Sluggish cover glass thickness adjustment on Leitz 40x and 63x apochromatic objectives

Introduction

In the early 1950's (I believe) Leitz introduced a new series of 40x and 63x high numeric aperture "dry" apochromatic objectives (Figure 1) as replacements for an earlier design of these objectives (Figure 2.)

Figure 1: The new Leitz 40x apochromatic objective with a cover glass correction collar. (Views of the objective from different sides.)

Figure 2: The older Leitz 40x apochromatic objective with a cover glass correction collar.

The new objectives received a characteristic bulky appearance which makes them easy to recognize. Like most Leitz microscope objectives from this period they were designed for a mechanical tube length of 170 mm and for a parfocal distance of 37 mm. Similarly as in the earlier objective design, Leitz included a graduated correction collar (a.k.a. correction mount or adjustment ring) that the user could use to minimize spherical aberration that negatively affects the image quality and that varies with the cover glass thickness. Such cover glass thickness correction is particularly important with dry objectives with very high numerical apertures. The correction range for the cover glass thickness was 0.11 to 0.23 mm. The new objectives also introduced a convenient novelty that Leitz called "automatic focusing compensation" which meant that refocusing of the microscope no longer was necessary (or at least considerably smaller than previously) when the cover glass correction collar was changed to any different setting. It must have been a welcome improvement for struggling microscopists.

It may be worth mentioning that Leitz later provided a parfocality adapter ("PLEZY") that made it possible to conveniently (parfocally) use an objective with 37 mm parfocal distance together with the newer objectives with 45 mm parfocal distance (but still for the 170 mm tube length.) The adapter contains a mildly diverging (concave) lens that optically compensates for the extra 8 mm it adds to the mechanical tube length. It has the usual objective RMS threads and is simply attached between the microscope turret and the objective.

As could be expected, the objective is protected by a spring-loaded tip that is retractable by approximately 1 mm.

The table below lists the members of the new objective family:

Magnification, type [1]	**Numerical aperture**	**Free working distance [2]**
Apo 40x	0.95	0.09 mm (0.12 mm) [3]
Apo 63x	0.95	0.09 mm (0.12 mm) [3]
Pv Apo 40x	0.70	0.33 mm (0.38 mm) [3]
Pv Apo 63x	0.70	0.25 mm (0.35 mm) [3]

[1] Apo = apochromatic objective, Pv = phase contrast objective of to the Heine phase contrast system.

[2] Free working distance is the distance between the objective's front lens surface and the upper surface of the cover glass.

[3] Varying free working distances provided in Leitz' documentation.

The phase contrast versions of the objectives had a somewhat lower numerical aperture than the corresponding regular objectives - probably this was to match the Heine condenser's maximal dry numerical aperture of 0.70. A consequence of the lower numerical aperture was that the phase contrast objectives could be given longer working distances. Later the phase contrast objectives received the letter "L" engraving on the objective barrel to indicate that the objectives were designed for a longer working distance. Normally the phase contrast objectives were supplied with regular absorption (75%) positive phase rings (with engraving "n") but could also be purchased with increased absorption (88%) positive or negative phase rings (with engravings "h" and "-h", respectively.)

I was recently baffled by receiving an Apo 40/0.95 objective that looks exactly like the one in Figure 1, except that the barrel inscription reads 160/0.11-0.23 instead of 170/0.11-0.23. In other words, it is a hybrid objective designed for use with the newer 160 mm tube length Leitz microscopes (i.e., post-1976) while at the same time retaining the old and by then obsolete parfocal distance of 37 mm. Obviously, the objective must be used with the above mentioned "PLEZY" adapter to acquire parfocality with the 160 mm tube length objectives. Thinking about it, one realizes that the required modification of the objective could be quite simple. It is known that if a cover glass is too thick, then the excess spherical aberration can be compensated away by a corresponding decrease of the microscope's mechanical tube length. Conversely, if the mechanical tube length is reduced, then a thicker cover glass would save the image quality. Or, with an objective that has a cover glass correction collar, then its scale could be set to a lower value. Without going into details (the interested reader can recreate the reasoning with the help of the Overney and Loveland References below) it seems that changing the objective from 170 mm to 160 mm mechanical tube length would only require a factory recalibration of the correction collar's cover glass thickness scale by approximately 0.02 mm.

Scope

Today, more than half a century since manufacturing, it appears that the cover glass correction collar of these objectives shows a tendency to get sluggish due to aging grease. A sluggish correction collar is not only inconvenient to use, but the increased force required to turn the collar may bump the microscope, making the specimen come out of focus and even changing the field of view.

Two remedial procedures for a sluggish cover glass correction collar are proposed; one is a simple hack; the other is a more proper and thorough remedy. The hack is quick, simple and safe; it will make the collar easier to turn but will most probably leave it with some remaining sluggishness. The proper remedy, on the other hand, is riskier and more laborious as it requires that the objective is disassembled before the collar can be cleaned from old grease and regreased. It will, however, leave you with a better result where you can to some extent determine how smoothly the collar will turn by your selection of the grease.

