Micro Spherometer

For very small lenses.

This describes modifications so a standard microscope will measure

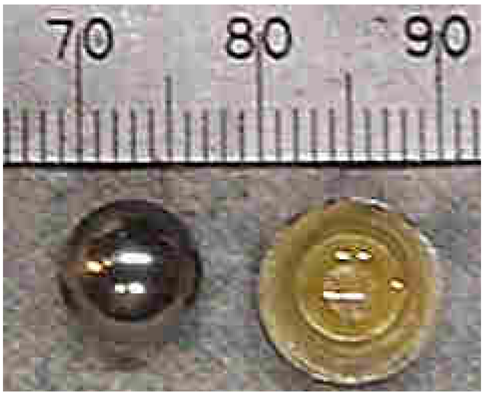
the radius of curvature of extremely small lenses to a high precision.

Background

I have more and more felt the need to measure and test extremely small lens surfaces. These are mostly destined for eyepieces.

The radius of curvature may be as small as 2 mm.

Here is a typical example. .



A steel ball was used as a lap although this lap is for a slightly smaller lens than the one pictured . The lens is bonded to an aluminium disk

Clearly these small lenses cannot be measured successfully with normal spherometers.

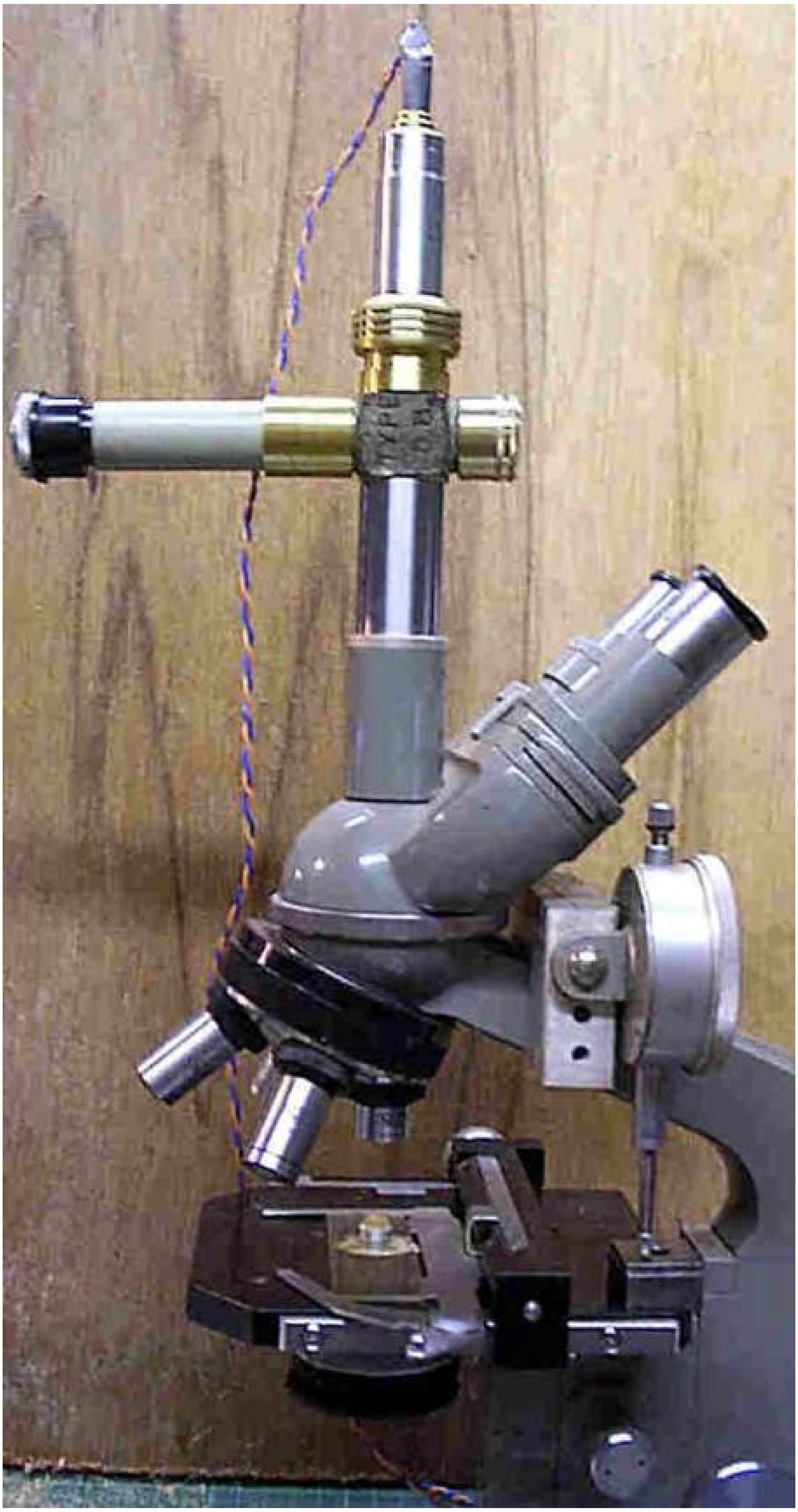
This brought to mind the devices described in ATM 3 (a chapter by Gardner) and in Optics and Optical Instruments by B. K. Johnson which always intrigued me but were previously relegated to 'someday projects'.

