LIGO-T1100603: TMS Telescope Alignment Procedure

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1   Introduction and Prerequisite

This document briefly describes the TMS alignment procedure which originally started from LIGO-T1100258 -v4 and evolved considerably both in procedure and equipments. Readers are simply referred to LIGO-T1100258 -v4 whenever it makes sense.

2   References

1. M. Smith and V. Sannibale, "TMS Telescope Alignment", LIGO-T1100258-v4

2. K. Kawabe, "Requirement For Adjustment Procedure Of Advanced LIGO Transmission Monitor Telescope", LIGO-T1100600

3. M. Evans, "ISC Alignment Sources", LIGO-T1100474-v1

4. B. Slagmolen, M. Evens and K. Kawabe, "TMSY Telescope focal tuning results", LIGO-G1101254-v1

5. John Smith, "TMS Pedestal Setup", LIGO-Txxxxxx.

3 Initial Assembly and Setup

See LIGO-T1100258-v4, Section 2.1.

3.1 Experimental Setup

See Figure 1 for experimental setup.

The reference plane is the inside surface of the primary plate.

The pedestal has a breadboard, on which a light source for the fine adjustment as well as the ModeMaster head for beam profile measurement are set up.

The distance between the front edge of the pedestal and the primary plate should be about 2 meters. Though it is not important to set it exactly, it is important to measure the distance from the reference plane to the ModeMaster head, and from the reference plane to the fiber launcher telescope.

3.2 Note on Autocollimators

Autocollimators are never used in double path configuration in this document. This is because the adjustment range of the autocollimators we use is not large enough to accommodate the wave front curvature the telescope adds to any incoming field when the telescope is close to an ideal tuning.

Also note that there is at least one, and in some cases two, condition(s) where users cannot measure the angle of the reflected beam with an autocollimator even if a clear reticle pattern is observed. One is an internal reflection inside the autocollimator itself. It is easy to distinguish this from a true image reflected off of a mirror by by blocking the exit hole of the autocollimator. If it goes away it is a true image. The other condition is more troublesome, as the image does go away when the exit hole is blocked, but the reticle pattern appears to be insensitive to the mirror angle. Empirically, this never happens if the optical system under investigation comprises only flat mirrors and space.
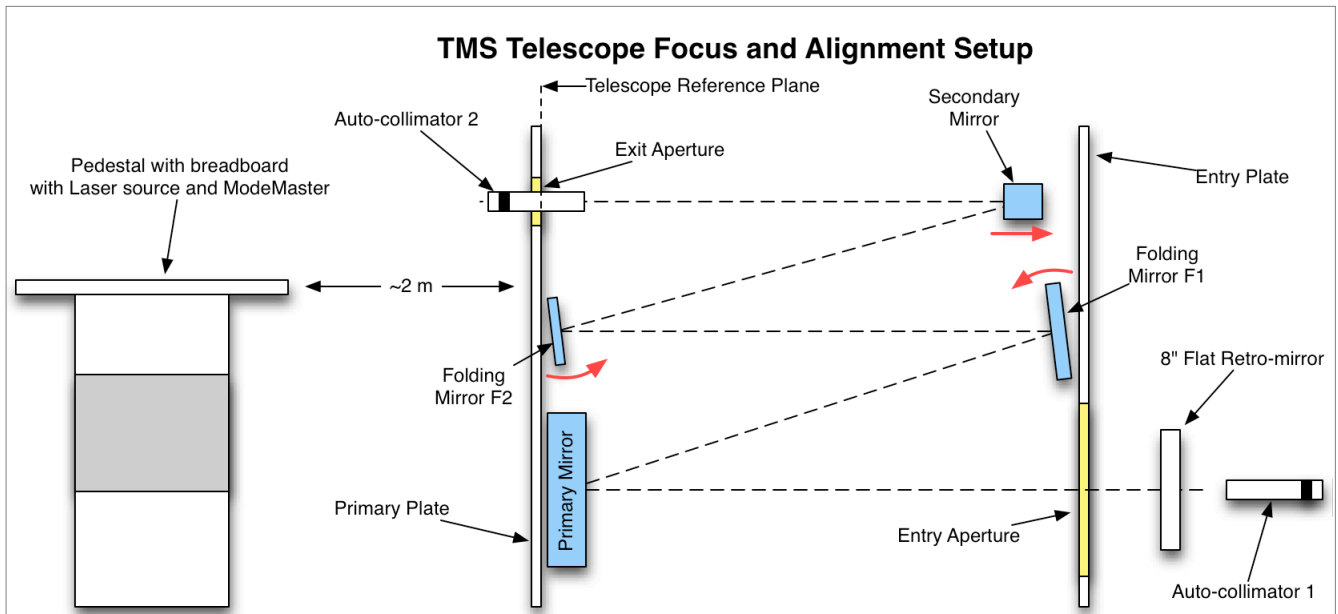
Figure 1: Experimental setup. Autocollimators are primarily used for rough adjustment. On the pedestal are the laser source and ModeMaster that are to be used in the fine adjustment procedure.

