ACTIVE SURFACE ADJUSTMENT TO NOMINAL VS. NEARBY PARABOLOID

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In some of our earlier discussions, it has been assumed that an active surface adjustment system need only move the surface from the shape to which it would distort in the absence of adjustments (under the influence of all disturbances) to the paraboloid that best fits this shape. This assumption is very much like the homology principle, so that the adjustment system might be called "active homology" to distinguish it from the "passive homology" that characterizes the design of several existing telescopes.

It is natural to think this way under a scenerio of open loop control, where there is no direct measurement of the surface shape. In this case, the distortion at the support point of each adjuster is computed from some model and the length of that adjuster is changed to compensate for this distortion. There is no direct check on the success of this compensation, so any errors in the model and in the adjusters' settings become part of the residual surface error. However, for the GBT to achieve its ultimate performance (and perhaps to achieve the minimum performance goals we have set), we expect that it will be necessary to implement closed-loop control, i.e., to make an independent measurement of the surface shape and to operate the adjusters so as to force this measurement to indicate the desired shape. In either case, adjustment to the best-fit paraboloid (BFP) results in the smallest range of adjuster motion. With open loop control, there seems to be no strong reason to do anything else; but the following discussion shows that with closed loop control there are good reasons to maintain a fixed nominal shape.

First, consider the dynamic range requirement on the surface measuring system. If the surface is once set to the desired shape and then maintained in this shape by closed-loop control, then the measurement sensors (regardless of their technical details) need only detect deviations from the initial shape; there is no requirement that these deviations be measured accurately, as long as there is sufficient sensitivity, resolution, and stability. On the other hand, if the surface must be maintained in a sequence of "desired shapes," each of which is the BFP to some naturally occuring shape, then the measurement system must be capable of accurately determining each of these shapes; the sensors must then operate with sufficient accuracy over the full range of naturally occuring surface distortions, and any sensor errors become part of the residual surface error. For example, an accuracy of 50 microns over a range of 5 cm requires that the combined effects of scale error and linearity error be less than 0.1%, in addition to requirements on noise and stability. In the first case, where the shape is held fixed, the adjusters must move over a larger range; but there are *no requirements on accuracy* for the adjusters (only on their resolution), since accuracy is set by the sensors through the closed loop.

Next, consider the need to maintain not only the surface shape but also the focus and pointing of the antenna. If the surface shape is allowed to change (being corrected only to the

BFP), then the location of the focal point also changes, generally in all three coordinates (gravity causes movement in only two coordinates, axial and vertical, provided that there is lateral symmetry, but other perturbations are more general). The reflector axis direction changes too. Quite separately (even if the reflector shape is held fixed), the structure holding the subreflector or feed or both is subject to distortion. If the net de-focusing is significant (as we expect for the GBT), then the subreflector or feed or both must be moved with respect to their support structures in order to avoid loss of gain. In any case, we must know the location of the axis, focus, subreflector and feed in order to point the antenna correctly.

If, however, the surface shape is held fixed then the focus and axis are also fixed with respect to a coordinate system attached to the surface. It is then only necessary to keep the subreflector and/or feed fixed in this same coordinate system. They will still have to be moved with respect to their supporting structures, but knowing where to put them now becomes much simpler. We can implement a direct measuring system (probably optical) for the subreflector and feed locations with respect to the main reflector. Just as with the main reflector surface, this system has no stringent accuracy requirements; it need only detect deviations from an initial, good alignment. The pointing problem is also simplified: it reduces to finding the orientation in inertial space of a coordinate system attached to the surface, since the optical path is now fixed with respect to these coordinates.

To further clarify the difference, consider in more detail what would be needed with BFP adjustment of the main reflector. We could still define a reference coordinate system with repect to three selected points on the main reflector. The surface measuring system can be assumed to supply the focus and axis locations in these coordinates, within the limits of its accuracy (which we recall is affected by its dynamic range requirement). It is then necessary to move the subreflector and/or feed to *variable* locations. This might be done by measuring their locations with respect to the same reference coordinates, but then the measuring system must maintain accuracy over the full range of desired locations. It might be done by keeping track of only the actuator lengths controlling the subreflector/feed positions, but this would require additional, separate knowledge of the movement of their support structures with respect to the reflector coordinates. For pointing, we must still find the orientation of the reference coordinates in inertial space, but now we must correct to the current position of the main reflector, subreflector, and feed; and our knowledge of each of these is subject to errors that add to the pointing error.

Finally, consider the shapes of the individual panels, which are not adjustable. These are manufactured to fit only one paraboloid, so an attempt to adjust the surface to a different paraboloid incurs an additional error to the extent that the new shape fails to fit the actual panel shapes. If the panels are perfectly rigid, this error is avoided by keeping the surface shape fixed. But the panels do distort internally; if the surface measuring system is able to observe some components of this individual panel distortion, then it is possible to make the overall surface somewhat better by adjusting to the BFP. This is very limited, in that we have at most four degrees of freedom available (three coordinates of focus position and the axis orientation) with which to compensate all panel distortions. Whether the improvment is significant depends on the magnitude of the panel distortions and on the extent to which they are detectable by the measuring system.

The above discussion has been almost entirely qualitative. Quantitative analysis depends on the specific implementations of the structure, the surface adjusters, the surface measuring system, and the subreflector/feed measuring system. None of these is yet known. Nevertheless, I think that the case for maintaining a fixed surface shape is rather compelling. The argument for BFP adjustment is based mainly on minimizing the adjuster motion, so unless the detailed design work shows that the necessary range is very difficult to achieve, I urge that we adopt the fixed-shape scheme.