MrFit: Deformable mirror simulator

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1 Introduction

MrFit is a program for simulation of membrane and continuous facesheet deformable mirrors (DM). ("Mr" means mirror and "Fit" means to fit a specified wavefront). It calculates the voltages which should be applied to the actuators, to achieve the best possible to a given wavefront aberration. As an output, the program calculates surfaces the mirror shape and the approximation error surface.

The demo version of the software works only with the mirror files supplied by OKO Technologies: three files for a 15-mm 37-ch membrane mirror and 2 files for a 30mm 37-ch piezoelectric continuous facesheet mirror. These files have extensions ".ef".

The full version of the software is able to calculate the influence functions based on the actuator geometry, both for membrane and continuous faceplate mirrors.

2 Theory

Consider a DM with N actuators. The shape of the mirror surface can be calculated as:

$$F(x,y) = \sum_{i=1}^{N} P_i * \phi_i(x,y). \tag{1}$$

where i is a number of an actuator, ϕ_i is a mirror i'th influence function (response to a unit voltage applied to the i'th actuator) and P_i is the voltage applied to actuator.

An aberrated wavefront Ψ has to be approximated by the DM, resulting in an optimization problem: to find the values of P_i which make the mirror shape F most close to the wavefront Ψ. Mathematically it can be expressed as:

$$min_{P_i} \int_{S} \left(\Psi - \sum_{i=1}^{N} P_i * \phi_i \right)^2 ds \tag{2}$$

, where S is the mirror aperture. Applying the necessary conditions of the extremum, the problem of Eq.(2) can be converted to a system of linear equations which can be solved numerically by the calculation of the inverse

system matrix. However, in practise the maximum and minimum values of the voltage are limited by the mirror hardware. If some of the calculated voltages exceed the limits, MrFit can perform a constrained optimization to find the best approximation allowed by the hardware.

3   User interface

The program window is presented in Fig.1.

Figure 1: Program window

It consists of three main parts presenting graphical and text data for the reference wavefront, the mirror and the approximation error. In the down left corner of the program window the current working directory (where all calculation results are saved) is displayed. Immediately after the program starts, the working directory is set to the program own folder. However after a user has loaded the wavefront data the working directory of the program changes to the location of the loaded wavefront file. In Figure 1 the following situation is demonstrated: a spherical aberration (wavefront deviation is from -1μ to 1μ) was approximated by the 37 channels PDM mirror (mirror name is displayed in the middle of the window above the iterferogram: "37 actuators d0.030 h1"). A user can see the interferograms of the aberrated wavefront, the mirror surface and the error surface - the difference between wavefront and mirror surfaces. For each of the surfaces text data below

the iterferograms represents the calculated difference between the maximum and the minimum values (peak-to-peak) and RMS deviation of the surface calculated according to Eq.3.

$$f_{rms} = \frac{\sqrt{\int\limits_S (f - f_0)^2 \, ds}}{S}.$$ (3)

In Eq.(3) f_0 is the mean value of the function f. Sometimes, if the interferogram is difficult to interpret, it can be convenient to see the surface as a gray-scale image, where the brighter pixel corresponds to the higher point on the surface. It is possible to switch between interferogram and gray-scale representations using program menu as demonstrated in Fig.2.
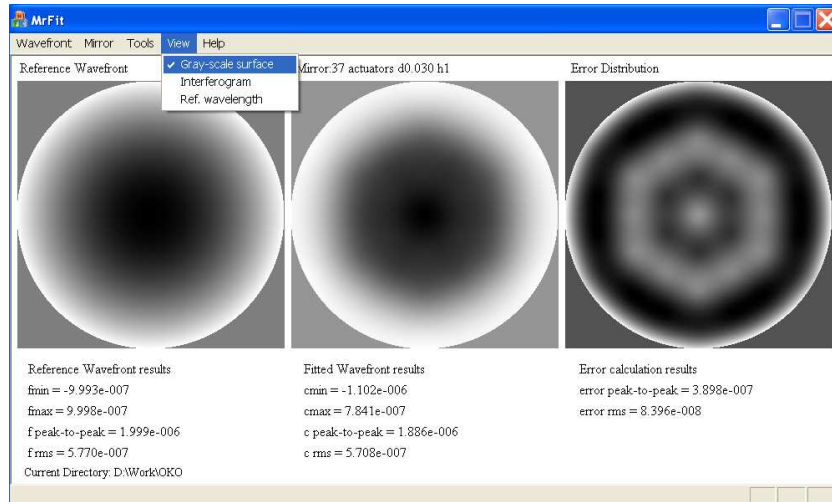

Figure 2: Program window. Gray-scale representation of surfaces.