3.3 Note on Light Source for Fine Adjustment.

We use a fiber-coupled laser as our light source for fine adjustment. See LIGO-T1100474 . Though the laser profile after the light leaves the launcher telescope was already measured, it is recommended to measure the profile every time the apparatus is moved and/or reassembled.

See for the H2:TMSY source measurement G1101254, as well as the final telescope tuning results.

3.4 Numbers Needed Before You Start

Before starting alignment, you need to measure and write down the following numbers at least:

- ⚥ Beam profile numbers of the laser beam to be injected:
  - ⚥ Waist radius.
  - ⚥ Waist position measured from the secondary mirror.
  - ⚥ (Half-)Divergence angle.
  - ⚥ Rayleigh range.
  - ⚥ M^2.
- ⚥ Distance from the reference plane to the ModeMaster head.
- ⚥ Distance from the 8-inch mirror reflective surface to the outer surface of the entry aperture.

Using these numbers, run a matlab script (see the end of this document) to obtain an ideal beam profile of the returning beam in double path configuration when the telescope is ideally set up.

3.5 Necessary Tools

- ⚥ Computer running ModeMaster and Matlab. ModeMaster requires Windows, though Windows in virtual machine works fine.

- ⚔ Assortment of class B tools.
- ⚔ Specialized class B tools for this procedure, such as allen key for secondary mirror mount adjustment.
- ⚔ CCD camera and a monitor.
- ⚔ Usual assortment of tools for IR laser work, e.g. IR viewer cards, IR viewer, and laser goggles/glasses, all wiped using iso-propanol.

4 Rough Alignment Using Autocollimators

4.1 Secondary Mirror Holder Rough Adjustment

4.1.1 Rough Angle Adjustment

- ⚔ Mount the autocollimator #2 (AC2) to the primary plate exit hole using the autocollimator holder bushings. To minimize the reproducibility problem, make sure that only the metal part of the autocollimator contacts the bushing.
- ⚔ Install a 1.5 inch parallel mirror into the secondary mirror mount using screws and washers.
- ⚔ Adjust the focus of AC2 until you see a reticle pattern of the returning beam.
- ⚔ This can be done using your eye through the eyepiece, or project the image through the eyepiece onto a clean paper laminated in plastic. Either is fine, though you need to be careful about the parallax when looking through the eyepiece.
- ⚔ Adjust the angle of the secondary mirror holder until the reticle pattern in AC2 is centered.

4.1.2 Rough Lateral Adjustment

- ⚔ Uninstall the 1.5 inch mirror and mount the secondary mirror plug on the secondary mirror holder of the telescope.
- ⚔ Using a light source connected to AC2, adjust the focus of AC2 to project a reticle pattern onto the plug. The plug should have a scribed lines showing the center. Move the secondary mirror holder laterally and horizontally so the cross hair centers on the center of the plug.
- ⚔ Alternatively, you can also use the eyepiece of AC2 and check the centering on the plug through AC2.

4.1.3 Iterating Over

- ⚔ Go back to the configuration with 1.5 inch mirror. If the reticle pattern is not centered, adjust the secondary mirror mount angle and go back to the plug configuration.
- ⚔ Repeat until it converges, though just one run is usually good enough.