Maintenance Notes: The hack

For the hack, penetrating oil, like WD-40 or CRC-56, is used to soften the old, hardened grease on the cover glass correction collar's sliding surfaces. The main components of penetrating oils are a petroleum-based solvent (like white spirit) and a mineral oil. The oil is obviously there for the lubrication, while the solvent contributes to efficient penetration into crevices, seams, cracks or threads, it also loosens and dissolves any old grease, and finally, it carries some fresh oil into places that otherwise would be inaccessible for lubrication.

Typically, penetrating oil is purchased and used in spray cans. Clearly, trying to spray the objective with penetrating oil would be disastrous, therefore, you will need to start by spraying some penetrating oil into a small vial. Controlled amounts of penetrating oil can then precisely be dispensed from the vial.

Figure 3: The green arrows indicate the crevice where the penetrating oil should be applied.

Put the objective sideways on the table. Use a dropper, cotton swab, wood stick, or anything else that you find suitable, to apply one or a few small drops of the penetrating oil from the vial to the crevice between the objective base and the collar (as indicated by the green arrows in Figure 3.) Try to target the crevice as precisely as possible; avoid wetting adjacent areas and use the penetrating oil sparsely. Turn the correction collar back and forth some 30 times to allow the penetrating oil to penetrate and distribute within the collar's slide. Immediately wipe off any superfluous penetrating oil. Now you will probably be elated when you find that the collar almost miraculously releases and suddenly moves very easily. Unfortunately, it will not last. After a day, or so, the collar will stiffen again. It will turn considerably easier than it did originally, but it will not feel perfectly light. The initial lightness happens because the solvent component of the penetrating oil dissolves and dilutes the old grease. Eventually, as the solvent evaporates and disappears, the old, hardened grease again returns to its old, sluggish condition, albeit this time less serious, because now it has been mixed with some of the fresh oil component from the penetrating oil.

By repeating the penetrating oil treatment one or two more times you may be able to get the collar to turn even somewhat lighter. But don't expect to get the typical Leitz smoothness.

Maintenance Notes: The proper fix

This procedure requires the objective to be disassembled before cleaning of the old, hardened grease in the cover glass thickness correction collar and having it regreased. It requires some effort and some special equipment, but above all, it requires the utmost care that no dust or contamination is allowed to get into the objective. In short, there is an increased risk for damage.

1. Remove the objective barrel from the objective

The objective barrel is attached to the objective base by a thread, which means that it can be screwed off. The yellow line in Figure 4 indicates the crevice where the barrel will separate from the objective. It is immediately tempting to get a good grip with each hand around the two knurled rims (see Figure 4) and forcefully unscrew the barrel. If however the barrel doesn’t easily release, that approach may be dangerous because it will put a lot of strain on the internal mechanism (made of brass, which, as we all know, is a soft alloy) that limits how much the cover glass thickness scale can be turned. I don’t know how much force the stop mechanism can take (and I don’t wish to test it), but somewhere it will reach a threshold where it will break. To safely remove the barrel, you should ideally hold on only to the scale (the lower green arrows in Figure 4) and leave the narrow, knurled rim next to it free and untouched (indicated with the red arrows in Figure 4.) Unfortunately, because the scale is so narrow, this is difficult to realize. Instead, I propose a compromise as follows:

Turn the correction collar to its lowest setting, i.e., at just below 0.11 mm on the scale. Wrap a small rubber band around the scale as shown in Figure 5. Without disturbing the small rubber band on the scale wrap two wide rubber bands over the objective as shown in Figure 6. Note that the lower rubber band should go over the small rubber band and cover both the scale and the narrow, knurled rim. Get a steady, hard grip over the rubber bands (particularly the lower rubber band) and try to release the cover from the base. It is important to squeeze the lower rubber band as hard as you can to prevent that the scale slips against the rubber. The small rubber band over the scale should hopefully give us some leverage. Some slipping is acceptable (we got ourselves some margins because we started with the collar at its lowest setting) but avoid letting the scale slip all the way until the collar hits the other stop just above the 0.23 mm scale number.

Figure 4: The objective before applying rubber bands.

Figure 5: The objective with a small rubber band over the cover glass thickness scale.

Figure 6: The objective after two wide rubber bands have been additionally applied.

If this doesn’t work, the efforts can be escalated with the help of some tools. I have found it convenient and safe to use two small-sized strap wrenches (Figure 7.)

Figure 7: One example of a commercially available strap wrench (jar opener.) Here the strap is wrapped over an eyepiece.

Wrap two strap wrenches over the wide rubber bands (as indicated in Figure 6 and Figure 8); for the release make sure to have the strap wrenches turned in the proper opposite directions. Tighten the straps well and then release the barrel from the objective (Figure 9.)

Figure 8: Two small-sized strap wrenches wrapped around the objective.

Figure 10 explains the various parts that now are visible and accessible. Be aware that with the objective barrel removed the small cam wheel (Figure 10) is free to fall off from the cam pin and can easily be lost.

Figure 9: The objective after the barrel has been removed.

