Variation Facts and Fallacies

By R Cicala

Lens sharpness is widely discussed on the internet, so it shouldn't come as any surprise that lens softness is also a major topic. However, my experience both as a photographer and as the owner of a lens rental business has shown me that much of this discussion is based on a fallacy. So just what is it reasonable to expect from a lens and how doggedly should you pursue the 'best copy?'

A Bit of Background

When I started in photography most of the forums I learned from had at least one thread a day about someone's "soft lens". They knew the lens was soft because their camera worked 'fine' with all their other lenses. After a few years of running a rental business, though, I found myself in the following situation three or four times a week:

> 'The lens you sent me front-focuses, it's not good.'
>
> 'OK, we'll overnight you a replacement.'

Only to find, when the first lens came back, that all our tests suggested it was perfectly fine. And the customer is very happy with the replacement lens - apparently, this one is 'fine.'

So what causes this problem? It's rather simple, actually. The fallacy here is the definition of 'fine.' Most people assume that 'fine' means, 'perfectly calibrated.' It became apparent to me that cameras and lenses are not perfectly calibrated, but rather, they all have some variation. That realisation shouldn't have been shocking; every manufactured product has variation, why should cameras and lenses be any different?

For the next several years I continued to investigate this issue, writing articles about it as I went. Reading all of them now is an overly-long exercise and I've learned a lot since I began writing on this subject. So it seems time to put a summary article together.

Manufacturing variation affects all lenses from all brands – the only difference is the tolerance levels considered acceptable.

Some Semantics

In most online discussions, things derail when different people understand the same terminology differently. Discussions of lens quality are particularly prone to that, so let me define the terms as I intend to use them.

- A soft or bad copy is a copy of lens X that clearly does not perform as well as other copies of lens X. There are bad lenses out there. They happen.

- A design choice affects all the copies of Lens X. Every lens has some design choices made that we may not like.
- Copy/sample variation is a slight difference that can be detected between different copies of lens X, or different copies of Camera B. Copy variation is detectable, but usually not significant (compared to a bad copy which is always significant).

The Search for the Holy Lens Grail

Before we go further, there are some people that should probably stop reading here. If you ever think 'for $1,500 I demand perfection,' this is not the article for you, it will just get you upset. The laws of physics are not suspended, nor are techniques of manufacturing altered, just because you demand it be so. If you enjoy The Quest for the Perfect Lens and other fantasy games, just move along and save yourself the aggravation of being administered this particular dose of reality.

Why Variation is Inevitable

First, I should mention that the problem has received more attention in recent years, oddly enough, because our equipment has improved so much. A 6MP crop-sensor camera didn't expose the flaws in a lens that now, a 24MP full-frame camera makes painfully obvious. Better lenses contribute too: when a lens had four really soft corners it was hard to tell if one side was worse than the other. On a newer lens with sharp corners the difference may be instantly obvious.

It's probably not a coincidence that photographer and blogger Lloyd Chambers brought attention to the fact that camera mounts aren't always perfectly parallel to the sensor when he was testing Zeiss ZF 21mm lenses on a 24MP Nikon D3x. There's every chance it would not have been apparent if he had been shooting a lesser lens on a lesser camera.

The key thing to realize is that the problem is not limited to one brand, one type of lens, or even just SLR gear. Landscape photographer Joseph Holmes found significant variation in medium format lenses and focusing. Testing website SLR Gear found a batch of 50mm lenses that were all softer on the right side than the left. At Lensrentals we found a group of 300mm f/4 lenses from the same serial number run almost all suffered electrical failures. Why is this so?

Manufacturing Tolerances

Manufacturing tolerances are just that: a range of acceptable values, not an exact point. In other words, what is specified as a 1/4 inch diameter screw may be anything between 0.247 inches and 0.253 inches in diameter (see this chart from an internationally-renowned industrial fastener manufacturer). The machines that make them can't be more accurate than that at reasonable cost.

Did you know that every time a glass manufacturer makes a run of a given optical glass, the refraction index and dispersion vary a tiny bit? The glass manufacturer furnishes a melt sheet to the lens manufacturer so they can make tiny adjustments in thickness or curvature of that element to compensate for the differences.

The glass is probably a tiny source of variation compared to the other components that make up a lens or camera. In addition to the multiple glass elements, there are clips, shims, and grips that hold them in place within the lens. There are helicoids, barrels, gears, and rings move them around to focus. Electrical motors and circuit boards tell them what to do, and, as Chambers has shown us, even the lens mount that connects the lens to the camera is a source of variation.