4.1.4 Rough Focal Adjustment

This is done according to T1100258-v4, Section 2.2.2.

- ⚔ Remove the autocollimator holder and place a 0.25 thick mirror against the mounting pads of the autocollimator holder in the inside face of the telescope back plate. The mirror faces toward the outside of the telescope.
- ⚔ Use the focus gauge rod to set the distance between the 2ndary mirror metal alignment plug and the back of the mirror—adjust the focus screw on the 2ndary mirror mount until the gauge rod touches both the metal alignment plug and the back of the mirror.

4.2 Installing Secondary Mirror

⌖ Install AC2 again.
⌖ Install an alignment helper plug for the folding mirror #2 (FM2) holder.
⌖ Install the secondary mirror to the secondary holder.
⌖ Adjust the focus of AC2 so you can look at the FM2 alignment plug.
⌖ The secondary can rotate in the holder. Adjust the rotation until there is no yaw offset on the FM2 plug seen from AC2.

4.3 Primary Mirror Installation and Rough Adjustment

4.3.1 Setting up Autocollimator #1

⌖ Install the primary alignment disk on the primary plate.
⌖ Place the autocollimator #1 (AC1), mounted on 4-degrees-of-freedom stage, in front of the entry aperture of the entry plate. You need enough space between AC1 and the plate so that you can insert a 8-inch flat mirror later.
⌖ Use AC1 as an autocollimator and adjust the angle of AC1 until the reticle pattern centers on the cross hair.
⌖ Use AC1 as a telescope and adjust the lateral position of AC1 until it looks at the center of the alignment disk.
⌖ Check if AC1 is still properly angled by going back to autocollimation. If necessary, switch back and forth between autocollimation and telescope until it converges.

4.3.2 Mounting Primary Mirror

⌖ Install a metal alignment plug for the Folding Mirror 1 (FM1).
⌖ Remove the primary alignment disk and install the primary mirror.
⌖ Adjust the focus of AC1 so you can look at FM1 alignment plug.
⌖ The mirror can rotate inside the mirror mount. Rotate the primary mirror such that there is no yaw offset on the FM1 plug seen from AC1.

4.4 FM1 and FM2 Installation and Rough Adjustment

⌖ Install FM1 and FM2.
⌖ Install a metal alignment plug for autocollimator on AC2.
⌖ Project a reticle pattern on AC2 plug from AC1.
⌖ Adjust FM1 angle until the reticle pattern is centered on AC2 plug.
⌖ Remove AC2 plug and install it on AC1.
⌖ Project a reticle pattern on AC1 plug from AC2.
⌖ Adjust FM2 angle until the reticle pattern is centered on AC1 plug.

5 Fine Adjustment

5.1 Setting Up the Pedestal

See Document XXXXXXXX.

5.2 Installing 8-inch Flat Mirror

⚔ An 8-inch flat mirror is placed between AC1 and the front (or entry) plate.

⚔ Use AC1 as an autocollimator to set the angle of the flat mirror.

⚔ When done, don't uninstall AC1 just in case you need to go back to the earlier stage.

5.3 Installing Irises

⚔ Install an adjustable iris mounted on a ½ inch class 2 rod in front of the secondary mirror between the secondary and AC2. The rod is attached to a class 2 cross clamp, which is attached to another ½ inch class 2 rod, and this rod is screwed onto the entry plate through one of the top holes on the plate.

⚔ Use AC2 to precisely center the iris.

⚔ Flip AC2 so it points to the pedestal.

⚔ Install an iris on the breadboard on the pedestal.

⚔ Use AC2 to precisely center the iris on the pedestal.

⚔ Remove AC2.

5.4 Fine Adjustment

⚔ Turn the laser on.

⚔ Inject the laser through the two irises. Make sure that the beam is centered on iris using CCD camera.

⚔ Most probably the beam is not coming back centered. This is OK. Adjust FM1 and FM2 so the beam is reasonably centered on the primary and clears the irises at the same time.

⚔ Measure the returning beam using ModeMaster. Make many measurements, as the current in the air disturbs the measurement, and sometimes what seems to be a mechanical "bump" in a lens translation mechanism makes an ugly scan. Discard ugly data and accumulate at least 5 sets of good measurements.