The knurled periphery of the removed objective barrel (Figure 9) may be dirty and benefit from a good cleaning. To clean it, soak the barrel in lukewarm water with dishwashing detergent and clean the knurls by brushing with an old toothbrush. It may be tempting to speed up the cleaning by using an ultrasonic bath, but I have found that ultrasonic cleaning tends to strip off the paint in the engraved letters and numbers on the barrel. It is however not difficult to repair any faded characters by applying black (or red, as applicable) acrylic paint over the engravings and then immediately wiping off any excessive paint with a lightly moistened tissue.

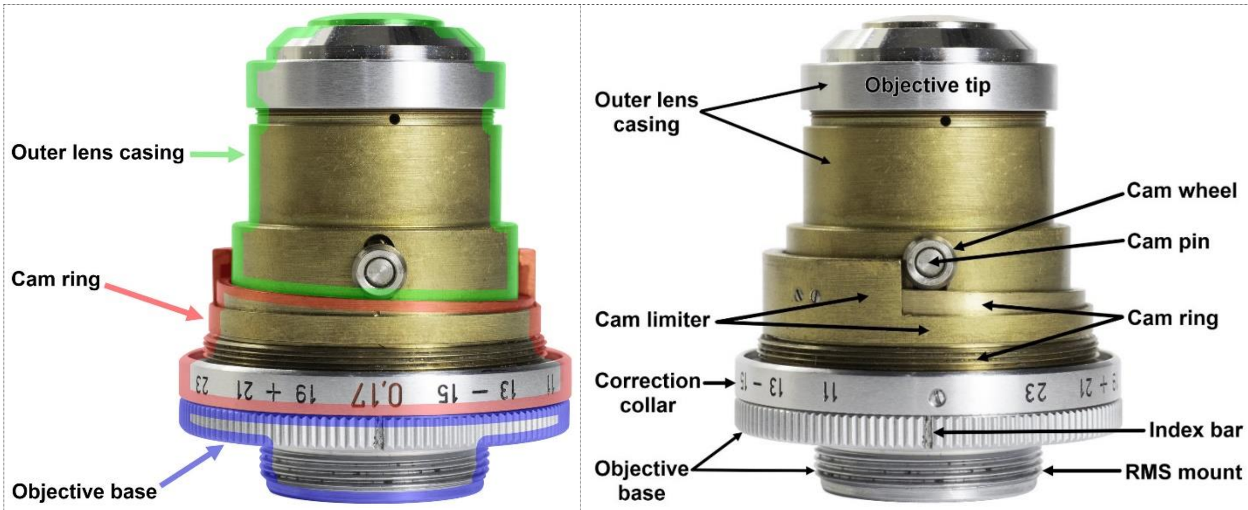

Figure 10: The various parts and their names (as used in these notes.)

2. The correction collar

The correction collar with the cover glass thickness scale (Figure 11) is attached to the objective's cam ring (Figure 10) with two very small M1.2 grub screws on opposite sides (Figure 12.) For our purposes it is however strongly recommended not to remove the collar and just leave it attached as it is.

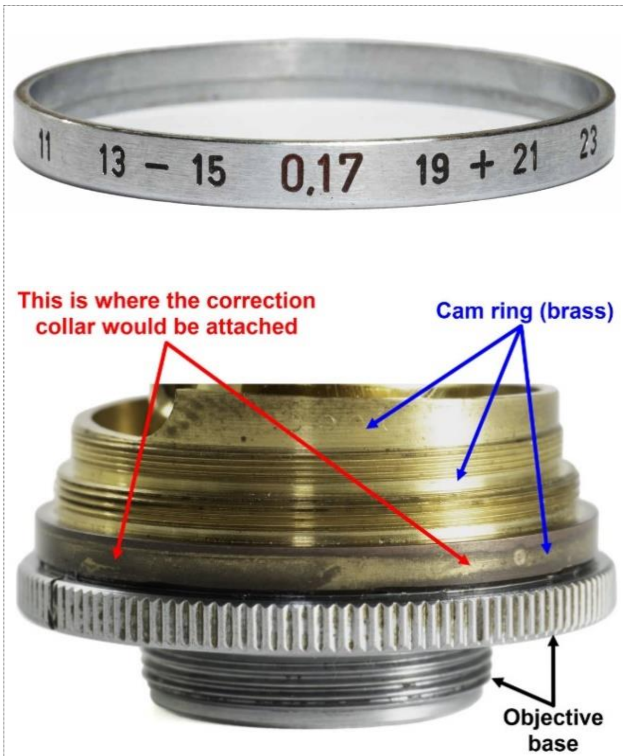

Figure 11: The removed correction collar with its cover glass thickness scale. There is also an identical scale on the opposite side of the ring.