It is also possible to change the wavelength on the basis of which interferograms are calculated using the button "Ref. wavelength" in the menu.

3.1 Wavefront

The operation starts with the loading of the wavefront data using the menu shown in Fig.3. A user has a choice to define the wavefront via the coefficients of Zernike polynomials or to load a wavefront defined as a 2D matrix with dimensions of 320 by 320. For the first option a .txt file containing three space

separated columns has to be created. The integer numbers in the first and second columns define Zernike polynomials while the numbers in the third column define the corresponding amplitude of the polynomials. Example of the wavefront definition via Zernike polynomials is given in the Appendix A. Wavefront matrix should be defined in a .dat or .txt file using space separated columns.
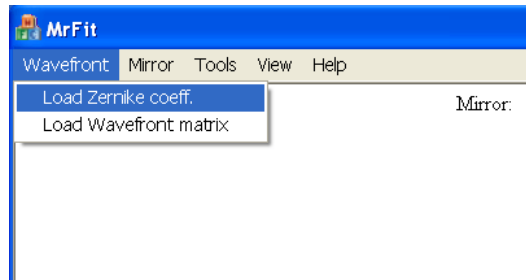

Figure 3: Program menu. Loading wavefront data.

After the wavefront is loaded, the program draws the interferogram to demonstrate it's shape and calculates the peak and RMS values.
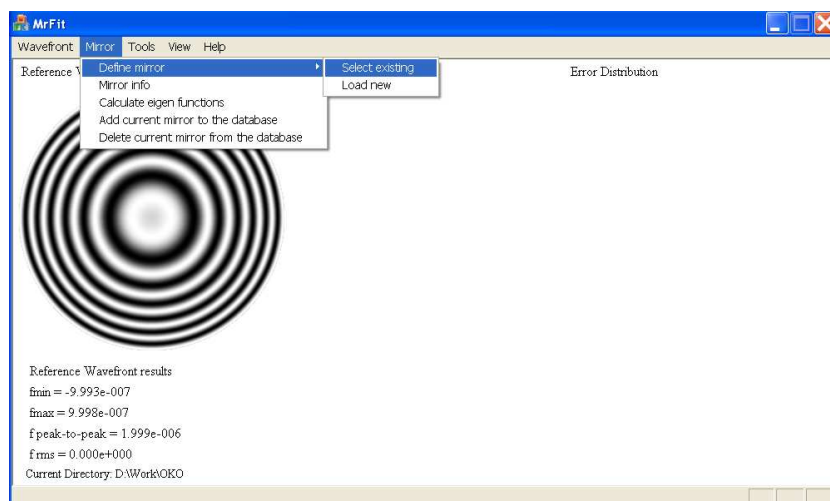

Figure 4: Program menu. Work with a mirror, wavefront data is already loaded.

3.2 Mirror

MrFit allows various operations to be done with the deformable mirror. The user can define a DM using a .txt (for PDM mirrors) or .bmp (for MMDM mirros) file. Examples of the PDM and MMDM mirror definitions are given in the Appendices B and C respectively. A full version of MrFit is capable to calculate mirror influence functions and save them in a database. The functions are stored in files with the extension ".ef" and the information about all available mirrors is stored in a single database file "mirrors.mrf". As soon as MrFit starts, it checks whether the file "mirrors.mrf" is available in the working directory and if the file is found the program reads the information about the available mirrors. The free MrFit version can not calculate eigen functions for a user defined mirror and works with the database supplied with the program. The functions responsible for the mirror definition, selection from database, saving or deleting from database are located in the program menu "Mirror" as presented in Fig. 4. The mirror to work with can be selected from the database via menu "Mirror− >Define mirror− >Select existing". The selection dialog presents all available mirrors sorted by type (piezo-electric or membrane) as shown in Fig.5.
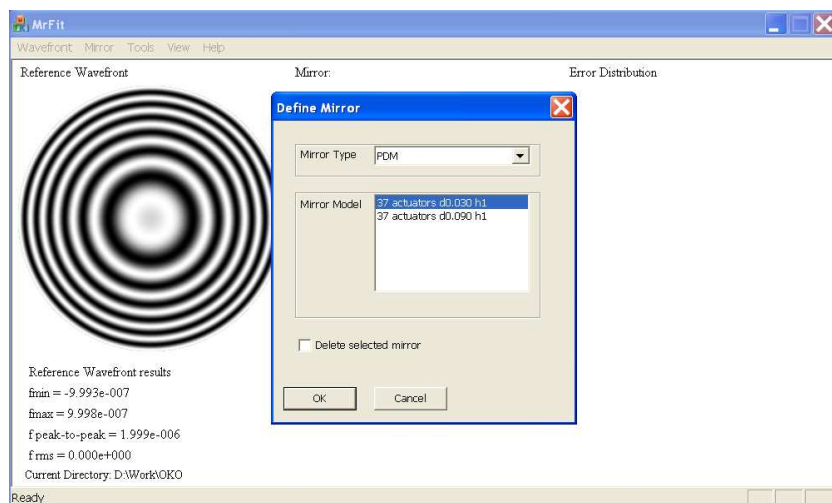