Many, if not most, of those components are outsourced to other companies or factories. A change in subcontractor could result in a slightly different part being supplied. Something as simple as a set of ribbon cables more likely to crack or a solder that is slightly less conductive being used on a circuit board could result in significant changes to a camera or lens.

If you delve into the manufacturer's parts lists (when you can get them) you'll find they take these variations into account and plan for them within a given tolerance range. For example, if you need to replace the front element of your Nikon 14-24mm lens (part # 1K104-xxx) you need to replace the adjustment washer behind it with one of five specific thicknesses - each copy of the lens requires a slightly different thickness for proper spacing of the front element to focus sharply.

There are numerous other variable-sized spacers and parts for every lens (most lenses have variable thickness spacers in at least three different places). In many lenses even the lens mount comes in several thicknesses or with shims so that the image focuses properly on the sensor. As someone who has to shim lenses fairly frequently, I can assure you it can be done close to perfection, but not perfectly. When a 0.06mm shim is indicated, we often have the choice of 0.05mm or 0.07mm shims - close, but not perfect.

Similarly, the lens must be electronically calibrated. The circuit boards inside each lens with its own AF motor contain adjustment screws to calibrate the frequency and current of the electronic pulses sent to the motor used to move the lens during focusing. Manufacturers don't build in this adjustment because every lens is exactly the same; they build it in because every lens is slightly different and adjustments are necessary. And by the way: the factory manual gives an acceptable range for the adjustment, something like 150 +/- 2 MHz.

It’s not my purpose to list every source of variation in a given copy of a lens or camera body. They are far too numerous. But just to give an idea of some major ones:

- A lens has eight to 23 elements, each of which may vary slightly in its spacing from the other elements, centering along the axis of the lens, and tilting from right angles to the axis of the lens.
- The focusing and zooming elements must move certain distances front to back within the lens and during their travel their tilt or centering may vary slightly.
- The barrels and helicoids, and various slots in them, must machined so that the elements are not only aligned properly within them, but they are aligned properly with other barrels.
- The lens mount may not be perfectly parallel to the camera’s sensor.

For everything on the list there is a slight variation within an allowable tolerance. You can demonstrate this for yourself if you have some friends (or camera club members) and can get several copies of the same lens. Mount a camera to a tripod and focus on a target that is very visible in live view at 10X magnification. Then, just change from one lens to another and watch the target be a bit off center in different directions with each lens. Just a bit for most lenses, but you might find one that's off target by half of the screen or so.

Camera bodies are no different than lenses with regard to variation, and in fact could be even more problematic. Is the sensor perfectly parallel to the lens mount? Is the AF sensor properly calibrated to the imaging sensor? Is the AF mirror exactly aligned and angled in relation to the AF sensor? The list goes on and on. And in every case the camera is made nearly perfect, but not exactly perfect.

Lens-Camera Matching

During, and at the end of, the assembly process, the lenses and cameras are tested to make sure they are within the manufacturer’s specifications. If they are out-of-spec and get by quality control, then someone, somewhere gets a truly bad camera or lens. It doesn’t happen frequently, but it happens. When it does, it isn't a subtle call; it's very obvious the lens is bad. In mass-produced elements, quality control is likely to be conducted on a 'sample' basis - only one in every ten or every hundred units will be checked.

But even the cameras and lenses that meet specifications are still going to vary slightly. Many people think, “I’ll try eight lenses and take the best one.” The reality though is that the only sensible definition of “best” is “best with the camera body you are using,”. This is because there is plenty of room for variance in the behavior of bodies, too.

Let’s consider just the lens mount as a theoretical example. First, we say the lens mount of a camera must be parallel to the sensor with a range of +/ - 0.05 degrees (I have no idea what an acceptable range is, I only know that they cannot consistently be made perfectly parallel). Then,

let’s say camera A's lens mount has a tilt of 0.04 degrees to the right. Lens #32 has a tilt of 0.04 degrees to the left. The two tilts would cancel each other out, all would be magical, and the owner would write sonnets on the various forums praising his lens.

But let's say he sells his lens to someone whose camera's lens mount has a tilt of 0.03 degrees to the left. The lens and camera now both tilt to the left and the new owner may say, 'the lens you sold me is a bad copy, it’s horribly soft on the sides.'

And this is just tilt. The mounts may also vary in thickness. There is variation, too, in autofocus systems. Certainly more than there is in lens mounts. Through-the-viewfinder manual focus will also vary (you might be surprised to know that viewfinder focusing screens are shimmed by hand). Even exposure metering varies slightly from camera to camera, and requires recalibration if it’s out of specification.