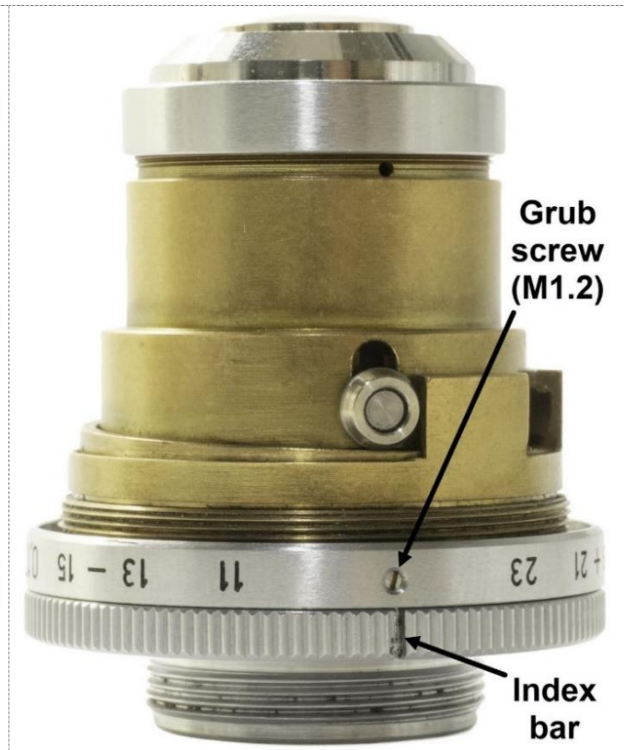

Figure 12: Photo documenting the correction collar's cover glass thickness scale vs. the index bar on the objective when the collar is turned as far as possible towards the lowest number.

Should you however find that you indeed need to remove the collar, be aware that its alignment is important. Once the grub screws are loosened, then the collar is no longer locked to the cam ring below and the scale may lose its correspondence with the objective's cover glass thickness correction. Therefore, if you need to remove the collar, first save a note together with a photo to document how the collar's scale is aligned relative to one of the two the index bars on the objective. This will later help you to be able to put back the collar with the scale aligned in the same way as before you removed it.

Turn the collar as far as it goes toward and beyond its lowest number representing a cover glass thickness of somewhere less than 0.11 mm. Now take a photo of the collar that includes the scale and the adjacent index bar on the objective (like in Figure 12.) For the user's convenience the objective has two index bars on opposite sides of the knurled rim and correspondingly the collar has two identical scales on opposite sides – the index bars and scales are symmetrical, so it doesn't matter which of them you read or take a picture of.

Now you can safely remove both grub screws from the correction collar with a 0.8 mm watchmaker screwdriver and carefully pry off the collar - it may be somewhat stuck in old grease.

3. The cam limiter

With the objective barrel removed we can begin to understand the mechanics of the cover glass thickness correction. When the correction collar is turned to the desired cover glass thickness setting the cam on the cam ring (Figure 10 and Figure 13) pushes on the cam wheel with the cam pin. The purpose of the cam wheel is to run along the cam to evenly guide the cam pin's vertical movements. The cam pin then moves the inner lens casing (not visible yet because it is still on the inside of the objective) up and down to bring about the cover glass thickness correction. The inner lens casing is spring-loaded which ensures that the cam wheel tracks the cam exactly.

The correction collar set to its maximal cover glass thickness (above 0.23 mm.)	*The correction collar set to a cover glass thickness of 0.17 mm.*	*The correction collar set to its minimal cover glass thickness (below 0.11 mm.)*

Figure 13: Illustration of how the cam pin is forced to move vertically by the cam ring when the correction collar setting is changed. Through the entire range the cam pin moves by only 1.5 mm.

The cam limiter (Figure 13) is the mechanism that we briefly mentioned in subsection 1 and that restricts the correction collar's turning range as its vertical edges bump into the cam wheel (Figure 10.)

The cam limiter is attached over the cam ring by a thread (Figure 14 and Figure 15) and locked in place with two M1.2 grub screws (the empty screw holes can be seen in Figure 14.)

For our purposes it is strongly recommended not to remove the cam limiter and just leave it attached as it is. Because the cam limiter can be turned to different angles in its thread, there again will be an alignment issue for the cover glass thickness scale if we remove it.

Figure 14: The cam limiter still attached on the cam ring, but with the grub screws removed.

Figure 15: The cam limiter removed from the cam ring.

4. The brass bushing

On the opposite side of the cam pin with the cam wheel is another pin that is loosely attached to the outer lens casing by a small brass bushing (Figure 16.) I'm not sure of the bushing's purpose because it seems that this other pin could just as well have been sitting in a plain hole in the side of the outer lens casing. The bushing is anyway threaded and has grooves for some type of spanner which means that it is removable. I have however found that it is not necessary to remove the brass bushing, our work can easily be completed with it left where it is.

Figure 16: View of the brass bushing with the other pin.

5. The objective's rear aperture

The objective's rear aperture must be removed to gain access to the inside of the inner lens casing. The rear aperture is made of blackened metal and is attached by threads to the upper end of the inner lens casing (Figure 17 and Figure 18.) Its aperture (inner) diameter is 7.5 mm. On the upper surface it has two grooves to accommodate a suitable spanner.

Use one of the commonly available and inexpensive camera lens spanners to unscrew the rear aperture from the back of the objective. For maximal flexibility, I favor spanners that have removable and replaceable tips, like the one in Figure 19. The spanner must in any case be equipped with flat screw-driver type pins (Figure 20) that fit snugly into the rear aperture's grooves – if you find that the grooves are shorter than the width of the spanner tips, then you will need to reshape the tips by grinding. Camera lens spanners are notoriously prone to slipping, so be careful with how you use it.