Figure 5: Program menu. Select a mirror available in the database.

In case you don't need anymore one of the mirrors stored in the database, you can select checkbox "Delete selected mirror" and press OK button. An ".ef" file can be also loaded via menu "Mirror− >Define mirror− >Load

new". In the appearing file open dialog window ".ef" extension should be chosen. Then it is possible to work with the mirror defined by that file.
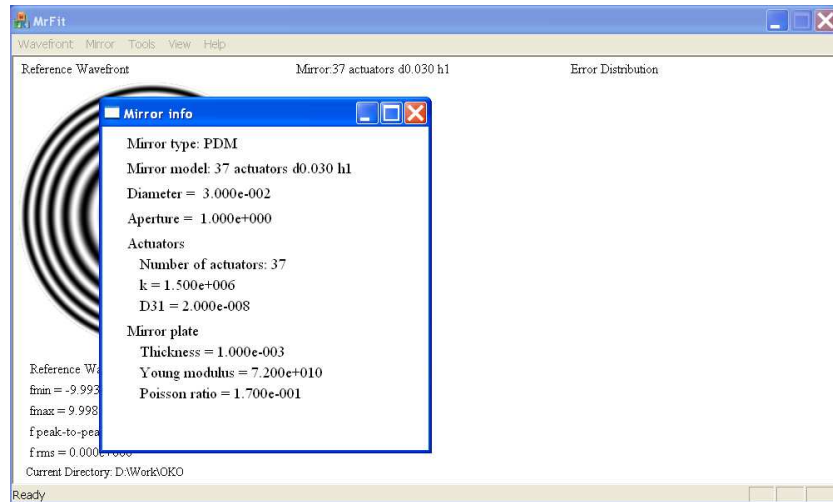

Figure 6: The window displaying mirror data

You can see all information about the loaded mirror (except the locations of the actuators) in the "Mirror info" dialog window available via menu "Mirror− > Mirror info" as demonstrated in Fig. 6.

3.3 Tools

Functionality required to start simulation, display three - dimensional data or save the results of calculations is available via menu "Tools" as presented in Fig. 7.

The command "Tools − > Calculate approximation" starts optimization procedure to find the values of the voltages to be applied to the actuators to achieve the best possible approximation of the reference wavefront. This is an unconstrained optimization, which does not take into account the hardware limitations. After the program calculates voltages it immediately displays the approximation results: the shape of the mirror surface, the difference between the reference wavefront and the mirror (error surface) in form of a gray-scale distribution, or an interferogram and numerical values of the error and surface deviation (peak-to-peak and rms). A 3D plot available via "Tools − > Show 3D plot" can provide a better representation of the surface
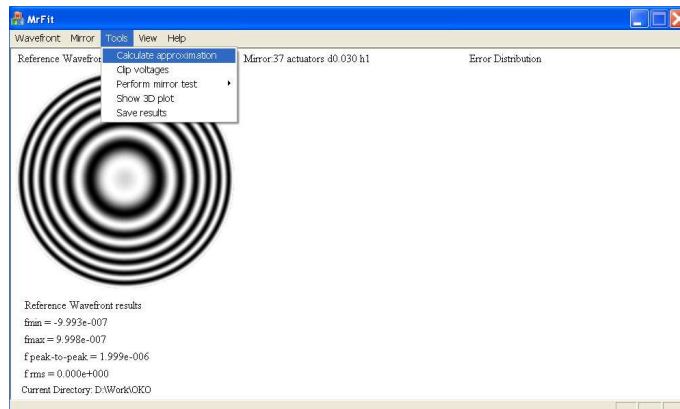
Figure 7: Program menu. Tools.

