulate the optical table layout in Figure 1 in order to doublecheck the results.

3.1 Matlab simulation

The directory "matlab" contains a MATLAB code called "beam" written by Alexei Ourjoumtsev, the correspondent file is "beam.m"; this is a very friendly package that allows one to check the beam characteristics according to the position on the optical table once defined the optical system.

To run this program, open a matlab framework in the directory where the file "beam.m" is and just type "beam", a GUI environment appears.Then, go to "Optical table layout" at the top of the figure, choose "open" from the menu and load the file "$MC_{WFS}.mat''$ located in the same directory: this file contains the settings of the optical system for the new Gouy telescope. You are now ready to simulate the Gouy telescope and to check the beam characteristics all over the optical table. The main beam characteristics at different locations on the optical table are reported in Table 3: the Rayleigh range, the beam size, the waist size, the Gouy phase and the radius of curvature (ROC).

Table 3: *Gouy telescope parameters*

	Rayleigh range [mm]	beam size [mm]	waist size [mm]	Gouy phase [deg]	ROC [mm]
q_0	8106.871	1.657	1.657	0	8106.871
q_1	8106.871	1.6696	1.657	7.032	8244.4743
q_2	8106.871	1.6696	1.657	7.032	8244.4743
q_{2a}	276.4906	1.2302	0.30601	10.8747	342.0961
q_3	276.4906	0.30659	0.30601	90	277.016
q_4	276.4906	0.30659	0.30601	90	277.016
q_5	276.4906	1.6893	0.027355	94.191	136.4419

The same "matlab" directory contains a graph, corresponding to the files "graph.fig" and "graph.eps"shown in Figure 2. The top figure is the beam size in millimeters from the MC reflected light to the second WFS. The bottom figure is the Gouy phase in degrees for the same distance; the positions of the two lenses are marked.

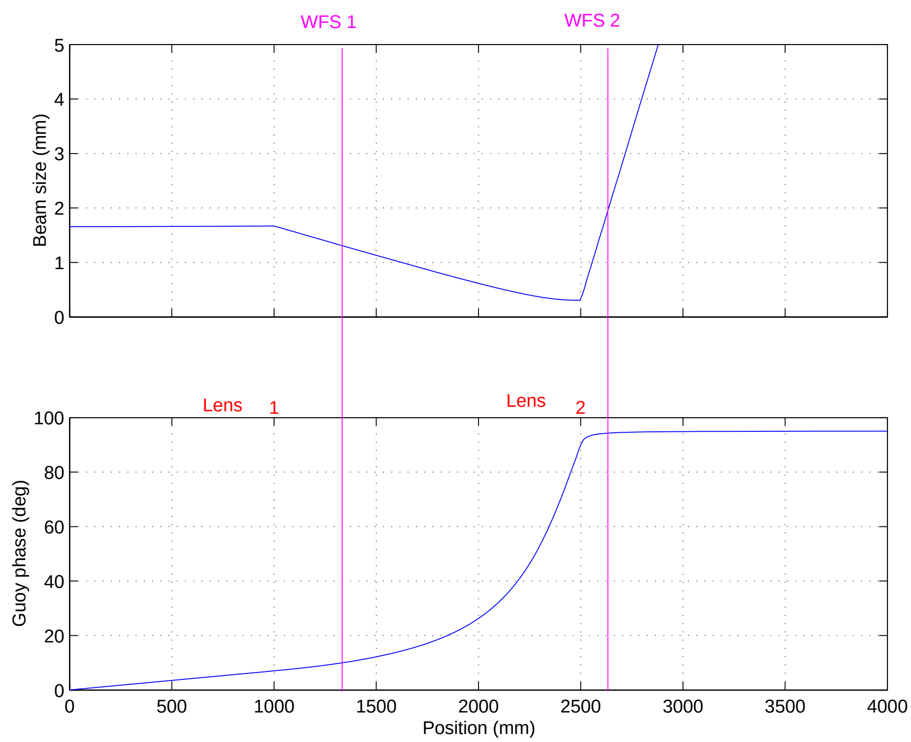

Figure 2: *Lenses and WFS positions.*

3.2 Mathematica simulation

The other procedure is less friendly for the user but gets the same results.

The second directory, called "mathematica" and located in the main directory "MC_WFS''", contains a Mathematica code written by G.Heinzel, then adapted by Hartmut Grote to compute the autoalignment of LIGO Livingston interferometer WFS1 at AP port and now adapted for the WFS of the 40m MC. The code is in the file "$MC\_WFS.nb''$", contained in one single mathematica cell: it is sufficient to open a Mathematica framework in the same directory.

Referring to Table 1, the distances d_0 and d_1 are fixed at the same values, while d_2 is determined by the program and d_3 has been fixed as for the Matlab simulation. The focal length of the two lenses are the same than in Table 2. The calculated distance between the two lenses L_1 and L_2 is $d_2 = 1.47719\ m$. Table 4 summarizes the main values of the beam size and the Gouy phase.