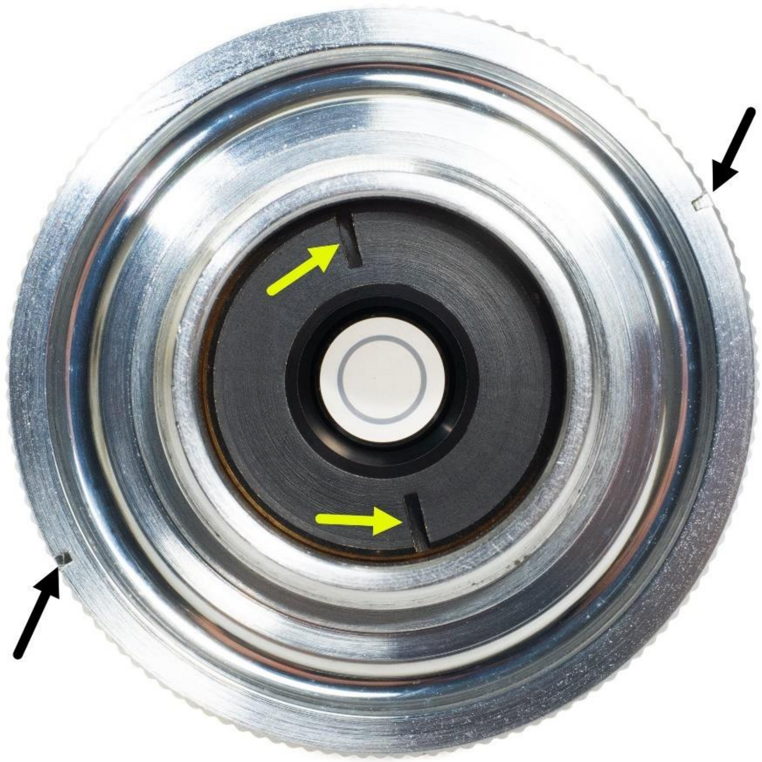	
Figure 17: The objective's rear aperture (black) viewed from the mount end of the objective. The yellow arrows point to the spanner grooves. The black arrows point to the index bars for the cover glass thickness scale.	*Figure 18: The rear aperture after removal from the inner lens casing.*

	
Figure 19: One example of a camera lens spanner with removable tips.	*Figure 20: Flat screwdriver type spanner tips.*

6. Disassemble the objective

We are now ready to (partially) disassemble the objective by removing the inner and the outer lens casings from the objective base. These three parts are held together only by the two 2.5 mm steel pins that can be seen sitting in the side of the objective (Figure 10 and Figure 16.) The pins are attached by M2 threads to a bushing on the inside of the inner lens casing. Immediately as the pins are removed, a coil spring will pull apart the inner and the outer lens casings, so you will need to be careful and ensure that the disassembly proceeds in a controlled way.

To distinguish between the pins, I will tag the pins and their corresponding openings in the various objective parts by the letter "A" (which will pertain to the cam pin in Figure 10) and by the letter "B" (pertaining to the pin with the drive in Figure 16.)

Prepare your work environment by taking any necessary precautions to avoid dirt, dust or fingerprints that could compromise the objective during the disassembly.

Start by removing the small cam wheel from the cam pin, i.e., pin "A" (Figure 10.) The wheel is easy to remove because it only sits loosely attached over the cam pin.

Then use a small screwdriver to loosen the pin on the other side of the objective, i.e., pin "B" (Figure 16.) This pin has a drive (slot) on its upper surface. Just barely loosen the pin, don't remove it.

Go back to the cam pin and use needle nose pliers to release and unscrew it. It is somewhat challenging to get a good grip with the pliers (Figure 21), but with the help of the serrated plier jaws and some patience you should be able to release and remove the cam pin (Figure 23.)

Now carefully remove the loosened pin "B" (Figure 16 and Figure 24) to disassemble the objective into its parts (Figure 22.) While removing the pin you will need to hold the suddenly released outer and inner lens casings with your fingers to prevent them from shooting out from the objective base and get damaged.

Figure 21: Needle nose pliers holding the cam pin (i.e., pin "A".)

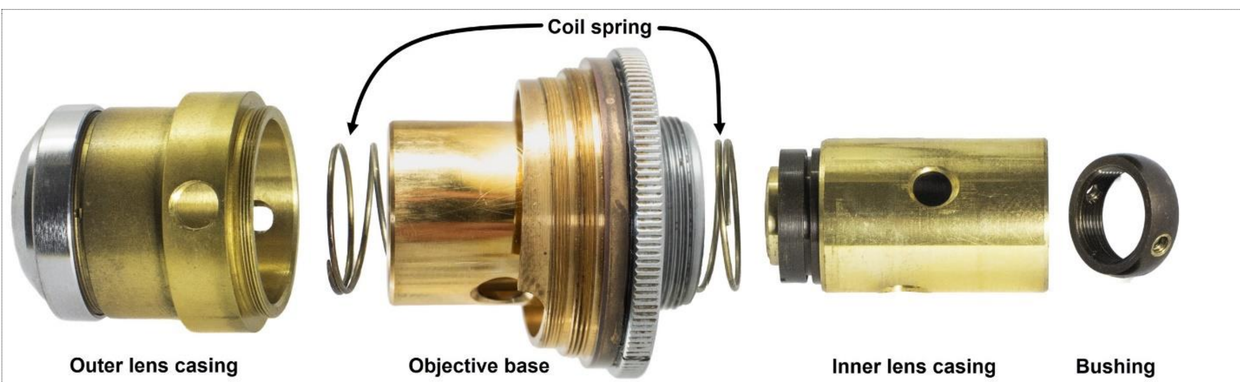

Figure 22: How the objective separates into its parts as soon as the two connecting pins are removed.