The bottom line is every lens varies slightly, in several respects. And every camera varies slightly too, in a number of different ways. A given lens on four different cameras will behave slightly differently on each of them, and four different copies of the same lens will each perform slightly differently on a given camera body. How differently? Well the short version is you probably will notice the differences if you’re a 'pixel-peeper'. If you use cameras and lenses to take pictures, though, it would be very unlikely you’d notice normal variation, even with large prints. The one exception might be high quality wide aperture lenses because the narrow depth of field may make subtle differences apparent.

So how much of a difference does this make? Click here to read page 2

What is Normal Variation?

When we at Lensrentals started using computerized analysis (we use the Imatest package) to assess the MTF of large numbers of lenses, it became obvious that there is sharpness variation among copies.

There clearly is variation between the different copies of each lens. On average the Canon 100mm f2.8 IS L lenses are among the sharpest, but some copies are sharper than others. And some copies of other lenses are sharper again. You can see how this might lead two different reviewers to hold slightly different opinions on which 100mm macro lens is the best.

Second, a true 'bad lens' is truly an outlier. The difference between a soft or bad copy and the main group is very large. The copy-to-copy variation that occurs between the other lenses is really minor. If you want to know how bad that bad copy is: our techs could identify it looking at JPEGs at 50% on a computer screen, but they'd be unlikely to spot it by looking at a web-sized image.

When you change the body the results change - the overall pattern will look the same, but each lens result will be slightly different. The sharpest lens on test camera A may well not be the sharpest on test camera B.

As suggested by our name, Lensrentals is a lens rental house, and as such I'd like to clarify one point: the variations that Ive been talking about don't occur because we're looking at used lenses. When we first started testing lenses, we made sure to carefully compare brand new lenses with our stock lenses to make sure that our quality assurance was keeping the stock lenses in good shape.

We buy new lenses in significant quantities; so we usually start testing a given lens by examining a dozen new copies right out of the box, then we start testing our rental copies.

Focusing Variation

To give some idea of how small the difference between various lenses really is, we can examine the variation of a single camera's autofocus with a single lens. It's reasonable to assume that you shoot dozens of images with your camera and depend on autofocus to be accurate. You never notice, unless you look very carefully, that if you automatically focus on the same shot several times the camera focuses slightly differently each time.

Without changing anything, I then moved the focus ring to one extreme or the other, let the camera autofocus again, took a single shot, and repeated that process six times. The camera autofocuses the shot a bit differently each time (and this is with center focus point on a star chart: a near ideal situation). Finally, I focused the lens using live-view magnified focusing four consecutive times (represented here by the green triangles).

It should be obvious that the variation of the camera’s autofocus system on repeated shots with a single lens is about 1/3 as great as the variation between different lenses. Autofocus microadjustment to the camera would improve the average AF performance to be nearly as good as the live-view focusing but it wouldn’t change the shot-to-shot variation.

So How Big is This Variation in Real Life?

The variation described is easy to detect using modern computerized optical analysis. And we’ve seen that the variation between a truly bad lens and the group of acceptable lenses is very large. But how big is the variation between the different acceptable copies?

The best answer I can give is probably that it might be detectable by pixel-peepers, but not working photographers, at least hardly ever. Lensrentals has six full-time pixel-peepers on our staff (the inspection technicians) who are armed with a large array of well-lit charts to analyze sharpness, aberration, back and front focus, you name it. They can pick out a bad lens fairly easily.

But there's a more scientific way to look at things than 'our techs said so.' The Subjective Quality Factor (SQF) is a measurement developed by Ed Granger and K.N. Cupery in the 1970s for Kodak and used by Popular Photographer for their lens reviews. Basically, SQF uses a mathematical formula, taking the MTF data from the lens (which we get from these tests) to predict with good accuracy how sharp a print would be perceived at various sizes and distances.

I'm not going into detail about SQF (for a more thorough discussion, see Bob Atkins' excellent article or the references below). The important part is that several experts have shown an SQF difference of less than 5 for a reasonably sized print is basically not detectable by human vision.

It's a simple matter to have the computer calculate the SQF from the data we've obtained in our testing. We arbitrarily calculate it for 8 X 10 inch print size, but the SQF difference would be the same for any reasonably sized print.

As you can see the variation in SQF is less than 5, meaning theoretically, you wouldn't be able to detect the difference in a print. The difference is real and can be detected by Imatest, or by a careful pixel-peeper armed with a few test charts, a large monitor, and too much time on their hands. But it wouldn't be significant enough to make an obvious difference in a print.

So What's the Point of All This?