⚔ Use the statistics function of ModeMaster to see the mean and the standard deviation of beam parameters. Compare the waist radius, the waist position and the divergence angle with the ideal profile numbers obtained before you started the adjustment procedure (see Section) and judge if you want to make the telescope longer or shorter.

⚔ Adjust the telescope lens by turning the focus adjustment screw of the secondary mirror mount.

　　⚔ This will cause the misalignment mainly in pitch. Adjust FM1 and FM2 such that the beam is still reasonably centered on the primary and the beam clears irises at the same time.

　　⚔ Don't try to center the beam on FM1 and FM2.

⚔ Measure the beam profile. Repeat measurement-adjustment cycles.

⚔ As you get closer to the ideal profile, you'll want to adjust the astigmatism by tilting the secondary.

⚔ Repeat. Stop when all three parameters (i.e. waist radius, waist position and divergence angle)

are inside the tolerance range shown by the matlab script.

See G1101254 for telescope tuning results, as well as the final telescope tuning.

6 Mating and Aligning the Table to the Telescope

6.1 Initial Table Alignment

⚵ Install all mirrors, beam-splitters, beam-dumps and QPD sleds as per D1201457 for X and D1201458 for Y, except for the ALS receiving mirror (M8). Note: we will use the mirror labels from D1201457 and D1201458.

⚵ In place of ALS receiving mirror, place a mounted collimator, of which a 532nm fiber couple laser is attached (**PIC**)

⚵ Use green beam to align mirrors M3 and M6, until the beam is centered on the periscope hole.

⚵ Lay a flat window over the hole to retro-reflect the beam green beam.

⚵ Adjust mirrors M3 and M6 until the green beam reflects back on itself, while keeping it centered.

⚵ Adjust mirrors M1 and M2 until the green beam that is transmitted through M3 is centered on the QPDs in the green QPD sled.

⚵ Some of the retro-reflected green light will be reflected off of M4, how much depends on the polarization. Use this 'ghost beam' to roughly align mirrors M4 and M9-M15. If the ghost beam is too faint, use a Half Wave Plate or a Quarter Wave Plate or both, to increase the power of the ghost beam

⚵ Align M4, M14 and M15 until the green ghost beam is centered on the QPDs in the infrared QPD sled.

⚵ Align M12, M11 and M9 until this beam is centered in the beam dump.

⚵ Align M10 to center of M13.

6.2 Mating the Table and Telescope

⚵ Mount two irises to telescope, between exit aperture and secondary. Ensure there is enough room between exit aperture and iris to eventually fit bottom periscope mirror. (**PIC**)

⚵ Secure the telescope with stabilization bars.

⚵ Dis-mount the telescope from the 'Telescope Alignment Bridge' (D1100460).

⚵ Move to the lower optical table and secure with stabilization bars. Be sure to place the telescope so that there will be enough room to fit the bridge and 8" retro mirror. Some planning may be required.

⚵ Mount the table on top of the telescope.

⚵ Secure table to telescope with three bolts and washers.

⚵ Place 'TMS Tele and Table Alignment Bridge' (D1100531) over mated telescope-table assembly. Attach bridge vertical support bars to the table. Raise the bridge height to suspend the mated telescope-table assembly.

6.3 Align table mirrors to Telescope

⚔ Move higher table next to the lower table (**distance?**) on the ALS receiving mirror side.

⚔ Remove the mounted fiber collimator and replace it with the ALS receiving mirror.

⚔ Mount the collimator in a holder (PART NUMBER), attach 4 (PART NUMBER) posts in the holes of holder. Mount the fiber collimator holder to the rotation plate (PART NUMBER). Mount the rotation stage on a post, and the post to the translation stage. (PICS OF END PRODUCT)

⚔ Place rotatable collimator on high table, so that beam is pointing towards ALS receiving mirror.

⚔ Set the declination angle of the rotation plate to 20.5 degrees. Move this stage until the beam is centered on the ALS receiving mirror, while maintaining its orientation.