Figure 23: The removed cam pin with its cam wheel. The length of the pin is 9.5 mm. The cam pin is tagged "A".

*Figure 24: The other removed pin with its brass bushing. The length of the pin is 7.6 mm. (The bushing should <u>not</u> be removed from the outer lens casing.)
This pin is tagged "B".*

Figure 25: The bushing inside of the inner lens casing. The bushing is symmetric, so there is no need to be concerned about how it is turned.

Remove the dark brown metal bushing (Figure 25) from the inner lens casing. The bushing is symmetric, so you don't need to make a note of how it was turned before you removed it.

The outer lens casing with the objective's front lens is shown in Figure 26. The thread in the casing's open end is somewhat puzzling because it's not used for anything. Perhaps Leitz used the casing for other optical instruments. After all, they were known for their adaptability and willingness to branch out into so many extraordinary and tailored optical applications.

Figure 26: The removed outer lens casing (viewed from different angles.)

Figure 27 shows the inner lens casing.

One of the unused openings	*The "A" opening*	*The other unused opening*	*The "B" opening*

Figure 27: The inner lens casing viewed from different angles. The "A" and "B" openings are a few mm closer to the lenses of the inner lens casing than the unused openings.

We will not need to do any work on the outer and inner lens casings, so for now, put them away in a clean and safe space.

The objective base (with the cam ring still attached) is shown in Figure 28 and Figure 29.

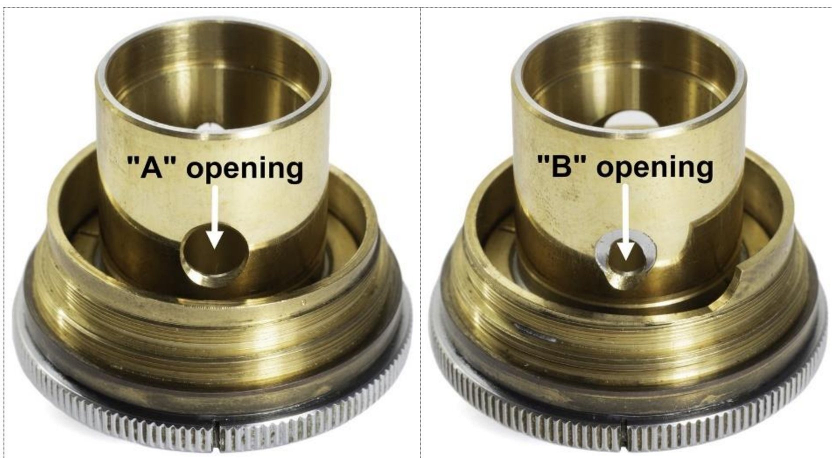

Figure 28: The objective base after the inner and the outer lens casings have been removed. Here the cam limiter has also been removed from the cam ring (against recommendations…)

Figure 29: The objective base. The blue arrows point to the spanner grooves in the locking ring.

As suggested in subsection 3 it's best not to remove the cam limiter (Figure 14 and Figure 15) and just leave it attached on the cam ring. Should you however find that you for some reason need to remove the cam limiter, then you must ensure that you can recreate its alignment over the cam ring when you later are ready to put it back. The easiest way is probably to use a pen or a steel needle to make marks on adjacent locations on the cam limiter and the cam ring.

If you forget to make the marks, all is not lost. Typically, the grub screws that hold the cam limiter fixed would have left faint dents (imprints) on the cam ring (Figure 30.) This may be helpful to recreate the original alignment.

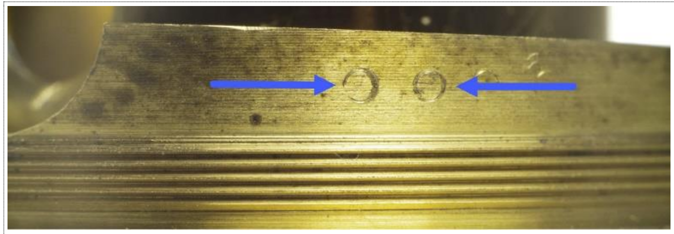

Figure 30: Closeup of the dents left by the grub screws.

7. Clean and regrease the cover glass correction collar's slide

To open up and access the cover glass correction collar's slide we will need to remove the cam ring from the objective base. These parts are however held together with a threaded locking ring that is made of brass and has two spanner grooves (Figure 29.) You will use the same camera lens spanner (Figure 19 and Figure 20) as was used to remove the rear aperture in subsection 5. Because the spanner grooves in the locking ring are somewhat difficult to access, it may be necessary to grind at least one of the spanner pins (Figure 31) to allow them to reach all the way down to the ring. The choice of grinding tool is not critical. A Dremel drill with an aluminum oxide grinding stone completes the task swiftly, but it can also be done with a handheld metal file.