Table 4: *Gouy telescope parameters*

Rayleigh range	beam size [mm]	Gouy phase [deg]
q_0	1.657	0
q_1, q_2	1.6851	10.4827
q_3, q_4	0.306591	74.8195
q_5	3.49514	90.5795

The directory "mathematica" contains also two graphs, "aalens1.gif" and "aalens2.gif" corresponding to the beam size in millimeters (Figure 3) and the Gouy phase in degrees (Figure 4)for all the optical path.

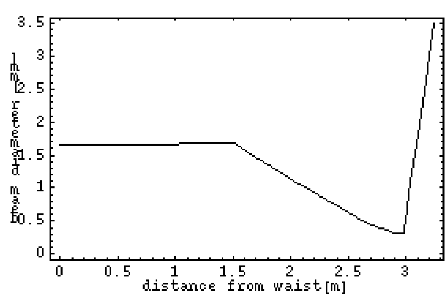

Figure 3: *Beam size*

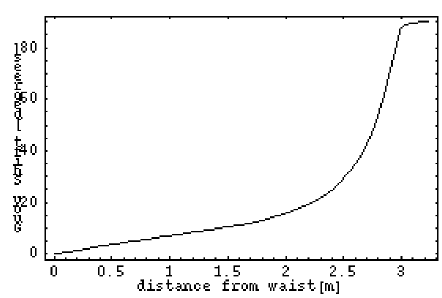

Figure 4: *Gouy phase*

4 MC WFS recommissioning

Once the simulation gave an idea of the location of the WFS lenses have been installed on the Asymmetric Port (AP) table. The WFS are tilted of 45 degrees allowing their quadrants to be combined more robustly. According to the simulation results the first WFS has been placed at 16 inches (406.4 mm) from the first lens, i.e. the converging one. The second lens has been placed 44 inches (1117.6 mm) from the first lens, utilizing folding mirrors. Finally, the second WFS has been placed after the second lens choosing an appropriate beam size.

Since the 45 degree rotation, the appropriate matrix had to be put in the *WFS_Setting* screens.

4.1 WFS Scripts

The diagonalization of the output matrix is based on driving the MC2 Pitch and maximizing the signal in the I quadrature because each of the quadrants is sensitive to both the Pitch and the Yaw motion. The first step is measuring the PITCH and YAW for the two WFS This procedure is done by a script located in the directory */cvs/cds/caltech/scripts/MC/WFS*; the script is named "sens" and it is a csh file. When it runs it gives automatically two data channels, one for PITCH and the other for YAW. At the end of the script there is a variable that has to be given to the MATLAB file "MCWFSanalyze.m". This file gives the sensing matrix for the WFS, compares the new values with the existing ones and assign the new values to the output matrix. Unfortunately this last task is not totally automatically done by the script: some improvements are needed for this last step.

Figure (5) shows the EPICS panel of the output matrix of the MC WFS with the values calculated by the script: the correspondent files calculated by sense are *pit_060622_1635.txt* and *yaw_060622_1635.txt* that can be inserted in the MATLAB file to re-calculate the values of the output matrix.

The diagnostics of the output matrix has been started too: the purpose is to create a 4x4 matrix and check the elements off-diagonal. In the same directory */cvs/cds/caltech/scripts/MC/WFS* there is the file "SensActDiag" that is a csh file.

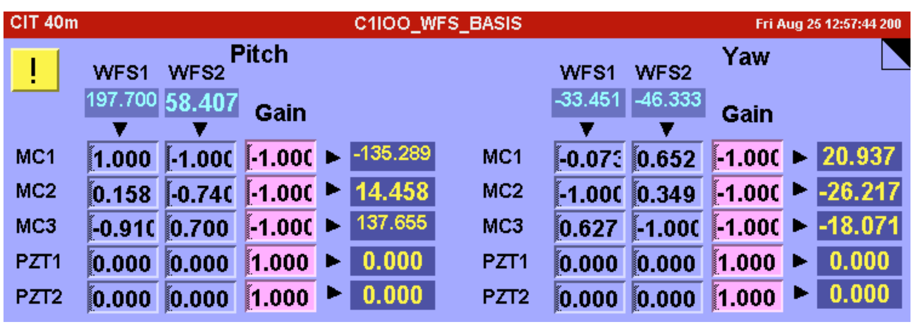

Figure 5: *EPICS panel of the WFSs output matrix*

4.2 MC WFS loop gains

The loop gains for the MC WFS have been measured for the Pitch and Yaw angles. Figure (6) shows the four transfer functions (Pitch and Yaw for WFS1 and Pitch and Yaw for WFS2). The unity gain frequency (UGF) has been set at 2 Hz for all the loops.