⚔ Make sure the green beam is centered on the hole and reflects back on itself (lay the window over the whole again. If its not, adjust the fiber collimator and ALS receiving mirror.

⚔ Install the bottom periscope mirror under the table.

⚔ Adjust this mirror and the previous steering mirror until the green beam is centered on both irises. At this point the laser alignment into the telescope should be the same as that used during the focusing.

⚔ The iris in front of the secondary may be blocking the reflected beam. If this is the case mount another iris, upstream of this iris, to the bottom of the table, and center on the beam. Remove the iris in front of the secondary mirror.

⚔ Place the 8" retro mirror at the entry aperture.

⚔ Adjust the 8" retro in pitch and yaw until the return green beam is centered on the back of the irises. Note: The return beam may be difficult to find. Closing one of the irises and increasing the power of the green beam may help (ELABORATE).

⚔ Align the green beam that is transmitted through M3, using M1 and M2 so that it is centered on the green QPDs.

⚔ Align the leakage beam through the beam splitter, to the QPD sled.

6.4 Infrared mirror alignment

⚔ Set-up fiber coupled infrared laser, in a rotation stage, same as green laser

⚔ Adjust position until laser beam is centered on the infrared exiting mirror.

⚔ Use the ghost green beam to help align the infrared beam into the telescope.

⚔ Align the return beam to the QPD sled.