Figure 31: One of the spanner pins ground down.

Once you have managed to grind the camera lens spanner pins sufficiently to safely reach the locking ring grooves, unscrew the locking ring from its thread on the objective base. And again, remember that camera lens spanners are prone to slipping, so be careful. With the locking ring removed it's easy to take the cam ring (Figure 32 and Figure 33) off from the objective base.

Figure 32: The cam ring removed from the objective base.

Hopefully the locking ring will be easy to remove, but it may happen that the ring is stuck. Because camera lens spanners are prone to slipping, one has to be mindful not to use excessive force – trying very hard to release the ring will inevitably result in shaking and wobbling, which easily may result in slipping and damage to the grooves. I have however been able to release a stuck locking ring by putting the objective base in a freezer for a few hours before using the spanner. Alternatively, you could try to heat the objective base with a heat gun or by putting it in an oven at 50-60°C (120-140°F.)

A modification to improve the inherent instability of the camera lens spanner is to remove the pins from the spanner and instead firmly clamp them in a heavy vise as illustrated in Figure 34.

Figure 33: The underside of the cam ring. The 8 grease grooves support the lubrication.

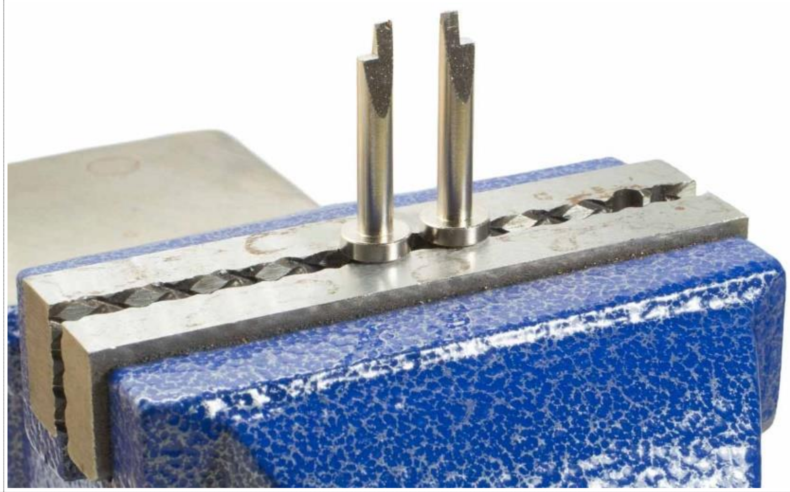

Figure 34: Spanner tips clamped in a heavy vise.

Use white spirit to thoroughly clean off any old grease from the sliding surfaces.

Apply fresh grease to the sliding surfaces of the objective base as indicated by the green arrows in Figure 35.

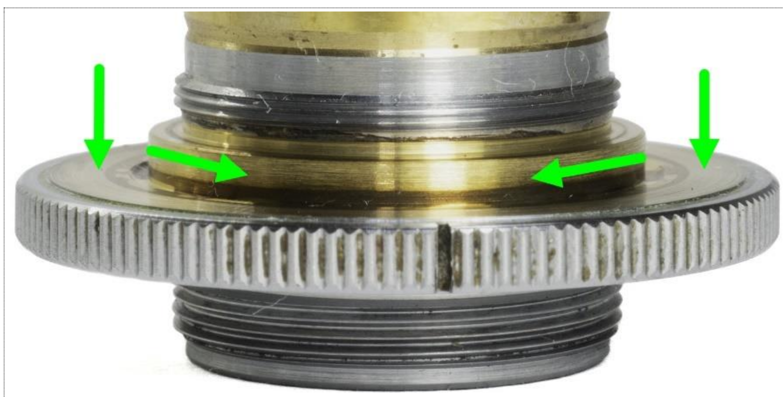

Figure 35: The green arrows point to the surfaces on the objective base that need to be greased.

The thickness of the grease will to some extent determine how easily or heavily the correction collar will turn. I have tried out two consistency NLGI grades (grade 0 and 2) of Super Lube Multi-Purpose Synthetic Grease with Syncolon. Both provide pleasant and light turnings of the correction collar, with grade 2 yielding a barely perceptible higher resistance (for those who prefer some protection from inadvertent changes during use.) Feel free to use any other grease that suits you.

Reattach the cam ring to the objective base and then reattach the locking ring. Tighten the locking ring moderately only. Turn the cam ring back and forth several times to distribute the grease while also checking that the turning resistance is to your liking. Thoroughly wipe off any excess grease that may have been squeezed out from the slide.

8. Reassemble the objective

If you previously removed the cam stop from the cam ring, you should reattach it now. Don't forget to recreate its original alignment as described in subsection 6.

During reassembly of the objective be sure to keep everything clean to avoid contamination of the objective.

