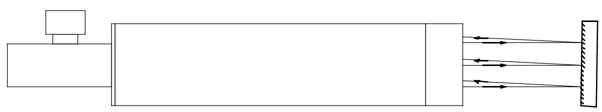
Q: How do I measure radius of curvature of a surface?

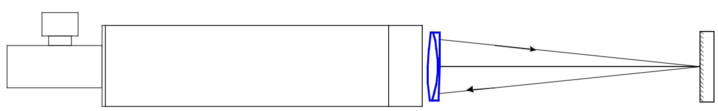
How accurate is the measurement?

A: The classical way to make this measurement uses an autocollimator

You are probably familiar with using an autocollimator to measure tip angles, as shown below:

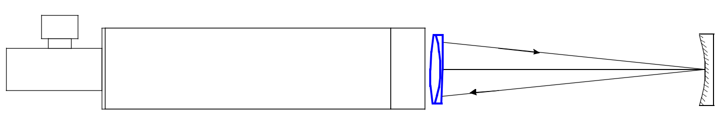


However, it's also possible to add a closeup lens to an autocollimator, converting it to an autocollimating microscope.

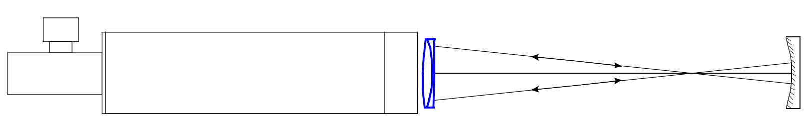


Such an instrument is no longer very sensitive to tilt[1], but it is exquisitely sensitive to axial displacement. Because the setup is 'double pass' the sensitivity to focus is twice a normal microscope.

Now consider what happens if we replace the flat mirror with a curved surface.



If the vertex of the surface is at exactly the same axial location as the plane mirror, then the return image will still be in focus[2]. Now, move the surface away from the autocollimating microscope. At some point the image will come back into focus:



This happens when the microscope focal point falls at the center of curvature of the surface.
If the surface is mounted on a stage with a position readout, then we can measure the distance between the two positions of best focus. At the risk of stating the obvious, the amount of motion is exactly equal to the radius of curvature.

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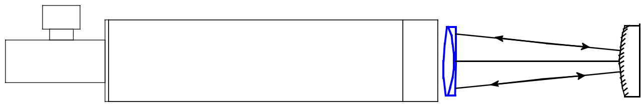
1 If the return mirror is tilted quite a lot, then the return beam will miss the autocollimator entirely. However, small amounts of tilt will have almost no effect.

2 This may seem counterintuitive, but I assure you it is true. Here's a quick explanation: Rays from one point on the reticle inside the autocollimator come to focus at a point on the surface of the mirror. OK, perhaps not a true point, but a very tiny area indeed. Over this tiny area the curvature is completely negligible (For exactly the same reason the Earth seems flat to us.)

It turns out that this technique works just as well with a positive surface, although it may be a little harder to visualize.



Am I measuring the whole surface, or just a part of it?

As the photos suggest, the “footprint” of the autocollimator beam on the surface depends on the radius of the surface. You will get a sharper peak focus if the surface is large enough to fill the F8 cone from the Autocollimator.

Does the surface have to be highly reflective?

No, the 4% reflection from uncoated glass is sufficient. However, you should not expect this technique to work well on AR coated elements.

How accurate is this technique?

Under ideal circumstances this technique can measure the radius to micron-level accuracy. Obviously, in most cases this much precision is not required. Let's look a the possible sources of error:

(1) How good is the surface? If it is not a perfect sphere, then there is not a single radius of curvature. You can't expect to measure a single 'radius' value to .001% when the radius varies from place to place by 1%. The good news is that you can use this technique to actually map the variation in the the radius at different locations on the surface.

(2) How accurately can you determine the position of best focus? By plotting through-focus MTF, and then fitting a parabola to the results, we have demonstrated sub-micron repeatability. However, this requires a very precise motorized stage. With a simple cross-roller stage and hand micrometer, you should expect to be able to identify the position of best focus with a repeatability of ~10 microns.

(3) How accurately can you measure the distance between the two points? We can supply a Mitutoyo digital readout with 10 micron resolution and 300 mm travel. If this level of precision is not needed, you can use a large vernier caliper, or in the extreme case just use the mm scale on our rails.

Geometric limitations:

When measuring positive surfaces the radius of curvature must be less than the working distance of the closeup lens. Our standard closeup lens has a focal length of 400 mm, but longer lenses are available.

Numerical example:

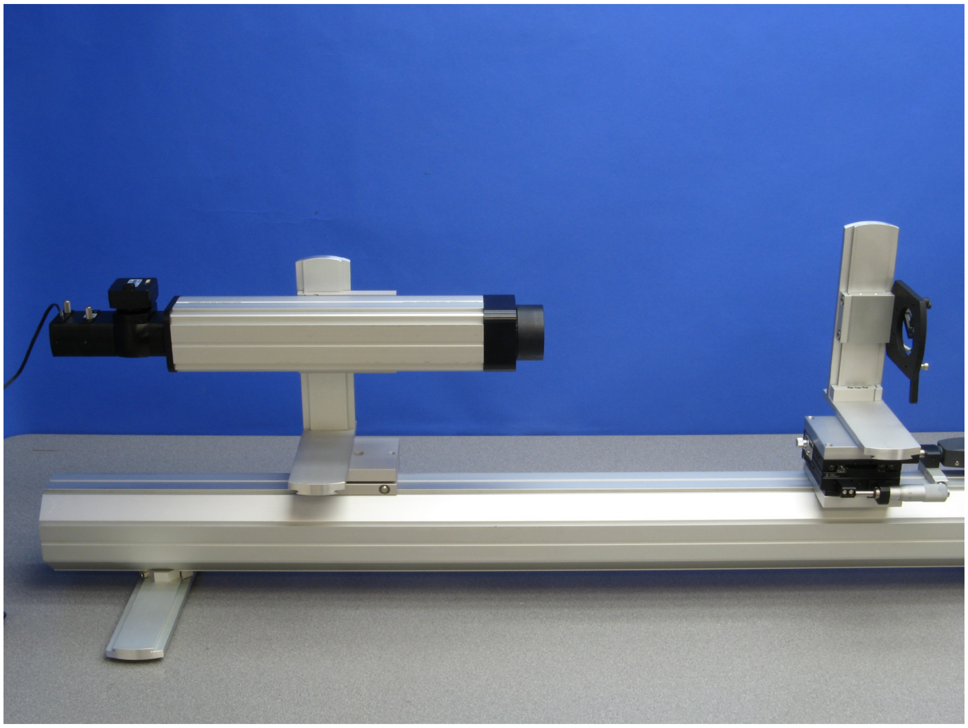
Lets say we have an optical element with 100 mm radius of curvature, and clear aperture large enough to fill the F8 beam from the autocollimator.

With the Mitutoyo readout, we would expect repeatability of measurement to be better than 50 microns (remember there are two measurements involved.) This corresponds to a precision of 1 part in 2K.

To put this in perspective, let's say the element has a clear aperture of 10 mm, and a true radius of 100.05 mm. If we compare it to a test plate with exactly 100.00 mm radius, we'll see about 1/8 wave peak-valley wavefront error.

Can I do this technique with an OS200?

Yes, you can. You'll need two extra components: A closeup lens, and a beamsplitter attachment for the collimator. The photo below shows a typical setup:



In this case the surface radius was small, about 6 mm, so a digital indicator with 1 inch travel was sufficient.