as shown in Fig. 8. It opens in a new window and it is possible to rotate the plot using the left mouse button and switch between surfaces presented on a plot using the button in the upper part of the window.
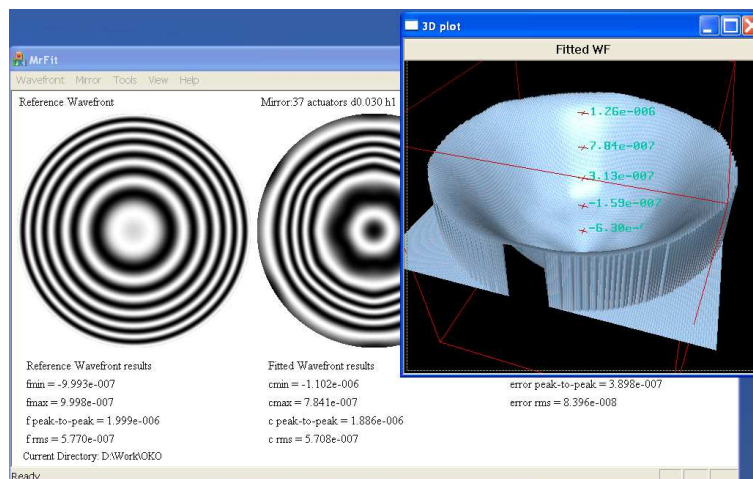

Figure 8: 3D graphical representation of a surface.

Saving the calculation results is possible via the menu "Tools − > Save results". This command opens a dialog window asking a user which data to save (see Fig. 9). All the selected items will be saved in the corresponding files in the working directory (displayed in the left bottom corner of the MrFit window).
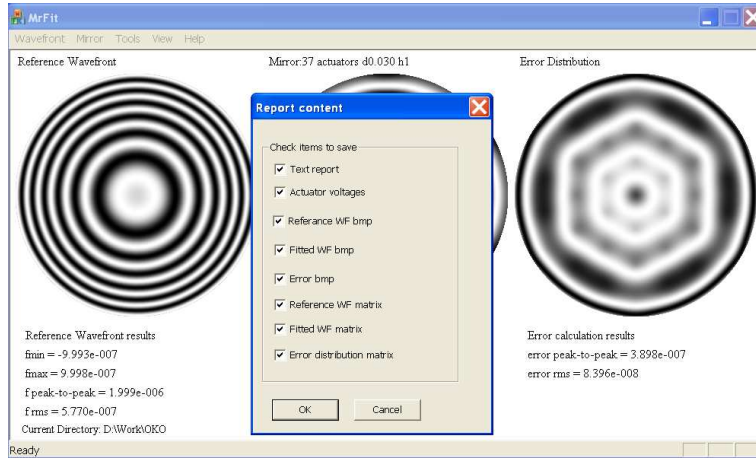
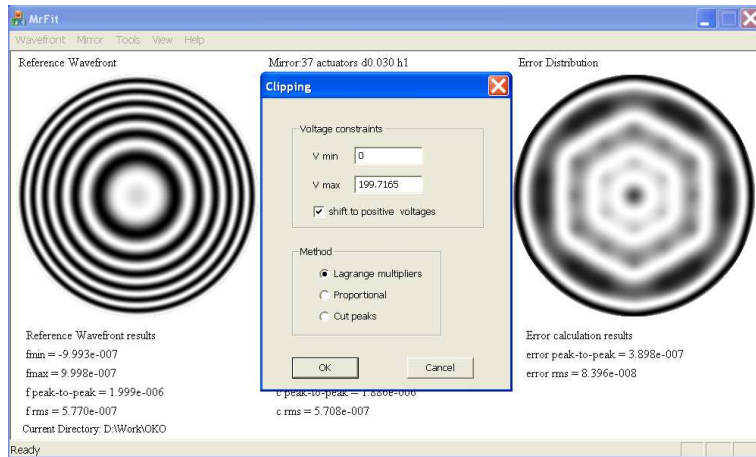Figure 9: Exporting results of calculations.