7 Sample Matlab Script

Below is a verbatim copy of a matlab script used for generating the final result plot in LIGO-G1101254. It uses BeamPath matlab script.

```
clear all
close all
%% some constants. Don't change these.
```

```
YAG=1.064e-6;% IR light
nom_Det=2.58636e-3; % nominal detuning in meters
n_air= 1.00027398; %http://refractiveindex.info/?group=GASES&material=Air
offsets=(-0.7:0.01:0.4)*1e-3; % offset of the telescope, in mm
figidx=0;
detuningTolerance=[-0.5 +0.2]*1e-3;


%% input parameters. Change these as you wish.
wSH=[ 1 1 ] * 2.85e-3; % input beam waist radius.
waistPos=[-2 -2]; % zero=at the secondary, minus means upstream of the secondary
% the above two are used as a pair and should have the same number of data.

%% Set MM input parameter correctly if you want to use it for final adjustment.
MM2retro=2.83-.63627+.56; % distance from MM head to the telescope back plate (i.e. the one with primary)
reference plane (i.e. inside surface).

%% telescope parameters.
retro2sec=.63627;
returnROC=zeros(length(wSH), length(offsets)); % storage space for return beam geometry
returnWidth=zeros(length(wSH), length(offsets));
returnWaist=zeros(length(wSH), length(offsets));
returnZ=zeros(length(wSH), length(offsets));
returnDiv=zeros(length(wSH), length(offsets));

%% Modemaster double path results
MMW=[.811 .863]*1e-3/2; %radius mean [X Y]
MMWstd=[.0307 0.0293]*1e-3/2; % radius std [X Y]

MMZ= - [-1.458, -1.417]-(MM2retro+retro2sec) ; % waist pos mean [X Y]
 % Zero means that the waist is at the 2ndary
 % Positive mean = waist is downstream of the 2ndary towards MM
MMZstd=[ .0262 0.0081]; % the data was minus! what?

MMDiv=[2.79  2.75] /2 *1e-3; % divergence angle (half), radian
MMDivstd=[0.061    0.041]/2 *1e-3;% divergence angle (half), std
% actual detuning based on interpolation from MM results
off_interpW=[0 0];
off_interpZ=[0 0];
off_interpDiv=[0 0];
%%
for kk = 1:length(wSH);
   for ii=1:length(offsets);
      clear mypath;
      %% Source laser beam
      mypath = beamPath;

      mypath.seedz=0-1e-6; % secondary position
      mypath.seedq = beamq(-waistPos(kk) + 1i*pi*(wSH(kk))^2 / YAG ); % q parameter at the secondary

      %% telescope system
      Tele2ROC= -0.2; % secondary focal length -0.1m
      zTele2 = 1e-6; %on the secondary is the waist of S-H beam when offsets==0.

      Tele1ROC=4; %primary focal length 2m
      % nominally correct pri-sec spacing when offsets=0.
      % This is 2.6mm off of a truly afocal system,
      % i.e. distance = 1.9m + 2.6mm.
      % Though it is different from the actual procedure, we assume that
```

```matlab
        % the secondary doesn't move and instead the primary is adjusted.
        dTele2_1=((Tele1ROC+Tele2ROC)/2 +nom_Det+offsets(ii));%*n_air;
        zTele1 = zTele2+dTele2_1;

%       ReflectorROC1=-1.548671e+03; % ETM-like mibrror including the lens of the substrate
        ReflectorROC1=inf; % flat mirror

        dTele1_Reflector=0.9-offsets(ii); % 0.9m is somewhat arbitrary,
        zReflector=zTele1+dTele1_Reflector;

        % add a return path
        zTele1_return = zReflector+dTele1_Reflector;
        zTele2_return = zTele1_return + dTele2_1;
        zZeroPosition_return = zTele2_return+zTele2;
        %%
        mypath.addComponent(component.curvedMirror(Tele2ROC, zTele2, 'sec1'));
        mypath.addComponent(component.curvedMirror(Tele1ROC, zTele1, 'pri1'));
        mypath.addComponent(component.curvedMirror(ReflectorROC1, zReflector, 'refl'));
        mypath.addComponent(component.curvedMirror(Tele1ROC, zTele1_return, 'pri2'));
        mypath.addComponent(component.curvedMirror(Tele2ROC, zTele2_return, 'sec2'));
        %%
        qout = mypath.qPropagate(zZeroPosition_return);
        mypath.targetq=qout;
        returnROC(kk, ii)=qout.radiusOfCurvature;
        returnWidth(kk, ii)=qout.beamWidth;
        returnWaist(kk, ii)=qout.waistSize;
        returnZ(kk, ii)=qout.waistZ;
        returnDiv(kk, ii)=qout.divergenceAngle;
        mypath.targetz=zZeroPosition_return;
        qReflector = mypath.qPropagate(zReflector);
        ReflectorP=beamPath;
        ReflectorP.seedWaist(1, 1,  YAG/n_air); % this is just to set lambda
        ReflectorP.seedq=qReflector;
        ReflectorP.seedz=zReflector;
        %%