Recently, I made a simplified version in the form of an attachment for a standard microscope. It has so successful that I am thrilled with its performance.

General Description

This photograph shows a microscope and attachments. No modifications have been made to the microscope which cannot be undone. This unit simply lifts out of the eyepiece tube.

While this microscope has a trinocular head, it is not necessary. During use, the binocular eyepieces are not used. More important is the optical and mechanical quality allowing positive and convenient movements.



1/ The surface under test can be seen in this photograph. It is a miniature concave piece of F4 glass bonded to a small Aluminium disk for the lens polishing machine. It is visible on the stage. The stage has fine X and Y movements. This makes operation a pleasure.

In fact, I would go so far as to say the XY stage allows much better centring and consequently improves accuracy. It certainly reduces profanity during use.

2/ A dial indicator and gauge blocks are visible on the right. This measures rise and fall of the stage.

It has been used very effectively in this and various other optical measurements involving refractive index and focal length with this microscope.

The indicator is attached to an aluminium block. This itself clamps around the microscope frame so it may be removed easily.

If extended measuring range or higher precision is needed, gauge blocks are necessary.

One possible error with this setup is cosine error. The plunger should be parallel to the stage movement, which hopefully is exactly perpendicular to the stage surface. Of course all dial indicators have errors, which should be investigated. One usual scheme is for manufacturers to guarantee repeatability to 0.2 of one division but over the range (excluding the very far extremes) only guarantee an accuracy of 1 division.

The Attachment

The attachment is constructed from readily available plumbing fittings, aluminium tube, an eyepiece, a cheap laser pointer, and a small half silvered mirror (from Surplusshack).

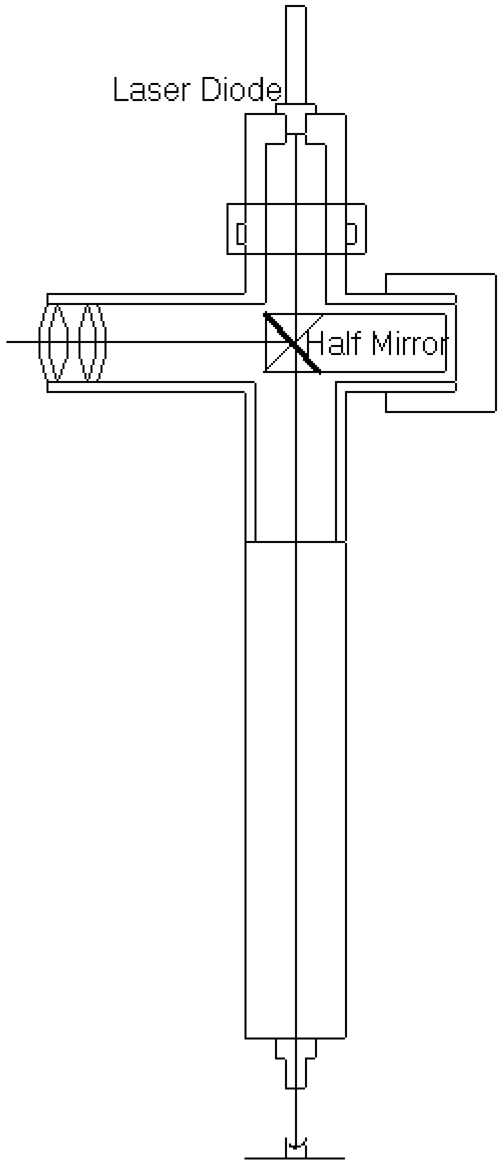
Because a Laser diode is used, the eyepiece does not have to be colour corrected. And because a microscope works at a high F:NO an old fashioned Ramsden or Huygens eyepiece works just as well as a more expensive alternative. I used a Symmetrical eyepiece because it was available. The eyepiece does not need a separate focusing mechanism..