The main points are fairly straightforward:

- Every lens and every camera exhibits slight variations relative to its twins that are detectable, but rarely significant.
- Variations that wouldn't make the slightest difference in a print may seem quite different when the numbers are presented in a lens review. And, just because one copy of lens X is sharper than one copy of lens Y, doesn't mean they all are, or that they all will be in your camera.
- Occasionally, an acceptable lens mounted to an acceptable camera combine their variations in a way that makes them unacceptable together. The lens may be fine with a different camera, and the camera fine with a different copy of the lens.
- Really bad, soft, out-of-acceptable range lenses do occur. They are fairly rare though and easy to detect.
- Camera autofocus is more variable and less accurate than you think.*

* Before you go all Major League Fanboy about the superiority of your camera's autofocus system: autofocus variation exists in every camera from every brand we've tested. Want to prove it? Put a wide aperture prime on your camera, mount it to a tripod, and focus on something in the middle distance. Now move the focus ring to infinity, let the camera autofocus and note exactly where it ends up on the distance scale. Now turn the focus ring to near focus, let the camera autofocus on the subject at middle distance, and note the number on the distance scale. They will be slightly different.

When you buy a lens, and assuming your camera allows you to, you should microfocus adjust it. If you do it properly, using a sensible focus distance, it really does make a difference. Then do some very basic tests to make sure it functions properly, and go take some pictures. If you like the pictures it makes, then keep it.

Oddly enough, the conclusion I've reached from several years of dedicated pixel-peeping and lens analysis is this: Trying to find exactly the sharpest copy of the sharpest lens is a fool's errand: you'll be looking for something that doesn't exist.

Comments

▸ Your term "allowable tolerance" I would presume is a floating definition. Again I would presume that more expensive lens productions lines have more stringent definitions of 'allowable' applied. Indeed you seem to argue the opposite, in that the potential tolerances are much greater with lenses with more elements/groupings (ie. more expensive lenses) than lenses of simpler construction, and that therefore buyers should expect more expensive lenses to perform worse than cheaper lenses.

▸ Real eye opener. So LiveView remains the most reliable focusing tool ever, and if you use a tool like Magic Lantern on Canon cameras, where you can zoom in 10x in LV to focus, is even better.

Feel better now not having MFA on my 60D.

Thanks!!!

▸ I always thought depth of field and a relatively fast shutter speed would save my a$$ from bad lenses... looks like this confirms it.

Cameras today still beat what came before and why should we worry anyway? After all aren't the youngsters all trying to achieve the blurry box camera look with their HOLGA's and HOLGA-apps in post-production as well as lensbabies?

▸ Good stuff, although I personally think you rather underplay how easy or not it is to notice differences. I didn't find it difficult at all to notice difference between various liveview AF or MF attempts and you show those to have been rather more minor than other differences you claim are hard to spot.

Maybe you lucked out with the liveview focusing though. I've found that unless you take at least six tries, and sometimes you even need more, the simple difference in focusing can completely alter results of how one lens appears to fair against another. In terms of details shown maybe it's not a lot, but the bite of the microcontrast, how fast thin dark details next to light can be pretty easily spotted.

▸ In the movie industry we use $70,000 zoom lenses and $24,500 prime lenses, that are ostensibly made to a very high standard by companies like Zeiss and Leica. Before every job the camera assistants get a camera prep that is anywhere from one day to a month long depending if it's a relatively simple commercial or an epic feature film. Even though the quality of the lenses has gotten better over the 34 years that I've been in the Biz, we still have to have adjustments made to our Flange Depth and/or lenses during the Prep in order to get the lenses/cameras as close to perfect as possible. Note that in high end filming, the camera assistant usually keeps things in focus while NOT looking through the camera. He gets Focus Marks on the lens or Follow Focus by taking measurements and then gauges the subject matters relationship to focus marks and camera. The Camera Operator is the one looking through the camera during the shot.

... We had a weird situation last week where a 16 mm Zeiss Master Prime, a T1.3, 4.8 LB beauty, with a front diameter of 114 mm, and a price tag in the $15K range. It focused short, ie. at a measured 4' it eye focused to 3' 9". All of our other lenses focused right on. When we put the that lens on a Lens Projector ... a projector that uses an etched metal resolution chart, it came up right on. Our other 10 lenses also came up correct on the projector. We had to use a different size shim in order for it to focus correctly with our $70K, Arri Alexa HD digital cameras ... but then it didn't focus correctly on the projector?! We had two technicians and two camera assistants checking each other. Weird stuff happens even with the most expensive gear!?

▸ Great article. It has now come to be a painful truth to most pixel peepers but good to see it written for the non believers.