        if offsets(ii)==0 |offsets(ii)==-2;
            figure
            z=-1:0.01:(zZeroPosition_return+1);
            mypath.plotBeamWidth(z);
            hold on
%           set(gca, 'yscale', 'log')
            mypath.plotComponents(z);
            mypath.plotBeams(z);
            ReflectorP.plotBeams(z);
            title(['w=' num2str(wSH(kk)*1e3) 'mm waist injected, ' num2str(offsets(ii) ) ' mm offset in primary-
secondary distance, flat ETM'])
            figidx=figidx+1;
            print('-depsc', ['beamsize_flatETM' num2str( figidx) '.ps'])
        end
    end

    % find detuning point close to measured W and Z
    [dummy, idx]=min(abs(returnWaist(kk,:)-MMW(kk)));
    if idx(1)==1
        idx1=1; idx2=2;
    elseif idx(1)==length(offsets);
        idx1=length(offsets)-1; idx2=length(offsets);
    elseif (MMW(kk)-returnWaist(kk,idx(1)))*(MMW(kk)-returnWaist(kk, idx(1)+1))<0
        idx1=idx(1); idx2=idx1+1;
```

```matlab
    else
        idx1=idx(1)-1; idx2=idx1;
    end

    if returnWaist(kk, idx2)==returnWaist(kk, idx1)
        off_interpW(kk)=mean(offsets(idx1:idx2));
    else
        off_interpW(kk)=(offsets(idx1)*(returnWaist(kk, idx2)-MMW(kk)) + offsets(idx2)*(MMW(kk)-returnWaist(kk, idx1)))/(returnWaist(kk, idx2)-returnWaist(kk, idx1));
    end

    [dummy, idx]=min(abs(returnZ(kk,:)-MMZ(kk)));
    if idx(1)==1
        idx1=1; idx2=2;
    elseif idx(1)==length(offsets);
        idx1=length(offsets)-1; idx2=length(offsets);
    elseif (MMZ(kk)-returnZ(kk, idx(1)))*(MMZ(kk)-returnZ(kk, idx(1)+1))<0
        idx1=idx(1); idx2=idx1+1;
    else
        idx1=idx(1)-1; idx2=idx1;
    end
    if returnZ(kk, idx2)==returnZ(kk, idx1)
        off_interpZ(kk)=mean(offsets(idx1:idx2));
    else
        off_interpZ(kk)=(offsets(idx1)*(returnZ(kk, idx2)-MMZ(kk)) + offsets(idx2)*(MMZ(kk)-returnZ(kk, idx1)))/(returnZ(kk, idx2)-returnZ(kk, idx1));
    end

    [dummy, idx]=min(abs(returnDiv(kk,:)-MMDiv(kk)));
    if idx(1)==1
        idx1=1; idx2=2;
    elseif idx(1)==length(offsets);
        idx1=length(offsets)-1; idx2=length(offsets);
    elseif (MMDiv(kk)-returnDiv(kk, idx(1)))*(MMDiv(kk)-returnDiv(kk, idx(1)+1))<0
        idx1=idx(1); idx2=idx1+1;
    else
        idx1=idx(1)-1; idx2=idx1;
    end
    if returnDiv(kk, idx2)==returnDiv(kk, idx1)
        off_interpZ(kk)=mean(offsets(idx1:idx2));
    else
        off_interpDiv(kk)=(offsets(idx1)*(returnDiv(kk, idx2)-MMDiv(kk)) + offsets(idx2)*(MMDiv(kk)-returnDiv(kk, idx1)))/(returnDiv(kk, idx2)-returnDiv(kk, idx1));
    end

    figure
    subplot 311
    plot(offsets, returnWaist(kk, :), 'r');%, offsets, returnWidth(kk, :));
    hold on
    errorbar(off_interpW(kk), MMW(kk),  MMWstd(kk), 'g');
    plot([1 1]*detuningTolerance(1), [min(returnWaist(kk, :)), max(returnWaist(kk, :))], 'k', ...
        [1 1]*detuningTolerance(2), [min(returnWaist(kk, :)), max(returnWaist(kk, :))], 'k')
    ylim([min(returnWaist(kk, :)), max(returnWaist(kk, :))]);
    legend('Gaussian calc from measured input', 'measured \pm std(10)');%, 'width@sec')
    ylabel('return waist radius (m)')
    grid on
    title(['w=' num2str(wSH(kk)*1e3) 'mm waist injected'])
    subplot 312
    plot(offsets, returnZ(kk, :), 'r');
```

```matlab
    hold on
    errorbar(off_interpZ(kk), MMZ(kk),  MMZstd(kk), 'g');
    plot([1 1]*detuningTolerance(1), [min(returnZ(kk, :)), max(returnZ(kk, :))], 'k', ...
        [1 1]*detuningTolerance(2), [min(returnZ(kk, :)), max(returnZ(kk, :))], 'k')
    ylim([min(returnZ(kk, :)), max(returnZ(kk, :))]);
    ylabel('return waist pos (m)')
    grid on
    subplot 313
    plot(offsets, returnDiv(kk, :), 'r')
    hold on
    errorbar(off_interpDiv(kk), MMDiv(kk),  MMDivstd(kk), 'g');
    plot([1 1]*detuningTolerance(1), [min(returnDiv(kk, :)), max(returnDiv(kk, :))], 'k', ...
        [1 1]*detuningTolerance(2), [min(returnDiv(kk, :)), max(returnDiv(kk, :))], 'k')
    ylim([min(returnDiv(kk, :)), max(returnDiv(kk, :))]);

    grid on
    ylabel('return div angle (rad)')
    xlabel('tele offset (m)');
    FillPage('tall')
    figidx=figidx+1;
    print('-depsc', ['beamsize_flatETM' num2str( figidx) '.ps'])

    %%
end
%%

system(['cat beamsize_flatETM?.ps > beamsize_design_flatETM_all_' date '.ps; ps2pdf
beamsize_design_flatETM_all_' date '.ps; rm *ps'])
```