The instrument as described in the original articles used cross hairs illuminated by a half silvered mirror. But as I used a small laser to adjust the mirror orientation it occurred to me to try the laser diode as a ‘point source’. The small collimating lens on the laser was simply unscrewed and removed.

This has worked very well and I have no inclination to change the system. There is a double image but this is no problem. In fact, there are some advantages.

While some speckle and diffraction rings are very evident, focus is repeatable to a few tenths of a thousandth of an inch with a 4 X objective and even less with a 10 X objective. The diffraction pattern – especially when slightly defocused, is very sensitive to centring of the surface under test. Simply move the test surface until the image shows no signs of coma or astigmatism as evidenced by a round out of focus diffraction pattern.

It is worth baffling and a good black paint/sawdust treatment in the laser tube as the uncollimated light from the laser diode bounces everywhere unless checked.



The half silvered mirror is a unit from Surplusshack. It is mounted in a small square tube. I have a quality beam splitter but consider this cheap half silvered mirror perfectly adequate for this use. The cross piece is bored so the mirror unit is a firm push fit. It can then be pushed and twisted into position and a cover screwed in place.

The cross piece is a rough brass fitting from my junk box and the other screw on fittings are made from brass plumbing fittings. These are a cheap way to purchase brass.

The optical paths to eyepiece and laser diode should be equal so the position of the laser diode should be adjustable. More on this later.

Unfortunately, when it was constructed, the unit was a quick prototype. Some shortcuts were taken. Since it works so well, I now regret not taking more care with the unit, although it would not work any better.

One change I would make is to reduce somewhat the length of the eyepiece tube. This would also mean a corresponding reduction in the length of the laser tube. I made the laser mounting tube first without enough thought as to its length.

WARNING.

It would be possible with inappropriate choice of a laser diode and inappropriate use of this instrument to cause irreversible eye damage.

Crucial considerations are :-

1/ The laser diode should NOT be extremely close to infrared wavelengths. Laser diodes beyond about 660 nm appear very faint to the eye – yet still send as much energy in concentrated form to the retina. Thus one of the eyes' safety mechanisms is overridden. Newer laser diodes from laser pointers are closer to 650 nm and under 5 mw. Only these should be used in such a way that the beam is greatly attenuated. Even one of these used inappropriately is potentially hazardous.

2/ The laser diode is used UNCOLLIMATED. That is, the COLLIMATING LENS IS REMOVED. Unlike gas lasers, a laser diodes produces a diverging cone of rays which is inherently safer unless collimated. In this application, only a small fraction ever reach the microscope objective for return to the eye. Substituting a narrow beam or collimated laser diode could be dangerous. If in doubt, another type of source should be considered. Do NOT consider a gas laser for this project.

3/ The surfaces under test should not be silvered or aluminised. Thus the returned beam is reduced further by another 1/20th.

Total attenuation in this instrument, even with a perfect beamsplitter, is well under 1000.

This has been achieved by both a rejection of rays (uncollimated) and inefficient reflections (glass/air surfaces). An unsilvered glass surface used as a beamsplitter would reduce this much further if desired.

If in doubt, do your own research on laser safety or substitute a different source.

There is excellent material on the web relating to Laser safety.

Theory and Use

For any surface, whether concave or convex, there are two positions of the microscope objective for which the rays are exactly returned. These correspond to the positions where the microscope forms a clear image of the laser diode.

One position is when the focal plane of the microscope is on the surface. The other is when the focal plane is at the centre of curvature.

Thus, the difference gives the radius of curvature.

If the optical paths from laser diode and eyepiece are equal, this relationship is exact.

As pointed out in the article by Gardner (ATM 3), there is a correction to be applied if the optical path lengths are different.