Figure 10: Voltage clipping. Define the minimum and maximum allowed voltage and optimization method.

In some cases the calculated actuator voltages can exceed the maximum limit allowed by the real DM hardware. It means that the maximum constraints have to be taken into account in the optimization. The constraints can be introduced via menu "Tools − > Clip voltages" using the dialog window presented in the Fig. 10. It shows the current minimum and maximum voltages. The voltage value displayed in the window can be negative. Some mirrors work only with positive voltages, therefore if there is a negative voltage displayed, the user can select checkbox "shift to positive voltages". Then it is possible to choose between three options: "Lagrange multipliers", "Proportional" and "Cut peaks". If the first option is selected, the program will perform a constrained optimization procedure. The resulted mirror shape may be asymmetrical, but it is still the best approximation within the imposed constraints. The Proportional clipping shrinks all the voltages proportionally to fit within the constrains. The last options just cuts voltages which are above the limits and set them equal to the constraints, simulating the clipping effect in an AO system.

The last menu item "Tools − > Perform mirror test" allows to see mirror response to the action of a single actuator. With the command "Tools − > Perform mirror test − > print eigen functions" it is possible to save the influence functions of the current mirror in the working directory in form of the gray-scale bmp images.
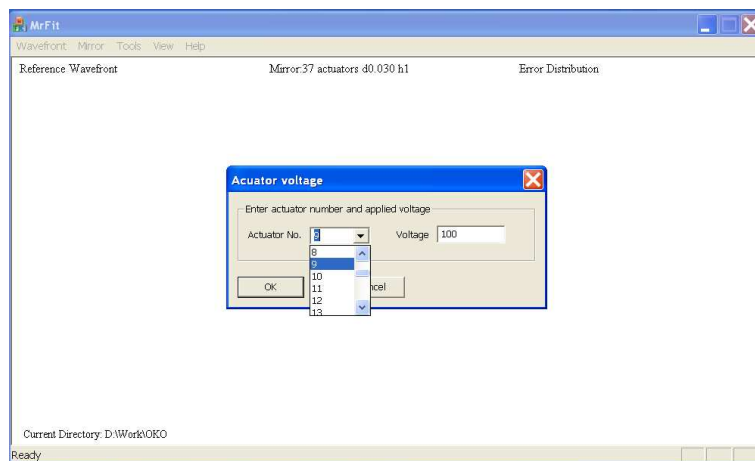

Figure 11: Apply voltage to a single actuator.

With the command "Tools − > Perform mirror test − > apply voltage

to actuator" the user can simulate mirror with a voltage applied to a single actuator. In a dialog shown in Fig. 11 one can select an actuator and enter the voltage value to be applied. The result will be displayed in the program window as shown in Fig. 12.
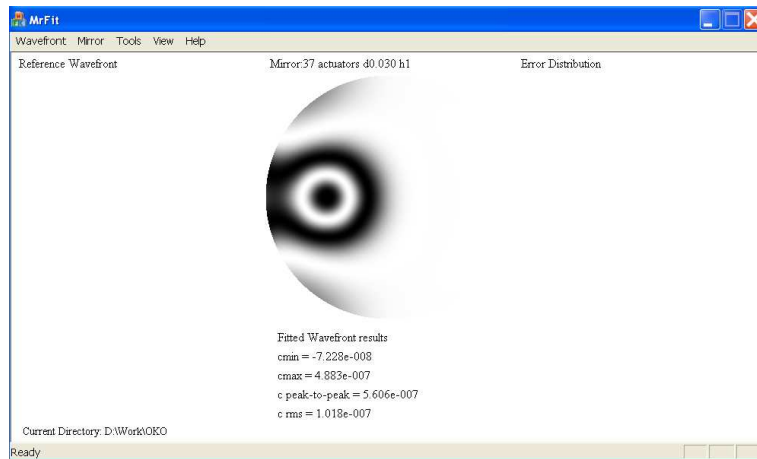

Figure 12: Mirror after the voltage was applied to one of the actuators.

4   Appendix A.

A text file presented in the Fig. 13 defines a wavefront consisting of three aberrations: defocus, coma and astigmatism. It is allowed to use comments separated by a symbol "%" in the definition file (as shown in the Fig. 13).