It's a good idea to take the opportunity to do some elementary cleaning before reassembling the objective. Begin by using a compressed air can or a camera lens blower to blow out any dust from the in- and outsides of the two lens casings and the objective base. Then use clean, dry cotton swabs to wipe the in- and outsides of these parts while taking care not to touch any lenses. Finish by again blowing clean air into the casings.

Put the bushing (Figure 25) into the **inner lens casing** (Figure 27) – the bushing is symmetrical so there is no need to turn it in any particular way. A small shoulder on the inside of the casing will stop the bushing before it reaches the lenses. Place the casing horizontally (like in Figure 22) on the table. With the help of Figure 27 identify which of its four openings is the "B" opening and turn the casing so this opening faces upward. Use some clean, pointed tool (for example, a forceps tip) to align one of the bushing's screw holes with the casing's "B" opening.

With the help of Figure 26 identify which of the **outer lens casing**'s two openings is the "B" opening, and with the help of Figure 28 identify which of the **objective base**'s two openings is the "B" opening. Push the outer lens casing over the top of the objective base making sure to correctly align the "B" openings of both parts. Insert the coil spring (Figure 22) through the bottom of the objective base and into the outer lens casing.

Keeping all parts horizontally oriented (as in Figure 22) push the inner lens casing (with the pre-aligned bushing) against the coil spring and into the objective base. This is somewhat challenging as you need to keep pushing both lens casings with your fingers against the spring while at the same time trying to align the "B" openings of all three parts including the bushing's screw hole. It can help a lot to poke with the pointed tool through the "B" openings to get all four openings aligned. And avoid touching the lenses!

Once all four openings are aligned, stick the "B" pin (Figure 24) through the openings and screw it all the way down into the bushing's thread, but don't yet tighten it. Having the "B" pin attached will stabilize the objective and allow you to let go of it. It will also make it easier to attach the "A" pin.

Turn the cam ring to a position where the cam is out of the way and not obscuring the "A" opening in the objective (as in Figure 36) leaving an approx. 3 mm gap between the pin and the stop (as shown by the blue arrow in Figure 36.) The gap provides some space for the needle nose pliers which makes it much easier to attach the "A" pin.

Proceed by aligning all three "A" openings with the bushing's other screw hole. This will require some poking with the pointed tool through the "A" openings, and probably also some light pushing with a clean cotton swab on the bushing inside of the inner lens casing.

Once all four openings are aligned stick the "A" pin (Figure 23) through the openings and use the needle nose pliers to screw it all the way down into the bushing's other thread. Even with the help of the pliers you may find that it is challenging to manipulate and turn the "A" pin to catch the bushing's thread at the same time as you struggle to preserve the alignment of all involved parts. When you have caught the thread, tighten the pin well with the pliers.

Secure the objective by also tightening the “B” pin.

If you previously removed the correction collar (Figure 11) from the cam ring, you should reattach it now. Don’t forget to recreate its original alignment as described in subsection 2.

Reattach the small cam wheel over the cam pin (the “A” pin) as in Figure 10.

Check that the correction collar turns as expected and moves the cam pin (hold a finger on the cam ring so it doesn’t fall off from the cam pin.)

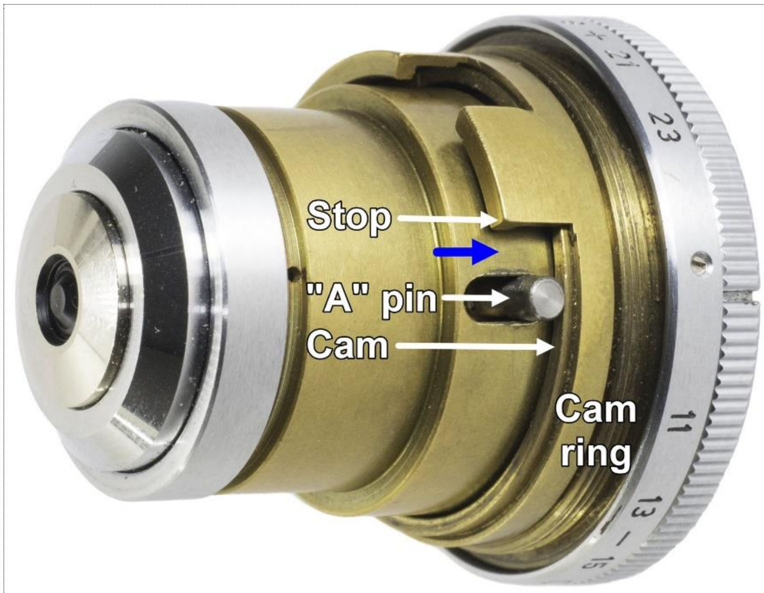

Figure 36: The cam ring turned to leave maximal space for attaching the “A” pin.

Reattach the objective barrel (Figure 10) to the objective. Tighten it well with your fingers so it doesn’t release when the cover glass correction collar is turned during regular use.

Reattach the rear aperture (Figure 17 and Figure 18) to the objective’s backside. Tighten it only lightly.

Do a final check that the correction collar appears to work as expected.

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Roger P. Loveland, Photomicrography – A Comprehensive Treatise, Volume 1, John Wiley & Sons, 1970, p. 57-64.