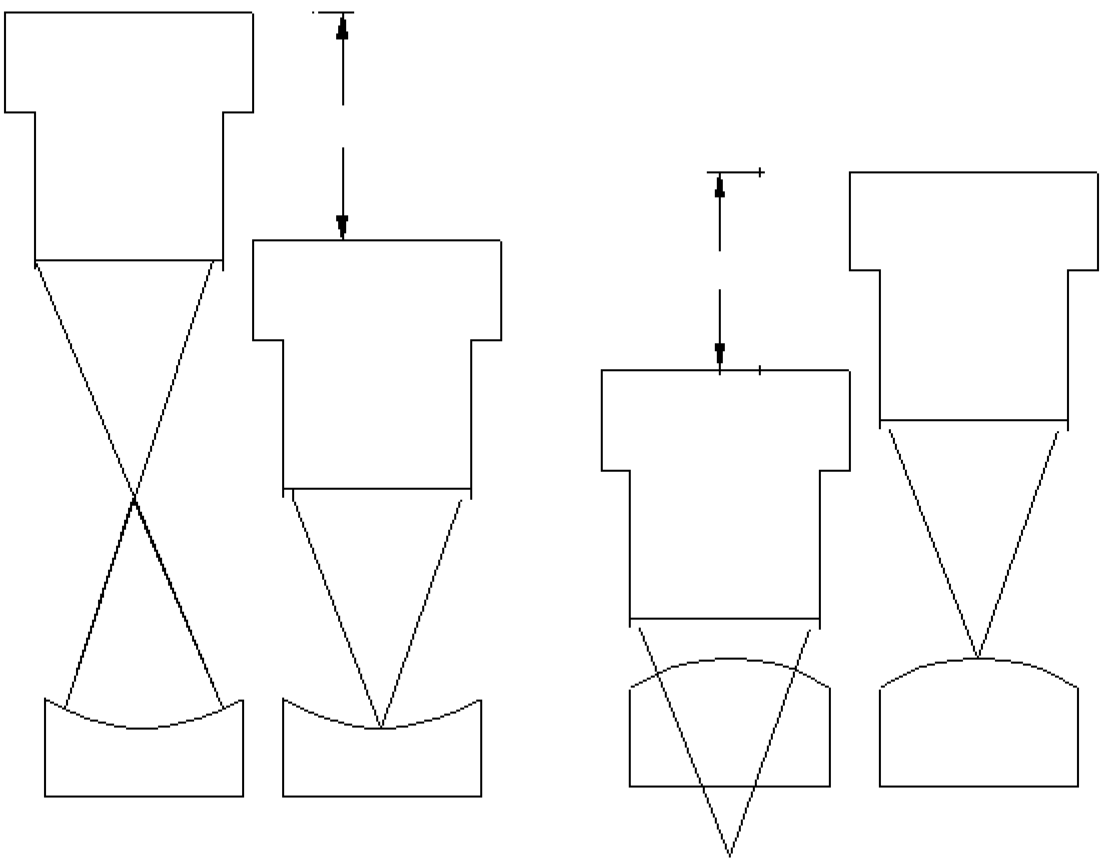
But it is easy to ensure these path lengths are equal by :-

1/ Place a flat glass surface under the microscope

2/ Focus on some fine scratches or dust on the surface using normal microscope illumination.

3/ Without changing the position of the microscope, adjust the position of the laser diode so the image reflected from the flat surface is sharp.

Now the difference of height of the microscope gives radius of curvature directly.



Note that the microscope objective is always further from a concave surface. This means that longer focal length objectives must be used for convex surfaces.

One potential pitfall is ghost reflections from different surfaces. Johnson warns that it is better to coat unwanted surfaces with vaselene to stop unwanted reflections and I tend to agree. It is easy to focus on the wrong image.

Also beware of testing a lens on a microscope with the substage condenser in place. This will return many reflections which are confusing. The stage can be easily removed or an opaque object placed in such a way as to stop the laser rays entering the condenser..

Performance.

It is easy to attain 1 % accuracy and with attention to detail I would expect 0.1 % is possible. This is estimated from two methods and the repeatability of settings.

Both a steel ball lap and some small test plates which have been originated from ball lenses of known diameter were used.

Certainly, the instrument will be accurate enough for my purposes.

If higher accuracy is needed then :-

1. Higher power, or more particularly higher NA objectives on the microscope may be used to better define the focus.

2. More care in equalising the optical paths - or applying the correction may be needed.

3. A guaranteed accurate dial indicator perfectly aligned perpendicular to the direction of travel should be used.

It is possible that an accuracy of 1/10000 inch is achievable with these very small lenses. This I find stunning.