Table (5) shows the gain values for the two WFS for Pitch and Yaw.

Table 5: *WFS gain*

channel	gain
$C1 : IOO - WFS1\_PIT\_GAIN$	-0.5
$C1 : IOO - WFS1\_YAW\_GAIN$	-0.15
$C1 : IOO - WFS2\_PIT\_GAIN$	-0.333
$C1 : IOO - WFS2\_YAW\_GAIN$	-0.2

5 Conclusion

A new Gouy telescope for the Mode Cleaner Wave Front Sensors has been designed and implemented on the Asymmetric Port table. The output matrix and the gain values of the WFSs loops have been adjusted on the EPICS panel after having diagonalized the system.

References

[1] 40m Proposal.
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[2] 40m website.
http://www.ligo.caltech.edu/~ajw/40m_upgrade.html

[3] 40m/AdvLIGO Parameters.
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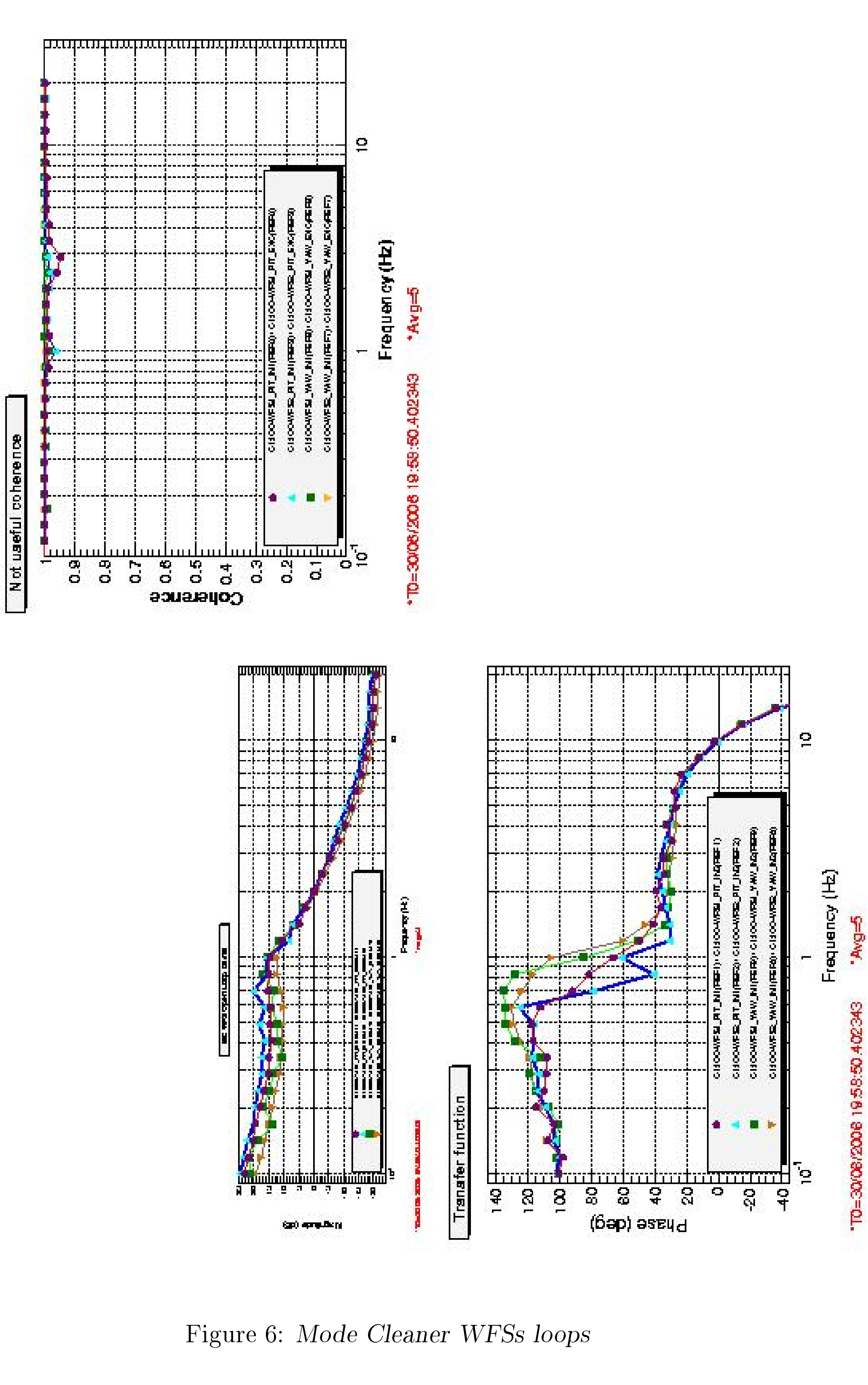

Figure 6: *Mode Cleaner WFSs loops*