5   Appendix B.

Example of a file defining a 37 actuators PDM mirror is presented in the Fig. 14. It is possible to use comments separated by a symbol "%" as this file demonstrates. Mirror definition includes type, model, diameter of the mirror plate and the number of actuators, physical coefficients of the mirror plate and actuators in SI system of units and coordinates of actuators. The format of the definition file is clear from Fif. 14. For a mirror to be added to the database, MrFit creates an .ef file using the string defining mirror model (the second string in the Fig. 14) to name this .ef file.
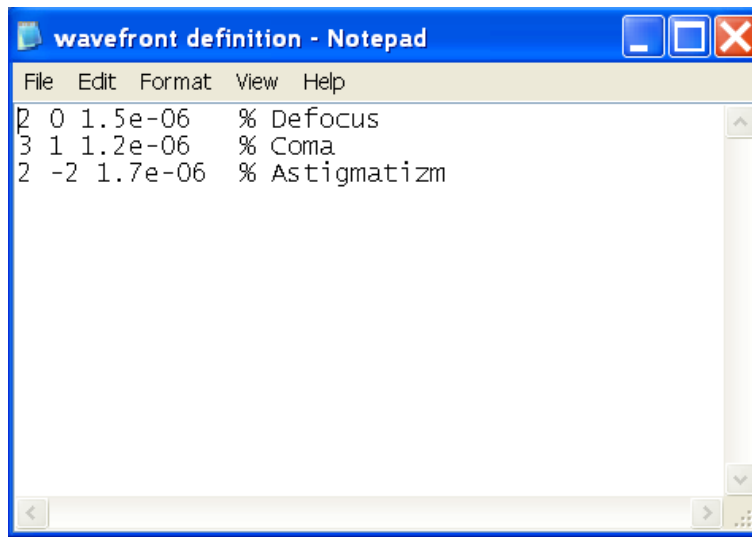
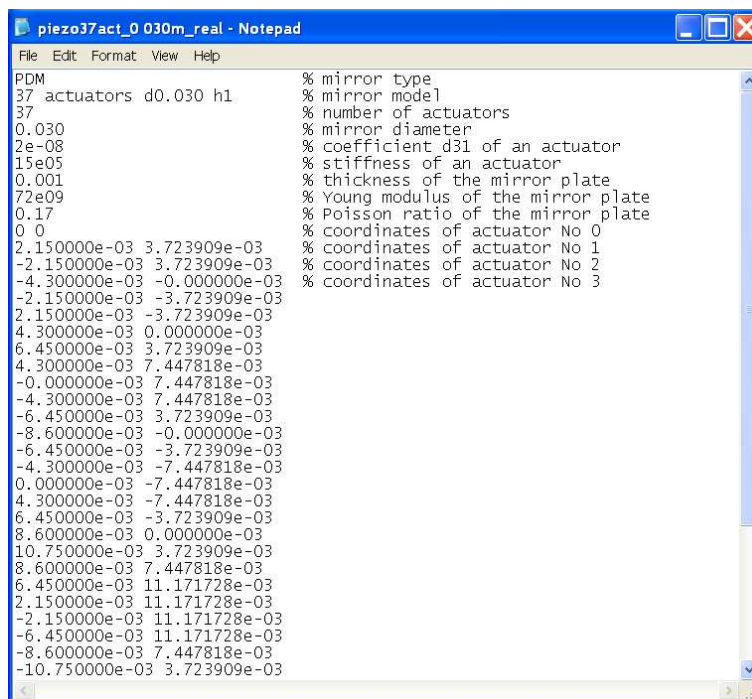Figure 13: Definition of the wavefront via Zernike polinomials.

Figure 14: Definition of the PDM mirror.

6 Appendix C.

For the definition of a MMDM mirror a .bmp gray-scale picture presenting the pattern of actuators is used. Example of such a picture difining a 37 channels MMDM mirror is demonstrated in Fig. 15. Each actuator should be drawn with it's own scale of the gray color. Having loaded the .bmp pattern, MrFit counts the number of scales of gray to define actuators. The mirror receives it's name according to the name of the corresponding .bmp file. Before proceeding with the mirror MrFit asks to enter a "membrane stretching force" which is a coefficient used to fit the deflection of the membrane to the applied voltage.

Figure 15: Definition of the MMDM mirror.